Chapter 2

Sustainability and Biomass Utilisation

March 2008

This chapter should be cited as

Working Group for Sustainable Biomass Utilisation Vision in East Asia (2008), ‘Sustainability and Biomass Utilisation’, in Sagisaka, M. (ed.), *Sustainable Biomass Utilisation Vision in East Asia*, ERIA Research Project Report 2007-6-3, Chiba: IDE-JETRO, pp.23-37.

CHAPTER 2

SUSTAINABILITY AND BIOMASS UTILISATION

2.1. Introduction

Biomass has been crucial for human subsistence as food, energy source as well as feedstock for various materials. One of the major issues around the current increasing use of biomass, especially for energy purposes, is the food versus fuel debate. If excessive land is utilised for producing biofuels feedstock, it is anticipated that there will be competition for land resulting in increased food prices thus negatively affecting the world's poorest. However, this argument is too simplistic as the evaluation of the effect of biomass for fuel on socio-economics is complicated by the fact that increased price of agricultural products will actually also benefit farmers who comprise a large portion of the world's poor. In fact, the anticipated positive effect on the rural economy and employment generation are two of the major areas for promotion of biofuels in many countries. Another major concern is the conversion of lands rich in biodiversity to monoculture plantations. On the other hand, the other argument is that biomass could be planted on degraded land which cannot be used for cultivation of food crops. This would help restore soil organic matter and nutrient content, stabilize erosion and improve moisture conditions (Johansson and Azar, 2007). In fact, it has even been argued that using surplus agricultural land for biofuel production is more advantageous for greenhouse gas reduction than afforestation (Schlamadinger and Marland, 1998). Thus, it is clear that the sustainability of biomass utilisation needs to be rigorously assessed.

Sustainable development has set the framework for policy making in various fields, including bioenergy, over the past two decades. It has been defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainability of biomass implies that the biomass resources are utilised without degrading the environment or having negative socio-economic impacts.

The concept of sustainable development, though noble in intent, needs to be operationalised through development of indicators to quantify the ecological viability, social desirability and economic feasibility of systems (Figure 2.1). Indicators are quantified information which helps to explain how things are changing over time. They have three basic functions: simplification, quantification and communication. Indicators generally simplify in order to make complex phenomena quantifiable so that information can be communicated.

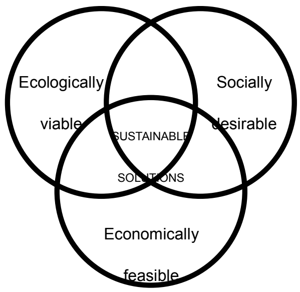

Figure 2.1: Sustainable solutions

Development of sustainability indicators that are relatively easy to characterize is a key to addressing the quest for sustainable development. Well-designed indicators can help assess progress towards policy objectives, as well as provide a basis for communicating with stakeholders.

While assessing biomass utilisation and developing sustainability indicators, one important thing to be considered is the life cycle or systems approach. This is important to ensure that the decisions made a one life cycle stage do not create adverse consequences at other stages, although these stages may seem disconnected from a narrowly focused objective. A very simple example is the comparison of only tail-pipe emissions from vehicles powered by fossil fuels and biofuels. From the perspective of greenhouse gas emissions, the biofuel-driven vehicles will obviously perform better as the CO_2 emissions from these, being assimilated into the biomass during its growth, are considered neutral. However, consideration of the biomass plantation stage shows significant greenhouse gas emissions from fertilizer production and use.

2.2. Classification of sustainability indicators

There is no single indicator which can embody all the issues of sustainability. Hence, a suite of indicators are needed.

2.2.1. Ecological sustainability indicators

<u>(1) Thermodynamic metrics</u>

Thermodynamic metrics are measures of intensity of use of materials and energy normalized to representative units such as per unit service or product. They are useful indicators of the efficiency of resource and energy utilisation; however, they do not directly indicate the environmental consequences thereof.

Material and energy intensity are easily quantifiable metrics based on the first law of thermodynamics – mass and energy balance. They are expressed in units of material used per unit (mass) of product or service (MIPS) and energy used (in joules) per unit (mass) of product or service. The disadvantage of such metrics is that they do not take into account the quality of the material or energy. For example, sand and gravel are lower quality materials as compared to refined metals. Similarly, coal and wood are lower quality energy sources (per joule) than electricity.

Nevertheless, these concepts have been widely used for assessing biomass systems. Net energy balance (NEB), which is the difference of energy output and energy input, is used as an indicator for comparing the energy efficiency of biofuels (Shapouri et al,, 2006; Nguyen et al., 2007; Nguyen et al., 2008; Prueksakorn and Gheewala, 2008). A negative NEB indicates that more energy is used to produce the biofuel than can actually be gained from the final product. Another commonly used measure for estimating the net energy value of fuels is the net energy ratio (NER) which is the ratio of the energy output to energy input. NER greater than 1 indicates a net energy gain whereas that less than one indicates a net energy loss.

The energy balance approach, as described above, is a relatively simple, but useful thermodynamic metric. It has, however, been criticized as it does not take into account the quality of energy. This issue can be critical in certain assessments of biomass systems where the end products have a high exergy and thus an exergy analysis may yield results that differ substantially from an energy analysis (Ulgiati, 2001; Dewulf et al., 2000; Hovelius and Hansson, 1999). The second law of thermodynamics dictates that due to entropy generation, the total energy available from the outputs (exergy of the outputs) is less than the total energy available from the inputs (exergy of the inputs) even though the total output energy is equal to the total input energy based on the first law of thermodynamics (Dewulf and Van Langenhove, 2006). Exergy is thus a very useful metric that has been successfully utilised for assessing the sustainability of biomass systems (Dewulf et al., 2006). From a life cycle perspective, the cumulative exergy consumption (CExC) is used as the metric (Dewulf et al., 2007).

(2) Environmental metrics

Environmental metrics quantify the environmental loadings or changes unlike thermodynamic metrics which are mainly focused on resource use. Environmental metrics of significance for biomass systems are mainly climate change, acidification, nutrient enrichment and toxicity. These metrics are captured in a life cycle assessment which is a tool for environmental assessment of products and services throughout the entire period of their lives from cradle to grave.

Climate change, which may lead to a broad range of impacts on ecosystems and our society, is calculated as global warming potential (GWP) which is an expression of the time integrated radiative effects of an atmospheric pollutant. It is characterized based on the extent to which the pollutants (GHGs) enhance the radiative forcing in the atmosphere, i.e. their capacity to absorb infrared radiation and thereby heat the atmosphere. There are several GHGs contributing to climate change, the major ones being carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). The total effect of all the GHGs gases is expressed in terms of CO_2 equivalents over a specific time period (usually 100 years). Biomass systems play in important role in trapping CO_2 during photosynthesis as well as carbon storage in the soil. On the other hand, GHGs can also be released from land use changes as well as nitrogen fertilizer applications. The total GWP over the entire life cycle of the system is used for comparison of biomass systems and is referred to also as the "carbon footprint".

Nutrient enrichment, leading to eutrophication, is another important metric for assessing the environmental sustainability of biomass systems. Excessively high levels of nutrients, usually from the application of fertilizers during biomass growth, can lead to shifts in species composition and increased biological productivity for example algal blooms (Baumann and Tillmann, 2004). Nitrogen and phosphorus are the main substances contributing to nutrient enrichment. This metric is expressed in terms of N, NO_3^- or PO_4^{3-} equivalents.

(3) Land use

It is quite apparent that land use is intimately connected with biomass systems. Several methods have been proposed for land use impacts: impacts of land occupation (Guinée et al., 2002), soil degradation (Wegener et al., 1996; Mattsson et al., 2000), and loss of biodiversity and productivity species (Antón et al, 2005; Goedkoop and Spriensma, 2000; Koellner, 2000; Weidema and Lindeijer, 2001). Even indicators based on ecosystem thermodynamics are being developed (Wagendorp et al., 2006). But there is lack of single definition due to lack of adequate impact indicators and scarcity of data.

Most commonly, land use is characterized by the area of land used (m^2) by the biomass system or total area of different types of land (m^2 forest, m^2 agricultural land, etc.) (Baumann and Tillmann, 2004). Due to competing uses of land, the time component of the land use must also be accounted for. To reflect this, occupancy is characterized as the area of land use for a given period of time (m^2.year).

(4) Combined Ecological Indicators

Parameters such as ecological footprint and human appropriation of net primary production are composite indicators of ecological sustainability encompassing the overall effect of several environmental impacts including land use.

Ecological footprint analysis (EFA) was introduced as a tool for quantifying the biophysical load that human populations or industrial processes impose on ecosystems around the world (Rees, 2006). Recognizing that energy and resource exploitation (and the assimilation of wastes associated with resource consumption) can be associated with a corresponding dedicated land/water ecosystem area, EFA determines the total ecosystem area (hectares) required to produce the resources consumed and to assimilate certain wastes in the production of biomass (Kissinger et al., 2007). In addition to the direct physical land requirement, EFA also includes the land/aquatic ecosystem area required for sustainable assimilation and recycling of GHG was well as nutrient emissions. Thus, in effect, EFA includes global warming, nutrient enrichment and land use in a single metric.

In contrast to the ecological footprint, which accounts for the demand for and supply of land area for maintaining a socio-economic system (or product), the human appropriation of net primary production (HANPP) measures how intensively these land areas are used in terms or ecosystem energetics (Haberl et al., 2004). HANPP is defined as the difference between the net primary production (NPP) of potential vegetation, i.e. the amount of biomass energy that would be available in an ecosystem without human intervention, and the proportion of the NPP of the actually prevailing vegetation remaining in the ecosystem after human harvest has been subtracted (Haberl and Erb, 2007). Like EFA, HANPP considers all three-core functions of ecosystems for humans – resource supply, waste absorption and occupied area for human infrastructure. HANPP is expressed in terms of Joules, kilograms of dry-matter biomass or kilograms of carbon. HANPP is an indicator of the intensity with which land is used in producing biomass. As mentioned earlier, limiting the assessment only to the physical area (m^2) without accounting for the intensity of usage is obviously not sufficient. The species-energy hypothesis holds that species numbers in ecosystems depend on the availability of trophic energy; hence, HANPP may be an important driver of biodiversity loss (Haberl and Erb, 2007).

2.2.2. Economic sustainability indicators

Economic development is the main reason for starting any business venture. Hence, economic viability is the most easily understood of the three pillars of sustainability. Its characterization has been well developed in accounting systems. Economic indicators characterize the competitiveness of the production system and hence its sustainability in general. The farmer will continue operation and invest in ecological sustainability only if the production system is profitable. Economic sustainability will lead to research in market innovations and new technologies including development of new agricultural technologies, innovation in culture techniques, development of new processing techniques, etc.

The specific indicators for agriculture/biomass systems are related to the maintenance of farm revenue at sustainable level, the level of multi-functionality, multiple vertical and horizontal connections with producers, organizations and business partners, continuous supply of agriculture products, profitability, etc. These attributes are characterized by annual turnover, production values, production volumes, percentage contribution of income from various services to the total, share of production cost due to energy, environment and staff, profitability of the enterprise, level of production per unit labour and efficient use of fertilizers.

Economic sustainability of biomass utilisation needs to be assessed at the national as well as local levels. For example, at the national level biofuel production from local resources will help to reduce fossil imports and contribute to energy security. Also, investing in locally produced fuels will generate increased employment in rural areas thus internalizing the economic value of the fuels.

The reduced fossil imports can be expressed in terms of foreign exchange savings per unit investment in the biomass project and per unit area of biomass planted. So the unit of such an indicator would be $USD_{saved}/(USD_{invested} \times ha_{plantation})$.

At the local level, the economic sustainability indicator could be total value added from the biomass project per unit investment in the biomass project and per unit area of biomass planted. As in the case of the reduced imports indicator above, the unit of the local value added indicator would be $USD_{value\text{-}added}/(USD_{invested} \times ha_{plantation})$.

2.2.3. Social sustainability indicators

From the point of view of the local communities, social sustainability entails employment and stability of livelihood whereas from the point of view of consumers it means quality of the product and public acceptance of biomass activities. A livelihood is considered sustainable when it can cope with and recover from stresses and shocks (drought, pests, price volatility, etc.), i.e. it is resilient. The livelihood of the poor in agricultural areas is directly dependent on the maintenance of local ecosystem goods and services and thus linked to ecological sustainability. The improved integration of agricultural activities in local society reduces conflicts with other stakeholders.

Social sustainability indicators are difficult to quantify and are often qualitative. Some of the indicators are as follows: economic and social contribution to local society; age, gender and education level of people involved in agriculture and related activities; and measurement of society acceptance (Anon, 2005).

A quantitative indicator for social sustainability assessment could be the number of jobs per unit investment or unit area. The Food and Agriculture Organization of the United Nations has identified a similar indicator, agricultural population per cultivated hectare.

The Human Development Index (HDI) developed by the United Nations combines many of the social issues of importance such as equity in wealth distribution, access to education and quality of life. The marginal HDI could possibly be used as a social sustainability indicator for a biomass project at the local or regional level. However, further research is needed to establish the methodology since the HDI as defined presently is relevant at the national level.

2.3. Integration of sustainability indicators

The sections above present a suite of indicators for assessing ecological, economic and social sustainability of biomass utilisation. The indicators are summarized in Table 2.1 for quick reference. It must however be appreciated that not all the indicators presented above are relevant for every situation; the choice of indicators to be used is case-specific. Indicators such as eco-efficiency have been developed which combine environmental and economic sustainability whereas others such as employment generation combine social and economic sustainability. To facilitate decision-making there may be a need for developing an integrated indicator which could combine ecological, economic and social sustainability.

Table 2.1: Summary of sustainability indicators

Aspect	Indicator	Unit
Ecological	Net Energy Balance (NEB)	MJ
	Net Energy Ratio (NER)	-
	Net Exergy Balance (NExB)	MJ
	Carbon Footprint	$kgCO_2$-eq
	Eutrophication	kgN, NO_3^- or PO_4^{3-}-eq
	Land use	$m^2 \cdot y$
	Ecological Footprint	$m^2 \cdot y$
	Human Appropriation of Net	kg-dry matter biomass or kgC
Economic	Reduced Fossil Imports	$USD_{saved}/(USD_{invested} \times ha_{plantation})$
	Total Value Added	$USD_{value\text{-}added}/(USD_{invested} \times ha_{plantation})$
Social	Employment Generation	No. of jobs/$(USD_{invested} \times ha_{plantation})$

References

Anon, 2005. Defining indicators for sustainable aquaculture development in Europe, CONSENSUS – A multi-stakeholder platform for sustainable aquaculture in Europe, Workshop report, Oostende, Belgium, November 21-23, 2005.

Antón, A., Castells, F., Montero, J.I., 2007. Land use indicators in life cycle assessment. Case study: The environmental impact of Mediterranean greenhouses. *Journal of Cleaner Production*, 15(5), 432-438.

Baumann, H., Tillman, A-M., 2004. The Hitch Hiker's guide to LCA: an orientation in life cycle assessment methodology and application, Student Literature AB, Lund, Sweden.

Dewulf, J., Bösch, M. E., Meester, B. D., Vorst, G. V. d., Langenhove, H. V., Hellweg, S., Huijbregts, M. A. J., 2007. Cumulative Exergy Extraction from the Natural Environment (CEENE): a comprehensive Life Cycle Impact Assessment method for resource accounting, *Environmental Science and Technology*, 41(24), 8477-8483.

Dewulf, J., Van Langenhove, H., 2006. Exergy, in: DeWulf, J. and Van Langenhove, H. (Ed.), Renewables-based technology: sustainability assessment. John Wiley & Sons Ltd, England.

Dewulf, J., Van Langenhove, H., Mulder, J., van den Berg, M. M. D., van der Kooi, H. J., de Swaan Arons, J., 2000. Illustrations towards quantifying the sustainability of technology, *Green Chemistry*, 2, 108-114.

Dewulf, J., Van Langenhove, H., Van De Velde, B., 2006. Exergy-Based Efficiency and Renewability Assessment of Biofuel Production, *Environmental Science and Technology*, 39, 3878-3882.

Goedkoop, M., Spriensma, R., 2000. The Eco-Indicator 99: A damage oriented method for life cycle impact assessment. Amersfoort: PRe´ Consultants B.V.

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G.R.K., de Koning, A., Wegener Sleeswijk, A., et al., 2002. Handbook on life cycle assessment. Operational guide to the ISO standards, Eco-efficiency in industry and science, Kluwer, the Netherlands.

Haberl, H., Erb, K.-H., 2007. Assessment of sustainable land use in producing biomass, in: DeWulf, J. and Van Langenhove, H. (Ed.), Renewables-based technology: sustainability assessment. John Wiley & Sons Ltd, England.

Haberl, H., Wackernagel, M., Krausmann, F., Erb, K.-H., Monfreda, C., 2004. Ecological footprints and human appropriation of net primary production: a comparison, *Land Use Policy*, 21, 279–288.

Hovelius, K., Hansson, P. A., 1999. Energy- and exergy analysis of rape seed oil methyl ester (RME) production under Swedish conditions, *Biomass and Bioenergy*, 17, 279-290.

Johansson, D.J.A., Azar, C., 2007. A scenario-based analysis of land competition between food and bioenergy production in the US, *Climatic Change*, 82, 267-291.

Kissinger, M., Fix, J. and Rees, W.E., 2007. Wood and non-wood pulp production: Comparative ecological footprinting on the Canadian prairies, *Ecological Economics*, 62, 552-558.

Koellner, T., 2000. Species-pool effect potentials (SPEP) as a yardstick to evaluate land-use impacts on biodiversity, *Journal of Cleaner Production*, 8, 293–311.

Mattsson, B, Cederberg, C., Blix, L., 2000. Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops, *Journal of Cleaner Production*, 8, 283-292.

Nguyen, T. L. T., Gheewala, S. H., Garivait, S., 2007. Full chain energy analysis of fuel ethanol from cassava in Thailand, *Environmental Science and Technology*, 41, 4135-4142.

Nguyen, T. L. T., Gheewala, S. H., Garivait, S., 2008. Full chain energy analysis of fuel ethanol from cane molasses in Thailand, *Applied Energy* (in press)

Prueksakorn, K., Gheewala, S.H., 2008. Full chain energy analysis of biodiesel from *Jatropha curcas L.* in Thailand, *Environmental Science and Technology* (in press)

Rees, W.E., 2006. Ecological footprints and biocapacity – essential elements in sustainability assessment, in: DeWulf, J. and Van Langenhove, H. (Ed.), Renewables-based technology: sustainability assessment. John Wiley & Sons Ltd, England.

Schlamadinger, B., Marland, G. 1998. Some results from the Graz/Oak Ridge Carbon Accounting Model (GORCAM), in IEA, 1998. Greenhouse gas balances of bioenergy systems. International Energy Agency, Paris.

Shapouri, H., Wang, M., Duffield, J.A., 2006. Net energy balancing and fuel-cycle analysis, in: DeWulf, J. and Van Langenhove, H. (Ed.), Renewables-based technology: sustainability assessment. John Wiley & Sons Ltd, England.

Ulgiati, S. A., 2001. Comprehensive energy and economic assessment of biofuels: When "green" is not enough, *Critical Reviews in Plant Science*, 20, 71-106.

Wagendorp, T., Gulinck, H., Coppin, P., Muys, B., 2006. Land use impact evaluation in life cycle assessment based on ecosystem thermodynamics, *Energy*, 1, 112-125.

WCED, 1987. Our Common Future, World Commission on Environment and Development (WCED), Oxford University Press, New York, 400 pp.

Wegener Sleeswijk, A., Kleijn, R., van Zeitjs, H., Reus, J.A.W.A., Meusen van Onna, H., Leneman, H., et al., 1996. Application of LCA to agricultural products.Leiden: Centre of Environmental Science Leiden University (CML), Centre of Agriculture and Environment (CLM), Agricultural-Economic Institute (LEI-DLO).

Weidema, B.P., Lindeijer, E., 2001. Physical impacts of land use in product life cycle assessment. Technical University of Denmark.