Evaluating methods to account for the greenhouse gas emissions from Land Use Changes in agricultural LCA

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ABSTRACT

Approaches to account for land use change-related GHG emissions (LUCE), differing on the basis of the spatial allocation of the emissions, were compared in this study, and the justification of their application was evaluated based on generally accepted criteria from ISO 14040, PAS 2050 and IPCC guidelines. In general, most methods technically fulfilled those criteria, with exception of the "Worst case" or marginal approach which resulted in multiple counting of global emissions. The selection amongst the acceptable methods still remains rather subjective. The conclusions of agricultural LCA studies, related for example to the GHG emissions from livestock feed, are strongly dependent on the selected method, and for this reason a universally accepted single method is needed. One solution might be an application of a modified "Top down" method, which takes into account emissions from indirect LUC and the actual drivers affecting them.

Keywords: global warming potential, greenhouse gas emissions, land use change, livestock feed, soy

1. Introduction

It is becoming increasingly evident in agricultural LCA, especially of livestock production, that selecting the method for accounting for the greenhouse gas (GHG) emissions from land use change (LUCE) is probably the most critical step of the assessment (e.g. Leinonen et al. 2013; Middelaar et al. 2013). At present, there are several different approaches to LUCE, which may give highly varied estimates for the emissions for different agricultural crops, and therefore may have strong impacts on the conclusions of the study in question. Therefore, it is obvious that some kind of agreement on the LUCE accounting methodology is needed, and the criteria for selecting the method should be clearly specified.

Most of the recent LCA studies on agricultural production have aimed to fulfil the requirements of the ISO 14040 standard (BSI 2006), the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), and more recently, also the more detailed methodological criteria described in the Publicly Available Specification PAS 2050:2011 (BSI 2011). As a result, it could be expected that the methods quantifying the GHG emissions arising from land use change (LUC) should follow the same criteria.

Some common principles required for the methods accounting for LUCE can be identified from the three documents mentioned above. One of such principles is that when quantifying existing LUC emissions, an attributional approach should be applied, meaning "*LCI modelling frame that inventories the inputs and output flows of all processes of a system as they occur*", as defined in ILCD (2010) . This requirement is the one of the overall principles of PAS 2050:2011, and it is stated there as "*unless otherwise indicated, the assessment of the life cycle GHG emissions of products shall be made using the attributional approach, i.e. by describing the inputs and their associated emissions attributed to the delivery of a specified amount of the product functional unit*". Similarly, as the IPCC guidelines aim to quantification of the national GHG emissions, they also concentrate on the existing state, i.e. apply attributional approach as opposed to consequential, which would be applicable for scenarios of potential changes in the future.

A logical consequence of the attributional approach is that the analysis must fulfil the criteria of mass and energy conservation. This is directly stated in the ISO 14040 as "*As each unit process obeys the laws of conservation of mass and energy, mass and energy balances provide a useful check on the validity of a unit process description*". Also, the IPCC Guidelines recommend checking the mass balance of the emissions, "*to avoid omissions or double counting*".

The requirement of mass conservation is also related to some of the criteria of PAS 2050. These criteria include the following:

1) Completeness: "*all product life cycle GHG emissions and removals arising within the system and temporal boundaries for a specified product which provide a material contribution to the assessment of GHG emissions arising from that product have been included*", and

2) Consistency: "*assumptions, methods and data have been applied in the same way throughout the quantification and support reproducible, comparable outcomes*".

In the following, some generally used methods for accounting for LUC-related emissions in LCA studies are considered, the justification of their use is evaluated in terms of the criteria specified above, and their consequences on the application in agricultural LCA are demonstrated. In the latter, the Global Warming Potential of broiler feed is used as an example.

2. Methods

2.1. Alternative approaches to LUCE accounting

In an ideal situation, the net emissions of greenhouse gases from a certain land area, arising as a result of agricultural LUC, should be quantified and allocated to crops that are grown within this area during the time period when the LUC-related emissions are considered to occur. In PAS 2050:2011, this is the preferred situation and is defined as "*where the country of production is known and the previous land use is known, the GHG emissions and removals arising from land use change shall be those resulting from the change in land use from the previous land use to the current land use in that country*". In this paper, this approach is referred as the "Actual LUC scenario". In practice, this approach could be applied to crops originating from a country where no LUC is known to occur, or alternatively to crops that come from a country where LUC may have occurred, but that specific crop is certified to originate from "mature" agricultural land, i.e. land from which no more LUC emissions are assumed to arise. This stage is generally considered to be reached after a selected amortization period (typically 20 years).

In several practical situations, it is not possible to know the exact origin of a certain agricultural commodity, and therefore it is not known whether it originates from land recently converted to agricultural use and whether the LUC-related emissions should be included in the carbon footprint of that product. A solution for this is to quantify the overall LUC emissions from the production of a certain crop within a bigger area, e.g. a country or a region, and then allocate the emissions evenly to that crop, produced at any location within that area. PAS 2050:2011 gives two options for that approach. First, it is stated that "*where the country of production is known, but the former land use is not known, the GHG emissions arising from land use change shall be the estimate of average emissions from the land use change for that crop in that country*". Second, an even more general option in PAS 2050:2011 says that "*where neither the country of production nor the former land use is known, the GHG emissions arising from land use change shall be the weighted average of the average land use change emissions of that commodity in the countries in which it is grown*". In this paper, this approach is referred as the "Best estimate scenario".

An alternative approach to account for the LUC-related emissions considers both the direct and indirect LUC related to crop production. It can be argued that all agricultural activity has indirect LUC effects, i.e. growing more of any crop in any economically-connected location in order to meet global demand will increase the land use pressure elsewhere (although the opposite could happen in the case of intensification of the production). Thus, the global LUC emissions should be equally allocated to all crops per ha, regardless their actual location (Audsley et al. 2009). According to this scenario, equal LUC emissions of 1430 kg CO_2 ha^{-1} y^{-1} should be included in the production of all crops, regardless the country of their origin or the previous land use (Audsley et al. 2009). The GWP from LUC per kg of each feed ingredient is thus dependent on the land area required for its production, so for example crops with high yield per ha have lower LUC emissions than crops with low yield. There is also no distinction in the attribution of LUCE to crops with high or low rates of expansion. In this paper, this approach is referred as the "Top-down" scenario"

The main difference between the approaches described above is how the GHG emissions arising from LUC are allocated spatially, ranging from the level of a single field of a specific crop ("Actual LUC" scenario) to allocation evenly to all agricultural land ("Top-down" scenario). However, a completely different approach to account for LUC emissions has also been proposed, and it was actually included in the earlier version of PAS 2050 (BSI 2008). According to this approach, if the actual LUC emission factor for a certain crop is not known, the highest emission factor for the country of origin in question should be applied. In practice, this would generally mean that transformation from forest to agricultural land is automatically assumed. The idea of this approach is close to the concept of the marginal process, which is generally applied in consequential LCA. For example, according to this approach it can be considered that cultivation of soya is the driving force of the LUC occurring in South America. Therefore, any increase in the demand of soya will automatically lead to increasing LUC (for example clearing of the rainforest), and therefore all related emissions should be allocated to this specific crop. In this paper, this approach is referred as the "Worst case scenario"

2.2. Example problem: GWP of broiler feed

The importance of the selection of the LUCE accounting method is demonstrated in the following by calculating the Global Warming Potential (GWP) for broiler feeds, based on two alternative diets as applied during the whole production cycle. The diets applied here were the standard soy meal-based diet, generally used by broiler industry, and an alternative diet, where part of the soy has been replaced by field peas (up to 30% of the total mass of the feed). Leinonen et al. (2013) gives the more details and the justification of the composition of these diets.

In the calculations carried out for this study, the GHG emissions for soy production were included in the diets using each of the four accounting methods described above, i.e. 1) "Actual LUC", 2) "Best estimate", 3) "Top down" and 4) "Worst case" scenarios. The GHG emissions for soy production were calculated as follows. First, following UK import statistics, it was assumed that the soy originates mainly from Brazil (48%) and from Argentina (41%), i.e. from countries where recent LUC related to soy production has occurred. Then, the GHG emissions per land area for different LUC types and countries were specified on the basis of the guidelines given in BSI (2011). After that, the LUCE emissions were allocated to soy beans and subsequently to soy bean meal (and to other crops, depending on the scenario), following each of the above mentioned accounting method. In practice, this was done by using one of the following options: 1) It was assumed that the origin of the soy was known and certified, i.e. it originated from "mature" agricultural land, so no LUCE was allocated to soy ("Actual LUC" scenario). 2) The relative proportion of soy growing in land with a certain land use history, including "new" agricultural land converted from other land use types during the last 20 year period, was estimated on the basis of FAO (2011) statistics, and the weighted average of LUC emissions from these land use types was allocated to soy ("Best estimate" scenario). Leinonen et al. (2013) gives the details of the LUC calculations related to South American soy production. 3) The global LUCE were evenly allocated to all agricultural crops, so the emissions of 1430 kg CO_2 ha^{-1} y^{-1} were applied for all crops used in broiler feed, including soy ("Top-down" scenario). 4) The maximum LUCE, i.e. assuming conversion from tropical rainforest to agricultural land, was applied for all South American soy used in the feed ("Worst case" scenario). Finally, the GHG emissions from feed production, processing and transport were calculated using the method by Williams et al. (2010), and after adding the LUCE, as calculated separately for each scenario, the overall GWP per 1000 kg broiler feed was quantified.

3. Results

The results of the comparison of broiler diets (Table 1) show that the LUCE accounting method has a strong effect on the overall GWP estimate of the broiler feed. For example, in the case of the standard soya diet, the GWP is almost four times as high in the "Worst case" scenario as in the scenario where no LUCE are allocated to soy. However, even a more important consequence can be found when the two alternative diets are compared with each other. The question to be asked here is: does the use of alternative protein sources (in this case field peas) replacing soy reduce the GHG emissions arising from the feed? The answer depends clearly on LUCE accounting method selected. With the "Actual LUC" and the "Top down" methods, no major benefit can be achieved with the use of the alternative pea diet. If the "Best estimate" scenario is used, a relatively high 17% reduction in GWP occurs if the soya diet is replaced by the pea diet. However, with the "Worst case" scenario, a dramatic reduction by 41% can be achieved with the use of the alternative diet. All these different figures can be obtained without any actual physical differences in the systems in consideration; they are only a result of a subjective selection of the method, or traceability of the origin of feed ingredients. Thus the conclusion of agricultural LCA studies that have involved potential LUCE may have been strongly affected by other factors than the actual properties of the system themselves, as discussed below.

Table 1. Global warming potential per 1000 kg broiler feed (kg CO_2e) for either standard soy–based diet, or for the diet where up to 30% peas are used as protein source, using different methods for accounting for LUCE related to soya production.

	Actual LUC[a]	Best estimate	Top down	Worst case
Soy diet	788	1085	1003	3026
30% pea diet	770	902	983	1771
Pea/soy	0.98	0.83	0.98	0.59

[a] Assumes certified sustainable source i.e. no LUCE

The principal differences in the spatial allocation of LUCE of different accounting methods are demonstrated in Figure 1. This figure assumes a theoretical, simplified situation where the global crop production is equally divided between two countries (Country 1 and Country 2). Further, it is assumed that the Country 1 produces one single crop, and half of this crop is produced in an area that has been recently converted from another land use type (e.g. forest). Now in the "Actual LUC" scenario, all LUCE are allocated to the area where they occurred, while in the "Best estimate" scenario only half is allocated to this area, and in the "Top Down" only one fourth. However, in all these cases the global sum of the LUCE is the same, and equal to the actual emissions from the converted area. In contrast, in the "Worst case scenario", although the LUCE of the actually converted area equals the actual emission occurring in that area, the global estimate for the emissions is in this example double compared to its actual amount.

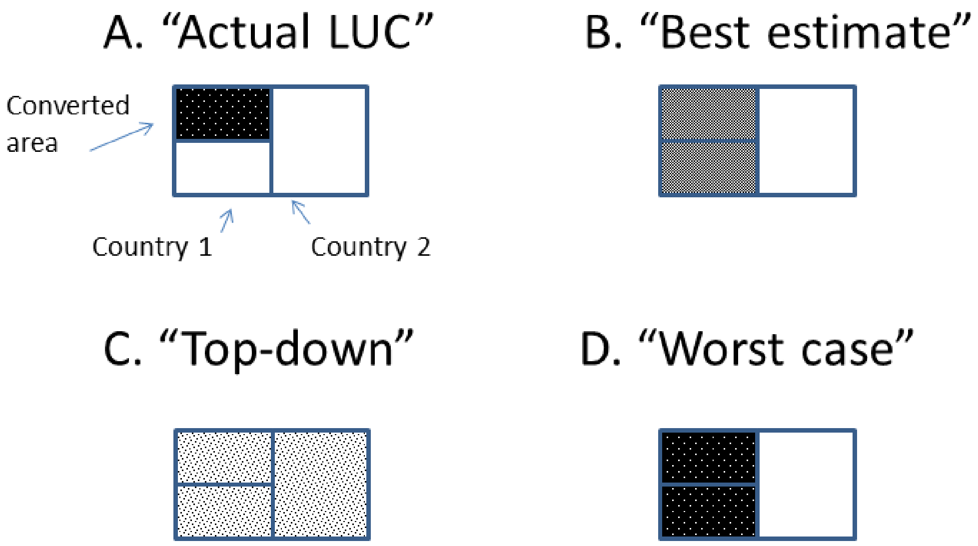

Figure 1. Demonstration of the spatial allocation of LUCE when different accounting methods are used. The darkness of the shading indicates the amount of emissions allocated per unit of land area. In the "Worst case" scenario, the total emissions are estimated to be higher than in the other scenarios, thus indicating double counting.

4. Discussion

When evaluating the alternative LUCE accounting methods against the criteria described above, the key questions are the following: First, does the method follow the principles of attributional LCA, i.e. does it model the systems as they occur or have occurred? Second, does it follow the principle of mass conservation, i.e. accounts for all emissions arising from LUC and allocates them to the products, and at the same time makes sure that no double counting occurs?

In theory, the first approach discussed above, the "Actual LUC" scenario clearly follows all these criteria. It considers a certain, known area of crop production, and as the history of this area is expected to be known, all emissions that have occurred as a result of possible LUC can be quantified, and allocated to the crops grown in this specific area.

It can be considered that the "Best estimate" scenario follows basically the same principles as the "Actual LUC" scenario. The only difference between these two approaches is the spatial scale. While the "Actual LUC" scenario specifies an actual location of certain crop, in the "Best estimate" scenario this area is extended to the whole area of this crop grown in a certain country, or in the extreme case in the whole world. Again, in theory, all the LUC emission within this extended area are accounted for and allocated to the specific crop grown in this same area. Thus, also this approach follows the principles of mass conservation, completeness and consistency.

Although the starting point of the third approach, the "Top-down" scenario, seems different than the first two approaches, as it is based on the concept of including both direct and indirect LUC, it actually can be seen as a further extended version of the "Best estimate" scenario, and it also avoids any double counting. In this approach, all agricultural crops are considered as a uniform group, instead of separating single crops as in the other approaches. The area under consideration is the whole cropland of the world, not the area of any specific crop as in the other approaches. Therefore, it can be concluded that theoretically all these three approaches to LUC accounting are based on the principle of mass conservation, and they fulfil the requirements of ISO 14040, PAS 2050:2011 and the IPCC guidelines. As a result, there is no scientific reason to reject any of these three approaches, and the selection of one of these methods is very much dependent on aim of the study and the availability of the data.

The fourth method, the "Worst case" scenario, is based on the principles of marginal processes, generally applicable in consequential LCA. However, by definition, PAS 2050:2011 is based on the attributional approach, and the same principle is also obvious in the IPCC guidelines. Therefore, it is clear that in any studies following these principles, marginal LUC accounting would not be an acceptable method. The practical consequence when using this approach would be multiple counting of the LUC effect, and therefore considerable overestimation of the GHGs arising from LUC. However, in reality this approach is widely used in literature, also in connection of attributional studies, and this can partly explain the big differences observed in the LUC effect in different studies.

As the results of the broiler feed example above demonstrate, the conclusions of an LCA study on agricultural products, whenever crops with potential LUC are involved, can be solely determined by the selected LUCE accounting method. Probably one of the most significant areas where this problem occurs is the evaluation whether reduction of soya in feeds can reduce the GHG emissions arising from livestock production, and this is where the profound effect of the selection of the methodology has been demonstrated in earlier studies by for example Leinonen et al. (2013) and Meul et al. (2012). In another similar study, Nguyen et al. (2012) quantified the global warming potential of poultry feed, and found a relative moderate potential for reduction of the impact by changing the composition of the feed. One reason for this result is that they used the "Best estimate" approach for LUCE from Brazilian soy (Prudêncio da Silva et al. 2010), based on regional, rather than national averages of production. As a result, the LUCE allocated to soy were relatively low, and therefore removing soy from the diet had only slight effect on the overall GWP. A completely different approach was taken in a recent FAO report, (McLeod et al. 2013), where the global GHG emissions from global pig and poultry production were estimated. In this case the "Worst case" scenario was applied for Brazilian soy, as stated by the authors: "*We thus assume that all incremental soybean area [in Brazil] is gained at the expense of forest area*".

In general, despite its inconsistencies and double counting of the emissions, the "Worst case" approach is apparently still used in agricultural LCA studies. One reason for this is that it was recommended in the earlier version of PAS 2050, the UK specification for assessment of GHG emissions (BSI 2008), before it was replaced by the "Best estimate" approach for its current version (BSI 2011). However, it is interesting that recently some supplementary requirements of PAS 2050 for horticultural products have been published (BSI 2012), and in these requirements further details for LUCE accounting were provided in a way which seem to contradict the general guidelines of PAS2050:2011. In these new requirements, it is stated that: "*To promote the collection of primary data on land use change the principle is adopted that these emissions should not be underestimated. Therefore in deviation of PAS 2050:2011 5.6.2.b, the highest calculated value of the average and weighted average is taken*". This indicates that, despite seemingly conflicting with their Completeness and Consistency principles, the PAS 2050 guidelines are moving back towards the "Worst case" approach.

Although in principle each of the three methods “Actual LUC” scenario, “Best estimate” scenario and the “Top-down” scenario fulfils the requirements of mass conservation, care should be taken when combining these methods, in order to avoid violation of the PAS 2050:2011 consistency principle. For example, it may be possible that in a single LCA study, some of the crop data can be considered to belong to a category “where the country of production is known and the previous land use is known”, while for some other crop production data this cannot be applied. In such a case, either the “Actual LUC” scenario or the “Best estimate” scenario could be applied for separate crops, depending on the traceability of the crop in each dataset. However this combination of the methods is actually against the consistency principle. This problem can be demonstrated with an example where the environmental impacts of soya coming from different sources in Brazil are compared in an LCA study. Assume that one subgroup of this soya is certified so that it is does not cause LUC, and the exact origin of the other subgroup is not known. According to PAS 2050, the “Actual LUC” scenario can be applied to the first subgroup. However, if the “Best estimate” scenario i.e. the LUC effect for “average” Brazilian soya is applied to the other subgroup, this will actually lead to an underestimate of the combined LUC effect of the both groups, as in reality the proportion of the non-LUC related soya in the “unknown” subgroup is smaller than the national average, as part of it is included in the “certified” subgroup.

Another example of the problems of combining the LUCE accounting methods was presented by Meul et al. (2012). In that paper, the authors propose the use of a two-step decision rule to formulate livestock diets with low GHG emissions, i.e. first try to minimize direct LUC (e.g. by using the “Best estimate” approach) and then within this precondition, minimize total land use change risk (i.e. the “Top down” approach) by selecting ingredients with low land use requirements. The problem with this method is that, although technically the LUCE obtained from these two methods are not treated additively, in effect the final conclusions would be based on double counting. Although this principle would effectively eliminate both direct and indirect LUCE from the diets, it would lead to an underestimate the effects of other, potentially significant components of the GWP arising from feed production.

It can thus be concluded that there are three different approaches to account for the LUCE, which can be considered to fulfill the requirements of attributional agricultural LCA, and which differ only in their method of spatial allocation of the emissions. The choice between these methods remains subjective, and is complicated by the fact that despite being justifiable, each of these methods still has its own limitations. Although the “Actual LUC” appears to be able to quantify accurately the LUCE of any crop in consideration, in practice in many cases it could be almost impossible to get specific enough data on the exact origin that crop as this could require site visits to several countries of crop origin. This would be the case especially when the consistency principle is taken into account and double counting is strictly tried to be avoided. This would require that the origin of each crop in any specific study should be precisely tracked, so that a combination of different approaches could be avoided. The problem of traceability can be avoided by using the “Best estimate” approach which has relatively low demands for data if based on national FAO statistics. However, here the question can be raised whether it is justified to make the LUCE country specific, rather than considering the actual global drivers of LUC, or ignoring for example regional differences within a certain country. The idea of the indirect LUC in the “Top down” approach can be justified when considering the land requirement as part of global market of agricultural commodities. In terms of applicability, this approach has an intermediate data need to set up the analysis, but after that it is trivial to implement. However, this approach does not consider any certain crop to be any stronger driver of LUC than any other. A direct consequence of using this method is that higher LUCE are allocated for example to rapeseed oil than to palm oil, just because of the differences of the yield and hence land requirements of these crops.

Due to the limitations discussed above, it seems likely that none of these LUCE accounting approaches, including those which were found technically correct, is likely to become generally accepted “universal” approach to be used in LCA studies. Instead, an attempt should be made to create a new approach that would combine the generally acceptable aspects of the existing methods, while still following all the requirements discussed above. One suggestion for such an approach has been recently presented by Williams et al. (2014), where the “Top down” method is further developed by including the actual drivers of LUC, and still avoiding double counting in spatial allocation of LUCE.

5. Conclusion

Several approaches to account for LUCE of agricultural products appear to fulfil the generally accepted requirements for attributional LCA and avoid double counting. The acceptable methods differ in their spatial allocation of the emissions, and the selection between them remains subjective. However, it should be possible to combine the benefits of several methods to achieve only one generally accepted approach to be used universally in agricultural LCA. A modified "Top down" method, weighted for different crops based on their roles as actual drivers of LUC, might be one option.

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