A Model of Indirect Land Use Change

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ABSTRACT

Around 9% of global carbon emissions in 2010 originated from deforestation. Often, these emissions are not appropriately addressed in life cycle assessment (LCA). The link between demand for land in one region and deforestation in other regions is referred to as indirect land use changes (iLUC). Existing models for iLUC most often operate with arbitrary amortisation periods to allocate deforestation emissions over time, and the causal link between land occupation and deforestation is generally weekly established. This paper presents an iLUC model where amortisation is avoided by use of IPCC's global warming potential. The causal link between demand for land and land use changes is well established through markets for land. The land use effects include changes in land cover, i.e. deforestation, as well as intensification of land already in use. The presented iLUC model is applicable to all types of land, all crops and in all regions of the world.

Keywords: indirect land use changes, iLUC, consequential, attributional, land use change transition matrix

1. Introduction

According to Peters et al. (2012), around 9% of global carbon emissions in 2010 originated from deforestation. Often, these emissions are not addressed in life cycle assessment (LCA) because the causal link between the use of land and deforestation is not well described and because there is a missing consensus on how to establish this link. Further, several studies suggest that effects from intensification of cropland may be caused by changes in demand for land. In the following a new model and data for establishing the causal link between the use of land and the effects on land use changes and intensification are presented. Here, this link is referred to as indirect land use changes (iLUC).

iLUC is defined as the upstream consequences of the occupation of land, regardless of what you do to it. Whereas indirect land use changes are upstream life cycle impacts of an activity which induces the land use change, direct land use changes take place only in the land transforming activity. It should be noticed that the upstream effects, i.e. deforestation and intensification, of occupying land in one region of the world are likely to take place in other parts of the world.

The model is based on the assumption that current demand for land causes current land use changes. The market for land is defined as a service that supplies capacity for production of biomass. This market has inputs from different suppliers, e.g. land already in use, expansion of land (which may cause deforestation) and intensification. The presented model is applicable to all regions in the world and to all types of land use. The standard reference flow for the use of land, 'land tenure', is the land's potential production capacity, measured as the potential net primary production, NPP_0 (in unit kg carbon). This can easily be converted to occupation in units of hectare years (ha yr), e.g. by use of data in Haberl et al. (2007). The concept is illustrated in Figure 2.

The starting point of the model is an inventory of the total global observed land use changes. The accounting framework for this is a land use change transition matrix, see Table 2. The land use change transition matrix is mainly based on FAO's Global Forest Resources Assessment (FAO 2010). Distinction is made between different markets for land; land suitable for arable cropping, land suitable for forestry, land suitable for rangeland, and other land (barren, deserts, ice caps etc.). The land tenure market activities have four types of inputs: land already in use, expansion, intensification and crop displacement. The emissions related to deforestation and intensification are based on IPCC (2006) and Schmidt (2008) respectively. The inventory framework allows for the application of consequential and attributional modelling assumptions. Time related effects are addressed by use of a fate function of CO_2 pulse emissions in the atmosphere opposed to the amortisation approach which is typically used in iLUC models.

2. Methods

2.1 Goal and scope

The purpose of the presented iLUC model is to provide a life cycle inventory of the upstream consequences of land occupation. These consequences include land transformation as well as intensification. The model is applicable to all types of land in all regions of the world for all types of crops regardless of what they are used for; food, biofuel, fiber or other.

The model is applicable to so-called small scale changes, i.e. changes that do not change overall market trends (Weidema et al. 2009). An example of a large scale change would be if the change under study required a considerable share of the remaining land available for arable cropping so that the ratio between expansion and intensification would be affected. It should be noted that a large scale change would require really large changes in demand for land; more than most current biofuel policies imply. Large scale changes needs to be analysed specifically by use of scenario modelling.

The model only includes long-term changes in supply caused by a change in demand. Hence, short-term effects on prices and subsequent price-elasticity effects are not included. This implies that reduced food consumption as a result of increased demand for land is not included.

2.2 Functional unit

Activities which include occupation of land obviously need a specified area in a specified period of time. This can be measured in hectare years (ha yr). An LCA market activity is defined in order to model this. This activity is called ‘Market for land tenure’. It is the inputs and outputs of the market for land tenure that is the modelling of iLUC. An obvious option for a reference flow of a land tenure activity would be occupation of land (ha yr). However, this approach does not take into account that the potential production on 1 ha yr land in e.g. a dry temperate climate is very different from the potential in wet tropical climate. This could be overcome by operating with a kind of productivity weighted occupation of land. Another option would be the potential net primary production (NPP_0), measured in unit of kg carbon. Since the latter provides a simple way to include land with different productivities, this option is chosen. Thus, the reference flow of the LCA activities that supply land tenure is defined as the contribution to the production capacity. This can be interpreted in parallel to a production facility’s capacity to produce a product. It is up to the current production facility to utilise the capacity, like e.g. a 400 MW power plant has the capacity to produce 400 MW, but most often the installed capacity is not fully utilised. In the case of a land-using activity, it is up to the land-using activity to utilise the land’s capacity to produce biomass. Hence, the functional unit (or reference flow) of the land tenure market activity is defined as of Table 1.

It should be noted that the current iLUC model covers all regions in the world. Some areas have very low or even zero potential net primary production. This is valid for barren land, deserts, ice caps, high mountains etc. Since the productive function of these lands cannot be production of plant material, NPP_0 is not a feasible reference flow. Instead, the reference flow is measured in units of area*time. The environmental impacts from transforming these lands into e.g. urban area or mining sites is not associated with changes on below and above ground carbon (which causes GHG-emissions) and the effect on biodiversity, measured as the absolute number of species affected, is very limited.

Table 1. Functional unit of the land tenure market.

Functional unit
Productive land (plant material): The functional unit is defined in terms of potential net primary production (NPP_0) as 1 kg C. The reference flow of the land tenure market activity is ‘biomass production capacity, measured in kg NPP_0’. Data on potential net primary production (NPP_0) in different parts of the world can be obtained from Haberl et al. (2007, SI figure 2).
Other land: Another functional unit has been used for the land tenure market ‘other land’, which includes barren land, deserts, ice caps, high mountains etc. The functional unit is defined as 1 ha yr, and the reference flow is measured in units of area*time.

2.3 System boundaries, causalities and time perspectives

To understand the concept of iLUC, it must be realised that there are two types of land use change, i.e. direct land use changes (dLUC) and indirect land use changes (iLUC). dLUC is defined as the consequences of what you do to the land that you occupy. These effects take place within the same LCA activity that uses (occupy) the land. iLUC is defined as the upstream consequences of the occupation of land, regardless of what you do to it. These effects have previously been called the competition effect (Lindeijer et al. 2001). The iLUC and dLUC are illustrated in Figure 1. In Figure 1, the area “a” is occupied by the product under study. Figure 1 shows two situations; left illustrates the situation when the product under study is not demanded/produced, and right illustrates the situation where the product is demanded/produced. The situation in the right side obviously requires some land occupation (“a”) in the country where the product is produced.

This is illustrated as a_{after}. The difference between a_{before} and a_{after} illustrates the direct land use effects. Often the dLUC only involves replanting of existing arable land, or other shifts between land use types which are already in use. The land use change related emissions of this are most often insignificant. However, drainage of organic soils which is included in dLUC is significant in terms of GHG-emissions. This paper does not focus on dLUC. When a_{before} is transformed to a_{after} the net output of the land in the affected country is reduced from 10 t to 9 t (quantities are just for illustration). To compensate for this reduction, new production capacity is needed. This is illustrated as the transformation from b_{before} to b_{after}. b_{before} represents a situation where the land is not in use. The transformation of the area b often involves deforestation, and this is what is referred to as iLUC. Notice that iLUC is illustrated as transformation of land only; as it is described later in this paper, iLUC also include intensification and crop displacement.

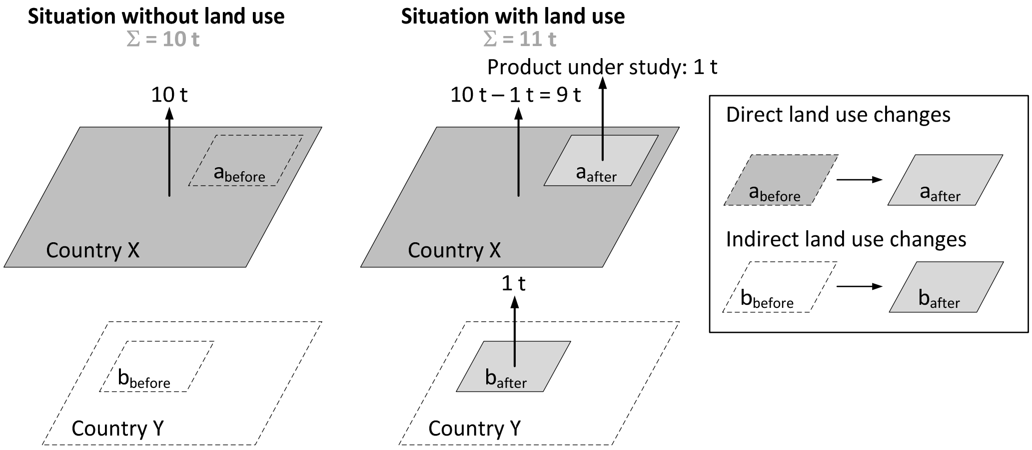

Figure. 1: Illustration of direct and indirect land use changes. The land under study is the area “a”. To fully account for land use changes, the sum of direct and indirect land use changes shall be included.

The overall concept of the model is that it is assumed that the current use of land reflects the current demand for land, and that land use changes are caused by changes in demand for land. This concept is equivalent to all other modelling in life cycle inventory, i.e. the demand for a product determines the production volume. The market for land is defined as a service that supplies capacity for production of biomass. This capacity can be obtained from the market, which has inputs from different suppliers, e.g. expansion of land (such as deforestation) and intensification.

The link between LCA activities that occupy land and the land use changes is established via the markets for land, and indirect land use changes are modelled as upstream inputs to the product system. The upstream effects (indirect land use changes) related to the occupation of land are illustrated in Figure 2. Notice that all inflows to the land tenure LCA activity are measured in kg NPP_0 (as kg C). This is explained further in section 2.5.

When the occupation of land causes deforestation, a critical point is often to decide the period of time, the deforestation emissions should be 'amortised' over. The current model does not operate with amortisation. If only expansion is considered, occupation of 1 ha in 1 year will cause 1 ha deforestation. After the duration of 1 yr, the land is given over to other crops, which can then be grown without deforestation. Hence, the occupation of 1 ha yr is modelled as 1 ha deforestation in year 0 and -1 ha deforestation in year 1. The Bern Cycle, which represents the fate of a CO_2 pulse emission and which is used to calculate the global warming potential (GWP100), is used to calculate the GWP100 associated with speeding up deforestation as referred to above.

The model enables for operating with consequential and attributional modelling assumptions. The difference between the two approaches is here defined as; attributional modelling includes the average of all suppliers to a market for land whereas consequential modelling excludes constrained suppliers. Therefore, the difference is that the consequential inventory only includes inputs of expansion and intensification (see Figure 2), whereas the attributional inventory also includes inputs from land already in use.

2.4 Segmentation of the land tenure market, five land markets

The relevant functions of land to be modelled is the land’s ability to produce products, i.e. crops, grass and wood, and the function to provide area for human structures, i.e. buildings, infrastructure and production facilities such as mines. When forests and human structures occupy land suitable for agriculture, it will have similar land use related effects as when crops are grown, because it is related to the acquisition of the same type of land. The following five distinct markets for land are considered (All land tenure markets can be used for urban, industrial or infrastructure area):

- Extensive forest land: not fit for more intensive forestry (e.g. clear cutting and reforestation), e.g. because it is too hilly, too remote, or it is growing on very infertile land making intensive forestry uneconomic. Forests grown on extensive forestland are typically harvest after natural regrowth with mixed species.
- Intensive forest land: fit for intensive forestry (e.g. clear cutting, reforestation, species control etc.), but not fit for arable cultivation because the soil cannot be treated for arable cultivation, e.g. because the soil is too rocky. Forests grown on intensive forestland may be managed as intensive or extensive forestry. Intensive forest land may also be used for other land use, e.g. livestock grassing and extensive forestry.
- Arable land: fit for arable cultivation (annual crops and perennial crops). Arable land may be used for cultivation of annual or perennial crops, for intensive or extensive forestry, and pasture.
- Rangeland: too dry for forestry and arable cultivation. Therefore, when in use, rangeland is most often used for livestock grassing.
- other land: not fit for biomass production; barren land, deserts, ice caps, high mountains etc.

It should be noted that the above mentioned land markets are regarded as separate markets for land, i.e. acquisition for a specific type of land is not associated with upstream effects on the other land use types. This is also the reason that the term ‘not fit for agriculture’ is added to forest land; if forest is grown on agricultural land then the upstream effects will be caused by the effect on the crop cultivation on this land.

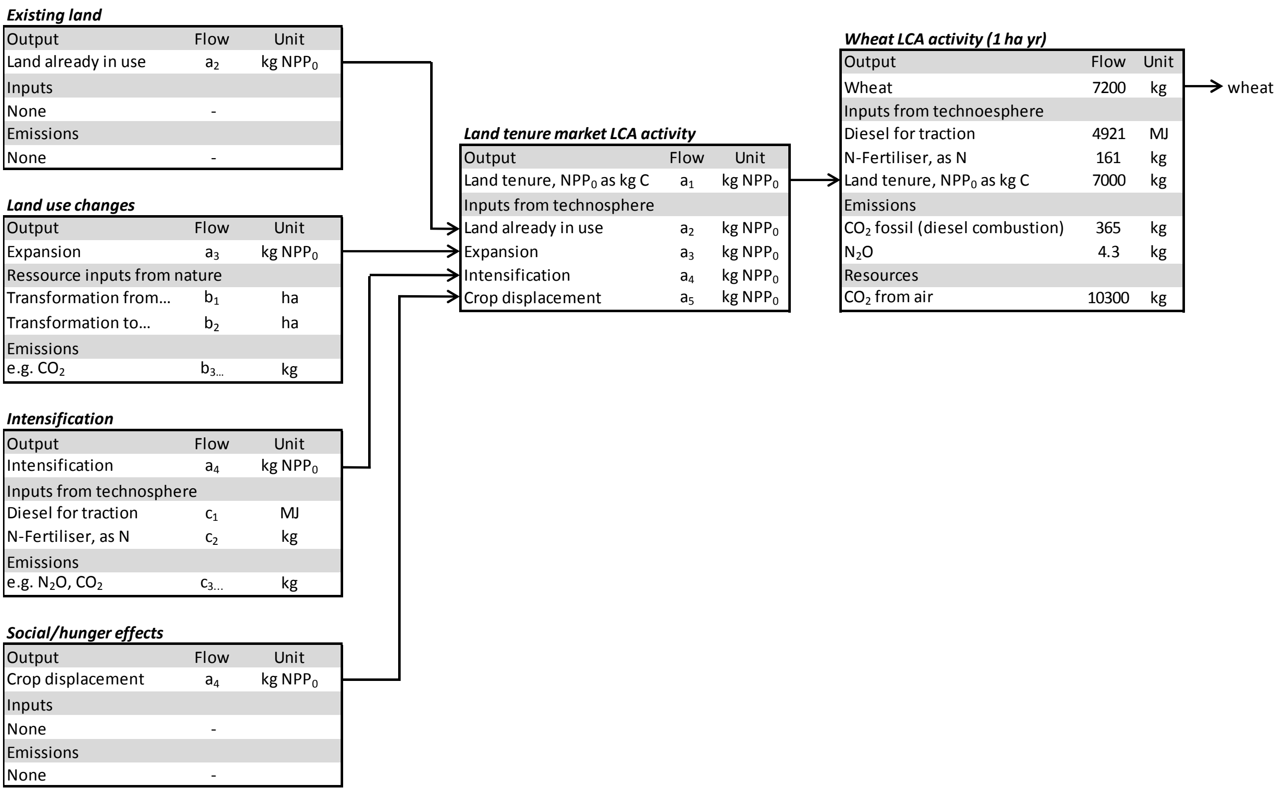

Figure 2. Illustration of the land tenure market activity and it’s inputs and outputs. An agricultural activity, here wheat, has inputs from the land tenure market activity. The land tenure market activity has inputs from four different supplies of biomass production capacity. Each of these suppliers is associated with emissions. The sum of these emissions is referred to as iLUC emissions.

2.5 Life cycle inventory data

As illustrated in Figure 1, the land tenure market LCA activity has inputs of land already in use, expansion, intensification, and crop displacement. The LCA activity ‘Land already in use’ is not associated with any inputs or emissions because this land’s production capacity is already established, and because maintenance of this capacity is inventoried as emissions belonging to the agricultural activity that occupies the land. The activity ‘Expansion’ has emissions of CO_2 and N_2O associated with land transformation (most often deforestation). The emissions are determined based on the land use change transition matrix presented in Table

2 combined with data on above and below ground carbon stocks in IPCC (2006, chapter 4, 5 and 6) and N_2O model in IPCC (2006, chapter 11). By-products as timber and emissions related to diesel etc. in the deforestation activity are not included in the current version of the iLUC model. The activity 'Intensification' has inputs of fertilisers and traction, and emissions associated with the fertiliser. The inventory data of intensification are described further in Schmidt (2008). The activity 'Crop displacement' (not included in the iLUC model) has no inputs or emissions. If the activity was included, inventory items related to social impacts should be considered.

All inflows to the land market tenure activity are measured in kg NPP_0 (as kg carbon). The NPP_0 from land already in use and expansion are determined based on general NPP_0 per ha yr figures (Haberl et al. 2007) and figures on total area of land already in use and annual deforestation (FAO 2010; FAOSTAT 2011). The NPP_0 from intensification is calculated as the carbon in crop produced via intensification during one year. The intensification is determined based on crop dose-response figures for fertiliser input (Schmidt 2008) combined with information on which crops and where intensification takes place (data from FAOSTAT 2011) and current fertiliser levels for these crops (IFA 2011).

Table 2. Land use change matrix, unit: million ha. The global land use transition matrix is established for an average year in 2000-2010. The top column headings divide the total land into land not in use and land in use. For the land in use there are four land tenure markets. The growth of these markets, which involves deforestation and land degradation, can be seen as inputs in the rows. (Schmidt et al. 2012)

Transformation to:	**Non use**			**Markets**				
	Primary forest	Secondary forest	Other (grassland, wetland and scrub-land)	Extensive forest land	Intensive forest land	Arable land	Rangeland	**Total land use ref. year**
Transformation from:								
Primary forest	1,102	0	0	1.09	0.084	3.02	0	**1,106**
Secondary forest	0.34	1,798	0	0	4.85	9.98	0	**1,813**
Other (grassland, wetland and scrubland)	0	1.30	3,769	0	0	0.60	1.88	**3,773**
Extensive forest	0	0	0	930	0	0	0	**930**
Intensive forest	0	0	0	0	196	0	0	**196**
Arable	0	0	0	0	0	1,624	0	**1,624**
Range	0	0	0	0	0	0	3,569	**3,569**
Total land use ref. year + 1	**1,102**	**1,799**	**3,769**	**931**	**201**	**1,638**	**3,571**	**13,012**

3. Results

Table 3 summarizes some results calculated with the iLUC model. The first column shows the affected region/country, the second column converts 1 ha yr to NPP_0. The last three columns presents the results divided into contributions from expansion and intensification.

Table 3. Results for the occupation of 1 ha yr of different land tenure markets (for global average). Further, in the lower part of the table example results are shown for arable land and rangeland in different countries in the world. Results are shown when applying the consequential modelling assumption.

Affected land market	**NPP_0, t C ha-1 yr-1**	**Result, consequential**		
		Expansion, t CO_2-eq.	**Intensification, t CO_2-eq.**	**Total, t CO_2-eq.**
Global averages for 1 ha yr				
Arable	6,110	1,010	6,820	**7,830**
Forest int.	7,220	3,340	-	**3,340**
Forest ext.	7,220	1,670	-	**1,670**
Range	4.860	1,160	-	**1,160**
Examples of country specific results for 1 ha yr				
Arable, Malaysia	12,000	2,000	13,400	**15,400**
Arable, Denmark	7,000	1,170	7,800	**8,970**
Arable, Brazil amazonas	9,000	1,500	10,000	**11,500**
Range, Brazil Cerrado savannah	5,000	1,190	-	**1,190**

Table 3 only shows results using the consequential modelling assumption. If the attributional modelling assumption is applied, the results for arable land will be around 4% of the results for consequential. Similarly, the results for forestland and rangeland are significantly lower. The reason for this is that in the attributional modelling a large market share of the inputs to the land tenure market is comprised by 'land already in use' which is not associated with any emissions.

4. Discussion and conclusion

This paper presents a model of iLUC. The model has the following characteristics; it includes effects on deforestation and intensification, allocation of deforestation emissions using a chosen amortisation period is avoided, the model is applicable to any land use type in any location, and the model can handle both consequential and attributional modelling assumptions.

The results show significant iLUC effects on global warming; crops with yields 5-7 t/ha yr grown on average yielding land will be associated with iLUC effects at 1 to 1.5 kg CO2-eq./kg crop. For many arable crops this means a factor 2-4 increase in GHG-emissions. For arable land the effect from intensification comprises around 87% of the total iLUC where the remaining is related to deforestation. The iLUC from forestry and rangeland are also significant. Here no intensification is considered. For forestland, the emissions are caused by transformation of natural forest to cultivated forest, and for rangeland, the emissions originate from transformation of natural savannah/scrub to grassland.

The major uncertainties in the model are a) the market for land is assumed to be global, b) the determination of NPP_0 as of Haberl et al. (2007) is relative coarse grained, so 10-15% uncertainty is associated with reading maps which only show intervals, c) the determination of the relative distribution of inputs of expansion and intensification to the land tenure market is associated with uncertainties since it is based on indirect estimation methods, d) the modelling of intensification as of Schmidt (2008) only considers additional NPK fertiliser as an affected mean of intensification, and e) also the dose-response effects in Schmidt (2008) of crop-yields relative to additional fertiliser are associated with uncertainties.

Despite the uncertainties listed above, the model results are regarded as being within reasonable uncertainty intervals. It should be noticed, that the model concept is open for improved data input at almost any level. This means that the presented model can be seen as a proposal for solving the conceptual challenges with the modelling of iLUC, and that future improvements of the model will focus on improving input data.

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