DESIGNING DECENTRALIZED SMALL-SCALE BIOENERGY SYSTEMS BASED ON SHORT ROTATION COPPICE FOR RURAL POVERTY ALLEVIATION

Thomas Buchholz[a], Timothy Volk, Timm Tennigkeit[b], Izael Pereira Da Silva[c]
[a]State University of New York, College of Environmental Sciences and Forestry, 345 Illick Hall Syracuse, NY 13210, USA, Phone: +1 315 470 6775, Fax: +1 315 470 6934, E-mail: tsbuchho@syr.edu, tavolk@esf.edu
[b]UNIQUE forestry consultants, Egonstr. 51-53, 79106 Freiburg, Germany, Phone: +49 761 21172843, Fax: +49 761 1560767, E-mail: timm.tennigkeit@unique-forst.de
[c]Centre for Research in Energy and Energy Conservation, Makerere University, P.O. Box 7062 Kampala, Uganda, Phone: +256 77505792, Fax: +256 41250415, E-mail: creec@tech.mak.ac.ug

ABSTRACT: Access to modern energy is crucial for the attainment of the Millennium Development Goals of poverty reduction and environmental sustainability. In East Africa, increasing environmental degradation and modern energy supply are major obstacles to sustainable rural development. Small-scale bioenergy systems can supply clean, reliable, renewable, and affordable energy to rural communities while at the same time creating new job opportunities and having beneficial impacts on natural resources, especially when supplied with biomass from locally produced Short Rotation Coppice (SRC). Bioenergy systems are complex because their three components feedstock supply, conversion technology and energy allocation are influenced by environmental, economic and social factors. Assessing these factors and their interdependency is essential to determine the potential success of a project and its contribution to sustainable development as failure of one component can lead to failure of the entire system.

The complex array of interactions in bioenergy systems can be addressed by applying a systems approach using a standardized decision process or Decision Support Tool (DST). DSTs enable transparent and informed decisions even when limited information is available and many participants with different expertise and interests are involved to consider all relevant criteria. This paper introduces an approach to develop a DST assessing sustainability of small-scale bioenergy systems designed for rural communties.

Keywords: bio-energy management, developing countries, decision support tools

1 INTRODUCTION AND PROBLEM STATEMENT

1.1 Modern energy and human development

Access to modern energy, like electricity, is crucial for the attainment of the Millennium Development Goals of poverty reduction and environmental sustainability [1]. The close relation between the Human Development Index and electricity per capita [2] indicates that without electricity, development beyond a certain level is virtually impossible. A good example for this relationship is the toll on human health taken by indoor air pollution caused by burning wood in inefficient conversion systems [3]. This is especially true in rural areas where the need for electrification tends to be neglected due to the urban bias of political and administrative power [4]. Despite having high growth rates in rural areas, East Africa is dramatically behind other regions of the world in rural electrification. For example, in Uganda, about 84% of the households are in rural areas. Less than 1% of them have access to electricity. Which primarily comes from unsustainable sources like diesel generators [5].

1.2 Small-scale energy production

Compared to grid power, decentralized and community based small-scale energy production projects have the potential to deliver affordable, reliable and sustainable energy in rural areas. Costs for grid power in rural areas can be as much as seven times the cost of urban areas [6]. The development of renewable energy systems can provide local income generation opportunities, lower the reliance on energy imports, and reduce impacts associated with fossil fuel based systems, increase community self-reliance, capacity building and economic growth. Reliable power can dramatically improve health care, education and other services.

1.3 Biomass production for energy

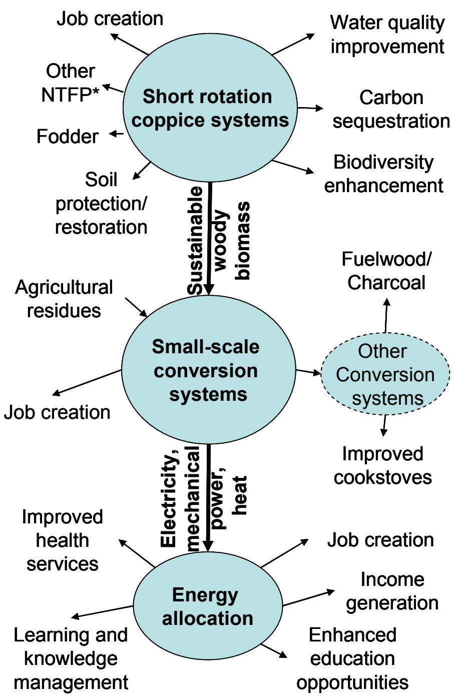
Although biomass has been the primary energy source in East Africa for thousands of years, modern biomass production and conversion systems have not received the attention they deserve. Small biomass conversion units that use wood and other locally available biomass like agricultural residues are being deployed in India, China and Brazil. Through south-south technology transfer and with a limited amount of appropriate training, these systems can be installed, operated and maintained at the local level. Bioenergy systems are characterized by low investment and mechanisation (in erection as well as operation) resulting in high local labour demand and the lowest investment rate per local job created compared to other energy sources [6;7]. East Africa is a prime location for the application of bioenergy systems because it has one of the highest biomass production potentials for energy purposes [8]. However, technology and innovative institutional mechanisms to ensure the sustainability of these systems are lacking.

1.4 Short Rotation Coppice (SRC) for biomass production

Sustainable rural power supplies can be developed based on the conversion of woody biomass, which is grown locally in SRC production systems and combined with other biomass sources, to useful energy (e.g. heat, electricity, mechanical power). In SRC, trees or shrubs with high biomass production are planted and harvested at 1-4 year intervals. Species selected will resprout (coppice) after harvest so that additional crops do not have to be replanted. In addition, SRC systems produce multiple environmental and rural development benefits like soil conservation, desertification mitigation, stable nutrient cycling, enhanced biodiversity, and reduce pressure on natural forests [9;10;11]. SRC based bioenergy systems are CO_2 neutral [12;13], so power is created with no new additions of CO_2 to the atmosphere and may provide local communities the opportunity to benefit from the global carbon market under the Kyoto Protocol. Furthermore, SRC systems do not compete with food production because they can be established on marginal or degraded cropland or on agricultural fallows, which has been demonstrated already in an East African context [14]. Biomass harvested from SRC can fuel small-scale conversion systems like gasifiers or combustion units to generate electricity, heat and mechanical power. Suitable small-scale technology can be modified to meet the specific community needs in terms of reliability, energy mix and costs.

2 INTEGRATED BIOENERGY SYSTEMS

Energy supply by itself does not guarantee human development since many of its benefits tend to accrue to wealthier groups [4;15]. Therefore, in order to lead to sustainable human development, systems are needed to develop and evaluate integrated, participatory and innovative rural bioenergy production and utilization systems. These systems need to incorporate the whole chain from developing biomass production systems to the use of energy produced in and by the local community and consider relevant ecological, economical and social issues. Bioenergy systems are complex because their three components - feedstock supply, conversion technology and energy allocation - are influenced by ecological and environmental factors simultaneously with economic and social factors (Figure 1). Understanding these factors, their interdependency and integration is essential for success because failure of one component can lead to failure of the entire system.



* Non Timber Forest Products

Figure 1: System linkages and multifold direct benefits of Short Rotation Coppice – bioenergy systems.

This interdependence of components is especially important when applying bioenergy systems in a rural community setting. For example, the connections between employment, environmental impacts of biomass production and beneficiaries of the energy produced can be made clear to everyone as they all take place on a strictly confined local level. Therefore, an integrated participatory approach and effective collaboration with stakeholders and governance structure on a local, regional and potentially national level is of immense importance (Figure 2).

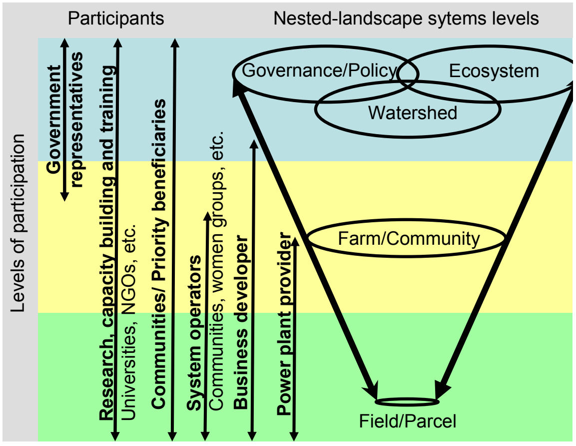


Figure 2: Institutions involved and levels of interaction.

Although some of the production, conversion and socio-economic components for bioenergy systems mentioned above are available or being developed, integrated research is necessary along the value chain from SRC production through to innovative applications for using the power. Sustainability of bioenergy systems can only be achieved if all relevant disciplines and stakeholders are integrated. The complexity of bioenergy components and their interactions is a hallmark of bioenergy systems and has caused the failure of many earlier attempts of introduction [15]. Still, standardized and integrated approaches to decide when, how and where to deploy bioenergy systems for sustainable rural development are (i) virtually absent [16], (ii) result in high project preparation costs and time [17] and (iii) make replication of successful projects nearly impossible.

3 DECISION SUPPORT TOOLS

The complex array of interactions in bioenergy systems can be addressed by applying a systems approach using a standardized decision process or Decision Support Tool (DST). Properly designed DSTs can focus the evaluation of bioenergy systems in accordance to common sustainability criteria. A DST structures the collection and evaluation of quantitative and qualitative information about social, economic and environmental impacts at scales ranging from local to national level. Such tools are especially valuable in situations where sustainability is especially hard to measure, i.e. limited information is available and a systematic derivation of optimal decisions requires many participants with different expertise and interests to consider all relevant criteria [18]. Subsequently, the standardized application of a DST makes the decision process more transparent and comprehensible to third parties, which is important when wide acceptance of the idea is neccesary. DSTs can be used to investigate the sustainability of existing systems or facilitate the development of emerging systems and are already widely used in forestry [19] or agroforestry systems [20].

For bioenergy applications, there are first attempts to develop a DST comparable in its structure to the sustainability guidelines used in forestry (e.g. Montreal Protocol, Forest Stewardship Council - FSC). Such a DST is built up of different modules (or criteria) which are tested independently. Criteria are verified by means of several measurable indicators. Approaches to compile a set of criteria and indicators for bioenergy systems exist already in theory for the feedstock component of bioenergy systems [11;21;22].

However, in order to allow the implementation of sustainable bioenergy projects, an approach based on criteria and indicators as described above needs to be extended to a dynamic, self-renewing process with broad and ongoing participation. In order to react on constant changes in priorities and conditions, it has to address social, economic and environmental impacts on local, municipal, provincial and potentially national levels.

4 DESIGNING A BIOENERGY DST

The first step in designing a DST is the definition of goals, principles serving the goals and criteria and indicators as evaluation tools to measure the success in achieving goals. A second step involves the development and ranking of alternatives, i.e. the evaluation of bioenergy systems differing from each other in the arrangement of their components.

4.1 Overall goal

Goals are the necessary prerequisite when making decisions. For small-scale bioenergy systems, the overall goal is to contribute to sustainable human development through alleviation of rural poverty by assessing the potential for success and facilitating the implementation of community-based bioenergy systems.

4.2 Principles

Principles are broadly formulated and might be not directly measurable. In order to reach sustainability, one approach is to subdivide the principles in three aspects covering social and ethical (distribution of benefits and costs), economic (efficient allocation of goods), environmental and natural (extent of impact or scale) aspects and evaluated independently on their sustainability (Table 1).

Alternatively, the Human Development Index as applied by the United Nations might serve as a set of principles, namely life expectancy, educational attainment and adjusted real income.

4.3 Criteria and indicators

An extensive set of criteria to measure the sustainability of the feedstock component of bioenergy systems has been compiled [21;22]. By means of a participatory process, this set can be adapted and extended to the conversion and energy allocation components. Individual criteria have to be identified, defined, and weighted in this process to express the relative importance of each criterion. For example stekaholders may decide on a mix or loose and strict sets of criteria [22]. This step reveals the stakeholders perception of sustainability.

Table 1: Possible principles to measure sustainability of bioenergy systems.

Environmental aspects	Economic aspects	Social and ethical aspects
• Enhancing biodiversity • CO2 neutrality • Improved soil conditions (erosion, soil composition, nutrient cycling) • Reduce deforestation	• Economically viable • Full cost allocation to end users, affordable • Rural diversification • Reduced regional trade balance • Increased productivity • Support food production	• Empowering women • Mitigating /arresting rural depopulation • Increased standard of living (security, health, education) • Social cohesion and stability • Self sufficiency • Self-determination

The definition of the criteria and indicators is highly influenced by the definition of the system's boundaries in space, time and social hierarchy (see Table 2). The choice of boundaries depend mainly on the level of social hierarchy like the extend of national (e.g. national environmental laws) or international (e.g. international carbon emissions trade) involvement.

Table 2: Boundary options of bioenergy systems.

Space	Time	Social hierarchy
• Community boundary • Watershed • Ecoregion • National level	• Project's expenses paid off • Environmental degradation arrested • Infinite	• Community seen as closed social system • National laws must be considered

4. 4 Developing and ranking alternatives

The alternatives for bioenergy systems are built on the framework given by the three firmly interconnected components feedstock, conversion technology and energy allocation (Figure 1) and ranked according to the weights assigned to the criteria. After developing and ranking alternatives, a sensitivity analysis reveals possible loopholes and weaknesses. The outcome of the process will be an informed decision by a diverse group of stakeholders on the future source of energy supply and based on the bioenergy system being considered to contribute the most to the goal of sustainable rural development.

4. 5 Step-wise approach

Successful implementation of the concept should include the following participatory methodologies. As a first step, target communities, stakeholders and project boundaries would be identified. Then, a set of sustainability criteria and alternatives would be developed, weighted and ranked based on the assessment of i) the socio- economic structure of the target communities like current and future energy demand, allocation and purchase power and likely impact on job creation; ii) feedstock production and management schemes; iii) appropriate technology application and maintenance schemes and iv) funding options. In case of a decision to support a bioenergy system, a bioenergy consortium would be developed encompassing the target community and linking institutions across vertical and horizontal levels.

5 CONCLUSIONS

SRC-based bioenergy has the potential to have a significant and positive impact in rural communties when they are located, designed and implemented properly. The development of a DST to design integrated community based bioenergy systems is an important step in this process. The approach outlined in this paper provides a framework for assessing and deciding on employing bioenergy systems with the currently available information. The next step is to refine the DST and apply it to local case studies. The call for further research and information on bioenergy systems is justified to strengthen the knowledge base on which decisions are made but should no longer delay the employment of bioenergy.

6 LITERATURE

[1] United Nations (2000): UN millennium development goals. United Nations, New York.

[2] UNDP, (2001): Human Development Report. United Nations Development Program, New York.

[3] Bailis, R.; Ezzati, M.; Kammen, D.M. (2005): Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. Science 308: 98-103.

[4] World Energy Council (1999): The Challenge of Rural Energy Poverty in Developing Countries. Report to FAO; Rome, 120p.

[5] Ugandan Ministry for Water, Land and Environment (2001): Capacity building in clean development mechanism in Uganda. The ministry of water, lands and environment, department of meteorology, 30p.

[6] Remedio, E.M.; Domac, J.U. (2003): Socio-economic analysis of bioenergy systems: a focus on employment. Food and Agriculture Organization of the United Nations, Forestry Department, Wood Energy Programme, 45p.

[7] Broek, R. van den; Burg, T. van den; Wijk, A. van; Turkenburg, W. (2000): Electricity generation from eucalyptus and bagasse by sugar mills in Nicaragua: A comparison with fuel oil electricity generation on the basis of costs, macro-economic impacts and environmental emissions. Biomass and Bioenergy 19: 311-335.

[8] Hoogwijk, M.; Faaij, A.; Eickhout, B.; Vries, B. de; Turkenburg, W. (2005): Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy 29: 225-257.

[9] Aronsson, P. G.; Bergstrom, L. F.; Elowson, S. N. E. (2000): Long-term influence of intensively cultured short-rotation Willow Coppice on nitrogen concentrations in groundwater. J. Environ. Manage. 58: 135-145.

[10] Tolbert, V. R.; Todd Jr., D. E.; Mann, L. K.; Jawdy, C. M.; Mays, D. A.; Malik, R.; Bandaranayake, W.; Houston, A.; Tyler, D.; Pettry, D. E. (2002): Changes in soil quality and below-ground carbon storage with conversion of traditional agricultural crop lands to bioenergy crop production. Environ. Pollut. 116: S97-S106.

[11] Volk, T.A.; Verwijst, T.; Tharakan, P.J.; Abrahamson, L.P. (2004): Growing Energy: Assessing the Sustainability of Willow Short-Rotation Woody Crops. Frontiers in Ecology and the Environment. 2 (8): 411-418.

[12] Mann, M. K.; Spath, P. L. (1999): Proceedings of 1999 ACEEE Summer Study on Energy Efficiency in Industry: Industry and Innovation in the 21st Century, Washington, DC. American Council for and Energy-Efficient Economy, 62p.

[13] Heller, M. C.; Keoleian, G. A.; Volk, T. A. (2003): Life cycle assessment of a willow bioenergy cropping system. Biomass Bioenerg. 25: 147-165.

[14] Siriri D., Raussen T. (2003): The agronomic and economic potential of tree fallows on scoured terrace benches in the humid highlands of Southwestern Uganda. Agriculture Ecosystems and Environment 95: 359–369.

[15] Karekezi, S. (2003): Renewables in Africa – Meeting the energy needs of the poor. AFREPREN 22p.

[16] Lettens, S.; Muys, B.; Ceulemans, R.; Moons, E.; Garcia, J.; Coppin, P. (2003): Energy budget and greenhouse gas balance evaluation of sustainable coppice systems for electricity production. Biomass and Bioenergy 24: 179-197.

[17] White, R. (2002): GEF/FAO workshop on productive uses of renewable energy: Experience, Strategies, and Project development. FAO headquarters Rome, 43p.

[18] Mendoza, G.A.; Prabhu, R. (2005): Combining participatory modelling and mulit-criteria analysis for community-based forest management. For. Ecol. And Management 207: 145-156.

[19] Rauscher, M. H. (1999): Ecosystem management decision support for federal forests in the United States: A review. For. Ecol. and Management 114: 173-197.

[20] Ellis, E.A.; Bentrup, G.; Schoeneberger, M.M. (2004): Computer-based tools for decision support in agroforestry: Current state and future needs. Agroforestry Systems 61: 401-421.

[21] Lewandowski, I.; Faaji, A. P. C. (2004): Steps towards the development of a certification systrem for sustainable Bio-energy trade. Department of Science, Technology and Society, Copernicus Institute, Utrecht University, 52pp.

[22] Smeets, E.; Faaij, A.; Lewandowski, I. (2005): The impact of sustainability criteria on the costs and potentials of bioenergy production. Copernicus Institute, Utrecht University, 104pp.