Abstract code:

Modelling foreground and background land use impacts in agricultural systems: the dilemma of highly detailed or universally applicable

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Abstract

Purpose A major challenge in LCA is to perform a detailed and specific assessment for the foreground system, even though the information in the background system is limited; we need a method, that is globally applicable. This paper presents a strategy for addressing this issue by combining a detailed method for assessing the effects of foreground (i.e. on-farm) processes with a general, but universally applicable, method for the background system.
Methods The conceptual work is based on the following methods:
- *Soil quality*

Foreground: SALCA soil quality model (SALCA-SQ) developed by Oberholzer *et al.* (2012).
Background: LANCA® (LANd use indicator value CAlculation) proposed by Bos *et al.* 2016.
- *Biodiversity*

Foreground: SALCA biodiversity model (SALCA-BD) developed by Jeanneret *et al.* (2014)
Background: Global Biodiversity loss model by Chaudhary and Brooks (2018)
- *Visual landscape quality*

Foreground/background: normalised composite landscape indicator (Schüpbach *et al.* (2020).
Results and discussion
Biodiversity and soil quality: The study illustrates that it is feasible to use models of different complexity, spatial resolution and data requirements for assessing the biodiversity and soil quality of the foreground and background system.
The methodical design of the suggested models applied to the foreground and background system differ significantly. Nevertheless, overlapping components of the two models allow to build submodels.
We face the challenge that the reference situation clearly differs between the foreground and background system, but harmonisation is possible for certain research questions.
Visual landscape quality: Preliminary results from initial applications show that the contribution from land occupied by the background system can substantially influence the land use impacts of a farm.
Conclusions
Biodiversity and soil quality: For the impact of agricultural activities on biodiversity and soil quality that, the models applied to the (local) foreground and to the (global) background system share certain conceptual similarities, which allows impacts calculated by the two models to be combined.
Visual landscape quality: The indicator for landscape visual landscape quality can simply be expanded to account for both foreground and background land use.

Keywords: *soil quality, biodiversity, landscape quality, LCA, background system*

Introduction

Production of food is one of the major determinants of environmental degradation at global scale and a driver of land use impacts. Assessment of land use impacts in agricultural LCA is challenging for several reasons. One is that a detailed knowledge on management practices on a field or farm (foreground system) and a specific assessment method are needed to assess the impacts. Another is that the impacts are strongly dependent on pedo-climatic conditions and spatial context. When a farm purchases inputs, we also need to assess the impacts of the upstream processes, which are in the background system. Collection of detailed and specific inventories of the foreground system (e.g. a farm) is feasible, whereas data on the background system (purchased inputs) are of generic nature, much less specific and detailed. There is thus a trade-off between the level of detail in the method and its universal applicability. It is unrealistic to expect a single method to be both specific and detailed, and at the same time globally applicable and work with generic data. A more promising solution is to combine two assessment methods, a detailed method for the foreground system and a generic method for the background system.

This paper discusses some of the challenges encountered when trying to include impact assessment methods that consider background processes and combine them with methods suited for the foreground processes for biodiversity, soil quality and landscape quality in LCA.

Material and methods

Soil quality: The impact of on-farm management activities on soil quality can be estimated using the SALCA soil quality model (SALCA-SQ) developed by Oberholzer *et al.* (2012), which contains nine soil quality indicators for physical, chemical and biological soil properties. SALCA-SQ assesses changes in these indicator values at the field level due to specific agricultural management activities.

LANCA® (LANd use indicator value CAlculation) is a method specifically developed for soil quality assessment within LCA (Bos *et al.* 2016). In order to assess the impact of land use on soil quality, LANCA calculates the following five soil functions at the midpoint level: (i) erosion resistance, (ii) physicochemical filtration, (iii) mechanical filtration, (iv) groundwater recharge and (v) biotic production. In LANCA agricultural soil management is condensed into a few agricultural land use classes.

Biodiversity: The SALCA biodiversity model (SALCA-BD) developed by Jeanneret *et al.* (2014) allows to compute the potential impact of management activities at plot and farm level on 11 indicator species groups (ISG). The model computes a score for each ISG, which can be aggregated to a single score per crop and per farm. The model allows computation of the so-called biodiversity deficit, as it provides a maximum score for each crop assuming "best possible" management.

The Chaudhary and Brooks (2018) model (CHBR) permits accurate determination of spatially explicit biodiversity loss at global level depending on the type and intensity of land occupation and transformation. CHBR computes the effects of land use changes on five indicator species groups (mammals, birds, reptiles, amphibians, vascular plants), leading to specific regional characterisation factors (CFs). This method is applicable worldwide, but it does not cover the effect of individual farm management practices such as tillage, fertilization or harvesting. CHBR is a further development of the method recommended by the UNEP-SETAC for estimating impacts on biodiversity related to land use in LCA.

Visual landscape quality: The normalised composite landscape indicator (CLI) for a farm can be estimated by the method of Schüpbach *et al.* (2020), which accounts for seasonal diversity and the farm's contribution to perceived naturalness. CLI consists of the arithmetic mean of

two sub-indicators. The first sub-indicator, area-weighted preference value (AWPV), essentially captures the aesthetic value of the landscape, while the second, aggregated diversity index (ADI), mainly considers landscape diversity.
Land use in the background system is computed with the commercially available LCA software tool *SimaPro*, using the ecoinvent database as a background database.

Results and Discussion
For reasons of higher explanatory power, it is reasonable to use different models for the foreground and background impacts of agricultural activities, since the framework conditions of processes in the foreground (i.e. on-farm processes) are known in much more detail than those of background processes. For instance, it is crucial that the effects of on-farm soil management activities such as tillage, crop establishment, fertiliser application, field traffic and harvesting on biodiversity and soil quality are accurately recorded and assessed. Furthermore, the foreground system is the primary field of action, where the management can be improved. However, the origin and production conditions for e.g. imported concentrate feedstuffs are often not well known. To assess background effects, it is therefore appropriate to use a model which does not need a detailed description of on-farm agricultural activities but rather acts on a more generic level, based on geographical and pedo-climatic site conditions.
In a pre-evaluation of biodiversity models, we found that SALCA-BD is ideally suited for assessing the impacts of agricultural activities on biodiversity in the foreground system, while the global model CHBR is optimal for accounting for the additional impact induced by upstream processes that take place in the background system. For evaluation of soil quality, including upstream processes, our model selection step revealed that on-farm soil quality (foreground system) can be accurately simulated by SALCA-SQ and the background system by LANCA. This distinction makes it possible to account for differing levels of knowledge regarding management practices, production conditions, soil conditions and production location.
Below, we illustrate and discuss some conceptual challenges arising when linking the foreground model with the background model. We focus on two main aspects: (i) Selection of the reference situation, and (ii) differences in methodological design between the foreground and background models.

Selection of the reference situation
Land occupation and/or transformation impacts caused by land use activities are quantified in relation to a land quality difference between two states, which thus requires a reference situation (RS) against which the actual state is compared. Numerous studies have shown that the definition used for the RS strongly influences the LCA results (Milà i Canals *et al.* 2007; Koellner *et al.* 2013). The following three options for RS are recommended by Koellner *et al.* (2013):

1) Potential natural vegetation (PNV): vegetation that would develop if all human influences ceased.
2) (Quasi-)natural land cover (NLC) in each biome/ecoregion.
3) Current land use mix (CLM): current composition of land-use types within each biome. For biodiversity, CLM can be expressed as current mean number of species (Köllner & Scholz, 2008).

Comparison of the methods selected to assess the effects of foreground and background systems on soil quality revealed that the RS definition in the two selected models differs. SALCA-SQ estimates effects of current soil management activities on soil quality by comparing them to a RS assuming site-specific sustainable agricultural land use according to "good agricultural practices". In LANCA, the user can decide which land-use type to use as the RS in a specific study. In an LCA study, we need to combine impacts of the foreground system with those of the background system to assess the full life cycle. This is not possible, if the reference states differ between the models. We therefore have to adapt one method to match the reference state of the other, i.e. we need to choose one of the three above options for both methods. Otherwise, it is not possible to aggregate all impacts and we can only perform a separate assessment for the foreground and background systems.

The two methods selected here for calculating the impact of land use and agricultural activities on biodiversity have fundamentally different RS. SALCA-BD uses the most positive management for each culture as its RS, whereas CHBR compares biodiversity damage per taxa against the natural undisturbed habitat (NLC), as its RS. Thus the biodiversity impact of an intervention, quantified as the difference between the quality of the land resulting from agricultural use and the RS, differs strongly between SALCA-BD and CHBR.

Conceptual design

Some of the indicators in SALCA-SQ and LANCA are closely linked, suggesting that the main conclusions of the two models may be similar for a specific study. For example, the soil function "erosion resistance" specifies the ability of the soil to resist erosion exceeding the naturally occurring level. The LANCA procedure for determining "erosion resistance" is based on the same methodological framework as the SALCA-SQ indicator "rooting depth", as both are linked to the risk of soil erosion. On the other hand, the LANCA indicators "mechanical filtration capacity", "physicochemical filtration capacity" and "groundwater recharge" rely on algorithms depending strongly on soil and site data (closely resembling pedotransfer functions) and considering only one or a few management impact factors. For the foreground system, SALCA uses actual soil management inventory data and an expert model approach to consider anthropogenic impacts in a differentiated way.

The methodical design of SALCA-BD and CHBR also differs substantially. However, there are also certain similarities between the two methods which can help to derive one single, final composite biodiversity deficit score covering both the foreground and background systems. Both methods calculate changes in the number of certain species and three of the five taxa considered in CHBR (mammals, birds, reptiles, amphibians, vascular plants) are among the indicator species groups assessed in SALCA-BD (mammals, birds, amphibians). The same applies to land use types: SALCA-BD differentiates between arable crops, grassland and semi-natural habitats (SNHs) (e.g. extensively managed and low-input meadows, wild-flower strips, hedges), which partly match three of the six land use types suggested in CHBR (annual crops, permanent crops, pasture). Another feature shared by SALCA-BD and CHBR is that they both account for vulnerability of a taxon (or species group) in a certain ecoregion (or farmland type). In summary, despite crucial methodological differences between the SALCA-BD and CHBR approaches, through model simplification and adaption it should be possible to build "submodels" containing overlapping model components that can be directly compared.

Calculation of the indicator CLI differs from calculation of biodiversity and soil quality, since the required input data for CLI comprise solely the areas occupied by different land-use types (crops, grassland and semi-natural habitats). The foreground CLI can easily be computed using farm survey data. Assuming the same preference values for the foreground and background system, computation of the background CLI only requires data on the land area occupied by upstream chains, as retrieved from the background database ecoinvent.

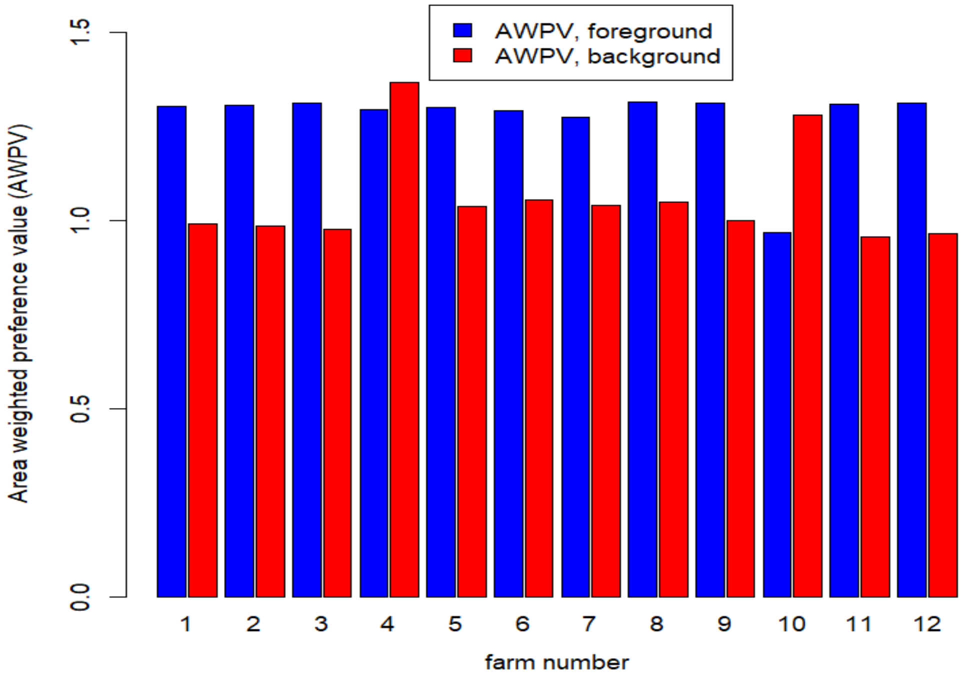

Figure 1. Area-weighted preference value (AWPV) for both the foreground and background system, based on data from 12 dairy farms analysed in the project 'Hohenrain 2' (Zumwald *et al.* 2018).

This method was applied to data retrieved in the project Hohenrain II (Zumwald *et al.* 2018), which compared three production systems: full-time grazing with reduced concentrate supplementation and partial grazing with reduced/ increased concentrate supplementation. The background processes included all land occupied for off-farm feed production, but excluded land required for production of machinery and energy, since no preference values are available for built-up areas.

The sub-indicator AWPV for both the foreground and background systems is shown in Figure 1. As can be seen, the on-farm AWPV is generally significantly higher ($p=0.0002$) than the AWPV for upstream processes. This derives from the fact that purchased (concentrate) feed often consists of crops that are generally assigned lower preference values than (extensive) grassland and semi-natural habitats.

Further development is needed to make the modelling system fully operational, e.g. to fully combine the two assessment approaches into a single impact indicator. This is critical for comparison of farms regarding all three impacts (landscape quality, biodiversity, soil quality) in line with LCA principles.

Conclusions

We present a framework that can be used in LCA to explore land use impacts on biodiversity and soil quality by treating the foreground and background systems in different ways. For reasons of improved interpretability and higher informative value, we suggest assessing foreground processes using a detailed model that accounts for the impacts of agricultural activities on biodiversity and soil quality, and assessing background processes using average or more generic data. Successful combination of the two models for evaluating background and foreground processes requires detailed analysis of differences in their general design. Our evaluation shows that, despite major differences, these models share also conceptual similarities, which allows impact assessments computed by the two models to be linked.

Concerning visual landscape quality, the same method can be applied to both the foreground and background systems, assuming that preference values are independent of country.

Preliminary results from an initial application showed that the contribution from land occupied by the background system may be substantial.
Further development is needed to make the modelling system fully operational also for soil quality and biodiversity. This is an essential precondition for comparison of farms concerning all their environmental impacts, in line with LCA principles.

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