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A participatory systems approach to modeling social, economic, and ecological components of bioenergy

Thomas S. Buchholz*, Timothy A. Volk, Valerie A. Luzadis

Department of Forest and Natural Resource Management, College of Environmental Sciences and Forestry, State University of New York, One Forestry Drive, Syracuse, NY 13210, USA

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Abstract

Availability of and access to useful energy is a crucial factor for maintaining and improving human well-being. Looming scarcities and increasing awareness of environmental, economic, and social impacts of conventional sources of non-renewable energy have focused attention on renewable energy sources, including biomass.

The complex interactions of social, economic, and ecological factors among the bioenergy system components of feedstock supply, conversion technology, and energy allocation have been a major obstacle to the broader development of bioenergy systems. For widespread implementation of bioenergy to occur there is a need for an integrated approach to model the social, economic, and ecological interactions associated with bioenergy. Such models can serve as a planning and evaluation tool to help decide when, where, and how bioenergy systems can contribute to development.

One approach to integrated modeling is by assessing the sustainability of a bioenergy system. The evolving nature of sustainability can be described by an adaptive systems approach using general systems principles. Discussing these principles reveals that participation of stakeholders in all components of a bioenergy system is a crucial factor for sustainability.

Multi-criteria analysis (MCA) is an effective tool to implement this approach. This approach would enable decision-makers to evaluate bioenergy systems for sustainability in a participatory, transparent, timely, and informed manner.
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1. Bioenergy for human well-being

Human well-being depends on the availability of food, access to energy for cooking, shelter and heating, health care, and cultural components like political rights, education, communication, transport, and material comfort (Daily and Ehrlich, 1997). The availability of and access to many of these aspects can be traced back to access to energy in any form.

Maintaining and improving human well-being, in its various forms, is the moral foundation of most societies. The term "development", defined as "the process of change towards those future conditions desired by those targeted" (Leclerc, 2007), is the struggle of each society towards improved well-being. This process, whose components necessitate energy availability, is itself therefore highly dependent on societies' access to energy. Hall (2006) describes the importance of energy supply for wealth creation and sustained development, concluding that generation of wealth (in terms of products and services) has a close to one-to-one relationship with the use of energy per capita. The recognition of this relationship between energy and human well-being has led many to conclude that improving access to modern energy, like electricity, for the poor is a key component to achieve the United Nations Millennium Goals of halving poverty by 2015 (Department for International Development, 2002; Modi et al., 2006). A sustainable supply of energy, on the other hand, will necessarily influence development by keeping levels within the resources available and work as a tool to measure sustained growth.

Looming scarcities and associated social, economic, and ecological impacts associated with conventional sources of

*Corresponding author. Tel.: +1 315 470 6775; fax: +1 315 470 6934.
E-mail address: tsbuchho@syr.edu (T.S. Buchholz).

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modern energy like fossil fuels or nuclear energy are again pushing the development of the renewable energy sources, namely biomass, hydro, wind, and geothermal. On a global scale, biomass use as a source of energy clearly dominates among the renewable energy sources. Solid biomass provides 45% of all primary renewable energy in member countries of the Organization for Economic Co-operation and Development, and over 90% of all energy needs of many Asian and African countries (Sims, 2003). Biomass is humanity's oldest non-food energy source; it requires minimal to no technology and is easily and widely obtainable.

Biomass sources vary broadly from fuelwood gathered randomly from forests and agricultural residues to dedicated energy crops like short-rotation coppice, manure, or industrial organic residues (e.g. wood, sugar, or food processing). Tapping into biomass to produce useful energy can be as simple as open fires using gathered fuelwood or as complex as "modern bioenergy chains" (Reijnders, 2006) encompassing advanced concepts from biomass feedstock production, supply chain logistics, and conversion technologies (e.g. combustion, gasification, fermentation, anaerobic digestion). End uses of biomass-derived energy (heat, shaft power, liquid or gaseous fuels, electricity) can range in scale from household applications to international distribution chains.

It can be expected that future development of bioenergy follows two principal directions: (i) an increase in bioenergy production in industrialized countries as part of the shift away from non-renewable energy sources and (ii) an increase in total bioenergy production in non-industrialized countries due to population growth and a change from traditional biomass use (e.g. cooking on open fire) to modern conversion technologies.

Bioenergy is complex because its three components—feedstock supply, conversion technology, and energy allocation—are influenced simultaneously by social, economic, and ecological factors. Understanding these factors, their interdependency, and their integration is essential, because failure of just one factor has led to the failure of many earlier attempts to introduce bioenergy systems delivering modern energy (Karekezi, 2001).

Most of the work on bioenergy systems to date has been on the various technical components to make them function. For instance, Volk et al. (2004) discussed several criteria related to sustainable short-rotation coppice production with willow. Lewandowski and Faaij (2006), Smeets et al. (2005), International Energy Agency (2006) and the Sustainable Bioenergy Wiki (2006) outline potential criteria and indicator sets to assess sustainability of bioenergy feedstock production and trade only. Heller et al. (2003, 2004) investigated the energy efficiency for bioenergy derived from short-rotation coppice by means of a life cycle analysis. Other authors discussed overall sustainability criteria for bioenergy systems (Reijnders, 2006), van den Broek et al. (2000, 2002) assessed socio-economic factors of bioenergy and non-bioenergy alternatives in different countries based on cost-effectiveness and jobs created.

While these efforts are crucial to success, there are broader considerations which are also essential to success and which have not received much attention: namely, approaches enabling decision-makers to choose when, how, and where to deploy bioenergy systems for sustainable development. Considering all the components of the system—feedstock production, conversion technology, and energy allocation—while paying attention to social, economic, and ecological factors is crucial for assessing different bioenergy systems or comparing bioenergy with other energy sources. This always requires involving people other than technical experts. However, integrated methods serving as an analytical tool by modeling bioenergy systems encompassing all components, factors, and interactions while allowing for participation are lacking. This methodological gap is one of the bottlenecks for broad replication of bioenergy systems (Food and Agriculture Organization, 2006; Lettens et al., 2003) resulting in high project preparation costs and time (White, 2002) and making replication of successful projects difficult.

For a wide implementation of bioenergy systems, we need to create methods to model the components and factors of bioenergy systems and their interactions, which in turn allow us to make decisions that contribute to development. In other words, we need an integrated approach to model the social and economic impacts of bioenergy for planning and evaluation purposes, to check whether a bioenergy system can fulfill our social and economic goals (Domac et al., 2005). By compiling criteria sets, the first steps towards such a tool have been taken but a holistic concept is still missing. In order to make a tool that is universally acceptable, we must ask the following questions: How can we generalize the obstacles experienced by bioenergy implementations? How can we predict the impact of bioenergy implementation on society?

2. Considering all factors—sustainabilty

We suggest that an adaptive systems approach to assess the sustainability of a bioenergy system provides a solid basis for such integration. Assessing sustainability not only integrates social, economic, and ecological values, but it also provides useful information for decision-making through participation. Such a participatory systems approach would enable decision-makers to evaluate bioenergy systems for sustainability in a transparent, timely, and informed manner. We propose that multi-criteria analysis (MCA) is an appropriate decision support tool towards these ends.

Sustainability is a dynamic, indefinite, and contested concept (Costanza and Patten, 1995; Mog, 2004). Holling (2001) defined sustainability as "the capacity to create, test, and maintain adaptive capability", meaning that systems are sustainable when they possess now and in future the necessary infrastructure and material wealth to make