Ascribing land use changes to its drivers

- conceptual framework for the modelling of indirect land use changes in life cycle inventory

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Aalborg 10th May 2022

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DCEA | DET DANSKE CENTER FOR MILJØVURDERING

CEO, 2.-0 LCA consultants

The role of LULUCF

Global GHG ($Gt\ CO_2$-eq)	Total global	Food system	Food as share of total
Land use changes	5.8	4.9	9%
Agriculture	6.2	6.2	12%
Other	40	3.9	8%
Total	**52**	**15**	**29%**

11% of global GHG emissions

If LUC is not included in LCA
If LUC is not modelled correctly

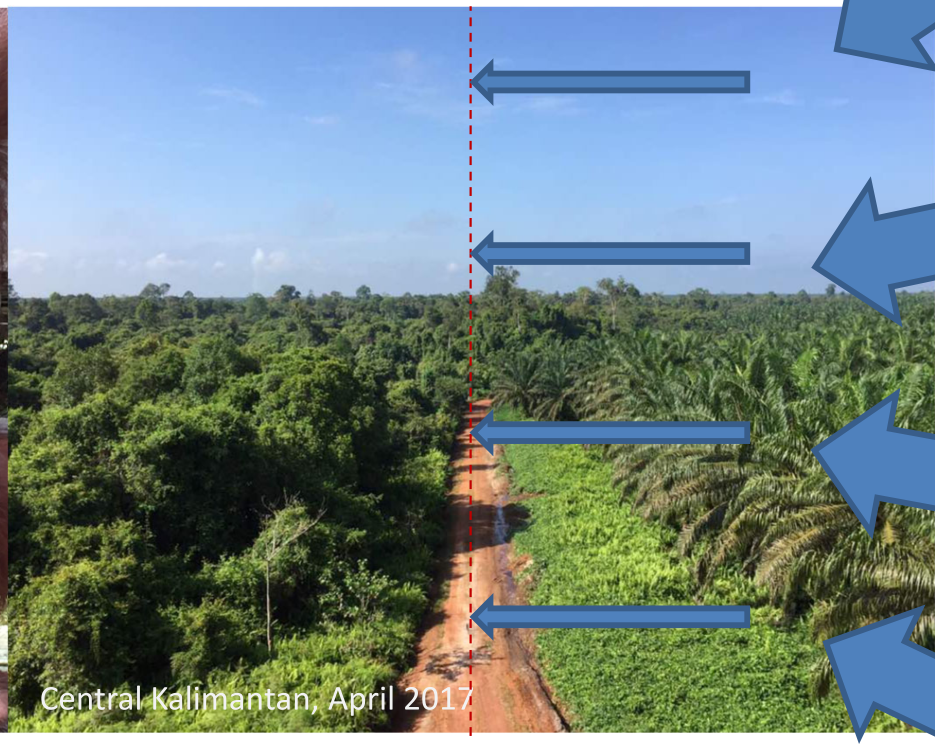
misleading decision support and bad decisions for the environment

IPCC (2020), Climate Change and Land - An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems Summary for Policymakers. Intergovernmental Panel on Climate Change.

LUC is serious today
- what about the future?

- Population growth by 2050: **+28%**
- Economic growth by 2050: **+200%**
  - food consumption per capita
  - share of meat
- Biofuels by 2030: **+ >25-100%**


Orangutan rehabilitation center, Central Kalimantan, April 2017


Central Kalimantan, April 2017

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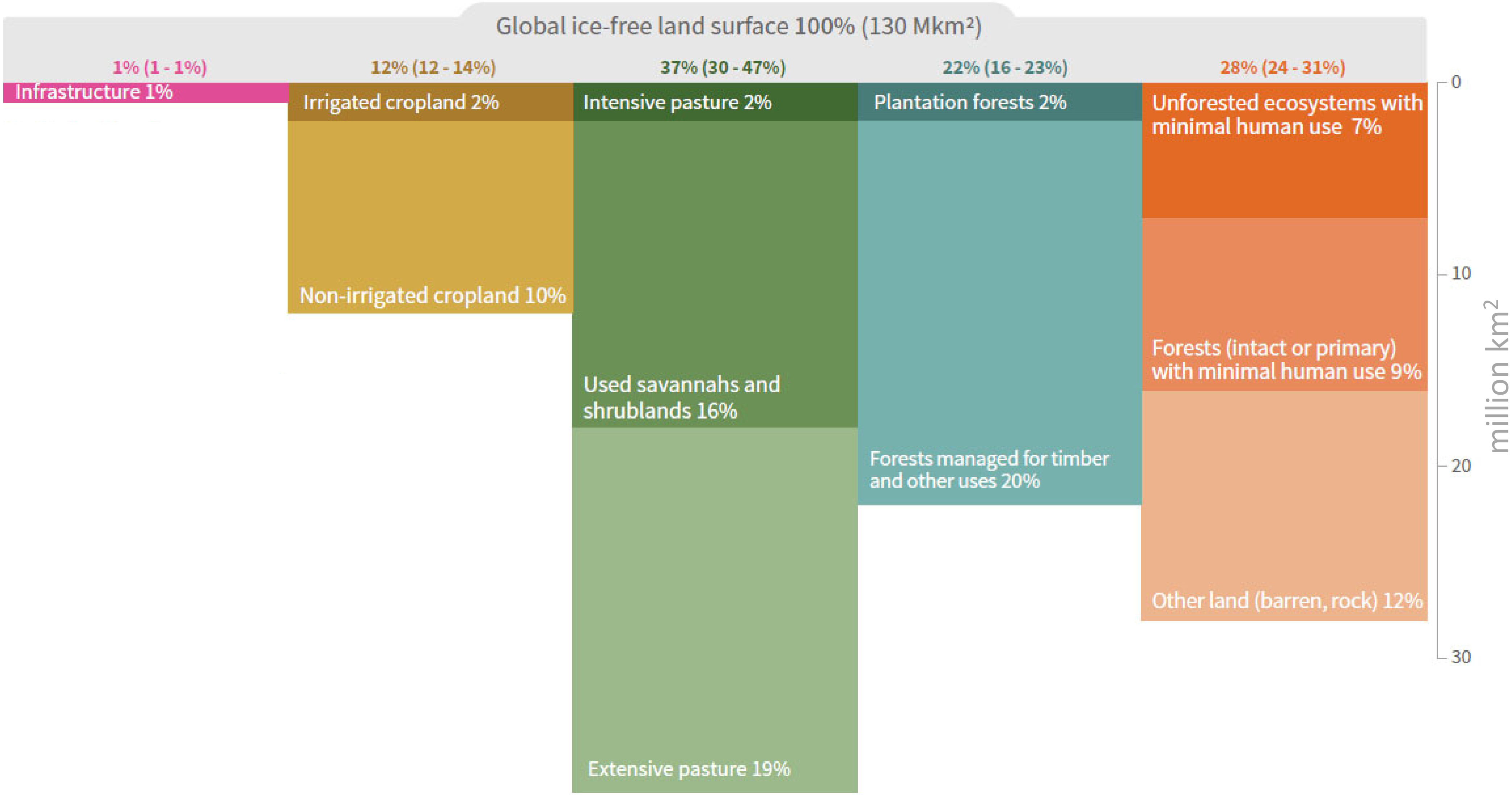
UN (2019) https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

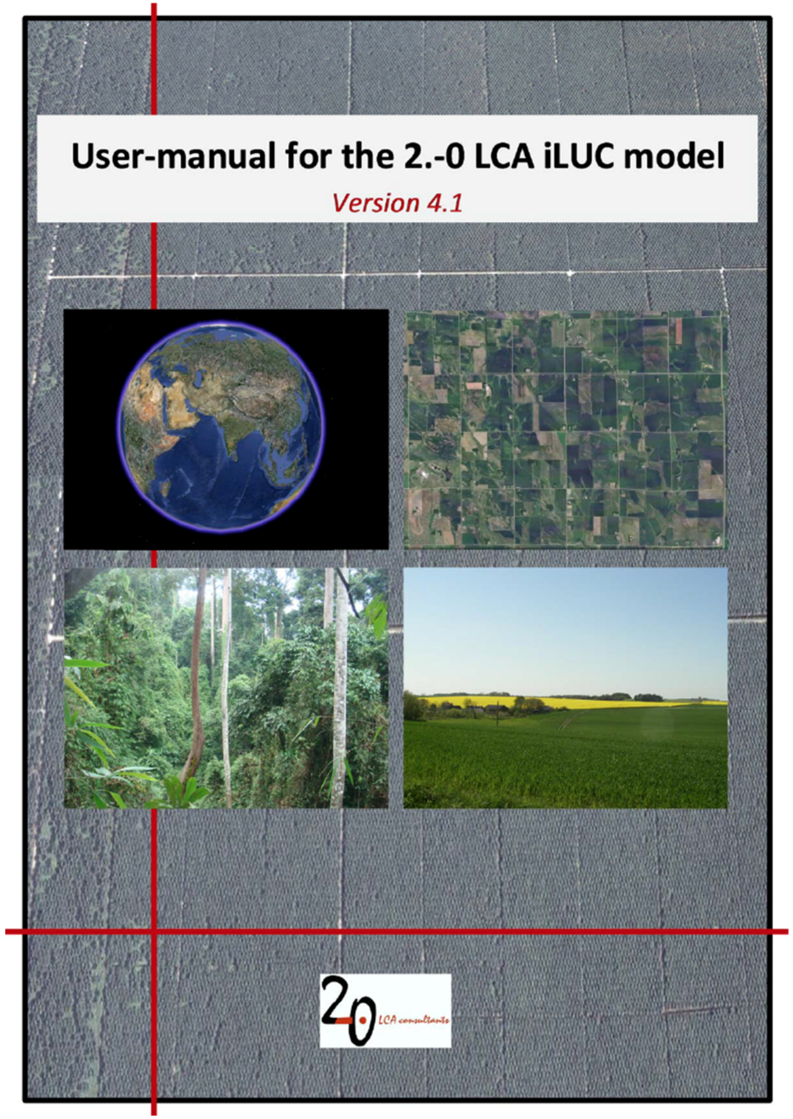
Global land cover



IPCC (2020), Climate Change and Land - An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems Summary for Policymakers. Intergovernmental Panel on Climate Change.

2.-0 LCA consequential iLUC: crowdfunded project

- Aalborg University, Department of Planning and Development, AAU (plan.aau.dk)
- Aarhus University, Department of Agroecology - Agricultural Systems and Sustainability (scitech.au.dk)
- Arla Foods (arla.com)
- Asplan Viak (asplanviak.no)
- Centre for Environmental Policy, Imperial College London (imperial.ac.uk)
- Concito (concito.dk)
- CSIRO (csiro.au)
- Technical University of Denmark, DTU (dtu.dk)
- DuPont Nutrition and Health (dupont.com)
- ecoinvent (ecoinvent.org)
- Mahidol University, Department of Civil and Environmental Engineering (eg.mahidol.ac.th/)
- IFP Energies Nouvelles (ifpen.fr)
- Joint Research Centre (JRC) EU Science Hub (ec.europa.eu/jrc/en)
- Miljögiraff (miljogiraff.se)
- National Agricultural Research Center, Japan (naro.affrc.go.jp)
- Niras (niras.dk)
- NSW Department of Primary Industries (dpi.nsw.gov.au/)
- Ørsted (orsted.dk)
- PRé Consultants (pre-sustainability.com/)
- PT SMART (smart-tbk.com)
- Round Table on Sustainable Palm Oil, RSPO (rspo.org)
- Sustainability Consortium (sustainabilityconsortium.org)
- Swedish University of Agriculture Sciences, SLU (slu.se)
- TetraPak (tetrapak.com)
- United Nations Life Cycle Initiative (lifecycleinitiative.org)
- Unilever (unilever.com)
- United Plantations Berhad (unitedplantations.com)
- University of Copenhagen, The Faculty of Life Sciences, LIFE (life.ku.dk)



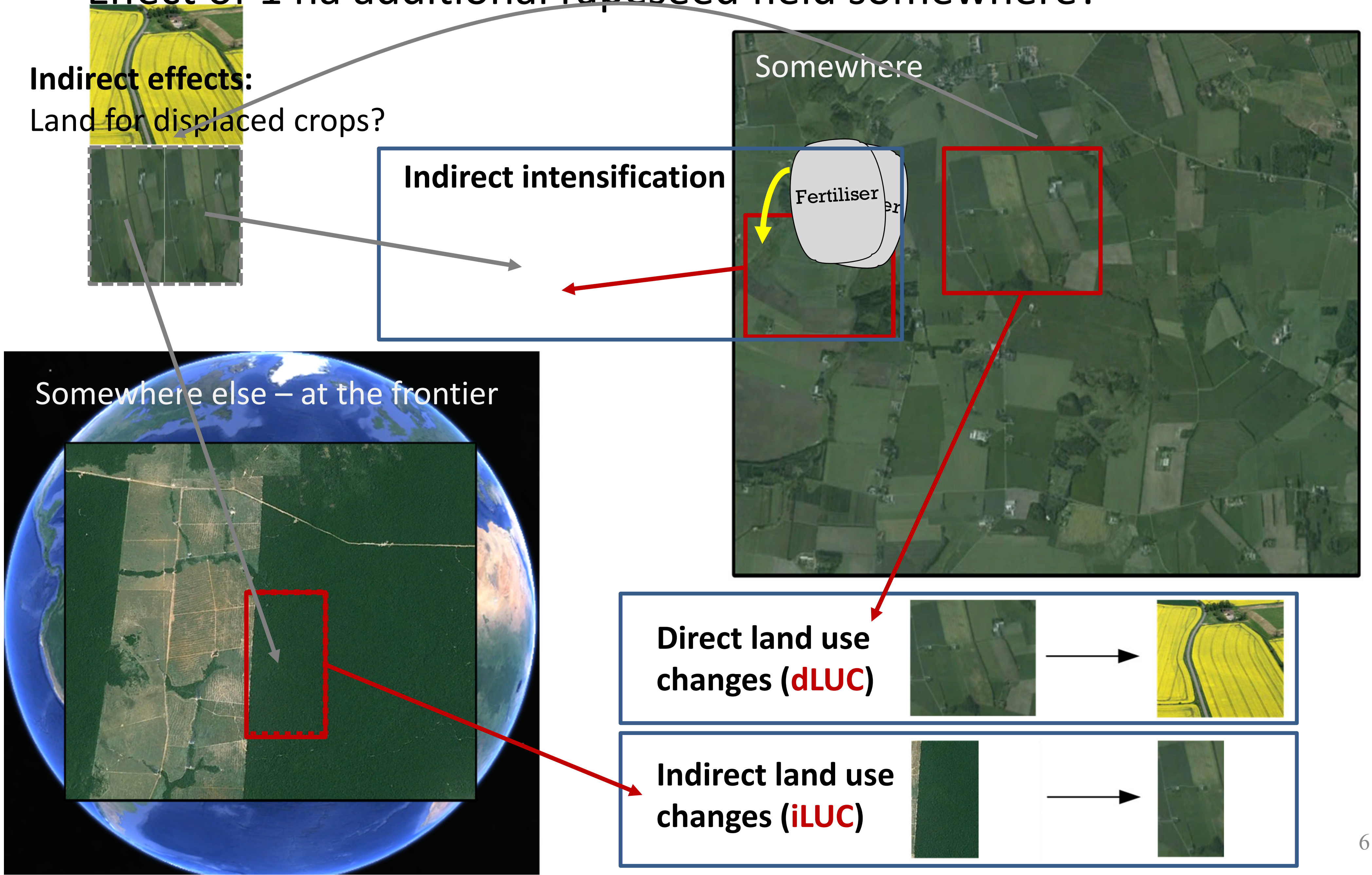
More info at:

https://lca-net.com/clubs/iluc/

Schmidt J, Weidema B P, Brandão M (2015). *A framework for modelling indirect land use changes in life cycle assessment*. Journal of Cleaner Production 99:230-238

Direct and indirect Land-Use Changes

- Effect of 1 ha additional rapeseed field somewhere?



Land use change models

- Consequential ⇨ iLUC + dLUC
- PAS2050/PEF/GHG Protocol ⇨ LUC (sometimes called dLUC)

Land use change models

Consequential

- Consequence of using land
- Focus = effect on remaining forests
- (past deforestation not included because this cannot be affected)

PAS2050

- Emissions of historical LUC last 20 years allocated to current activities on a given land plot
- Focus = forest that has already been destroyed
- Missing = all the forests, we want to protect (!?)

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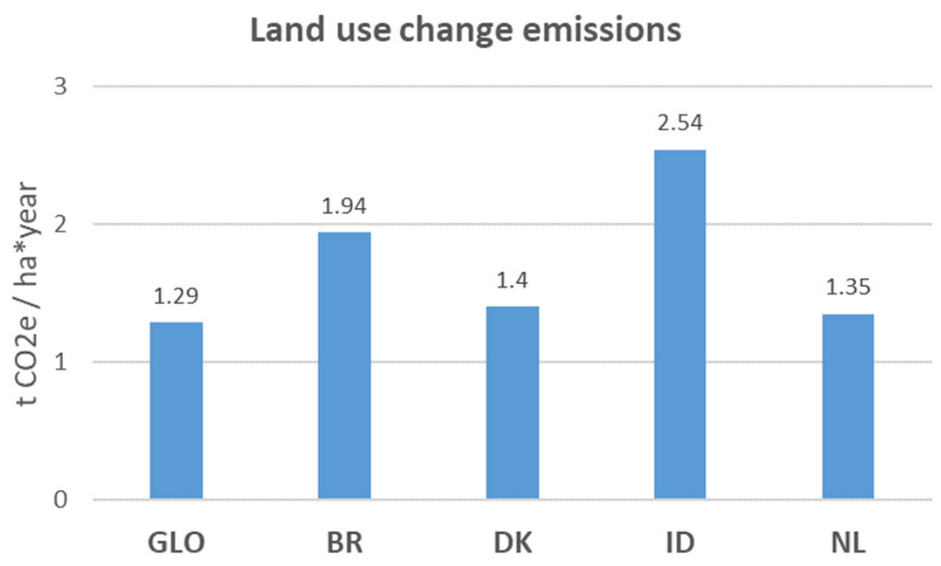
Land use change models
- difference in results for CLCA and ALCA

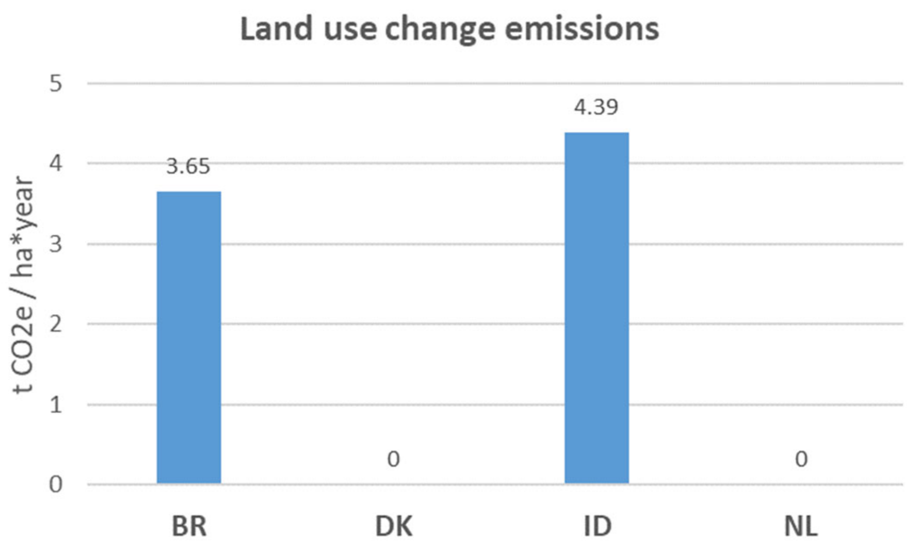
consequential
cause-effect

- **iLUC:** All crops have input of market for land
- **dLUC:** Only relevant for oil palm
- **Geographical** differences for arable land by actual NPP_0 relative to global aver. NPP_0
- **Results per 1 ha*year**



PEF (attributional)
normative (no link to actually effect on LUC)

- **PAS2050 approach**
- **National averages:** 20 year change in arable land and forest cover => % of arable on previous forest land
- **Carbon stock:** IPCC (2006)
- **Results per 1 ha*year**



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The iLUC model in five bullets

- Key assumptions

1. Land use changes are **caused** by the **demand** for land

2. There is a **market** for land i.e. for land's **capacity for growing biomass**

3. The market for land is **global**:
   - crops can be grown in different **regions**
   - Food/biomass is **substitutable** and traded on the global market

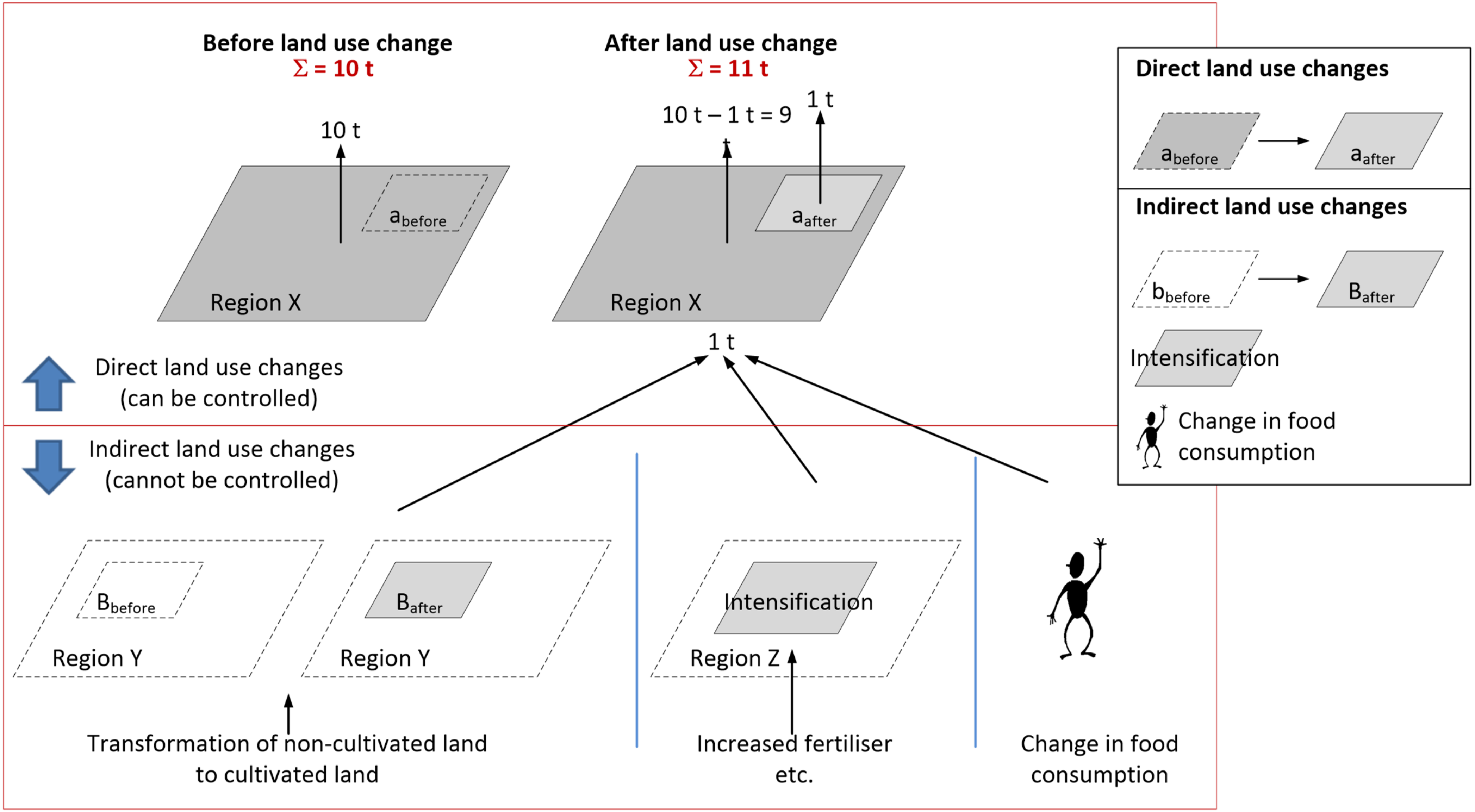
4. Different markets for land can be distinguished: **arable, forest, range**

5. **Change** in demand for land **cause**:
   - Transformation of land
   - Intensification of land already in use
   - Crop displacement

   (reduced consumption)

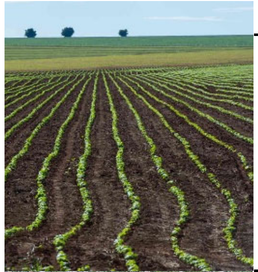
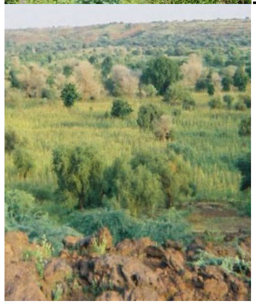
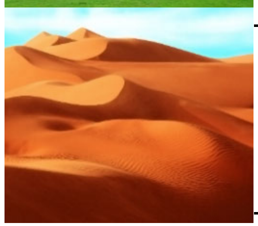
iLUC – "the mass balance proof"

Implications from using land: 1 t crop from land *a*



What is land?

- Functional unit considerations

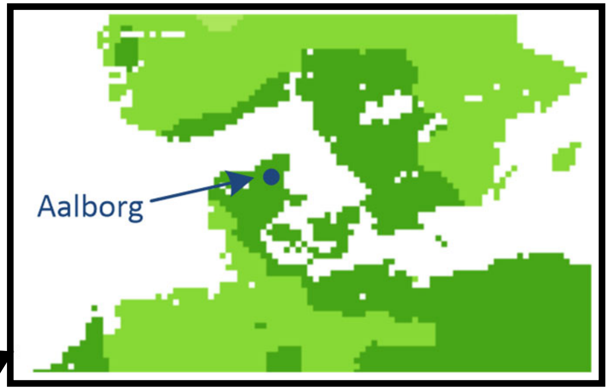
	Markets for land
	Market for arable land (fit for arable and other)
	Market for intensive forest land (fit for intensive/extensive forestry and grazing)
	Market for extensive forest land (fit for extensive forestry and grazing)
	Market for grassland (fit for grazing)
	Market for barren land (not fit for biomass production)

- Functional unit
  - For each market: Capacity for biomass production from 1 ha*year global average

  - Barren land: 1 ha*year global average

Global potential net primary production (NPP_0)
- How to weight land use in different locations?

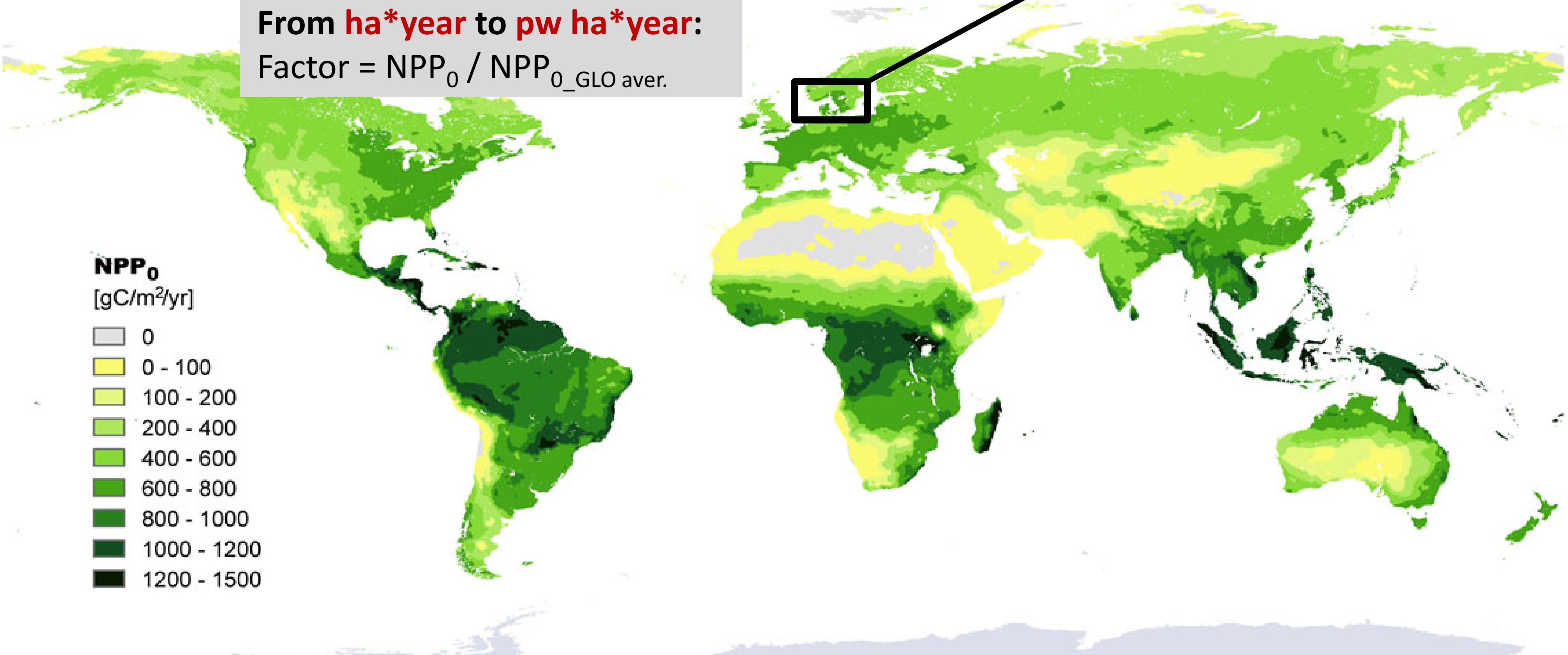
1 ha*year in the Aalborg area expressed as pw ha*year
(GLO aver. arable is 5680 kg C ha^{-1} $year^{-1}$)



$NPP_{0,DK}$ = 6150 kg C ha^{-1} $year^{-1}$

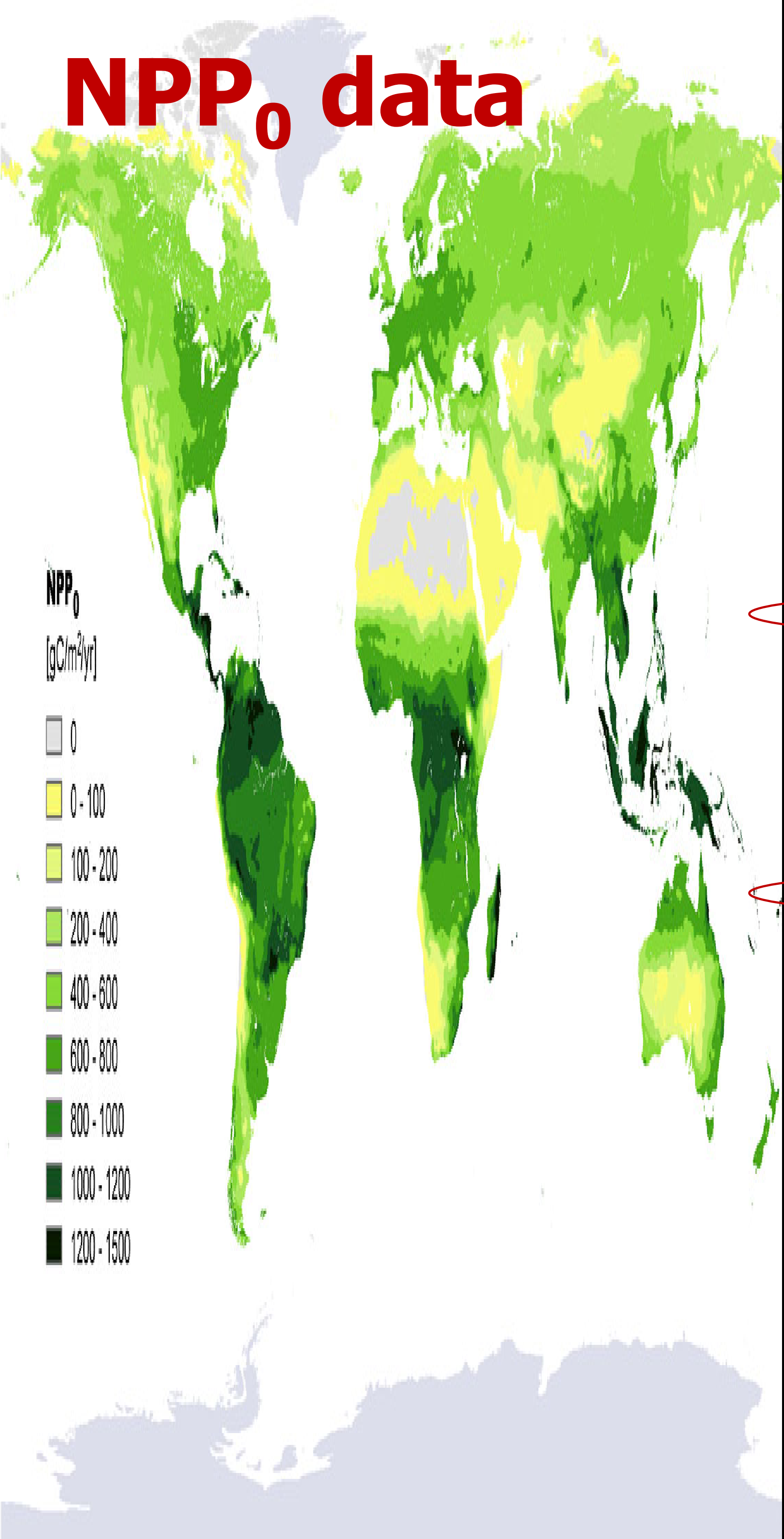
$Factor_{DK}$ = 6150/5608 = 1.08

From ha*year to pw ha*year:
Factor = NPP_0 / $NPP_{0\_GLO\ aver.}$



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

NPP_0 data



Acronym for country/region	Country/region	NPP0 for each land cover, normalized to global NPP0 (ha-eq/ha)		
		Arable	Forest	Grassland
GLO	**Global**	**1.00**	**1.00**	**1.00**
AT	Austria	1.14	0.86	1.37
AU	Australia	0.90	0.91	1.19
BE	Belgium	1.11	0.82	1.57
BG	Bulgaria	0.95	0.75	1.39
BR	Brazil	1.51	1.25	2.27
CA	Canada	0.99	0.70	0.58
CH	Switzerland	1.14	0.77	1.23
CN	China	0.94	0.81	0.84
CY	Cyprus	0.72	0.57	1.05
CZ	CzechRepublic	1.10	0.84	1.62
DE	Germany	1.08	0.82	1.52
DK	Denmark	1.08	0.81	1.58
EE	Estonia	1.02	0.76	1.43
ES	Spain	0.94	0.77	1.35
FI	Finland	0.93	0.69	1.17
FR	France	1.16	0.85	1.59
GB	UnitedKingdom	1.01	0.66	1.34
GR	Greece	0.79	0.59	1.13
HU	Hungary	1.07	0.83	1.56
ID	Indonesia	1.97	1.53	2.85
IE	Ireland	1.09	0.78	1.52
IN	India	0.91	0.90	1.37
IT	Italy	0.98	0.73	1.28
JP	Japan	1.04	0.79	1.48
KR	SouthKorea	1.10	0.84	1.60
LT	Lithuania	1.08	0.81	1.57
LU	Luxembourg	1.12	0.84	1.60
LV	Latvia	1.06	0.79	1.53
MT	Malta	0.72	0.54	1.05
MX	Mexico	1.08	0.96	0.98
NL	Netherlands	1.05	0.77	1.49
NO	Norway	1.04	0.69	1.08
PL	Poland	1.12	0.84	1.63
PT	Portugal	0.98	0.77	1.45
RO	Romania	0.91	0.77	1.14
RU	Russia	0.93	0.66	0.91
SE	Sweden	1.08	0.71	0.96
SI	Slovenia	1.21	0.92	1.74

Life cycle inventory

- Market, transformation and intensification

Land use changes

Output	Flow	Unit
Transformation	a_1	ha*year eq.
Ressource inputs from nature		
Transformation from…	b_1	ha
Transformation to…	b_2	ha
Emissions		
e.g. CO_2	$b_{3...}$	kg

Intensification

Output	Flow	Unit
Intensification	a_2	ha*year eq.
Inputs from technosphere		
Diesel for traction	c_1	MJ
N-Fertiliser, as N	c_2	kg
Emissions		
e.g. N_2O, CO_2	$c_{3...}$	kg

Not included

Social effects

Output	Flow	Unit
Changes in consumption	a_3	ha*year eq.
Inputs		
n.a.	-	
Emissions		
n.a.	-	

Land market activity

Output	Flow	Unit
Land	$\Sigma (a_1:a_3)$	ha*year eq.
Inputs from technosphere		
Transformation	a_1	ha*year eq.
Intensification	a_2	ha*year eq.
Changes in consumption	a_3	ha*year eq.

Wheat LCA activity (1 ha yr)

Output	Flow	Unit
Wheat	7,296	kg
Inputs from technoesphere		
Land	1.08	ha*year eq.
Diesel for traction	3,306	MJ
N-Fertiliser, as N	198	kg
P-Fertiliser, as P_2O_5	46	kg
K-Fertiliser, as K_2O	84	kg
Emissions		
CO_2 fossil (diesel combustion)	245	kg
N_2O	4.15	kg
Resources		
CO_2 biogenic from air	11,370	kg

→ wheat

Using the model - in practice

1.29 t CO_2-eq ha^{-1} $year^{-1}$

What does the model provide?

- *Simple*: Elementary flows per unit of land use (pw ha*year-eq.)
- *Advanced*: iLUC effects of land using activity, linking foreground activities to model in LCA software

Input data:

1. Land occupation → How much land is used per FU?
2. Market → Identify market segment (arable, forest or range)
3. Productivity factor → Identify the productivity factor of land (pw)

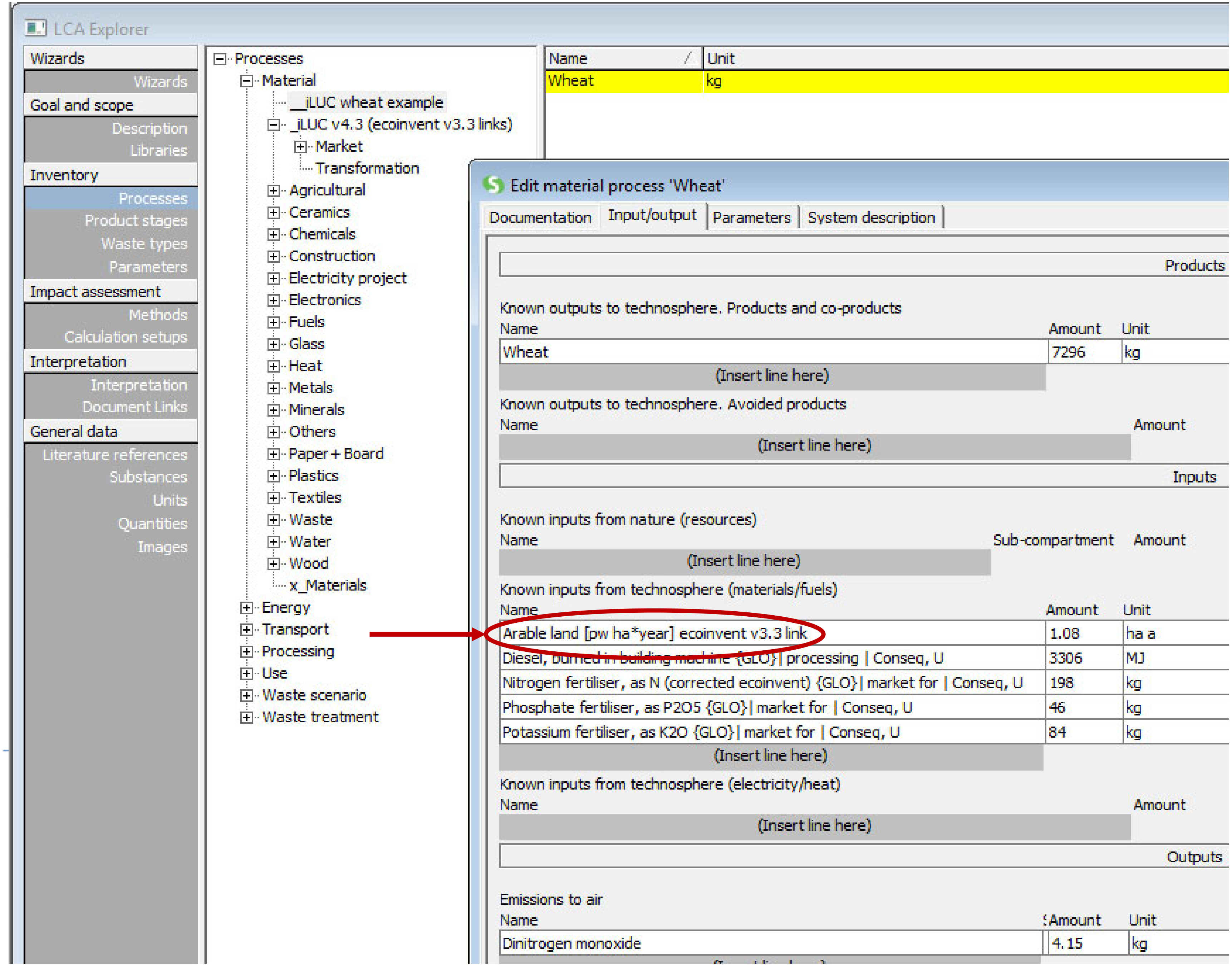
Calculations

1. Calculate the weighted productivity of land

   = land occupation [ha*year] x productivity factor [pw]

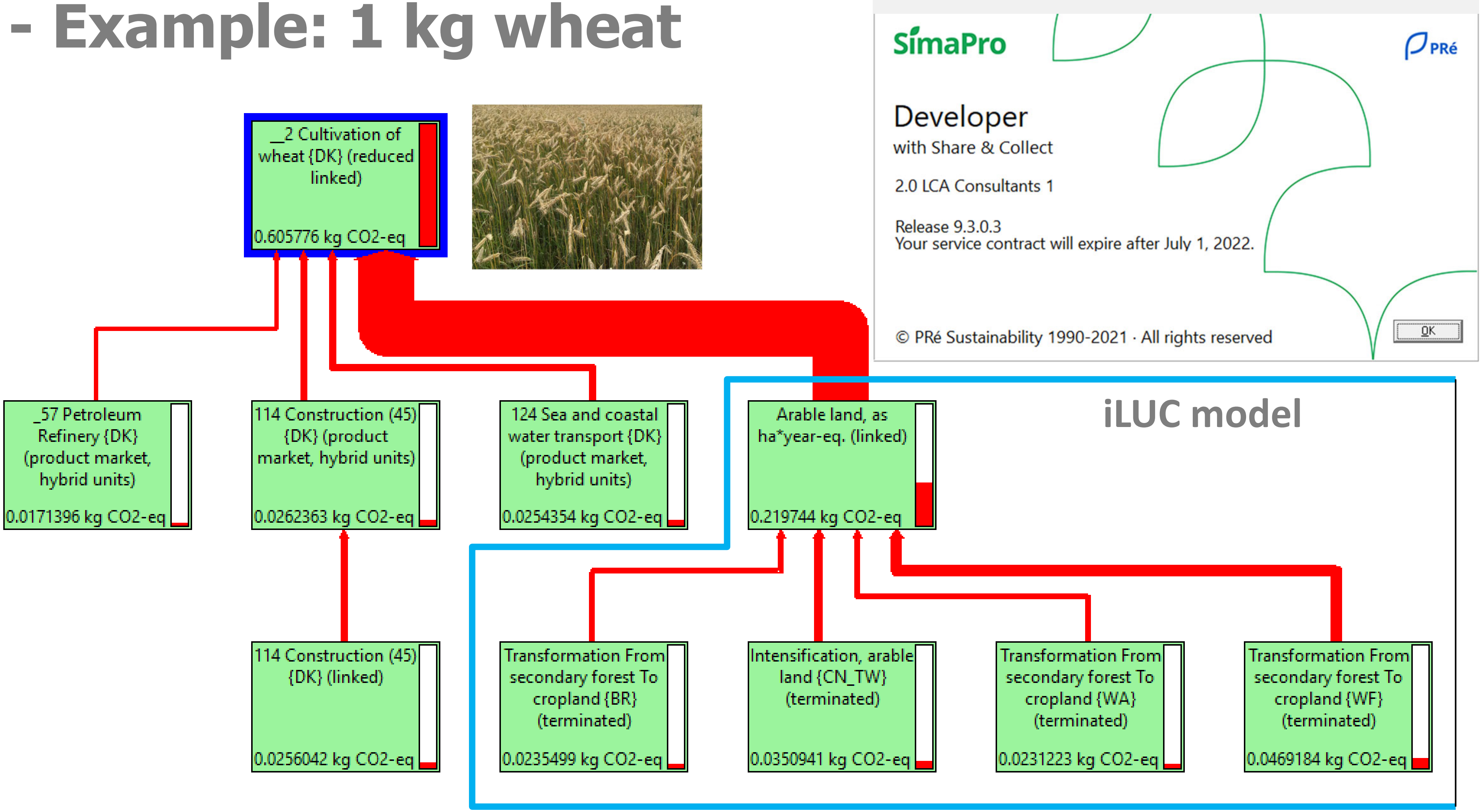
2. Multiply (1) with global iLUC LCI per [emissions / pw ha*year]

The model in SimaPro
- Example: Wheat



The model in SimaPro
- Example: 1 kg wheat

exiobase v3.3.16b2



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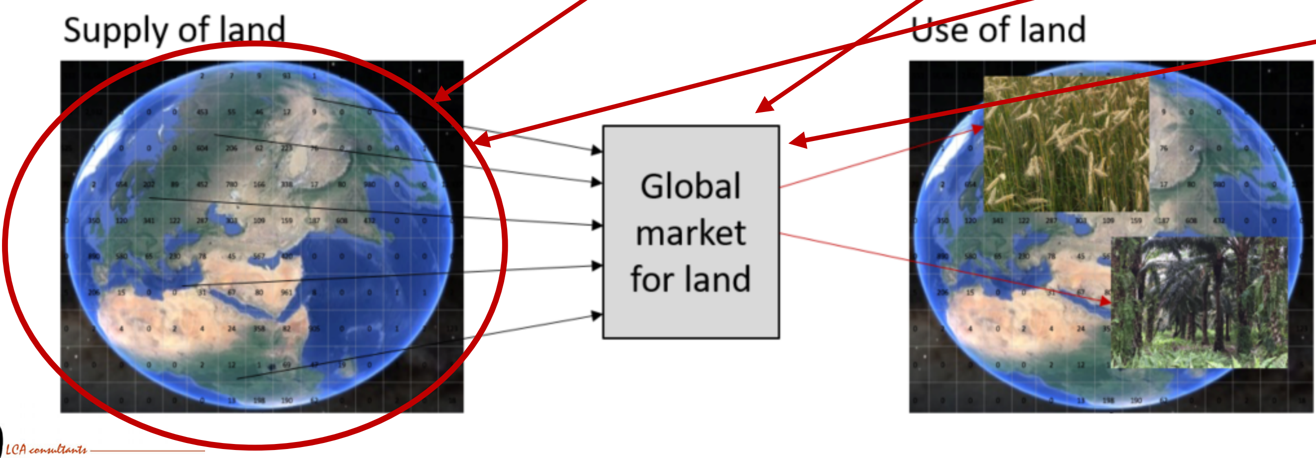
Integration of iLUC in EXIOBASE

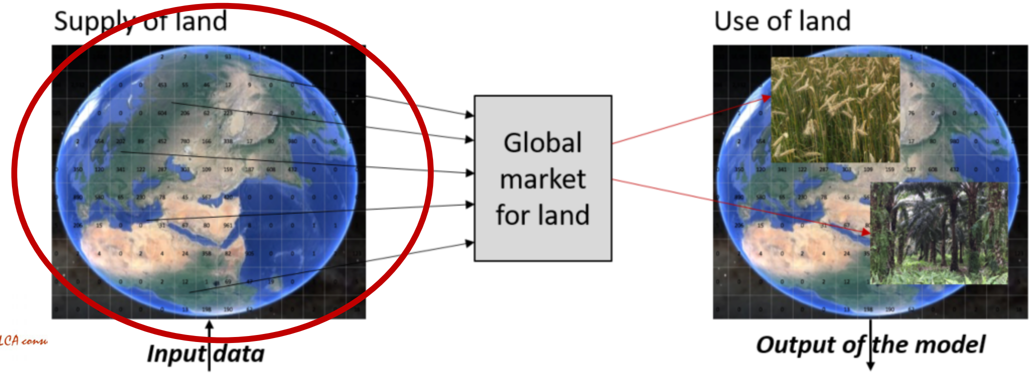
exiobase v3.3.16b2

- Transformation of non-use to arable: Δha-eq$_{trans}$
  - AT ha arable 2011 - 2006 = Δha ; Δha_{AT} * $PW_{factor,AT}$ = Δha-eq$_{trans,AT}$
  - AU ha arable 2011 - 2006 = Δha ; Δha_{AU} * $PW_{factor,AU}$ = Δha-eq$_{trans,AU}$
  - BE ha arable 2011 - 2006 = Δha ; Δha_{BE} * $PW_{factor,BE}$ = Δha-eq$_{trans,BE}$
  - …
  - **GLO** **Σ = Δha-eq$_{trans,GLO}$**
- Intensification of land already in use: Δha-eq$_{int}$
  - AT (yield2011 – 2006)*area = $\Delta prod_{int}$; $\Delta prod_{int,AT}$ / Yield * $PW_{factor,AT}$ = Δha-eq$_{int,AT}$
  - AU (yield2011 – 2006)*area = $\Delta prod_{int}$; $\Delta prod_{int,AU}$ / Yield * $PW_{factor,AU}$ = Δha-eq$_{int,AU}$
  - BE (yield2011 – 2006)*area = $\Delta prod_{int}$; $\Delta prod_{int,BE}$ / Yield * $PW_{factor,BE}$ = Δha-eq$_{int,BE}$
  - …
  - **GLO** **Σ = Δha-eq$_{int,GLO}$**



Integration of iLUC in EXIOBASE (1 of 4)

- **Supply of land**
  - Transformation (one per country)
  - Intensification (one per country)
  - Market for land (one global)
- **Use of land**
  - All uses of land link to global market



Supply table

		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
Country 1	Products							
	Land, trans							
	Land, int							
Country 2	Products							
	Land, trans							
	Land, int							
GLO	Mar							

Use table

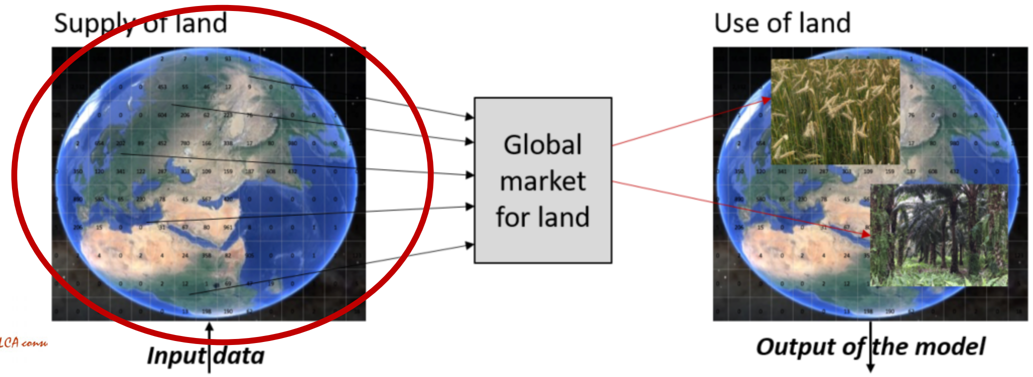
		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
Country 1	Products							
	Land, trans							
	Land, int							
Country 2	Products							
	Land, trans							
	Land, int							
GLO	Land	use of land			use of land			

Emissions

		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
LUC	CO_2							
LUC	N_2O							

Integration of iLUC in EXIOBASE (2 of 4)

- **Supply of land**
  - Transformation (one per country)
  - Intensification (one per country)
  - Market for land (one global)
- **Use of land**
  - All uses of land link to global market



Supply table

		Country 1 Industries	Tra	**Int**	Country 2 Industries	Tra	**Int**	GLO Mar
Country 1	Products							
	Land, trans							
	Land, int							
Country 2	Products							
	Land, trans							
	Land, int							
GLO	Mar							

Use table

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Country 1	Products							
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	Land, trans							
	Land, int							
GLO	Land	use of land			use of land			

Emissions

		Country 1 Industries	Tra	**Int**	Country 2 Industries	Tra	**Int**	GLO Mar
LUC	CO_2							
LUC	**N_2O**							

Integration of iLUC in EXIOBASE (3 of 4)

- **Supply of land**
  - Transformation (one per country)
  - Intensification (one per country)
  - Market for land (one global)
- **Use of land**
  - All uses of land link to global market

Supply table

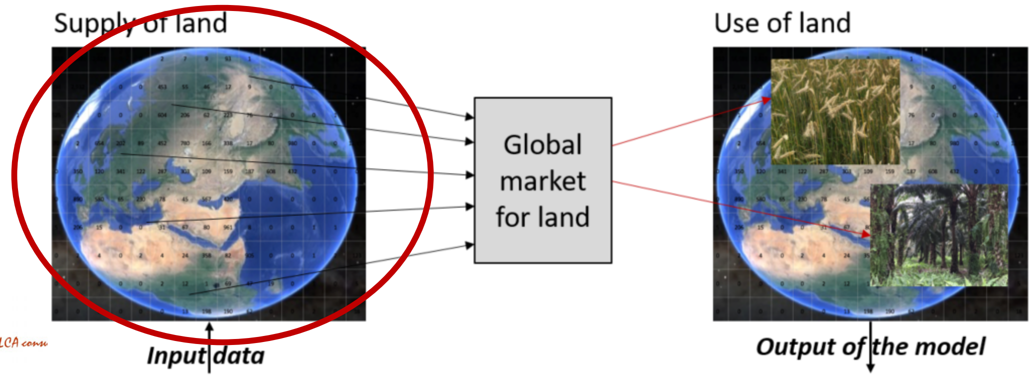
		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
Country 1	Products							
	Land, trans							
	Land, int							
Country 2	Products							
	Land, trans							
	Land, int							
GLO	**Mar**							

Use table

		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
Country 1	Products							
	Land, trans							
	Land, int							
Country 2	Products							
	Land, trans							
	Land, int							
GLO	Land	**use of land**			**use of land**			

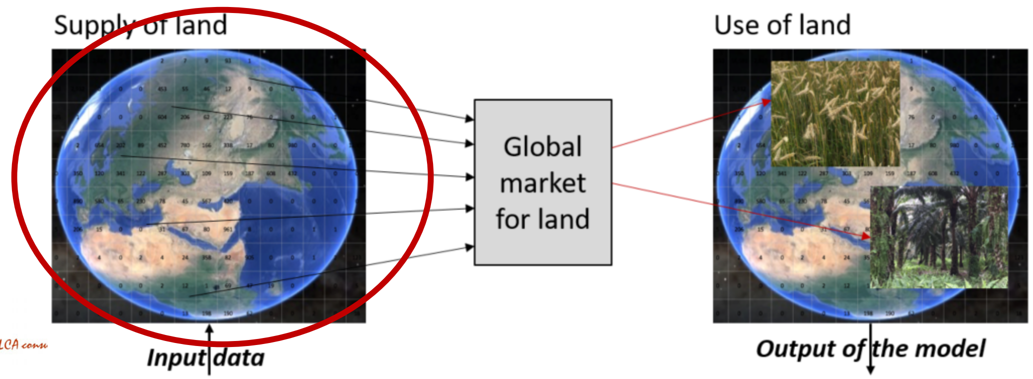
Emissions

		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
LUC	CO_2							
LUC	N_2O							



Integration of iLUC in EXIOBASE (4 of 4)

- **Supply of land**
  - Transformation (one per country)
  - Intensification (one per country)
  - Market for land (one global)
- **Use of land**
  - All uses of land link to global market



Supply table

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	Land, trans							
	Land, int							
GLO	Mar							

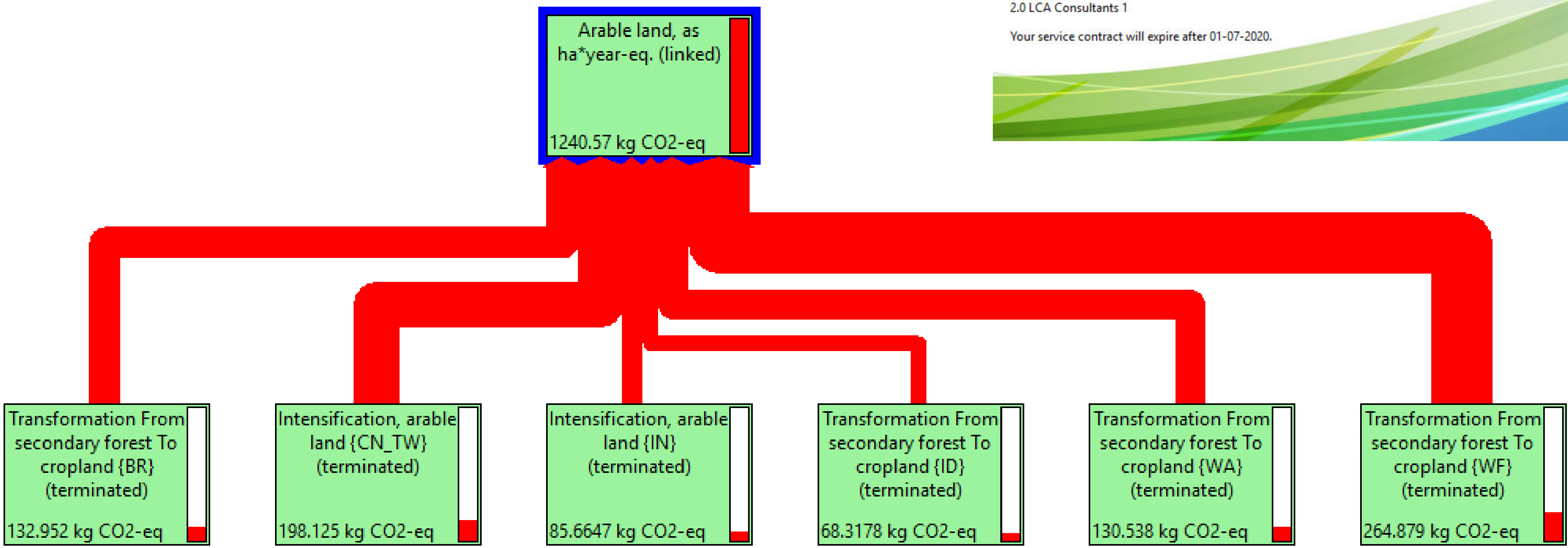
Use table

		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
Country 1	Products							
	Land, trans							
	Land, int							
Country 2	Products							
	Land, trans							
	Land, int							
GLO	Land	use of land			use of land			

Emissions

		Country 1 Industries	Tra	Int	Country 2 Industries	Tra	Int	GLO Mar
LUC	CO_2							
LUC	N_2O							

Market for land: 1 ha yr arable land (world average)



Market for land: 1 ha yr arable land (world average)

Flows

Name: Arable land, as ha*year-eq. (linked)

Contribution: 0 | 0 %

Inflows (41)	Flow	Unit
Total	1240.57	kg CO2-e
Transformation From secondary forest To cropland {WF} (terminated)	264.879	kg CO2-e
Intensification, arable land {CN_TW} (terminated)	198.125	kg CO2-e
Transformation From secondary forest To cropland {BR} (terminated)	132.952	kg CO2-e
Transformation From secondary forest To cropland {WA} (terminated)	130.538	kg CO2-e
Intensification, arable land {IN} (terminated)	85.6647	kg CO2-e
Transformation From secondary forest To cropland {ID} (terminated)	68.3178	kg CO2-e
Intensification, arable land {WA} (terminated)	54.1957	kg CO2-e
Transformation From secondary forest To cropland {IN} (terminated)	44.5362	kg CO2-e
Intensification, arable land {BR} (terminated)	42.7122	kg CO2-e
Transformation From secondary forest To cropland {CN_TW} (terminated)	39.8631	kg CO2-e
Transformation From secondary forest To cropland {WL} (terminated)	35.9921	kg CO2-e
Intensification, arable land {WF} (terminated)	28.2936	
Intensification, arable land {US} (terminated)	26.3771	
Intensification, arable land {ID} (terminated)	21.1271	
Intensification, arable land {WL} (terminated)	16.0874	
Transformation From secondary forest To cropland {AU} (terminated)	15.3878	
Intensification, arable land {WE} (terminated)	13.8208	
Intensification, arable land {RU} (terminated)	6.13298	
Transformation From secondary forest To cropland {WE} (terminated)	4.68031	kg CO2-e
Transformation From secondary forest To cropland {RU} (terminated)	3.33006	kg CO2-e
Transformation From secondary forest To cropland {WM} (terminated)	3.05101	kg CO2-e
Transformation From secondary forest To cropland {FR} (terminated)	1.13644	kg CO2-e
Intensification, arable land {LT} (terminated)	0.803806	kg CO2-e

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Contribution	GWP100	Resp. inorg.	Nature occ.
Transformation	60%	0%	100%
Intensification	40%	100%	0%

ILCA International Life Cycle Academy

Market for land: 1 ha yr forest land (world average)

exiobase v3.3.16b2

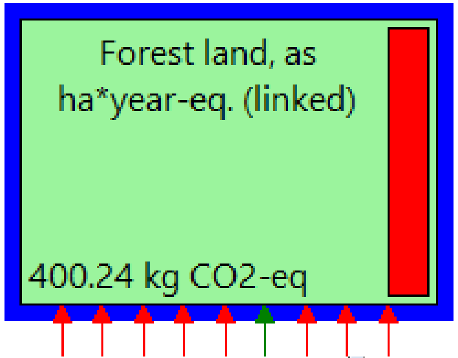
SimaPro

Developer
with Share & Collect

Release 9.0.0.49

2.0 LCA Consultants 1

Your service contract will expire after 01-07-2020.

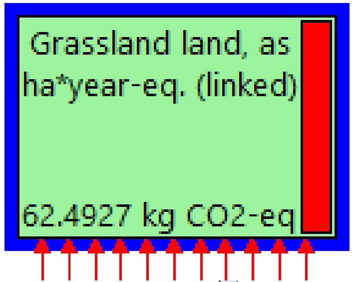


Name: Forest land, as ha*year-eq. (linked)

Contribution: 0 | 0 %

Inflows (37)	Flow	Unit
Total	400.24	kg CO2-e
Transformation From primary forest To managed forest {WA} (terminated)	109.938	kg CO2-e
Transformation From primary forest To managed forest {WF} (terminated)	86.6657	kg CO2-e
Transformation From primary forest To managed forest {BR} (terminated)	78.4189	kg CO2-e
Transformation From secondary forest To managed forest {WA} (terminated)	73.6732	kg CO2-e
Transformation From secondary forest To managed forest {ID} (terminated)	69.3673	kg CO2-e
Transformation From primary forest To managed forest {ID} (terminated)	46.1193	kg CO2-e
Transformation From secondary forest To managed forest {BR} (terminated)	42.0654	kg CO2-e
Transformation From secondary forest To managed forest {CN_TW} (terminate	27.7012	kg CO2-e
Transformation From primary forest To managed forest {WL} (terminated)	24.9523	kg CO2-e
Transformation From secondary forest To managed forest {AU} (terminated)	16.9694	kg CO2-e
Transformation From secondary forest To managed forest {TR} (terminated)	10.1221	kg CO2-e
Transformation From secondary forest To managed forest {IN} (terminated)	8.59951	kg CO2-e
Transformation From primary forest To managed forest {AU} (terminated)	4.56334	kg CO2-e
Transformation From secondary forest To managed forest {JP} (terminated)	1.93607	kg CO2-e
Transformation From secondary forest To managed forest {SE} (terminated)	1.46704	kg CO2-e
Transformation From secondary forest To managed forest {IT} (terminated)	1.04499	kg CO2-e
Transformation From primary forest To managed forest {BG} (terminated)	0.697472	kg CO2-e
Transformation From secondary forest To managed forest {NO} (terminated)	0.638964	kg CO2-e
Transformation From secondary forest To managed forest {GR} (terminated)	0.213984	kg CO2-e
Transformation From primary forest To managed forest {CA} (terminated)	0.205374	kg CO2-e
Transformation From secondary forest To managed forest {PT} (terminated)	0.0735356	kg CO2-e

Market for land: 1 ha yr grass land (world average)



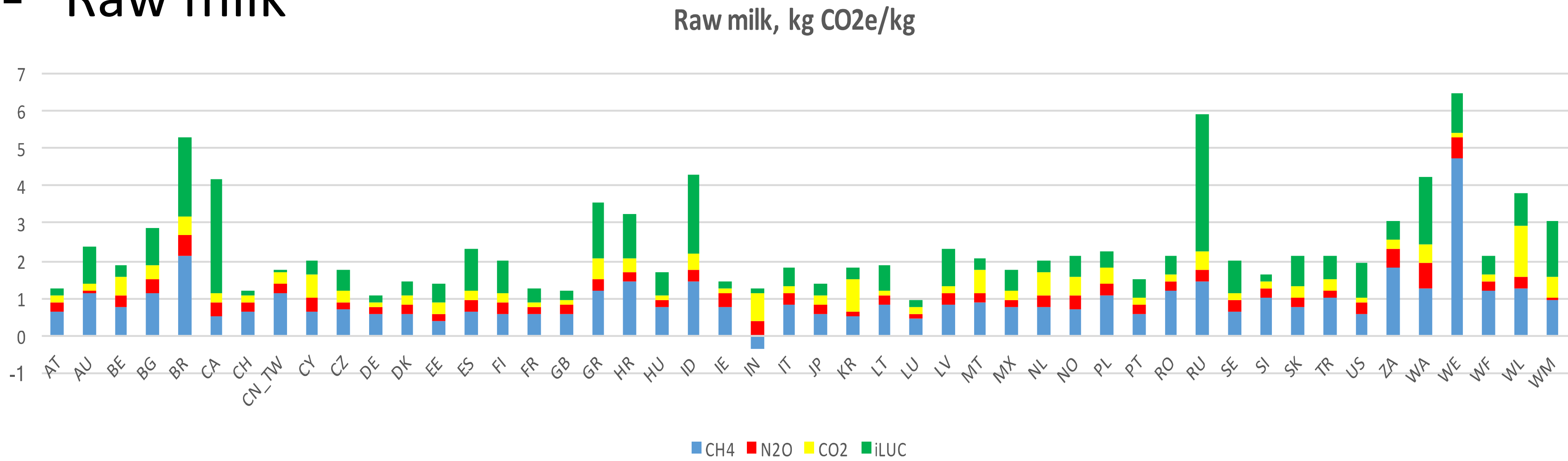
Name: Grassland land, as ha*year-eq. (linked)

Contribution: 0 | 0 %

Inflows (24)	Flow	Unit
Total	62.4927	kg CO2-e
Transformation From grassland To pasture {US} (terminated)	23.9839	kg CO2-e
Transformation From grassland To pasture {WL} (terminated)	17.6819	kg CO2-e
Transformation From grassland To pasture {WF} (terminated)	15.1361	kg CO2-e
Transformation From grassland To pasture {RU} (terminated)	3.28549	kg CO2-e
Transformation From grassland To pasture {PT} (terminated)	0.713007	kg CO2-e
Transformation From grassland To pasture {IE} (terminated)	0.481235	kg CO2-e
Transformation From grassland To pasture {IT} (terminated)	0.437004	kg CO2-e
Transformation From grassland To pasture {MX} (terminated)	0.247695	kg CO2-e
Transformation From grassland To pasture {EE} (terminated)	0.199925	kg CO2-e
Transformation From grassland To pasture {HR} (terminated)	0.161709	kg CO2-e
Transformation From grassland To pasture {LV} (terminated)	0.0707699	kg CO2-e
Transformation From grassland To pasture {CZ} (terminated)	0.0406927	kg CO2-e
Transformation From grassland To pasture {NO} (terminated)	0.028308	kg CO2-e
Transformation From grassland To pasture {FI} (terminated)	0.0123847	kg CO2-e
Transformation From grassland To pasture {LU} (terminated)	0.00467081	kg CO2-e
Transformation From grassland To pasture {CY} (terminated)	0.00442312	kg CO2-e
Transformation From grassland To pasture {KR} (terminated)	0.00353849	kg CO2-e

Results

- Raw milk



- iLUC increases the GHG emissions with:
  - agricultural crops 100-200%
  - beef cattle 20-60%
  - pigs 40-80%
  - dairy products 40-60%
  - wood products 50-300%
  - primary plastics 2-15%

Examples of application

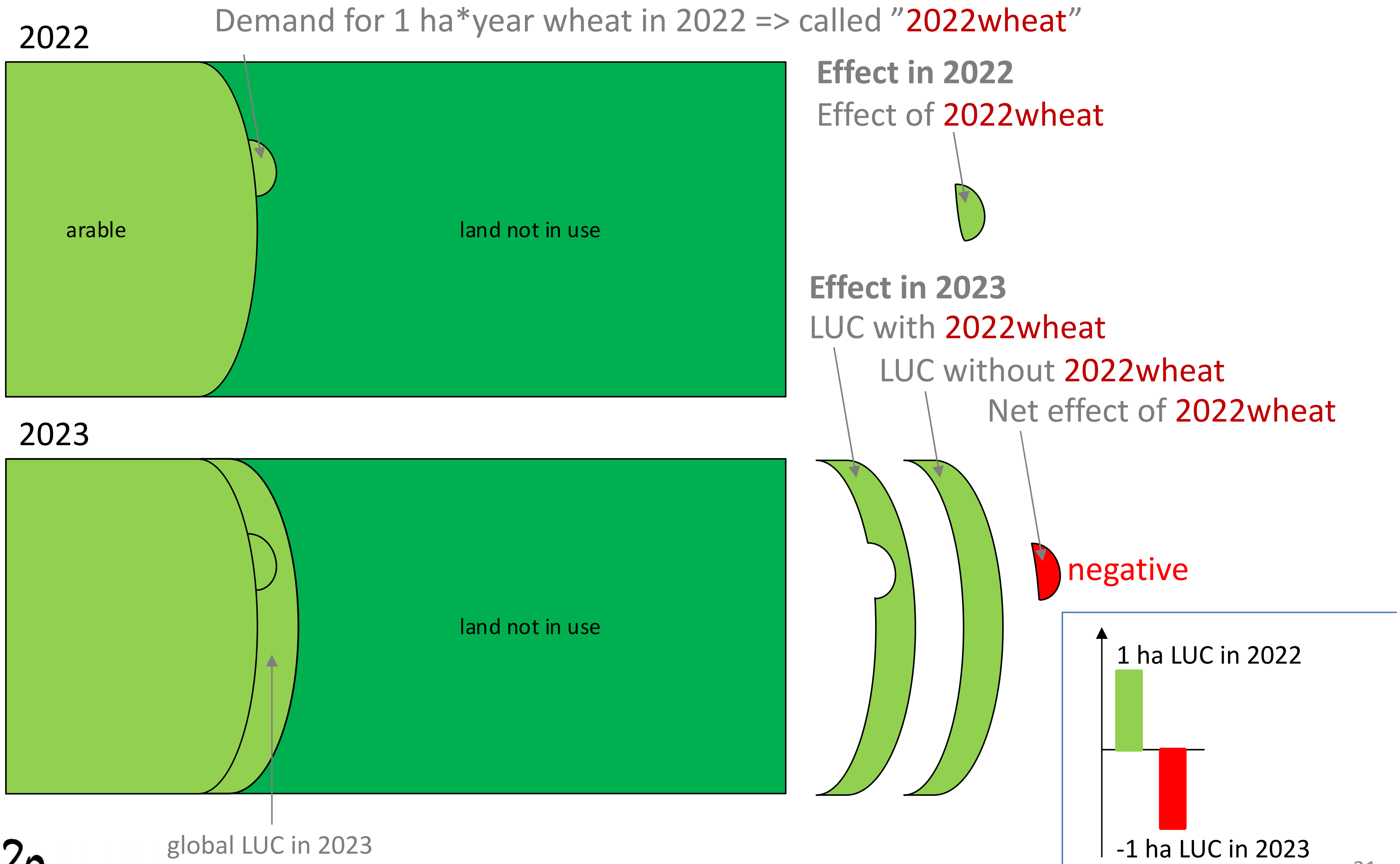
- Vegetable oils (palm, rapeseed, sunflower, peanut, soybean)
- Milk (Germany, Denmark, Sweden and United Kingdom)
- Chicken
- Specialty food ingredients
- Canteens (eco-labelled and conventional)
- Nature conservation in Kalimantan
- Global food consumption
- Biofuels (liquid and solid)
- Electricity models
- Structural timber
- Aggregates
- Buildings
- Apparels
- Corporate footprints for large, multinational companies, e.g. Arla Foods, Novo Nordisk, Nordic Alcohol Monopoly, and many others
- Danish consumption footprint
- Municipal level production and consumption footprint
- Global input-output table (the model is integrated in a special version of Exiobase v3)
- And many more...

All examples can be accessed here:
https://lca-net.com/projects/show/indirect-land-use-change-model-iluc/

Timing issues related to iLUC

- LCIA: Global warming

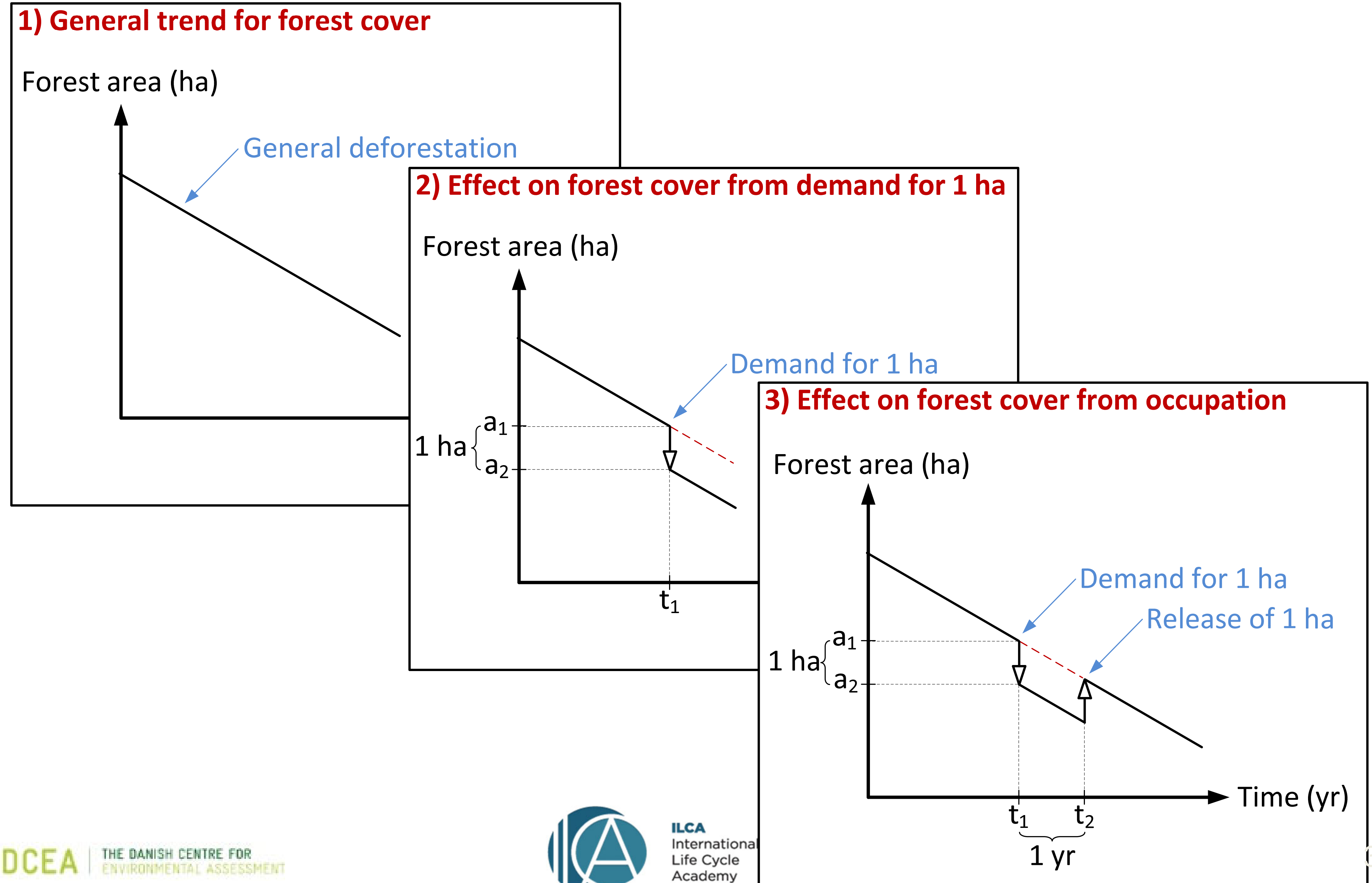
Transformation of land
- How to deal with timing issues?



Occupation and transformation

- Accelerated deforestation

Effect of occupation (1 ha yr)



GHG effect of timing of emissions
IPCC's global warming potential (GWP)

- Originally used to differentiate different GHG-emissions (unit: CO_2-eq)

$$GWP_i = \frac{\int_0^{TH} RF_i(t)dt}{\int_0^{TH} RF_{CO_2}(t)dt}$$

- TH = time horizon
- RF = Radiative forcing (W/m^2)

GHG effect of timing of emissions
IPCC's global warming potential (GWP)

- Effect of accelerating deforestation = emitting CO_2 emissions in year 0 instead of year 1:

$$GWP_{CO2,\Delta t} = \frac{\int_{\Delta t}^{100} CO_{2,fraction}(t-\Delta t)dt}{\int_{0}^{100} CO_{2,fraction}(t)dt}$$

$GWP_{CO2,\Delta t=0} = 1$
$GWP_{CO2,\Delta t=1} = 0.9922$

Effect of emitting 1 kg CO_2 in year 0 instead of year 1:

$GWP100_{CO2,t=1\rightarrow 0}$
$= 1 - 0.9922$
$= 0.00783$ kg CO_2-eq.