Development of indicators for energetic biomass utilisation

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Abstract:
The degree of sustainability of different renewable energy options is often connected to the net greenhouse gas reduction of this option in comparison to the conventional energy generation. In the discussion of pros and cons eventually the land issue and the production costs are used as an additional argument for the relative competitiveness of an alternative. In this work an effort is undertaken to combine the three main elements: greenhouse gas emission, land use and costs into one numerical indicator. This is demonstrated with two solutions for the calculation of an indicator. The results can be used to classify different options into more or less favorable ones. It would also be possible to compare biofuel production from biomass with electricity produced from biomass resources. Rankings can be made in a manner, that an indicator for example as K1 below 25 is good, K1 between 25 and 75 is in limits and any value above 75 is not sustainable according to the definition. In a first evaluation the electricity production from biomass by-products seems to be better or more sustainable in the above-defined combination compared to biofuels from biomass resources.

Keywords: *Biomass, Biofuels, Sustainability, Indicators, Land Use Change, Production Costs*

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1. Introduction

Biomass is a highly versatile energy carrier. Besides the traditional use for cooking and heating the modern application of biomass is as fuel in power plants for the production of electricity (and steam in certain applications) or as input into liquid biofuel production. The assessment on sustainability of different alternatives and options uses a range of different criteria, out of which the greenhouse gas balance is an important one. Issues on land utilization and other factors are added in the discussion (Fritsche et al., 2010). Objective of this research paper is the development of indictors, which include besides the climate change impact through greenhouse gas savings also criteria like land use and production cost. Because Thailand employs already a range of different production alternatives, the country offers a good opportunity for a detailed analysis.

2. Methodology

Different methodologies are in use to define the sustainability of a technical solution. Data for a sustainability assessment are generated during a life-cycle-analysis (LCA). The certification efforts for bioenergy result in facts and figures as well. Thereby the different systems employ objectively calculated figures but also subjectively discussed criteria. Out of several options the application GEMIS was chosen for calculating results for the different LCA for relevant bioenergy routes in Thailand (Anonymus, 2013). In these cases, where agricultural products for bioenergy are in competition to food or fodder, the impacts of land use changes on the climate balance are assessed as well (IPCC, 2006). For the completion of the overall analysis economic models are necessary for assessing the production costs and few other technical data are needed for the complete analysis.

Two different indicators are proposed. Both indicators shall combine the figures for greenhouse gas emissions (GHG), land demand and production cost. The first figure, K1, is the sum of input energy, land demand and costs divided by the specific savings of GHG. In essence, the figure gives: with which efficiency, with which costs and with how much land can we achieve a certain saving of GHG. The second figure, K2, is multiplying above impacts and is defined in a way to be dimensionless. In both ways low values of the indicator represent a high sustainability.

The relevant bioenergy routes in Thailand have been analyzed and assessed. These include power production from bagasse and fieldrest, bioethanol production from the sugar sector, power production from rice husk and rice straw, bioethanol production from cassava and biodiesel from palm oil products (JGSEE, 2010; JGSEE, 2010-1). The field research was conducted in Thailand while being positioned at the Joint Graduate School of Energy and Environment (Siemers, 2010).

The definition of indicator K1 follows in eq. (1):

$$K1 = (PE+PK+FB) / KE \qquad (1)$$

with
PE = primary energy demand (fossil and renewable), kWh/kWh,
PK = production cost, €ct/kWh,
FB = land demand, m^2/kWh,
KE = savings in carbon dioxide equivalent, kg CO_{2eq}/kWh.

The figure FB is defined as in eq. (2):

$$FB = 1*10^4/P*\eta \qquad (2)$$

with
P = productivity, kWh/ha
η = energetic conversion efficiency of total chain, %
10^4 = conversion from ha to m^2.

The GHG-savings KE are defined as the difference between the reference system and the emissions according to the LCA of the process analysed:

$$KE = CO_{2eqReference} - CO_{2eqProcess} \qquad (3)$$

with the following condition, unit CO_{2eq}/kWh:

$$CO_{2eqReference} - CO_{2eqProcess} < 0 \Rightarrow KE = 0 \qquad (4)$$

The definition of the alternative indicator K2 uses more or less the same input figures. In contrast to above defined K1 this indicator K2 multiplies the different factors and is dimensionless in the end.

3. Results

For all of the different bioenergy options the relevant input data are generated and discussed, before the LCA chain is completed and calculated. One advantage in this aspect is the similar methodology for the different alternatives, which reduces possible misinterpretation. First results can be discussed at this stage. Bagasse and fieldrest are a cheap and GHG reducing alternative. For bioethanol from sugar this is only true, if during the processing renewable energy is consumed and if an allocation is allowed between sugar and molasses. Power production from rice husk and rice straw is less favorable in comparison to the sugar sector, because fossil energy is needed for transport and processing. A risk for increasing the GHG balance exists for cassava based ethanol, if fossil fuels are used during the major production steps. Efficient production methods and use of biogas reduce these risks. Direct land use changes have only a minor effect. Especially biodiesel from palm oil is criticized in the international discussion. For Thailand it can be shown that effects of direct land use change have less impact on the GHG balance as anticipated. In addition, several byproducts are also used for biodiesel. This gives a wide range of possible results for the complex biodiesel from palm oil resources. For the selected processes the GHG emission for the respective process can be seen in

Fig. 1. Due to the land use change benefit biodiesel from CPO is negative in GHG emissions (bottom in Fig. 1). Other bioelectricity options from bagasse and fieldrest (sugar production) follow. Bioethanol from cassava and some biodiesel option show relatively high GHG emissions. After the LCA with the help of GEMIS further data are generated and finally the indicators K1 and K2 are calculated. This allows now the comparison of different technologies, i.e. the power production from solid residues versus the liquid biofuel production in terms of GHG savings, costs and land demand. In the final analysis only 25 representative routes are compared. In general, the power production routes result in low indicators, representing a better sustainability. Main reason is the use of byproducts. Biofuels show higher values resp. less sustainability because inputs for agricultural production for the main product have to be included. The range of figures is higher because more options regarding production methods, efficiency and possible land use changes have to be considered (compare all values in Fig. 2).

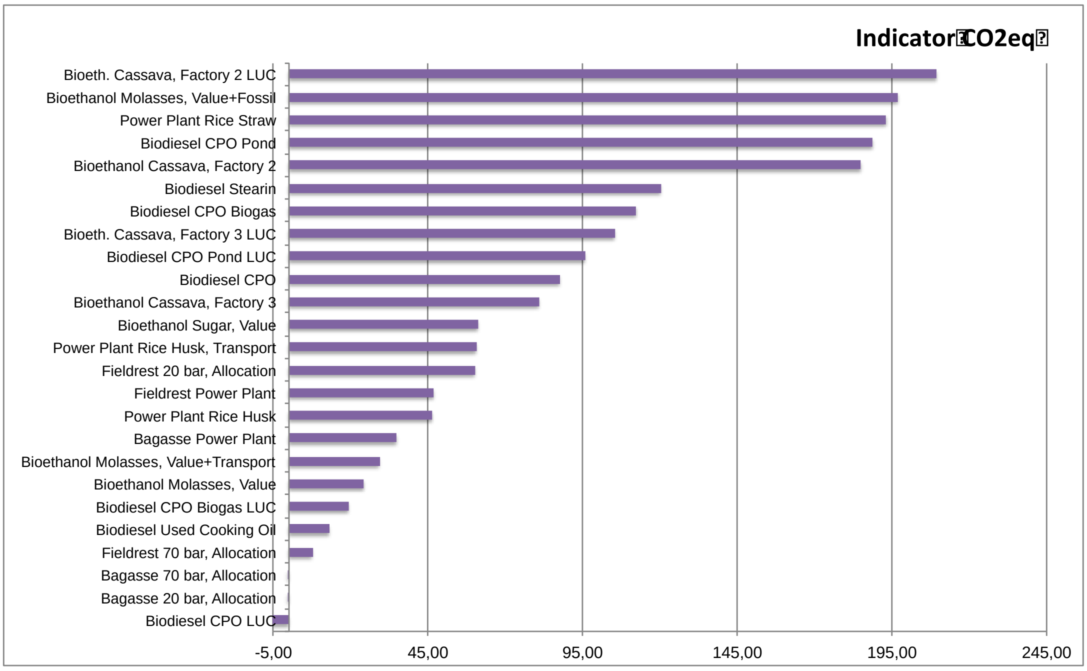

Fig. 1 Ranking of selected processes according to GHG emissions

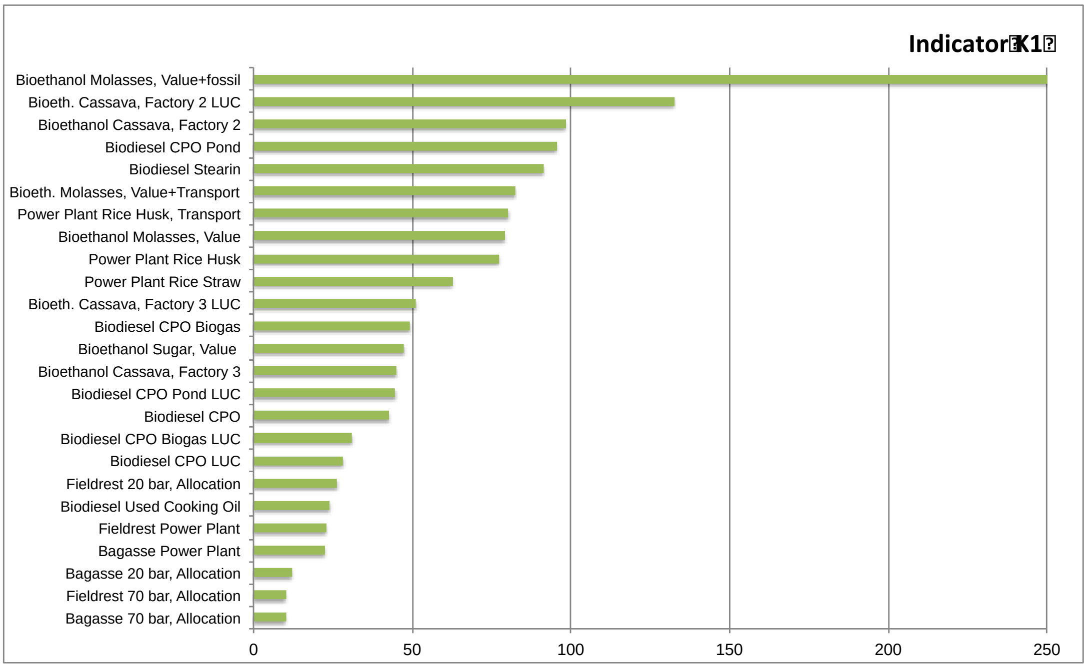

Fig. 2 Ranking of selected processes according to definition of indicator K1

4. Discussion

The application of indicator K1 has changed the ranking order by comparing Fig. 1 and Fig. 2. Biodiesel from CPO with land use change (LUC) is not the most favorable option as had it been before in the GHG balance only. In the group for bagasse technologies, which are the lowest values for K1, now the 70 bar technologies are better in K1 than the 20 bar option for GHG. The power plants for rice husks are valued less in K1 in comparison to GHG. This shows the influence of the price for the product (e.g. rice husk) and the relatively low productivity or high land use (although being a by-product). In some other cases there is not much of a difference, for example looking at bagasse power plant or fieldrest power plant. In K1 these options are better than several bioethanol routes. One reason is that electricity production has a higher net GHG saving effect (based on the kWh) as biofuels. The trend for bioethanol from cassava and from molasses is similar. In both indicators the use of fossil energy and the lower conversion efficiency influence the competitiveness substantially.

5. Conclusion

In looking at the different production methods for bioenergy in Thailand, one could classify the degree of sustainability according to the final value of the indicator K1 resp. K2. For K1 a final value below 25 would be regarded as very good. Up to 75 it could be regarded as sufficient and in line with the political direction. Figures above 100 are risky and less suitable for a possible promotion. A similar range exists for the indicator K2. A figure up to 1 is very good, below 3 still good and above 10 questionable. In the final discussion it is proposed to employ the indicator K1.
The combination of GHG emissions, land demand and production cost can lead to a single numerical value, which can compare different bioenergy sources and final products and allows a classification with respect to sustainability and the important criteria land use competition and production costs. This has been shown for Thailand by using extensive field research data. It may also be applied in general, if a national base case for the indicator (K1*) is defined and consequently a relative indicator K1 / K1* be calculated.

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