# Indirect land use changes (iLUC)

- Methodological context: ascribing land-use changes to their drivers

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## ascribing land-use changes to their drivers


?

Important:
iLUC = the most important LCA
=> one LCA ~10% of global GHG

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## 2.-0 LCA iLUC club

- Aalborg University, Department of Planning and Development, AAU (plan.aau.dk)
- Arla Foods (arla.com)
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- CSIRO (csiro.au)
- DuPont Nutrition and Health (dupont.com)
- DONG Energy (dong.dk)
- ecoinvent (ecoinvent.org)
- National Agricultural Research Center, Japan (naro.affrc.go.jp)
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- Round Table on Sustainable Palm Oil, RSPO (rspo.org)
- Sustainability Consortium (sustainabilityconsortium.org)
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- TetraPak (tetrapak.com)
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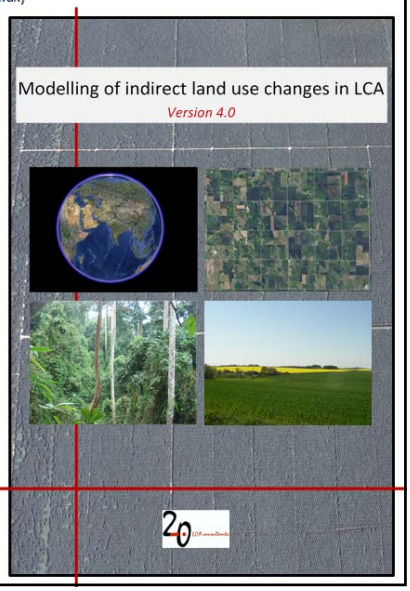
More info at:
www.lca-net.com/projects/iluc_model/

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## The concept – in six bullets……

- Features of the model:
  - is applicable to all crops (also range, build etc.) in all regions in the world
  - The model overcomes the allocation/amortisation of transformation impacts
  - consequential and attributional modelling assumptions can be applied

1. The function of land: Capacity for growing crops/biomass
2. Land use changes are caused by the demand for land
3. There is a market for land => land tenure market
4. This market is global
   - crops can be grown in different regions
   - crops/food/biomass are traded on the global market
5. The model operates with different markets for land (arable, forest, range)
6. The effects of demand for land tenure include:
   - Transformation of land
   - Intensification of land already in use
   - Crop displacement

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## indirect vs direct land use changes

**iLUC:** Indirect land use changes are upstream life cycle impacts of an activity which induces the land use change,

**dLUC:** … whereas direct land use changes take place only in the land using/occupying activity.


5230 kg barley ?

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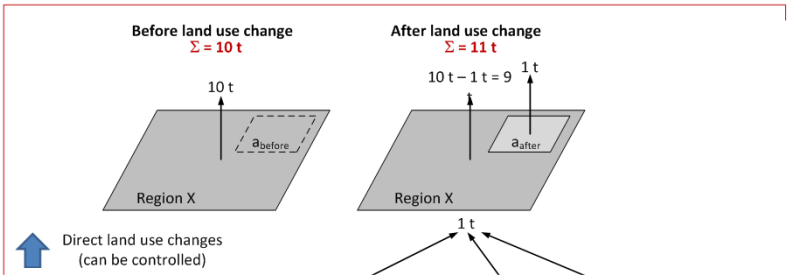
## iLUC – the causal chain

Implications from using land 'a': 1 t crop from land a

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## Land tenure - what is land?

### - Reference flow considerations

- Land = capital input for biomass production;
  - to produce electricity, input of capacity is needed: powerplant
  - to produce biomass, input of capacity is needed: productive land
- Land's capacity for producing biomass can be expressed as:
  - Hectare years [ha yr]
  - Productivity weighted hectare years [pw ha yr]
  - Potential net primary production ($NPP_0$) as a common currency for productivity [kg C]
  - Other...?
- Chosen reference flow: $NPP_0$. Justificiation:
  - Good global data, see next slide
  - $NPP_0$ has units of mass
  - Mass balance of a land tenure market LCA process

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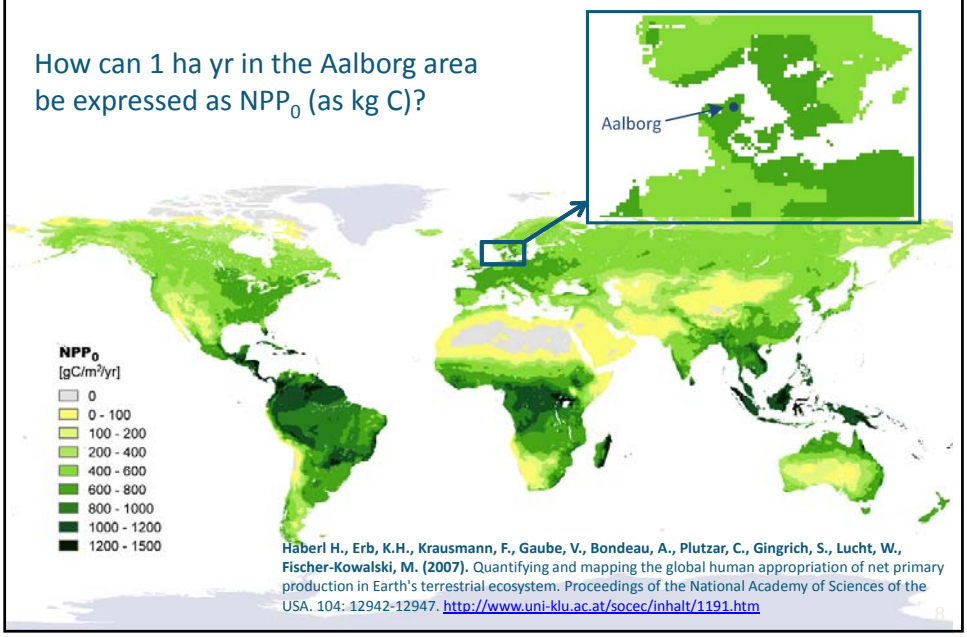
## Global map of potential net primary production ($NPP_0$)

How can 1 ha yr in the Aalborg area be expressed as $NPP_0$ (as kg C)?




**Haberl H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M. (2007).** Quantifying and mapping the global human appropriation of net primary production in Earth's terrestrial ecosystem. Proceedings of the National Academy of Sciences of the USA. 104: 12942-12947. http://www.uni-klu.ac.at/socec/inhalt/1191.htm

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## Land classification (land cover)
### - what is there…

| Land use classes | Description |
|---|---|
| **Land in use** | |
| Cropland | Arable and permanent crops (FAOSTAT 2011) |
| Intensive forest | Productive intensive forest, mainly even-aged trees and clear cut (Weidema 2011) |
| Extensive forest | Productive extensive forest, mainly selective logging (Weidema 2011) |
| Pasture | Permanent meadows and pastures (FAOSTAT 2011) |
| **Land not in use** | |
| Primary forest | FAO (2010) |
| Secondary forest | Other naturally regenerated forest (FAO 2010) |
| Grassland | (Weidema 2011) |

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## Markets for land
### - potential use of the land

| Land tenure markets | |
|---|---|
| Extensive forest land | Not fit for more intensive forestry (e.g. clear cutting and reforestation, species control etc.) because e.g. it is too hilly, too remote, or it is very infertile making intensive forestry uneconomic. Forests grown on extensive forestland are typically harvested after natural regrowth with mixed species. |
| Intensive forest land | Fit for intensive forestry but unfit for arable cropping because e.g. the soil is too rocky. Forest crops grown on intensive forestland may be managed as intensively or extensively. Intensive forestland may also be used for other uses, e.g. livestock grazing and extensive forestry. |
| Arable land | Fit for arable cropping (both annual and perennial crops), for intensive or extensive forestry, and pasture. |
| Grassland | Too dry for forestry and arable cropping. Grassland is most often used for grazing. |

## Land tenure as an LCA activity

- iLUC model as LCA processes – ecoinvent compliant
- LCA activity with four principal inputs
- Mass balance of land tenure activity

*Market for land tenure*

| Output | Flow | Unit |
|---|---|---|
| Market for arable land tenure, $NPP_0$ as kg C | $\Sigma(a_1:a_4)$ | kg |
| Inputs from technosphere | | |
| → Land already in use | $a_1$ | kg |
| → Expansion | $a_2$ | kg |
| → Intensification | $a_3$ | kg |
| → Crop displacement | $a_4$ | kg |

*Wheat (1 ha yr)*

| Output | Flow | Unit |
|---|---|---|
| Wheat → wheat | 7200 | kg |
| Inputs from technosphere | | |
| Diesel for traction | 4921 | MJ |
| N-Fertiliser, as N | 161 | kg |
| Market for arable land tenure, $NPP_0$ as kg C | 7000 | kg |
| Emissions | | |
| $CO_2$ fossil (diesel combustion) | 365 | kg |
| $N_2O$ | 4.3 | kg |
| Resources | | |
| $CO_2$ from air | 10300 | kg |

**Haberl H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M. (2007).** Quantifying and mapping the global human appropriation of net primary production in Earth's terrestrial ecosystem. Proceedings of the National Academy of Sciences of the USA. 104: 12942-12947.

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## The inputs to the market for land tenure LCA activity

*Land already in use*

| Output | Flow | Unit |
|---|---|---|
| Land already in use, $NPP_0$ as kg C | $a_1$ | kg |
| Inputs | | |
| None | - | |
| Emissions | | |
| None | - | |

*Land use changes*

| Output | Flow | Unit |
|---|---|---|
| Transformation, $NPP_0$ as kg C | $a_2$ | kg |
| Ressource inputs from nature | | |
| Transformation from… | $b_1$ | ha |
| Transformation to… | $b_2$ | ha |
| Emissions | | |
| $CO_2$ | $b_{3...}$ | kg |

*Intensification*

| Output | Flow | Unit |
|---|---|---|
| Intensification, $NPP_0$ as kg C | $a_3$ | kg |
| Inputs from technosphere | | |
| NPK-Fertiliser | $c_2$ | kg |
| Emissions | | |
| $N_2O$, $CO_2$ … | $c_{3...}$ | kg |

*Social effects*

| Output | Flow | Unit |
|---|---|---|
| Crop displacement, $NPP_0$ as kg C | $a_4$ | kg |
| Inputs | | |
| None | - | |
| Emissions | | |
| None | - | |

*Market for land tenure*

| Output | Flow | Unit |
|---|---|---|
| Market for arable land tenure, $NPP_0$ as kg C → | $\Sigma(a_1:a_4)$ | kg |
| Inputs from technosphere | | |
| Land already in use | $a_1$ | kg |
| Expansion | $a_2$ | kg |
| Intensification | $a_3$ | kg |
| Crop displacement | $a_4$ | kg |

**Input is presumed to be =0**
Because of full elasticity assumption in LCA

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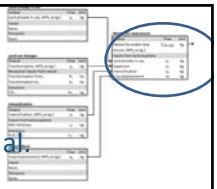
## Life cycle inventory



- **Land tenure activity**
  - Average year 2000-2010, data: FAO, FAOSTAT, Haberl et al.
  - $NPP_0$ – equivalents from existing land in use
  - $NPP_0$ – equivalents increase from new land in use
  - $NPP_0$ – equivalents increase from intensification
- **Expansion activity**
  - Which types of land: FAO forest stat
  - Where do land use changes take place: FAO forest stat
  - Carbon stocks and $CO_2$ emissions: IPCC (2006)
- **Intensification activity**
  - Which crops and where: FAOSTAT timeseries
  - Current fertiliser levels for crops in regions where intensification takes place
  - Emissions: based on dose-response effects of fertiliser

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## Expansion: Transformation of land

- Challenge:
  - In LCI we have land occupation (ha yr)
  - We want to model effects of transformation (ha)
  - Occupation and transformation are not proportional
- Land transformation is modelled as accelerated deforestation
  - Demand for 1 ha yr causes:
    - 1 ha deforestation in year t=0
    - 1 ha avoided deforestation in year t=1
  - Emissions from accelerated deforestation
    - Net emissions = 0
    - Effect via time dependant global warming potential (GWP)

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# Results


Table 6: GHG-emissions (GWP100) for the occupation of 1 ha yr of different land-tenure markets in different countries. The results are shown when applying the consequential modelling assumption. The $NPP_0$ are obtained from Harberl et al. (2007b).

| Country/Region | $NPP_0$, kg C $ha^{-1}$ $yr^{-1}$ | Market for land tenure (kg $CO_2$-eq. $ha^{-1}$ $yr^{-1}$) | | | |
|---|---|---|---|---|---|
| | | Arable land | Intensive forestland | Extensive forestland | Grassland |
| World average | 6,110 | 4,592 | 1,491 | 1,343 | 3,116 |
| Argentina (Pampas) | 7,000 | - | - | - | 4,488 |
| Baltics | 7,000 | 5,261 | 1,449 | 1,306 | - |
| Brazil Central (Cerrado) | 9,000 | 6,764 | 1,864 | 1,679 | - |
| Brazil North (Amazonas) | 11,000 | 8,268 | 2,278 | 2,053 | - |
| Brazil South (Pampas) | 7,000 | - | - | - | 4,488 |
| Canada | 5,000 | 3,758 | 1,035 | 933 | - |
| Canada South central (Praire) | 4,000 | - | - | - | 2,564 |
| France | 7,000 | 5,261 | 1,449 | 1,306 | - |
| France (Alp highlands) | 5,000 | - | - | - | 3,205 |
| Malaysia&Indonesia | 11,000 | 8,268 | 2,278 | 2,053 | - |
| Russia | 5,000 | 3,758 | 1,035 | 933 | |
| USA east | 7,000 | 5,261 | 1,449 | 1,306 | - |
| USA mid | 5,000 | 3,758 | 1,035 | 933 | - |
| USA Central (Praire) | 5,000 | - | - | - | 3,205 |



# Results per $NPP_0$ and clca vs. alca

Table 7: GHG-emissions for the four land tenure markets. Results are shown as kg $CO_2$-eq. (GWP100) per $NPP_0$ (kg C) and per global average hectare-year. Global average potential productivity from Table 2 are used for the conversion of results per ha yr (see bottom line of current table). clca=consequential; alca=attributional.

| Land tenure market | Arable land | | Intensive forest land | | Extensive forest land | | Grassland | |
|---|---|---|---|---|---|---|---|---|
| Average potential productivity, $NPP_0$ (kg C ha-1) | 6,110 | | 7,200 | | 7,200 | | 4,860 | |
| Modelling | clca | alca | clca | alca | clca | alca | clca | alca |
| GHG-emissions per $NPP_0$ as kg C | 0.756 | 0.019 | 0.207 | 0.00379 | 0.187 | 0.00077 | 0.641 | 0.00816 |
| GHG-emissions per ha yr (global average) | 4,619 | 116 | 1,490 | 27 | 1,346 | 6 | 3,115 | 40 |

## Effects when occupying land in the frontier

- Logics is straight forward when occupying land in established regions
- But… any differences when:
  - Occupying land in newly established land in Indonesia or Brazil (oil palm/soybean) compared to:
  - Occupying land in Europe/US (rapeseed/soy)
- Intuitive reasoning:
  - Frontier: you can see/feel the bad
  - Established: you can't see any deforestation
- No difference:
  - When affecting the frontier, it is likely that this piece of land would be the next to be brought into use anyway

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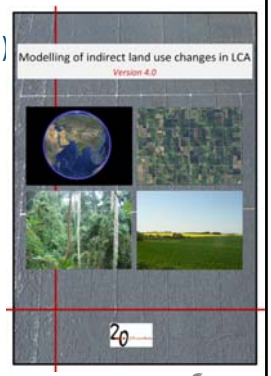
## Conclusions on the 2.-0 LCA iLUC model

- iLUC model applicable to all crops in all regions in the world
- The model considers land transformation AND intensification
- The model operates with different markets for land (arable, range, forest)
- Based on global statistics and models (FAOSTAT, FAO, IPCC)
- Enable for consequential and attributional modelling (ecoinvent v3 compliant)
- Amortisation (or allocation of deforestation emissions) avoided by use of time-dependant GWP
- The major uncertainties are related to data inputs ($NPP_0$ levels, carbon stocks, crop yield to fertiliser dose-response functions)
- Current markets for land may be sub-divided in more segments and regions if this can be justified
- More info at:

http://www.lca-net.com/projects/iluc_model/

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