Indirect Land Use Change and GHG emissions of two biodiesel pathways in Spain

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ABSTRACT

Imported biodiesel has accounted for a large share of the total amount consumed in Spain, the main supplier of which was Argentina at least until anti-dumping duties on biodiesel imports from this origin were approved by the European Commission in November 2013. A consequential LCA is carried out in the present study to compare this pathway, which was the prevailing one until almost 2014, with the alternative of using domestic biodiesel from Used Cooking Oil (UCO). System expansion is performed in order to take the indirect functions of both systems into account, functions arising from interactions between co-products (protein meals) in the animal feed market. The marginal suppliers of these co-products in the international market are identified and emissions from direct and indirect Land Use Change (LUC) are calculated. When they are not considered, imported soybean biodiesel leads to lower GHG emissions, due to the carbon uptake by biomass. However, when global LUC is taken into account, UCO biodiesel generates a much lower impact, because it causes a contraction in the area diverted to biofuel feedstock production in other parts of the world. The results underline the importance of considering emissions from LUC when comparing biodiesel alternatives and, thus, interactions in the global market must be addressed.

Keywords: biodiesel, consequential LCA, greenhouse gas, land use change, Used Cooking Oil

1. Introduction

Over the last ten years, the worldwide consumption of biofuels has been on the rise for both economic and political reasons. Together with rising oil prices, public policies have been instrumental in promoting the use of non-petroleum based fuels in countries such as the United States (US), Brazil or the European Union (EU). Specifically, European Directive 2009/28/CE aims to reduce the greenhouse gas (GHG) emissions by introducing a blending mandate of 10% biofuel share in the motor fuel market of the Member States by 2020. However, despite the increased demand for biodiesel in Spain as a consequence of this Directive, the biodiesel sector is currently working at around 10% of its total production capacity. While the renewable energy target in transport, which was 6.5%, was nearly reached in 2012, in that very year imported biodiesel accounted for 79% of the market share (Datacomex 2013). Most of this biodiesel was imported from Argentina, providing almost half of the total consumed.

In addition, this Directive sets out a sustainability criterion requiring biofuels to emit at least 35% less GHG than the replaced fossil fuel; emissions must be calculated over the entire life cycle and must include the emissions from land conversion necessary for the cultivation of the raw materials. This phenomenon, known as Land Use Change (LUC), refers to potential changes in the carbon stock of the soil and biomass that take place when the land is diverted to biofuel production. Apart from the direct LUC (dLUC) as a consequence of an increased demand for biofuels, indirect LUC (iLUC) takes place through global market-mediated effects, prompted by the displacement of existing productive uses. In an attempt to promote the production of biofuels which do not lead to substantial losses of land carbon stock either in the producing region or elsewhere (known as *advanced* biofuels), the EU recently launched another proposal, COM 595 (European Commission, 2012), still under debate. It seeks to minimize GHG emissions from iLUC by limiting the contribution of conventional biofuels to that 10% target, and obliging Member States to report the estimated iLUC emissions from the biofuels they produce.

Against this background, the production of biodiesel from Used Cooking Oil (UCO) in Spain may help to increase the energy independence and boost the national industry, given the requirements imposed by COM 595. In fact, UCO was the second most commonly used feedstock for producing domestic biodiesel in 2011 (CNE 2013). Hence, it constitutes a viable alternative to the importing of biofuels, especially to those coming from feedstock used in the food and feed markets (known as *first generation* biofuels). The aim of this study is to compare overall GHG emissions –including those from iLUC– of two current pathways for biodiesel consumption in Spain: importing soybean biodiesel from Argentina and producing biodiesel from UCO. It must be taken into account though that the imports of biodiesel from Argentina have markedly declined during the first few months of 2014, as a consequence of the anti-dumping duties which have recently been approved by the European Commission (Regulation 490/2013). However, most of the biodiesel is currently produced from imported feedstock, and imports of vegetable oil into the EU have been increasing sharply. Soybean oil from Argentina accounts for a remarkable market share in Spain, only surpassed by palm oil imports from Malaysia and Indonesia. Therefore, this pathway for biodiesel consumption still has iLUC effects, similar to those arising from importing the manufactured product, with the only difference that now the transesterification takes place in Spain.

2. Methods

2.1. System description

A consequential approach is used to perform LCA according to the ISO standards (ISO 2006a, b); this is because crop displacement is the result of interactions among global agricultural markets and, as such, this is the way to quantify these future indirect responses. Economic modeling is a very useful tool with which to quantify these effects, and it has been used by authors such as Banse et al. (2010), Hertel et al. (2010) or Kløverpris et al. (2008) in the field of bioenergy. However, some practitioners have developed a methodology for quantifying the environmental consequences of increased biofuel consumption within the LCA framework (Dalgaard et al. 2008; Reinhard and Zah 2009, 2011; Schmidt 2010; Schmidt and Weidema 2008). It is based on system expansion, in order also to include interactions due to biofuel co-products such as protein meals, which may fulfill different functions in other markets. These studies are built on causal relationships, which model the substitution effects between those *marginal suppliers* affected by changes in the production system. The marginal supplier of a co-product is defined by Weidema (2003) as the most competitive in the international market. For each co-product, the marginal supplier of the substitute must be identified.

According to the procedure described by Weidema (2003), two scenarios are defined: Scenario 1, where soybean biodiesel is imported from Argentina, and Scenario 2, where it is produced from UCO collected in Spain. The functional unit is 1 MJ of biodiesel in regional storage in Spain. Scenario 1 mainly consists of *soybean farming*, *soybean oil extraction* and the subsequent oil refining, *soybean methyl-ester (ME) production* by transesterification and *soybean ME export to Spain* by tanker. Scenario 2 includes *UCO collection*, *UCO-ME production* and *transport within Spain*. Furthermore, due to market responses, a loop between co-products is identified and iterated against 0 to estimate the indirect effects of 1 additional MJ of biodiesel consumed in Spain, following the same principles used by Dalgaard et al. (2008) and Reinhard and Zah (2009).

In Scenario 1, it is assumed that increasing the production of soybean ME in Argentina to meet the Spanish demand reduces the amount of soybean oil in the international market, the shortage of which has to be compensated for by Malaysia as the marginal supplier of vegetable oil. According to the *ceteris paribus* assumption (Ekvall 2000), the demand for Malaysian oil expands 1:1, with the subsequent expansion in the agricultural land. As side effects, palm kernel meal production increases too, affecting the demand for Brazilian soybean meal in the animal feed market. The loop between the soybean meal and the soybean oil leads to a net increase in the production of palm oil in Malaysia (+25.27 g), and to a decrease in the production of soybean meal in Brazil (-3.44 g), as can be seen in Figure 1. The Argentinian soybean meal, obtained as a co-product of the oil extraction, is a stable commodity in the feed market, with a global demand which is assumed to remain constant despite the increase in demand for biodiesel in Spain. Hence, it is not involved in the loop.

In Scenario 2, using UCO to produce domestic biodiesel avoids the need to import crude palm oil from the marginal supplier, which is again assumed to be Malaysia, since palm oil stands out as the least expensive oil in the international market and Malaysia is the world's largest exporter (MPOB 2012). Similarly to Scenario 1, it is assumed that this country reduces palm oil production, and less palm kernel meal is thus available. The gap left in the market supply is filled with meal from Brazil, with the subsequent LUC effects. The resulting loop causes a contraction of palm oil production in Malaysia (-26.31 g) and an expansion of soybean meal production in Brazil (+3.58 g), as shown in Figure 2.

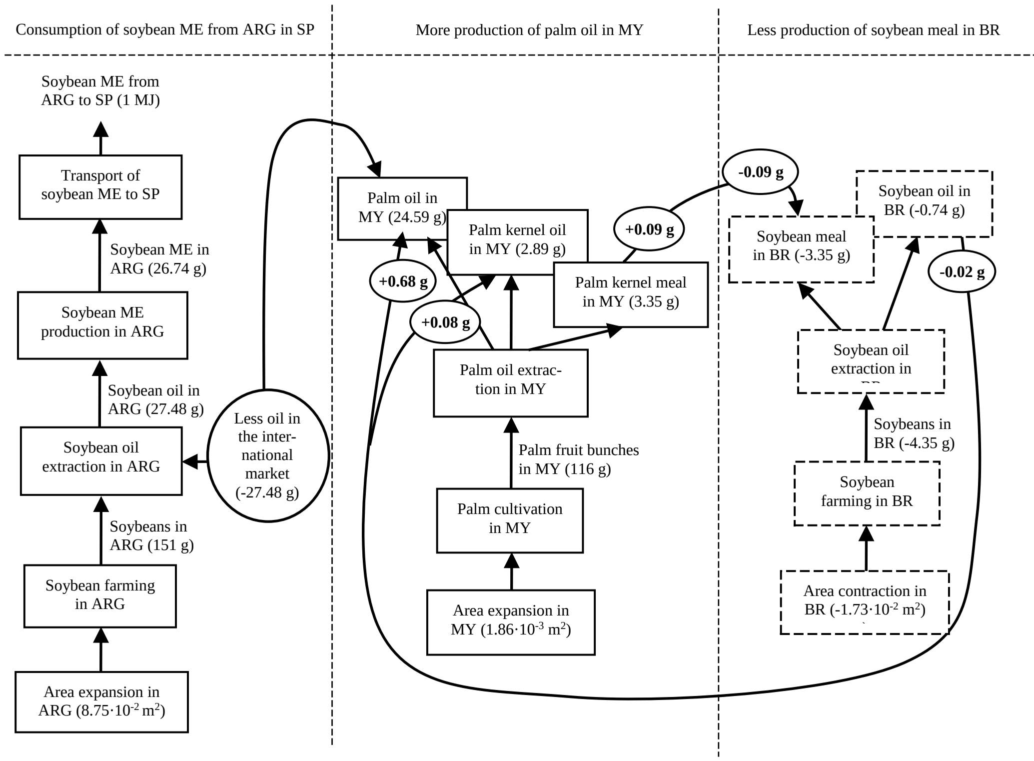

Figure 1. Delimitation of the system under study in Scenario 1. The loop between palm oil and soybean meal in the global market is iterated against zero and the resulting amounts of both are shown in the circles. SP: Spain; ARG: Argentina; BR: Brazil; MY: Malaysia.

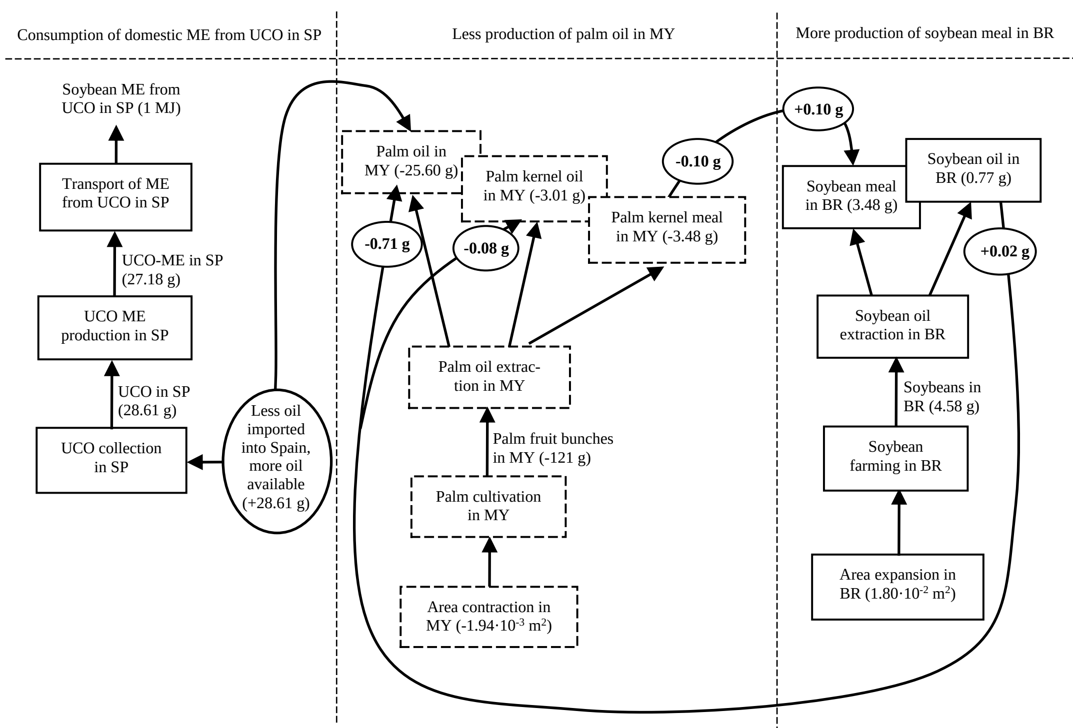

Figure 2. Delimitation of the system under study in Scenario 2. The loop between palm oil and soybean meal in the global market is iterated against zero and the resulting amounts of both are shown in the circles. SP: Spain; BR: Brazil; MY: Malaysia.

2.2. Inventory data

Inventory is drawn from primary and secondary data sources. In Scenario 1, the soybean ME pathway in Argentina is entirely gathered from the inventory of Panichelli et al. (2009). For the export sub-stage, it is considered that the biodiesel is transported first by lorry to the port of Rosario, then to Rotterdam (The Netherlands) by transoceanic tanker, and finally to Valencia (Spain) by lorry. In Scenario 2, all the data relative to the UCO-ME pathway in Spain is provided by the company Bionorte (Asturias, Spain), a representative company of the sector. The distance for the transport of UCO-ME within Spain is that between Bionorte and Valencia, whereas the UCO collection distance is estimated to be 100 km, the same as in the study by Vinyes et al. (2013) analyzing the system consisting of urban collection points. The processes for the production of palm oil in Malaysia and soybean meal in Brazil, common to both scenarios, are taken from the Ecoinvent v.2.2 database (Hischier et al. 2010). The production and provision of all the inputs, including fuel and energy, is included in each sub-stage and taken from the same database, as well as the average transportation systems.

The CML 2 impact assessment method (Guinée et al. 2002) is applied to analyze the impact category Global Warming (GW, 100 years). GHG emissions from dLUC and iLUC are calculated and taken into account for the GW assessment. With this aim in mind, the area diverted to arable land must be multiplied by different emission factors depending on its previous use (forest, grassland, shrub land or other crops). These area values associated with each land transformation are taken from Ecoinvent v2.2 for the palm oil production in Malaysia. Updated values from Prudêncio da Silva et al. (2010) are used for the soybean production in Brazil, since they represent the situation in the Mato Grosso, a state which accounts for 87% of the soybean area in the country. Area values from Panichelli et al. (2009) are considered for the soybean crop in Argentina. Emission factors for each land conversion in each country are calculated by following the guidelines of the IPCC (2006), for a baseline of 20 years. Carbon losses are the result of differences in the carbon content in biomass, soil and dead organic matter before and after the LUC. When deforestation takes place, biomass burning is included, following the process in Ecoinvent v2.2.

3. Results

The GW results show that, without considering the LUC effects, imported soybean biodiesel leads to lower GHG emissions. The contribution of each sub-stage to the impact is shown in Figure 3, depending on whether they cause net GW *input* or GW *output*. Overall, Scenario 1 causes a negative impact (carbon uptake), whereas Scenario 2 causes net CO_2-eq. emissions. As can be seen, this is due to the photosynthesis of the soybean plants and palm trees in Argentina and Malaysia, respectively, which makes GW *input* larger than GW *output* in Scenario 1. In Scenario 2, the only process causing carbon uptake is the soybean farming in Brazil, which is not enough to offset net CO_2-eq. from the decreased palm oil production in Malaysia (through plant photosynthesis) and emissions from the other processes in the system. Carbon uptake by Malaysian palm trees counts as negative GW *input* (implying net emissions) in Figure 3 because 121 g fewer palm fruit bunches are produced due to interactions in the global market. As a result, GHG emissions from producing UCO-ME in Spain are 139% higher, relative to the reference situation of importing soybean ME from Argentina.

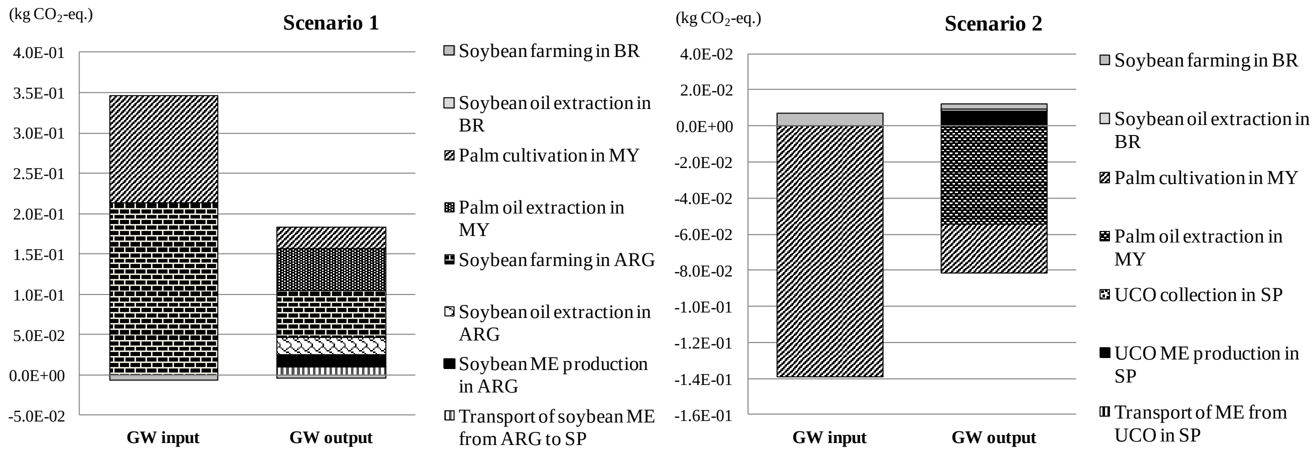

Figure 3. GW results of Scenario 1 and Scenario 2 without considering emissions associated with LUC. SP: Spain; ARG: Argentina; BR: Brazil; MY: Malaysia.

Figure 4 shows the GW results but includes GHG emissions from LUC in their calculation. The UCO-ME pathway then leads to an impact reduction of 103%. In Scenario 1, dLUC in Argentina releases 1137.5 g of CO_2 into the atmosphere, while iLUC in Malaysia is responsible for 221.1 g more, entirely caused by the deforestation of tropical forests; iLUC in Brazil generates an uptake (GW *input*) of 133.8 g of CO_2, because soybean production is falling. Emissions from the entire import chain of soybean biodiesel into Spain are 1028.6 g CO_2-eq., while compensating for the drop in the oil available in the international market with Malaysian palm oil releases another 35.1 g of CO_2-eq. into the atmosphere, even including net carbon uptake in Brazil. As a result, GW *output* is greater than GW *input*, and Scenario 1 generates 1063.7 g of CO_2-eq. On the contrary, Scenario 2 causes a negative overall GW (GW *input* > GW *output*). UCO-ME avoids the production of 28.6 g of CO_2-eq., mainly as a consequence of the area contraction in Malaysia, which causes an uptake of 230.6 g of CO_2, while increasing the agricultural land diverted to soybean in Brazil generates 139.4 g of CO_2.

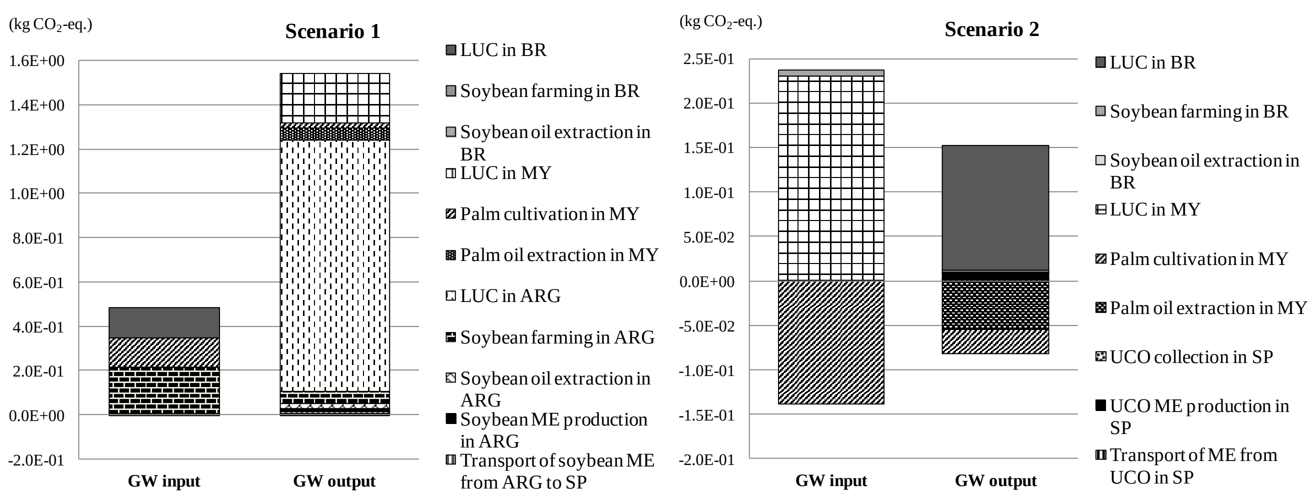

Figure 4. GW results of Scenario 1 and Scenario 2 by taking emissions associated with global LUC into account. SP: Spain; ARG: Argentina; BR: Brazil; MY: Malaysia.

4. Discussion

In Scenario 1, increasing the consumption of biodiesel in Spain by 1 MJ triggers market-mediated responses which, in turn, cause direct land transformation in Argentina, deforestation in Malaysia and area contraction in Brazil. As a result, $8.75 \cdot 10^{-2}$ m^2 of land are diverted to soybean in Argentina, which come from other crops (32%), forest (22%), pasture (27%) and shrub land (19%), according to Panichelli et al. (2009). Similarly,

$1.86\cdot10^{-3}$ m^2 of forest are diverted to palm in Malaysia, whereas in Brazil there is an area contraction of $1.73\cdot10^{-2}$ m^2. These values are reported in Table 1. Scenario 2 causes an increase of $1.80\cdot10^{-2}$ m^2 in the agricultural land in Brazil, while there is a contraction in Malaysia of $1.94\cdot10^{-3}$ m^2, as shown in Table 2. Emissions from iLUC are responsible for 92.8% of the GW *input* in Scenario 2, whereas iLUC emissions account for only 8.2% of the overall CO_2-eq. released into the atmosphere by the system in Scenario 1. The most influential sub-stage in Scenario 2 is thus related to an indirect function.

Table 1. LUC results per MJ of biodiesel consumed in Spain in Scenario 1, including direct (in Argentina) and indirect effects (in Malaysia and Brazil).

	Soybean farming in ARG	Palm cultivation in MY	Soybean farming in BR
Transformation from arable land, non-irrigated crops [m2/MJ]	$2.80\cdot10^{-2}$	0	$-1.65\cdot10^{-2}$
Transformation from forest, clear cutting [m2/MJ]	$1.93\cdot10^{-2}$	$1.86\cdot10^{-3}$	$-1.73\cdot10^{-4}$
Transformation from pasture and meadow [m2/MJ]	$2.36\cdot10^{-2}$	0	0
Transformation from shrub land [m2/MJ]	$1.66\cdot10^{-2}$	0	$-5.88\cdot10^{-4}$
Land Use Change, transformation to arable land [m2/MJ]	$8.75\cdot10^{-2}$	$1.86\cdot10^{-3}$	$-1.73\cdot10^{-2}$

Table 2. LUC results per MJ of biodiesel consumed in Spain in Scenario 2, in terms of only indirect effects (in Malaysia and Brazil).

	Palm cultivation in MY	Soybean farming in BR
Transformation from arable land, non-irrigated crops [m2/MJ]	0	$1.72\cdot10^{-2}$
Transformation from forest, clear cutting [m2/MJ]	$-1.94\cdot10^{-3}$	$1.80\cdot10^{-4}$
Transformation from pasture and meadow [m2/MJ]	0	0
Transformation from shrub land [m2/MJ]	0	$6.12\cdot10^{-4}$
Land Use Change, transformation to arable land [m2/MJ]	$-1.94\cdot10^{-3}$	$1.80\cdot10^{-2}$

These land transformation values for Malaysia correspond to the estimations of Jungbluth et al. (2007), based on historical data for different bioenergy crops. From this, it follows that 100% of the LUC in Malaysia takes place at the expense of tropical rainforests. This type of land conversion leads to substantial carbon losses according to the IPCC (2006), mainly due to the changes in the carbon stock in aboveground and belowground biomass, including dead organic matter, such as wood debris, whose presence is remarkable in areas of tropical rainforests. On the contrary, the establishment of palm oil plantations can generate a gain in the soil carbon stock if it implies reduced tillage with low input, which can even improve the characteristics of the prevailing acidic soils. As can be seen in Figure 4, GHG emissions from iLUC in Malaysia make a significant contribution in both scenarios, since they are enough in themselves to offset the carbon fixation by palm trees during the photosynthesis after the land conversion. However, it must be taken into account that the land transformation values associated with each bioenergy crop are subject to change depending on the temporal and spatial framework considered. As an example, Germer and Sauerborn (2008) found that establishing palm oil plantations in anthropogenic grasslands, which are readily available in Southeastern Asia (long ago converted from forest), can significantly improve the GHG balance of palm oil, after rehabilitation.

Similarly, in our case study, LUC in Brazil occurs at the expense of other arable crops in almost the entire area, but also at the expense of forest (1%) and shrub land (3.4%), according to the situation described by Prudêncio da Silva et al. (2010) for the Mato Grosso. These values are based on historical data for the period 2005-2008. However, soybean expansion has also taken place in Southern States, such as Paraná or Rio Grande do Sul, with a long-standing tradition of agriculture. According to estimations by the same authors, if this second possibility was considered, there would be neither transformation from rainforest nor from savanna. This would even improve the GHG balance of Scenario 2, since the GW *output* would decrease, whereas the GW *input* would be lower in Scenario 1.

As regards LUC in Argentina, land transformation values assumed by Panichelli et al. (2009) are based on 2000-2005 data (Gasparri et al. 2008), a period of great expansion in soybean production in Argentina due to the consolidation of the biodiesel sector in regions such as the EU. It can be assumed though that this situation barely changed during the 2005-2008 period (consistent with data for Brazil). In fact, deforestation still takes place in the region of El Chaco (Aide et al. 2013; Gasparri and Grau 2009). However, considering LUC patterns in the central region of the country (Buenos Aires, Córdoba and Santa Fe) would lead to different results, since there are no native forests and soybean expansion mainly occurs at the expense of other crops.

Considering LUC in Indonesia instead of in Malaysia may have led to different transformation values in Tables 1 and 2 as well, although the emission factors calculated from the IPCC (2006) guidelines for tropical forests should be the same. According to data from the UN-RED programme launched by the United Nations and with the support of the Food and Agriculture Organization (FAO) –among other partners–, in the 20 years from 1983 to 2003, there was a reduction of about 4.9 Mha of forest cover in Malaysia, or an average of 250,000 ha of forest lost annually. However, a recent study by Margono et al. (2014) reveals a loss of primary forest in Indonesia of over 6.02 Mha from 2000 to 2012. Only in 2012, Indonesia lost 840,000 ha of its primary forest, becoming the world's third largest producer of GHG behind China and the US, with 85% of its emissions coming from forest destruction and degradation. This shows that deforestation rates can be highly variable depending on the period considered, and highlights the need to update conversion rates (in terms of ha/year) for each country in databases such as Ecoinvent, in particular for tropical regions in which the palm industry is still expanding. Thus, new rates should be consistent with spatially and temporally explicit observations, since they ultimately determine overall LUC.

This discussion may also contribute to the debate on land use transitions. This concept simply refers to any change in land use systems from one state to another one, while trying to understand the ecological, social and economic circumstances which trigger specific transitions observed in different regions. Specifically, forest transitions have been widely studied, firstly in Europe and the US, and more recently in tropical and sub-tropical regions, in order to explain alternating periods of deforestation and reforestation. According to Lambin and Meyfroidt (2010), LUC is a non-linear phenomenon, which is associated with other biophysical and societal changes and must thus take into account both socio-ecological and socio-economic considerations. For the present study, it has been assumed that LUC effects occur on a global scale, implying that reforestation in one region must be compensated by deforestation in another region, in order to produce the commodities which are no longer produced in the first region. The globalization of timber and agricultural markets is also mentioned by Lambin and Meyfroidt (2010) as an example of a socio-economic force influencing land use transitions. However, due to its dynamic nature, a transition is not a fixed pattern and other political, technological or demographic scenarios could be considered, also including micro-economic considerations about the land tenure system in each region. For instance, it still remains to be seen what will happen with that degraded grassland declared available by Germer and Sauerborn (2008) in Southeastern Asia, whether it will be converted to palm plantations or to tropical forest, depending on government initiatives.

5. Conclusion

As could be expected, biodiesel produced in Spain from domestic UCO performs better than imported soybean biodiesel from Argentina in terms of GW. However, these environmental benefits are not detected if emissions from LUC are not taken into account for the LCA, which can be used as biased results in favor of first generation biofuels, arguing that feedstock production causes carbon uptake due to the photosynthesis and soil carbon storage. Fortunately, most of the recent biofuel policies have mainstreamed iLUC concerns, arising from the increase in the worldwide production of bioenergy. Addressing iLUC effects is thus not temporary, and the consequential approach appears to be an appropriate way of quantifying them within the LCA framework, although there is no consensus on the methodology to apply. The present study shows a case study by using a methodology already developed and accepted within the LCA community, which can contribute to the promotion of the use of biofuels from non-edible biomass (as required by COM 595). This procedure provides additional insights in the analysis of ILUC effects due to a biofuel mandate at country level, which can be used for policy analysis. The results underline the importance of considering indirect effects of biofuel pathways; for this purpose, an analysis of interactions between co-products in the international market is required. A thorough analysis of the uncertainty is recommended in order to reinforce confidence in the comparative assessment, including the variability in land transformation values.

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