Ecotoxicology
DOI 10.1007/s10646-008-0293-y

GUEST EDITORIAL

Good policy follows good science: using criteria and indicators for assessing sustainable biofuel production

Alan D. Hecht · Denice Shaw · Randy Bruins · Virginia Dale · Keith Kline · Alice Chen

Accepted: 4 December 2008

Abstract Developing scientific criteria and indicators should play a critical role in charting a sustainable path for the rapidly developing biofuel industry. The challenge ahead in developing such criteria and indicators is to address the limitations on data and modeling.

Keywords Biofuels · Criteria · Indicators · Sustainability

Mark Twain said, "Buy land; they are not making it any more." The fabled humorist's emphasis on the nearly immutable amount of land is still on the mark today. Leaders in industry, agriculture, and government are struggling to determine how land can best be managed to serve many functions: feeding people and livestock, protecting ecosystem services, preserving biodiversity, supporting recreational and cultural activities, and supplying biomass feedstock for the emerging biofuel industry. The competition to use land for these multiple purposes is exacerbated by growing energy consumption in industrialized nations, rapidly increasing population and economic aspirations in the developing nations, and escalating impacts on the environment of agriculture, industry, and consumption of goods and services. Addressing these conflicting objectives of land management raises new policy and research questions. One issue central to these questions is how to promote and demonstrate sustainable production of biofuels. In this editorial we argue that scientific criteria and indicators should play a critical role in charting a sustainable path for this rapidly developing industry, but we also caution that, in the process of developing and using criteria and indicators, the limitations of data and modeling deserve careful attention.

The conversion of biomass to transportation fuel involves many steps from growing, harvesting, transporting, and converting the feedstock to distributing and using the end product as a liquid fuel. Policy makers and scientists have come to recognize that it will be the economic and environmental soundness of the whole system that determines the degree to which biofuels reach their full potential as an alternative to fossil-based fuels. Given the dependence of biofuel production on natural systems, demonstrating that production proceeds in an environmentally sound and sustainable manner is essential for its success.

Both government and the private sector have begun to wrestle with the concept of a sustainable biofuel system as a necessary framework for the production, use, distribution, and international trade of biofuels. The 2007 US energy

Views expressed are those of the authors and do not necessarily reflect official positions of the U.S. EPA or the U.S. Department of Energy.

A. D. Hecht (✉)
U.S. Environmental Protection Agency, Office of Research and Development (ORD), Washington, DC, USA
e-mail: Hecht.alan@EPA.gov

D. Shaw
National Center for Environmental Assessment (ORD), Washington, DC, USA

R. Bruins
National Exposure Research Laboratory (ORD), Cincinnati, OH, USA

V. Dale · K. Kline
Environmental Sciences Division, Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, USA

A. Chen
AAAS, EPA ORD, Washington, DC, USA

Published online: 19 December 2008

independence and security act (EISA) promotes sustainability by limiting the target output of corn-based biofuel to 15 billion gallons per year and by requiring life cycle analysis (LCA) of greenhouse gas (GHG) emitted from the biofuel system (production, use, and distribution). The LCA will include assessing and measuring GHG effects from indirect changes in land use, such as the conversion of previously non-agricultural land (within and outside the US) to cultivation of crops for biofuel production. The results of LCA analysis will be included in the proposed renewable fuel standard (RFS) developed by the U.S. Environmental Protection Agency (U.S. EPA) for producing the volumes of biofuels from the different categories of feedstock defined in EISA.

While land use change and GHG emissions are difficult to measure, both are paramount criteria for ultimately achieving a sustainable biofuel system. But they are not the only considerations. The multi-stakeholder international Roundtable on Sustainable Biofuels has proposed a set of criteria covering 12 major environmental, social, and economic factors associated with measuring the sustainability of the biofuel life cycle. Examples include compliance with domestic and international laws for biofuel production ("Biofuel production shall follow all applicable laws of the country in which they occur, and shall endeavor to follow all international treaties relevant to biofuels' production to which the relevant country is a party") and protection of ecosystems ("Biofuel production shall avoid negative impacts on biodiversity, ecosystems, and areas of High Conservation Value") http://cgse.epfl.ch/page70341.html.

The Global Bioenergy Partnership (GBEP), a G-8 endorsed partnership that currently includes 14 member nations and 10 international organizations, is developing another set of criteria and indicators that also include environmental, social, and economic considerations. GBEP's role is "to develop a set of global science-based criteria and indicators as well as examples of experiences and best practices including benchmarks regarding the sustainability of bioenergy. The main deliverable of the GBEP Task Force, expected to be completed by April 2009, will provide a useful platform for stakeholders interested in bioenergy sustainability, to facilitate sharing of information, data, experiences and best practices." http://www.globalbioenergy.org/programmeofwork/en/. Going beyond the notion of "facilitating and sharing information," some governments and the EU are considering using criteria and indicators for certification schemes or mandatory trade guidelines.

It is useful to recognize that criteria and indicators can be defined in a number of ways. One of several possible approaches developed by the European Environment Agency uses the driving forces-pressures-state-impacts-responses (DPSIR) framework to assess and manage environmental problems (Tapio and Willamo 2007). In this approach, *driving forces* are the natural conditions and socio-economic and socio-cultural forces driving human activities, which increase or mitigate pressures on the environment. *Pressures* are the stresses that human activities place on the environment. *State*, or state of the environment, is the condition of the environment. *Impacts* are the social or ecological effects of environmental degradation. *Responses* are society's responses to the environmental situation.

Given the above framework, biofuel criteria and indicators can fall into a number of categories. For example, *driving forces* of environmental change include GHG reduction targets and proposed production volumes of biofuel. *Pressures* on the environment include GHG discharges, fertilizer use, and water consumption. *State* of the environment encompasses water quality in rivers, lakes, and estuaries. *Impacts* reflect increases or losses of ecosystem services and changes in measures like rural development and energy security. And *response* of the society could reflect standards or guidelines for sustainable production.

Federal agencies in the US have begun to collaborate to identify criteria and indicators for assessing the impact of expanded biofuel production and use both domestically and internationally (Biomass Research and Development Board 2008). Initial discussion has identified 16 criteria and dozens of possible indicators that reflect environmental and land use changes, social and economic factors, and energy security issues. Some criteria, such as GHG reduction targets, reflect *driving forces.* Possible *state* indicators include measures of long-term soil quality, water quality and use, and criteria air pollutants and other toxicants. Examples of *impacts* include changes in crop productivity, land conversion from food to biofuel production, and ecosystem services. Efforts are being made in all cases to measure current impacts against historical trends, but models will be used in cases where measurements alone are insufficient. This scientifically grounded federal work parallels and contributes to the GBEP project described above.

While it is relatively easy to propose a suite of criteria for a sustainable biofuel system, our capacity to measure and objectively verify critical indicators corresponding to these criteria is limited in many cases. Consider, for example, the zones of coastal eutrophication and hypoxia that have steadily grown in size since the 1960s as agricultural production and fertilizer use have increased (Dale et al. 2009; Diaz and Rosenberg 2008). Expansion of the biofuels sector using traditional agriculture could exacerbate these trends, while applying more sustainable practices for biofuel production could reduce them. How can the biofuel impacts be discerned from other factors?

Even if biofuel production could be segregated from estimates of production by other crops—a challenge in itself—many geographic areas lack adequate historical trend data for indicator nutrients; moreover key sampling stations have recently been eliminated as funding for monitoring has declined. If a change is detected, nutrients could come from a wide variety of sources including food and fiber production, livestock production, sewage systems, fuel production (bioethanol conversion produces NO_x, which can enter the water system), and acid precipitation (in the form of nitric acid).

Analysis of pesticide usage in biofuel production poses a similar challenge to fertilizer use, as illustrated by data presented in "EPA's 2008 Report on the Environment" (U.S. Environmental Protection Agency 2008). The US economy uses more than a billion pounds of active pesticide ingredients each year, of which about 80% is used in agriculture. Although pesticide use benefits crop production, pesticide contamination of streams, rivers, lakes, reservoirs, coastal areas, and ground water can cause adverse effects on aquatic life, recreation, drinking water, irrigation, and other endeavors. Since pesticide use may change with expanding biomass production, it is important to understand the quantity and quality of existing data relevant to assessing effects of biofuel production. EPA's pesticide indicators are based on stream water samples collected between 1992 and 2001 as part of the national water-quality assessment (NAWQA) program of the US Geological Survey, which surveys the condition of streams and aquifers in study units throughout the contiguous US. These data represent streams draining agricultural watersheds in 36 major river basins sampled by the NAWQA program in the contiguous states. While the basins were chosen to be representative of US agricultural watersheds, they result from a targeted sampling design and may not accurately reflect the distribution of concentrations in all streams in US agricultural watersheds. Available pesticide measurements do not indicate where the pesticides originated, illustrating the difficulty in associating pesticide changes with biofuel production.

These examples suggest that both detection and straightforward interpretation of changes in environmental measurements are difficult. The usefulness of many possible indicators in the US could be limited by what the Heinz Center describes as the "*ad hoc* nature of federal and state monitoring programs and no overall mechanism to determine the most appropriate and highest priority investments in monitoring and reporting capacity" (Heinz Center 2008). Models are often useful for filling gaps in the monitoring record and for apportioning pollutants to particular sources, but model limitations with respect to biofuel impacts are apparent as well. For example, several models currently used to simulate the impact of EISA biofuel mandates on international land use change infer future land conversion rates based on assumptions about projected commodity prices, exports, crop yields, and availability of land. These economic models do not reflect field research showing that changes in land use are driven by complex interactions among cultural, technological, biophysical, political, economic, and demographic forces operating within specific spatial and temporal contexts. Reports that indirectly link new land clearing to bioenergy production depend on similar assumptions rather than empirical evidence (Kline and Dale 2008). Models used to estimate impacts of biofuel production on air and water quality are better established yet still carry uncertainties.

Many additional examples could be given to illustrate the data and modeling limitations to assessing the full impact of expanded biofuel production. These uncertainties create challenges as EPA, in cooperation with the U.S. Departments of Agriculture (USDA) and Energy, addresses EISA's Section 204 by preparing the first triennial report for submission to Congress in 2010 on the impacts of the RFS on environmental quality, natural resources, and dispersal of invasive plants.

Policy makers always face the dilemma of making good decisions with limited information. In the case of biofuels, while there is a clear need to devote more resources to improve data and models, policy makers must balance risk and uncertainty and in some cases take precautionary action in spite of large uncertainties. A relevant example is the EISA provision to reduce government incentives for corn-based ethanol to 15 billion gallons per year in order to reduce the effects on food and water quality related to the high levels of water and fertilizer use associated with corn.

In sum, governments are on the right track in trying to define sustainable biofuel production. Good policy is informed by good science. The challenge for scientists is to provide the best available information to policy makers while disclosing uncertainties derived from the paucity of data, deficiencies in existing models, and difficulties in elucidating cause and effect and in allocating attributions in such a complicated large-scale system. A comprehensive review of initiatives on biomass certification from viewpoints of different stakeholders, including national governments (such as the Netherlands, UK, Belgium, and Germany), the European Commission, non-governmental organizations, and corporations, provides some thoughtful conclusions supporting the theme that good science precedes good policy: "To some extent criteria categories can be covered using existing systems, but others (such as GHG and energy balances and changing land use) require the development of new methodologies. A gradual development of certification systems with learning (through pilot studies and research) and expansion over time linked to the development of advanced methodologies can provide valuable experience and can further improve the feasibility and reliability of biomass certification systems" (van Dam et al. 2008).

Around the world, governments are considering a number of biofuel policy options. The development of criteria and indicators is an important first step in promoting sustainable biofuel production and helping government make the right regulatory and policy choices. The efforts of many diverse organizations are focusing attention on long-standing and unresolved environmental problems and opportunities regarding agriculture and land use. These studies are also helping decision makers assess current impacts and anticipate future risks from use of feedstocks such as corn stover, perennial grasses, trees, algae, and wastes that are being considered for bioenergy use—in comparison to risks from other energy options. These combined efforts, supported by good science, can promote an informed, orderly, predictable, and responsible transition towards increased use of biofuels around the world.

Acknowledgments We thank Terry McIntrye (Environment Canada), Andy Miller (U.S. EPA), Bryce Stokes and Jeff Steiner (USDA), Gary Sayles (University of Tennessee), and Robin O'Malley (Heinz Center) for their review and helpful comments. The Office of the Biomass Programs of the U.S. Department of Energy (DOE) supported research by Virginia Dale and Keith Kline on sustainability issues related to bioenergy. Oak Ridge National Laboratory is managed for DOE by UT-Battelle, LLC under contract DE-AC05-00OR22725.

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