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Research paper

Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement

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ABSTRACT

Continued development of cellulosic-based biofuels is needed to provide renewable energy and strengthen rural investment and development in the United States (US). To ensure biofuel development is sustainable and does not negatively affect ecosystem services, stakeholder input is necessary to identify sensitive and meaningful indicators. A major challenge is that there are substantial differences in terminology, perspectives, and methods used to quantify sustainability and ecosystem services with regard to processes, biodiversity, and socioeconomic effects. Our objectives were to identify relevant indicator categories for both perspectives using a case study from the US state of Iowa. A scientific literature review and engagement with stakeholders were used to identify 11 indicator categories associated with production, harvest, storage, and transport of cellulosic feedstocks. Five categories focus on environmental concerns (soil quality, water quality and quantity, greenhouse gas emissions, biodiversity, and productivity) and six on socioeconomic concerns (social wellbeing, energy security, external trade, profitability, resource conservation, and social acceptability). Although these indicators reflect sustainability concerns of these stakeholders, additional monitoring and stakeholder engagement are needed to support the continual improvement that is part of adaptive management.

1. Introduction

Environmentally, economically, and socially sustainable technologies are needed for sustainable development of industries that produce liquid fuels from plant biomass [1,2]. For some countries, legislative mandates associated with renewable transportation fuels require quantitative assessment of changes to indicators of progress toward sustainability [3]. While biofuels are only one part of an overall energy portfolio, they are essential for achieving renewable energy goals in the transportation sector since aviation, ocean shipping, and long-haul trucking require liquid fuels, and transitions to other renewable technologies will take time [4].

Biofuel production can provide positive ecological, social and economic opportunities for many agricultural regions including the Great Plains and Midwestern United States (US) where populations have declined as income, and employment opportunities have diminished [5]. Previous studies have identified several significant benefits that biofuels could provide in the state of Iowa, including over 40,000 jobs, $2 billion in household income, and contributing nearly $5 billion to state gross domestic product (GDP) (approximately 3.5% of the total state GDP) [6]. However other studies have raised concerns about who benefits from the current biofuel industry. For example, a 2011 study of local perceptions regarding the costs and benefits of the ethanol industry in Iowa found that residents observed some employment opportunities but only modest economic benefits [7]. At the same time traffic increased and water competition amplified in those communities establishing ethanol plants, and there was recognition of emerging social vulnerabilities if the biofuel industry does not prove to be viable [7]. Farmer and non-farmer participants involved with a switchgrass biofuel

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project in southern Iowa found that local and regional economic revitalization is the benefit most desired, as well as least expected [5].

Recently there has been a growing academic literature (including the studies in this special volume) that aims to understand the effects of biofuels on ecosystem services (i.e., the benefits that people derive directly and indirectly from ecosystems [8,9]). Biofuel systems can provide a variety of ecosystem services such as feedstock for fuel and climate regulation, as well as affect other ecosystem services such as food and water services in positive or negative ways [10–12]. From an ecosystem services perspective, cellulosic-based biofuel production can positively or negatively affect several categories of services including provisioning services (e.g., food, feed, water, and fiber), cultural services (e.g., aesthetic values related to scenery and recreation), and regulating and supporting services such as the (a) mediation of water and nutrient flows, (b) mediation of waste, toxins, and other nuisances, and (c) maintenance of physical, biological and chemical conditions [8,12–14]. Transitioning from first generation to second generation biofuel feedstocks can provide significant benefits to a variety of ecosystem services including hazard regulation, disease and pest control, and maintenance of water and soil quality [14].

The effects of biofuel feedstock production and use are context specific [15]. Therefore, general statements regarding the costs or benefits of cellulosic-based biofuels on ecosystem services may omit or misrepresent important local effects. The environmental costs and benefits associated with cellulosic biofuel production depend on which, where, and how cellulosic biofuel feedstocks are produced [4,16], and the fuels displaced, as well as the alternative disposal of the cellulosic resources. For example, some potential feedstock material such as agricultural or forest wastes are otherwise burned on site [17] while other biomass materials have productive uses as forage, bedding, or fiber products [18]).

Documenting progress toward sustainability and identifying appropriate options to improve the outcomes of biofuel expansion on the provision of ecosystem services calls for the development of meaningful indicators and their effective use to support informed decisions [19]. The identification of appropriate indicators is a necessary first step toward the quantitative assessment of impacts and benefits of biofuel, and a variety of indicators is needed to cover the diversity of potential effects [20]. However, there are practical limitations on the time and resources allocated for such analyses that can affect the choice and prioritization of indicators. For example, the desire to monitor and measure indicators is often stymied by real world constraints such as the high cost of collecting information about the indicators, the paucity of data, and inconsistent definitions of indicators, units, and methods of measurement [21,22]. Furthermore, an overabundance of indicators may confuse rather than inform decision-makers, and the investment required for tracking and documenting excessive indicator lists can become counter-productive to sustainability goals [23].

Stakeholder perspectives and values are core components of sustainability assessments [24–27], so it is crucial to understand and meaningfully integrate such viewpoints to fully comprehend the local and regional implications of biofuel development [28]. Stakeholders in the biofuel systems discussed in this paper include anyone that is affected positively or negatively by changes in the provision of ecosystem services and socioeconomic conditions associated with the production of feedstock or biofuels. Stakeholders across the biofuel supply chain are diverse and range from rural feedstock suppliers and farmers to the final consumers of renewable fuel (Fig. 1). Developing some agreement on the key issues surrounding biofuel production and use is important for identifying paths toward biofuel sustainability. For example, understanding stakeholder values and perspectives about important sustainability effects and appropriate indicators can be a prerequisite to building community and policy support for programs that enhance biofuel sustainability [22]. Deploying systems that can monitor effects on indicators is challenging but necessary to maintain support and guide decisions that result in the long-term sustainable management of feedstocks used in biofuel production [23]. Efforts to effectively assess sustainability may lack public support if stakeholders are not engaged in the identification of the metrics, do not understand the value of such measures, or do not see the reporting as reflecting their concerns and priorities [29–31].

Considering the points made above, this paper addresses three research questions. First, given limited resources, what means can be used to document stakeholder priorities as a first step towards identifying indicators of progress toward biofuel sustainability? Second, how are ecosystem services reflected in the commonly identified sustainability issues and indicators of progress related to biofuel production and use? Third, what are the differences between a sustainability indicator approach and an ecosystem services approach for tracking the effects of biofuel production and use?

We use ethanol production in the US state of Iowa as a case study to address these questions. In regions of increasing biofuel production like Iowa, a lack of consensus on key indicators and probable effects contributes to confusion among the public and policymakers. When project goals and stakeholder priorities are not clear, critics may call for a plethora of measures that can delay or even kill a biofuel project. Because learning about stakeholders' perspectives can be costly, frustrating, and time consuming, stakeholder engagement and consultation is often limited or omitted from project development plans. We propose an approach that builds progressively, beginning by reviewing existing information and then expanding to engage stakeholders. Stakeholder engagement and identification of indicators are the first steps of a framework for assessing progress toward sustainability [32]. In this study, we document these initial steps in a specific case study: a landscape design approach [22] for biofuel production in the Midwestern US.

2. Methodology

2.1. Study context

Two potential strategies for enhancing the sustainability of feedstock production are the collection of a sustainable amount of corn (*Zea mays* L.) stover and the increased cultivation of perennial crops such as switchgrass (*Panicum virgatum*) on less-productive or environmentally sensitive areas within current agricultural fields. While a fraction of corn stover residue is needed to reduce erosion and maintain soil organic matter, in areas with high corn yields, harvesting a sustainable portion of the corn stover can help alleviate "residue management" problems such as nitrogen immobilization and cool soil temperatures [33]. Removal of some residue also facilitates the adoption of no-till agriculture, which can significantly reduce soil erosion and nutrient runoff and promote growth of microbes that enhance denitrification [33]. Planting perennial grasses as buffers on marginally productive lands can reduce nutrient, phosphorous and sediment loads [34].

In combination, corn stover removal and the cultivation of perennial grasses are well-suited to the Midwestern US. They provide opportunities for expanding biofuel production, particularly on marginally profitable cropland, where they can both provide a biofuel feedstock and enhance the provisioning of other ecosystem services [35]. Benefits to soil microbes are especially critical, since microorganisms drive many of the processes

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