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Integration of biodiversity assessment into LCA in agriculture: the AgBalance® approach

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Abstract

Intensive agriculture can cause a sharp decline in biodiversity in a given landscape. Sustainable agriculture therefore requires assessment methods in order to predict potential impacts of agricultural management practices on farmland biodiversity. Based on the principles of Life Cycle Assessment (LCA), BASF has developed AgBalance® to enable farmers analyzing and improving the sustainability of their farming operation. AgBalance® is based on the Product Environmental Footprint Category Rules Guidance (PEFCR) by the European Commission (2017), which includes most of the relevant impact categories for agriculture, like climate change, acidification, eutrophication, etc. but misses a biodiversity impact category. To close this gap, a new methodological approach called "Biodiversity Calculator" was developed, by using the characterization model of Chaudhary and Brooks (2018) and combining it with a set of interventions previously identified as effective in terms of positive impacts on biodiversity by the "Conservation Evidence" meta-analysis (Sutherland et al., 2019). The results from the "Biodiversity Calculator" are incorporated into AgBalance® using an adapted normalization and weighting scheme of the Product Environmental Footprint method of the EU commission (PEF). The resulting "Biodiversity Calculator" comprises a versatile tool that complements the AgBalance® methodology and informs farmers on how to adapt their agri-environmental strategies to mitigate their impact on biodiversity.

Keywords: *biodiversity; sustainable agriculture; LCIA; AgBalance®*

1. Introduction

It has been described by various authors that agriculture is the main threat for 87 % of globally threatened bird species (IUCN, 2016) and other taxa (Macdonald et al., 2015). Thus, preventing further biodiversity loss in agricultural production systems comprises a pre-requisite for their sustainability (Benton et al. 2003), underlining the importance of assessing biodiversity on farm.

BASF has been using AgBalance® since 2012 for LCA-based sustainability assessment of various farming practices. AgBalance® contributes to an adequate assessment of sustainable agriculture, by incorporating state-of-the-art scientific methods for LCA analysis in agriculture, including the impact categories recommended by Product Environmental Footprint (PEF) method (European Commission, 2017), like climate change, eutrophication, etc. However, the PEF method does not include a biodiversity impact category. Even though the necessary integration of biodiversity as an impact category is recognized by the European Commission (2017), the inclusion of biodiversity in LCA-based environmental methods imposes difficulties to the methodological framework of LCA itself (Curran et al., 2011). Moreover, site-specific data are necessary to accurately assess biodiversity loss at regional and local scale (Teixeira et al. 2016). Lastly, species richness has been considered a useful basis for these models, but it must be complemented with land use intensity-based indicators (Teixeira et al., 2016).

The objective of this research was to develop an action-based, LCA-compatible biodiversity assessment, which can be integrated into the AgBalance® methodology. The so-called "Biodiversity Calculator" is a software tool developed for agricultural systems to estimate the impact of specific farming practices and to develop scenarios on how to improve biodiversity on-farm, through a management-driven approach.

Of the already existing methodological approaches, the UNEP-SETAC working group endorses the model proposed by Chaudhary et al. (2015) and Chaudhary and Brooks (2018) as most suitable to assess the land use driven impacts on biodiversity (Frischknecht et al., 2016). In order to derive information on the biodiversity on farm, action-based approaches take into account interventions and farm management (Sutherland et al., 2019) to assess the impact of farming on biodiversity. The most comprehensive evidence base for the effectiveness of such measures comprises the meta-analysis "Conservation Evidence" (Sutherland et al., 2019). By focusing on interventions that positively impact the biodiversity potential, this meta-analysis can support the operationalization of interventions for farming as a building block of sustainable agriculture (Shackelford et al., 2017).

2. Material and methods

Technically, the "Biodiversity Calculator" includes the characterization factors from Chaudhary and Brooks (2018) and allows users to adjust them with so called "interventions", i.e. factors that describe farmers' management practices. These factors were calculated based on the information extracted from "Conservation Evidence" (Sutherland et al., 2019). The "Biodiversity Calculator" was developed with the scientific advice of the Fraunhofer Institute for Building Physics. In detail the methodological background of the "Biodiversity Calculator" and its integration in the AgBalance® methodology can be summarized as follows:

2.1. Modelling with regional and country specific characterization factors

To capture the predicted species loss due to land use, the characterization model of Chaudhary and Brooks (2018) was used. The model provides mean global characterization factors (CF) for land occupation and transformation of 804 ecoregions and 245 countries and islands, for five land use types and three levels of intensity each. For the "Biodiversity Calculator," these CFs were extracted for all ecoregions, countries and islands, covering the relevant land use types for AgBalance®: cropland, pasture and plantation forests[1].

2.2. Selection of agricultural interventions with impact on biodiversity

Data for the impact of management practices on biodiversity was extracted from the meta-analysis "Conservation Evidence" (Sutherland et al., 2019). In "Conservation Evidence," the interventions had been assessed by an expert panel in terms of effectiveness (effectiveness score in percentage) and

[1] In the "Biodiversity Calculator," permanent crops were assigned to the land use type of plantation forests. However, Chaudhary (2018) included permanent crops in the cropland land use type.

strength of the evidence (certainty score in percentage). Furthermore, the interventions were classified in several overall effectiveness categories, ranking from "beneficial" to "harmful" (Sutherland et al., 2019). A total of 39 interventions from the conservation categories "Farmland Conservation" and "Mediterranean Farmland"[2] with evidence classified as "beneficial" or "likely to be beneficial," were chosen as a basis for the Biodiversity Calculator, to provide farmers with measures that mitigate their biodiversity impact due to land use intensity as demonstrated by Chaudhary and Brooks (2018). The choice was narrowed down to 29 interventions, after 10 redundant interventions were excluded in order to avoid double-counting of interventions in the calculation of action scores (see section 2.3).

2.3. Calculation of action scores

To rank these interventions, the effectiveness (EC_i) and certainty components (CC_i) of each intervention i were multiplied to yield a single action score AS_i (see Eq. 1).

$$AS_i = \frac{(EC_i \cdot CC_i)}{100} \qquad [\%] \qquad \text{Eq. 1}$$

The single action score of each intervention i was divided by the total sum of action scores of all applicable interventions of land use type j, to obtain a scaled action score ($SAS_{i,j}$) that ranges between 0 % and 100 % (see Eq. 2). The applicability of each intervention i for land use type j is provided in the respective synopsis in "Conservation Evidence". In the calculator, the number of applicable interventions n varies for each land use type: out of 29 interventions, 21 apply to cropland management, 24 to pasture and 8 to plantation forests.

$$SAS_{i,j} = \left[\frac{EC_{i,j} \cdot CC_{i,j}}{\sum_{i=1}^{n} EC_{i,j} \cdot CC_{i,j}}\right] \cdot 100 \qquad [\%] \qquad \text{Eq. 2}$$

Action scores of selected interventions were summed into a total action score of the farm (AS_{farm}) as shown in Eq. **3**, where higher values are considered better for biodiversity. The binary variable s_i equals 1 if the intervention i is selected, otherwise it equals 0.

$$AS_{farm} = \sum SAS_{i,j} \cdot s_i \qquad [\%] \qquad \text{Eq. 3}$$

2.4. Effect of action scores on the characterization factors

The characterization factors (CF) for minimal and intense use of each land use type and ecoregion or country were fitted in linear regressions as a function of the action score of the farm. A linear function was assumed, as the exact cause-and-effect relationships between the interventions and biodiversity remain largely unknown. Accordingly, it was assumed that the action score of 0 % corresponds to the CF of intense use as a starting point, and the action score of 100 % corresponds to the CF of minimal use, the CF values for action scores between 0% and 100% are derived by interpolation as follows.

Eq. **4** and Eq. **5** represent the linear regressions that estimate the characterization factor of potential species loss on the farm due to land occupation ($CF_{occ,j,k}$) and transformation ($CF_{trans,j,k}$) respectively, as a function of the action score of the farm, given a land use type j and country or region k. The characterization factors of minimum and intense use are different for each land use type, country and

[2] The conservation categories "Farmland Conservation" and "Mediterranean Farmland" refer to the effect on biodiversity of farmland wildlife and human dominated landscapes that add economic and ecological value. Effects of these interventions were assessed for northern and western Europe and Mediterranean climates (Dicks et al., 2013) (Shackelford et al., 2017).

ecoregion, so the slopes $m_{occ,j,k}$ and intercepts $b_{occ,j,k}$ of the linear regression will also vary accordingly. Subsequently, the $CF_{occ,j,k}$ and $CF_{trans,j,k}$ are multiplied with the area of land occupation and transformation respectively to obtain the species loss per functional unit, which is the result of the LCA-based biodiversity assessment.

$$CF_{occ,j,k} = m_{occ,j,k}(AS_{farm}) + b_{occ,j,k} \quad \text{[species loss/m}^2\text{]} \quad \text{Eq. 4}$$

$$CF_{trans,j,k} = m_{trans,j,k}(AS_{farm}) + b_{trans,j,k} \quad \text{[species loss·year/m}^2\text{]} \quad \text{Eq. 5}$$

2.5. Integration of biodiversity assessment into AgBalance® methodology

The results of the biodiversity assessment are incorporated into the AgBalance® methodology using an adapted normalization and weighting scheme of the PEF method of the European Commission (2017). As normalization factor for the biodiversity impact, an annual average of number of species gone extinct is used, based on the data from IUCN database of species gone extinct in the last 100 years (IUCN, 2019) of the same taxa covered by Chaudhary and Brooks (2018). The AgBalance® weighting scheme is based on the PEF methodology for the development of a weighting approach for the Environmental Footprint by Sala et al. (2018). Therefore, to include the biodiversity impact category, a weighting factor and a robustness factor were derived by determining the importance of the topic and the robustness of the assessment tool. According to the concept of the Planetary Boundaries, climate change and biodiversity rank on the same level of importance for life on earth (Steffen, et al., 2015). Therefore, the weighting factor of biodiversity was allocated equivalent to that of climate change in the AgBalance® methodology. Twelve experts of two fields of expertise (experts in method development and experts in biodiversity) provided their assessment of the robustness of the methodology implemented in the "Biodiversity Calculator," as defined by Sala et al. (2018). Subsequently, a mean value of the assessment of the experts was calculated to obtain a robustness factor for the biodiversity impact category. With the robustness factors and corresponding weighting factors of each impact categories of the AgBalance® methodology, a weighting scheme including a biodiversity assessment for sustainability analysis of farming practices was implemented.

3. Results and discussion

The "Biodiversity Calculator" was initially developed as an Excel tool and a web-based interface was created to facilitate the usability. For assessments using the "Biodiversity Calculator," the first step is the selection of the country or ecoregion where the farm is located in the section "Region definition" (see Figure 1), followed by the land use type to be assessed in the pre-selection of interventions. An optional feature enables the customization of the tool through the application of filters, allowing users to select subsets of interventions that correspond to their farm management conditions. As a next step, the interventions to be applied at the farm or in the farmland can be selected to predict the impact on species loss. The numerical outcome of the Biodiversity Calculator comprises three values: i) the action score of the farm (AS_{farm}), an index from 0 % to 100 %, ii) a CF for land occupation of the farm expressed in potential global species loss per square meter and iii) a CF for land transformation expressed in potential global species loss per square meter times regeneration years. While the CFs are relevant for LCA applications, the results are graphically displayed, showing the Action score as well as the change in species loss due to the implemented interventions. Figure 1 shows a partial view of the interface of the "Biodiversity Calculator" and the graphic with the results, where higher action scores reduce the potential species loss. A calibration and validation of the tool is anticipated for next year, using field monitoring data on changes in the abundance and diversity of different species in response to the implementation of the interventions included in the calculator.

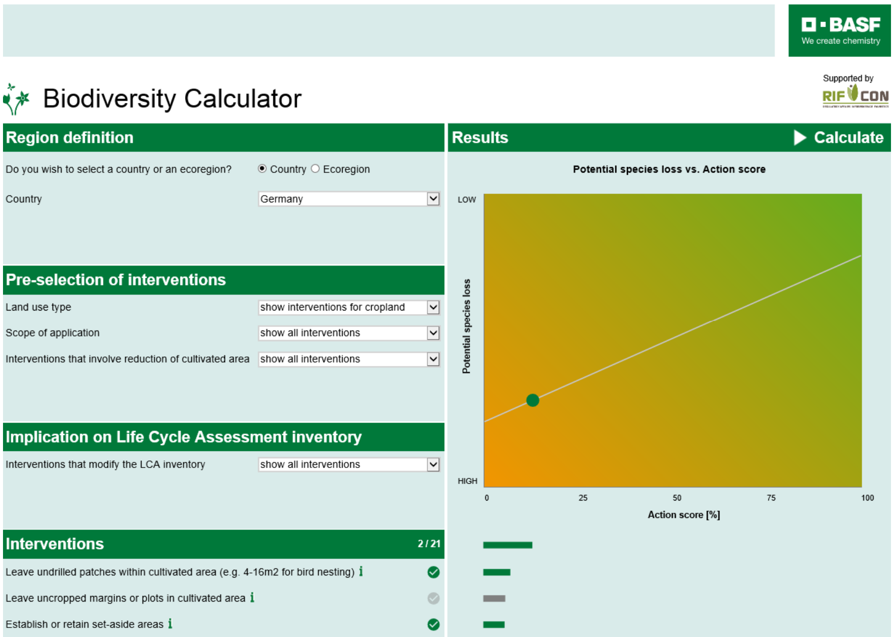

Figure 1: Partial view of the interface of the "Biodiversity Calculator"

4. Conclusions

The "Biodiversity Calculator" comprises a versatile tool to support decisions about how to maintain and restore biodiversity on the farm and an LCA-compatible assessment method, with a focus on cropland, pasture and (to a lesser extent) permanent crops. This method is seamlessly integrated into the existing AgBalance® framework and allows for a site-specific biodiversity impact assessment based on the location of the farm, land use type and the management strategies chosen by farmers. It can also be easily integrated into other LCA frameworks as well.

Limitations due to simplifications for the sake of practicality are known. Furthermore, customization and expansion of the tool is required for case studies focused on permanent crops. Additionally, the evidence base of "Conservation Evidence" is restricted to regions with Mediterranean climates and to northern and western Europe. Improvements like adaptation of interventions to different geographies and the extension to permanent crops are currently discussed. Further development is necessary to account for the decline in biodiversity, as well as its interrelations with other impact categories leading to an endpoint-oriented damage category.

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6. References

Benton, T. G., Vickery, J. A., and Wilson, J. D. (2003, April). Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology and Evolution, 18(4), pp. 182-188. https://doi.org/10.1016/S0169-5347(03)00011-9

Chaudhary, A., Brooks, T. M. (2018). Land Use Intensity-Specific Global Characterization Factors to Assess. Environmental Science and Technology, 52(9). doi:10.1021/acs.est.7b05570

Chaudhary, A., Verones, F., de Baan, L., and Hellweg, S. (2015). Quantifying Land Use Impacts on Biodiversity: Combining Species−Area Models and Vulnerability Indicators. Environmental Science and Technology(49), 9987−9995. doi:10.1021/acs.est.5b02507

Curran, M., de Baan, L., Schryver, A. M., van Zelm, R., Hellweg, S., Koellner, T., Sonnemann, G., Huijbregts, M. J. (2011). Toward Meaningful End Points of Biodiversity in Life Cycle Assessment. Environ. Sci. Technol (45), 70–79. doi:10.1021/es101444k

Dicks, L. V., Ashpole, J.E., Dänhardt, J., James, K., Jönsson, A., Randall, N., Showler, D. A., Smith, R. K., Turpie, S., Williams, D. & Sutherland, W. J. (2013) Farmland Conservation: Evidence for the effects of interventions in northern and western Europe. Exeter, Pelagic Publishing.

European Commission (2017). Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3

Frischknecht, R., Jolliet, O., Milà i Canals, L., Antón, A., Boulay, A., Fantke, P., Levasseur, A., McKone, T., Pfister, S., Verones, F. (2016). Global Guidance on Environmental Life Cycle Impact Assessment Indicators, Volume 1.

IUCN Red List of Threatened Species. (2016, July 26). Retrieved from International Union for Conservation of Nature and Natural Resources: http://www.iucnredlist.org

IUCN. (2019). The IUCN Red List of Threatened Species. Version 2019-2. Retrieved October 11, 2019, from http://www.iucnredlist.org

Macdonald D. W., Raebel E. M., Feber R. E. (2015) Farming and wildlife: A perspective on a shared future. In: Wildlife Conservation on Farmland Vol. I, eds. Macdonald, D. W. and Feber R. E.; Oxford University Press; p. 3

Sala, S., Cerutti, A., and Pant, R. (2018). Development of a weighting approach for the Environmental Footprint. Luxembourg: Publications Office of the European Union.

Shackelford, G. E., Kelsey, R., Robertson, R. J., Williams, D. R., and Dicks, L. V. (2017) Sustainable Agriculture in California and Mediterranean Climates: Evidence for the effects of selected interventions. Synopses of Conservation Evidence Series. University of Cambridge, Cambridge, UK.

Steffen, W., Richardson, K., Röckström, J., Cornell, S., Fetzer, I., Benett, E., Biggs, E., Carpenter, S., De Vries, W., de Wit, C., Folke, C., Gerten, D., Heinke, J., Mace, G., Persson, Linn M., Ramanathan, V., Reyers, B., Sörlin, S. (2015, February 12). Planetary boundaries: Guiding human development on a changing planet. Science Vol. 347.

Sutherland, W.J., Dicks, L.V., Ockendon, N., Petrovan, S.O., and Smith, R.K. What Works in Conservation 2019. Cambridge, UK: Open Book Publishers, 2019. https://doi.org/10.11647/OBP.0179

Teixeira, R. F., de Souza, D. M., Curran, M. P., Anton, A., Michelsen, O., and Mila i Canals, L. (2016). Towards consensus on land use impacts on biodiversity in LCA:UNEP/SETAC Life Cycle Initiative preliminary recommendations based on expert contributions. Journal of Cleaner Production, 112 , 283-4287. doi:10.1016/j.jclepro.2015.07.118