

## Review of Bioenergy Life-Cycles:

### Results of Sensitivity Analysis for Biofuel GHG Emissions

- Final Report -

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## Foreword

This report builds on the UNEP (2008) report

*"Existing knowledge and limits of scientific assessment of the sustainability impacts due to biofuels by LCA methodology"*; Menichetti, Emanuela/Otto, Martina (UNEP-DTIE), May 2008, Paris

and adds sensitivity analysis for selected liquid biofuel pathways to illustrate overall data variation of biofuel life cycles, focusing developing countries.

The sensitivity is analyzed with regard to GHG emissions as a key indicator of environmental sustainability.

In Annex I, data for LCA results including international seaborne transport of biofuels are given, while Annex II gives illustrative results for the sensitivity of the use phase, but with respect to European settings only.

Annex III offers a brief description of the "iLUC factor" approach for the GHG emission potential from indirect land use change, and in Annex IV, a summary of sustainability issues "beyond LCA" is included.

This report is a revised version of an earlier draft, taking into account comments on the draft from UNEP-DTIE and the Resource Panel. All remaining errors or shortcomings are the sole responsibility of the authors.

Darmstadt, January 2009

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## 1 Scope of the Sensitivity Analysis

Based on the previous work of UNEP-DTIE, sensitivity analysis was carried out for selected biofuel life-cycles in order to indicate the robustness of results.

Sensitivity analysis has the objective to assess the consistency of assumptions, to identify which parameters or life-cycle stages have the greatest influence on results, and to evaluate possible improvement options.

Based on the analysis of the studies and the considerations given in the UNEP-DTIE report, sensitivity analysis was recommended with respect to the following life cycle stages, and parameters:

*Table 1 List of Recommended Sensitivity Analysis Parameters*

| <b>Life cycle stage</b>        | <b>Parameter to be varied</b>   |
|--------------------------------|---|
| Production phase (agriculture) | assumed fertilizer input  |
|                                | assumed yield   |
|                                | hypothesis and assumptions for the land reference scenario on the carbon stock balance                |
|                                | IPCC method for N <sub>2</sub> O emissions vs. another method   |
| Conversion phase               | allocation methods (economic, energy, mass) versus system expansion (substitution/crediting approach) |
|                                | treatment of residues and wastes  |
|                                | current technology vs. BAT/future improvements  |
| Use phase                      | engine combustion efficiency, existing vs. (projected) future concepts                                |
| Cross-cutting                  | life-cycle inventory data (one life cycle from different databases, e.g., GEMIS, NREL)                |

*Source: Adapted from UNEP-DTIE (2008)*

The respective analyses were carried out using GEMIS, a publicly and freely available LCA model and database which runs under Microsoft Windows® operating systems<sup>1</sup>.

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<sup>1</sup> see [www.gemis.de](http://www.gemis.de)

To illustrate the relevance of the analysis for **developing** countries, two major current settings and a prospective one were used:

- sugarcane-based ethanol in Brazil;
- palmoil-based biodiesel in Indonesia, and
- future Jatropha-based plant oil in India (from arable and marginal land).

There is a wealth of recent literature dealing with sensitivity analysis of GHG emissions of other biofuel life cycles (mainly Europe and US) which finds similar results<sup>2</sup>.

The system boundary for the analysis was set to the provision of biofuels in the country of origin, i.e. no international transport was included<sup>3</sup>. The background systems for electricity, heat, and domestic transport were modeled to reflect the situation in the respective countries.

In the **base** case of the analysis, **no** land-use change impacts were included, and by-products were included based on energy allocation to reflect the EU regulation for GHG accounting<sup>4</sup>.

### 1.1 Sensitivity Analysis versus Data Variation and Data Uncertainty

Life cycle analysis (LCA)<sup>5</sup> for bioenergy in general, and for biofuels in particular, concerns a broad range of feedstocks, conversion technologies, and end-uses.

The environmental footprint of biofuel feedstock production varies with respect to specific commodity, country of origin (e.g. climate and soil conditions), agricultural practice, and regional or country-specific background data such as energy and transport infrastructure.

This is data **variation** which should not be mixed with the issues of data **uncertainty** (e.g. N<sub>2</sub>O emission factor), or **sensitivity** of results regarding a specific parameter (e.g., yield):

- Data **variation** is an issue of the scope of LCA – as said, circumstances in life cycles vary from one location to another one, so that the same e.g. conversion processes of biomass to biofuels can give different results due to variations in

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<sup>2</sup> see for Europe: ADEME (2008); IFEU (2008); JRC (2008); OEKO (2008); VTT (2008); Zah et al. (2007); for Canada: CSI (2008 a+b); for the USA: Dale (2008); von Blottnitz/Curran (2007)

<sup>3</sup> In Annex I, results are given which reflect international seaborne transport to oversea export markets (US, EU).

<sup>4</sup> The effects of changing the method to factor in by-products are presented in Section 1.3 **Fehler! Verweisquelle konnte nicht gefunden werden.**

<sup>5</sup> LCA is originally the acronym for “life cycle assessment”, as codified in the ISO Standards 14000ff. In this report, we use LCA for life cycle analysis, indicating that not a “full” LCA according to ISO is carried out, but only the **analytical** parts, i.e. life cycle inventorization and sensitivity analysis.

feedstock production. To address variety, the scope of LCA should be wide enough to reflect relevant differences between biofuel production systems. The scope should cover possible pathways and situations, and be structured into **clusters** which refer to specific **regions** (e.g., EU, Latin America, sub-Saharan Africa, etc.), and **time scales** (current, future time horizons).

Any differences between results of different clusters do neither represent sensitivity, nor uncertainty. In that respect, the scope of the sensitivity analysis presented here covers a developing country “cluster” with three different countries, and several “cases” which represent e.g. potential future developments.

- Data **uncertainty** is a core issue of LCA – not for all processes, adequate data is available on in- and outputs, efficiencies etc., so that often, estimates with a **range** of certainty must be used. In some cases, knowledge on the physical, chemical or biological processes under given climates, soils etc. is missing, so that e.g. nitrous oxide (N<sub>2</sub>O) emissions from fertilizer applications can be expressed only with an uncertainty range. The **potential** impact of an uncertainty range of a parameter in LCA can be measured in sensitivity analysis, though (as addressed in this report).
- Data **sensitivity** – the subject of this report – is the relative change of a LCA result (e.g., GHG emissions) with regard to changes of a certain parameter used in the life-cycle calculation, e.g. yield assumptions of feedstock production. The sensitivity is a useful **measure of the relevance** of data variation or data uncertainty for a given result.

## 1.2 Sensitivity Analysis of Key Input Parameters for the Production Stage

The environmental performance of biofuel life-cycles depends mainly on the following key data inputs for the production stage:

- fertilizer use;
- yields;
- assumed land-use change (if any), and
- conversion factors for N to N<sub>2</sub>O emissions.

For the selected biofuel settings, different ranges of those key data were analyzed according to the specific circumstances of production.

### 1.2.1 Fertilizer Use

For the sugarcane ethanol setting in Brazil, the fertilizer input in the base case is assumed to be a mixture of agrochemicals (N, P, K) as given in Macedo et al. (2008) for the current situation. For the “low-N” sensitivity case, it is assumed that machine harvest allows mulching of half of the sugarcane leaves, and that vinasse is used for irrigation, thus returning more nitrogen to the field, and reducing 15% of N-input from fertilizer without compromising yields.

For the palmoil setting in Indonesia, fertilizer input in the base case is assumed to be a mixture of agrochemicals (N, P, K) according to OEKO (2008) and WWF (2007) for the current situation. This data reflect also the default data for palm oil in the EU approach for GHG accounting. The “low-N” sensitivity case assumes increased mulching of empty fruit bunches, and intercropping for N-fixing in the first 10 years of the plantation, thus reducing 20% of N-input from fertilizer without compromising yields.

For Jatropha, no industrial N-fertilizer is assumed for the base case, so that no sensitivity can be determined<sup>6</sup>.

### 1.2.2 Yield Assumptions

For the sugarcane ethanol setting, the base case yield was taken from Macedo et al. (2008), reflecting the current situation. For the “hiYield” sensitivity case, the projection from OEKO (2008) is taken which is based on the prospective further yield increases given by Almeida (2007)<sup>7</sup>.

For the palmoil setting, the base yield data are taken from IFEU (2007) which are mainly based on FAO data, and EUCAR/JRC/CONCAWE (2007). For the “hiYield” sensitivity case, the 2030 yield projection in OEKO (2008) was used<sup>8</sup>.

For Jatropha, the base case reflects yield assumptions from OEKO (2008), and the “hiYield” sensitivity case assumes a 25% increase through improvements in plant breeding and seedling selection.

### 1.2.3 Land-Use Change Assumptions

The evidence of significant GHG emissions from potential land use change (LUC) has been increasingly recognized in the recent literature<sup>9</sup>.

While GHG emission impacts from **direct** LUC (dLUC), i.e. the changes in above- and below-ground carbon induced by cultivation of biomass crops, are reasonably understood and can be based on IPCC default data, there is still variation<sup>10</sup> in **which** dLUC could occur: is arable land affected, or pasture land, permanent grassland, peatland, savanna, or (tropical) forests?

This is not an uncertainty, but needs reflection in the definition of the setting.

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<sup>6</sup> The N demand of jatropha especially in the first years of establishing the culture is assumed to be covered by unused plant residues (mulch).

<sup>7</sup> The 2005 annual yield of 650 GJ/ha (gross biomass growth) will rise to 700 GJ/ha.

<sup>8</sup> The 2005 annual yield of 500 GJ/ha (gross biomass growth) will rise to 660 GJ/ha.

<sup>9</sup> See e.g., Dale (2008); Fargione et al. (2008); Fehrenbach/Fritsche/Giegrich 2008); IFEU (2007); JRC (2008); Searchinger et al. (2008); VTT (2007); WWF (2007)

<sup>10</sup> See Section 1.1 for this term.

To analyze the sensitivity of this parameter, several dLUC cases were defined for biofuel feedstock production: cultivation on arable land as well as extreme cases of converting high carbon stock land, i.e. savanna (for Brazil) and tropical rain forest (in Indonesia). Furthermore, dLUC is calculated for cases using degraded<sup>11</sup> land with low carbon stock for biomass cultivation.

The respective case matrix is given in the following table.

| Sensitivity Case | land for cultivation  |
|------------------|---|
| base             | no LUC  |
| dLUC             | arable (previous production is displaced)                   |
| dLUC degr.       | degraded land (low carbon stock) , no displacement          |
| dLUC hi-C        | savanna (BR) and tropical rain forest (ID), no displacement |

Another relevant element of LUC emissions lies in the potential **indirect** effects: there is a lively debate in the literature (and beyond) on how to conceive, model, and interpret indirect land use change (iLUC) from displacement and the respective potential GHG emissions<sup>12</sup>.

As the impact of including iLUC on the GHG balance of bioenergy is quite large, it is clearly an issue for sensitivity analysis<sup>13</sup>.

To address this, the concept of the “iLUC factor” is used here which describes the **theoretical potential** for GHG emissions from iLUC, based on the 2005 global trade patterns, and land use for agricultural commodities<sup>14</sup>.

The results were determined for the 25% (low) and 50% (medium) levels of the theoretical iLUC factor<sup>15</sup>.

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<sup>11</sup> For a discussion of the term „degraded“, see “International Joint Workshop on Bioenergy and Biodiversity and Degraded Land”, Paris, June 30-July 1, 2008 held jointly by Oeko-Institut, RSB and UNEP and in collaboration with CI, FAO, IUCN and WWF: [http://www.bioenergywiki.net/index.php/Joint\\_International\\_Workshop\\_Mapping](http://www.bioenergywiki.net/index.php/Joint_International_Workshop_Mapping)

<sup>12</sup> See e.g., RFA (2008) for a more detailed discussion of the current state.

<sup>13</sup> Note that as iLUC is related only to biomass from cultivation of land which has competing uses, there is **no** iLUC for biomass from residues and wastes, and also **none** for biomass grown on abandoned, marginal or degraded land.

<sup>14</sup> A brief summary of the “iLUC factor” approach is presented in Annex II.

<sup>15</sup> See Annex II for a description on the respective levels. The “maximum” iLUC level is not included as the 50% level already increases GHG emissions for most biofuels beyond the level of their fossil competitors. In the case of ethanol from Brazil, the 75% level would lead to higher GHG emissions than fossil gasoline. It should be noted that the GHG emissions from the 25% and 50% iLUC factor levels are still lower than those calculated by e.g. Searchinger et al. (2008).

### 1.2.4 Nitrogen to N<sub>2</sub>O Conversion Factors

The conversion of nitrogen from fertilizer application into nitrous oxides (N<sub>2</sub>O) is usually done by using IPCC default data (IFEU 2007). Still, there is uncertainty about the validity of the default data, as little empirical evidence is available especially for e.g., non-temperate soils, and no-till agriculture, and the uncertainty range of the IPCC data is quite large.

Crutzen et al. (2007) brought the discussion of the “right” level of N-N<sub>2</sub>O conversion factors to a broader public, and the discussion is still going on.

As N<sub>2</sub>O is a comparatively strong<sup>16</sup> GHG, the N-to-N<sub>2</sub>O conversion factor has a significant impact on the GHG emissions of bioenergy feedstock cultivation, so that the conversion factor is an important issue of the sensitivity of respective GHG emission calculations.

Therefore, the sensitivity of the N-to-N<sub>2</sub>O conversion is modeled here using the IPCC default data as a base case (1% conversion), and increasing the range to the upper limit of 5% in the “hiN<sub>2</sub>O” case.

### 1.3 Sensitivity Analysis of By- and Co-Product Treatment

The treatment of co- and by-products in biofuel life-cycles is another important issue that significantly can influence the results of GHG balances. The distribution of the environmental burden of a process between its “main” and “co-” (or by-)products is called allocation<sup>17</sup>.

The base cases use this **energy** allocation. For the sensitivity cases, the co-product treatment in conversion processes was varied to cover

- **substitution** (credit for co-products for avoided equivalent processes, based on electricity/heat), with excess electricity replacing either the **average** generation mix in the respective country, or generation from a **new coal-fired** powerplant in the same country;
- **economic allocation** through the monetary value of the products, with taking the production cost for the main product, and the market value of by-products<sup>18</sup>.

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<sup>16</sup> The mass-based Global Warming Potential (GWP) of N<sub>2</sub>O relative to CO<sub>2</sub> is 296 for a 100-year time horizon, according to the IPCC.

<sup>17</sup> ISO 14000 ff gives priority to system expansion, (or substitution by crediting with equivalent processes), but this is meant for analytical - not “political” – purposes; ISO also recommends that if allocation cannot be avoided, then the sensitivity of results should be shown using different allocation methods. In contrast, the mandatory sustainability schemes for biofuels (especially in the EU) require **one** non-discriminating allocation rule – and as of now, this is allocation by the energy content of products.

<sup>18</sup> Note that mass-based allocation was not included, as there is no mass equivalent for electricity which is a key co-product of the ethanol life-cycle.

## 1.4 Sensitivity Analysis of Waste Treatment

In the palmoil life-cycle<sup>19</sup>, there is a significant impact from the waste-water treatment of the oil mill.

In the base case, the ponds used to decompose the high organic liquid effluents emit CH<sub>4</sub>, while in the sensitivity case, the waste-water treatment is assumed to apply biogas production which reduces nearly all CH<sub>4</sub>, and also generates onsite electricity used to partially provide for the milling electricity demand.

## 1.5 Sensitivity Analysis for Technology Status, and Time

The status of a technology in LCA is usually set to a “reference” or **base** situation describing a given year (e.g., 2005) with “typical” design, operation conditions etc.

Still, there are various options to increase e.g., conversion efficiency, to reduce auxiliary energy and materials demands, and also to change supply systems for auxiliaries (e.g. for process heat).

To capture those options in LCA, one can define “advanced” conversion processes as well as “advanced” production systems. For the latter, there is an overlap to the “yields” sensitivity, as yields are typically assumed to increase over time (see Section 1.2.2). Time sensitivity also occurs, both regarding process efficiencies, and background data, as e.g., electricity generation will evolve over time (see Section 1.7).

To indicate the sensitivity of the technology status, the 2005 base cases were compared with their 2030 equivalents in which technology learning is assumed based on OEKO (2008).

## 1.6 Sensitivity Analysis for the Use Phase

The use phase of biofuels for transport concerns the combustion of the fuel in a vehicle (e.g., airplane, bus, car, ship, train, truck) equipped with an engine which converts the biofuel into motive power so that a certain transport service (e.g. moving persons or freight) is delivered.

There is a very large variety of possible vehicle/engine configurations as well as operating conditions and driving modes which all influence the GHG emission characteristics of the transport service delivered, as biofuels could be used not only in existing otto and diesel engines, but also in more advanced powertrains such as e.g. fuelcell systems with electric motors, or full-fledged battery-electric vehicles. Furthermore, biofuels could be used in e.g. public transport systems such as buses or light rail instead of burning them in individual cars. Similarly, biofuels could be used for freight transport in trains or ships instead of trucks.

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<sup>19</sup> This is not the case for the ethanol life-cycle in Brazil, and also not for the jatropha life-cycle. Therefore, the sensitivity case is only modeled for biofuels from palmoil.

It is rather simple to say that a more efficient vehicle (e.g. car) will use less (bio)fuel than a “standard” vehicle, thus having lower GHG emissions per vehicle-kilometer traveled. More of interest would be to compare biofuel use in “standard” vehicles with other options to reduce GHG emissions, e.g., using more efficient cars running on fossil fuels, or using different vehicle technologies such as fuel-cell cars using H<sub>2</sub> from biomass, or electric vehicles running on biomass-derived electricity.

But today, there are only few data on person and freight vehicles and their respective efficiencies and emission characteristics available for developing countries, and even less is known about the potentials to increase efficiencies, switch transport modes etc. under the specific circumstances of developing countries.

So instead of carrying out a sensitivity analysis with fictitious or speculative data, Annex II gives some results of a “use phase analysis” carried out for the European (future) situation. Note that these results cannot be easily translated into the developing country context, though, as the system boundaries were set to EU conditions for both the fuel life cycles (i.e. including seaborne transport of imported feedstocks, and conversion to e.g. PME in Europe) and cars (i.e. all vehicles reflect EU regulation on efficiency and emissions). The results given in Annex II are meant to **illustrate** the possible range of options, and the resulting bandwidth of emissions.

### 1.7 Sensitivity Analysis for Overall Background Data

In addition to the sensitivity of key data along the biofuel life-cycles, there is also a potential source of data variation in the so-called “background” data, i.e. the energy, material and transport process which are not specific to biofuels, but linked to their life-cycles at various stages.

With regard to the selected biofuels in developing countries, the key background data influencing the GHG emission balances indirectly are

- agrochemicals productions, especially nitrogen fertilizers
- electricity generation
- process heat production, and
- transport processes and systems.

It is beyond the scope of this brief study to fully encompass the possible sensitivities of the selected biofuels regarding these background data – and there are too few data sources for background life cycle data in developing countries<sup>20</sup>.

Therefore, the sensitivity of these aspects **cannot** be addressed here.

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<sup>20</sup> Publicly available LCA databases for bioenergy or biofuels with detailed, country- or region-specific background data are available mostly for industrialized countries (e.g. US GREET model), and other databases such as e.g., ecoinvent, GABi, SimaPro, TEAM/DEAM or umberto are **proprietary** software for which disaggregated process information is **not** available in the public domain.

## 2 Results of the Sensitivity Analysis

In the following, the results from the sensitivity analysis for the various life-cycle stages are shown in comparison to the respective reference cases<sup>21</sup>.

### 2.1 Sensitivity Analysis for the Production Stage: Inputs and N<sub>2</sub>O

The results for the production stage of biofuels with regard to inputs and N<sub>2</sub>O emission calculation are shown in the following table and figure.

Table 2 Sensitivity of GHG Emissions in the Production Stage: Inputs and N<sub>2</sub>O

| life-cycle emissions<br>[kg CO <sub>2</sub> eq/GJ <sub>biofuel</sub> ] | EtOH, BR | PME, ID | JT arable, IN | JT marginal, IN |
|--|----------|---------|---------------|-----------------|
| base case  | 22.6     | 58.7    | 25.0          | 24.3            |
| low N  | 21.5     | 51.9    | -             | -               |
| hi-yield   | 19.3     | 50.3    | 19.2          | 18.6            |
| hi-N <sub>2</sub> O  | 37.4     | 97.1    | 59.7          | 51.9            |

Source: own calculations using GEMIS Version 4.5;

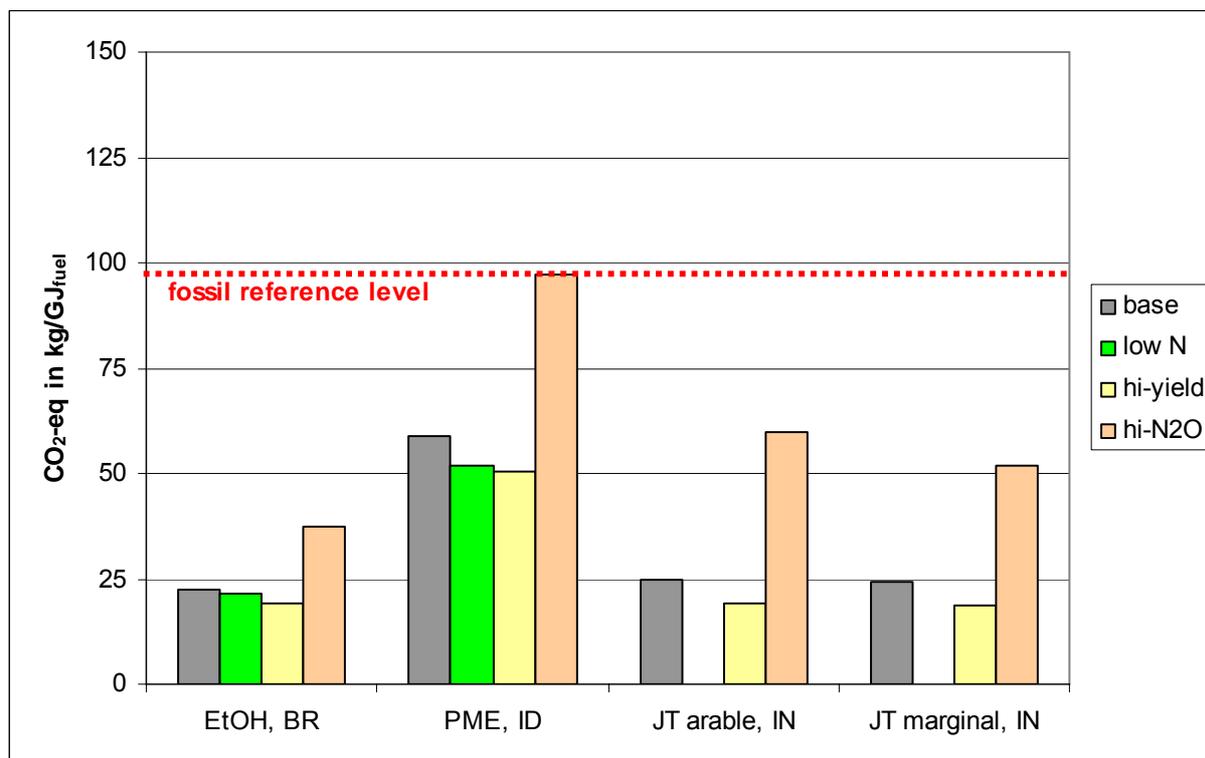
EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India; N= nitrogen fertilizer

low N = 15% reduction of N input for sugarcane, 20% for palmoil, N/A for Jatropha

hi-yield = 2030 projection for sugarcane and palmoil, 25% increase assumed for Jatropha

hi-N<sub>2</sub>O = 5% conversion factor for N<sub>2</sub>O emissions instead of 1% IPCC factor

<sup>21</sup> Note that in each sensitivity case, **only one** aspect is changed, i.e. no cumulative changes were modeled. Due to the nature of life-cycles, individual sensitivity cases **cannot** be added. It is possible to model cumulative effects of several simultaneous changes of attributes, but this was beyond the scope of this brief study.

Figure 1 Sensitivity of GHG Emissions in the Production Stage: Inputs and N<sub>2</sub>O

Source: own calculations using GEMIS Version 4.5;

EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India; N= nitrogen fertilizer

low N = 15% reduction of N input for sugarcane, 20% for palmoil, N/A for

hi-yield = 2030 projection for sugarcane and palmoil, 25% increase assumed for Jatropha

hi-N2O = 5% conversion factor for N<sub>2</sub>O emissions instead of 1% IPCC factor

The sensitivity of the biofuels GHG emission balances with regard to lower fertilizer input and potential higher yields is **comparatively low**, while using the five times higher N-to-N<sub>2</sub>O conversion rate results in a more than 50% increase for EtOH and PME, and more than a doubling for the Jatropha cases. Thus, the sensitivity of biofuel GHG emissions is **significant**, especially for PME:

With the high conversion rate, PME would not achieve net GHG reductions when compared to fossil diesel, while EtOH and Jatropha would still perform quite well.

## 2.2 Sensitivity Analysis for the Production Stage: Land-Use Change

The results for the production stage of biofuels with regard to the assumptions for direct and indirect land-use change (LUC) are shown in the following table and figure.

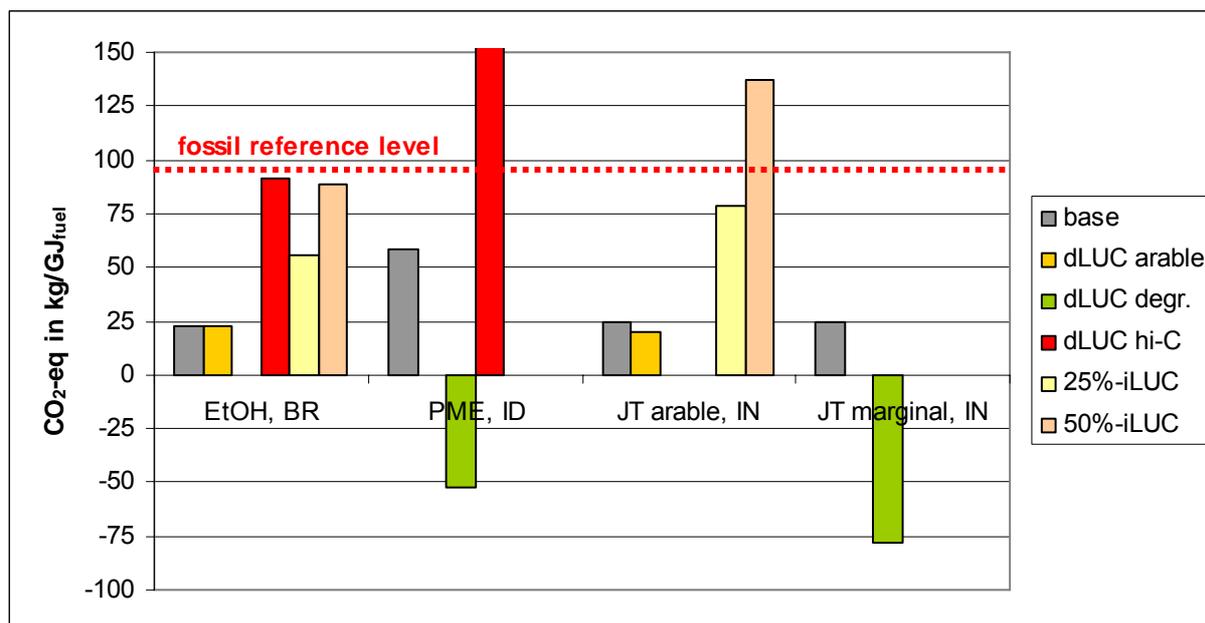
Table 3 Sensitivity of GHG Emissions in the Production Stage: LUC

| life-cycle emissions<br>[kg CO <sub>2</sub> eq/GJ <sub>biofuel</sub> ] | EtOH, BR | PME, ID | JT arable, IN | JT marginal, IN |
|--|----------|---------|---------------|-----------------|
| base case (no LUC)   | 22.7     | 58.7    | 25.0          | 24.3            |
| dLUC arable  | 22.3     | -       | 19.6          | -               |
| dLUC degr.   | -0.2     | -52.8   | -             | -77.6           |
| dLUC hi-C  | 91.0     | 153.2   | -             | -               |
| 25%-iLUC   | 55.3     | -       | 78.6          | -               |
| 50%-iLUC   | 88.4     | -       | 137.6         | -               |

Source: own calculations using GEMIS Version 4.5;

EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India; dLUC= direct land use change; iLUC = direct + indirect LUC; degr.= degraded land wit low carbon stock; hi-C= land with high carbon stocks (above- and below-ground)

Figure 2 Sensitivity of GHG Emissions in the Production Stage: LUC



Source: own calculations using GEMIS Version 4.5;

EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India; dLUC= direct land use change; iLUC = direct + indirect LUC; degr.= degraded land wit low carbon stock; hi-C= land with high carbon stocks (above- and below-ground)

The sensitivity of taking into account **direct** LUC effects is small if **arable** land is considered (EtOH, Jatropha) – but then the **indirect** LUC are rather high, depending on the level of the iLUC factor assumed.

The direct LUC effects are very high if high-carbon stock land is concerned, though: in those cases, there are **no** iLUC effects, but the magnitude of **direct** LUC emissions leads to very small or no GHG reductions compared to fossil fuels.

If biofuel feedstocks are grown on **degraded** land, the overall GHG balance becomes even **negative** - slightly less than zero for EtOH, and even higher reductions for PME and Jatropha. The reason for this is the absence of indirect effects, and the **increase** of carbon stock on the cultivated land.

These results clearly indicate that LUC is a **key driver** for the GHG results, and can lead to very positive and very negative impacts, depending which LUC is assumed.

The magnitude of the LUC sensitivity is **higher** than **any** of the other factors.

## 2.3 Sensitivity Analysis for the Conversion Phase

The results for the conversion stage of biofuels are shown in the following table and figure.

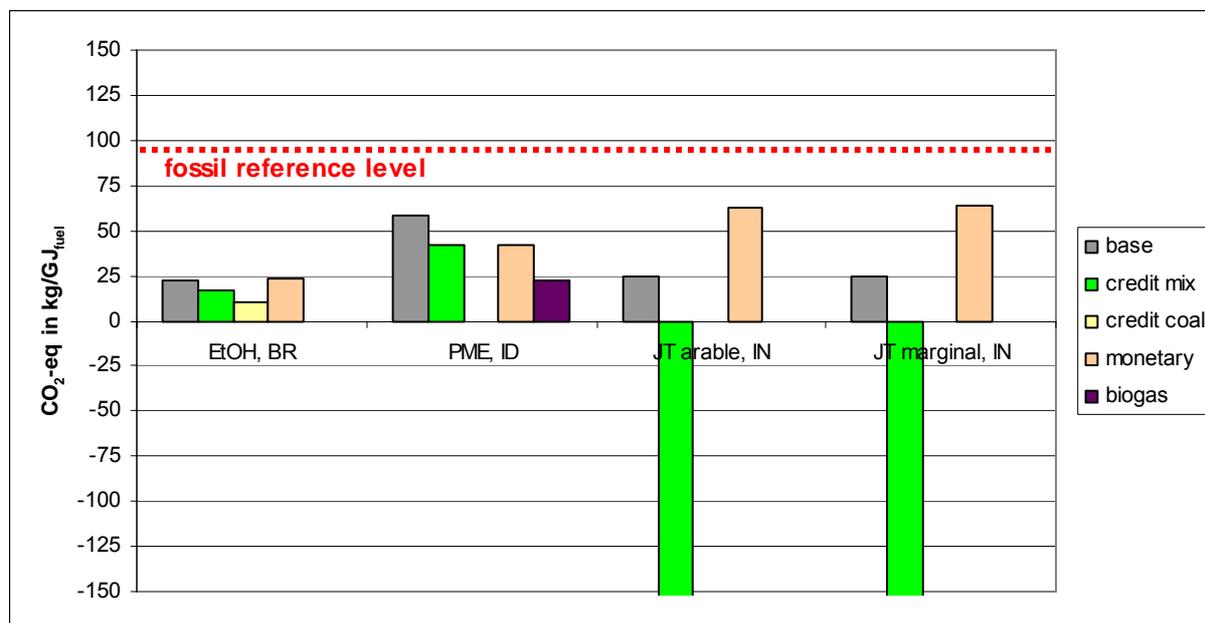
Here, the first three sensitivity cases reflect changes in by-product treatment, while “biogas” stands for wastewater treatment with biogas production (PME only).

Table 4 Sensitivity of GHG Emissions at the Conversion Stage

| life-cycle emissions<br>[kg CO <sub>2</sub> eq/GJ <sub>biofuel</sub> ] | EtOH, BR | PME, ID | JT arable, IN | JT marginal, IN |
|--|----------|---------|---------------|-----------------|
| base   | 22.7     | 58.7    | 25.0          | 24.3            |
| credit mix   | 16.7     | 41.7    | -157.9        | -159.9          |
| credit coal  | 10.4     | -       | -             | -               |
| monetary   | 23.2     | 41.7    | 62.4          | 63.7            |
| biogas   | -        | 22.6    | -             | -               |

Source: own calculations using GEMIS Version 4.5; EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India; credit mix = credit for electricity based on national generation mix; credit coal = credit for electricity based on new coal-fired powerplant; monetary= economic allocation based on price; biogas= CH<sub>4</sub> from waste-water treatment used as biogas

Figure 3 Sensitivity of GHG Emissions at the Conversion Stage



Source: own calculations using GEMIS Version 4.5; EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India; credit mix = credit for electricity based on national generation mix; credit coal = credit for electricity based on new coal-fired powerplant; monetary= economic allocation based on price; biogas= CH<sub>4</sub> from waste-water treatment used as biogas

For EtOH and PME, the sensitivity of by-product treatment is comparatively low, as there are rather few by-products. For PME, the use of CH<sub>4</sub> from waste-water as biogas results in a significant reduction of GHG emissions.

For plant oil from Jatropha, the effect of crediting which assumes offsetting fossil-oil based heat production with unused Jatropha fibers is significantly positive – the credit would be far higher than the total emissions of the biofuel life-cycle.

If monetary allocation is used, the low market value of the by-product leads to a higher allocation of the total GHG emission balance to the main product.

This clearly demonstrates that crediting and monetary allocation can have drastic effects on the overall GHG performance of biofuel life-cycles, especially if a life-cycle shows large amounts of by-products<sup>22</sup>. This sensitivity is one of the reasons for the mandatory EU regulation which requires energy allocation for by-product accounting.

<sup>22</sup> This would be the case for straight vegetable oil or biodiesel from soy which offers a large share of extraction cake, and also for ethanol from maize where also a high amount of by-product (protein-rich distillers grains and solubles = DDGS) is part of the biofuel life-cycle.

## 2.4 Technology Status and Time Horizon

The results for the overall biofuel life-cycles with regard to the technology status are shown in the following table and figure.

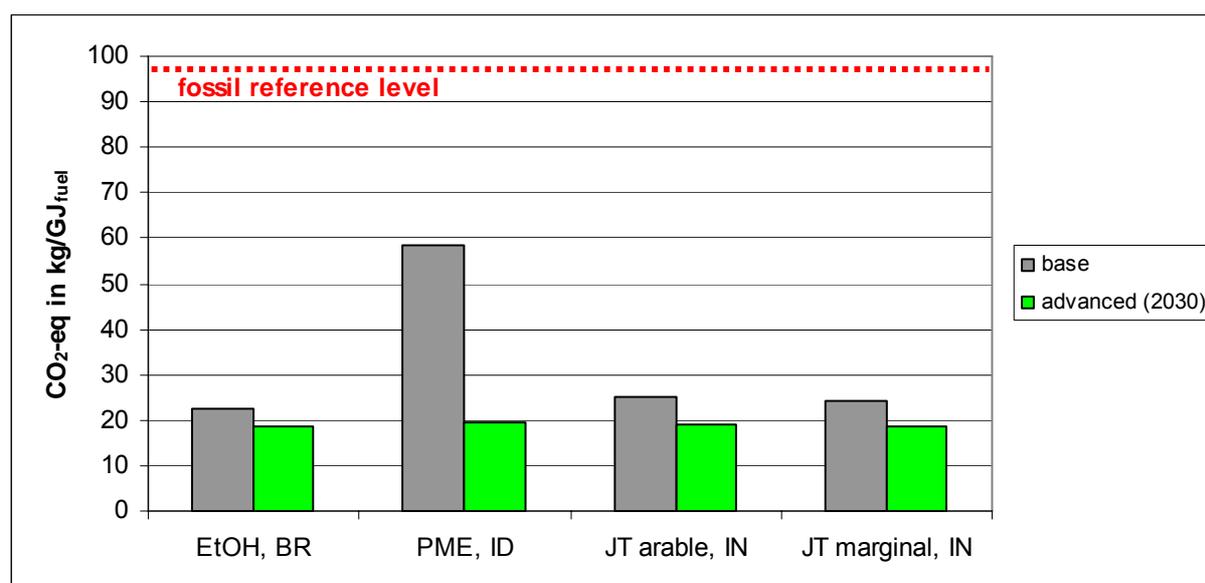
Here, the reference cases reflect the 2005 situation, while the “advanced (2030)” cases represent the possible improvements along the life-cycles until the year 2030.

Table 5 Sensitivity of GHG Emissions with respect to Technology Status

| life-cycle emissions<br>[kg CO <sub>2</sub> eq/GJ <sub>biofuel</sub> ] | EtOH, BR | PME, ID | JT arable, IN | JT marginal, IN |
|--|----------|---------|---------------|-----------------|
| base (2005)  | 22.7     | 58.7    | 25.0          | 24.3            |
| advanced (2030)  | 18.5     | 19.6    | 19.2          | 18.6            |

Source: own calculations using GEMIS Version 4.5; EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropa-oil; IN= India

Figure 4 Sensitivity of GHG Emissions with respect to Technology Status



Source: own calculations using GEMIS Version 4.5; EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropa-oil; IN= India

These results indicate that for the selected biofuels, only **relatively small** improvements can be expected over time – with the noteworthy exception of **PME**: here, the future will allow a drastic reduction of overall GHG emissions through the use of biogas from wastewater treatment (see Section 0).

### 3 Conclusions from the Sensitivity Analysis

The exemplary cases used to illustrate the sensitivity of GHG emission balances for biofuels in developing countries underline that

- the most important sensitivity for GHG emissions of biofuels is concerned with the inclusion of direct and indirect land use changes (LUC);
- in addition, the treatment of by-products (via crediting or allocation) can be relevant if the by-products to main product ratio is high;
- the N<sub>2</sub>O emissions and the conversion rate of N to N<sub>2</sub>O can also be of importance.

For comparing GHG emissions from biofuel life cycles without introducing arbitrary bias, it is highly needed to **develop agreed methodologies** for LUC – especially indirect LUC – and for the treatment of by-products.

The European Union's mandatory GHG accounting rules for biofuels are an important step in that direction<sup>23</sup>, and the ongoing work in the GHG Task Force of the Global Bioenergy Partnership (GBEP)<sup>24</sup> could help to broaden the realm of agreement in the near future.

Second to that, there is an urgent need to develop more (and more transparent) data which reflect the biofuel life cycles **in developing countries**, especially for the **production** stage: Data on yields and fertilizer use are available only from a few studies, and need refinement (e.g. for no-till cultivation) and better empirical evidence.

The scientific analysis of the “correct” N-to-N<sub>2</sub>O conversion rate will continue, and field measurements in developing countries could help to narrow down the currently broad range of uncertainty.

Last but not least, the **use phase** of biofuels should be explored in more detail under the conditions of developing countries to broaden the scope for possible sectoral priorities. The illustrative example given in Annex II demonstrates that the role of vehicle and powertrain efficiency is crucial, and that advanced vehicles could be of high significance in reducing GHG emissions from transport.

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<sup>23</sup> The EU Renewable Energy Sources Directive (RES-D) specifies sustainability requirements for liquid biofuels, especially minimum GHG reduction levels, an accounting system with details rules on how to calculate GHG emission balances, and default data for several biofuel settings. The RES-D establishes mandatory requirements for biofuels eligible under the EU biofuel quota scheme.

<sup>24</sup> see [www.globalbioenergy.org](http://www.globalbioenergy.org)

## Literature

- ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) 2008: Elaboration d'un référentiel méthodologique pour la réalisation d'Analyses de Cycle de Vie appliquées aux biocarburants de première génération en France; Rapport final; Paris
- Almeida, Edmar F. de 2007: The performance of Brazilian Biofuels: An economic, environmental and social analysis; presented at the OECD Round Table "Biofuels: Linking Support to Performance"; Paris, June 2007
- CSI (Cheminfo Services Inc.) et al. 2008a: Sensitivity Analysis of Biodiesel LCA Models to Determine Assumptions With the Greatest Influence on Outputs; Final Report; Ontario
- CSI (Cheminfo Services Inc.) et al. 2008b: Sensitivity Analysis of Bioethanol LCA Models to Determine Assumptions With the Greatest Influence on Outputs; Final Report; Ontario
- Crutzen, Paul J./Mosier, A. R./Smith, K. A./Winiwarter, W. 2007: N<sub>2</sub>O release from agro-biofuel production negates global warming reduction by replacing fossil fuels; in: Atmos. Chem. Phys. Discuss. vol. 7 (2007) p.11191–11205  
[www.atmos-chem-phys-discuss.net/7/11191/2007/](http://www.atmos-chem-phys-discuss.net/7/11191/2007/)
- Dale, Bruce E. 2008: Life-cycle analysis of biofuels & land use change; presented at the 5th Annual California Biomass Collaborative, Sacramento, California, May 28-30, 2008
- EUCAR/JRC/CONCAWE 2007: Well-to-Wheels analysis of future automotive fuels and powertrains in the European context - Well-to-Wheels Report Version 2c; Ispra <http://ies.jrc.ec.europa.eu/WTW>
- Fargione, J. et al. 2008: Land Clearing and the Biofuel Carbon Debt; in: Science vol. 319 (5867), p. 1235 – 1238  
<http://www.sciencemag.org/cgi/content/abstract/1152747>
- Fehrenbach, H./Fritsche, U./Giegrich, J. 2008: Greenhouse Gas Balances for Biomass: Issues for further discussion; Issue paper for the informal workshop, January 25, 2008 in Brussels  
[http://www.oeko.de/service/bio/dateien/en/ghg\\_balance\\_bioenergy.pdf](http://www.oeko.de/service/bio/dateien/en/ghg_balance_bioenergy.pdf)
- FNR (Fachagentur Nachwachsender Rohstoffe) 2008: Bioenergy – Plants, Raw Materials, Products; Guelzow [http://www.fnr-server.de/ftp/pdf/literatur/pdf\\_330-bioenergie\\_gb\\_finale.pdf](http://www.fnr-server.de/ftp/pdf/literatur/pdf_330-bioenergie_gb_finale.pdf)
- Fritsche, Uwe R. 2008: Beyond the German BSO: Scope of Further Work on Land-use Related GHG; presented at the Brussels Workshop 'Sustainability requirements for biofuels - German Perspectives', January 25, 2008  
[http://www.oeko.de/service/bio/dateien/en/presbeyond\\_bso\\_fritsche.pdf](http://www.oeko.de/service/bio/dateien/en/presbeyond_bso_fritsche.pdf)
- Fritsche, Uwe R./Hennenberg, Klaus 2009: The "iLUC Factor" as a Means to Hedge Risks of GHG Emissions from Indirect Land-Use Change Associated with Bioenergy Feedstock Provision; working paper prepared for BMU by Oeko-Institut; Darmstadt (forthcoming)

- IFEU (Institut für Energie- und Umweltforschung) 2007: Greenhouse Gas Balances for the German Biofuels Quota Legislation: Methodological Guidance and Default Values; Fehrenbach, Horst et al.; prepared for the German Federal Environment Agency (UBA); Heidelberg
- IFEU (Institut für Energie- und Umweltforschung) 2008: Bioenergie aus Getreide und Zuckerrübe: Energie- und Treibhausgasbilanzen; Endbericht (Kurzversion); i.A. des Verbandes Landwirtschaftliche Biokraftstoffe e.V. (LAB), Berlin; Heidelberg, 13. August 2008
- JRC (EU Joint Research Centre) 2008: Biofuels in the European Context: Facts and Uncertainties. Technical report of the EU Joint Research Centre, April 2008; Netherlands and Italy. [www.jrc.ec.europa.eu/](http://www.jrc.ec.europa.eu/)
- Jungbluth, Niels et al. 2007: Life Cycle Assessment of BTL-fuel production: Life Cycle Impact Assessment and Interpretation; RENEW - Renewable fuels for advanced powertrains - Integrated Project Sustainable energy systems Deliverable D 5.2.10; Report SES6-CT-2003-502705  
[www.esu-services.ch/renew.htm](http://www.esu-services.ch/renew.htm)
- Jungbluth, Niels et al. 2008: Life-cycle Assessment of Biomass-to-Liquid Fuels; Final Report for BFE/BAFU/BLW; Ulster <http://www.esu-services.ch/bioenergy.htm>
- Jungbluth, Niels/Zah, Rainer 2008: ecoinvent: Methodological issues around LCA GHG emissions - the Swiss approach; presented at the Expert meeting LCA GHG methodologies for bioenergy: Beyond biofuels; European Environment Agency, Copenhagen, 10 June 2008
- Kløverpris, J./Wenzel, H./Nielsen, P. 2008: Life cycle inventory modelling of land use induced by crop consumption; in: International Journal of Life Cycle Assessment 13:13-21
- Macedo, I.C. 1998: Greenhouse gas emissions and energy balances in bio-ethanol production and utilization in Brazil (1996); in: Biomass & Bioenergy vol. 14, (1998) no. 1, p 77-81
- Macedo, I.C./Seabrab, J./Silva, J. 2008: Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020; in: Biomass and Bioenergy <http://doi:10.1016/j.biombioe.2007.12.006>
- MNP (Milieu en Natuur Planbureau) 2008: Local and global consequences of the EU renewable directive for biofuels – testing the sustainability criteria. MNP Report 500143001; Bilthoven <http://www.mnp.nl/nl/publicaties/2008/index.html>
- OEKO (Oeko-Institut e.V.) 2008: GHG Balances and cumulated primary energy demand of bioenergy conversion pathways including possible land-use changes; Fritsche, Uwe R./Wiegmann, Kirsten; study prepared for WBGU; Darmstadt (in German) [http://www.wbgu.de/wbgu\\_jg2008\\_ex04.pdf](http://www.wbgu.de/wbgu_jg2008_ex04.pdf)
- RFA (Renewable Fuels Agency) 2008: The Gallagher Review of the indirect effects of biofuels production; St Leonards-on-Sea  
[http://www.dft.gov.uk/rfa/db/documents/Report\\_of\\_the\\_Gallagher\\_review.pdf](http://www.dft.gov.uk/rfa/db/documents/Report_of_the_Gallagher_review.pdf)

- Searchinger, Timothy et al. 2008: Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change; in: Science vol. 319, p.1238-1240 [www.sciencexpress.org;10.1126/science.1151861](http://www.sciencexpress.org;10.1126/science.1151861)
- UNEP (United Nations Environment Programme) 2008: Existing knowledge and limits of scientific assessment of the sustainability impacts due to biofuels by LCA methodology; Menichetti, Emanuela/Otto, Martina; draft report; Paris
- van Dam, J./Junginger, M./Faaij, A./Jürgens, I./Best, G./Fritsche, U. 2008: Overview of recent developments in sustainable biomass certification; in: Biomass and Bioenergy vol. 32, no. 8 (2008), p 749-780  
<http://dx.doi.org/10.1016/j.biombioe.2008.01.018>
- von Blottnitz, H./Curran, M.A. 2007: A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life-cycle perspective; in: Journal of Cleaner Production vol. 15, p. 607-619
- VTT (Technical Research Centre of Finland) 2007: Greenhouse Gas Balances of Transportation Biofuels in Finland - Dealing with the Uncertainties; Soimakallio, Sampo/Mäkinen, Tuula/Ekholm, Tommi; presented at the Int. Energy Workshop 2007; Stanford University, June 25-27, 2007
- WWF (World Wide Fund for Nature) 2007: Rain Forest for Biodiesel? Ecological effects of using palm oil as a source of energy; study of WWF Germany, Netherlands, and Switzerland; Frankfurt
- Zah, Rainer et al. 2007: Life-cycle Assessment of Energy Products: Environmental Impact Assessment of Biofuels - Executive Summary; EMPA (Swiss Federal Institute for Materials Science and Technology); St. Gallen  
<http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=00000009552.pdf&name=000000280006>
- Zimmer, Wiebke/Fritsche, Uwe 2008: Technological Opportunities in the Transport Sector; in: Discussion Paper for the Symposium "Future Challenges of Transport and Environment" held in Berlin, June 24 – 25, 2008 on behalf of the William and Flora Hewlett Foundation; p. 59-89  
[http://www.duh.de/uploads/media/Petersen\\_Hook\\_Zimmer\\_Fritsche\\_discussion\\_paper.pdf](http://www.duh.de/uploads/media/Petersen_Hook_Zimmer_Fritsche_discussion_paper.pdf)

## Annex I: Selected GHG Emission Results for Biofuels including International Seaborne Transport

The results on life-cycle GHG emissions of selected biofuels presented in Section 2 of this report concerned the production, conversion and domestic transports of biofuels, but not any effects of exporting the biofuels to other countries. To indicate the magnitude of additional GHG emissions from exports, the “base” cases were re-calculated with the assumption that a one-way seaborne transport of all biofuels over **10,000 km** by a tanker (ocean-going vessel) would occur. The respective results in comparison to the base case without international transports are shown below.

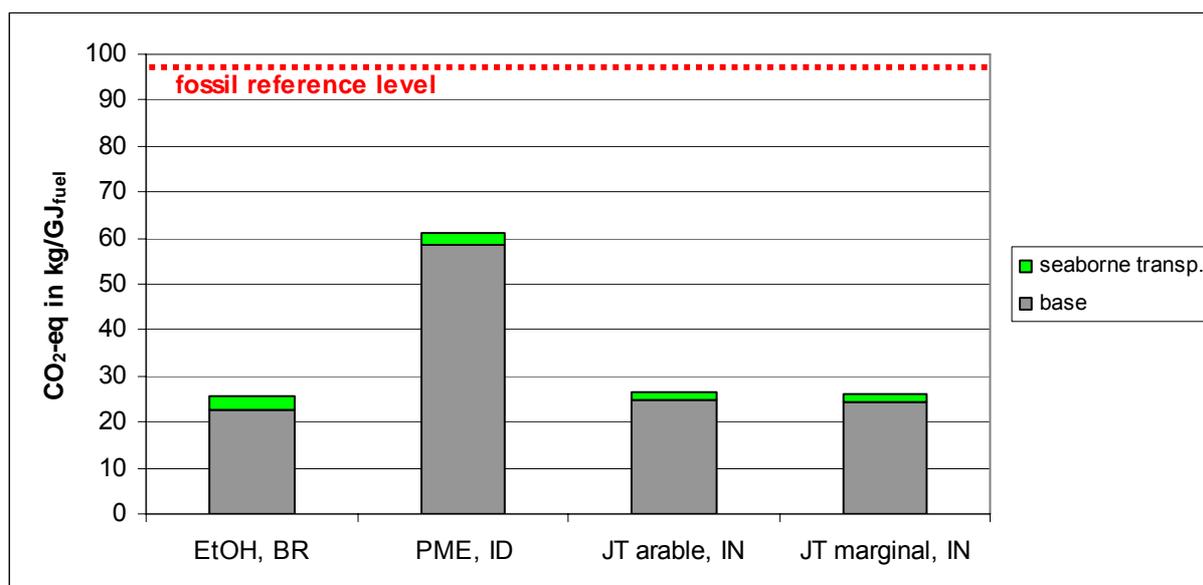
Table A-1 Sensitivity of GHG Emissions with respect to Transport for Exports

|                                       | EtOH, BR | PME, ID | JT arable, IN | JT marginal, IN |
|---------------------------------------|----------|---------|---------------|-----------------|
| base                                  | 22.6     | 58.7    | 25.0          | 24.3            |
| seaborne transp. (10 <sup>3</sup> km) | 2.9      | 2.4     | 1.7           | 1.7             |
| base + transport (10 <sup>3</sup> km) | 25.5     | 61.0    | 26.7          | 26.0            |

Source: own calculations using GEMIS Version 4.5; EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India

For EtOH, the impact of including ocean transport along 10,000 km is in the order of 10% of the base case GHG emissions, for PME and JT oil in the order of 5%. With global transport distances between e.g. Indonesia and Europe in the 20,000 km range, and BR to EU in the 10,000 km range, the respective effects are in the same order – in the European context - for both bioethanol, and biodiesel imports.

Figure A-1 Sensitivity of GHG Emissions with respect to Transport for Exports



Source: own calculations using GEMIS Version 4.5; EtOH= bioethanol; BR= Brazil; PME= palmoil-methyl ester; ID= Indonesia; JT= Jatropha-oil; IN= India

## Annex II: Indicative Sensitivity Analysis for the Use Phase (EU Data)

The following illustrative results for the sensitivity of the use phase assumptions for biofuels are taken from a recent study which refers to European (EU) conditions, and concerns only the use of biofuels in passenger-cars (Fritsche/Wiegmann 2008)<sup>25</sup>.

Starting with a fossil-fueled **reference** car (REF) which reflects the future configuration and fuel efficiency of a **new** mid-sized vehicle in the EU in the year 2020 running on either fossil gasoline or fossil diesel, the next option is an **advanced** car which still consumes fossil fuel, but has a higher efficiency due to “mild” hybridization. The **best** car is assumed to be a full hybrid, but also to have been subject to lightweight and aerodynamic design, reduced-friction powertrain and lubrication, and further efficiency improvements<sup>26</sup>.

The use of various biofuels – from 1<sup>st</sup> generation ethanol and biodiesel to advanced “2<sup>nd</sup> generation” ethanol from lignocellulose, compressed biomethane (bioCNG) and BtL from Fischer-Tropsch synthesis – in the “reference” car would be further options.

In addition to that, two future vehicles with different powertrains could be used:

- **Fuelcell** cars with electric motors would make use of hydrogen derived from either natural gas (to compare with the fossil-fuel reference), or hydrogen derived from bio-syngas production using either wood residues, or short-rotation coppice.
- Full **electric cars** with batteries would use electricity from combined-cycle powerplants operated with natural gas (to compare with the fossil-fuel reference), or with biomethane produced from bio-syngas production using either wood residues, or short-rotation coppice, or biogas from maize.

The life cycle GHG emissions associated with the delivery of a passenger transport service of **one vehicle-kilometer** was then computed, factoring in the production of both the fuel used, and the respective cars<sup>27</sup>.

For simplicity, the results are shown only for the life cycles **without** impacts of land use changes possibly associated with biofuel production (see Section 1.2.3 and 2.2, respectively)<sup>28</sup>.

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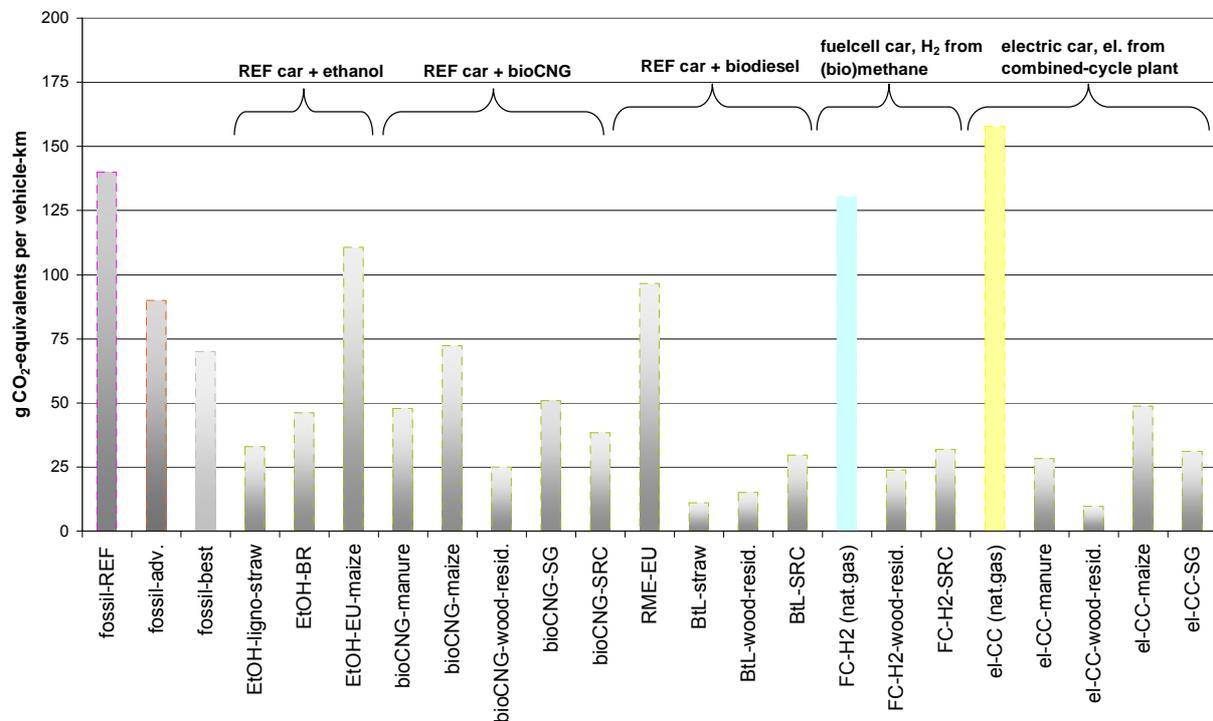
<sup>25</sup> The principal findings of this study can be translated to other transport modes, e.g. to buses, ships, trains, and trucks. The respective reference systems and potential efficiency gains would need adjustment, though. Similarly, the overall findings are also applicable to developing countries, but for that, caution is needed regarding e.g. infrastructure needs for hydrogen or electricity transmission, driving modes, and reference systems.

<sup>26</sup> For details on the advanced and “best” vehicles, see Zimmer/ Fritsche (2008).

<sup>27</sup> The inclusion of the vehicle production is needed to capture the effects of the fuelcell stacks and the batteries for the “alternative” vehicles, and the different material composition of the “advanced” and “best” conventional cars. Furthermore, the electric powertrains weigh less than the fossil-fuel combustion engines.

<sup>28</sup> In Fritsche/Wiegmann (2008), the implications of LUC-related GHG emissions are given also.

Figure A-2 Indicative Sensitivity of Transport-Related GHG Emissions from New Passenger Cars with Respect to the Use Phase in Europe



Source: based on data from Fritsche/Wiegmann (2008) for upstream life cycles, and Zimmer/Fritsche (2008) for vehicle efficiencies; REF = reference system; adv. = advanced vehicle (higher efficiency); best = best available technology (regarding efficiency); EtOH = bio-ethanol; BR= Brazil; EU = European Union; bioCNG = compressed biomethane; resid.= residues; SG = switchgrass; RME = rapeseed oil methyl ester (= 1<sup>st</sup> generation biodiesel); BtL = biomass-to-liquid (= 2<sup>nd</sup> generation biodiesel); SRC = short-rotation coppice; FC = fuelcell; H2 = hydrogen; el.= electric; CC = combined-cycle powerplant

The results shown above indicate that using fossil fuels in “advanced” or even “best” cars could reduce transport-related GHG emissions more than using 1<sup>st</sup> generation biofuels such as e.g., RME or EtOH from maize.

On the other hand, the results underline that even “alternative” car concepts such as fuelcell/H<sub>2</sub> or full electric vehicles would **not** allow to reduce GHG emissions compared to fossil-fueled “reference” cars if the hydrogen or electricity needed to operate the alternative vehicles come from natural gas. If their “fuel” would be derived from biomass, though, these vehicles could achieve lower life cycle GHG emissions than using the same feedstocks for 2<sup>nd</sup> generation biofuels in “reference” cars.

It should be recalled that this indicative comparison is restricted to passenger cars, and refers to (future) EU conditions only. The use-phase of biofuels for transport also concerns other transport modes and fuel pathways which may differ much between countries, assumed timeframes, and operating conditions.

## Annex III: The “iLUC factor” Approach

In contrast to analytical approaches to determine GHG emissions from potential indirect land use change which make use of econometric models, a **deterministic** approach has been developed by Oeko-Institut to include potential GHG emissions from indirect land use change in **regulatory policies** for biofuels. This approach has first been called “risk adder” (Fehrenbach/Fritsche/Giegrich 2008), but was renamed to “**iLUC factor**” to reflect its applicability in both “malus” and “bonus” schemes for GHG accounting (Fritsche/Hennenberg 2009)<sup>29</sup>.

### Background of the iLUC factor

In a **strict** definition, indirect land use change could occur for all biomass feedstocks derived from land which has been used previously for food/feed production, or from land which has the potential to be used for food/feed production. In that regard, **all** arable land used for **additional** biomass feedstock production will induce indirect land use change due to displacement, even if such displacement is hypothetical only<sup>30</sup>.

A more “loose” definition assumes displacement from bioenergy feedstock production only for land which **actually was used** previously for food/feed or fiber production, thus excluding set-aside and abandoned land as well as biomass feedstocks derived from intensified land use which gives higher yields.

In **both** definitions, biomass feedstocks derived from biogenic wastes and from abandoned and degraded land have a zero displacement risk, thus inducing **no indirect** land use change.

The iLUC factor approach uses the “loose” definition of indirect land use change risks, as it is meant to be practically applicable in **regulating** GHG emissions from biofuels, and not to reflect all analytically possible (including hypothetical) situations.

### Key Considerations for the iLUC factor

The iLUC factor approach assumes that the **potential** release of CO<sub>2</sub> from land use change caused by displacement is a function of the land used to produce agro products for export purpose, as only trade flows will be affected by displacement.

Next, the estimation takes into account that **all** countries trading agro-products across borders might be subject to LUC from displacement, so that displacement can impact different land with different (above- and below-ground) carbon stocks.

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<sup>29</sup> A “malus” system will **add** a certain amount of GHG emissions from indirect land use change to those biofuels which are derived from feedstocks with a **non-zero** risks for displacement, while a **bonus** system would **credit** zero-risk biofuels (e.g. from wastes, or degraded land) with the amount of indirect GHG emissions they **avoid**.

<sup>30</sup> The underlying hypothesis of the strict definition is that **any** arable land has potential to be used for food/feed production, so that its **opportunity value** would be reduced by using it for biomass feedstock production.

Countries participating in global trade are potentially incited to increase food/feed production to “balance” the global market if increased feedstock production for biofuels displaces previous food/feed production through respective land use.

The iLUC factor as a **deterministic** approach aims to describe **average impacts**. For that, the share of land utilized for producing the amount of food/feed displaced by increased biofuel feedstocks production is derived from the share of land used by each country for agro commodity exports, taking into account country-specific yields (based on FAO data for 2004/2005). For that, the share of land use of each export country can be determined by using the key commodities (rapeseed, maize, palmoil, soy, and wheat), and the countries/regions can be simplified to reflect Brazil (BR), the European Union (EU), Indonesia (ID), and the United States of America (US).

With the shares of land potentially affected derived from the share of land used for the selected agricultural commodity exports, and explicit assumptions on which land use change will be most likely (e.g. grassland to maize), the respective IPCC-based **direct** land use change factors for carbon releases can be coupled with the regional land use shares of each agro commodity. From that, an **average** CO<sub>2</sub> emission factor per ha of displaced land can be derived, and discounted over a time horizon of 20 years.

This calculation gives the **theoretical average iLUC factor as 20 t CO<sub>2</sub>/ha/year**. This full iLUC factor would have to be applied if the risk for displacement from a certain amount of biofuel feedstock production would be 100%.

### The iLUC factor: Practical Levels

In reality, however, the risk will be lower, as biofuel feedstocks come from a variety of sources, and circumstances (use of set-aside and abandoned land, intensification of existing cultivation schemes, etc.) which change over time. Therefore, the iLUC factor should be dynamic, i.e. the more biofuel feedstocks are produced, the higher the cumulative risk of displacement will become for the average biofuel feedstock.

To derive **indicative** values for the iLUC factor, i.e. numbers reflecting the order of magnitude, the following cases were defined:

- “low level”, assuming that 25% of all non-zero risk biofuels are subject to the theoretical full iLUC factor, which gives 5 t of CO<sub>2</sub>/ha/year
- “medium level”, meaning a 50% share of all non-zero risk feedstocks are subject to the theoretical full iLUC factor, resulting in 10 t of CO<sub>2</sub>/ha/year, and
- “maximum level”, representing a 75% share<sup>31</sup> of non-zero risk biofuel feedstocks, i.e. 15 t of CO<sub>2</sub>/ha/year.

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<sup>31</sup> The maximum case is **not** 100% of the theoretical iLUC factor as it is assumed that in the longer-term, 25% of all biofuels come from **yield increases** for which the “loose” definition assumes a zero displacement risk. The 25% figure is derived from an average yield increase of 1% per year until 2030, starting in the base year 2005.

To translate the low, medium or high iLUC factor to a given biofuel, the land-based values given above (t CO<sub>2</sub>/ha/year) are divided by the fuel-specific yield (GJ<sub>biofuel</sub>/ha/year), resulting in energy-specific emission factors (t CO<sub>2</sub>/GJ<sub>biofuel</sub>).

The key simplifying assumption of the iLUC factor approach to avoid complex modeling of agricultural markets is that **current patterns** of land use for the production of traded agricultural commodities are an adequate proxy to derive global **averages** of potential GHG emissions from indirect LUC.

This does **not** indicate which land is **likely** to be affected by displacement in the future. As noted in Fehrenbach/Fritsche/Giegrich (2008), one might argue that the **incremental** (marginal) displacement might well affect mainly land that is cheapest and easiest, which could be high-carbon stock land.

In that regard, the iLUC factor is nothing more than a first proxy – and not necessarily a conservative one - meant to offer a practical approach for policy makers to address potential GHG emissions from indirect LUC.

The iLUC factor concept is still under development and discussion, and could be refined further to reflect more specific situations and timeframes than just the global averages of land use patterns and feedstock production in the year 2005.

## Annex IV: Beyond LCA

LCA was developed as a method to compare the environmental “profiles” of products and services on a “per-unit” base (“functional unit”), and is in most applications a **static** approach.

With competing uses of biomass in different sectors, the scope of LCA (system boundaries) needs extension to address cross-sectoral issues.

A “full-scope” LCA would avoid allocation issues and the problem of indirect effects through taking into account **all relevant flows** and resources as well as the **competing uses**, so that it would develop from product-oriented “per-unit” focus into a more material/energy-flow system approach.

As regard time, the dynamic aspects (technological learning, especially for 2<sup>nd</sup> generation feedstocks/conversion; changes in land availability and characteristics etc.) need to be addressed as well, so that “scenario LCA” should be the key approach.

Together with the broader scope, LCA for biomass should be developed further into **material/energy flow analysis**.

### A-1 Non-GHG environmental impacts

Besides GHG emissions, other environmental impacts of bioenergy production can arise from feedstock production, processing, and distribution. Most dominantly are impacts on land used for feedstock production, and the respective effects on water, soil quality, and biodiversity. These impacts depend on various factors such as feedstock, cultivation practice and land management, location, and downstream processing routes.

The current draft addresses this in reflecting on the existing studies, but it would be important to extend the analysis into discussing the state-of-the-art of LCA for food/feed (and even timber/textile) products, as the environmental impacts of feedstock production are similar to those of traditional agriculture, as the same crops and cultivation systems are applied in most cases.

#### A-1.1 Water Quantity and Quality

Globally, agriculture uses more than  $\frac{2}{3}$  of the available freshwater, with even higher shares in some (developing) countries. Biofuel feedstock production has two key impacts of water supplies: the amount of water required for feedstock production could deplete fresh water resources, and the runoff of agrochemicals can affect the quality of water bodies.

Here, the limits of current LCA are in data availability, and the “non-local” approach (see Sections 0 and 0).

Furthermore, even water-efficient perennial plants such as *Jatropha* and *Pongamia* which can be grown in semi-arid areas on marginal or degraded lands require some

irrigation during hot and dry summers which could put pressure on scarce water resources.

The processing of feedstocks into biofuels can use large quantities of water, mainly for washing plants and seeds, and for evaporative cooling. Biodiesel and ethanol production result in organically contaminated waste water that, if released untreated, could increase eutrophication of surface water bodies.

Existing wastewater treatment technologies, though, allow dealing effectively with organic pollutants and wastes. Fermentation systems can reduce the biological oxygen demand of wastewater by more than 90 percent, so that water can be reused for processing, and methane can be captured and used for power generation.

In Brazil, the majority of milling waste water (vinasse) is used for irrigation and fertilization of the sugarcane plantations, thus reducing both water demands, and eutrophication risks.

As regard impacts in downstream distribution and storage, ethanol and biodiesel are biodegradable, reducing potential impacts on soil and water from leakage, and spills.

### **A-1.2 Soils**

As a general rule, organic carbon in soils decreases over time when land is converted from natural cover to agricultural production. Intensive farming can cause soil erosion by removing permanent soil cover, ploughing and tilling, and by using machinery for harvesting. Erosion further reduces organic carbon in soils.

Intensive harvesting methods can further compact the soil, thus reducing its capacity to hold moisture. Depending on the biophysical composition of soils, the removal of whole plants (or respective residues) can reduce nutrient recycling and – hence - soil quality, and lead to increased GHG emissions through losses in soil carbon.

In contrast, growing perennials such as palm, short-rotation coppice, sugarcane or switchgrass instead of annual crops can **improve** soil quality by increasing soil cover and organic carbon levels. In combination with no-tillage and reduced fertilizer and pesticide inputs, also positive impacts on biodiversity can arise.

Cultivating perennials (including *Jatropha* and *Pongamia*) in semi-arid climates and on degraded lands can reduce erosion, and restore organic matter in the soil due to their extended root system which is not subject to harvesting.

All those effects should be reflected in LCA to address the full range of bioenergy options.

### **A-2 Non-quantifiable Effects: Biodiversity**

The impacts of biofuel feedstock production on biodiversity are closely linked to the land-use practices, and to the **location** of the production. The potentially most severe threat comes from expanding the cultivated land into biodiversity-rich ecosystems such as rain forests, savannahs, and wetlands. The conversion of “virgin” land through

deforestation, for example, causes the destruction of habitats for many species, and the loss of ecosystem functions.

In that regard, the biofuels' displacement effects of shifting agriculture to previously "unused" lands, and the potential intensification of existing agricultural land-use will both reduce valuable biodiversity resources in natural forests, grasslands, and wetlands, which are habitats for a large number of mammals, birds, and wild plants.

On the other hand, biofuel feedstock production using perennial crops could increase biodiversity when compared to annual agricultural crops: there is evidence of more biodiversity in palm oil plantations than in fields of annual grains.

The equation is evident only if palm oil replaces these crops, not tropical forests or wetlands, though, and even then indirect effects ("displacement") must be considered.

Biofuel feedstock production on fallow and degraded lands could also increase biodiversity by offering shelter, nutrients, and moisture in previously harsh environments.

Here, perennial crops could provide all-year ground cover, improving the soil and water retention. Nevertheless, even marginal and degraded lands can have significant biodiversity value on their own in offering habitats for species adapted to local conditions.

As regard agrobiodiversity, key concerns of biofuel feedstock production is that high-intense monoculture systems will dominate, and potentially, genetically modified organisms might be used in parallel.

On the other hand, 2<sup>nd</sup> generation feedstocks consist of many cellulosic crops (perennial grasses, woody biomass) which offer greater diversity and variability than traditional agricultural crops, and require fewer agrochemical inputs.

Still, crop selection must consider effects on native species, and should avoid invasive species which might dominate also natural areas outside of the plantation.

Another opportunity for biodiversity is **intercropping** with grasses and trees, or bushes. "Stepping stones" of vegetation left undisturbed from harvesting or mowing foster diversity and habitats for small mammals and birds.

Still, there is concern that biofuel monoculture crops could replace existing small-scale farming of varied crops which may have a high nature conservation value.

Furthermore, expansion of bioenergy crops into previously "set aside" land (e.g. in Europe) or "conservation reserve land" (e.g. in the USA) will increase erosion and reduce wildlife habitats.

Similarly, sugarcane expansion into lands previously used for cattle grazing might displace cattle to find pasture in rainforests, or the *cerrado*, a savannah covering more than 25 percent of Brazil, and home to 50% of Brazil's endemic species and 25% of its threatened species.

Leaching from sugarcane plantations, and spills from processing plants could also endanger the Pantanal in Brazil's southwest, one of the world's largest wetland areas.

In South-East Asia, palm plantations are extended into natural forests, instead of being operated on degraded land.

Here, the interest is to combine timber sales from forest cutting with investments in the new plantations, but the consequences are endangered species such as tigers, Asian elephants, and the Sumatran rhinoceros.

To contain these risks, key biodiversity areas – those of high-nature conservation value – must be identified and protected against both direct biofuel developments, and indirect pressure from displacement.

Land-use mapping, satellite-based monitoring and verification and sustainable resource management are needed to reduce the threads of uncontrolled biofuel feedstock expansion, and revenues from biofuels sales (and potentially for carbon fixation in soils) could be used to finance such schemes.

In that regard, LCA will not help, and needs to be accompanied by additional methods such as material/energy flow analysis and full system accounting which allow consider spatial distribution, and boundary conditions such as “no-go” areas.

### **A-3 Potentials and Restrictions**

It must be noted that arable land to grow biofuels on is a scarce resource, and might become even scarcer in the long-term, with a growing global population, changing diets, and impacts from climate change.

Furthermore, biofuel feedstock cropping needs water, and thus competes with water demand for feed and food crops. Both factors will restrict global biofuel development severely.

On the other hand, feedstock cultivation for biofuels can make use of non-edible plants such as short-rotation coppice, and can take place on land unsuitable to food and feed production (e.g., *Jatropha* on marginal or degraded lands).

Plant varieties and cropping schemes with low water demands are more feasible for bioenergy production than for food and feed schemes, so that in principle, this factor of competition can be reduced also.

Still, all options to minimize or avoid competition of biofuel feedstocks with food and feed crops will lead to higher production costs, as feedstock yields will be reduced by minimal irrigation, marginal soil fertility, and low-input farming.

This, in addition to non-quantifiable effects, calls for a broader view when using accounting and analytical methods.

## A-4 Setting Approach

While current LCA tries to address “typical” situations for bioenergy and biofuel provision, the reality and the potential for future developments are much broader, and need a different approach:

The **variety** of farming and forestry systems, residue extraction or waste collection systems, downstream conversion routes, and waste treatment options as well as their respective links to auxiliary energy, fuel and material inputs and associated transports is impressive:

Nearly **all** steps within bioenergy fuel-cycles vary with **location and time**, and **each** step can be realized with different processes, intensity and efficiency, emission characteristics, land-use patterns, etc. **and** under very different social and economic circumstances.

To allow for a conceptual framing of this multitude of cases, the so-called **setting approach** has been developed.

“Setting” means a generic<sup>32</sup> representation of **combining** fuel chains (life cycles)<sup>33</sup> with socio-economic (e.g. ownership structure, intensity and scale of production) and environmental (geo- and biophysical, climatic) categories.

All settings form a **multidimensional matrix** which describes the full multitude of combinations. In practical terms, this can be represented by a **sequence** of matrices (e.g., spreadsheets) which is valid for a specific sub-set.

For example, only small-scale farming systems (“smallholders”) can be considered, or a specific time frame.

An example of how the setting concept could be implemented is given below.

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<sup>32</sup> i.e. non-localized: an abstract (categorical) definition of land which could represent a variety of locations, but not referring to any real-world “space” or territory.

<sup>33</sup> This means feedstocks production (including agricultural practices) plus conversion systems (including their infrastructure requirements) to deliver a specific fuel, including transports between processes, and the respective inputs (energy, materials, land etc.)

Table A-2 Conceptualization of the Setting Approach

| SOCIO-ECONOMIC SYSTEM      |                                    | TECHNOLOGICAL SYSTEM (life-cycle)  |                                      | ECO-SYSTEM                  | PRODUCTION SYSTEM   |                         |
|----------------------------|------------------------------------|------------------------------------|--------------------------------------|-----------------------------|---------------------|-------------------------|
| Social                     | Economic                           | Technical                          | Fuel type                            | Ecological                  | Crop                | Practice                |
| Rural small holder farmers | Subsistence farming                | No processing                      | Unprocessed biomass (dung, wood)     | Agro-ecological Zones (AEZ) | Mono crop           | very high intensive     |
| Landless rural poor        | Viable small to medium scale farms | Household scale processing and use | Charcoal                             | Landscape level             | Multi-crop rotation | GAP                     |
| Urban poor                 | Rural business                     | Small business processing and use  | Liquid biofuels (ethanol, biodiesel) | Watershed system            | Perennial           | Low input/traditional   |
| Community                  | Large scale industrial             | Community scale processing and use | Biogas                               | Soil type                   | Annual              | conservation (no till)  |
|                            | Export                             | industrial scale processing        | Electricity                          | Water availability          | Agro-forestry       | Invasive slash and burn |
|                            |                                    |                                    | (Process) Heat                       |                             | residues or wastes  |                         |

Source: based on current work in the FAO BIAS project; dark boxes indicate selected elements of the setting

This matrix still ignores time horizon, and “compresses” regional scopes into agro-environmental “zones” which reflect biophysical conditions. The very large number of potential combinations can be reduced by focusing on the **most important** and **most likely deployed** combinations, or those which are potentially “optimal”.

The settings approach increases the applicability of the framework across countries, regions, and against socio-economic backgrounds. In theory, LCA addressing each “setting” would, in principle, be applicable world-wide, so that results could be compared, and further data needs identified<sup>34</sup>. The approach is flexible so that

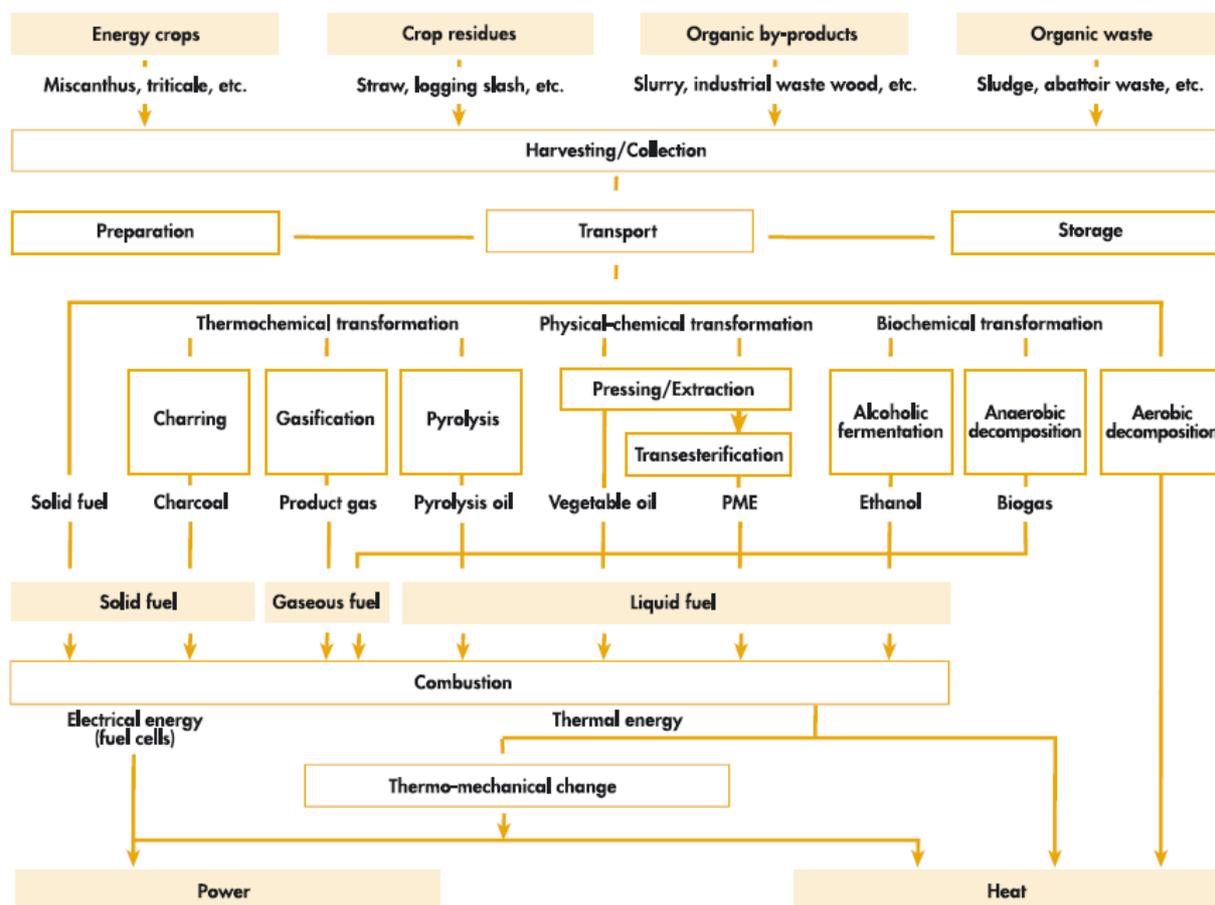
<sup>34</sup> Note that restrictions regarding availability of data, or resolution of results may occur.

combinations of sub-settings (e.g. feedstock production for biodiesel on marginal lands in dry climates in small-scale farming) can be formed and compared to other sub-settings with different conversion routes of the same feedstock etc.

The **regional** attributes of settings with respect to geo- and biophysical as well as climate characteristics should be based on the Agro-ecological Zone (AEZ) concept (FAO 2005)<sup>35</sup>.

The settings also include various combinations of biomass production and use, i.e. biomass supply chains that consist of biomass production, logistic (transport and storage), conversion and use. Different energy carriers can be produced from biomass, i.e. electricity, heat and transportation fuels. The type of conversion technology determines the biomass feedstock that can be used.

Figure A-3 Different Pathways to Convert Biomass to Energy



Source: FNR (2008)

<sup>35</sup> As regard the spatial attributes (location class), the characterization of databases for global land cover should be used (see FAO BIAS project).