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Biodiversity Impact Assessment of Land Using Processes in the Supply Chain of Passenger Cars

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Abstract. Biodiversity loss has been recognized as one of the major global challenges of current and future society. Land-using processes have been found to be among the most important direct drivers for biodiversity loss. Life cycle assessment (LCA) has established itself as a standardized tool for measuring environmental impacts of products and processes. However, there is no clear consensus on the integration of land-use related impacts on biodiversity in LCA-frameworks due to a lack of methodological guidance, suitable datasets and experience in real-world applications. Closing these gaps could enable political institutions and companies to determine the effects of their products on biodiversity over the entire life cycle. In this study, a method, aiming to integrate the biodiversity impact in LCA, is successfully applied on a product with a complex supply chain. A suitable dataset of the material composition of a modern electric vehicle adapted to match the specifications of the Volkswagen ID.3 is developed. To estimate land use requirements of five important metals a GIS-based approach is elaborated. 164 mines covering an area of 4,123 km^2 in eight different countries are inspected by means of satellite imagery and enhanced with data from industrial reports to build suitable datasets for the impact assessment. Based on these datasets, five unit processes are developed and applied to the VW ID.3 model. The results indicate that cobalt, lithium and copper account for the major biodiversity impact among the assessed metals. A scenario analysis reveals a biodiversity impact reduction potential of at least 23%. To the best knowledge of the authors, this study presents the first biodiversity impact assessment in the supply chain of a modern vehicle. The datasets, the application example and the workflow developed and applied in this study can serve as methodological guidance to support LCA-practitioners and researchers in the integration and application of biodiversity impacts in LCA-frameworks and LCA-studies. Thus, it supplements existing indicators in a meaningful way and makes them usable for future LCA studies.

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1 Introduction

A healthy state of biodiversity is essential for maintaining the provisioning of ecosystem services [1]. Human activities are fundamentally changing and impacting biological diversity which, in turn, has implications on human health and the economy [1,2]. The producing industry as one of the main indirect drivers for biodiversity loss needs appropriate measures to identify and regulate "hotspots" along the value chain and improve the environmental impact of unsustainable production patterns. Life cycle assessment has been a proven tool for years to analyze the environmental performance of products, processes, or services systematically and holistically. However, the influence of industrial production on biodiversity has only been sparsely addressed due to a lack of methodological guidance, real-world applications and best practices [3-5]. The aim of the present study was to apply the biodiversity impact assessment method proposed by Lindner et al. [5] and, thus, to develop a workflow for the biodiversity impact assessment of a product with a complex supply chain. A GIS based approach is developed and integrated into the biodiversity assessment method to (1) build suitable datasets and (2) estimate the biodiversity impact of raw material provisioning for a modern battery electric vehicle (BEV). The results serve as a blueprint for the consultation for further methodological development and push towards a consensus building in finding a suitable biodiversity impact assessment method. Further, the exemplary biodiversity impact assessment presented in this study provides guidance and serves as a "real-world" application example for LCA-practitioners.

2 Methods

This paper aimed to apply and test a recently published method to assess the biodiversity impact of an industrial product in a real-world scenario. In Section 2.1, we give an overview of the methodological approach published by Lindner et al. [5] which serves as a calculation base for the biodiversity impact assessment. Section 2.2 provides information about the development of a suitable data inventory for the reference product, the Volkswagen ID 3. Section 2.3 describes the development of unit processes which are employed to calculate the biodiversity impact. Section 2.4 presents how data inventory, and unit processes are integrated into the biodiversity impact assessment methodology.

2.1 Valuing Biodiversity in LCA

The main causes of biodiversity loss are effects related to land use (LU) and land use change (LUC) [1,6]. The biodiversity impact assessment method applied in this study ties in at the widely adopted UNEP/SETAC framework [2]. The framework adopts the principle that any land use related activity has an impact on land quality (Q) and/or environmental quality. The main function for land-using processes presented in [2] determines the volume integral of an object spanned by the quality loss of a certain patch of land (ΔQ), the considered timespan (Δt) and the affected area (A). For occupation impacts the integration can be simplified to a multiplication of three parameters:

$$Impact = \Delta Q * \Delta t * A \qquad (1)$$

The appropriate quantification of land quality (Q*)* and its difference to a reference state (ΔQ) are subject to current research. In this context, Lindner et al. interpret land quality (Q*)* as a value for biodiversity and quantify this value based on the hemeroby-scale [5]. The hemeroby concept describing human influence on ecosystems was adapted to be integrated into LCIA and to be compatible with the UNEP/SETAC framework [5-11]. Lindner et al. estimate land use impacts by assessing land use type and intensity, assigning one of seven hemeroby-levels and transfer this to a local biodiversity value (BV_{loc})[5,10]. The quality difference or rather the biodiversity difference (ΔQ) to the reference state is calculated according to equation (2). The global weighting of impacts in different ecoregions (ER) is achieved by the introduction of ecoregion factors (EF) (cf. [5, 10]). The globalized difference in biodiversity (here ΔQ*)* can be calculated by subtracting the globalized local biodiversity value ($EF * BV_{loc}$) from the maximum possible biodiversity value ($EF * BV_{max} = EF * 1$).

$$\Delta Q = EF * BV_{max} - EF * BV_{loc} = EF * (1 - BV_{loc}) \quad (2)$$

The strength of this approach is that the hemeroby concept is recognized as an adequate characterization of the diversity of naturalness [9,11] while at the same time matching the requirements of LCA practitioners [5]. For more differentiated and also more data-intensive applications Lindner et al provide a variation in recent publications [10].

2.2 Product system development

In this study, the Volkswagen ID.3, a modern BEV, was chosen as the reference product. Because a comprehensive and compatible product system of the VW ID.3 was not available, we developed an estimated product system based on openly accessible data (e.g. publications of VW, industry reports, scientific publications). Around 20 publications serve as a basis for this product system. The material shares are adapted to match the known characteristics of the VW ID.3 while unknown values are estimated based on current publications of technology provider (e.g. Bosch), LCAs of similar BEV (e.g. Renault Zoe, Nissan Leaf), the GREET 2 model, and several scientific publications. An overview of the simplified product system is provided in Fig. 1. The full material shares of the VW ID.3 model (34 material categories) are provided in the supplementary material. To calculate the area occupation and to identify the affected ecoregions (see section 2.1), we extended the product system by adding information of raw material import shares to Germany for the most relevant sourcing countries, average ore grades and average recycling rates (see Fig. 1).

2.3 Unit process development

The method provided by Lindner et al. [5] gives a methodological background on how to calculate biodiversity impacts assuming the availability of certain datasets. An approach to gather and prepare suitable inventory data is not presented. Because a suitable dataset for land occupation (occupied area [m^2] per time unit [a] and extracted material [kg] on ER level) and evaluation of assessed materials was not available, we elaborated a GIS-based workflow to gather, prepare and process inventory data. To exemplarily assess the biodiversity impacts for steel, cobalt, copper, aluminum and lithium, five unit processes were developed.

The unit processes cover the biodiversity impact of the procurement of main raw materials (lithium brine, spodumene, copper ore, iron ore, cobalt ore, bauxite) for five metals (see above) obtained in Germany. Raw material extraction sites are mostly located in remote places and cannot be assessed on site without extensive expense. Therefore, the specification of area occupation and affected ecoregions is achieved by analysing satellite imagery using the geographic information system QGIS. No suitable comprehensive and freely available database of mining locations could be identified. However, by combining a variety of information and data from different sources, we developed an appropriate dataset. First, general information about mining locations is obtained from a variety of industry reports, reports by official authorities, government reports, and non-government organizations whereas spatial data (location, polygons and data layers) are provided by FINEPRINT and Open Street Maps. Data about extraction sites are merged to build complete data sets. Missing information is added, when possible, while wrong information is readjusted and corrected in many iterations. Finally, an ER layer is imported to QGIS and matched with the mining locations to complete the data sets with information about the affected ER. Included are all open cast mines and lithium brine extraction sites which could be clearly observed in satellite images. Mines which could not be clearly identified are excluded. The calculation of mining area includes all facilities, stockpiles and tailings identified as supporting infrastructure and located within or near the extraction sites. Transporting infrastructure, such as railways or harbours, are out of scope and therefore excluded. A full data set of an extraction site comprises information about the location, the main commodity type, the ER, the affected area, the country, the name (optional), the operator (optional) and the production rate (optional). A complete list of identified mining locations can be found in the supporting information. The calculation of biodiversity impact on country level is achieved in three steps: First the area occupation is estimated by dividing the total yearly production of a country by the total identified mining area. In the next step, ΔQ is determined (eq. (2)) by assigning a hemeroby level to the extraction sites (based on extraction type), estimating the local biodiversity value ([5]) and including appropriate EF. The biodiversity impact on country level per kg of raw material is calculated as the sum of weighted impacts (eq. (3)).

$$Impact_{country} = \sum w_i * AF * x_i \, [\frac{UBU}{kg}] \tag{3}$$

$$w_i = area\ share\ of\ ecoregion\ i\ of\ total\ assessed\ mining\ area\ in\ one\ country;$$
$$x_i = biodiversity\ impact\ in\ ecoregion\ i\ in\ one\ country; AF: Allocation\ factor$$

Cobalt and lithium which are usually mined as byproduct of copper and potassium are economically allocated based on the average raw material price in 2018 and the share of production (AF_{co}: 0.48; $AF_{li(cl)}$: 0.32; $AF_{li(au)}$: 1; $AF_{li(ar)}$: 0.96). The AF for copper, iron ore and bauxite is set to one since these materials are considered as mainproducts. The aggregation of biodiversity impacts to unit processes requires to include average ore grades and recycling rates. Equation (4) describes the aggregation process.

$$Impact_{aggr.} = \omega_{pm} * \frac{1}{\varepsilon} \sum a_{eco,i,j} * \Delta Q_{eco,i,j} * at_{cou,j} * \sigma_{cou,j} \tag{4}$$

with ω_{pm}: Share of primary material in %, ε: Ore grade of commodity [in %], $a_{eco,i,j}$: Share of area of ER i in country j, $\Delta Q_{eco,i,j}$: Quality difference of ER i in country j, $at_{cou,j}$: Calculated area time of country j, $\sigma_{cou,j}$: Share of import for country j.

3 Results

An area of more than 16,000 km^2 was screened by means of satellite imagery. 164 mines covering an area of more than 4,000 km^2 were selected for the impact assessment. Fig. 1 shows the product system of the ID.3 model as it is applied in section 3.1. The full ID.3 model including all 34 material categories and the unit processes for aluminum, lithium, cobalt and copper can be found in the supplementary material.

The unit processes and the product system are applied in two different scenarios. First, a comparative impact assessment with a Golf A4 model (ICEV) published by Schweimer & Levin [12] and the ID.3 model (BEV) developed in this study is conducted. In the second scenario the biodiversity impact hot spots of the ID.3 model are assessed in more detail to roughly estimate the reduction potential. The system boundaries for both assessments are set to include material procurement of steel, aluminum, copper, cobalt and lithium only, which excludes other materials and energy carrier materials consumed during extraction or further processing of raw materials. Scrap and secondary material are excluded according to the cut-off approach. Economic allocation is done for cobalt and lithium as stated in section 2.3.

3.1 Comparative impact assessment

Table 1 shows the results of the comparative impact assessment. The functional unit is scaled to one kg BEV, respectively, ICEV.

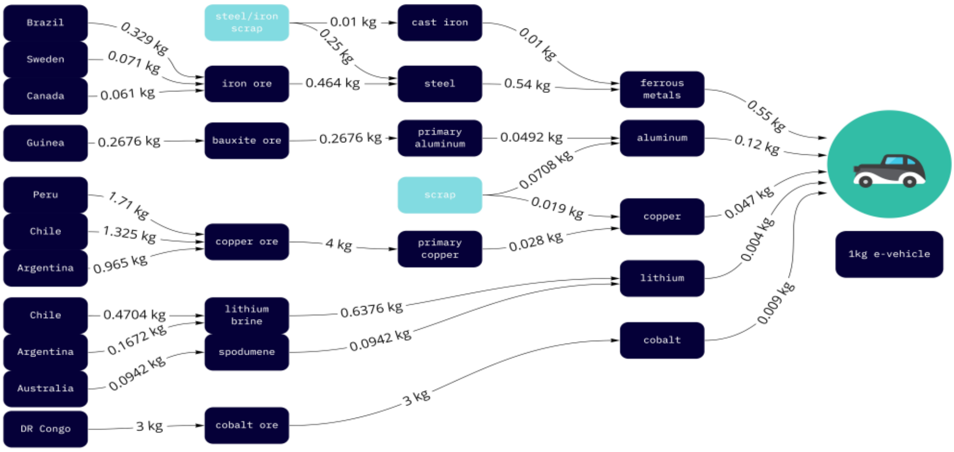

Fig. 1: Simplified product system VW ID.3 model

Table 1: Comparative biodiversity impact assessment Golf A4 and ID.3 model in 10^{-3} UBU/kg vehicle

Model	Total	Steel	Aluminum	Copper	Cobalt	Lithium
Golf A4	1.08	0.33	0.05	0.71	0	0
VW ID.3	15.54	0.27	0.1	4.42	7.18	3.58

3.2 Detailed impact assessment

Fig. 2 shows the results of the detailed impact assessment for one vehicle of the VW ID.3 model. The assessment is distributed among distinctive assemblies of a vehicle.

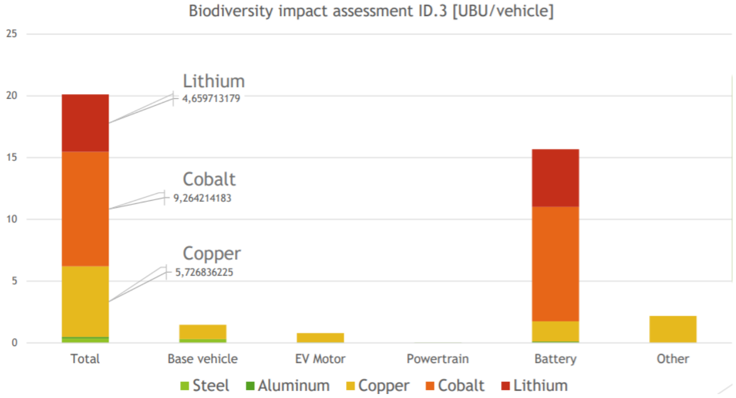

Fig. 2: Detailed impact assessment of VW ID.3 model

A simplified scenario analysis is performed to analyze the influence of the Argentinian raw material supply to the total biodiversity impact. Two scenarios are developed, where scenario one refers to the calculation presented in Fig. 2 2. In scenario two, Argentina is excluded as sourcing country while the resulting import share is rescaled to 100%. The scenario analysis reveals a reduction potential of around 23% when excluding Argentina as a sourcing country for lithium. The reduction potential of different extraction methods was out of scope of this study. Detailed results are presented in the supplementary material.

4 Conclusion

Mineral extraction sites account for major disturbances of the local ecosystem which lead to biodiversity loss by degrading large areas of land. The globally extending land degradation associated with open pit mining is rising due to increasing demands and decreasing ore grades. The main objective of this study was to test the applicability of a novel biodiversity impact assessment method in real-world applications. A simplified LCIA of a product with a complex supply chain was conducted. Suitable inventory data of a modern BEV matching the specifications of the VW ID.3 were developed. A GIS based approach for gathering and processing land use data was developed and tested. The LCIA covers the biodiversity impact for the procurement of five important and critical metals in the automotive supply chain. The results show that cobalt, lithium and copper account for the major biodiversity impact among the assessed metals. Impacts of steel and aluminum are comparatively low. Modern BEV show higher biodiversity impacts than ICEV due to a higher copper content and the application of critical battery materials (cobalt, lithium). The developed unit processes for steel, copper, aluminum, cobalt and lithium are applicable in a wide range of future LCA studies. The applied methodology is feasible for applications characterized by complex supply chains. Although the presented LCIA covers only single parts of the automotive supply chain, as far as known, this study presents the first work on biodiversity impact assessment of selected raw materials in the supply chain of passenger cars. It provides basic data sets and guidance to support the application of biodiversity impact assessment methods among LCA-practitioners and in the industry. Further research bears potential for increasing accuracy and reducing limitations (e.g. expand number of unit processes). Industry wide application of such methodologies can support in developing sustainable production patterns and reduce industry’s impact on biological diversity.

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