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Oak Ridge National Laboratory
Highlights of Recent Work
2013 (version 2)

Biofuels and Land-Use Change

The current generation of land-use-change (LUC) models is limited by the availability of appropriate data sets and knowledge of driving factors of change (CBES 2010). An improved understanding of the forces behind LUC can lead to multiple opportunities for biofuels to enhance ecosystem services and reduce greenhouse gas emissions (Kline and Dale 2008; Kline et al. 2009). LUC estimated by economic models has sparked sharp international debate. Models estimate how much LUC might be induced under prescribed scenarios and assumptions to generate LUC values (Oladosu and Kline 2010; Oladosu et al. 2011). It is critical to clearly document underlying assumptions and to test and validate model input values and assumptions with empirical evidence (Dale and Kline 2013a). However, current approaches to global economic modeling cannot answer if any specific indirect effects are actually caused by biofuel policy. Answering this question requires causal analysis.

Given that there is no accepted approach to estimate the global effects of biofuel policy on land-use change, it is critical to assess the actual effects of policies through careful analysis and interpretation of empirical data (Kline et al. 2011). Because landscapes are dynamic, it is crucial to develop ways for the scientific community to work together to collect data and develop tools that will enable better analysis of causes and effects of changes and to develop robust management recommendations. Systematic measurement over time of spatially explicit land qualities such as carbon and nutrient stocks, water and soil quality, net primary productivity, habitat and biodiversity can improve abilities to assess and interpret LUC and develop representative models (Dale and Kline 2013b).

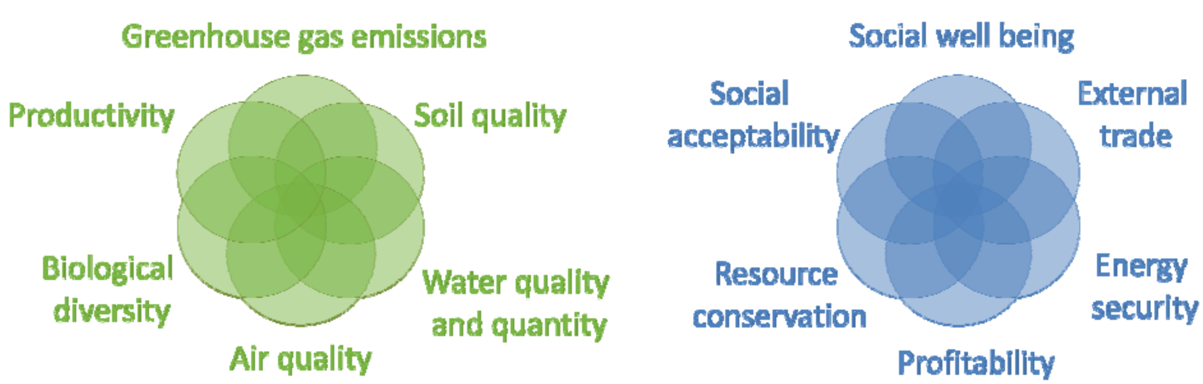
Furthermore, recent increases in biofuel production offer the opportunity to design ways to select locations and management plans that are best suited to meet human needs while also protecting biodiversity (Dale et al. 2010). Although land-use changes and carbon emissions associated with bioenergy feedstock production are dynamic and complicated, lignocellulosic feedstocks may provide opportunities that enhance sustainability when compared to other transportation fuel alternatives (Dale et al. 2011). Decision makers need quantitative and qualitative measures of the effects of bioenergy feedstock choices at different spatial and temporal scales to allow comparisons among available options for renewable liquid fuels. While sustainable biofuel production systems could play a positive role in mitigating climate change, enhancing environmental quality, and strengthening the global economy, it will take sound, science-based policies and additional research efforts (Robertson et al. 2008).

Selecting and Deploying Sustainability Indicators

Indicators are needed to assess both socioeconomic and environmental sustainability of bioenergy systems. Effective indicators can help to identify and quantify the sustainability attributes of bioenergy options. A team at Oak Ridge National Laboratory (ORNL) has selected key indicators of bioenergy sustainability and proposed how they are best used in particular contexts. The analysis addressed three goals: (1) choosing from the plethora of indicators proposed by many groups those that appear to be most *useful* to decision makers; (2) selecting measures of sustainability that are *applicable* across the entire bioenergy supply chain; and (3) identifying a *minimum* set of indicators that are practical, doable and incorporate key areas of interest to science.

The proposed environmental and socioeconomic indicators represent a suite designed to reflect major sustainability considerations for bioenergy. McBride et al. (2011) identify major environmental categories of sustainability to be soil quality, water quality and quantity, greenhouse gases, biodiversity, air quality, and productivity and discussed 19 indicators that fit into those categories. Dale et al. (2013a) identify 16 socioeconomic indicators that fall into the categories of social well-being, energy security, trade, profitability, resource conservation, and social acceptability. Ten of those 16 socioeconomic indicators are proposed as a minimum list of practical measures of socioeconomic aspects of bioenergy sustainability. The utility of each indicator, methods for its measurement, and applications appropriate for the context of particular bioenergy systems are described along with future research needs. Together, this suite of indicators is hypothesized to reflect major enviroenmental and socioeconomic effects of the full supply chain for bioenergy, including feedstock production and logistics, conversion to biofuels, biofuel logistics and biofuel end uses. These indicators provide a basis to quantify and evaluate sustainability of bioenergy systems across many regions in which they are being deployed. For example, they have recenty be used to consider the sustainability implications of using *Eucalyptus* for bioenergy in the southeastern united Sates (Dale et al. 2013b).

Figure1. Categories for indicators of environmental and socioeconomic sustainability [from McBride et al. (2011) and Dale et al. (2013A].



The importance of interpreting these indicators of bioenergy sustainability in particular contexts is described in Efroymson et al. (2013). The context of an application strongly affects the choice, measurement and interpretation of sustainability indicators. Context considerations include the purpose of the analysis, the specific fuel production and distribution system, policy influences, stakeholders and their values, baseline attributes, available information, and spatial and temporal scales of interest (Efroymson et al. 2013). Knowing the context is essential for setting priorities for assessment, defining the purpose, setting the temporal and spatial boundaries for consideration, and determining practicality and utility of measures.

The ORNL team has also worked with agronmists to analyze how agricultural sustainability can consider the effects of farm activities on social, economic, and environmental conditions at local and regional scales (Dale et al. 2013c). Adoption of more sustainable agricultural practices entails defining sustainability, developing easily measured indicators of sustainability, moving toward integrated agricultural systems, and offering incentives or imposing regulations to affect farmer behavior. Landscape ecology is an informative discipline in considering sustainability because it provides theory and methods for dealing with spatial heterogeneity, scaling, integration, and complexity (Dale and Kline 2013b). To move toward more sustainable agriculture, the team proposes adopting a systems perspective, recognizing spatial heterogeneity, and integrating landscape-design principles and addressing the influences of context, such as the particular products and their distribution, policy background, stakeholder values, location, temporal influences, spatial scale, and baseline conditions. Topics that need further attention at local and regional scales include (1) protocols for quantifying material and energy flows; (2) standard specifications for management practices and corresponding effects; (3) incentives and disincentives for enhancing economic, environmental, and social conditions (including financial, regulatory and other behavioral motivations); (4) integrated landscape planning and management; (5) monitoring and assessment; (6) effects of societal demand; and (7) integrative policies for promoting agricultural sustainability.

Special Feature of *Environmental Management* to be published in February 2013 on "Sustainability of Bioenergy Systems: Cradle to Grave"

Defining and measuring sustainability of bioenergy systems are difficult because the systems are complex, the science is in early stages of development, and there is a need to generalize what are inherently context-specific enterprises. These challenges, and the fact that decisions are being made now, create a need for improved communications among scientists as well as between scientists and decision makers. We propose communication guidelines for scientists whose work can contribute to decision making (Dale et al. 2013d). The papers in this special issue on "Sustainability of Bioenergy Systems: Cradle to Grave" offer a framework under which the effects of bioenergy can be assessed and compared to other energy alternatives with the hope of facilitating steps toward increasing sustainability over time (Efroymson et al. 2013, Parish et al. 2013, Johnson et al. 2013).

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