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Attributional land use (aLU) and attributional land use change (aLUC)

A new method to address land use and land use change in life cycle assessments

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In this ifeu paper, the institute publishes its position on a cross-sectional scientific topic with societal relevance and aims to promote scientific discourse. The authors welcome feedback on the content.

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Content

1 Overview

Land use change and the associated changes in carbon inventories have played an important role in life cycle assessments of agricultural and forestry products for many years. The most common approaches to attribute consequences of land use change (LUC) to individual products in LCA are the methodological approaches dLUC (direct Land Use Change) and iLUC (indirect Land Use Change). However, both methods require a value-based selection of critical input parameters. This impedes the acceptance of recommendations based on such LCA results in practice.

This ifeu paper describes the method for calculating attributional land use change (aLUC) and associated attributional land use (aLU) for use in life cycle inventories and life cycle assessments, which addresses these limitations. This method was developed to be able to assign concrete inventory data on land use change to a product such as palm oil, regardless of a value-based selection of write-off periods, the availability of supply chain information (see dLUC) and regardless of market-related drivers (iLUC) that can never be unambiguously determined.

In addition to detailed background information, it is explained in the beginning what distinguishes it from the frequently discussed approaches of direct (dLUC) and indirect (iLUC) land use change (Chapter 2). In short, according to the aLULUC approach, all emissions from land use change and organic soils in a reference period and area are allocated to all uses of arable or grassland in that period and area. In most cases, it is appropriate to choose a country-specific allocation and a period of 10 years for averaging (but not depreciation). This results in an emission factor that allocates actual and measurable emissions in a defined agricultural area (reference area) to all producers in that agricultural area.

Chapter 3 describes in detail how emission factors for aLUC are determined; Chapter 4 explains the same for aLU. Subsequently, normalisation and application are discussed (Chapter 5 and 6). For the practical application, country-specific emission factors of the aLULUC method are provided in the Annex.

2 Background

2.1 Environmental impacts of land use change

2.1.1 Why another approach to land use change determination?

Land use change (LUC) describes the relative change in the use or management of an area compared to a previous use of the same area and the associated emissions (or emission avoidance) [German Environment Agency 2018]. This change in land use can have both direct and indirect consequences. The methodological categories dLUC (direct Land Use Change) and iLUC (indirect Land Use Change) have become established in practice for their determination. The decisive factor for the question of which approach is the "right" one is the scope and the object of the study to be evaluated. This can include the overall climate balance of a country, the traceable direct consequences of a specific product in its supply chain (dLUC) or the indirect consequences of a change in

the market, e.g. triggered by the specific support of a specific product such as biofuels (iLUC). The implications of each way of determining LUC are discussed in section 2.1.2.

The issue of land use change and the associated impacts, including on climate protection, is discussed in particular in connection with the use of palm oil-based products, because the increase in palm oil plantations in tropical countries is associated with the clearing of carbon-rich rainforests and the associated emissions of greenhouse gases (GHG emissions). This relationship has been the subject of life cycle assessments for several years [Reinhardt et al. 2007] and also influences current EU legislation[1].

The question is: Which approach is suitable for the application in life cycle assessment in order to be able to assign concrete inventory data on land use change to a product such as palm oil, irrespective of the existence of supply chain data (see dLUC) and irrespective of political or market-related drivers (iLUC)? The methodology of aLUC was developed for this purpose as an operationalisable parameter to be able to assign emissions caused by land use changes to a good or service.

Due to its close relationship to the Climate Convention, LUC is always addressed in the context of greenhouse gas emissions accounting. From the perspective of the life cycle assessment, however, land use change also affects other environmental categories. In particular, land-related categories (natural environment, biodiversity) can also be assessed using the life cycle inventory method aLUC. However, no emission factors have yet been derived for this purpose.

2.1.2 Basic framework of LUC for GHG accounting

In the accounting of CO_2 emissions caused by land use change, a distinction is usually made between changes in the carbon stock in the biomass and in the soil. The change in land use affects the carbon stock of the biomass by removing the biomass associated with the previous use and thus releasing the carbon it contains[2]. This is compared with the carbon stock of the biomass associated with the new use. The carbon stock in the soil differs depending on the use, too. The use of the land as forest or grassland, for example, is usually associated with a higher carbon stocks in mineral soils than the use of the same land as arable land (see for this [German Environment Agency 2018 p. 530]).

The main approaches for calculating land use change are as follows:

- In the context of national reporting within the United Nations Framework Convention on Climate Change, as well as
- Within the framework of the sustainability requirements of the Renewable Energy Directive [European Parliament & Council of the European Union 2009] in the form of
  - direct land use change (dLUC) as well as
  - the indirect land use change (iLUC).

The approaches are briefly outlined in the following sections.

[1] DIRECTIVE (EU) 2018/2001, Article 26 No. 2: The quota for biofuels with a high iLUC risk that can be counted towards targets will be reduced to zero by 2030; this target was introduced by the EU Parliament and specifically targets palm oil.

[2] In the case of a longer-term material use of the biogenic carbon in products (e.g. construction timber, furniture), carbon stocks may be found elsewhere in the life cycle balance.

Land use change in the context of national reporting

With the Kyoto Protocol in 1997, changes in land use in the context of national greenhouse gas inventories were addressed for the first time. With the concept of sources and sinks, renewable carbon (carbon of biogenic origin as opposed to fossil carbon) and renewable carbon dioxide (or their net balance) were included in the category of climate-relevant gases.

The countries listed in Annex I to the Kyoto Protocol are obliged to carry out their accounting according to the approach described in the [IPCC 1996]. Land use changes are recorded at the national level and listed under the category Land Use, Land Use Change and Forestry (LULUCF). In Germany, the annual changes in the national carbon balance resulting from changes in land use are calculated using an equilibrium model. For this purpose, national areas are divided into forest, arable and grassland, (terrestrial) wetlands, settlements and other areas.

The national LULUCF balance thus not only reflects the official and realistic total emissions (or sinks) from land use, it also contains the data for the land use change itself as a basis for the calculation. It can be differentiated into the relevant land use types forest, arable land, grassland and raw material extraction areas. However, it is not possible to refer to products and services within the framework of the national LULUCF balance. This requires a precise allocation approach.

Direct land use change (dLUC)

Direct land use changes (dLUC) refer specifically to the actions of a producer. The term has gained relevance with the introduction of sustainability requirements for biofuels by the Renewable Energy Directive (RED) (RL 2009/28/EC) [European Parliament & Council of the European Union 2009]. For each delivery of a biofuel that can be counted towards to the blending quota, certification is required to prove whether the raw material originates from an area with land use change (after 2008) or not. If so, this must be included in the greenhouse gas balance.

In theory, dLUC would be able to accurately determine the actual LUC emissions from a product such as rapeseed diesel. After all, the official German register system for sustainable biomass systems (NaBiSy) maintained by the Federal Agency for Agriculture and Food (BLE) contains all GHG emissions data of biofuels from quota obligated parties that are counted towards the quota. However, this is not useful in practice for several reasons: Firstly, the aggregated data in the NaBiSy system and any LUC values contained therein are not easily available and are subject to data protection. On the other hand, it can be assumed that the biofuels included in the quota calculation in Germany are almost never associated with a change in land use among registered farmers. Moreover, data would only be available for biofuels, since certification does not apply to other options for the use of crops. Thus, dLUC is not the appropriate approach for the general determination of land use change factors for products and services.

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Indirect land use change (iLUC)

The crediting of a dLUC burden for products, for which special sustainability requirements apply, such as the RED example, is not sufficient to exclude land use changes caused by the policy supporting biofuels (blending quota). Irrespective of whether used as food, raw material for products or for energy purposes, an increase in the demand for biomass can also be assumed to increase the amount of land required. The "classic" way to cover an increasing demand for land is to convert land that was not previously used or used for other purposes. The fact that the production of a product induces a

change in land use elsewhere than where the actual production takes place physically is referred to as indirect land use change (iLUC).

The RED was amended by the iLUC Directive. However, the iLUC factors contained therein are not to be applied to individual product batches, but should only be included in the reporting of the fuel suppliers and the commission. iLUC factors are calculated by combining land use models with an economic equilibrium or partial system and are intended to estimate the overall impact of a targeted or shock-like increase in production on global land use. Since 2008, many of these estimates for biofuels have been published. [Fehrenbach 2014], among others, analysed and described the wide range of results depending on the choice of model.

The iLUC approach is therefore only of limited use in the context of life cycle assessment due to the disagreement among experts about the suitability and reliability of the various iLUC models. More decisive, however, is the following aspect: The consideration of indirect effects in life cycle assessments or for the carbon footprint is problematic primarily for reasons of consistency of system boundaries. The idea of the indirect effect presupposes that a product system interacts with another product system (or the entire economic system). Of course, nobody would deny the existence of these interactions, but they do not take place on a physical level, but on an economic level. The trigger of the effect is always an external measure. If one accounts for the effects of the measure (e.g. introduction of a 10 % blending quota for biofuels), then this does not result in the life cycle inventory of a certain biofuel, but that of the measure. This results in an assessment that can be used as decision support in the context of, for example, possible policy-supported product launches, but not in information about the status quo. [Finkbeiner 2013] also discussed these aspects in detail.

A further example should illustrate this problem: If one adds burdens from another product system to the life cycle inventory of a product, the question arises which life cycle inventory then applies to the product of the other system. For reasons of consistency, palm oil produced on deforested land, for example, would be free of LUC for the detergent market because this load is already attributed to biofuel via iLUC.

In short, if the entirety of products and services is to be represented, then the consistent allocation of indirect surcharges or discounts is an unsolvable task for reasons of system integrity. Thus the iLUC approach, as it is rightly discussed in biofuel policy worldwide and implemented in EU law (consistent assessment of a change), is not applicable to the life cycle assessment of all products/services (attributive assessment of the status quo).

2.1.3 The concept of attributional land use change (aLUC)

With which approach can LUC be handled in Life Cycle Inventories? A decisive premise is that land use changes to arable land take place in real terms, both in Germany (within agriculture mainly at the expense of grassland [BfN 2014]) and especially in countries with a high rate of deforestation. These land use changes are usually recorded and associated emissions are backed up with data. This includes one-time emissions from actual LUC and continuous emissions mainly from organic soils caused by LUC but occurring for many decades of land use (LU) that can only be stopped if land use is given up and appropriate protection measures are taken.

In the same systematic way as real emissions are attributed to the processes of a life cycle, real LUC processes can be attributed to the associated processes. However, even if actual land use changes can be clearly assigned to certain agricultural products, all agricultural products of a production area compete for limited availabilities on the local market for cropland. The reaction of the markets on e.g. the EU biofuels policy has shown that crops on and products from recently logged land (or from "LUC-free" land) can be flexibly allocated to customers according to their preferences.


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For that reason, a market-based attribution of LULUC related burdens to products produced on that land following the aLULUC concept is a more consistent representation of the underlying processes than a direct attribution following the dLUC concept. Three levels of attribution are generally possible for each geographical area, in this case countries, which are each based on different markets connected with different data requirements:

- **Attribution based on national product markets:**
  This requires a clear connection between a measurable change in land use and the concrete end product, which is the subject of the life cycle assessment.
  Example: In a country, the area of plantations for a crop for a specific market is expanded at the expense of forest areas (e.g. the expansion of palm oil plantations in Colombia exclusively for the purpose of biodiesel production). In this case, LULUC related burdens can be fully attributed to the product "Colombian palm oil biodiesel".
- **Attribution based on national crop markets:**
  This requires a clear connection between a measurable change in land use and a crop that is used for the production of several products including the specific end product, which is the subject of the life cycle assessment.
  Example: The expansion of palm oil plantations in Indonesia is recorded with data accuracy and can therefore be attributed to palm oil production - but not to the various uses of palm oil (food, material products, bioenergy). In this case, LULUC related burdens can be distributed evenly to all these products in relation to their respective palm oil inputs.
- **Attribution based on national cropland markets:**
  This requires agricultural production statistics on a country level as available worldwide e.g. from FAO. In many cases, the relationship between a particular agricultural commodity and the documented land use change cannot be established. This is at least usually the case for annual crops, which cannot be attributed a specific contribution to LULUC due to normal crop rotation practices. Also in the case of perennial crops, the attribution of LULUC to specific crops requires economic assumptions and models that seek to establish causalities. These do not necessarily reflect the complex socio-economic and political processes that can cause, promote or prevent LULUC. Thus, according to this perspective, all crops represent the wider range of causes of LULUC.
  Example: The ploughing up of grassland in Germany cannot be directly attributed to any of the field crops. It simply represents a general (net) expansion of agricultural land compared to grassland, which is why LULUC is attributed to all agricultural products (rapeseed, wheat, etc.) according to their respective land use.

These three stages describe the principle of attributive land use/land use change (aLULUC), which was developed within the framework of the German Environment Agency project BioEm [Fehrenbach et al. 2016] on the basis of such relationships and has already been applied to relevant bioenergy sources.

Even if actual land use changes can be clearly assigned to certain agricultural products , all agricultural products of a production area compete for the limited amount of available cropland. For a broad application of the approach with generalised aLULUC values for all types of products, an attribution based on national cropland markets should therefore be the standard case.

Overall, aLULUC provides a basis to depict the actual situation of land use/land use change due to agricultural activity on an empirical basis. On that basis, it can provide a general emission factor that assigns the actual and measurable LULUC in a defined agricultural area to all producers in the agricultural area. The real land use changes caused by agriculture (of a defined region) are allocated to all agricultural products (and thus also to bioenergy) in proportion to the land requirements. It is therefore an attributional allocation. This approach deliberately does not consider presumed causal relationships to individual drivers, as they can be established in consequential accounting. Even if a certain application, e.g. maize for biogas, is assumed to be the driver for LUC [KLU 2013], the aLULUC does not differentiate in that case. All agricultural products are subjected to the same burden.

Generally, a country is chosen as the geographical reference area because changes in land use can usually be limited (or not) at country level and markets for agricultural land within a country usually have no barriers. In some contexts, other reference areas may also be useful.

The procedure is described using the example of the conversion of grassland in Germany.

Determination of the area size and calculation of the relation between the area sizes for LUC:

- On average, about 30,000 ha of grassland were converted into arable land in 2016 [German Environment Agency 2018].
- At the end of this period, the total arable land amounted to approx. 13.5 million ha. Every hectare used for agricultural purposes therefore has an annual grassland conversion value of 0.0022 hectares.
- The allocation to the individual paths is carried out according to the same proportional procedure, i.e. every type of crop receives the same LUC value per hectare (0.0022 ha of grassland conversion per hectare and year of arable land used).

Determination of the aLUC emission factor:

- The Thünen Institute regularly determines emission factors for LULUCF in Germany for annual reporting on the German greenhouse gas inventory in accordance with the Kyoto process. According to [German Environment Agency 2018], this is 60 t CO_2 per hectare in 2016 for the transition from grassland to arable land. The resulting aLUC emission factor for 2016 is thus 0.0022 ha / (ha·a) · 60 t CO_2 equivalent / ha = 0.13 t CO2 equivalent per hectare and year.

It should be mentioned at this point that LUC, in accordance with the guidelines of the [IPCC 1996], only considers CO_2 emissions caused by changes in the carbon stock of above-ground and underground biomass. Emissions of nitrous oxide (N_2O), methane (CH_4) and CO_2 from dead biomass (peat) resulting from the drainage of organic soils as a result of land use changes are classified under the category "land use" (LU, see Chapter 2.2).

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2.2 Environmental impacts of land use

2.2.1 Existing evaluation approaches

Some of the environmental impacts of land use, such as impacts on water scarcity or nutrient inputs, are specific to the crops grown and can therefore be clearly attributed to them. This part can be mapped using the standard life cycle assessment methodology and is not the subject of this publication.

In addition, the use of organic soils for the cultivation of crops is usually accompanied by drainage of the peat soils. This measure leads above all to greenhouse gas emissions, which can extend over several decades depending on the peat layer. They are of considerable importance in some countries and should therefore not be neglected in the life cycle assessments. Germany, for example, has a share of organic soils of 3 % per hectare of total arable land, which causes greenhouse gas emissions (including N_2O and CH_4) of 1 tonne CO_2 eq. / (ha · year) [according to German Environment Agency 2018].

These GHG emissions are consequences of land use changes that can be prevented by setting-aside and rewetting the land, even if this happens very rarely in practice. Thus the environmental impacts are caused by land use per se and there is a very similar allocation problem as described in Chapter 2.1 for land use changes. There are direct and indirect assessment approaches analogous to dLUC and iLUC with similar limitations and problems.

2.2.2 The Concept of Attributive Land Use (aLU)

As with the aLUC concept, the aLU concept allocates real emissions from organic soils (currently covered: CO_2, CH_4 and N_2O) to total land use. Since the emissions do not only originate from recently converted areas, but from all drained areas with organic soils, the aLU concept is based on an analogous but not identical concept to the aLUC.

3 Methodological Approach to Attributional Land Use Change (aLUC)

3.1 Calculation of the aLUC emission factor

The methodological approach of attributional land use change is presented in detail below for greenhouse gas emissions. It is possible to inventorise further environmental impacts of land-use change analogously. It is based on the cultivation practise and data structure as they exist for agricultural products in Germany and Europe. This means that no specific LUC can be attributed to individual crops (such as rapeseed or wheat), since the whole group of crops contributes to LUC as a whole. The calculation of the aLUC for arable land is explained below. Similarly, the aLUC can also be calculated for other types of land such as grassland.

As shown in the example given in Section 2.1.3, the aLUC emission factor includes the following two factors:

- firstly, the ratio of the area with land use change, for example grassland or forest to arable land, to the total arable land, and

- the emission factor associated with the change in land use, which reflects the change in the carbon content of the biomass and the mineral soil;

In detail, the following parameters are therefore relevant for the calculation of the aLUC emission factor:

- Total arable land area in the reference year:
  A (unit: ha)
- Areas with change from previous use U to arable land (A) in the reference year (net change from category N to category arable land):
  LUC_A^N (unit: ha/year), with N = e.g. wetlands (W), grassland (G) and forest (F)
- Proportion of organic and mineral soils in LUC areas with prior use U:
  ORG^N and MIN^N [%], with $ORG^N + MIN^N = 100\%$.
- Emission factor for the change in the carbon stock in the biomass, starting from previous use U:
  EF^N_{BIO} [kg C / ha]
- Emission factor for the one-off change in carbon stocks in mineral soils due to land use change, starting from previous use U:
  EF^N_{MIN} [kg C / ha]
- Emission factor for the one-off change in carbon stocks in organic soils due to land use change, starting from previous use U:
  EF^N_{ORG} [kg C / ha]

  In the case of organic soils, the main emissions occur annually due to the degradation of organic matter after drainage. These are categorised as related to land use and not to land use change (see Chapter 4). Often one-time emissions from organic soils due to land use *changes* are not reported separately. In the first few years after land use change, these would usually only lead to insignificantly higher emissions than in subsequent years. That is why in practise $EF^N_{ORG} = 0$ often applies for reasons of classification and to avoid double counting, respectively.

The region- and year-specific aLUC factor is composed of the specific emissions for each previous use U and is calculated as follows:

$$aLUC_{year}^{Region}\ [\text{kg } CO_2 / (\text{ha} \cdot \text{year})] = \frac{44}{12} \sum_{N=F}^{W} \left(\frac{MIN^N \cdot LUC_A^N}{A} \cdot EF_{MIN}^N + \frac{ORG^N \cdot LUC_A^N}{A} \cdot EF_{ORG}^N + \frac{LUC_A^N}{A} \cdot EF_{BIO}^N \right) \quad \text{Eq 1}$$

All CO_2 emissions due to a change in the carbon stock in above-ground and underground biomass are attributed to the year in which the change in use takes place. It is not distributed over an amortisation period of e.g. 20 or 100 years. Although actual CO_2 emissions may be partially delayed by a few years, the majority of emissions should take place in the first 1-2 years. This means that the aLUC approach is much closer to real emission times than the amortisation approach.

The average aLUC emission factor for a region should ideally reflect the average of the previous ten years (e.g. 2007 - 2016) in order to include possible extreme events of land conversions in individual years.

The primary preferred source for the parameters is the National Inventory Report required for the implementation of the Framework Convention on Climate Change and the Kyoto Protocol, in which the annual greenhouse gas emissions of a country are accounted for and explained. All countries that have signed the Kyoto Protocol are obliged to submit this report. Alternatively, the FAOSTAT [FAO 2018] database can be

used, whose emission factors are also based on the IPCC approach [IPCC1996], albeit in a simplified form. It should be noted, however, that according to FAOSTAT only land conversion is reported in the forest category, whereas inventory reporting takes into account all land categories (e.g. including grass land) listed in chapter 2.1.2.

The following sections deal in detail with the determination of the individual parameters.

3.1.1 Total agricultural area A

The total area used for arable crops in a given year and region refers to the agricultural area used for the production of annual and perennial arable crops. Grassland is not included.

For countries reporting their annual greenhouse gas inventories under the Kyoto Protocol, the source for total arable land may be the Land Transition Matrix, which corresponds to the CRF (Common Reporting Format), Table 4.1. The total area of arable land corresponds to the area of land that remains and is converted into arable land, the sum of which is referred to as the 'final area'. This means that land that was converted from arable land to other uses, such as settlements, in the year under consideration, i.e. losses of arable land, is taken into account.

Figure 1 shows an example of the land transition matrix for 2016 for Germany. From the initial acreage of 13,491 kilo hectares (kha) (column: "Initial area") 52.5 kha (3 + 21 + 0.5 + 28.5 with rounding difference) are converted into other forms of use (row: "FROM: Cropland (2)"). In contrast, an area of 52 kha (column: "TO: Cropland") is converted into arable land, so that a net decrease of 0.5 kha of arable land and a total arable land of 13,490 kha (row: "Final area") are recorded for the year 2016.

Table 4.1 LAND TRANSITION MATRIX
Areas and changes in areas between the previous and the current inventory year(1)

Inventory 2016
Submission 2018 v1
GERMANY

TO: / FROM:	Forest land (managed)	Forest land (unmanaged)	Cropland	Grassland (managed)	Grassland (unmanaged)	Wetlands (managed)	Wetlands (unmanaged)	Settlements	Other land	Total unmanaged land	Initial area
	(kha)										
Forest land (managed)(2)	11153,45	NO	0,47	2,58	NO	0,13	NO	4,63	NO	NO	11161,26
Forest land (unmanaged)(2)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Cropland(2)	2,95	NO	13438,15	20,81	NO	0,36	NO	28,45	NO	NO	13490,72
Grassland (managed)(2)	10,34	NO	50,59	6410,12	NO	1,33	NO	13,82	NO	NO	6486,19
Grassland (unmanaged)(2)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Wetlands (managed)(2)	0,08	NO	0,00	1,20	NO	728,37	NO	0,13	NO	NO	729,78
Wetlands (unmanaged)(2)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Settlements(2)	0,70	NO	1,08	3,89	NO	0,59	NO	3885,46	NO	NO	3891,73
Other land(2)	NO	NO	NO	NO	NO	0,10	NO	NO	19,85	IE	19,95
Total unmanaged land (3)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Final area	11167,52	NO	13490,28	6438,60	NO	730,88	NO	3932,49	19,85	NO,IE	35779,63
Net change(4)	6,26	NO	-0,44	-47,59	NO	1,10	NO	40,76	-0,10	NO,IE	0,00

Figure 1: Section of CRF Table 4.1: Land Use Matrix for Germany and the Year 2016 (NO: not occurring; IE: included elsewhere)

The database FAOSTAT [FAO 2018] can be used as a further data source for arable land.

Since the area values of a certain use category vary depending on the stored method and nomenclature, it is important to use the same data source for the calculation of the aLUC value when calculating the area ratios (see Eq 1).

3.1.2 Land converted to cropland

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The aLUC emission factor should include the areas that led to a net positive change in a certain use category to the cropland category in the year under consideration. The net change in area takes account of the fact that arable land was also converted for other uses. The areas can be derived from the transition matrix (CRF Table 4.1, see Figure 1) provided as part of climate reporting.

For Germany, for example, it is reported in 2016 that 20.81 kha of arable land were converted into grassland and 50.59 kha of grassland into cropland. In net terms, this means that 29.78 kha of grassland were converted into cropland.

Land transition matrices are only available for selected countries that have committed themselves to climate reporting. For the aLUC value of countries for which there are no detailed land changes between use categories, the FAOSTAT database is used as an alternative. As already mentioned above, however, only the converted forest areas are available in FAOSTAT, which in the case of the aLUC are allocated in a simplified approach to the full extent of the conversion of cropland.

3.1.3 Share of organic soils

Due to the different emission behaviour of organic and mineral soils during use change (see also Sections 3.1.5 and 3.1.6) it is necessary to determine the proportion of organic or mineral soils in the converted area.

The proportions of organic soils in the converted areas can be taken from the sectoral background data of the CRF tables (Table 4.B Cropland) in the greenhouse gas inventories of the reporting countries. These area values take into account that the converted area is cumulated in this category for a transitional period of 20 years. Although this approach does not correspond to the approach of the aLUC to reflect the respective area changes in the year under consideration, it allows a good approximation of the proportion of organic area of the converted area in the year under consideration.

If the shares of organic soils in the converted area are not available, which is also the case for countries reporting under the Kyoto Protocol, the FAOSTAT database, which outputs data on organic soils under grassland and arable land, can be used as an alternative. Even if this area refers to the use and not to the change in use, the area values are sufficient for a first approximation.

3.1.4 Emission factor carbon from biomass

The EF^{N}_{BIO} emission factor quantifies the release or sequestration of biogenic carbon associated with the change in carbon stocks in the biomass due to land use change. In the case of land use change from grassland to cropland, biogenic carbon is released because more carbon is bound in the biomass of grassland than in that of arable land. The biomass carbon of arable land is even set to zero in annual crops, because the carbon is removed from the area by the crop within a year and therefore no biomass growth is recorded. The biomass and thus also the carbon stock on grassland vary annually depending on the growth conditions. As a result, the EF^{N}_{BIO} emission factor is variable for each year and is also reported on an annual basis by Germany, for example, within the framework of climate reporting.

For the countries providing national greenhouse inventories, the reports and CRF tables can be used to determine the emission factors for the specific land use changes.

For those countries that have not committed themselves to reporting their greenhouse gas inventories, the emission factors can be found in the FAO database FAOSTAT. Here, too, emission factors refer exclusively to changes in forest use.

3.1.5 Emission factor soil organic carbon from mineral soils

The emission factor for the change in soil carbon due to land use change can also be found in the CRF tables of the greenhouse gas inventories. However, it must be taken into account that the emissions are distributed over or depreciated over the entire transitional period of 20 years in which the area is reported in the land use change category.[1] Within the framework of the aLUC calculation, the emission factor must therefore be multiplied by a factor of 20 in order to allocate all emissions to the conversion year.

3.1.6 Emission factor soil organic carbon from organic soils

When determining the emission factor for organic soils, a distinction must first be made between emissions due to use and those due to land use change. Since the aLUC value is specifically aimed at the effects of land use change, emissions due to the use of drained organic soils are deliberately not included in this context. These are covered via attributional land use (aLU. see chapter 4). The emission factor EF^{N}_{org}, on the other hand, results from the difference between emissions from areas recently converted to arable land and those that have been arable land for some time. In the CRF tables, identical values are often given here, presumably because the additional LUC-related emissions are not or cannot be recorded separately in addition to the significantly higher LUC-related emissions in the medium term.

In addition, the EF^{N}_{org} refers to the change in the carbon stock and the associated carbon dioxide emissions in the same way as the RED. Other greenhouse gases such as nitrous oxide (N_2O) or methane (CH_4) are explicitly excluded, as they are included in the aLU.

Emission factors for the use of organic soil should normally be reported in the CRF tables, but are not available for all countries reporting their greenhouse inventories. Alternatively, the emission factors for the use of arable land and grassland can be taken from the FAOSTAT database, which is based on the IPCC approach.

3.1.7 Carbon stocks of perennial crops

Carbon stocks of land under perennial crops can be much higher than for annual crops. This needs to be taken into account for a proper attribution of LUC to the crops. Two properties make an attribution challenging:

- Carbon stocks vary strongly depending on the perennial crop. For e.g. berry bushes, stocks may only be marginally higher than average stocks of annual cropland and plantation lifetimes are comparatively short while the situation is totally different for e.g. coconut palms. This creates a continuum of land occupation types.

[1] After conversion, an area remains by definition in the new use category for 20 years.

Their establishment and clearing can have very different impacts on climate change and other environmental impacts. In some cases, this may rather be regarded as transient land management change and in others rather as land use change.

- Available data and its documentation is very heterogeneous regarding the carbon content of cropland that is taken into account as baseline for calculating the reported greenhouse gas emissions from land use change. Even if sources report annual and perennial cropland separately, the shares of individual perennial crops of all perennial cropland are mostly not available. Therefore, it is partially unclear whether aLUC factors calculated as detailed above, which cover the conversion of other land to "average" cropland, take into account the carbon stocks of perennial crops. In any case, this calculation results in only one aLUC factor independent of whether a crop is perennial or annual.

To overcome these challenges using available data, we introduced dedicated aLUC factors for perennial crops divided into five classes according to the carbon stocks of plantations and their lifetime (see Table 1).

Table 1: Plantation lifetimes and carbon stocks of plantations of perennial crops divided into five classes. These are used to determine aLUC factors for perennial crops.

		Examples	t C/ha in period of maximum yield	Reached after x years	Plantation lifetime	t C/ha average over plantation lifetime	t CO_2/ha on average
1	Like annual	Berries (also bushes), grape	0	-	-	-	-
2	Bush-like	Tea, coffee, apple plantation (spindle-bush)	5	5	20	4.375	16
3	Medium-sized plants	Papaya, banana/plantain	10	5	20	8.75	32
4	Tree, small	Apple, orange, pear (tall-stemmed), cocoa	30	10	20	22.5	83
5	Tree, tall	Palm trees, mango, coconut, rubber	70	20	20	35	128

These factors attribute newly generated carbon stocks of perennial crops, which are established on land converted into cropland, only to these perennial crops. This approach may in some cases lead to an underestimation of the LUC caused by perennial crops because, as detailed above, this carbon content may in some countries already be included in the baseline for cropland. Nevertheless, we consider the adjusted aLUC of perennial crops to be substantially closer to real situation caused by perennial crops than the aLUC for annual crops. The latter one may still be used in a sensitivity analysis depending on the goal of the study.

The adjusted aLUC for perennial crops is calculated as follows:

$$aLUC_{year}^{Region,perennial\ crop\ class}\left[\frac{\text{kg}\,CO_2}{\text{ha}\cdot\text{year}}\right] = aLUC_{year}^{Region,annual\ crop} - \frac{44}{12}\sum_{N=F}^{W}\left(\frac{LUC_A^N}{A}\cdot CC_{per.\ crop\ class}\right) \quad \text{Eq 2}$$

with CC being the carbon content of the perennial cropland exceeding the carbon content of annual cropland averaged over a typical plantation lifetime for each class of perennial crops as listed in Table 1.

3.2 Product specific application of the aLUC emission factors

The aLUC concept assigns to each hectare and year of land use in a reference area (usually a country) the burden of land use change occurring in that year in the same reference period. For the product-specific application of the aLUC emission factor within Life Cycle Inventories and Life Cycle Assessments, the country-specific arable land area ($A^{\,Country}$) is required, which depending on the stage (see Section 2.1.3) is required for the production of a product (e.g. one litre of rapeseed biodiesel). The total emissions of a product attributable to aLUC are determined as follows:

$$aLUC^{Product}\ [\text{kg}\,CO_2\ \text{eq}] = \sum\left(aLUC^{Country\ a}\cdot A^{\,Country\ a} + aLUC^{Country\ b}\cdot A^{\,Country\ b} + \cdots\right) \quad \text{Eq 3}$$

Country specific aLUC emission factors are listed in Table 4 in the appendix.

The procedure is described in simplified form using the example of rapeseed for biodiesel. For each GJ of biodiesel, 0.013 ha of arable land in Germany are included in the inventory. For the attributive land use change, emissions amounting to 0.21 t CO_2/ha/year) are to be allocated to this area (see aLUC for Germany in Table 4 in the Appendix). For the product biodiesel from rapeseed, an additional 2.7 kg CO_2 per GJ are to be taken into account due to the attributive land use change.

Within the BioEm project, aLUC values were developed for various bioenergy sources (see Table 8 in [Fehrenbach et al. 2016]). For data technical reasons, some simplifications were necessary, so these figures should be seen as indicative.

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4 Methodical Approach for Attributional Land Use (aLU)

4.1 Calculation of the aLU emission factor

The methodological approach of attributional land use is presented in detail below again using greenhouse gas emissions as an example. It is based on a cultivation situation and data structure as it applies to agricultural products in Germany and Europe. This means that no specific LU can be attributed to individual crops (such as rape seed or wheat), since all crops equally contribute to causing LU.

The following two factors are included in the aLU emission factor:

- on the one hand, the ratio of arable land with organic soils to total arable land, and
- the emission factor associated with the use of organic soils.

In detail, the following parameters are therefore relevant for the calculation of the aLU emission factor:

- Share of total arable land that has organic soils which is used in the reference year: ORG^{tot} [%]
- Emission factor for all continuous greenhouse gas emissions from organic soils used as arable land (here: CO_2, N_2O and CH_4):
  EF^{cont}_{ORG} [kg CO_2-eq / (ha·year)]

The aLU factor by region and by year is calculated as follows:

$$aLU_{year}^{Region}\ [\text{kg}\ CO_2 - \text{eq} / (\text{ha}\ \cdot\ \text{year})] = \text{ORG}^{tot} \cdot EF_{ORG}^{cont} \qquad \text{Eq 3}$$

In this approach, for the sake of simplicity, the influence of the cultivation method on the decomposition of organic soils is not considered. However, this could become relevant if, for example, annual and perennial crops as well as grassland on organic soils are to be compared. For clearly separable land categories such as arable land and grassland, separate aLU values should therefore be calculated.

A detailed description of how the individual parameters are determined is given below.

First of all, it is necessary to determine the proportion of organic soils ORG of the total arable land. Then an emission factor EForg needs to be determined which is consistent to the determined proportion of organic soils. This factor contains all greenhouse gas emissions arising from drained organic soils. In addition to CO_2, it also contains relevant contributions from the greenhouse gases nitrous oxide (N_2O) and methane (CH_4).

A comparison of the two most comprehensive sources available, the national inventory reports (NIR) under the Kyoto Protocol and the FAOSTAT database [FAO 2018], reveals some significant variations in the resulting aLU factors (see Table 5 in the appendix). In this context, obsolete emission factors, which were used in [FAO 2018], were replaced by more recent ones from [IPCC 2014]. These are largely due to different input data on the area fractions of organic soils in the respective countries. National soil inventories, on which the NIR data are usually based, largely use criteria different from those of the FAO, such as the carbon content and layer thickness starting from which soils count as "organic soils". These also differ in many cases from country to country. In addition, some NIRs only consider CO_2 when calculating EForg, others also consider N_2O and a few also consider CH_4.

A detailed analysis for several countries revealed that data reported in NIRs seems to reflect the real local situation better. Therefore, we recommend using NIR data instead of FAO/IPCC data if data quality is better in the individual case.

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4.2 Product-specific application of the aLU emission factor

The application of the aLU emission factors is identical to the procedure described in Chapter 3.2 for the aLUC. This is possible because both aLUC and aLU emission factors are calculated for one hectare and year of arable land used in a reference area (mostly country).

Country specific aLU emission factors are listed in Table 3 in the appendix.

5 Factors for normalisation

In many life cycle assessments, the results for product comparisons are presented on the basis of standardised values. Population averages, which are also proposed in this position paper, are a common reference value for normalisation.

aLUC and aLU are primarily methods for preparing a Life Cycle Inventory, even though they are currently used primarily for greenhouse gases. Therefore, depending on the application case and impact assessment method, the respective normalisation factors of the corresponding impact category, e.g. climate change, must be applied.

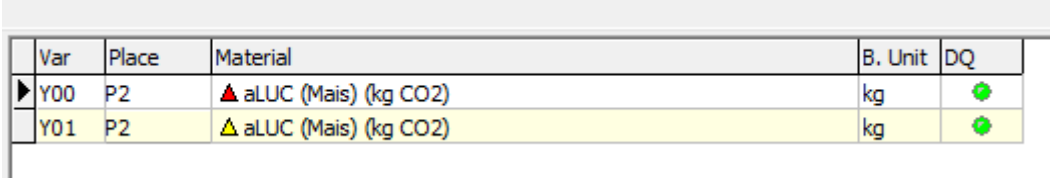
6 Application

The method of attributive land use / land use change is suitable for any LCA study whose object of investigation is directly or indirectly connected with the use or occupancy of land. The integration of country- and product-specific aLU / aLUC values into existing life cycle assessment software is usually possible without great effort. In the life cycle assessment software UMBERTO®, for example, a material or an information quantity can be calculated, created and shown separately for the aLU / aLUC of a product (see Figure 2). As emphasized at the beginning, the possible applications go beyond the category of climate protection and can also be included in other categories such as "land use" or "biodiversity".

Projects that have successfully applied the method or are currently included in the modelling process, for example:

- BioEm [Fehrenbach et al. 2016]
- Seemla [Rettenmaier et al. 2018]
- KEEKS https://www.klimaschutz.de/projekt/keeks-klima-und-energieeffiziente-kuche-schulen
- COSMOS http://cosmos-h2020.eu/
- Blauer Engel BioStoff [Hennenberg et al. 2018]
- HIGH [Wagner et al. 2020]
- Ecological footprints of food items and meals in Germany [Reinhardt et al. 2020]

We recommend that the share of the aLU / aLUC in the total loads be reported separately in an impact category (such as climate-relevant emissions) of the product systems, e.g. as part of a sensitivity or dominance analysis.



	Var	Place	Material	B. Unit	DQ
▶	Y00	P2	▲ aLUC (Mais) (kg CO2)	kg	
	Y01	P2	⚠ aLUC (Mais) (kg CO2)	kg	

Figure 2: aLUC as emission (red) and information size in UMBERTO® (Vers. 5.6).

7 Literature

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8 Appendix

This appendix contains the current status of emission factors determined so far for the climate impact of land use and land use change according to the aLU / aLUC concept for selected countries (Table 2 - Table 4). These can be used to assess the use of arable land in life cycle assessments and are currently used in ifeu studies. For convenience, aLULUC factors are additionally given as the sum of aLU and aLUC. These tables are available as Excel files at:

https://www.ifeu.de/fileadmin/uploads/S1_ifeuPaper_03_2018_aLULUC.xlsx

For the aLUC, as stated in Chapter 3.1, values based on the national inventory reports (NIR) under the Kyoto Protocol are preferably used rather than values based on data from the FAOSTAT [FAO 2018] database. As discussed in Chapter 4.1, the aLU is calculated based on values from [FAO 2018] supplemented by [IPCC 2014] by default unless better data from the NIR are available in individual cases. Exemplary comparisons of FAO and NIR based values are shown in Table 5.

Table 2: Overview of selected country-specific **aLULUC factors** (sum of aLU and aLUC) for annual and perennial crops cultivated on arable land. Data are averaged over the period 2007 – 2016. Contributions and data sources are shown in Table 3 and Table 4.

Country	aLULUC annual crops [t CO_2eq. /ha/year]	aLULUC perennials 1: like annual [t CO_2eq. /ha/year]	aLULUC perennials 2: bush-like [t CO_2eq. /ha/year]	aLULUC perennials 3: medium-sized [t CO_2 eq. /ha/year]	aLULUC perennials 4: small trees [t CO_2eq. /ha/year]	aLULUC perennials 5: tall trees [t CO_2 eq. /ha/year]
Argentina	1.88	1.88	1.80	1.73	1.49	1.28
Australia	0.02	0.02	0.01	0.00	-0.03	-0.05
Belarus	7.52	6.48	6.44	3.16	3.03	2.90
Brazil	5.51	5.51	5.31	5.10	4.47	3.89
Cambodia	4.99	4.99	4.51	4.04	2.55	1.19
Chile	0.80	0.74	0.72	0.53	0.46	0.40
China	0.02	0.02	0.02	0.01	0.01	0.01
Colombia	3.32	3.33	3.32	3.31	3.26	3.23
Costa Rica	10.73	10.74	10.24	9.73	8.10	6.66
Côte d'Ivoire	1.07	1.08	1.06	1.04	0.90	0.85
Ecuador	5.63	5.63	5.43	5.22	4.56	3.97
France	0.76	0.71	0.63	0.54	0.54	0.54
Germany	1.18	1.18	1.12	1.06	0.88	0.71
Ghana	1.11	1.11	0.85	0.85	0.85	0.85
India	0.03	0.03	0.03	0.03	0.02	0.02
Indonesia	12.87	13.00	12.76	12.48	10.46	9.77
Israel	0.01	0.01	0.01	0.01	0.00	0.00
Italy	0.20	0.18	0.17	0.13	0.08	0.04
Kazakhstan	0.00	0.00	0.00	0.00	0.00	0.00
Kenya	0.02	0.01	0.01	0.01	0.01	0.01
Malaysia	9.27	9.36	9.25	9.08	7.76	7.47
Morocco	0.11	0.11	0.10	0.09	0.05	0.02
Netherlands	2.05	2.05	1.93	1.80	1.41	1.06
New Zealand	4.23	4.23	4.12	4.02	3.70	3.40
Nigeria	2.12	2.12	2.04	1.96	1.72	1.50
Pakistan	0.41	0.41	0.40	0.38	0.34	0.30
Papua New Guinea	25.13	25.53	25.49	24.83	18.81	18.68
Peru	5.36	5.36	5.16	4.95	4.31	3.72
Philippines	0.67	0.67	0.64	0.60	0.50	0.41
Poland	2.09	1.80	1.80	0.90	0.90	0.90
Romania	0.09	0.07	0.07	0.05	0.05	0.05
Russian Federation	0.93	0.87	0.75	0.56	0.56	0.56
South Africa	0.01	0.01	0.01	0.01	0.01	0.01
Spain	0.03	0.02	0.02	0.01	0.01	0.01
Sri Lanka	0.73	0.74	0.69	0.65	0.41	0.29
Thailand	0.41	0.41	0.38	0.35	0.25	0.16
Tunisia	0.00	0.00	0.00	0.00	0.00	0.00
Turkey	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	0.60	0.52	0.52	0.26	0.26	0.26
United Kingdom	0.47	0.40	0.40	0.20	0.20	0.20
United States of America	0.20	0.16	0.16	0.09	0.09	0.09
Uruguay	0.04	0.03	0.03	0.02	0.02	0.02
Vietnam	0.90	0.91	0.88	0.85	0.64	0.55

Table 3: Overview of selected country-specific **aLU factors** for annual and perennial crops cultivated on arable land. Data are averaged over the period 2007 – 2016. Data sources: FAO (2018)/IPCC (2014) and National Inventory Reports (NIR).

Country	aLU annual crops [t CO_2eq. /ha/year]	aLU perennials 1: like annual [t CO_2eq. /ha/year]	aLU perennials 2: bush-like [t CO_2eq /ha/year]	aLU perennials 3: medium-sized [t CO_2 eq. /ha/year]	aLU perennials 4: small trees [t CO_2eq. /ha/year]	aLU perennials 5: tall trees [t CO_2 eq. /ha/year]	Data source
Argentina	0.03	0.03	0.03	0.03	0.02	0.02	FAO
Australia	0.01	0.01	0.01	0.01	0.01	0.01	NIR
Belarus	7.51	6.48	6.48	3.24	3.24	3.24	FAO
Brazil	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Cambodia	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Chile	0.40	0.35	0.35	0.17	0.17	0.17	FAO
China	0.02	0.02	0.02	0.01	0.01	0.01	FAO
Colombia	0.13	0.14	0.14	0.14	0.10	0.10	FAO
Costa Rica	0.20	0.20	0.20	0.20	0.15	0.15	FAO
Côte d'Ivoire	0.29	0.30	0.30	0.30	0.22	0.22	FAO
Ecuador	0.03	0.03	0.03	0.03	0.02	0.02	FAO
France	0.26	0.21	0.21	0.12	0.12	0.12	FAO
Germany	0.97	0.97	0.97	0.97	0.97	0.97	NIR
Ghana	0.01	0.01	0.01	0.01	0.01	0.01	FAO
India	0.03	0.03	0.03	0.03	0.02	0.02	FAO
Indonesia	4.69	4.83	4.83	4.79	3.54	3.54	FAO
Israel	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Italy	0.08	0.06	0.06	0.04	0.04	0.04	FAO
Kazakhstan	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Kenya	0.02	0.01	0.01	0.01	0.01	0.01	FAO
Malaysia	3.88	3.96	3.96	3.88	2.88	2.88	FAO
Morocco	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Netherlands	1.64	1.64	1.64	1.64	1.64	1.64	NIR
New Zealand	0.80	0.80	0.80	0.80	0.80	0.80	NIR
Nigeria	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Pakistan	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Papua New Guinea	23.29	23.69	23.69	23.08	17.19	17.19	FAO
Peru	0.02	0.02	0.02	0.02	0.02	0.02	FAO
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Poland	2.08	1.79	1.79	0.90	0.90	0.90	FAO
Romania	0.06	0.05	0.05	0.03	0.03	0.03	FAO
Russian Federation	0.43	0.37	0.37	0.19	0.19	0.19	FAO
South Africa	0.01	0.01	0.01	0.01	0.01	0.01	FAO
Spain	0.02	0.02	0.02	0.01	0.01	0.01	FAO
Sri Lanka	0.38	0.40	0.40	0.39	0.29	0.29	FAO
Thailand	0.04	0.04	0.04	0.04	0.03	0.03	FAO
Tunisia	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Turkey	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Ukraine	0.60	0.51	0.51	0.26	0.26	0.26	FAO
United Kingdom	0.47	0.40	0.40	0.20	0.20	0.20	FAO
United States of America	0.20	0.16	0.16	0.09	0.09	0.09	FAO
Uruguay	0.04	0.03	0.03	0.02	0.02	0.02	FAO
Vietnam	0.38	0.39	0.39	0.39	0.29	0.29	FAO

Table 4: Overview of selected country-specific **aLUC factors** for annual and perennial crops cultivated on arable land. Data are averaged over the period 2007 – 2016. Data sources: FAO (2018) and National Inventory Reports (NIR).

Country	aLUC annual crops [t CO_2 /ha/year]	aLUC perennials 1: like annual [t CO_2 /ha/year]	aLUC perennials 2: bush-like [t CO_2 /ha/year]	aLUC perennials 3: medium-sized [t CO_2 /ha/year]	aLUC perennials 4: small trees [t CO_2 /ha/year]	aLUC perennials 5: tall trees [t CO_2 /ha/year]	Data source
Argentina	1.84	1.84	1.77	1.70	1.47	1.25	FAO
Australia	0.01	0.01	0.00	0.00	-0.03	-0.06	NIR
Belarus	0.01	0.01	-0.04	-0.08	-0.22	-0.34	FAO
Brazil	5.51	5.51	5.31	5.10	4.47	3.89	FAO
Cambodia	4.99	4.99	4.51	4.04	2.55	1.19	FAO
Chile	0.39	0.39	0.37	0.35	0.29	0.23	FAO
China	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Colombia	3.19	3.19	3.19	3.18	3.16	3.13	FAO
Costa Rica	10.54	10.54	10.03	9.53	7.95	6.51	FAO
Côte d'Ivoire	0.78	0.78	0.76	0.74	0.68	0.63	FAO
Ecuador	5.60	5.60	5.40	5.19	4.54	3.95	FAO
France	0.50	0.50	0.42	0.42	0.42	0.42	NIR
Germany	0.21	0.21	0.16	0.10	-0.08	-0.25	NIR
Ghana	1.10	1.10	0.84	0.84	0.84	0.84	NIR
India	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Indonesia	8.17	8.17	7.93	7.69	6.92	6.23	FAO
Israel	0.01	0.01	0.01	0.01	0.00	0.00	FAO
Italy	0.12	0.12	0.11	0.09	0.05	0.01	NIR
Kazakhstan	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Kenya	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Malaysia	5.40	5.40	5.29	5.19	4.88	4.59	FAO
Morocco	0.11	0.11	0.10	0.09	0.05	0.02	FAO
Netherlands	0.41	0.41	0.29	0.16	-0.23	-0.58	NIR
New Zealand	3.43	3.43	3.32	3.22	2.89	2.60	NIR
Nigeria	2.12	2.12	2.04	1.96	1.72	1.50	FAO
Pakistan	0.41	0.41	0.40	0.38	0.34	0.30	FAO
Papua New Guinea	1.84	1.84	1.80	1.76	1.62	1.49	FAO
Peru	5.34	5.34	5.14	4.93	4.29	3.71	FAO
Philippines	0.67	0.67	0.64	0.60	0.50	0.41	FAO
Poland	0.01	0.01	0.01	0.01	0.01	0.01	NIR
Romania	0.03	0.03	0.03	0.03	0.03	0.03	NIR
Russian Federation	0.50	0.50	0.38	0.38	0.38	0.38	NIR
South Africa	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Spain	0.01	0.01	0.00	0.00	0.00	0.00	NIR
Sri Lanka	0.34	0.34	0.30	0.26	0.12	0.00	FAO
Thailand	0.37	0.37	0.34	0.31	0.22	0.13	FAO
Tunisia	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Turkey	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Ukraine	0.01	0.01	0.01	0.01	0.01	0.01	NIR
United Kingdom	0.00	0.00	0.00	0.00	0.00	0.00	FAO
United States of America	0.00	0.00	0.00	0.00	0.00	0.00	NIR
Uruguay	0.00	0.00	0.00	0.00	0.00	0.00	FAO
Vietnam	0.52	0.52	0.49	0.46	0.36	0.26	FAO

Table 5: Differences in aLU factors for selected countries according to data source.

Land	aLU according to NIR data [t CO_2-eq/ha/year]	aLU according to FAO/IPCC data [t CO_2-eq/ha/year]
Germany	0.97	1.48
Netherlands	1.64	3.06
New Zealand	0.80	0.54
Australia	0.01	0.07