Life Cycle Assessment (LCA) to Evaluate Environmental Impacts of Bioenergy Projects

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Abstract: The utilization of biomass for energy, particularly power and transportation fuels, is being promoted in many countries for various reasons such as use of local materials and the apparent environmental benefits. However, biomass utilization is not renewable and sustainable unless certain conditions are satisfied. The evaluation of environmental impacts requires the consideration of the entire life cycle to ensure that the impacts from one phase are not simply displaced to another, showing undue environmental advantages. Using the examples of three biomass chains – sugarcane, oil palm and jatropha – experiences are drawn from studies conducted on energy and environmental assessment using a life cycle approach. The results show that importance of using life cycle assessment (LCA) as the tool for evaluating environmental impacts of bioenergy systems. The LCA studies also reveal that for the utilization of biomass resources to be sustainable, it is important that all the by-products are efficiently utilized. The development of biomass conversion facilities in the form of biorefineries is highlighted as a means to this end.

Keywords: Biomass, Bioenergy, Biofuels, Life cycle approach, Sustainable utilization.

1. Introduction

Biofuels are being promoted worldwide as a means to provide additional national energy security benefits to countries relying on fossil fuel energy imports. They also provide under certain conditions of cultivation and production, environmental benefits particularly with regards to greenhouse gas (GHG) emissions reductions. The use of biofuels particularly for countries rich in biomass are therefore perceived not only to bring economic benefits from reduced importation of fossil energy but also contribute to mitigation of global warming.

Energy from biomass is being promoted in Thailand for many years. The latest 15-year alternative energy development plan by the Ministry of Energy proposes to increase the use of alternative energy to 20 percent of the national final energy consumption by 2022; biomass for heat, power and transportation fuels being one of the key parts of the plan. One of the primary reasons for the focus on biomass is that Thailand is an agricultural country with abundant biomass resources. Thus promoting biomass for energy would encourage the use of a local resource thus reducing dependence on imported fossil fuels, increasing the energy security and hopefully also contributing to a reduction in climate change-inducing, anthropogenic GHG emissions [1].

Biomass-based fuels were initially touted as "green" especially vis-à-vis their carbon neutrality at the use phase where the carbon dioxide emissions during combustion were not considered to contribute to global warming, the reason being that an equivalent amount of carbon dioxide was absorbed during the growth of the feedstock biomass from which the bioenergy carrier is produced. This initial euphoria was tempered down when the system boundaries were expanded to include the whole life cycle of the biomass-based fuel starting from the cultivation of the feedstock, including conversion and transportation, and final use. Thus, life cycle assessment (LCA) was established as a tool of choice for evaluating such systems. LCA can be applied for evaluation of environmental performance and identification of opportunities to improve the environmental efficiency of biomass energy systems. Many LCA studies have been conducted in the recent past in Thailand (and elsewhere in the world) for evaluating biopower [2-4] as well as biofuel (liquid transportation fuel) systems [5-7]. The results on the whole have been promising in terms of reduced impacts on climate change as compared to the fossil-based energy sources.

More recently, the "greenness" of biofuels has come under question once again as the system boundaries have been expanded further to go beyond the cultivation phase to include also the GHG emissions from the transformation of land use. This is a particularly significant contributor to GHG emissions when high carbon stock lands such as rainforests or peatlands are cleared making way for biomass plantations [8-9]. The "whole" life cycle has received yet another "expansion" to include indirect land use change; that is the change in land use as a consequence of displacement of other crops for bioenergy feedstocks which would induce a change in land elsewhere to satisfy the demand for the displaced crops.

Apart from the implications on GHG emissions mentioend above, changing the utilization of land is also of concern as land is a limited resource thus leading to questions about competition with food as well as the loss of biodiversity due to the monoculture nature of large-scale bioenergy feedstock plantations. Thus, biomass utilization is not implicitly renewable or sustainable; it is so only within certain constraints and efforts have to be made to achieve the anticipated benefits of biofuels [10].

This paper shows examples of how LCA is useful for the evaluation of bioenergy systems and the conditions under which some biomass utilization chains can be made environmentally sustainable using the results from studies conducted in the recent past. The examples will also lead to some general observations on achieving sustainable utilization of biomass resources. Three bioenergy chains in Thailand – sugarcane, oil palm and jatropha – all of which yield multiple products that can be used for energy, are considered for illustration. Energy balance and GHG emissions are used as a proxy for environmental impacts as these are usually used as the *raison d'être* to promote biomass-based energy though it must be emphasized that there are other impacts of significance too such as biodiversity, eutrophication and water use.

2. Sugarcane biomass utilization

Sugarcane is an important crop in Thailand with sugar being a major product of domestic consumption as well as export. Molasses, a by-product of sugar production was earlier used for low-end applications such as animal feed or for production of monosodium glutamate, etc. Much of the molasses is now used for production of ethanol following the government's promotion of bioethanol blends with gasoline.

The life cycle of the sugarcane chain starts at the plantation of sugarcane followed by sugarcane milling which produces sugar, molasses and bagasse as co-products (Figure 1). The molasses can further be used for production of ethanol which is one of the biofuels being promoted in Thailand to partially substitute gasoline. Transportation between all stages is also covered. The detailed system boundary for the LCA includes all inputs of materials and energy at every stage of the life cycle.

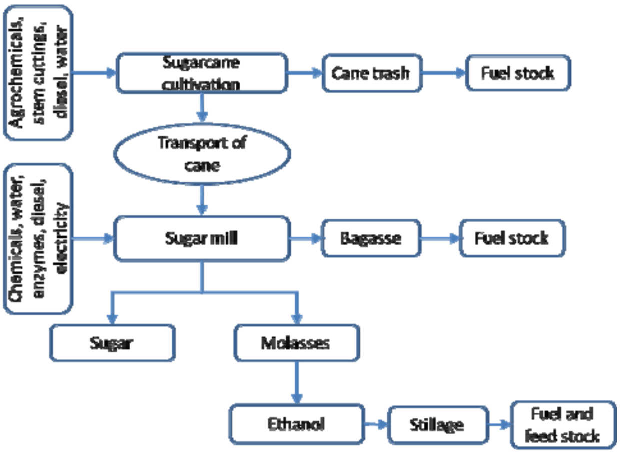

Figure 1. Sugarcane biomass chain – life cycle inputs and outputs.

Molasses ethanol in Thailand has been assessed by life cycle approach in order to present a full chain energy analysis and GHG balance to evaluate whether production and use of the molasses ethanol fuel can help reduce fossil imports and be a reasonable option for national climate policy. Several LCA studies have shown a positive energy balance of 2.5-5 and also reduced GHG emissions (as compared to gasoline after adjusting for energy content) when bioethanol is produced from sugarcane molasses [11-14]. A high contribution to GHG emisions is from the cultivation stage particularly due to the burning of cane trash during harvesting. Thus, the avoidance of burning of cane trash and its utilization for energy as well as efficient bagasse utilization have been vital in achieving these positive effects [15-16]. Similar benefits are obtained for utilization of stillage for energy via biogas production [17].

However, a point of concern is the greenhouse gas emissions associated with land use change. Change of grasslands to sugarcane plantations results in a carbon debt that could be paid off in less than a decade though replacement of tropical forests, if occurring, could have much more serious consequences [16].

3. Oil palm biomass utilization

Another interesting case is that of the oil palm. Oil palm has been planted in the southern region of Thailand for many decades and palm oil is popularly used for cooking and other products. Thailand is the third largest producer of palm oil after Indonesia and Malaysia. The supply chain of palm oil starts at the oil palm plantation followed by the palm oil mill which produces multiple products such as crude palm oil, palm kernels, shells, fibre and empty fruit bunches (Figure 2). Oil palm is a perennial plant, the fruits of which are used for extracting palm oil which is used both for food as well as for producing biodiesel. At the palm oil mill, the main product is crude palm oil which on a mass basis is only about 16% of the input fresh fruit bunches [18], the rest being, *inter alia*, the empty fruit bunches (EFB), fibres, shells and palm kernels (Figure 2).

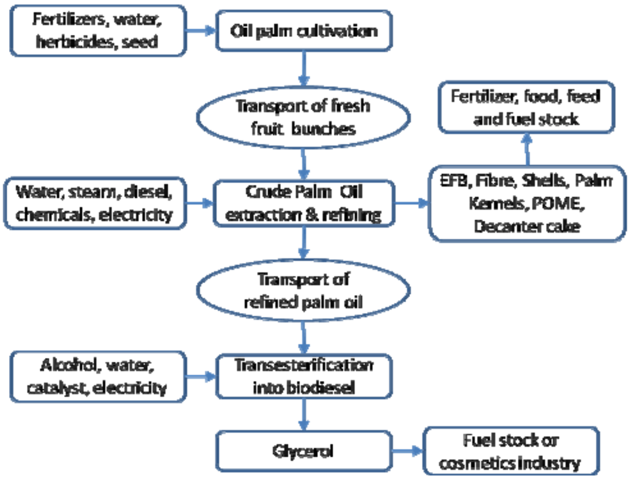

Figure 2. Oil palm biomass chain – life cycle inputs and outputs.

The wastewater, also known as palm oil mill effluent (POME), from the palm oil mill has a high organic matter content and thus has potential methane emissions which can be harnessed for energy. Like in the case of the sugar mill, the efficient utilization of the by-products is a key to improving the mill's performance. Part of the fibres, shells and empty fruit bunches are already utilized internally in the palm oil mills for energy. Some mills also utilize the biogas from the anaerobic treatment of wastewater for energy. Palm kernels are used for producing palm kernel oil which is a high value-added product. However, there is still potential to utilize the remaining by-products (especially empty fruit bunches as fertilizer or for mushroom cultivation, for example) efficiently to further improve the mill's performance. Studies have shown that the efficient utilization of all by-products can increase the net energy ratio by more than 50% [19]. The potential implications of such efficient utilization of by-products on overall greenhouse gas emissions as well as economic performance can easily be anticipated. This has in fact been validated by recent studies which show a large reduction in GHG emissions when palm biodiesel subsitutes petroleum diesel [18]. Production and application of fertilizers contribute about one fourth of the GHG emissions. Tranportation contributes almost half the emissions as the oil palm plantations and palm oil mills are mainly in the south of Thailand whereas the location of refineries and use of palm biodiesel is in Central Thailand. However, it must be mentioned here that the overall GHG emissions from palm biodiesel production are rather modest; hence the absolute values of the emissions from transportation are not so high despite the high percentages.

A key issue in the assessment of GHG emissions from the palm oil chain is that of land use change, especially as there have been concerns about large scale conversions of tropical rainforests and peatlands in Indonesia and Malaysia leading to a huge "carbon debt" [8-9]. It must be noted however, this has not been the case in Thailand where the land use changes have taken place mainly on abandoned land and on previously rubber or cassava plantations which show a positive effect on the GHG balance [20]. Thus contrary to popular perception about the negative effects of land use change on GHG emissions, if land areas with high carbon stocks such as forests and peatlands are avoided, such negative effects can be circumvented.

4. Jatropha biomass utilization

Jatropha curcas is another feedstock that has been considered for biodiesel production in Thailand. As a final case for illustration, the jatropha biodiesel life cycle is introduced. Like oil palm, jatropha too is a perennial plant which yields oil-bearing fruit. The life cycle of jatropha biodiesel includes cultivation, oil extraction, biodiesel production, and transportation at all stages (Figure 3). Biodiesel is the main product and seed cake, crude glycerin, wood, and peel are also counted in the analysis as they are significant co-products.

The peels and seed cake produced at the oil extraction stage constitute about 60% of the biomass and can be used as organic fertilizer or even as fuel stock. This indicates a large potential for utilization of the by-products which should not be ignored. Calculations on the life cycle energy balance revealed that if only biodiesel is used, then the net energy ratio is only 1.42, which being higher than 1 indicates a benefit but is still not very attractive. However, utilization of the by-products can increase the net energy ratio by almost a factor of 5 [21]. Utilization of the wood trimmings from the jatropha trees can further increase the energy output. In fact, some researchers have been considering the use of jatropha as an annual plantation to maximize the utilization of the by-products as the jatropha oil and hence biodiesel is very expensive if the by-products are not adequately utilized [22].

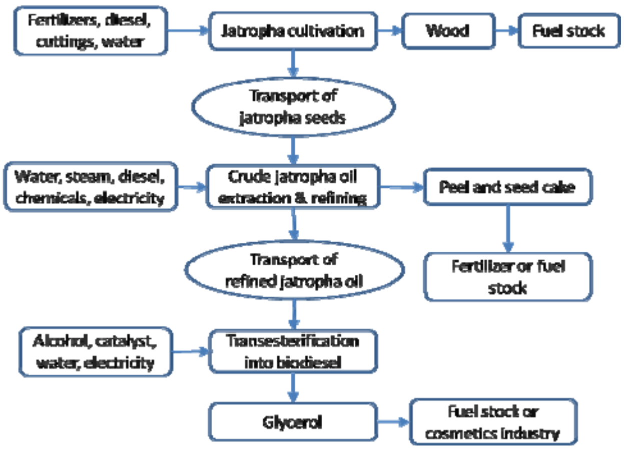

Figure 3. Jatropha biomass chain – life cycle inputs and outputs.

5. Conclusions

The various studies presented illustrate the utility of a life cycle approach when assessing the environmental implications of bioenergy systems. Such LCA analyses reveal the areas of environmental improvement which could not be known only by focusing on a single production process. The common trend in all the studies is the advantage of appropriate utilization of all the biomass in agricultural systems. Similar observations have been made even in other systems such as rice although not shown here (e.g. with rice husk and straw). This leads to the emphasis on sustainable utilization of biomass resources if energy, environmental and economic benefits are to be achieved. However, to realize these benefits, it would also be necessary to establish an appropriate infrastructure (powerplants, biogas production facilities, fertilizer factories, etc.) so that all the by-products could actually be utilized in practice. More recently, the concept presented in this paper has been further enhanced by the utilization of co-products from the biomass systems in so-called "biorefineries" that integrate bioconversion processes to produce fuels, power as well as value-added chemicals from biomass [23-24]. An integrated approach such as life cycle assessment for evaluating such systems is imperative to capture any trade-offs between the various life cycle stages [25].

References

[1] Silalertruksa T, Gheewala SH, Security of feedstocks supply for future bio-ethanol production in Thailand, *Energ Policy* 38 (2010) 7476-7486.
[2] Suramaythangkoor T, Gheewala SH, Potential of practical implementation of rice straw-based power generation in Thailand, *Energ Pol* 36 (2008) 3183-3187.
[3] Janghathaikul D, Gheewala SH, Environmental Assessment of Power Generation from Bagasse at a Sugar Factory in Thailand, *International Energy Journal* 6 (2005) 357-366.
[4] Chungsangunsit T, Gheewala SH, Patumsawad S, Environmental Assessment of Electricity Production from Rice Husk: A Case Study in Thailand, *International Energy Journal* 6 (2005) 347-356.
[5] Nguyen TLT, Gheewala SH, Life cycle assessment of fuel ethanol from cane molasses in Thailand, *Int J Life Cycle Assess* 13 (2008) 301-311.
[6] Nguyen TLT, Gheewala SH, Life cycle assessment of fuel ethanol from cassava in Thailand, *Int J Life Cycle Assess* 13 (2008) 147-154.
[7] Blottnitz HV, Curran MA, A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective, *J Cleaner Prod* 15 (2007) 607-619.
[8] Danielsen F, Beukema H, Burgess ND, Parish F, Brühl CA, Donald PF, Murdiyarso D, Phalan B, Reijnders L, Struebig M, Fitzherbert EB, Biofuel plantations on forested lands: double jeopardy for biodiversity and climate, *Conservation Biology* 23 (2008) 348–358.
[9] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P, Land clearing and the biofuel carbon debt, *Science* 319 (2008) 1235–1238.
[10] Daniel R, Lebel L, Gheewala SH, Agrofuels in Thailand: Policies, Practices and Prospects, Chapter 6 in: L. Lebel et al. (eds.), *Sustainable Production Consumption Systems: Knowledge, Engagement and Practice*, Springer, 2010.
[11] Silalertruksa T, Gheewala SH, Environmental Sustainability Assessment of Bio-ethanol Production in Thailand, *Energy* 34 (2009) 1933–1946.
[12] Nguyen TLT, Gheewala SH, Garivait S, Full chain energy analysis of fuel ethanol from cane molasses in Thailand, *Appl Energ* 85 (2008) 722-734.
[13] Nguyen TLT, Gheewala SH, Fuel ethanol from cane molasses in Thailand: Environmental and cost performance, *Energ Policy* 36 (2008) 1589-1599.
[14] Nguyen TLT, Gheewala SH, Garivait S, Fossil energy savings and GHG mitigation potentials of ethanol as a gasoline substitute in Thailand, *Energ Policy* 35 (2007) 5195-5205.
[15] Gheewala SH, Bonnet S, Prueksakorn K, Nilsalab P. Sustainability assessment of a biorefinery complex in Thailand, *Sustainability* 3 (2011) 518-530.
[16] Nguyen TLT, Gheewala SH, Sagisaka M, Potential greenhouse gas benefits of promoting sugar cane as a bio-energy resource, *J Clean Prod* 18 (2010) 412-418.
[17] Silalertruksa T, Gheewala SH, Long-term bio-ethanol system and its implications on GHG emissions: A case study of Thailand, *Environ Sci Technol* (in press).
[18] Pleanjai S, Gheewala SH, Garivait S, Greenhouse gas emissions from production and use of palm methyl ester in Thailand, *Int J Global Warming* 1 (2009) 418–431.
[19] Pleanjai S, Gheewala SH, Full chain energy analysis of biodiesel production from palm oil in Thailand, *Appl Energ* 86 (2009) S209-S214.

[20] Siangjaeo S, Gheewala SH, Unnanon K, Chidthaisong A, Implications of land use change on the life cycle greenhouse gas emissions from palm biodiesel production in Thailand, *Energ Sus Dev* 15 (2011) 1-7.
[21] Prueksakorn K, Gheewala SH, Full chain energy analysis of biodiesel from *Jatropha curcas L.*, Thailand, *Environ Sci and Technol* 42 (*Energ Sus Dev* 2008) 3388–3393.
[22] Prueksakorn K, Gheewala SH, Malakul P, Bonnet S, Energy analysis of Jatropha plantation systems for biodiesel production in Thailand, *Energy for Sustainable Development* 14 (2010) 1-5.
[23] Demirbas MF, Biorefineries for biofuel upgrading: A critical review, *Appl Energ* 86/1 (2009) S151–S161.
[24] Gutiérrez LF, Sánchez ÓJ, Cardona CA, Process integration possibilities for biodiesel production from palm oil using ethanol obtained from lignocellulosic residues of oil palm industry, *Bioresour Technol* 100 (2009) 1227-1237.
[25] Uihlein A, Schebek L, Environmental impacts of a lignocellulose feedstock biuu;orefinery system: An assessment, *Biomass Bioenerg* 33 (2007) 793-802.