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# Communicating About Bioenergy Sustainability

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**Abstract** Defining and measuring sustainability of bioenergy systems are difficult because the systems are complex, the science is in early stages of development, and there is a need to generalize what are inherently context-specific enterprises. These challenges, and the fact that decisions are being made now, create a need for improved communications among scientists as well as between scientists and decision makers. In order for scientists to provide information that is useful to decision makers, they need to come to an agreement on how to measure and report potential risks and benefits of diverse energy alternatives in a way that allows decision makers to compare options. Scientists also need to develop approaches that contribute information about problems and opportunities relevant to policy and decision making. The need for clear communication is especially important at this time when there is a plethora of scientific papers and reports and it is difficult for the public or decision makers to assess the merits of each analysis. We propose three communication guidelines for scientists whose work can contribute to decision making: (1) relationships between the question and the analytical approach should be clearly defined and make common sense; (2) the information should be presented in a manner that non-scientists can understand; and (3) the implications of methods, assumptions, and limitations should be clear. The scientists' job is to analyze information to build a better understanding of environmental, cultural, and socioeconomic aspects of the sustainability of energy alternatives. The scientific process requires transparency, debate, review, and collaboration across disciplines and time. This paper serves as an introduction to the papers in the special issue on "Sustainability of Bioenergy Systems: Cradle to Grave" because scientific communication is essential to developing more sustainable energy systems. Together these four papers provide a framework under which the effects of bioenergy can be assessed and compared to other energy alternatives to foster sustainability.

**Keywords** Biofuels · Benefits · Communication · Costs · Decisions · Landscape design · Risk · Scale

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## Introduction

This special feature in *Environmental Management* considers ways to improve sustainability of bioenergy systems. This introductory paper addresses the challenges of communicating scientific information as a means to resolve controversies about bioenergy policies and misconceptions about opportunities. It recognizes that communication must occur among all interested parties but focuses on exchanges about the science underlying differing concepts of sustainability. Other papers in this special feature discuss critical technical and scientific concepts essential to assess the relative sustainability of potential bioenergy systems. "Indicators of Bioenergy Sustainability: What about Context?" examines how aspects of place and time influence the way that assessments of sustainability can be enhanced by appropriate selection, monitoring, and modeling of key indicators (Efroymson and others 2013). "Comparing the Environmental Effects of Transportation Fuels: Why Scale Matters" identifies the different spatial extents and temporal durations of processes and environmental effects associated with fossil-fuel use as compared to biofuel use (Parish and others 2013). "Barriers to Sustainable Bioenergy: Stakeholder Interests and the Evolving Issue Domain" evaluates information and models that are needed to move from research to implementation of bioenergy and how costs, benefits, and a variety of sustainable outcomes can be compared to each other to optimize informed decision making (Johnson and others 2013). Together, these papers cover key issues regarding sustainability of bioenergy systems when considered from the cradle to the grave that arose from a workshop held in September 2009 (CBES 2009).

The purpose of this paper is to identify and discuss key issues in developing and exchanging information about bioenergy sustainability. The players and issues include scientists explaining assumptions and context of their analyses, stakeholders resolving their differences, and those who make decisions about the use and opportunities provided for bioenergy. Difficulties in communicating about bioenergy sustainability include problems in scientist-to-scientist communication, failure of scientists to adequately communicate the context of a study to decision makers, inadequate recognition of the diversity of stakeholders' goals, and errors in media reporting sound bites to the public. Furthermore, communicating about bioenergy is not always put in light of the fact that society requires energy and that bioenergy should be compared to other energy options as well as considered as part of a portfolio of strategies that begins with conservation.

The key communication challenges discussed in this paper arise from (1) the complexity of bioenergy systems, (2) the fact that bioenergy science and technology are still in an early phase of development, and (3) the need to generalize what is inherently a context-specific enterprise. Those obstacles require a focus on (1) how science can best inform policy and (2) the means of communication being employed. After a short background on sustainability of bioenergy systems, these five issues form the essence of this analysis and lead to several conclusions on how communications about bioenergy sustainability can be improved.

## Sustainability of Bioenergy Systems

Sustainability is the capacity of an activity to operate while maintaining options for future generations, including the environmental and socioeconomic systems that support the activity (Brundtland 1987). A constraint in defining sustainability is that different perspectives exist on what should be supported and for how long. Resolving differences among interested parties about sustainability goals and values depends on communication and compromise, for every sustainability goal is not shared by all stakeholders, and choices involve tradeoffs among competing values. That resolution often starts from the premise that society depends on finite natural resources to provide ecosystem services such as food, clean water, energy, and materials for human activities. Investment and innovation to improve resource-management systems are essential to meet the needs of people while conserving and sustaining ecosystem services and biodiversity for future generations.

Biomass and other renewable resources were the dominant forms of energy used by humans until the late nineteenth century when those energy sources were replaced by fossil fuels in many industrialized countries. This replacement initiated a trajectory of rapid economic growth, depletion of finite resources, and rapidly increasing emissions. Today, there is interest in developing renewable energy options in response to apprehension about the economic, environmental, and geopolitical costs of dependence on fossil fuels. Biomass is unique among renewable energy options in its suitability for conversion into liquid transportation fuels and thus in the potential for biofuel to supplement or displace gasoline. Greater use of bioenergy also offers sources of employment and income for rural communities.

Both opportunities for and controversies about bioenergy policies are often framed in terms of sustainability. Implications of bioenergy use on sustainability can include carbon flux, biodiversity, land-use change, energy security, rural development, food production, and genetically modified organisms (e.g., Robertson and others 2008; IPCC 2006, 2011; Wicke and others 2012; Pilgrim and Harvey 2010; Verbeke 2007). Whether a particular bioenergy system results in improvements or detriments to any of these conditions is specific to its context (e.g., type of energy being produced and feedstock used and social, economic, and environmental history of the area) (Efroymson and others 2013).

Yet controversies about whether bioenergy can be produced sustainably abound largely because of the difficulty of assigning and then communicating attribution of change to bioenergy. Causal attribution for changes in sustainability is hampered by poor definition of what "change" is actually being measured and by data not being at the appropriate temporal or spatial resolution to test hypotheses relevant to the situation.

Furthermore, what appear to be scientific disagreements about the potential for sustainable bioenergy may actually be the result of scientists coming to reasonable conclusions when asking different questions unique to their disciplines (Lynd and others 2011). For example, effects of a new biofuel policy may be quite different from effects of a market shock in demand or production (Sjolie and others 2011), which are often simulated under the assumption that such shocks appropriately represent policy changes.

Therefore this paper focuses on ways to improve communications about bioenergy sustainability among scientists from diverse disciplines as well as from scientists to decision makers. We take the tack recommended by Van de Velde and others (2010) to consider ways that communication can address barriers to sustainability rather than dwelling on problems. Nevertheless, communications about bioenergy sustainability must recognize the complexity of these systems, the early stages of their development, and the need to generalize context-specific endeavors.

## Complexity of Bioenergy Systems

Effective communication about forces influencing bioenergy sustainability is sorely needed (Peck and others 2009) but is challenged by the complexities inherent in bioenergy systems and variables associated with sustainability (Domac and others 2005). Bioenergy systems include feedstock production, feedstock logistics, conversion, energy distribution, and end use of the energy and co-products (Fig. 1). Assessment of bioenergy sustainability requires that enough knowledge about the components of the system be available to determine their interactions (Dale and others 2011). Hence, understanding bioenergy requires some knowledge about biogeochemical processes, soils, plant growth and diversity, environment and the state of natural resources, natural disturbance regimes, waste management, systems integration, chemical conversion processes, manufacturing systems, vehicle technology, markets, policy, logistics, and social systems. The science of bioenergy sustainability involves a literal alphabet soup of disciplines—agronomy, biology, chemistry, demography, environmental science, engineering, economics, forestry, genetics, geology, etc. Assessing sustainability builds from multidimensional information about large systems. Bioenergy systems involve a network of facilities, and their supporting feedstock, storage, and transport systems affect the environment and socioeconomic conditions. In spite of these complexities, communications about bioenergy sustainability should strive to use simple and logical language that can be understood by non-scientists yet still describe feedbacks and causal relations.

One communication difficulty relates to interfaces within the scientific community and between scientific disciplines and bioenergy decision makers (McCormick 2010). Each field has its own particular way to use language. For example the word "value" may mean worth, price, cost, quantity, assessment, spiritual importance, usefulness, or respect. Terms such as "decomposition rate" and "recalcitrance" have different meanings depending on discipline (Schmidt and others 2011). And terms such as "land-use change" and "indirect effects" are widely misunderstood due to inconsistent or contradictory applications in recent bioenergy literature. Furthermore, each field has its own underlying sets of assumptions about what factors are the foci and what are external to its purview. Thus, improving communication about the sustainability of biomass energy requires coordinated efforts across various sectors and disciplines that speak different languages, have disparate goals, and use different analytical tools.

Actors in bioenergy systems come from a variety of occupations, social groups, and economic sectors. Scientists develop ways to supply, transport, and process biomass into biofuel. Engineers implement the means to establish this industry. Farmers and foresters grow the biomass. Bioengineers and geneticists develop new opportunities for feedstock and processing. Chemists develop co-products. Consumers select and must pay for fuels and vehicles. Systems engineers explore opportunities

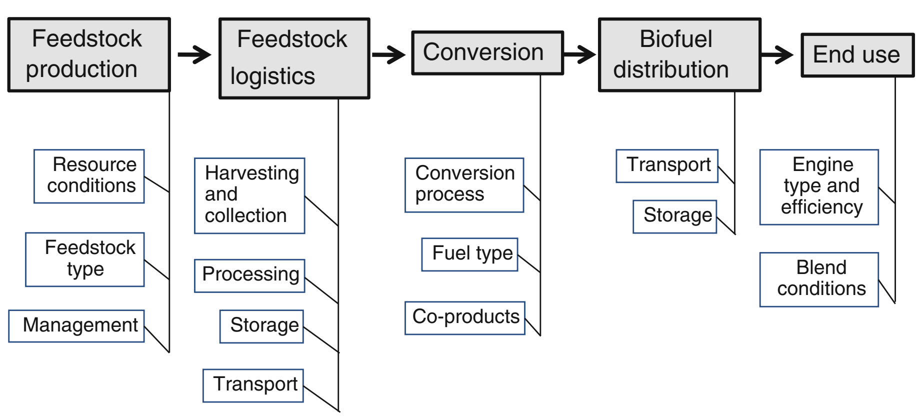


**Fig. 1** Biofuel supply chain (as an example of the bioenergy system) showing key components of each step in the chain

for integration. Policymakers establish regulations that can promote or discourage use of biofuels. Business people create economic value in bioenergy value chains. Financiers provide the capital necessary for constructing and operating commercial processing facilities, pipelines for transport of fluid fuels, vehicles that can use those fuels, and related infrastructure. Other sectors such as feed, sweeteners, and bio-oil industries are also affected by new products and price relationships that are emerging from bioenergy processing. Each actor interprets bioenergy challenges from a unique perspective. Each also faces limitations in access to and understanding of information about bioenergy's underpinning science, technical requirements, environmental effects, and social and economic costs and benefits (Van de Velde and others 2011).

Each step in the bioenergy supply system is comprised of different processes and involves a unique group of participants (Fig. 2), who are influenced by local policy and other contextual conditions (Efroymson and others 2013). Furthermore, components of bioenergy systems can generate multiple effects on both individuals and groups. For example, feedstock production involves farmers' decisions about what to plant and how to manage the land and may favor some producers or regions over others. The cumulative actions of many farmers result in changes to land cover and landscapes and may affect water quality, scenery, and other attributes valued by large communities. Decisions on the location of a biorefinery affect feedstock producers, facility owners, employment, alternative outlets for feedstock, and the community's infrastructure. And many sustainability standards focus on an "economic operator" who may represent a wide range of steps in the supply chain involving distinct scales ranging from single farm to multinational operations (e.g., RSB 2010; CSBP 2012). Hence, communications about sustainability issues should consider both individual and group perspectives associated with clearly defined scales and steps in the supply-chain context being assessed.

Another challenge is communicating information about bioenergy systems in ways that reveal the distribution of effects and complexities of potential tradeoffs among environmental, economic, and social outcomes (Peck and others 2009). For example, a project can result in "winners" and "losers" who may be highlighted or overlooked depending on how the steps, sectors, and population segments are defined in the analysis. Sustainability assessment requires identifying environmental and cultural, as well as socioeconomic, concerns (RSB 2010; GBEP 2011; McBride and others 2011; Dale and others 2013). Consideration of tradeoffs depends on the goals of the analysis, which also determine system boundaries. Those boundaries, in turn, affect the results and interpretation of the analysis. Clearly not every sustainability goal can be achieved for all places or systems. Thus, developing ways to identify, recognize, and balance multiple goals are essential. Effective communication mechanisms that address these tradeoffs are hampered by the lack of common definitions, the varying perceptions, beliefs and goals of stakeholders, the immaturity of knowledge about these systems, and the narrow focus of some stakeholders (Rohracher and others 2005).

## Early Stage of the Evolving Field of Bioenergy Systems

The science behind bioenergy systems is still evolving (Ridley and others 2012; Kline and others 2011; Parish and others 2013). Currently, information to describe, define, and examine the sustainability of bioenergy production systems is often inadequate, and thus basic understanding is under debate. Existing information is often used but may not be appropriate for the question being asked.

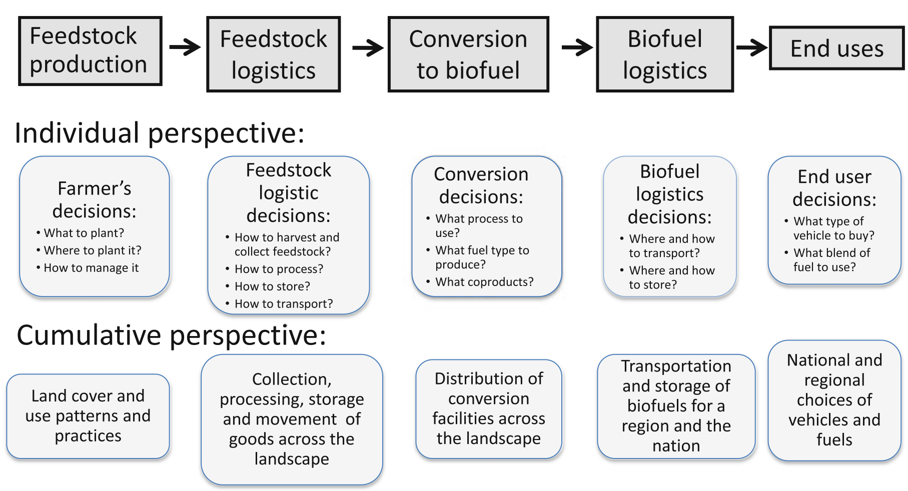


**Fig. 2** Decisions occur from both individual and cumulative perspectives and for all components of the biofuel supply chain (as an example of the bioenergy system) and are influenced by policy and other contextual issues

Efforts to evaluate broad-scale effects of planting bioenergy crops in the central United States (US) provide an example of the inadequacy of existing information and its implications for communication. To estimate such effects, it is necessary to know which bioenergy crops will be planted, what rotation and tillage systems will be used, and what fertilizer and pesticides inputs will be applied as well as to have information from water-quality sampling stations adequate to capture changes across the lower Mississippi River basin. Yet, the industries developing advanced biofuels have not settled on a narrow range of feedstocks, crops, or management systems, and water sampling from some key locations has been eliminated because of funding constraints. As a result, estimates of effects of accelerated bioenergy crop production on water quality in the Mississippi River rely largely on assumptions and extrapolations beyond the extent of the data (Dale and others 2010).

As another example of the communication problems incurred by having inadequate information, the debate continues about $CO_2$ emissions from bioenergy sourced from sustainably managed forests. There is strong evidence that this process generates less warming than the same mass of $CO_2$ from fossil fuels (Bright and others 2012). However, debate continues due in part to the lack of agreement on appropriate temporal and spatial system boundaries for analysis. Furthermore, the contribution of land changes to atmospheric carbon emissions is based on land-cover data, and yet there is no reliable global monitoring program for biomass or carbon stocks, much less emissions (Grainger 2008; Kline and others 2010). Furthermore, the dynamics surrounding the extent, nature, causes, and effects of land-use change are insufficiently understood (CBES 2010; Kline and others 2011). Even if adequate land-use change data were available, it is difficult to assess impacts of large land changes given that carbon emissions depend on complex dynamics among ecosystems, soil and feedstock characteristics, as well as land-management practices (NRC 2010). Current GHG emissions and productivity estimates rely on simple conceptual frameworks and models that are not consistent with analyses of the factors regulating soil organic matter (Schmidt and others 2011) and price-induced effects on land-use change (Oladosu and others 2011). Finally, prediction of new conditions cannot rely exclusively on the past (e.g., Oladosu and others 2011).

Incorrect or confusing information can be propagated by the use of models that are not validated under the conditions of use, do not contain key elements of the system, or are implemented at an inappropriate scale of resolution. For instance, many models that project effects of bioenergy systems on water quality do not contain the physiological attributes of new energy crops (but see Baskaran and others 2010) and have not been validated at the regional scale because there are limited data for large regions representative of where bioenergy effects may occur (e.g., the 48 % of the US that drains into the Gulf of Mexico). Potential model outcomes with unknowable uncertainties are often communicated without adequate discussion of their limited application in the real world or a balanced review of the implications of business-as-usual scenarios.

The evolving state of science behind bioenergy systems also poses challenges for establishing and communicating policy and regulations. An example is the difficulties of the US Environmental Protection Agency (EPA) in addressing biogenic $CO_2$ emissions from stationary power sources, one of EPA's regulatory mandates. EPA had proposed a framework based on the calculation of site-specific accounting factors, but its Science Advisory Board (SAB) found that approach was uncertain and difficult to apply (US EPA SAB 2012). The SAB proposed improvements in that framework but did not reach internal consensus; a dissenting SAB member listed five reasons why the proposed approach is flawed (US EPA SAB 2012). The dissention points out that while the SAB Advisory provides a useful critique of the framework, it tries to make that defective approach be functional. Hence, the report could increase miscommunications and transaction costs without providing improved accounting values. This disagreement in advice to the EPA exemplifies a common dilemma: how to make a policy decision before scientific consensus has been reached.

Scientific analysis and communication are also hampered by unidentified sensitivities to change as well as by key information not being known (Tannert and others 2007). Observations about bioenergy sustainability come from many sources with different precisions and reliabilities as well as spatial and temporal extents. Accuracy of assessment is affected by information gaps regarding emerging feedstocks and technologies, alternative energy pathways, and impacts on other natural and man-made systems. Estimating responses to change becomes speculative when there are large gaps in data necessary for assessing the current state of bioenergy, environmental, and social systems. Furthermore, the requirements for data and interpretation change as policies and technologies for bioenergy evolve, information and understanding are built, and new questions arise. While opportunities to fill key knowledge gaps have been defined and prioritized (e.g., CBES 2009; Wicke and others 2012; Schmidt and others 2011), much work remains to be done.

Effective communication is further hampered by the human tendency to adjust information to fit deeply held beliefs, rather than to adjust a belief to new information. Acceptance of new scientific understanding is often obstructed by resistance to consider alternative paradigms or counterintuitive thinking. For example, it took more than two centuries for the Copernican Revolution to overcome the idea that the sun circled around the Earth rather than vice versa. In a similar sense, there is a belief that economic incentives for cutting trees lead to wide-scale loss of forest lands, but, in fact, the existence of markets for tree products provides important incentives for maintaining or increasing forest stocks (Ince 2010; Eisenbies and others 2009) and improving forest health through management.

Resistance to new information often results in a lag between the time when new evidence supports a change in scientific understanding and the time when the cumulative weight of evidence is processed by enough individuals to overcome the widely held beliefs in a given community. On the other hand, models that reinforce current beliefs tend to be adopted quickly. This differential rate of acceptance of new scientific information can have significant effects on whether and when policy changes occur.

## Context Specificity of Bioenergy Systems

Communication about bioenergy sustainability requires generalizing about a phenomenon that varies over place, time, feedstock type, logistical details, conversion process, and fuel type. The deployment of particular types of bioenergy systems is context-specific, and yet communications about bioenergy sustainability often rely on average outcomes based on historic data or assumed scenarios that cannot adequately portray the diversity of pathways and scales. Thus, the most common and robust scientific conclusion about bioenergy sustainability is that “it depends.” So a research and communication challenge becomes determining what sustainability depends upon in particular situations.

Challenges for policies supporting bioenergy systems are the beliefs that bioenergy induces increases in carbon flux, biodiversity loss, changes in land use, and competition with food; whereas, in actuality, outcomes depend on the particular situation and implementation practices (Kline and others 2009; Efroymson and others 2013). There is an urgent need to fill gaps in scientific information about the actual and potential benefits, costs, and risks associated with policies designed to promote any specific energy source such as bioenergy. To resolve this deficiency, implications for uncertainty that derive from gaps in information must be shared in a clear, transparent, and expedient manner. Scientists must communicate what is known and unknown about the potential for unintended consequences of bioenergy policies and systems, including impacts on employment, food and fiber supplies, water resources, land-use patterns, and biodiversity (Hart Energy Consulting 2010) as well as implications for social and economic systems (Ridley and others 2012). These factors should be put into context to permit appropriate comparisons with other options to meet equivalent social, environmental, and economic needs.

Over recent decades, there have been significant gains in the body of knowledge related to biomass production, bioenergy, and sustainability. While grain-based biofuel production can intensify land use and exacerbate environmental problems, these impacts can be ameliorated by appropriate management (Robertson and others 2008). The opportunities provided by cellulosic feedstock are yet to be realized but may include improved water quality (Parish and others 2012) and sustainable use of residues as feedstocks (Muth and others 2012; Repo and others 2012) as well as soil conservation and biodiversity enhancement (Robertson and others 2008). However, the context of markets, co-products, feedstock choices, soil conditions, and past land use has a great influence on whether bioenergy can be sustainably produced (Efroymson and others 2013) making generalizations difficult.

Sustainable management frameworks can support communication by organizing and distilling information on bioenergy production and by linking research to practice through the creation of standards (Lattimore and others 2010). Organizations like the Roundtable on Sustainable Biofuels (RSB 2010), the Global Bioenergy Partnership (GBEP 2011), American Biofuels Now, the International Organization for Standardization (ISO 2011), and the Council on Sustainable Biomass Production (CSBP 2012) are working on voluntary schemes to facilitate development of more sustainable bioenergy industries, or at a minimum, in the case of the ISO, to define a standard process for analysis and comparison. These initiatives have taken admirable strides in reaching out to stakeholders and acknowledging their input by attempting to address potential issues that could arise when developing a sustainable source for liquid fuels. Many governments, states, and private groups are also striving to define and implement sustainable practices (e.g., the Center for International Forestry Research, the International Model Forest Network, and the Sand County Foundation). These efforts have spent much time in defining terms and developing goals, both of which are necessary first steps. But consensus-building processes take time and, global efforts that have wide engagement run the risk of becoming too general or too complex. Either of those outcomes may limit effective applications of voluntary certification schemes at local scales where requirements and priorities differ.

In the context of diverse bioenergy markets and value chains, it is important to communicate about successful environmental stewardship practices that involve low transaction costs while permitting adaptation to site-specific conditions. For example, forestry best management practices (BMPs) to protect water quality are being implemented by landowners throughout the US in diverse programmatic contexts defined by individual states to meet their local needs (Ice and others 2010). In contrast, many landowners are reluctant to develop Habitat Conservation Plans under the Endangered Species Act because transaction costs are often high and legal risks are perceived as substantial and open-ended by land managers (Wilhere 2009).

## Moving Between Science and Policy

Addressing biofuel sustainability involves both policy and science. Policy sets the path toward specific sustainability goals and can provide the means to address risks. For example, the Energy Independence and Security Act (EISA 2007) created economic incentives to expand production and use of biofuels while imposing a complex set of constraints on biofuel development to mitigate perceived risks to food supplies and the environment. Ideally, policies are built on sound evidence and understanding of how the policy will affect behavior, society, and the environment. However, policy is inevitably driven by current politicians, who are selected through processes operating on short-time scales compared to the long-time frames associated with sustainability. Thus, policies are based on imperfect information and tend to favor near-term interests rather than long-term goals and innovations.

The scientific process is an approach that policy makers and the public may not understand. It takes large amounts of time, resources, data (evidence), and analyses to generate good science, and, even then, conclusions are often over-shadowed by enumeration of limiting factors, uncertainties, and qualifying conditions. Rather than being declarations of fact, scientific statements are often hypotheses that are supported by empirical evidence and models. The difference may be subtle, yet it is critical. Scientific investigations follow a well-established procedure in which observations are made; a hypothesis is proposed to explain the observations, and attempts are made to *disprove* that hypothesis. Scientific information is not used to prove a premise; instead new information is used to show that the null hypothesis is not true, to assess the relative merit and plausibility of alternative hypotheses, or to improve the assumptions, calibration, and validation of supporting models. Scientific understanding is always changing and employs methods specifically designed to accommodate new information. This approach may be confusing to policy makers and the public, who find it frustrating when scientific hypotheses appear contradictory or when a revised hypothesis emerges to replace what many people had come to believe was fact.

Thus, a challenge for scientists is to make decision makers and the public aware of how the scientific process works and to communicate how new information affects established scientific knowledge and related policies. Decision makers should develop policies based on contemporary science but use prudence to ensure that the science is based on validated assumptions and models. Policy makers and the public should understand the differences between model projections, "best available science," and science that is a reliable guide to decision making. Likewise, the scientific process can benefit from models being used to test different hypotheses while models benefit from the scientific process (e.g., to generate improved model conceptual relationships, inputs, and assumptions based on reproducible observation and measurement).

One key problem in communicating science for policy use is that decision makers need quick answers when the scientific process may take years or even decades to accumulate the empirical evidence necessary to support or refute a hypothesis. In the absence of data, models are often used to bridge gaps between what is known and information needed to inform decisions. Politicians and regulators demand answers quickly, and models can provide timely responses whereas empirical observation and analysis of experiments may take too long or be deemed too expensive. Models that are designed and tested for particular applications can be valuable tools. However, when existing models are adapted to a new problem, they need to be tested and validated under the new conditions. In today's world, there is an expectation of immediate access to information, but the provision of quick answers using existing models can be problematic. Results that are not supported by evidence are sometimes reduced to sound bites and rapidly disseminated. Given issues of data, scales, and science discussed above, bioenergy model projections should be considered exploratory, and yet they are not always treated as hypothetical.

Unfortunately, conflicting modeling results and disagreements over the potential effects of bioenergy policies have left policy makers in a quandary [e.g., in projections of effects on land-use change, carbon flux, and competition with food (IPCC 2011; Wicke and others 2012)]. A constructive path toward resolution of current discrepancies about effects of bioenergy on land could be facilitated by agreeing on priorities for research plans; establishing validated reference data sets to document carbon stocks, current land cover, management and services provided; and developing institutional mechanisms to collect, maintain, and distribute those data.

The mode of communication used by scientists differs from that of most decision makers and the public. Scientific results are rarely expressed in simple terms that directly answer questions posed by decision makers or the public. Results are often presented in scientific journals that have limited dissemination or readership appeal. Furthermore, scientists tend to operate in a fashion that is quite different from that of policy makers [Dale (2002), building from ideas presented by Myers (1987) as analyzed by Tieger and Barron-Tieger (1992)]. Broadly speaking, scientists are invigorated by challenging questions, envision and then test solutions, and accept uncertainties as given components that do not necessarily deter problem solving. Scientists work in specialized fields and often have narrow interests or are reluctant to change ideas. In contrast, policy makers tend to seek support from their constituents and may not be attentive to underlying assumptions or the degree of uncertainty when interpreting scientific findings. A policy maker may seek a concordant solution, whereas a scientist may focus on identifying extreme possibilities under widely varying sets of assumptions or on the details needed to develop information to address new hypotheses. The differing motives and modes of thinking and processing data make communication among scientists and decision makers difficult (Dale 2002).

The science of communication has much to offer from the perspectives of social science and decision making (Fischhoff 2011). Effective communication on sustainability issues requires inclusion of all stakeholders and their values and presentation of information in a way that addresses their concerns. Broad outreach is necessary, for the bioenergy industry includes diverse stakeholders (Fig. 1). Reaching out to people and communities who might perceive economic and social benefits by engaging in the bioenergy industries is challenging (Domac and others 2005). Addressing the realities of smallholder production systems is also difficult (Lee and others 2011).

The scientist's role in support of decision making is to formulate appropriate questions, generate, and communicate relevant information, maintain the credibility of that information, and continue to develop new hypotheses that explore the opportunities and implications of alternative decision pathways. Science is often not the primary source of information used by decision makers or the public. Economic and political considerations are significant. Science best contributes to decisions when it is designed to address particular policy questions, is effectively communicated for such applications, and is widely substantiated by complementary research. While difficulties in scientific communication are not unique to the field of bioenergy, their implications are particularly relevant in light of current policy formulation.

Communicating uncertainty about scientific data to policy makers and the public is always difficult yet necessary, and its importance is gaining attention (Mastrandrea and others 2010; Morgan and others 2009). Any communication should explicitly describe options and the extent of uncertainty surrounding potential effects associated with each alternative to help users interpret the information. For example, the medical profession has undergone a transformation in recent decades to provide patients options to participate in decisions in spite of uncertainties, complexities, or lack of information (Gawande 2002). This example differs from bioenergy in that many aspects of medicine are relatively mature applied sciences, and the current level of discourse is based on decades of data and research based on established standards, protocols, rights, and regulations that are pertinent to the testing of scientific hypotheses. Furthermore, the public and policy makers have some common understandings of the language, terms, and the underlying science. A similar transformation, including improved data and agreement on goals, definitions, and standards, would help scientific assessment of bioenergy and sustainability advance in a more productive manner. In addition, care should be taken to disclose how uncertainty is included in models that provide policy guidance regarding bioenergy options.

## Means and Methods of Communicating About Sustainability of Bioenergy Systems

Tools to weigh tradeoffs and to improve design of integrated land-management systems are needed by decision makers at every level (international, national, federal, state, and local) as well as by private and public entities. Assessing the costs and benefits of bioenergy sustainability requires that these tools be applied at the appropriate spatial and temporal resolution for the questions being addressed. Current tools available to support scientific communication about the sustainability of bioenergy policies include system models, decision-support tools, pathway analysis, expert systems, sensitivity analysis, net-benefit analysis, life cycle assessments, technical economic analysis, multivariate statistics, cost-benefit analysis, multimetric optimization and risk assessment. However, these tools are only as good as the data inputs and assumptions on which they build.

Scientists produce manuscripts that are vetted via a peer-review process prior to publication in scientific journals. While publication output and the propagation of new and specialized journals have accelerated in recent years (Macrina 2011), the review procedures are much the same as they have been for decades and are difficult to implement for interdisciplinary research. For example, while the issues of bioenergy and sustainability are broad and often involve several fields of scientific endeavor, reviews and decisions about any given publication often involve a small group of two to five people within a specialized field. This process could reinforce one perspective or approach within a given discipline.

Furthermore, in recent years, there has been a proliferation of scientific journals and web-based information sources, which makes it difficult for scientists (much less decision makers) to keep up with the plethora of new data, research findings, and related literature even within a single discipline. Still more demanding is the time and effort needed to sort through details and supporting materials for data sources and methods; yet clarification of the data and their methodological basis is required to determine the validity, reliability, and ability to extrapolate data. It therefore becomes humanly impossible to stay abreast of all the research and findings across dozens of disciplines associated with sustainability.

The popular press (newspapers, magazines, and increasingly social media such as online blogs) plays an important role in interpreting ideas from the scientific literature and disseminating them to decision makers and the public. Yet some mainstream public media are failing to accurately report the consensus of the scientific community as much as 90 % of the time (Huertas and Adler 2012). The translation of scientific information to the public can involve simplifications, omissions of key caveats and assumptions, or occasional misrepresentations of science. Many factors are a part of this process. Scientific details exceed the interest and expertise of reporters and their target audiences or are so subtle as to defy description and analysis in brief terms. Methods and key assumptions often reference multiple prior scientific works and are framed in language that is turgid to those outside a narrow disciplinary field.

Moreover, communications to the general public have additional constraints. Reporters are usually subject to editorial control, which may be driven by political or commercial interests, for large media enterprises represent significant financial investments. In addition, "popular" media have incentives to generate short, eye-catching, controversial, or sensational news in headlines and sound bites rather than details about the limitations and uncertainties underlying scientific research. Some mainstream media may also reinforce conventional wisdom in line with sponsors or the interests of target audiences.

Today's media sources are becoming fractionated, with publications targeting the specific interests of small groups of readers who are increasingly able to find news sources supporting their perspectives and ignoring others. Multiple outlets with more narrow audiences generally reduce revenue streams from subscriptions and advertising that are needed to finance more in-depth or investigative reporting. Electronic media such as online blogs reduce travel, printing, and distribution expenses of production and can address interests of focused readerships at both lower costs and in a more timely fashion than more traditional printed predecessors. This situation creates pressures for the latter to also offer online versions of content. The communication of scientific information to the public is also affected by incentives for news organizations to be "first" with a story, which can result in lack of editorial discipline, fact checking, subject-area technical expertise, or objectivity.

On the other hand, when scientists communicate their results to general audiences, their efforts may range from over-simplifications that omit underlying assumptions, theory, and history to being so qualified by limiting caveats that the utility of reported findings is not apparent. The former is often too brief, superficial, misleading, or unconvincing; and the latter may be incomprehensible to decision makers. One strategy to reduce this problem is to ensure that the public understands the iterative nature of scientific procedures. Both the hypothesis and the information used to support it build from a set of assumptions, and the context of a particular analysis can have great effects on the inputs and outcomes.

## Conclusions

Communicating about bioenergy sustainability is difficult because the field is highly interdisciplinary and still evolving and policy decisions being made today call for data and analyses that are not yet available. Developing and vetting new ideas and scientific approaches to assess bioenergy sustainability require long-term research investments and a high level of interdisciplinary cooperation, conditions which are rare and difficult to achieve. Inevitably, new scientific discoveries will warrant reconsideration of policies that are based on previous scientific hypotheses. The established scientific process of disseminating new information via peer-reviewed literature is not an effective way to inform policy and society about bioenergy sustainability, nor is it designed for that purpose. Scientists who are conducting analyses meant to inform decisions should be attentive to what they communicate and to whom and should frame their analyses in view of clearly defined policy options.

To address complexity requires trustworthy data and analysis, and clear and frequent communication among the many actors involved in the biofuel industry. There is a need to reach agreement on terminology, standards, and protocols, so that we can move toward speaking the same language. For example, agreement on indicators of bioenergy sustainability and ways to measure and evaluate them would support a more consistent framework by which to quantify sustainability (Van Dam and others 2008).

Bioenergy policy sometimes appears complicated, contradictory, or even chaotic because it is. Elements of bioenergy policy are embedded in many other arenas, including agriculture, energy, rural development, environment, tax, trade, and national security. These elements occur at different levels in the decision-making hierarchy as well, for most land decisions are made at the local level (Dale and others 2000), while other policies typically emanate from state, regional, national, or international concerns. Renewable-energy policies have been enacted at the local, state, and national levels. Local and state policies may focus on use or conservation of specific resources, creating jobs, or lowering the cost of energy. National and international policies are generally unable to fully integrate regional issues and may even conflict with local or state interests. In the US, for example, conflicts may occur between some state policies (and definitions) related to bio-power and federal policies setting targets for biofuels with respect to implicit requirements for feedstock and infrastructure development.

Building upon Swartzman (1996), our analysis leads to several suggestions about ways that communications about bioenergy sustainability can be improved.

- Define relationships between the question asked and the analytical approach underlying the model or assessment.
- Make clear the terms, assumptions, methods, and limitations of the analysis and their implications.
- Assess both costs and benefits at appropriate spatial and temporal scales and using agreed upon standards and indicators.
- Clarify the situations and contexts in which the sustainability of bioenergy is being compared.
- Select an approach that is simple enough for non-scientists to understand (e.g., avoid jargon).

The bottom line is that both the public and the decision makers need to be educated about the scientific discovery process and how it relates to decisions regarding bioenergy sustainability. Scientists have a responsibility to explain clearly their results and the conditions under which those results can be applied as well as the uncertainties and sensitivities of the information. A positive note is that bioenergy issues have brought many different people together to identify options that help address long-standing issues surrounding land management and more sustainable provisioning of ecosystem services.

The papers that are a part of this special feature on sustainability of bioenergy systems brought representatives of different agencies together to examine some of the basic understandings that are needed for establishing and maintaining good channels of communication with regard to bioenergy industries. Many different actors play important roles in helping the public and policy makers to understand the costs and benefits of our different energy alternatives and how these choices interact with our aspirations to maintain options for future generations.

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