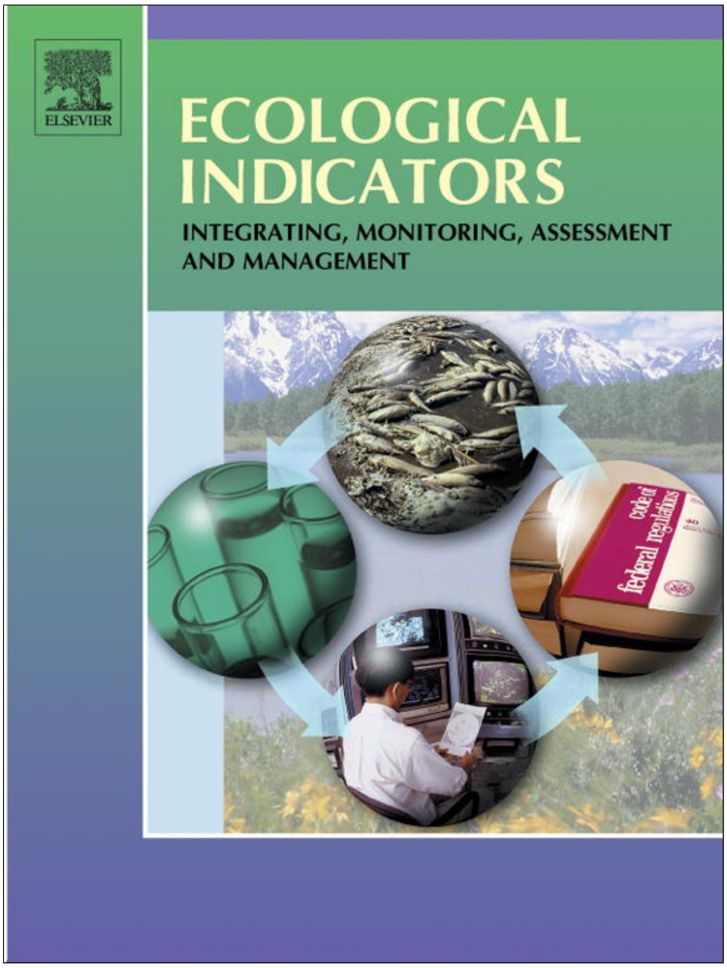
ELSEVIER
ECOLOGICAL
INDICATORS
INTEGRATING, MONITORING, ASSESSMENT
AND MANAGEMENT

Ecological Indicators 26 (2013) 87–102

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

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

Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures

Virginia H. Dale[a,c,*], Rebecca A. Efroymson[a], Keith L. Kline[a,c], Matthew H. Langholtz[a], Paul N. Leiby[a], Gbadebo A. Oladosu[a], Maggie R. Davis[a], Mark E. Downing[a], Michael R. Hilliard[b]

[a] Center for Bioenergy Sustainability, Environmental Sciences Division, Oak Ridge National Laboratory, 1 Bethel Valley Road, Oak Ridge, TN 37831-6036, USA
[b] Energy and Transportation Science Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[c] Climate Change Science Institute, Oak Ridge National Laboratory, USA

ARTICLE INFO

Article history:
Received 22 March 2012
Received in revised form 10 October 2012
Accepted 16 October 2012

Keywords:
Biofuel
Economic
Employment
Energy security
External trade
Food security
Profitability
Resource conservation
Social acceptability
Social well-being

ABSTRACT

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. We identify 16 socioeconomic indicators that fall into the categories of social well-being, energy security, trade, profitability, resource conservation, and social acceptability. The suite of indicators is predicated on the existence of basic institutional frameworks to provide governance, legal, regulatory and enforcement services. Indicators were selected to be practical, sensitive to stresses, unambiguous, anticipatory, predictive, estimable with known variability, and sufficient when considered collectively. 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 socioeconomic effects of the full supply chain for bioenergy, including feedstock production and logistics, conversion to biofuels, biofuel logistics and biofuel end uses. Ten indicators are highlighted as a minimum set of practical measures of socioeconomic aspects of bioenergy sustainability. Coupled with locally prioritized environmental indicators, we propose that these socioeconomic indicators can provide a basis to quantify and evaluate sustainability of bioenergy systems across many regions in which they will be deployed.

1. Introduction

Sustainability is often considered to be the capacity of an activity to continue while maintaining options and the ability to meet needs of future generations (Bruntland, 1987). While the science of sustainability is evolving, its definition depends on local conditions and stakeholders. Because sustainability is not a "steady state" or fixed target, assessing it involves comparing the relative merits of different options, and achieving it allows for continued adjustment in response to changing conditions, knowledge, and priorities. Sustainability assessment requires an understanding of how dynamic processes interact under alternative trajectories and how interpretations depend on the priorities of stakeholders in a specific place and time. We propose a set of socioeconomic sustainability indicators for bioenergy. The target audience for use of sustainability indicators includes policy makers, business people, and other stakeholders in all stages of the supply chain from land managers or waste suppliers to those involved in logistics, conversion facilities and end users.

Indicators provide information about potential or realized effects of human activities on phenomena of concern. Indicators can be used to assess both the socioeconomic and environmental conditions of a system, to monitor trends in conditions over time, or to provide an early warning signal of change (Cairns et al., 1993). It is widely recognized that some socioeconomic indicators are related to environmental indicators (e.g., resource conservation) and that public acceptance depends on environmental impacts (MEA, 2005; Collins et al., 2011). Yet social and economic conditions are important on their own as well.

This manuscript builds from prior work proposing environmental indicators of bioenergy systems (e.g., McBride et al., 2011) and adds socioeconomic metrics. While this analysis is designed to be broad enough to apply to bioenergy, generally, the indicators were selected based on transportation biofuel production pathways. The analysis was designed to address three goals: to choose indicators that can be useful to decision makers, to select measures of sustainability that are applicable across the entire bioenergy supply chain, and to identify a *minimum* set of indicators. The proposed indicators are meant to be complementary to efforts designed to assess performance of transportation systems (e.g., Transportation Research Board, 2011).

* Corresponding author. Tel.: +1 865 576 8043; fax: +1 865 576 3989.
E-mail address: dalevh@ornl.gov (V.H. Dale).

1470-160X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2012.10.014

The first goal is to identify a set of socioeconomic indicators that can effectively support policy makers and planners. We seek clearly specified, science-based metrics that can, for example, support decisions about implementation and expansion of more sustainable bioenergy options over time. Reaching agreement on how to define and measure socioeconomic effects of bioenergy can facilitate constructive dialogue and comparison by providing a common platform to evaluate relative merits. The data collected for these indicators and the understanding they provide could support programs such as voluntary certification and emerging sustainability standards (van Dam et al., 2008; ISO, 2010). Furthermore, since the focus is on energy, the indicators should allow the comparison of bioenergy to other energy systems and the identification of preferred pathways and practices for energy provision. For this reason we attempt to include indicators that are pertinent to both biofuels and other energy pathways.

A second goal is to identify indicators that apply across the supply chain, including feedstock production and logistics, conversion to biofuels, biofuel logistics and biofuel end uses, as defined by the players at each stage. For example, growers and suppliers are the major actors in the feedstock production stage; the conversion stage involves biorefineries; and fuels users (including the public) are at the end-user stage. It is important to consider the components of the supply chain both individually and collectively.

The third goal is to identify a minimum set of indicators of socioeconomic aspects of sustainable bioenergy systems based on defined selection criteria. The lack of consistent application of selection criteria can undermine attempts to promote sustainability indicators by generating well-intended but cumbersome wish lists. Too many indicators and data requirements thwart effective adoption because of prohibitive costs and unacceptable technical or administrative burdens. Selecting a set of indicators that is both complete in scope (sufficient when taken as a suite) and parsimonious is difficult.

Social aspects of sustainable bioenergy involve preserving livelihoods and affordable access to nutritious food; guaranteeing the reliability of energy supply; and ensuring the safety of people, facilities, and regions. They also include using open and transparent participatory processes that actively engage stakeholders, establish obligations to respect human rights, and emplace a long-term sustainability plan with periodic monitoring.

Economic aspects of bioenergy sustainability involve maintaining viable production, distribution and consumption of goods and services. This concept addresses short and long-term profitability of feedstocks, interaction with technical advances in society, differential costs of production and transport of various fuels, and the accounting and distribution of costs and benefits. The economic sustainability perspective recognizes the exigencies of production decisions, which are influenced by the expected price for a product and perceived risks of production and management practices. The potential for co-products also can affect economic costs and benefits across the supply chain (Vlysidis et al., 2011). Thus, interactions with other markets including animal feed, fiber, and food are considered. Economic factors are influenced by government policies, technology, energy and feedstock prices, demand resulting from diverse energy uses, and environmental consequences.

Our review of proposed indicators for bioenergy sustainability illustrates four significant challenges: (1) the sheer number and complexity of indicators required to cover the breadth of sustainability; (2) the costs of applying the indicators; (3) a lack of data – both now and in the foreseeable future –that are required to effectively apply proposed indicators; and (4) open-ended or inconsistent definitions of indicators, units and methods of measurement, leading to wide-ranging outcomes and incomparable results. The growing field of research and policies associated with the sustainability of bioenergy systems builds on decades of work in sustainable forestry and agriculture. Many organizations have identified measures to document practices for more sustainable agriculture [e.g., the Millennium Ecosystem Assessment (MEA, 2005), the National Sustainable Agriculture Information Service (Earles and Williams, 2005), U.S. Department of Agriculture Natural Resources Conservation Service, and Dale and Polasky (2007)], forestry [Forestry Stewardship Council, United Nations Food and Agriculture Organization (FAO, 2011b), state-wide best practices, etc.], bioenergy feedstock production [e.g. FAO (2012), Mata et al. (2011)] and economic development (e.g., USAID, 1998). Our work builds from those efforts as well as consideration of the indicators proposed by the Roundtable on Sustainable Biofuels (RSB, 2011), Global Bioenergy Partnership (GBEP, 2011), Council on Sustainable Biomass Production (CSBP, 2011), and several other national and international efforts that are in the process of selecting sustainability indicators for bioenergy. For example, the International Organization for Standardization (ISO) is developing criteria for bioenergy sustainability with plans to release a draft standard by 2014.

While prior efforts have gone a long way toward defining terms and building consensus about the importance of addressing sustainability associated with energy production and use, none have provided a short list of practical measures that cover socioeconomic aspects of sustainability. For example, GBEP lists 16 social and economic indicators, but the corresponding methodology sheets specify 40 sub-indicators and discuss about 30 additional measurements (GBEP, 2011). The RSB enumerates over 100 indicators under seven socioeconomic principles, and full compliance may require additional measurements and analyses, depending on the circumstances. Furthermore, many proposed indicators lack precision in definitions and protocols necessary for consistent measurement or equitable comparison. After considering recent efforts to establish indicators, we propose substantially fewer.

The objective of this paper is to present a small set of clearly defined indicators that focus on socioeconomic effects of bioenergy systems and that are feasible to measure. We identify a core suite of 10 indicators that can support monitoring and characterization of major effects that many bioenergy systems have or are likely to have on social and economic sustainability. We identify six additional indicators: four that require further refinement to be consistently applied and two that complement economic perspectives. The indicators are organized under six categories: social well-being, energy security, external trade, profitability, resource conservation, and social acceptability (Table 1). Together with environmental indicators, these socioeconomic indicators are proposed as a basis for moving forward in testing, evaluating and implementing a standard set of sustainability indicators for bioenergy systems across diverse settings and scales.

2. Approach

2.1. Criteria for selecting sustainability indicators

Our selection of indicators of bioenergy sustainability is based on the availability of information about socioeconomic conditions for each category, on other efforts to identify sets of indicators, and on established criteria for selecting indicators. Dale and Beyeler (2001) analyzed existing literature on indicator selection to identify key criteria:

1. *practical* (easy, timely, and cost-effective to measure),
2. *sensitive* and responsive to both natural and anthropogenic stresses to the system,
3. *unambiguous* with respect to what is measured, how measurements are made, and how response is measured,
4. *anticipatory* of impending changes,

Table 1
List of recommended indicators for socioeconomic aspects of sustainability of biofuels, conditions related to each indicator, and selected references on how each indicator could be measured. Evaluation of each of these indicators should consider the attribution due to the biofuel system being assessed. Food security, energy security premium, effective stakeholder participation, and risk of catastrophe require relatively more effort to develop data and measurement tools than the other indicators. Ten indicators in bold font are proposed to be the minimum list of practical measures of socioeconomic aspects of bioenergy sustainability.

Category	Indicator	Units	Potential related conditions	Selected references for methods and data
Social well- being	**Employment**	Number of full time equivalent (FTE) jobs[a]	Hiring of local people; rural development; capacity building; food security	Thornley et al. (2008), DTI (2004) and HM Treasury (2003)
	Household income	Dollars per day	Food security, employment, health, energy security, social acceptance	Smeets et al. (2008)
	Work days lost due to injury	Average number of work days lost per worker per year	Employment conditions, risk of catastrophe, social conditions, education and training	US Bureau of Labor Statistics (http://www.bls.gov/)
	Food security	Percent change in food price volatility[b]	Household income, employment, energy security	FAO (2011a)
Energy security	Energy security premium	Dollars per gallon of biofuel	Crop failures, oil or bioenergy price shocks; macroeconomic losses; shifts in policy, geo-politics or cartel behavior; exposure to import costs; new discoveries and technologies affecting stock/demand ratio	Leiby (2008)
	Fuel price volatility	Standard deviation of monthly percent price changes over one year		USDA or EIA bioenergy price data
External trade	Terms of trade	Ratio (price of exports/price of imports)	Energy security, profitability	US Department of Commerce and international agencies such as the International Monetary Fund and World Bank
	Trade volume	Dollars (net exports or balance of payments)	Energy security, profitability	
Profitability	Return on investment (ROI)	Percent (net investment/initial investment)	Soil properties and management practices; sustainability certification requirements; global market prices, terms of trade	Mankiw (2010)
	Net present value (NPV)[c,d]	Dollars (present value of benefits minus present value of costs)		
Resource conservation	**Depletion of non-renewable energy resources**	Amount of petroleum extracted per year (MT)	Total stocks maintained; other critical resources depleted and monitored depending on context (e.g. water, forest, ecosystem services)	IEA data for "Indigenous Production of Crude Oil, NGL and Refinery Feedstocks"
	Fossil energy return on investment (fossil EROI)	Ratio of amount of fossil energy inputs to amount of useful energy output (MJ) (adjusted for energy quality)	Petroleum share of fossil energy; imported share of fossil energy; energy quality factors; total petroleum consumed	Murphy et al. (2011), Mulder and Hagens (2008)
Social acceptability	**Public opinion**	Percent favorable opinion	Aspects of social well being, environment, energy security, equity, trust, work days lost, stakeholder participation and communication, familiarity with technology, catastrophic risk	Visschers et al. (2011) and related survey methods
	Transparency	Percent of indicators for which timely and relevant performance data are reported[e]	Identification of a complete suite of appropriate environmental and socio-economic indicators	McBride (2011) and this paper provide an initial suite of 29 indicators; ISO 26000 (2010) and ECOLOGIA (2011) provide guidance on public reporting
	Effective stakeholder participation	Percent of documented responses addressing stakeholder concerns and suggestions, reported on an annual basis[f]	Public concerns and perceptions; responsiveness of decision-makers or project authorities to stakeholders; full suite of environmental and socio-economic indicators	ISO 26000 (2010) and ECOLOGIA (2011) provide guidance on identifying stakeholders, establishing effective two-way dialogue, demonstrating responsiveness, and facilitating stakeholder participation
	Risk of catastrophe[g]	Annual probability of catastrophic event	Health, including days lost to injury; environmental conditions	Frequency of catastrophic events based on current incidence or similar technology

[a] FTE employment includes net new jobs created, plus jobs maintained that otherwise would have been lost, as a result of the system being assessed.
[b] The inherent complexity of establishing and measuring an indicator of food security implies that significant time, cost, and analytical effort will be needed to reach agreement on its definition, methodology, and application. In the meantime, we propose that the previous indicators for employment and household income serve as practical proxy measures for food security.
[c] Conventional economic models can address long-term sustainability issues by extending the planning horizon (e.g., projecting as an infinite geometric series) or calculating with a low discount rate.
[d] Can be expanded to include non-market externalities (e.g., water quality, GHG emissions).
[e] This percentage could be based on the total number of social, economic and environmental indicators identified via stakeholder consultation or on the indicators listed here and in McBride et al. (2011) for which relevant baseline, target and performance data are reported and made available to the public on a timely basis (at least annually).
[f] This indicator is relatively simple but may be difficult to interpret (e.g., whether an issue is effectively addressed is a subjective determination; and measurement is influenced by the ease with which stakeholder concerns and suggestions can be submitted, their comfort level in doing so, and how these inputs are tabulated).
[g] A catastrophic event can be defined as an event or accident that has more than 10 human fatalities, affects an area greater than 1000 ha, or leads to extinction or extirpation of a species.

5. *predictive* of changes that can be averted with *management* action,
6. *estimable* with known variability in response to changes, and
7. *sufficient* when considered collectively (i.e., a suite of indicators integrates changes in socio-economic sustainability) (Dale and Polasky, 2007).

Indicators meeting these criteria should allow users to set targets and create incentives for continual improvement toward more sustainable processes. Furthermore, indicators should provide comparable measurements of performance across different contexts where they will be applied. Additional standards apply to the data used to support indicator measurement, e.g., data validity, reliability, quality/uncertainty, timeliness, and representativeness (USAID, 1998). We acknowledge that some proposed indicators are more complex and costly to measure than others but contend that these costs become manageable if broad agreement to focus on a limited set of measures can be reached.

Collectively, the proposed suite of socioeconomic and environmental indicators forms a hypothesis of how effects on sustainability may be assessed. We submit that this suite of indicators could serve as a starting point to be adapted as necessary to address priorities for assessment in a specific place and time. The next step would be to test this hypothesis in diverse bioenergy systems and a variety of locations (see Section 4.3). The list of potential indicators should be reassessed as new information, technologies or data-collection techniques come online.

2.2. Prerequisites for selecting sustainability indicators

Legal and regulatory compliance are considered prerequisites for sustainability. Nations in protracted crisis and lacking adequate administration of justice show consistently high levels of food insecurity, poverty and deforestation (FAO, 2010, 2005). The Global Bioenergy Partnership (GBEP, 2011) notes that many institutional and policy aspects that are important and relevant for sustainability lie outside the scope of bioenergy indicators. GBEP lists 15 such issues with "good governance" at the top. In a specific example, the challenges of developing a sustainable biofuel industry in the context of ineffective governance are addressed for *Jatropha* in Tanzania (Habib-Mintz, 2010; Romijn and Caniëls, 2011).

Respect for clearly defined and socially accepted land tenure rights is another key prerequisite for measuring and achieving bioenergy sustainability. Situations that led to past land conflicts are unlikely to be resolved by a bioenergy project, no matter how well it fits sustainability strategies. While land ownership and resource tenure are highly varied and important for sustainability (Bailis and Baka, 2011), these concerns are neither new nor unique to bioenergy. A study by the Global Commercial Pressures on Land Project found that "four key failures of governance" were responsible for a long list of negative impacts associated with "land grabbing" (Anseeuw et al., 2011). We agree with guidelines proposed by the FAO that are applicable to any activity involving land transactions: the affected individuals, groups, and/or institutions should be consulted, traditional access to land by local communities should be safeguarded, and any affected parties should be identified and appropriately compensated (FAO, 2011a).

Given the role of governance discussed above, indicator selection depends on an assumed socio-political and legal context. Stable and transparent governance that is both legitimate and accountable is a prerequisite for energy security (Sovacool and Mukherjee, 2011), and we argue similar conditions are required for a suite of indicators to provide reliable information about sustainability. In other words, the socioeconomic effects of a bioenergy system cannot be consistently and reliably measured in settings where corruption, anarchy or personal insecurity is prevalent or in failing states and during periods of civil strife and crisis. Deployment of more sustainable production processes builds from a minimum institutional capacity for governance, health, safety, legal recourse, and protections of human rights. We assume these as pre-conditions for the selection of our proposed indicators. Exceptional circumstances typically require exceptional measures, and different indicators may be prioritized in those situations. But it is not practical or efficient to attempt to foresee or account for all potential extraordinary or illicit activities when devising indicators.

2.3. The challenge of attribution when selecting sustainability indicators

Obtaining sufficient evidence to show quantifiable relationships among causes and effects is a key challenge affecting the selection of indicators that meet our criteria. Determining influences on socioeconomic indicators is particularly vexing because social conditions vary greatly and depend on many different factors. Attributing social effects to particular causes is always difficult, and attributing particular effects to bioenergy or another cause is likely to be impossible in situations where minimum capacities to establish, promulgate, and enforce contracts, laws and regulations are lacking, when there is no recourse or due process available, or when human rights are abused.

This challenge leads to the need to define indicators so that the relative contribution of bioenergy is measurable. Some effects may differ not only in magnitude but in direction depending on how measurements are made (e.g., how stakeholders are grouped and assessed influences the distribution of effects and whether they are beneficial, neutral, or detrimental). Some of our proposed indicators can be directly measured and attributable to a biofuel supply chain (e.g., employment, profitability, public reporting), while others may require considerable research to discern and allocate relative causes.

3. Categories of indicators

Both socioeconomic and environmental aspects of sustainability are critical for bioenergy systems. McBride et al. (2011) identified 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. These environmental attributes, combined with the socioeconomic indicators proposed in this paper, represent a suite designed to reflect major sustainability considerations for bioenergy. Fig. 1 shows socioeconomic indicator categories that are influenced by different parts of the supply chain for biofuels. These categories and their component indicators are discussed below.

3.1. Indicators of social well-being

Well-being refers to the condition of the people and social systems with regard to prosperity, safety, and health. This category focuses on four indicators of social well-being: employment, household income, days lost to injury, and food security. Other services and health issues that affect social well-being are covered by environmental indicators (e.g., potential for disease can be related to measures of air quality while the provision of food and other services is related to indicators of productivity, soil quality, and water).

3.1.1. Employment

Employment has been considered in all known and proposed sustainability standards that incorporate socioeconomic issues. Policy makers have highlighted employment as a prime motivator of national policies supporting bioenergy research, development, and use. Perhaps most importantly, employment statistics are often

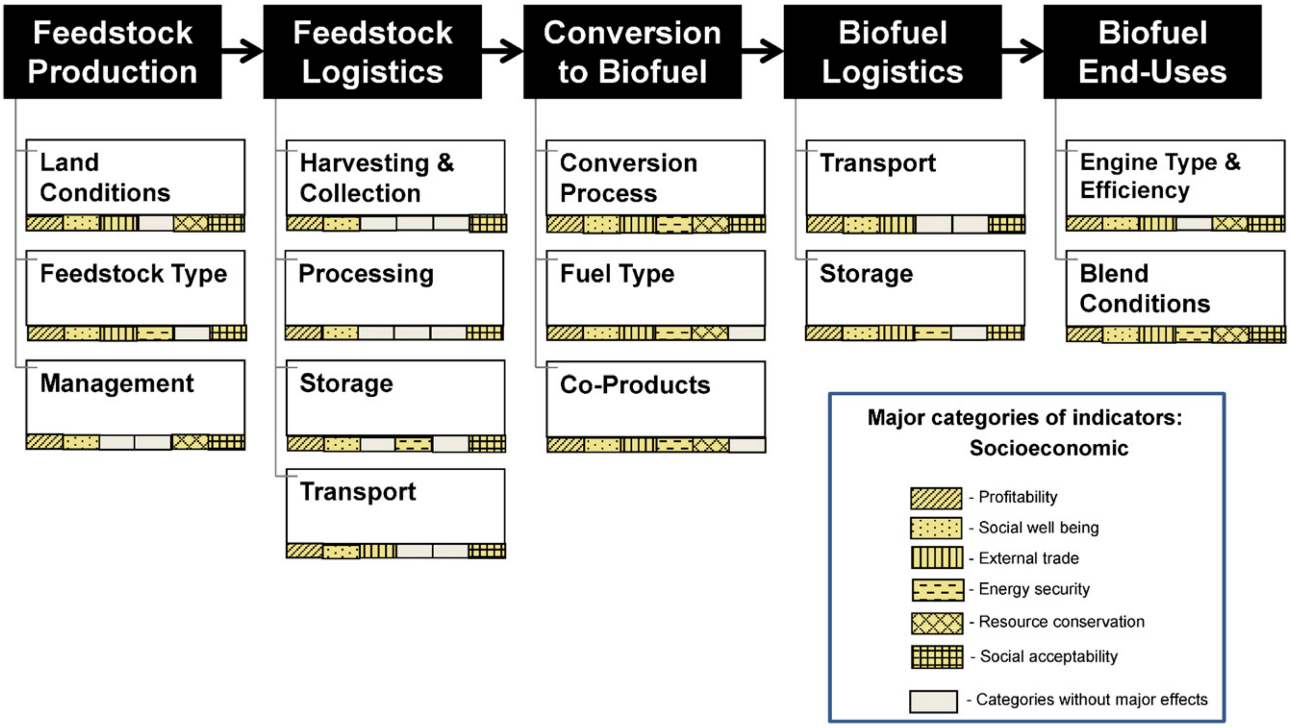

Fig. 1. Depiction of where categories of sustainability indicators experience major effects within the biofuel supply chain.

tracked and available. However, the quality of employment can vary widely and be considered at several temporal and spatial scales and in relation to specific steps in the supply chain. Therefore it is important to clarify terminology, units, and operational definitions when measuring employment in order to avoid ambiguity (Domac et al., 2005).

For local economies, the driving force behind the push for biofuels is often job creation and economic growth, while other potential benefits such as environmental protection and energy security may be considered bonuses (Domac et al., 2005). For example, US legislation for biofuels, as well as subsequent reports from the US Departments of Energy and Agriculture and renewable fuel lobbying organizations, highlights employment and domestic economic growth benefits (US GOV, 2007; Urbanchuk, 2011; Wallander et al., 2011; RFA, 2012). Similar analyses and reports in the European Union (EU) underscore the employment and economic growth benefits of biofuel policies (Kretschmer et al., 2009; Neuwahl et al., 2008).

Rural areas are expected to benefit from the establishment of biofuels industries through job creation related to biomass conversion facilities established near production sites (Berndes and Hansson, 2007) and the extensive supply chains involved in feedstock production. However, as with any industry, employment projections are contingent on assumptions about the configuration of the industry (e.g., feedstock choices and distribution and number of conversion facilities) and vary based on profitability of the production site and management choices across the supply chain (e.g., manual or mechanical harvesting). If profitability is low, optimistic job projections may not be achieved [as occurred for *Jatropha* plantations in Tanzania (Habib-Mintz, 2010)].

New bioenergy systems have impacts on the job market and local economy extending well beyond direct employment. Indirect employment refers to jobs that result from upstream and downstream suppliers of material and technology (Wei et al., 2010), and induced employment is secondary employment attributable to higher purchasing power (Domac et al., 2005). Employment impact analysis typically considers direct, indirect, and induced employment. For example, Urbanchuk (2011) estimated that in 2011 the US ethanol industry directly supported 90,200 jobs while an additional 311,400 indirect jobs were identified. Although indirect and induced employment can be difficult to estimate (e.g., Smeets and Faaij, 2010), including this information enhances the utility of employment measures for policy makers. Quantifying total effects on employment is especially difficult in some developing nations that lack reliable statistics, but sustainability analysis implies a need to account for intricate linkages among the various dimensions of a system. To quantify the relationship between direct, indirect, and induced employment, one could conduct an analysis similar to that of Thornley et al. (2008), which follows the methodology supplied by DTI (2004) and HM Treasury (2003).

One indicator, full time equivalent (FTE) employment generated (including both direct and indirect), is recommended to capture the number of jobs provided by the industry (Table 1). The selection of this indicator was motivated, in part, by the importance of measuring employment in both local and national economies and by the availability of data and methods for measuring direct and indirect employment (e.g., HM Treasury, 2003; Thornley et al., 2008).

There are many ways that employment could be interpreted with respect to other variables (e.g., FTE positions/unit of energy, total employment in person-years/ha of land devoted). When sufficient data on pre- and post-industry employment are available for the appropriate scale, comparing total employment in the energy sector before and after bioenergy systems development can be used to estimate the industry's net effect on overall employment. Bioenergy FTEs can also be compared to other available employment data or to state or regional statistics as a means to capture socio-economic effects of biofuel systems related to the employment of local labor. Studies using employment indicators with dissimilar units can be compared utilizing the methods explained by Wei et al. (2010). The spatial and temporal extent of the analysis influences the degree to which FTE incorporates indirect and induced employment as well as issues such as reallocation of employment among sectors or regions (e.g. shifting employment from one area or sector to another versus creating net additions to the workforce).

3.1.2. Household income

Household income of those employed in the bioenergy industry is a useful indicator of well-being and is measured as financial compensation received by workers for their labor. As with other indicators, the income should be attributable to biofuels and distinct from other non-bioenergy-related income. While wage rates are influenced by market forces, tradition, social structure, seniority, and other factors, they can be a useful way to compare welfare received from the bioenergy industry to welfare received from other industries. For example, Sydorovych and Wossink (2008) consider income stability and predictability to be important aspects of agricultural sustainability. Also, Smeets et al. (2008) found that wages were higher for sugarcane harvesting and ethanol refining than for comparable employment in other sectors.

Careful thought will be required to define what sources of household income are attributable to the bioenergy industry or project being analyzed. Methods consistent with those applied to the employment indicator should be used to identify activities that are clearly linked via the supply chain, such as biomass storage and management, trucking and transportation, and other agricultural or forestry-based employment associated with biomass production, harvesting and logistics. At a minimum, data should be collected to estimate the average income of employees in the industry. Our proposed indicator is dollars per day of household income (Table 1). However, collecting data to generate the distribution of income would allow better comparison to other industries and among alternative bioenergy production pathways.

3.1.3. Work days lost due to injury

Work days lost to injury associated with the bioenergy industry are indicative of social welfare and, particularly, health and safety issues. This indicator is often reported as average days lost per worker per year in a defined sector or industry (Table 1). In a calculation of average days lost per worker per year, one would consider the employment directly and indirectly generated by bioenergy industries as identified and described in Section 3.1.1 above.

3.1.4. Food security

The use of cropland to grow biofuel feedstocks has generated concern that the energy benefits of biofuels may come at the expense of food security. The majority of current ethanol and biodiesel production uses industrial feed grain, sugar, and oil crops as feedstock, including maize in the US, sugarcane in Brazil, oil seeds in Europe, and palm oil in Asia. Food security became a concern in 2007 and 2008 when global food prices rose rapidly. Initially, those price increases were largely attributed to biofuel production (Runge and Senauer, 2008; Mitchell, 2008; Rosegrant, 2008); however, subsequent analyses suggested that the impacts of biofuels on food prices were overstated (Zhang et al., 2010; Ajanovic, 2010; Baffes and Haniotis, 2010; Kim and Dale, 2011; Gallagher, 2010; Babcock, 2011). Several recent studies examined crop production and price data and reached some common conclusions: (1) biofuel production is responsible for a much smaller effect on food prices than initially expected; and (2) biofuel production has a smaller effect on crop exports from the US than previously estimated (Trostle et al., 2011; Oladosu et al., 2011; Gallagher, 2010). Furthermore, the analyses highlight that food price increases have lagged behind other traded commodity prices, all of which track the global price of oil. The divergent analyses of the effects of biofuels on global commodity prices and exports reflect the complexity of factors linking food and energy prices (Baffes and Haniotis, 2010; IMF, 2011). Indeed, recent studies suggest that food price trends follow oil prices, and short-term volatility is linked to weather and local import/export polices. Thus, biofuels could contribute to reducing food prices and price volatility to the degree that biofuel production mitigates oil price increases and provides a cushion in global supplies at times of inevitable shocks from weather and politics. Nevertheless, this issue will persist as long as there are hungry people in the world and land is used to produce biofuel.

Concerns in identifying indicators of food security are that (1) there is no clear measure for "food security," (2) no practical indicator for the effects of bioenergy on food prices is available and (3) most analyses, including those referenced above, focus on food price changes rather than food security. The United Nations (UN) states, "Food security exists when all people, at all times, have physical and economic access to sufficient amounts of safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006). While this definition is complete, it is difficult to translate into measurable indicators. The National Research Council recently released a report that emphasized a lack of consistent definitions and relevant data needed to assess food security at appropriate scales for sustainability analysis (NRC, 2012).

Acknowledging the complexity and difficulty associated with developing practical indicators to measure multiple dimensions of food security, the United Nations has historically focused on data reflecting food *insecurity* (e.g., thresholds for undernourishment or severe hunger) (FAO, WFP and IFAD, 2012). These data are published in annual State of Food Insecurity and related reports (FAO, 2009; FAO, 2010; FAO, WFP and IFAD, 2011, 2012), which note several issues: (1) recent changes in the number of undernourished people at global and national levels may merely reflect adjustments in definitions and new data; (2) food insecurity is strongly associated with poor governance; (3) food insecurity has been associated with persistent low-priced food commodities and food aid that undermine incentives for local production; and, perhaps most importantly, (4) food insecurity is largely caused by food price volatility. Thus, an effective indicator for food security is more complex than simply tracking changes in food prices and land use that may be attributable to bioenergy.

Based on the state of scientific data and analysis discussed here, we propose that the percent change in price volatility of food crops attributable to biofuels be developed as an indicator of food security (Table 1). While the percent change in price and the relative proportion attributable to biofuels are difficult to estimate, this information is required to assess effects on price volatility. Price volatility is a better indicator of food security than change in food price because sudden price swings harm both producers and consumers (Kline et al., 2009). Sudden price falls can put producers out of business while sudden increases affect consumers; the cycle of large and sudden changes increases risk and undermines investments in agriculture that could improve food security (FAO, 2010). If a policy or project generates confidence around more stable prices, then that stability can support local production opportunities even if prices are higher.

Our proposed food security indicator requires further work to implement because there is no agreed upon way to measure how food price volatility can be attributed to biofuels. Development of this indicator requires an approach that controls for major influences on changing food prices and distinguishes effects due to bioenergy projects or policies. FAO (2011b) provides a starting point with its indicator for changes in real prices of staple crops attributable to bioenergy. FAO (2011b) proposed indicators aimed at (1) measuring the domestic availability of staple foods and (2) determining whether use of staple foods for biofuels is met by additional production or replacement of existing production. Their estimation requires detailed data on the availability of staple foods and effects of biofuel production on land and food supplies. Still, the FAO measures may not reflect changes in food security, for other factors not considered in the analysis determine effective access to nutritional resources. However, the scope, methods, and potential data sources supporting the FAO indicators could be adapted for calculating the indicator proposed here. Many of the data sets needed for assessment of food security relate to commodity production, use and stocks and exist at national scales (e.g., from FAO or USDA), but local scale data and attributional evidence are often difficult and costly to obtain.

The food security indicator of food price volatility provides an overall measure of price stability as related to the balance between supply and demand in a region. The ratio of non-biofuel uses to total supply of crops provides a measure of the competition for crop supplies between biofuels and non-biofuels. For example, the change in this ratio would indicate whether a decline in per capita food and feed uses might have occurred because of biofuels, reductions in total supplies or changes in imports or preferences. Our proposed food security indicator differs from measures proposed by FAO and others in that we separate crop uses for food and feed from uses for fuels, measure crop uses in per capita terms, assess attribution, and then consider how biofuel production affects price volatility.

Other indicators that have been proposed for evaluating the food security effects of biofuels include the proportion of arable land devoted to biofuel production in a given region [as called for by GBEP (2011)]. This indicator is meant to represent the competition for land between food and biofuels. However at the global level, Gasparatos et al. (2011) estimated that biofuels account for less than 2% of the total harvested land area. It is also not clear what a change in the proportion of arable land represents in terms of food security, because if biofuels generate more income than other land uses, food security could increase with higher proportions of land dedicated to bioenergy. Hence, this indicator has to be considered in the context of land suitability for various purposes and variable market opportunities. And if a region has limited capacity to grow food efficiently but extensive ability to produce bioenergy feedstocks, increasing the portion of land in bioenergy feedstock may improve food security. Another proposed indicator of food security is the per-capita food and feed uses of crops (or alternatively the ratio of non-biofuel uses of crops to total supply). Selected indicators should be able to provide representative, unambiguous and unbiased measurements of change in sustainability. Yet per-capita consumption and crop-use ratios may not reflect food security and may provide false signals of change (NRC, 2012; FAO, 2010). For example, increasing per-capita consumption is associated with problems such as obesity, diabetes, and other health problems associated with eating too much of the wrong foods (WHO, 2011).

The inherent complexity of establishing and measuring an indicator of food security implies that significant time, cost and analytical effort will be needed to reach agreement on its definition, methodology, and application. In the meantime, we propose that the previous indicators for employment and household income serve as practical proxy measures for food security. While imperfect, these indicators help address concerns about bioenergy effects on food security. Given the fact that increasing coping mechanisms (including employment opportunities) and increasing wealth are known to mitigate food insecurity (FAO, 2010; FAO, WFP and IFAD, 2011), employment and household income indicators are relevant.

3.2. Indicators of energy (and supply) security

Energy security is closely related to economic security and has important military, foreign policy, and national security dimensions. Apart from the need for a reliable supply of military fuels, it can be argued that the military and foreign policy dimensions of energy arise almost entirely from economic interests related to energy security (Greene and Leiby, 2007; Stern, 2010). This relationship suggests that a focus on economic measures of energy security is appropriate. The economic costs depend upon the economy's exposure to energy shocks and its long-term dependence on energy imports, particularly from non-competitively supplied energy sources. Thus for biofuels to enhance energy security, they must lead to reduced imports of non-competitively supplied fuels and a shift in consumption toward more stably supplied fuels. For biofuels, energy security also requires reliability and security of resources and activities that support the biofuel supply chain, including water, nutrients, and production operations, in spite of highly variable commodity and product prices.

Three key factors promote biofuel energy and economic security: stability of energy feedstock supply, stability of product and co-product supply and demand, and flexibility of the feedstock and fuel system. Each of these influences is discussed briefly.

The stability of primary feedstock supply for biofuel depends on the volatility of biofuel feedstock production and the diversity of bio-feedstock supply sources for the biofuel system. Historical data on crop yield and price volatility indicate that supply stability (FAO, 2008) could be an issue for biofuel feedstocks. Yield fluctuations in response to some stressors (such as cyclic drought or pests) can be accommodated in the supply chain, especially if there is substantial diversity in that supply chain and the opportunity to adjust operations. Biofuel feedstock systems may be less resilient when faced with fluctuations due to unexpected disturbances such as hurricanes, floods, or disease. Feedstock supply stability is affected by the availability, choice, and engineering of crop varieties to achieve specific goals (e.g., drought and pest resistance) as well as management practices. There may be additional uncertainty regarding the stability of feedstock supply from new sources such as algae that may be susceptible to pond crashes and grazing pressure as well as sudden fluctuations in temperature or water chemistry that are out of operators' control. Feedstock supply stability, from the perspective of the biorefinery owner, can be increased by planned and regionally integrated logistics (advanced preprocessing such as pelletizing) and infrastructure (access to railroad) such that they can draw feedstock over large areas.

The stability of product supply and demand (and prices) depends on management of product inventories, availability of a stable market for biofuel co-products, long-term policies and subsidies, reliable production/conversion processes, transportation logistics, and the stability and level of oil prices. The relationship between agricultural commodity price volatility and inventory levels is widely reported (e.g., Munier, 2010). Feedstock and product inventory management may be as important to biofuel cost stability as it has been for petroleum fuels. Diversifying markets and production lines (e.g., for food, fuel, fiber, fodder, chemicals) for a given feedstock supports larger and more widespread production that may help absorb temporary or localized shocks to supply and demand. Access to a reliable market for biorefinery co-products is important for producers to weather shocks in feedstock or product prices.

Flexibility of the biofuel feedstock and fuel system enhances energy and economic security by allowing substitutions during short-run supply or demand fluctuations. Supply flexibility follows when feedstock producers and logistical systems can respond to multiple markets through, for example, greater feedstock uniformity and enhanced transportation systems. System flexibility also is increased by biorefinery technologies that can use multiple feedstocks and produce a range of products, in varying proportions. Petroleum product pipelines have the potential to expand the range of long-distance transport methods for drop-in, biologically produced fuels. Demand flexibility depends on the types of fuels produced, with a distinct advantage anticipated from drop-in-replacement fuels compared to fuels that are incompatible, or blend-limited, with fossil fuels and their infrastructure. The flexibility of end-use biofuel demand increases with the availability of biofuel refueling infrastructure and the extent to which the vehicle stock includes vehicles with capability for fuel switching or fuel flexibility. With respect to fuel flexibility, jet aircraft can use bio-based fuels in their fuel mix, but current refining processes do not produce fuels with the required aromatic compounds or density specification, and so fossil fuels need to be blended with the biofuels (Agusdinata et al., 2011).

3.2.1. Energy security premium

The energy security premium offers an effective computed indicator of biofuel energy security (Table 1). Energy-security specialists have developed an economic measure that combines the costs of supply disruptions and price shocks with the costs of reliance on high-cost, non-competitive oil supply. This "oil security premium" (Plummer, 1981; Bohi and Montgomery, 1982; Leiby et al., 1997; Leiby, 2008) estimates the difference between the marginal economic cost to society and the market price paid for petroleum. This approach has been extended to estimate the energy security benefits of substituting biofuels for petroleum in vehicle fuels, measured in $/gallon biofuel (Leiby, 2008; USEPA, 2010). This measure needs additional effort to develop consensus around a standard measure capable of capturing the range of energy security factors described above.

3.2.2. Fuel supply stability

The second indicator recommended is fuel price volatility (Table 1), which can be calculated as an expression of the volatility in the biofuel and feedstock prices under analysis. An advantage of using this indicator is that prices are directly observable, rather than requiring assumption-based calculations. Furthermore, the volatility of commodity prices reflects and integrates many factors including fluctuations in biomass supply, biofuel demand, oil price, and overall fuel demand. To the extent that system flexibility, redundancy and resilience are developed, those attributes are reflected in diminished price volatility. Finally, price volatility is a primary driver of the costs measured by the security premium and, therefore, is an informative "leading" indicator in that it can be used to predict changes in economic welfare.

3.3. Indicators of external trade

Trade is the movement of goods and services across borders. External trade is defined by the system boundaries of the sustainability assessment context and often refers to movement across national borders. Exports represent the portion of production that is sold outside a defined boundary, while imports represent the portion of internal consumption that is purchased from the exterior. Countries are considered to be open or closed based on the level of international trade relative to the Gross National Product (GNP). International trade promotes the overall efficiency of the global economy by enabling one country to exchange its production of goods and services for those that may be less cost-effectively produced domestically. Thus, international trade can have a strong influence on prices and the level of income, and hence on national economic health. Energy resources are currently a substantial fraction of global trade. In an international survey (largely of bioenergy industry stakeholders from Europe), import tariffs and sustainability certification systems were perceived by some experts as barriers to trade for ethanol and biodiesel, whereas logistical issues (lack of pretreatment methods to compact biomass at low cost) were thought to impede trade of wood pellets (Junginger et al., 2011). In the same survey, high oil prices and strict greenhouse gas emissions reduction policies were perceived to promote international bioenergy trade. Two indicators of international trade related to the socioeconomic sustainability of biofuels are recommended (Table 1). The two indicators discussed below measure different but related effects. Terms of trade (TOT) is a price advantage indicator; whereas the trade volume is a quantity indicator. We propose trade volume as a core indicator that is complemented by TOT.

These two indicators can be estimated at national levels from trade and external accounts data collected by agencies such as the United States Department of Commerce and international agencies such as the International Monetary Fund (IMF, 2011) and World Bank (2011). While these indicators are primarily relevant at the national or international scale and most of the available data are at those scales, sub-national data are often collected, and special studies have looked at the balance of trade in energy supplies at local (e.g. municipal) scales.

3.3.1. Terms of trade

Terms of trade (TOT) is defined as the ratio of the price (or price index) of exports to that of imports. TOT is a measure of the domestic gains from international trade. A higher TOT means the country can purchase more imports per unit of its exports. Thus, large changes in TOT can have significant socioeconomic implications through changes in the costs of goods and services and external earnings/expenditures. The net effects of bioenergy-related trade and substitution for fossil-based fuel imports could generate substantial impacts on the TOT for specific states or regions, as well as for the United States and other nations such as Brazil. The United States is both a big importer of crude oil (buying more than 20% of global crude exports) and a big exporter of maize (at about 60% of global maize exports). This large role can influence global prices in these markets (IEA, 2010). A number of recent studies have highlighted the potential implications of biofuel policy on TOT (e.g., Moschini et al., 2010). The displacement of imported fuels by domestically produced biofuels could have advantageous effects on TOT to the degree that the savings on imports exceed any offsetting reductions in the value of exports.

3.3.2. Trade volume

The second recommended indicator of external trade estimates the contribution of bioenergy to trade volume, measured as the amount of money expended for net exports or balance of payments (Table 1). Net exports measure the surplus/deficit in goods and services trade. The balance of payments captures the surplus/deficit in both the flow of current income and payments (current account), including net exports, and that of investments (capital account) across borders. Long-run surpluses or deficits in net exports and balance of payments are major impediments to the health of an economy (state, nation, or globe), since they represent large transfers of income from one area or nation to another. Depending on the sources of feedstocks, technology, investments, and final products, a nation's bioenergy policies may lead to substantial changes in its net exports and balance of payments. For example, Adeyemo et al. (2011) examine the balance of payments effects of biodiesel canola production in the Eastern Cape Province of South Africa using a partial equilibrium model.

3.4. Indicators of profitability (i.e., financial viability)

Economic viability represents one of the three pillars of sustainability, along with environmental and social requirements. Profitability is perhaps the most basic indicator of economic sustainability and appears in many sustainability frameworks (e.g., Sydorovych and Wossink, 2008). Profitability is pertinent to sustainability of the entire supply chain as well as to particular components (Fig. 1). It is a function of product price and costs of production, both of which are influenced by various policy and market conditions, which are subject to change. The sustainability of bioenergy plants is influenced by the relative profitability of alternative markets for biofuels feedstocks [e.g., maize for feed (Tepe et al., 2011) and wood for timber (Conrad et al., 2010)], as well as co-products. Profitability of biofuels production has been shown to be sensitive to the price of petroleum (Mallory et al.,

2011) and associated with the failure of some biorefineries in challenging economic times (Gillon, 2010).

While economists and analysts use many different measures to assess financial viability and profitability, we recommend return on investment (ROI) and net present value (NPV) as meeting the criteria for sustainability indicators, because of their practicality and ease of use. Both ROI and NPV are prominent indicators of profitability that are well established in conventional economic theory. As discussed below, these conventional indicators of profitability can also be adapted to better evaluate long-term economic sustainability. Related economic indicators that could be applied include internal rate of return, payback period, and benefit/cost ratio. Vlysidis et al. (2011) illustrate the use of most of these indicators in a study of the profitability of biodiesel plants producing a co-product, succinic acid.

If these and other conventional economic formulas are to be extended as indicators of economic sustainability from a societal perspective, they need to be expanded to include values of non-market externalities. Those externalities are unintended positive or negative consequences of a practice that is not considered within the boundaries of the economic system. In the incorporation of externalities, it may be necessary to apply unique discount rates and to extend the planning horizon to account for long-term costs and benefits (e.g., those associated with climate forcing or climate change adaptation).

Subsidies, co-products, and certification schemes can be important factors contributing to profitability. Government economic subsidies or payments can also be powerful factors that influence agricultural profits and sustainability (Sydorovych and Wossink, 2008). Subsidies can help start an industry such as algal biofuels, but profitability measures may change when these public investments are withdrawn. Production of co-products can contribute to profitability. For example, small-capacity biodiesel plants may not be profitable unless co-products are produced (Vlysidis et al., 2011). The premise behind voluntary certification schemes is that participating companies have a competitive edge because of improved marketability of their products. As participation grows in certification activities, producers of voluntarily certified products within the bioenergy market might achieve a price premium above non-certified producers, such as occurs for other green-labeled products like "fair trade" goods (e.g., Weber, 2011). However, to remain economically competitive, the price premium would need to offset fully any additional costs associated with achieving certification.

3.4.1. Return on investment

ROI is the ratio of money gained (or lost) on an investment relative to the amount of money invested, and is often expressed as a percentage. In simplest terms, it is calculated as:

$$\mathrm{ROI} = \frac{V_\mathrm{f} - V_\mathrm{i}}{V_\mathrm{i}}$$

where ROI is return on investment; V_f is the final value of the investment; V_i is the initial investment.

To account for the time value of money, V_f and V_i should be expressed as a sum of discounted present values. In discounting, lower interest rates emphasize long-term economic viability over short-term profit. Thus, the implications of ROI as a sustainability indicator are subject to the planning horizon and discount rate used in its calculation. Adapting ROI through the application of longer time horizons and lower discount rates can better reflect long-term economic sustainability. When ROI is greater than zero, the system is profitable. A biofuel system is competitive if its ROI is greater than that of alternative projects.

3.4.2. Net present value

NPV is the sum of discounted benefits minus the sum of discounted costs of a project, expressed in monetary terms:

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{R_t}{(1+\mathrm{i})^t}$$

where NPV is net present value; R is the net cash flow at time t; t is the time of the cash flow; i is the real interest (or discount) rate.

If the NPV is less than zero, the project is not profitable, while an NPV exceeding zero is profitable, with higher profitability indicated as NPV increases. Like ROI, NPV is sensitive to the discount rate used in calculating discounted present values, with long-term cash flows and economic sustainability more heavily weighted with lower discount rates. While there is no single, universally accepted discount rate, it should be noted that lower discount rates favor systems with distant future benefits, e.g., environmental, social, and/or economic sustainability.

3.5. Indicators of resource conservation

Goals for sustainable management of natural resources are illustrated by the South African Ministry of Water Affairs and Forestry in their simple slogan, "Some for all forever" (Funke et al., 2007). Indicators for resource conservation ideally reflect progress toward achieving "enough for all forever." This interpretation implies an equitable distribution of resources among all people on earth today and in the future – a challenging concept to define and measure. Indicators for resource conservation are recommended in cases where the energy supply chain affects a resource that is vital for sustainability, resource stocks are being depleted, and this depletion is not otherwise captured in the suite of sustainability indicators. Moreover, indicators of resource conservation draw attention to the renewability of bioenergy, a key element of sustainability that is not captured in other indicators. Two basic indicators for resource conservation are identified in Table 1: depletion of non-renewable energy resources and fossil energy return on investment (EROI).

Several possible indicators of resource conservation were considered but not selected for assessing bioenergy sustainability. We do not include measures thought to be redundant with EROI such as net energy value (Persson et al., 2009), net energy yield ratios, or absolute energy ratios. We note that "emergy," the total amount of energy of one form required directly and indirectly to make another form of energy (e.g., see Felix and Tilley, 2009), is similar in definition to the proposed protocol for measuring EROI, described by Murphy et al. (2011). While other changes in the quantity of agricultural land, water and forests are important, the corresponding effects attributable to fuel production processes should be reflected in the suite of environmental sustainability indicators [e.g., soil quality, water quality and quantity, greenhouse gases, biodiversity, air quality, and productivity (McBride et al., 2011)].

3.5.1. Depletion of non-renewable energy resources

A resource conservation indicator specifically proposed for biofuels is the amount of crude oil stock extracted each year. Unlike water and soil, non-renewable energy minerals are not typically considered among environmental indicators for bioenergy. Yet they represent valuable natural capital for a region, state or nation, the global community, and future generations. Some minerals can be conserved through efficient use and, with additional energy inputs, recycled to serve similar functions as the source mineral. But fossil fuels that are oxidized with use cannot be recycled. At current rates, over four billion tons of oil consumed annually (IEA, 2010) will never be available for future use. There is growing recognition that industrial societies have rapidly depleted a majority of the most accessible petroleum reserves (Aleklett et al., 2010; IEA, 2010), along with their option value for future use. Given that biofuels provide a liquid fuel alternative to petroleum products, the conservation of crude oil stocks is of special interest.

The proposed indicator, metric tons of petroleum extracted per year, is relatively easy to track at multiple scales, provides a simple measure of future options lost, and uniquely complements other sustainability indicators to reflect the interests of future generations. Data on petroleum removals are available [e.g., via the International Energy Agency (IEA), Energy Information Agency, and US Geological Survey]. The removal of petroleum stocks can be measured using standard units, definitions, and data sets. For example, the IEA releases annual reports on metric tons of crude oil, natural-gas-liquids, and refinery feedstocks extracted, by country. Petroleum fuels can also be monitored in terms of metric tons per unit of equivalent liquid fuel (MJ) supplied, and this information may be applicable for comparisons of pathways (as reflected in the indicator below). For smaller scale analyses and comparisons, the total use of petroleum associated with different energy production pathways is of strategic value.

We considered but rejected the use of value and price as indicators for natural resource scarcity and conservation. While a monetary value provides an important perspective on resource consumption, we focus on actual volumes of resources consumed or exported that are no longer available for future use within a defined geographic area or system boundary under analysis. This approach allows analysts to assign a monetary (or other) value to the resource that is appropriate to a given study and time frame. Also, prices are calculated differently across stocks and flows in the supply chain and may be impacted by varying resource quality, location, policies and other market fluctuations. Moreover, value and price depend on factors such as the potential for repurposing to provide services that are not envisioned today and potential substitutability (Bond and Farzin, 2008). Substitutability is important because, as prices rise to reflect scarce resources, "unconventional" resource extraction (for example, hydraulic fracturing and tar sands) becomes economically attractive and leads to potentially higher marginal social and economic costs.

3.5.2. *Fossil energy return on investment (fossil EROI)*

The second indicator for resource conservation, fossil EROI, refers to net energy produced. Heinberg (2009) defined EROI as "the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource." This measure has been applied to compare energy options for over twenty years, and there is a growing community of scientists working to standardize terminology and approaches (e.g., Cleveland et al., 1984; Murphy et al., 2011; Mulder and Hagens, 2008; Hall et al., 2009, 2011). EROI builds on disciplines and data sets associated with Life-cycle Assessment (LCA) (e.g., ISO 14000). Typically, EROI considers all direct energy consumed to provide a useful unit of energy, as well as energy associated with significant material inputs. Henshaw et al. (2011) suggest that EROI should account for energy associated with any significant monetary expenditures required to produce energy. For the purposes of a biofuel indicator, we recommend using the protocol and definitions provided by Murphy et al. (2011) for the fossil fuel EROI or "fossil energy ratio."

3.6. *Indicators of social acceptability*

Social acceptability of bioenergy technologies and management systems reflects many values that are not considered in environmental and economic analyses. These include aesthetic values, recreational values, cultural values, and public perceptions that may be as important in determining sustainability as are economic and environmental factors. A production system is not sustainable if the local community does not accept it (Cornforth, 1999). Social acceptability has influenced the prevalence and locations of nuclear power (Visschers et al., 2011), hydropower (Gandhi, 2003), oil drilling (Martin, 2011), and wind energy facilities (Devine-Wright, 2005). Social acceptability issues are pertinent to the entire supply chain but emphasized for the feedstock production stage (Fig. 1). In addition, perceptions concerning risk from genetically modified energy crops or algal biofuels may influence the viability of these technologies for bioenergy. Social acceptability is a dynamic concept that can change with technical solutions, social and economic interests, increasing knowledge and awareness, biological conditions, and scale of adoption (Shindler and Brunson, 2004).

Evolving social perceptions of bioenergy have influenced policies and regulations and will continue to be a factor in determining the sustainability of bioenergy systems because of the high visibility and importance given to issues such as land-use change and potential secondary effects on food security, biodiversity, climate forcing, human health, and aesthetics. Concerns about social conflict have led state officials in Indonesia to approve concessions for palm oil plantations preferentially in forests and peat wetlands, as these largely uninhabited areas avoid social conflicts that arise in other areas (Wicke et al., 2011). This process leads to direct, detrimental effects on sensitive landscapes despite ample availability of previously cleared and underutilized land (Koh and Ghazoul, 2010).

Many factors associated with the social acceptability of energy and other technologies influence risk perceptions, such as familiarity, control, potential for catastrophe, and uncertainty about probability or intensity of risk (Slovic et al., 1982). Other important factors associated with social acceptability of technologies include "affective" feelings (Finucane et al., 2000) and social trust (Siegrist, 2000; Visschers et al., 2011). For example, in Switzerland, social acceptance of nuclear power stations is determined largely by the perception of benefits for energy security and also by the perception of climate-change benefits and risk perception (Visschers et al., 2011). Social acceptability of different forest harvest treatments was found to be associated with aesthetics, effects on natural properties, trust in information given, community benefits, and significance of citizen participation in the planning process (Shindler and Collson, 1998). Reduction of wildfire risk and ecosystem restoration might be added to this list in considering woody feedstocks for bioenergy. Social acceptability pertains to resource and supply-chain managers as well as to the surrounding community. For example, Iowa farmers who are concerned about the potential water quality effects of removing maize stover are less likely to harvest it (Tyndall et al., 2011).

The proposed indicators (Table 1) were selected to reflect social acceptability when taken together as a group, while individually meeting criteria for being practical and cost-effective to measure and providing consistent information about the measured effects. They were also selected based on their ability to adapt to different scales and segments of the biofuel supply chain. These indicators are inter-related. For example, many proposed standards for sustainable bioenergy production include effective engagement of stakeholders and transparent reporting, including plans, potential effects and actual performance data after production starts (e.g., RSB, 2011; GBEP, 2011). The risk of catastrophe (Slovic et al., 1982; Jianguang, 1994; Visschers et al., 2011) is a well-known factor affecting social acceptance of technologies and hence, public opinion. Perceived risk, which is based on interpretation of information by stakeholders, influences many of the social acceptability issues discussed in this paper and is a motivating force behind stakeholder participation.

3.6.1. Public opinion

Public opinion (% favorable opinion) can be determined using a standard survey instrument to gather data on public perceptions of the bioenergy project under assessment. This indicator provides a direct measure of social acceptability. Surveys of public opinion regarding the social acceptability of a project or technology are measures that integrate variables across sectors and categories. These surveys are common for energy technologies (e.g., nuclear energy in Visschers et al., 2011) and measure the percentage of the surveyed community that rates the project as acceptable. Surveys may also include measures that categorize respondents as favorable, neutral or unfavorable. Surveys can be helpful but need to be crafted and interpreted carefully. Surveys should be designed to measure the public's reaction to high probability and low impact events in contrast to focusing on risk of catastrophe, a separate indicator which is discussed below. However, it can be unclear whether factors that are correlated to social acceptability are determinants or consequences of social sustainability. Research is sometimes needed to distinguish between these possibilities, as was done in a study of how public trust relates to the social acceptability of genetically modified food (Poortinga and Pidgeon, 2005). Standard protocols need to be validated and applied consistently over time to track changes in public opinion.

3.6.2. Transparency

Transparency can be demonstrated through periodic public reporting on social and environmental performance indicators. All interested parties should be provided free access to data reflecting sustainability indicators such as those described here and in McBride et al. (2011). The extent to which timely and accurate information is made available, and the degree to which this information addresses issues of interest to stakeholders, reflect measures of transparency supporting sustainability. The proposed unit of measurement, the percentage of indicators for which performance is reported in a timely manner (Table 1), is context-specific. This public reporting should provide relevant baseline, target and performance data for all environmental, social and economic indicators identified. The suite of indicators may be adapted and prioritized for a given project or situation based on stakeholder participation (discussed below). Furthermore, annual reporting should meet an established standard (e.g., such as that proposed by the Global Reporting Initiative: www.globalreporting.org).

3.6.3. Effective stakeholder participation

Stakeholder participation is a key component of social acceptability. Many aspects of stakeholder identification and participation are reflected in sustainability literature and proposed certification schemes (Huertas et al., 2010; Chalmers and Archer, 2011). The RSB, for example, enumerates nine indicators dedicated to stakeholder consultation, plus many other sub-requirements to demonstrate that biofuel operations are "planned, implemented, and continuously improved through an open, transparent, and consultative impact assessment and management process" (RSB, 2011). Stakeholder participation can contribute to more effective and enduring progress toward other environmental and socioeconomic goals reflected in McBride et al. (2011) and in prior sections of this paper. This process involves providing stakeholders with the necessary understanding of the technologies employed and building a sense of control, trust, and ownership in the project and its benefits. Stakeholder participation can be more effectively achieved when there is meaningful two-way dialogue with the industry, if concerns are acknowledged and addressed in a timely manner (ISO, 2010), and if documentation reflecting performance of the full suite of environmental and socioeconomic sustainability indicators is complete, trustworthy, and readily accessible (see Transparency indicator above). Mechanisms that permit effective exchange of ideas and concerns among stakeholders with different viewpoints are also important. Stakeholders should be involved in early stages of a process to define concerns, needs and priorities. Ongoing stakeholder involvement is key to achieving continual improvement in sustainability measures.

Many practical approaches can be employed to provide stakeholders with relevant information and access to decision-makers. For example, social media and web-based software, regular public meetings, participation in community events and organizations, and other communication strategies appropriate for the project and specific sub-groups of stakeholders can be used. Descriptions, options and guidance for working with stakeholders can be obtained by reading the documentation supporting the RSB Principles and Criteria (2011) and the International Organization of Standards (ISO 26000), a voluntary Guidance Standard for corporate social responsibility. ISO 26000 and the companion handbook published by ECOLOGIA (2011) provide specific recommendations for identifying and reaching out to stakeholders and for building accountability and sustainability into core business practices.

We propose a simple unit to reflect stakeholder participation, the percentage of stakeholder concerns and suggestions addressed in documented responses, reported on an annual basis. This indicator can provide a vehicle to express commitment to, and document progress toward, what are often difficult to measure sustainability values. However, for this indicator unit to be reliable, consistent and transparent reporting mechanisms should ensure that documented responses legitimately address the concerns and suggestions related to sustainability criteria and indicators and that the mechanisms for dialogue remain open to all without fear of reprisal.

Other potential indicators of stakeholder participation were considered but not selected. A relevant component of social acceptability that emerges from the literature is equity or fair distribution of costs and benefits. Equitable access to energy and associated benefits is a measure of sustainability and energy security (GBEP, 2011; Sovacool and Mukherjee, 2011; Kates, 2011). Equity relates to the distribution of benefits spatially, temporally, and among groups of producers and consumers. Internalizing social and environmental externalities (see discussion of profitability) is only a start to estimating benefits so that they may be distributed equitably (Bond and Farzin, 2008). Measures of wealth distribution and statistical dispersion such as the Gini Index have been proposed to augment indicators of household income (GBEP, 2011), but these indices can be costly and challenging to apply at the scales required for bioenergy. However, consideration of how an indicator affects prioritized stakeholder groups can be a valuable dimension of sustainability analysis when data are available. In addition, GBEP (2011) calls for an indicator of "bioenergy used to expand access to modern energy services," but there is no consistent and unambiguous measurement for this indicator. All choices (including taking no action) have a mixture of "winners and losers" from various perspectives, making it necessary to prioritize and weigh target beneficiaries, costs, and benefits, which further complicates comparability of analyses. Applying measures of equity and benefit distribution may add complexity and cost related to attribution or result in an index with limited value for guiding corrective actions to improve sustainability.

3.6.4. Risk of catastrophe

The probability of catastrophe is a measure of social acceptability of bioenergy that can be informed by transparent reporting and public participation and can affect public opinion (Table 1). A catastrophe is an adverse event that occurs at such a large scale or with such extreme intensity that it is not projected within the project life cycle (except in cases where worst-case scenarios are evaluated). In other words, they are events with high-consequences and relatively low probability of occurrence. Catastrophes could occur at many stages of bioenergy supply chains and may include rare events such as explosions at refineries or unexpected, rapid releases of algae and nutrients from very large-scale production facilities. The primary motivation for including this indicator in the suite is that catastrophes are known to affect risk perceptions and, therefore, social acceptability of competing energy technologies.

Concern about catastrophes varies depending on the situation and history. Some studies show that people do not worry much about low probability hazards (Slovic et al., 1982). Others show that low probability-high consequence events related to flooding (Merz et al., 2009), hazardous waste sites, and radiation (Slimak and Dietz, 2006) are more important to people than high probability events with greater effects (e.g., air pollution from coal-fired electricity generation) as calculated (Merz et al., 2009) or suggested by opinions of experts (Slimak and Dietz, 2006). Once an accident occurs, risk perception related to the technology or related activities increases substantially. For example, following the Three Mile Island partial nuclear meltdown, nuclear power became less socially and politically acceptable because of views that risks are unknown, dreaded, uncontrollable, inequitable, and likely to affect future generations (Slovic et al., 1982). Similarly, following the Deepwater Horizon oil spill, neighboring communities suffered psychological distress effects (Grattan et al., 2011), and deepwater drilling was temporarily suspended due to perceived risks of additional disasters.

While calculating perceived risk is desirable, there is no well-understood factor that can be multiplied by a risk estimate to produce indicators of perceived risk. We believe that the indicator of public opinion is a good proxy for perceived risk. See Hohenemser et al. (1983) for some of the subtleties of the relationships between technological risks and the perceptions of these risks.

The annual probability of a catastrophic event from a defined energy technology affects the perception of the technology and is therefore a suitable indicator of social acceptability. Some of the factors describing technological hazards that are pertinent to catastrophes include spatial extent, concentration of a chemical agent, persistence, population at risk, and human and nonhuman mortality (Hohenemser et al., 1983). We suggest that a catastrophic event as related to energy is one that occurs suddenly and results in 10 or more human deaths, more than 1000 ha of land or water intensely disturbed, or detectable species extinction or extirpation. The probability of future catastrophes can be estimated from the frequency of catastrophes from closely related supply-chain elements in the past, unless factors such as specific changes in procedure and safety improvements are assumed to alter the probability.

4. Discussion

It is a challenge to parse a simple set of socioeconomic issues from the expansive yet interconnected universe of sustainability goals (Kates, 2010, 2011). In his overview of global sustainability initiatives, Kates (2011) compared agendas and priorities for sustainable development and identified common themes, recommending that the following challenges be addressed: poverty, climate change, population growth, agriculture and food security, biodiversity, ecosystem services, energy and materials, urban growth, water and sanitation, health and well-being, and peace and security. For the purposes of this manuscript, we focus on social and economic aspects of sustainability that are most relevant to bioenergy production pathways and energy alternatives.

This paper identifies a suite of 16 indicators that can be used to characterize the socioeconomic attributes of sustainable bioenergy systems. The suite is not as detailed or comprehensive as other proposed approaches but may be more practical to apply. Even so, 16 measures is a large number for which information needs to be obtained across the supply chain for any industry. To improve future analysis and communication to decision makers, it is important to develop agreement around a manageable set of clearly specified sustainability indicators. We highlight ten indicators in Table 1 that could be tested to help meet this goal in the near term.

Proposed indicators were selected based on criteria of being practical, unambiguous, resistant to bias, sensitive to changes, related to those changes, predictive, estimable with known variability, and sufficient when considered collectively. For a few of the indicators, inadequate data and methodologies are available to meet all of those criteria. For example, while concerns have been raised about potential effects of bioenergy systems on land and food security, there is no consensus on a science-based framework to assess current food security and sustainability options (NRC, 2012), much less the data and methods necessary to assess causal factors (German et al., 2011). While applying the criteria more strictly reduces the number of indicators to 10 (Table 1), we believe that each proposed indicator reflects an important aspect of socioeconomic sustainability.

We envision that this set of indicators can be used as a reference to ensure that the major sustainability attributes of bioenergy systems are considered and relevant indicators measured. While various examples of checklists exist [see for example Ismail et al. (2011) and the Inter-American Development Bank Biofuels Sustainability Scorecard (http://www.iadb.org/biofuelsscorecard/)], they are not focused on a small number of measurements that permit consistent comparison of alternative feedstocks, conversion processes, or transportation options and capture changing indicator values over time. Tracking and analyzing changes in indicator values are important to enable adaptive management and continual improvement, key concepts to support sustainability.

Interest in understanding sustainability of bioenergy systems must be balanced by support for collecting and analyzing the data that are needed to quantify it. Those data should be reported in a way that is repeatable, reliable, timely, and representative of the spatial and temporal scales of interest. Where possible, we have tried to identify indicators that are complemented by established procedures for data collection, analysis, interpretation, and storage. Requirements for documentation and reporting for bioenergy systems should be consistent with and no more demanding than those for alternative sources of energy and land use.

Several potential indicators were not selected because they did not meet our criteria for providing practical and predictive measures that can be calibrated with known variability in responses to change. A specific example from RSB (2011) is, "The participating operator provides objective evidence demonstrating that the implementation of the relevant management plan ensures that impacts on food security are minimized and mitigated, and that access, availability, stability and utilization of food at the local level do not decrease as a result of her/his/its biomass/biofuels operation(s)." Over 100 similar certification requirements are recommended by RSB. Extensive and detailed reporting does not in itself assure a standardized or calibrated measure of change in sustainability. Although these RSB indicators reflect concerns identified through a global effort that included many stakeholders, the result involves multiple sub-requirements with indefinite feasibility and cost implications. Extensive reporting and documentation requirements can be counterproductive to sustainability by consuming material and energy without providing any real improvement to the sustainability of a process.

Indices provide another approach to address the complexities of sustainability. For example, the Index of Sustainable Economic Welfare (ISEW) has been proposed as a substitute for a country's Gross National Product (GNP) or Gross Domestic Product (GDP) (Neumayer, 1999) to better measure social well-being. Another example of evolving efforts to improve upon GDP is the Inclusive Wealth Index (United Nations, 2012). However, ISEW calculations lack theoretical foundations, depend on arbitrary assumptions, and neglect technological progress and increases in human capital (Neumayer, 1999). In addition, ISEW assumes perfect substitution between natural and other forms of capital (Neumayer, 1999), and ISEW is limited to the national scale. Furthermore, when data on diverse indicators are combined into one index, information about each measure is lost. Thus, ISEW and similar indices were not proposed as indicators of sustainability.

Stock depletion was considered as a resource conservation indicator. While stock depletion could be incorporated into national accounts such as GDP (e.g., Repetto et al., 1989; Solorzano et al., 1991; Hamilton and Lutz, 1996) or ISEW (Torras, 1999), stock depletion calculations are constrained by available data, are not easily adapted to different scales, and primarily reflect changes based on adjusted estimates of accessible stocks and new discoveries rather than monitoring total resource consumption.

The context of any particular 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., in press). 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. For example, the range of effects of an event and perceptions of associated risks are shaped by context. The socioeconomic context can amplify or attenuate risk (Kasperson and Kasperson, 1996). In addition, regional differences influence the selection, quantification, use, and interpretation of indicators as well as the scale of the production unit or industry. There is no fixed time frame for sustainability assessment, but most discussions refer to several future generations [e.g., an agricultural sustainability criterion could be indefinite continuity of the farm in the family (Sydorovych and Wossink, 2008)]. Different sustainability questions arise when considering future factors such as peak oil, climate change, or population growth. While the time frame of sustainability is long, some measures of sustainability (e.g., public opinion regarding acceptability) are transitory and relevant for short-term assessment and monitoring changes over time. Furthermore, the numerical values and interpretation of any of these indicators depend largely upon system boundaries, baseline or business-as-usual assumptions, the treatment of co-products, data sources, adjustments for energy quality, and assumptions used for new technologies and corresponding process efficiency (input-output relationships).

4.1. Use of socioeconomic indicators

Sustainability indicators are typically used to evaluate trends over time, to compare alternative energy sources, or to compare future bioenergy options to business-as-usual conditions (which often involve the use of fossil fuels). Some of the indicators described here have little meaning in the absence of comparative data. For example, trends in public opinion, stocks of natural resources and household income are more informative about sustainability trends than are isolated measures of these indicators. In this sense, Smeets and Faaij (2010) considered wage rates in comparison with international poverty level standards and with national average wages as part of their analysis of sustainability criteria for bioenergy production. In an agricultural sustainability framework, income stability is emphasized more than income level (Sydorovych and Wossink, 2008). Yield volatility and price volatility are more important than yield and price in determining energy and food security. Fossil energy ROI can indicate a representative and comparative value for a defined, short time frame in addition to providing a target for improvement over time. While favorable public opinion can be a useful measure in isolation, trends in public opinion provide more valuable information about long-term sustainability.

Some indicators could be measured for one component of the supply chain (e.g., employment in biomass production by a refinery); however, other indicators are less suited for component-level measures (e.g., terms of trade). Measurement of the latter indicators is dictated by data availability, which may be limited to the enterprise, regional or national level. Also, the concept of a linear supply chain is only a convenient abstraction. Even a single biofuel refinery will likely have multiple biomass sources, transportation providers, suppliers of enzymes or catalysts, equipment suppliers, customers for co-products, and waste stream disposal processes. Having multiple inputs and multiple products increases the difficulty of collecting relevant data and may raise issues of attribution (e.g., are jobs attributable to the fuel or the co-product). As indicators are selected and tracked, clear boundaries need to be defined, and methods to combine measurements need to be cognizant of those boundary conditions.

4.2. Relationships among sustainability indicators

Many of the recommended socioeconomic sustainability indicators for bioenergy systems are related (Table 1). Household income benefits are associated with the particular sector in which employment increases (Ewing and Msangi, 2009). For example, the social acceptability of maize stover removal among farmers as well as expected profitability depends, in part, on how new equipment and storage needs are met, and these factors influence the supply stability of maize stover feedstock (Tyndall et al., 2011). Reducing the amount of natural capital irretrievably consumed today also enhances long-term sustainability by improving political and economic security, which is tied to natural resource wealth. Food security strongly relates to household income, because welfare measurements are indicated by the fraction of marginal income spent on food (FAO, 2011b), which declines with rising income.

Furthermore, linkages between socioeconomic and environmental indicators are evident. Most directly, the profitability of bioenergy systems using energy crops and residues reflects productivity measures and is strongly affected by soil, water, climate, and other environmental conditions. Moreover, market mechanisms to account for environmental or social externalities (such as pollution or improvement of wildlife habitat) can improve economic competitiveness of more environmentally sustainable fuel pathways. For example, a carbon trading system could increase the profitability of a biofuel system that sequesters carbon; or a carbon tax could make conventional fuels more expensive, shifting a price advantage to renewable energy sources. Jobs, trade, and resource utilization would all be affected. In this way policies, market mechanisms and incentives can create interactions between multiple socioeconomic and environmental sustainability indicators. For sustainability assessments to be useful, socioeconomic and environmental indicators need to be considered together as integral aspects of sustainability of the bioenergy system.

4.3. Next steps

Next steps for the use of the proposed indicators of the socioeconomic aspects of bioenergy sustainability are reaching consensus on measurement protocols, selecting baselines and targets, testing the proposed suite of indicators in diverse situations, exploring and documenting the variability in indicators, soliciting feedback and recommendations based on field testing, and jointly considering socioeconomic and environmental indicators. All of these steps require communication among stakeholders.

It is important to consider environmental and socioeconomic aspects of bioenergy sustainability together. For example, multiple environmental and economic objectives can be pursued through product design, manufacturing process design, recycling, and other techniques (Srivastava, 2007) with full consideration of economic and environmental tradeoffs. Joint analysis of these issues requires attention to prioritizing indicators in a legitimate process that involves all relevant stakeholders. It also requires a focus on the priorities for the particular situation.

A critical next step in sustainability analysis is evaluation of the availability of supporting data and implementation of standard protocols to acquire, evaluate and archive needed information. Testing the proposed indicators via application to a diverse set of sample cases will help evaluate the availability of necessary data, prioritize data and methodological efforts, and generate ideas for improvement.

5. Conclusions

This paper identifies a *minimum* set of ten socioeconomic indicators that should be applicable across many bioenergy supply chains and larger scales. It focuses on indicators that are useful to diverse stakeholders, including resource managers, policymakers, planners and designers of proposed certification schemes. While one small set of indicators cannot characterize socioeconomic sustainability of bioenergy systems under all possible situations, these indicators provide a starting point that could be sufficient in many cases. The proposed socioeconomic indicators of bioenergy sustainability fall into six categories: social well being, energy security, trade, profitability, resource conservation, and social acceptability. As conditions change, the process of characterizing sustainability will need to evolve to reflect new information and society's changing priorities.

When focusing on ways to measure sustainability, it is important to recognize that a plethora of diverse indicators for bioenergy can confuse rather than inform decision-makers (Junginger et al., 2011). Burdensome and impractical demands for information can deter broad adoption of more sustainable practices. Agreement on a few common measures of bioenergy system sustainability is essential to develop clean energy markets. However, selecting a small set of specific indicators requires compromise. Some contexts demand unique indicators and some desirable indicators require information that is either not available or too expensive to obtain. It is important to develop a practical and consistent way to characterize what sustainability means and to structure a way to assess the ability of bioenergy systems to advance toward that goal.

Acknowledgments

Jeff Bielicki, Ranyee Chiang, Kristen Johnson, Alison Goss-Eng, Laurence Eaton and Rocio Martinez provided helpful comments on earlier versions of this paper. We also appreciate comments from participants at the Department of Energy workshop in Washington, DC, and subsequent webinar on “Social Aspects of Bioenergy Sustainability.” MJ Emanuel and Jennifer Smith assisted with drafting Fig. 1and resolving details in the manuscript. Katherine Ragle helped check the bibliography. This research was supported by the US Department of Energy (DOE) under the Office of the Biomass Program. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725.

References

Agusdinata, D.B., Zhao, F., Ileleji, K., DeLaurentis, D., 2011. Life cycle assessment of potential biojet fuel production in the United States. Environ. Sci. Technol. 45, 9133–9143.

Adeyemo, O., Wise, R., Brent, A., 2011. The impacts of biodiesel feedstock production systems in South Africa: an application of a partial equilibrium model to the Eastern Cape Social Accounting Matrix. J. Energy S. Afr. 22, 2–11.

Ajanovic, A., 2010. Biofuels versus food production: does biofuels production increase food prices? Energy 36, 2070–2076.

Aleklett, K., Höök, M., Jakobsson, K., Lardelli, M., Snowden, S., Söderbergh, B., 2010. The peak of the Oil Age – analyzing the world oil production reference scenario in world energy outlook 2008. Energy Policy 38, 1398–1414.

Anseeuw W., Wily L.A., Cotula L., Taylor M., 2011. Land rights and the rush for land. Findings of the Global Commercial Pressures on Land Research Project. International Land Coalition, Rome, Italy. www.landcoalition.org

Babcock, B.A., 2011. The impact of US biofuel policies on agricultural price levels and volatility. International Centre for Trade and Sustainable Development (ICTSD) Geneva, Switzerland. Available Online at http://www.iadb.org/intal/intalcdi/PE/2011/08442.pdf (accessed on December 21 2011).

Baffes, J., Haniotis, T., 2010. Placing the 2006/08 Commodity Price Boom into Perspective. World Bank Policy Research Working Paper 5371. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2010/07/21/000158349_20100721110120/Rendered/PDF/WPS5371.pdf

Bailis, R., Baka, J., 2011. Constructing sustainable biofuels: governance of the emerging biofuel economy. Ann. Assoc. Am. Geogr. 101 (4).

Berndes, G., Hansson, J., 2007. Bioenergy expansion in the EU: cost-effective climate change mitigation, employment creation and reduced dependency on imported fuels. Energy Policy 35, 5965–5979.

Bohi, D.R., Montgomery, W.D., 1982. Oil Prices, Energy Security and Import Policy. Resources for the Future, Johns Hopkins University Press, Washington, DC.

Bond, C.A., Farzin, Y.H., 2008. Alternative sustainability criteria, externalities, and welfare in a simple agroecosystems model: a numerical analysis. Environ. Resour. Econ. 40, 383–399.

Bruntland, G.H. (Ed.), 1987. Our Common Future: The World Commission on Environment and Development. Oxford University Press, Oxford.

Cairns, J., McCormick, P.V., Niederlehner, B.R., 1993. A proposed framework for developing indicators of ecosystem health. Hydrobiologia 236, 1–44.

Chalmers, J., Archer, G., 2011. Development of a sustainability reporting scheme for biofuels: a UK case study. Energy Policy 39, 5682–5689.

Cleveland, C., Costanza, R., Hall, C., Kaufmann, R., 1984. Energy and the U.S. economy: a biophysical perspective. Science 225, 890–897.

Collins, S.L., Carpenter, S.R., Swinton, S.M., Orenstein, D.E., Childers, D.L., Gragson, T.L., Grimm, N.B., Grove, J.M., Harlan, S.L., Kaye, J.P., Knapp, A.K., Kofinas, G.P., Magnuson, J.J., McDowell, W.H., Melack, J.M., Ogden, L.A., Robertson, G.P., Smith, M.D., Whitmer, A.C., 2011. An integrated conceptual framework for long-term social–ecological research. Front. Ecol. Environ. 9, 351–357.

Conrad, J.L., Bolding, C.B., Aust, W.M., Smith, R.L., 2010. Wood-to-energy expansion, forest ownership changes, and mill closure: consequences for U.S. South's wood supply chain. Forest Policy Econ. 12, 399–406.

Cornforth, I.S., 1999. Selecting indicators for assessing sustainable land management. J. Environ. Manage. 56, 173–179.

Council on Sustainable Biomass Production (CSBP), 2011. Draft provisional standard for sustainable production of agricultural biomass. Council on Sustainable Biomass Production. http://www.csbp.org/ (accessed December 2011).

Dale, V.H., Beyeler, S.C., 2001. Challenges in the development and use of ecological indicators. Ecol. Indic. 1, 3–10.

Dale, V.H., Polasky, S., 2007. Measures of the effects of agricultural practices on ecosystem services. Ecol. Econ. 64, 286–296.

Department of Trade and Industry (DTI), 2004. Renewable supply chain gap analysis summary report. Prepared by Mott MacDonald in association with the Bourton Group. Retrieved from http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file15401.pdf

Devine-Wright, P., 2005. Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. Wind Energy 8, 125–139.

Domac, J., Richards, K., Risovic, S., 2005. Socio-economic drivers in implementing bioenergy projects. Biomass Bioenergy 28, 97–106.

Earles, R., Williams, P., 2005. Sustainable Agriculture: An Introduction. ATTRA, National Sustainable Agriculture Information Service, National Center for Appropriate Technology, Fayetteville, Arkansas http://www.hfcsd.org/webpages/rlivingston/files/sustagintro.pdf

ECOLOGIA, 2011. Handbook for Implementers of ISO 26000, version Two. www.ecologia.org

Efroymson, R.A., Dale, V.H, Kline, K.L., McBride, A.C., Bielicki, J.M., Smith, R.L., Parish, E.S., Schweizer, P.E., Shaw, D.M. Environmental indicators of biofuel sustainability: what about context? Environ. Manage., in press. http://dx.doi.org/10.1007/s00267-012-9907-5

Ewing, M., Msangi, S., 2009. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. Environ. Sci. Policy 12, 520–528.

Felix, E., Tilley, D.R., 2009. Integrated energy, environmental and financial analysis of ethanol production from cellulosic switchgrass. Energy 34, 410–436.

Finucane, M.L., Alhakami, A., Slovic, P., Johnson, S.M., 2000. The affect heuristic in judgments of risks and benefits. J. Behav. Decis. Making 13, 1–17.

Food and Agriculture Organization of the United Nations (FAO), 2005. Best practices for improving law compliance in the forestry sector. FAO Forestry Paper 145. Food and Agriculture Organization of the United Nations and International Tropical Timber Organization. Rome, Italy. ISBN 92-5-105381-2.

Food and Agriculture Organization of the United Nations (FAO), 2006. Food Security, Policy Brief, Issue 2.

Food and Agriculture Organization (FAO), 2008. Volatility in Agricultural Commodities – An Update. Food Outlook, pp. 55–57 (June).
Food and Agricultural Organization (FAO), 2009. Hunger in the Face of Crisis: Global Economic Slowdown Underscores Urgency of Addressing Long-Term Challenges. http://www.fao.org/economic/es-policybriefs/briefs-detail/en/?no_cache=1&uid=35540, Economic and Social Perspectives, Policy Brief #6. September 2009 (this and other policy briefs at http://www.fao.org/economic/es-policybriefs).
Food and Agricultural Organization (FAO), 2011. BEFSCI brief: Good Socio-Economic Practices in Modern Bioenergy Production – Minimizing Risks and Increasing Opportunities for Food Security. Available Online at http://www.fao.org/bioenergy/31478-0860de0873f5ca89c49c2d43fbd9cb1f7.pdf (accessed on February 28, 2012).
Food and Agricultural Organization (FAO), 2011. Core Indicators on Bioenergy and Food Security. Available Online at http://www.fao.org/bioenergy/foodsecurity/befsci/69197/en/ (accessed on December 21 2011).
Food and Agriculture Organization (FAO), World Food Programme (WFP) and International Fund for Agricultural Development (IFAD). 2011. The State of Food Insecurity in the World 2011. How does international price volatility affect domestic economies and food security? Rome, FAO. http://www.fao.org/publications/sofi/en/
Food and Agricultural Organization (FAO), 2012. Good environmental practices for bioenergy feedstock production. Environment and Resource Management Working Paper No. 49. In: Rossi, A. (ed.). Rome, Italy. Available Online at: http://www.fao.org/docrep/015/i2596e/i2596e00.pdf (accessed on February 28, 2012).
FAO, WFP and IFAD. 2012. The State of Food Insecurity in the World 2012.Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Rome, FAO. http://www.fao.org/publications/sofi/en/
Funke, N., Nortje, K., Findlater, K., Burns, M., Turton, A., Weaver, A., Hattingh, H., 2007. Redressing inequality: South Africa's new water policy. Environment 49 (3), http://dx.doi.org/10.3200/ENVT.49.3.10-25.
Gallagher, P.W., 2010. Corn ethanol growth in the USA without adverse foreign land-use change: defining limits and devising policies. Biofuels Bioprod. Bioref. 4, 296–309.
Gandhi, A., 2003. Developing compliance and resistance: the state, transnational social improvements and tribal peoples contesting India's Narmada project. Global Networks J. Transnatl. Aff. 3, 481–495.
Gasparatos, A., Stromberg, P., Takeuchi, K., 2011. Biofuels, ecosystem services and human wellbeing: putting biofuels in the ecosystem services narrative. Agric. Ecosyst. Environ. 142, 111–128.
GBEP, 2011. The Global Bioenergy Partnership Sustainability Indicators for Bioenergy, 1st ed. (final version, December 15, 2011). GBEP Secretariat, FAO, Environment, climate change and Bioenergy Division, Rome, Italy ftp://ext-ftp.fao.org/nr/data/nrc/gbep/Report%2016%20December.pdf (accessed December 21, 2011).
German, L., Schoneveld, G.C., Pacheco, P., 2011. The social and environmental impacts of biofuel feedstock cultivation: evidence from multi-site research in the forest frontier. Ecol. Soc. 16, 24.
Gillon, S., 2010. ld of dreams: negotiating an ethanol agenda in the Midwest United States. J. Peasant Stud. 37, 723–748.
Grattan, L.M., Roberts, S., Mahan Jr., W.T., McLaughlin, P.K., Otwell, W.S., Morris, J.G., 2011. The early psychological impacts of the Deepwater Horizon oil spill on Florida and Alabama communities. Environ. Health Perspect. 119, 838–843.
Greene, D., Leiby, P.N., 2007. Oil Independence: Realistic Goal or Empty Slogan? Oak Ridge National Laboratory http://lugar.senate.gov/energy/links/commentary/08_greene_summary.cfm
Habib-Mintz, N., 2010. Biofuel investment in Tanzania: omissions in implementation. Energy Policy 38, 3985–3997.
Hall, C.A.S., Balogh, S., Murphy, D.J.R., 2009. What is the minimum EROI that a sustainable society must have? Energies 2, 25–47.
Hall, C.A., Dale, B.E., Pimentel, D., 2011. Seeking to understand the reasons for different energy return on investment (EROI) estimates for biofuels. Sustainability 3, 2413–2432.
Hamilton, K., Lutz E., 1996. Green National Accounts: Policy Uses and Empirical Experience Environment Department Paper No. 039. Pollution and Environmental Economics Division, The World Bank, Washington, DC.
Heinberg, R., 2009, Searching for a Miracle: "Net Energy" Limits and the Fate of Industrial Society, http://www.postcarbon.org/report/44377-searching-for-a-miracle
Henshaw, P.F., King, C., Zarnikau, J., 2011. System energy assessment (SEA) defining a standard measure of EROI for energy businesses as whole systems. Sustainability 3, 1908–1943.
HM Treasury, 2003. The Green Book: appraisal and evaluation in Central Government. Retrieved from: http://www.hm-treasury.gov.uk/d/green_book_complete.pdf
Hohenemser, C., Kates, R.W., Slovic, P., 1983. The nature of technological hazard. Science 220, 378–384.
Huertas, D.A., Berndes, G., Holmen, M., Sparovek, G., 2010. Sustainability certification of bioethanol: how it is perceived by Brazilian stakeholders? Biofuels Bioprod. Biorefining 4, 369–384.
International Energy Agency (IEA), 2010. World Energy Outlook – 2010. OECD/IEA, Paris, France www.worldenergyoutlook.org
International Monetary Fund (IMF), 2011. A barrel of oil or a bottle of wine: how do global growth dynamics affect commodity prices? IMF Working Paper (WP 11/1 by Cevik Serhan and Tahsin Saadi Sedik). Middle East and Central Asia Department.
Ismail, M., Rossi, A., Geiger, N., 2011. A Compilation of Bioenergy Sustainability Initiatives: Update. Food and Agriculture Organization of the U.N., Rome (Updated 01-02-2010).
ISO, 2010. International Standard 26000: Guidance on Social Responsibility. International Organization for Standardization, Geneva, Switzerland http://www.iso.org/iso/iso_catalogue/management_and_leadership_standards/social_responsibility.htm
Jianguang, Z., 1994. Environmental hazards in the Chinese public's eyes. Risk Anal. 14, 163–167.
Junginger, M., van Dam, J., Zarrilli, S., Mohamed, F.A., Marchal, D., Faaij, A., 2011. Opportunities and barriers for international bioenergy trade. Energy Policy 39, 2028–2042.
Kasperson, R.E., Kasperson, J.X., 1996. Ann. Am. Acad. Polit. Soc. Sci. 545, 95–105.
Kates, R.W. (Ed.), 2010. Readings in sustainability science and technology. CID Working Paper No. 213. Center for International Development, Harvard University. Cambridge, MA. http://www.hks.harvard.edu/centers/cid/publications/faculty-working-papers/cid-working-paperno.-213
Kates, R.W. (Ed.), 2011. From the Unity of Nature to Sustainability Sciences: Ideas and Practice. Working Paper No. 218. Center for International Development, Harvard University. Cambridge, MA, USA.
Kim, S., Dale, B.E., 2011. Indirect land use change for biofuels: testing predictions and improving analytical methodologies. Biomass Bioenergy 35, 3235–3240.
Kline, K.L., Dale, V.H., Lee, R., Leiby, P., 2009. In defense of biofuels, Done Right. Issues Sci. Technol. 25, 75–84.
Koh, L.P., Ghazoul, J., 2010. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. PNAS 107, 11140–11144.
Kretschmer, B., Narita, D., Peterson, S., 2009. The economic effects of the EU biofuel target. Energy Econ. 31, S285–S294.
Leiby, P.N., Jones, D.W., Curlee, T.R., Lee, R., November 1, 1997. Oil Imports: An Assessment of Benefits and Costs, ORNL-6851. Oak Ridge National Laboratory.
Leiby, P.N., 2008. Estimating the Energy Security Benefits of Reduced U.S. Oil Imports. Oak Ridge National Laboratory Report ORNL TM-2007/028.
Mallory, M.L., Hayes, D.J., Babcock, B.A., 2011. Crop-based biofuel production with acreage competition and uncertainty. Land Econ. 87, 610–627.
Mankiw, N., 2010. Principles of Economics, 5th ed. South-Western, 904 p.
Martin, P.L., 2011. Global governance from the Amazon: leaving oil underground in Yasuni National Park, Ecuador. Global Environ. Pol. 11, 22–42.
Mata, T.M., Martins, A.A., Sikdar, S.K., Costa, C.A.V., 2011. Sustainability considerations of biodiesel based on supply chain analysis. Clean Technol. Environ. Policy 13, 655–671.
McBride, A.C., Dale, V.H., Baskaran, L.M., Downing, M.E., Eaton, L.M., Efroymson, R.A., Garten, C.T., Kline, K.L., Jager, H.I., Mulholland, P.J., 2011. Indicators to support environmental sustainability of bioenergy systems. Ecol. Indicators 11, 1277–1289.
Millennium Environmental Assessment (MEA), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC (accessed January 2011 at http://www.maweb.org/documents/document.356.aspx.pdf).
Merz, B., Elmer, F., Thiken, A.H., 2009. Significance of 'high probability/low damage' versus 'low probability/high damage' flood events. Nat. Hazard. Earth Syst. Sci. 9, 1043–1056.
Mitchell, D., 2008. A Note on Rising Food Prices. Policy Research Working Paper 4682. The World Bank Development Prospects Group, July 2008.
Moschini, G.C., Lapan, H., Cui, J., 2010. Assessing the welfare effects of US biofuel policies. AgBioForum 13, 370–374.
Mulder, K., Hagens, N., 2008. Energy return on investment: toward a consistent framework. AMBIO 37, 74–79.
Munier, B., 2010. Commodity Price Volatility: Causes and Impact on the EU Agricultural Markets. Note for Directorate-General for Internal Policies Ag and Rural Dev, European Parliament, Jun 07. At http://www.momagri.org/UK/momagri-model/Commodity-Price-Volatility-Causes-and-Impact-on-the-EU-Agricultural-Markets_695.html
Murphy, D.J., Hall, C.A.S., Dale, M., Cleveland, C., 2011. Order from chaos: a preliminary protocol for determining the EROI of fuels. Sustainability 3, 1888–1907.
Neuwahl, F., Löschel, A., Mongelli, I., Delgado, L., 2008. Employment Impacts of EU Biofuels Policy: Combining Bottom-up Technology Information and Sectoral Market Simulations in an Input–output Framework. Center for European Economic Research, Mannheim, Germany, ftp://ftp.zew.de/pub/zew-docs/dp/dp08049.pdf
Neumayer, E., 1999. The ISEW – not and index of sustainable economic welfare. Soc. Indicators Res., 77–101.
NRC (National Research Council), 2012. A sustianability challenge: food security for all: a report of two workshops. US National Acadmey of Scicnces, Washington, DC, 261 p.
Oladosu, G., Kline, K., Uria-Martinez, R., Eaton, L., 2011. Sources of corn for ethanol production in the United States: a decomposition analysis of the empirical data. Bioprod. Bioref. 5, 640–653.
Persson, T., Garcia, A.G.Y., Paz, J., Jones, J., Hoogenboom, G., 2009. Maize ethanol feedstock production and net energy value as affected by climate variability and crop management practices. Agric. Syst. 100 (1-3), 11–21.
Plummer, J.L., 1981. Methods for measuring the oil import reduction premium and the oil stockpile premium. Energy J. 2, 1–18.
Poortinga, W., Pidgeon, N.F., 2005. Trust in risk regulation: cause or consequence of the acceptability of GM food? Risk Anal. 25, 199–209.

Repetto, R., Magrath, W., Wells, M., Beer, C., Rossini, F., 1989. Wasting Assets: Natural Resources in the National Income Accounts. World Resources Institute, Washington, DC.
RFA (Renewable Fuels Association), 2012. Accelerating Industry Innovation: 2012 Ethanol Industry Outlook, Washington, DC. www.EthanolRFA.org
Romijn, H.A., Caniëls, M.C.J., 2011. The *Jatropha* biofuels sector in Tanzania 2005–2009: evolution towards sustainability? Res. Policy 40, 618–636.
Rosegrant, M., 2008. Biofuels and Grain Prices – Impacts and Policy Responses. International Food Policy Research Institute http://www.ifpri.org/sites/default/files/publications/rosegrant20080507.pdf
Roundtable on Sustainable Biofuels (RSB), 2011. Roundtable on Sustainable Biofuels – Indicators of Compliance for the RSB Principles & Criteria. École Polytechnique Fédérale de Lausanne. RSB-IND-01-001 (Version 2.0). (RSB), 2011. Accessed December 2011 at http://rsb.epfl.ch/files/content/sites/rsb2/files/Biofuels/Version%202/Indicators/11-03-08%20RSB%20Indicators%202-0.pdf
Runge, C., Senauer, B., May 2008. How ethanol fuels the food crisis. Foreign Aff. http://www.foreignaffairs.com/articles/64915/c-ford-runge-and-benjamin-senauer/how-ethanol-fuels-the-food-crisis (Web. 30 Nov. 2011).
Shindler, B., Brunson, M.W., 2004. Social acceptability in forest and range management. In: Manfredo, M.J., Vaske, J., Bruyere, B.L., Field, D.R., Brown, P.J. (Eds.), Society and Natural Resources: A Summary of Knowledge. Modern Litho Press, Jefferson, MO, pp. 147–157.
Shindler, B., Collson, P., 1998. Assessing public preferences for ecosystem management practices. In: Soden, D., Lamb, B., Tennert, J. (Eds.), Ecosystems Management: A Social Science Perspective. Kendall-Hunt, Dubuque, IA.
Siegrist, M., 2000. The influence of trust and perceptions of risks and benefits on the acceptance of gene technology. Risk Anal. 20, 195–204.
Slimak, M.W., Dietz, T., 2006. Personal values, beliefs, and ecological risk perception. Risk Anal. 26, 1689–1705.
Slovic, P., Fischhoff, B., Lichtenstein, S., 1982. Why study risk perception? Risk Anal. 2, 83–93.
Smeets, E., Junginger, M., Faaij, A., Walter, A., Dolzan, P., 2008. The sustainability of Brazilian ethanol – an assessment of the possibilities of certified production. Biomass Bioenergy 32, 781–813.
Smeets, E.M.W., Faaij, A.P.C., 2010. The impact of sustainability criteria on the costs and potentials of bioenergy production – applied for case studies in Brazil and Ukraine. Biomass Bioenergy 34, 319–333.
Solorzano, R., de Camino, R., Woodward, R., Tosi, J., Watson, V., Vasquez, A., Villalobos, C., Jimenez, J., 1991. Accounts Overdue: Natural Resource Depreciation in Costa Rica. World Resources Institute, Washington, DC.
Sovacool, B.K., Mukherjee, I., 2011. Conceptualizing and measuring energy security: a synthesized approach. Energy 36, 5343–5355.
Srivastava, S.K., 2007. Green supply-chain management: A state-of-the-art literature review. Int. J. Manage. Rev. 9, 53–80.
Stern, R.J., 2010. United States cost of military force projection in the Persian Gulf, 1976–2007. Energy Policy 38 (6), 2816–2825, http://dx.doi.org/10.1016/j.enpol.2010.01.013 http://linkinghub.elsevier.com/retrieve/pii/S0301421510000194
Sydorovych, O., Wossink, A., 2008. The meaning of agricultural sustainability: evidence from a conjoint choice survey. Agric. Syst. 98 (10–20), 1191–1202.
Tepe, F., Du, X., Hennessey, D., 2011. The impact of biofuels policy on agribusiness stock prices. Agric. Econ. Resour. Manage. 27, 179–192.
Thornley, P., Rogers, J., Huang, Y., 2008. Quantification of employment from biomass power plants. Renewable Energy 33, 1922–1927.
Torras, M., 1999. Inequality, resource depletion and welfare accounting, applications to Indonesia and Costa Rica. World Dev., 27.
Trostle, R., Mari D., Rosen S., Westcott P., 2011. Why Have Food Commodity Prices Risen Again? USDA Economic Research Service WRS-1103.
Transportation Research Board, 2011. A Guidebook for Sustainability Performance Measurement for Transportation Agencies. National Cooperative Highways Research Program report 708. Washington, DC. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_708.pdf
Tyndall, J.C., Berg, E.J., Colletti, J.P., 2011. Corn stover as a biofuel feedstock in Iowa's bio-economy: an Iowa farmer survey. Biomass Bioenergy 35, 1485–1495.
United Nations, 2012. International human dimensions programme on global environmental change. Inclusive Wealth Rep., 2012.
Urbanchuk, J.M., 2011.Contribution of the ethanol industry to the economy of the United States in 2011. Report prepared under contract between Cardno ENTRIX and the Renewable Fuels Association, (2012). http://ethanolrfa.3cdn.net/c0db7443e48926e95f_j7m6i6zi2.pdf
USAID, 1998. Guidelines for indicator and data quality. Performance Monitoring and Evaluation TIPS Number 12. Washington. (PN-ACA-927).
U.S. Environmental Protection Agency (EPA), 2010. Assessment and Standards Division. Office of Transportation and Air Quality. "Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis", no. EPA-420-R-10-006 (2010). http://www.epa.gov/otaq/renewablefuels/420r10006.pdf (Chapter 5, Economic Impacts and Benefits).
United States Government (US GOV), 2007. The Energy Independence and Security Act of 2007 (H.R. 6).
van Dam, J., Junginger, M., Faaij, A., Jurgens, I., Best, G., Fritsche, U., 2008. Overview of recent developments in sustainable biomass certification. Biomass Bioenergy 32, 749–780.
Visschers, V.H.M., Keller, C., Siegrist, M., 2011. Climate change benefits and energy supply benefits as determinants of acceptance of nuclear power stations: investigating an explanatory model. Energy Policy 39, 3621–3629.
Vlysidis, A., Binns, M., Webb, C., Theodoropoulos, C., 2011. A techno-economic analysis of biodiesel biorefineries: assessment of integrated designs for the co-production of fuels and chemicals. Energy 36, 4671–4683.
Wallander, S., Claassen, R., Nickerson, C., 2011. The ethanol decade: an expansion of U.S. corn production, 2000-09. USDA Economic Research Service. Economic Information Bulletin Number 2011.
Weber, J.G., 2011. How much more do growers receive for Fair Trade-organic coffee? Food Policy 36, 678–685.
Wei, M., Patadia, S., Kammen, D.M., 2010. Putting renewables and energy efficiency to work: how many jobs can the clean energy industry generate in the US. Energy Policy 38, 919–931.
Wicke, B., Sikkema, R., Dornburg, V., Faaij, A., 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 28, 193–206.
World Bank, 2011. The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium. © 2011 The International Bank for Reconstruction and Development/The World Bank, Washington, DC, 20433. http://dx.doi.org/10.1596/978-0-8213-8488-6, www.worldbank.org
World Health Organization (WHO), 2011. World Health Statistics 2011. Geneva, Switzerland. http://www.who.int/whosis/whostat/EN_WHS2011_Full.pdf
Zhang, Z., Lohr, L., Escalante, C., Wetzstein, M., 2010. Food versus fuel: what do prices tell us? Energy Policy 38, 445–451.