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Editorial

Using an ecosystem services perspective to assess biofuel sustainability

1. Understanding the sustainability impacts of biofuels

The use of liquid biofuels for transport dates back more than a century when it was promoted by automobile industry leaders such as Henry Ford and Rudolph Diesel [1,2]. Ever since the oil crises of the 1970s pioneer countries in their respective regions such as Brazil, Sweden and Malawi have been promoting ethanol to substitute imported gasoline [3]. Since then governments around the world have provided considerable support for the development of viable biofuel markets through blending mandates, subsidies and other mechanisms. The U.S. has applied legislative and regulatory instruments to support biofuels for transport [4,5], while the EU has promoted renewable fuels in the transport sector through the Biofuels Directive of 2003 and the Renewable Energy Directive (EU-RED) of 2009 [6,7]. China, India and various other countries have also been supporting biofuels for transport [8–11]. Currently at least 36 countries and trading blocs have enacted mandatory policies for blending liquid biofuels into conventional transport fuel, with several more designing and enacting other types of biofuel policies [8]. Apart from transport, there has also been some limited promotion and pilot projects in some developing countries for the use of liquid biofuels for cooking and power generation [12,13].

Energy security has traditionally been the major driver behind biofuel expansion, while rural development, climate change mitigation and other economic factors (e.g. economic growth, foreign exchange savings) have been additional important motivations in some national and regional contexts [11,14,15].

However, as with any agro-industrial activity, biofuel feedstock production can have a wide range of sustainability impacts, which for any given context can be positive or negative when compared to the impact of other energy alternatives. Perhaps the most significant environmental impacts of biofuels are associated with GHG emissions and land use change (with its subsequent effects on carbon stock change and biodiversity loss) [16–19]. Other important environmental impacts relate to water use and air/water pollution [20–23]. On the other hand key socioeconomic impacts of biofuels include food security, rural development, energy security, land tenure, social conflicts, public health and gender issues among several others [24–31]. The negative impacts of biofuels are mostly associated with land use change such as competition with food production, GHG emissions, and biodiversity loss. However, at the same time, there are opportunities to enhance the positive impact of biofuels on sustainability impacts related to land use change [27].

There are several reasons why biofuels impacts are so variable. First, biofuel lifecycles are quite complex and comprise several stages (e.g. feedstock production, feedstock transport, biofuel production, biofuel distribution/storage/dispensing and biofuel combustion). Different studies often place different emphasis on the various stages [20]. Second, the drivers, impacts and trade-offs of biofuel production and use vary greatly depending on the feedstock, the mode of production (e.g. large plantations, smallholder-based), the mode of consumption (e.g. transport in cities, rural electrification), the social-ecological context where this production and use take place, and the institutions regulating biofuel production, use and trade [15,20]. Third, there is no single assessment methodology that can capture and meaningfully integrate the multiple biofuel sustainability impacts. For example, while standard tools such as life cycle assessment (LCA) can capture important impacts related to energy provision and emissions, it cannot assess meaningfully other important impacts related to biodiversity loss, food security and socioeconomic issues [32,33]. The above, combined with the fact that biofuel impacts can manifest across different spatial and temporal scales, undermine our ability to meaningfully compare and generalize between studies, and derive clear conclusions about the sustainability of different biofuel pathways (Section 2).

Despite efforts to systematize the current knowledge about biofuel impacts [19], we lack a clear and multi-disciplinary synthesis of the existing evidence about the trade-offs of biofuel production and use. To achieve such comprehensive and robust syntheses requires the use of conceptual framework(s) that can position specific findings about biofuel impacts in their appropriate context [34,35]. Such a conceptual framework(s) can also provide the basis for developing a new and much needed set of integrated assessment tools for evaluating biofuel trade-offs [35]. All of the above are major gaps in the current biofuel literature and practice.

This Special Issue explores how the ecosystem services perspective can provide this conceptual framework to identify and systematize biofuel trade-offs, as well as develop tools to assess them. Within its various contribution, this Special Issue highlights how the ecosystem services perspective can provide this valuable lens to study biofuel sustainability given its systems-oriented approach, ability to identify trade-offs across temporal and spatial scales, and growing acceptability among academics and stakeholders (Section 2). However there are several important gaps at the interface of biofuels and ecosystem services that need to be bridged (Section 3). The 14 papers included in this Special Issue employ different concepts, methods and tools from the ecosystem services literature to highlight how to apply effectively tools and concepts from the ecosystem services literature to study biofuel sustainability (Section 4).

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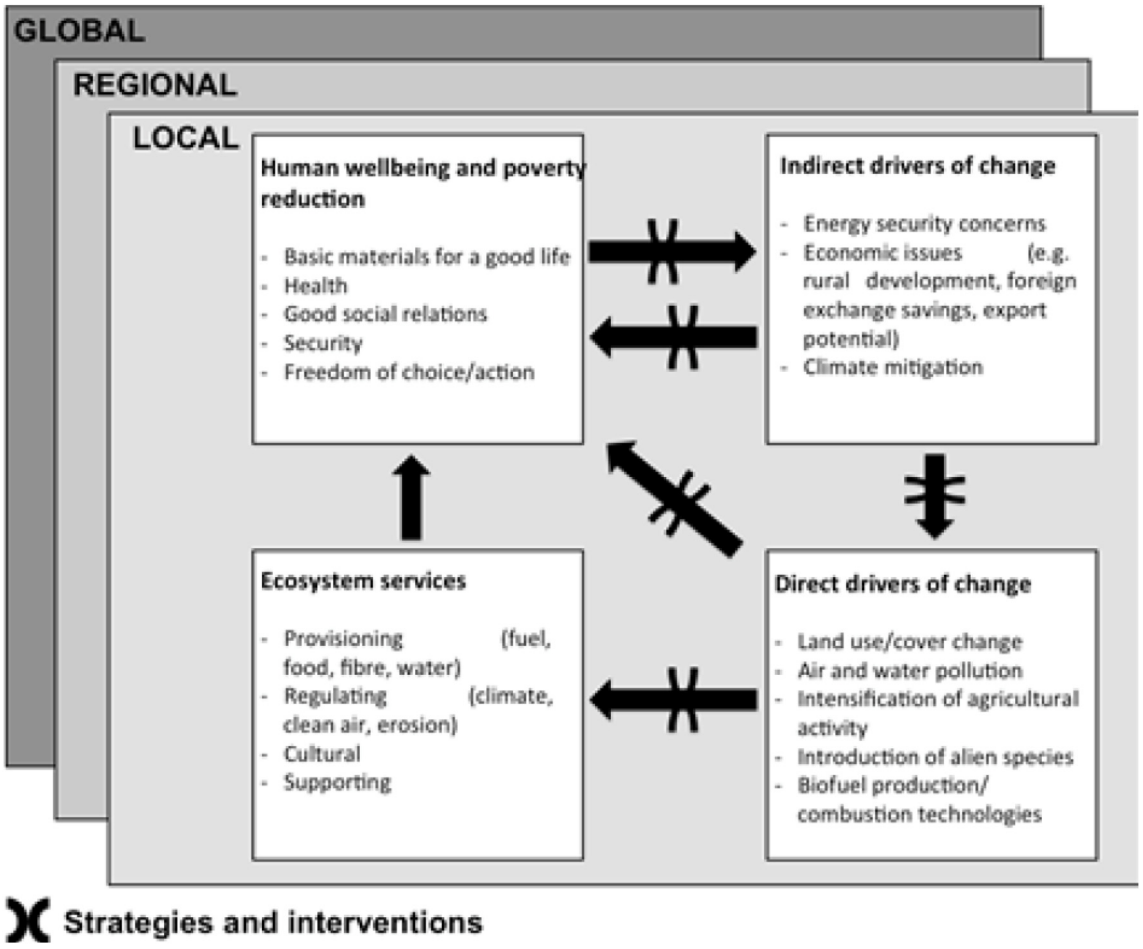

Fig. 1. The Millennium Ecosystem Assessment (MA) conceptual framework adapted for biofuel production and use. Source [34] adapted from Ref. [36].

2. Biofuels and ecosystem services

2.1. Conceptual foundations

The basic premise of the ecosystem services perspective is that ecosystems provide direct and indirect benefits to humans [36–38]. These benefits are defined as ecosystem services and can be provisioning (e.g. food, fuel, water, natural products), regulating (e.g. carbon sequestration, water purification) and cultural (e.g. recreation). Such ecosystem services can contribute manifold to human wellbeing [36,37]. The ecosystem services perspective has some further core elements such as the ability to (a) consider multiple scales, (b) link ecosystem services to different beneficiaries and (c) explicitly identify and consider trade-offs and synergies between ecosystem services [39–41].

Human activity can affect in multiple ways the capacity of ecosystems to provide these services. For example this can happen directly through mechanisms related to land use change, resource overexploitation or pollution (i.e. direct drivers of ecosystem change) (Fig. 1) or indirectly through underlying drivers such as institutions, technological change and changes in consumption patters [36,37]. These direct and indirect drivers of change can affect the capacity of ecosystems to provide ecosystem services, thus having important knock-on effects to human wellbeing. This systematic view of the linkages between ecosystems, human activity and human wellbeing can be invaluable for understanding the sustainability impacts of biofuels. Ecosystem services thereby provide an analytical perspective that can capture the interactions between the environmental and socio-economic impacts of biofuels [34,35]. Furthermore, the ecosystem services perspective has the relevance, theoretical foundations, versatility and acceptability amongst academics and policy makers to assess robustly the trade-offs of biofuel expansion [34,35] (Section 2.2). However, despite some few recent studies that have applied ecosystem services concepts to study biofuel systems [34] [42–52], this is the exception rather than the rule within both the biofuel and the ecosystem services research communities.

2.2. Strengths of the ecosystem services perspective for assessing biofuel sustainability

Ecosystem services theory and practices is based on powerful frameworks that can be used for synthesizing knowledge across both the natural and social sciences [38]. Such frameworks can highlight the links between biodiversity (natural assets), ecosystem functions, ecosystem goods/services and human wellbeing for very diverse ecosystem types and natural-resource management problems [36–38]. An ecosystem services perspective can thus make explicit the links between biofuel-driven environmental change and human wellbeing, two core aspects of the biofuel debate that are frequently evoked by biofuel critics and supporters alike. In this respect, the ecosystem services perspective has the potential to form the basis of a comprehensive framework for contextualizing the environmental and socioeconomic impacts of biofuels, and for synthesizing the often disjointed and contradictory evidence about the impacts of biofuel production and use. Some of the studies that have already adopted an ecosystem

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