INTEGRATING LAND USE CHANGE ESTIMATES AT STATE LEVEL IN THE ECOINVENT DATABASE STRUCTURE v3.3

Ana C.G. Donke[1], Renan M.L. Novaes[1], Ricardo A.A. Pazianotto[1], Emilia M. Ruiz[2], Jürgen Reinhard[3], Marília I.S. Folegatti-Matsuura[1]*

[1]Embrapa Meio Ambiente
[2]Ecoinvent,
[3]Quantis
** renan.milagres@embrapa.br*

Abstract: Land use change (LUC) emissions have a major importance to agricultural products, especially in countries where agriculture is a relevant economic activity, as in Brazil. Despite its importance, methodologies for LUC estimation are still under debate and there is a lack of regionalized data. To contribute in filling this gap, BRLUC method was developed by Novaes et al (2017), providing estimates of direct LUC and derived CO_2 emission rates disaggregated for 64 crops, pasture and forestry for each Brazilian state and a period of 20 years. However, to enhance its potential for use, BRLUC data should be also available in widely used LCA databases. The aim of this article is to present the general structure and adaptations needed to integrate Brazilian LUC estimates from BRLUC into the ecoinvent database v3.3, one of the main international life cycle databases. The main adaptation needs were diagnosed by a joint effort of Embrapa and ecoinvent teams and were: a) the inclusion of new products and land classes (*e.g pasture, man-made* and *forest, intensive),* b) segregation of emissions between 'land transformation' and 'land occupation' datasets; c) the conversion of the data structure to the 'land tenure' product model; d) the conversion of LUC substitution percentages into 'land tenure' production volumes and e) the inclusion and adaptation of new emission exchanges. By the automation of the data conversion through an algorithm in R, 418 datasets were generated for incorporation into ecoinvent database, which will increase and ease access to regionalized Brazilian LUC estimates to LCA practitioners.

Keywords: BRLUC method; land use change emissions; LCA of Brazilian products; regionalized LCA; LCA databases.

Introduction

Land use change (LUC) emissions represent a considerable share of global and agricultural products CO_2 emissions. Between 1990 and 2015, the world lost 129 million ha of forest area, mainly driven by conversion to agriculture and other land uses (FAO, 2015). In consequence, the global carbon stocks in forest biomass have decreased by almost 11 Gt in these 25 years (FAO, 2015). In 2010, approximately 11% of all anthropogenic greenhouse gases (GHG) emissions could be allocated to LUC (IPCC, 2014). Agriculture is a relevant economic activity in Brazil and GHG emissions derived from it occupy an important role in Brazilian total emissions. In 2010, the CO_2 emissions derived from LUC in Brazil were about 0,3 Gt, which corresponded to 42% of total CO_2 net emissions in that year (Brazil, 2016).
Despite the agreed importance of LUC emission for agroindustry activities, a methodological consensus for LUC estimations in LCA studies is still under debate (Nemecek et al, 2014, Rosa et al, 2016). Nemecek et al (2014) introduced an updated methodology to estimate LUC emissions, which was included in ecoinvent database version 3. In a first screening, Nemecek et al (2014) focused only on the LUC from natural ecosystems and selected only few product datasets for which LUC emissions had been considered of major importance to be updated, including soybean and sugarcane from Brazil. However, the lack of specific regional data and the consequent need of large extrapolations led to some significant misrepresentation of LUC patterns, e. g., assuming that the land transformation patterns of Mato Grosso state to be representative for entire Brazil in soybean production dataset.
To fill this gap, BRLUC method (Novaes et al., 2017) was developed by a researcher team of Embrapa and KTH institute. The method provides estimates of direct LUC and derived CO_2 emission rates disaggregated for 64 crops, pasture and forestry for each Brazilian state and a period of 20 years. Based on historical data and in accordance with the approaches in IPCC (2006) and PAS 2050 (BSI, 2012), BRLUC made available a tool[11] with very detailed and updated LUC data that can be used in Life Cycle Assessment (LCA) and Carbon Footprints (CF) studies, considering the ecosystem and historical specificities of each state of the country.
However, to enhance its potential for use by LCA practitioners, the method should be also available integrated into LCA databases. To this, a joint effort between Embrapa and ecoinvent has been carried out so that the BRLUC data is available in one of the most used LCA databases, which currently has more than 13,300 datasets. The aim of this

[11] The most updated data is available in <www.cnpma.embrapa.br/forms/BRLUC.php>.

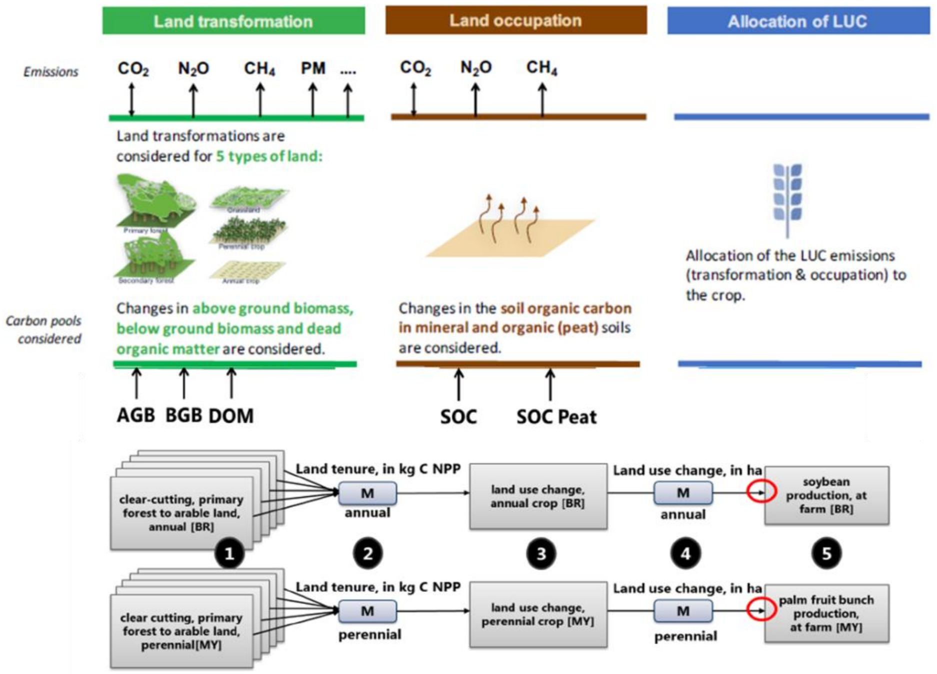
article is to present the general structure and adaptations needed to integrate Brazilian LUC estimates from BRLUC method into the ecoinvent database, that will be available in the next update of the ecoinvent database.

LUC modelling in ecoinvent v3.3

Nemecek et al (2014) presented the first updates of ecoinvent v3 database regarding LUC emissions. In version 3.1, the database first presented the methodological principles recommended by PAS 2050 to determine the expansion areas of land uses, considering a 20 years period. Also, in this version, four pools of carbon – i.e. aboveground biomass (AGB), belowground biomass (BGB), dead organic matter (DOM) and soil organic carbon (SOC) - were considered, as indicated by IPCC (2006). In addition, a new structure was conceived to consider the fluxes of land transformation activity separately.

During the update to ecoinvent database version 3.3, new data and a model for LUC from the World Food LCA Database (WFLDB; Nemecek et al, 2015) were included (Moreno-Ruiz et al, 2016). A major difference of this model is that LUC emissions were separated into three different new activities. Two of those, *clear-cutting* and *land already in use* activities, are related to land transformation and include fluxes of changes in vegetal carbon pools (AGB, BGB and DOM), other biomass burning emission etc. (Figure 1). The main difference between them is that *clear-cutting* refers to the land transformation from native vegetation and has emissions from biomass cutting and burning, which are not present in *land already in use*. The products of these activities are *land tenure*s, which are measured in kg C net annual primary productivity (NPP) and not square meters. The NPP concept was included to establish a common "currency" to account for the annual productivity of land in different geographies and to account for the productivity added by intensification (which cannot be accounted for with an area-based unit). Nevertheless, since all land transformation activities in a particular country rely on the same NPP value, the use of land tenure instead of m^2 does not cause any difference in area intensity among the land transformation activities.

Figure 20 – Summary of land use change modelling in ecoinvent v3.3.



Source: Reinhard, 2017 (modified)

The other new activity, *land use change,* is related to land occupation and includes emissions from changes in SOC, such as CO_2 and N_2O, and generates *land use change* as a product. Finally, the *land use change* can be allocated to the crop of interest (Figure 1), accordingly with land expansion data (Nemecek et al, 2015).

Another update in ecoinvent v3.3 was the consideration of five categories of vegetation for land uses, primary forest, secondary forest, grassland, perennial cropland and annual cropland (Figure 1).

Methodology

The methodology consisted of analyses of the LUC model adopted in ecoinvent v3.3 (Moreno-Ruiz et al, 2016, Nemecek et al, 2015) and identification of the required adaptations on BRLUC data (Novaes et al, 2017) to be incorporated to the ecoinvent database. In sequence, because of the numerous new datasets needed, a script in R software (R Core Team, 2016) had to be developed to replicate the required adaptations from BRLUC data for all Brazilian states and land uses and generate the Brazilian LUC datasets.

Results and discussion

In this section, we present the main adaptations and inclusions, segregated by topics, needed to integrate the Brazilian estimates from BRLUC (Novaes et al 2017) into ecoinvent v3.3. All changes were accorded among BRLUC and ecoinvent developers and always looking for an optimum between the level of detail and simplicity. The main differences between LUC approach in ecoinvent v2, v3.1, v3.3 and BRLUC datasets are summarized in Table 1 and in the following topics.

Table 1 – Structure comparative of LUC modelling in ecoinvent v2.2, v3.2, v3.3, BRLUC and BRLUC-ecoinvent data

	ecoinvent v2.2 2007	**ecoinvent v3.2 2013**	**ecoinvent v3.3 2016**	**BRLUC 2017**	**BRLUC–ecoinvent 2018**
Scope	Selected crops and countries: Soybean (BR), Palm fruit (MY)	Selected crops and countries: Soybean, Sugarcane (BR), Palm fruit (MY)	All crops in FAO database in country-level geographies	All crops in IBGE database plus forestry and pasture, all in state-level geographies for Brazil	All crops in IBGE database plus forestry and pasture, all in state-level geographies for Brazil
Method	No consistent methodology	Consistent methodology – Nemecek et al (2016)	Consistent methodology – WFLDB Method (Quantis adapted version of the Blonk tool)	Consistent methodology – BRLUC	Consistent methodology – this study
Land use classes	Primary (rain) forest to arable land	Primary forest, secondary forest, shrubland and grassland to arable land	Primary forest, secondary forest, primary grassland, secondary grassland and perennial land to arable land (annual crop and perennial crop)	Natural unspecified vegetation, sugarcane, annual crop, permanent crop, forest intensive and pasture/meadow to arable land (sugarcane, annual crop, permanent crop, forest intensive and pasture/meadow)	Primary forest, grassland, forest intensive, pasture man-made, perennial land and annual land to arable land (forest intensive, pasture man-made perennial crop and annual crop)

Source: Reinhard, 2017 (modified)

Inclusion and adaptation of new products and land use classes

Three land use classes that are segregated in the BRLUC model are not in ecoinvent v3.3: cultivated pastureland, forestry and sugarcane. In Brazil, they account for roughly 62%, 4% and 6% of the total agricultural area. Given their uniqueness and relevance, the first two classes were included as two new products in ecoinvent: *land tenure, arable land, pasture, man-made* and *land tenure, arable land*, *forest, intensive* and also as two new land use classes involved in land transformation and land use change activities. Their nomenclature was adjusted to reflect the standards used in ecoinvent 3 (Weidema et al 2013). In the third case, sugarcane is a separated land use class in BRLUC because of its nature as a semi-perennial crop with an intermediate carbon stock between annual and perennial crops and its relevance in terms of area in Brazil. However, given the uncertainty of sugarcane carbon stocks and the level of complexity it would add to the database as a separate category, it was decided to merge it into perennial cropland use class, as also assumed elsewhere (e.g. Moreira et al, 2014).

In the other hand, two disaggregations of land use classes are present in ecoinvent but not in BRLUC: native vegetation is segregated between forest and grassland types and also between primary and secondary types. Only the first case was implemented in BRLUC, following the classes from Brazil (2016). Regarding the second one, secondary forest and secondary grassland datasets weren't included for Brazil, as they have a low representativeness of native vegetation in the country according to the TNC (Brazil, 2016; only 4% in 2010).

Two other adaptions were implemented considered data structure. First, BRLUC tool considers crop areas disaggregated by species and, to be inserted in ecoinvent, they had to be grouped as annual or perennial croplands. Second, considering the ecosystem diversity of the country and the data source, BRLUC data is conceived to represent the mixture of ecosystems that form natural lands of each state. This means that BRLUC datasets of *clear-cutting, primary forest* and *grassland* consider average data of all ecosystems that correspond to those types of vegetation in each state, accordingly to Brazil (2016) which is currently not considered in ecoinvent.

Segregation of emissions between "land transformation" and "land occupation" datasets

When a land transformation is selected in BRLUC tool, the total CO_2 emissions derived from all the carbon pools together are shown. To adapt these data to ecoinvent v 3.3 structure, emissions had to be separated in datasets of *land transformation* and *land use change*, as described above (Figure 1). In practice, the main difference is that in the first group of datasets the exchanges related to biomass carbon pools (AGB, BGB and DOM) are accounted while in the second only soil carbon pools (SOC) do so.

Unit of land accounting

To create a land transformation dataset, a continental value of kg C net annual primary productivity (NPP) should be chosen to represent the potential productivity of a land tenure. This concept and estimated values are presented in Haberl et al. (2007), including the NPP estimate for Latin America and the Caribbean (0.811 g $C/m^2/yr$), which was considered for Brazilian LUC datasets.

Shares of land transformation and land 'Production Volumes'

In ecoinvent v3, all activities include data for annual production volume, which are used to compound global or regional market datasets in the system model database. In both cases, the datasets are generated by using a production-volume (PV) weighted average of all local datasets, or all relevant producers or importers for a specific market, determining the shares of different activities providing the same product (Wernet et al, 2016).

In case of land transformation datasets, the annual production volumes are expressed in NPP as an indirect measure of area. This is a key information for the emission results as it determines the proportion of each land transformation for the total current crop area under consideration. In BRLUC and most of the methods, this is expressed as the percentage of each land use the reference product expanded over, e.g. X% of current sugarcane area in São Paulo expanded over pastureland and Y% over annual cropland considering the last 20 years. In ecoinvent v3.3 all these information and associated errors are structured in the market datasets, which retrieve them from production volumes of land transformation activities. To integrate BRLUC data into ecoinvent, each of those percentages is multiplied by the total PV value of the reference product, which by Ecoinvent default is given by the Eq 1. The 6.23% value comes from the proportion Brazilian Total Biomass Appropriation (TBA) in relation to the total sum of TBA of the World, according to Krausmann et al. (2008, Supplementary Table 5).

$$(1)\quad Total\ PV\ ammount = Current\ area\ of\ reference\ product\ (ha) * NPP\ value * 6.23\% * (20-1)\ years$$

Moreover, for each type of land transformation, BRLUC presents percentages in proportional, maximum and minimum scenarios, which are derived from CO_2 emissions optimizations (see Novaes et al, 2017 for details). For the adaptation to ecoinvent v3, the proportional value is converted in the PV amount and the maximum and minimum values in the extremities of a triangular distribution in the uncertainty field of this PV. The same had to be conducted for land use change datasets, but in this case, the ecoinvent default is the current area of reference product multiplied by Brazilian TBA (6.23%; see above).

Inclusion and adaptation of exchanges

BRLUC tool presents only CO_2 emissions derived from carbon pools change while ecoinvent has many other exchanges related mainly to the cutting and burn of native vegetation. Seeking homogeneity, the integration of data in ecoinvent database demanded to complement it with more exchanges, both inputs and outputs, which are presented in Table 2. For land occupation datasets, the fluxes related to organic soil emissions were not accounted for Brazilian datasets because of the low representativeness of this kind of soil in the country (Brazil, 2016). Also, adaptations were made in some exchanges by changing parameters to local ones, e.g., the percentage of woodcut and wood burned in primary forest (taken from Brazil, 2016).

Not all datasets display all the listed exchanges as this depends on the specificities of land transformation. Some datasets present *Carbon dioxide, from soil or biomass stock* flow, due to the difference between before and after vegetation carbon pools results in a carbon emission, while other datasets present *Carbon dioxide, to soil or biomass stock* flow because of that difference results in a carbon sequestration. Furthermore, the flows can vary for different states with the same land transformation, for example for *clear-cutting, primary forest to arable land, perennial crop* dataset, the most part of states shows carbon emission, but for Alagoas, where the average ecosystems that compose the primary forest have a lower carbon pool than perennial croplands, this transformation results in a carbon sequestration.

Table 2 – Included exchanges for integration of BRLUC data into ecoinvent v3.3

Dataset type	Flows
Land transformation (e.g. ***clear-cutting, primary forest to arable land, annual crop***; ***land already in use, pasture, man made to perennial crop***; etc)	Energy, gross calorific value, in biomass…
	Occupation, construction site
	Transformation from…
	Transformation, to arable land, unspecified use
	Diesel, burned in building machine
	Power sawing
	Carbon dioxide, from soil or biomass stock
	Carbon dioxide, to soil or biomass stock
	Carbon, organic, in soil or biomass stock
	Carbon dioxide, in air
	Specific emissions from biomass burning (nitrogen oxides, propane, etc.)
Land occupation (e.g. ***land use change, annual crop***; ***land use change, forest, intensive***; etc.)	Land tenure, arable land, measured as carbon net primary productivity…
	Dinitrogen monoxide
	Carbon dioxide, from soil or biomass stock
	Carbon, organic, in soil or biomass stock
	Carbon dioxide, to soil or biomass stock
	Carbon dioxide, in air

Automation of datasets via R

The adaptation of BRLUC data came out the inclusion of 28 Activity Names for all the 27 Brazilian states (including the Federal District), resulting in 418 new datasets to be incorporated in the ecoinvent database. Given this volume, it was deemed unfeasible to fill the information though Ecoeditor. To overcome this, ecoinvent provided a spreadsheet model in which we could automate the information filling by using a script of R software (R Core Team, 2016), in which BRLUC was already structured. By doing this we optimized time in preparing the files, avoided mistakes in filling them and prepared a framework that will allow the easy update of the data according to advances in one of the models. In the end, the datasets were submitted to ecoinvent in a spreadsheet with a total of 10,446 lines and 42 columns.

Conclusion

This is the first effort to include regionalized LUC datasets for crops, forestry and pasture into ecoinvent database (Table 1). The diagnosis, evaluation and implementation of the adaptation needs in both frameworks proved to be a complex task and was only feasible through an intense collaboration between Embrapa and Ecoinvent, the dedication of five months and automation through an R script. All these adaptations are now implemented and resulted in a total of 418 datasets that are currently under ecoinvent review phase and are expected to be available in the next version of the ecoinvent database (v3.5).

Novaes et al (2017) first contributed to fill the gap of regionalized Brazilian LUC estimates for pasture, forestry and a large set of crops in a consistent way. With the effort presented here, we expect to increase the availability and ease of use of those estimates, by integrating them in one of the most relevant LCA databases in a standardized framework for all over the world. We expect to allow practitioners from Brazil as well as other interested countries to have their LCA studies based on more precise and reliable data of LUC associated to Brazilian agriculture.

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