Key Assumptions and Boundary Conditions for Life Cycle Assessment of Bio-energy Technologies

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Any energy system will interact with its surroundings through market mechanisms and other contextual relations, and the nature and scope of markets for electricity, fuels, food and animal feed influence on the outcome of the assessment of the environmental aspects of the system.

The key issues to be addressed are listed in the table below and further elaborated in the subsequent text.

Key issues	Framework condition in general	
	a	b
Scope of trade: Overall geographic scope of the trade on the markets for electricity, fuels, energy crops, food & feed crops	International	National/regional
Correlation: between energy and food/feed sectors	Correlation	No correlation
Fuel marginal on the fuel market	Fossil	Biomass/other non-fossil
Marginal supplies outside Denmark	Fossil	Biomass/other non fossil
Land-use marginal for energy crops	Natural land with high carbon sequestration	Natural land with low carbon sequestration
Land-use marginal for food/feed crop displacement-replacement	Natural land with high carbon sequestration	Natural land with low carbon sequestration

<u>The scope of trade: The geographic scope of the markets for electricity, fuels, energy crops and food/feed crops</u>

We can look at the significance of these market scopes by choosing 2 overall future scenarios at each 'end of the interval': one with very international markets and one with national/regional markets. Looking at the energy scenarios, i.e. the high wind versus high biomass, we will most probably end up by finding the same environmental priority independently of the scope of the trade, but potentially with much higher quantitative differences in case of an international scope (see later sections below for further justification of this statement).

<u>Correlation between the energy and the food/feed sectors</u>

If, in the future we are looking at, we have a significant part of the agricultural area on our planet dedicated to energy crop production – as well as food/feed crop production – there will be a significant correlation between the fuel markets and food/feed markets. Simply because farmers can choose crops for sale at both market categories. The price for crops on the food/feed market will/may, thus, have to follow the price on the energy crop market and vice versa. In case of significant correlation, changes in demand and supply of energy crops will through market mechanisms and price relations, thus, implicitly also influence demand and supply in the food/feed sectors and thus the environmental aspects of these sectors, which accordingly have to be modelled.

As we are looking at energy scenarios with high versus low biomass including high versus low use of agricultural land for energy crops, there will be differences in the amount of food & feed produced by Danish farmers between the two scenarios. If we do not assume any changes in import export ratios of food/feed between the two scenarios, we implicitly claim that Danish food/feed consumption will vary significantly depending on our choice of energy production scenarios. This, of course, is not a valid assumption, and of course Danish import-export will change with changing Danish food/feed production. An LCA is by convention made to compare scenarios with the same functional outputs on all goods and services produced by the alternative systems, in this case energy, transport, food, feed and more. Because of differences in price relations between scenarios, an assumption of fully equal functional outputs is not the whole truth either, but in any case the large differences between food/feed production from the two scenarios must be dealt with by modelling the reactions from the market when less food/feed is sold from Denmark in the high biomass scenario, i.e. the replacement of supply by other suppliers outside Denmark.

Fuel marginal

Our base assumption is that we do not use any fossil fuels in Denmark in the future we are modelling/designing. The question of the fuel marginal, i.e. whether it is of fossil or biogenic origin, is therefore only relevant for a future in which we assume a significant international trade on the fuel markets. As we do not, in the scenarios we are looking at, consume any fossil fuels in Denmark, the question is, if the biomass-for-energy market is international or not.

In case of an international market for energy biomass, and in case the surrounding world still use fossil fuels, the marginal fuel may be fossil, i.e. we can substitute fossil fuels only to the extent we have alternatives like biomass, meaning that any prioritisation of biomass for one use implies an equivalent use of fossil fuels for another purpose. If the biomass marginal is in fact a fossil fuel, it implies that biomass technologies disappear from the LCA being represented by their fossil marginals. The difference between wind and biomass will then be equal to the difference between wind and fossil.

Marginal supplies outside Denmark

Parts of the systems, we are studying, will be outside Denmark independently of the markets for electricity, fuels, food and feed – as we will in any case import components of the studied technologies. As the energy and material aspects of such marginals are the crucial ones, the most important aspect of this is again judged to be, if they are of a fossil or biogenic origin.

Land-use marginal for energy crops

Assuming that the biomass fuel marginal is biogenic, we must be able to define the area or land use marginal for the energy crops in question. This in turn has to be done in due respect for the market based displacement-replacement responses to changes in crop demands between scenarios, i.e. that the energy crop displaces a food/feed crop that in turn will be replaced fully or partly by other suppliers to the crop markets in question. Such chains displacement-replacement reactions will take place until they rest at final cultivation of new land (marginal land) at the frontier between agriculture and nature or till they are counteracted by changes in agricultural yields driven by the demand change in question. This holds true independently of the geographical scope of the markets, but requires the most complex modelling for international markets.

If the land use marginal fully or partly ends up in environmentally sensitive areas, e.g. nature types with a high carbon binding in soil and vegetation (e.g. primary forest, peat land, wetlands), there

will be high implications on global warming from the high biomass scenarios. As the latest articles from Science and Nature suggests, the greenhouse implications of energy crop consumption may in this case be even higher than if the fuel marginal was fossil.

If the land use marginal ends up in other less sensitive nature types, the implications will be less. But even so, biomass consumption is judged to have higher environmental impacts on the traditional LCA impact categories from releases of N, P, N_2O and CH_4 from agricultural production.

Land-use marginal for food/feed crop prduction
Same considerations as above.

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