Environmental Impact Assessment Review 67 (2017) 88–100

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Including biodiversity in life cycle assessment – State of the art, gaps and research needs

Lisa Winter*, Annekatrin Lehmann, Natalia Finogenova, Matthias Finkbeiner

Technical University Berlin, Department of Environmental Technology, Straße des 17. Juni 135, 10623 Berlin, Germany

A R T I C L E I N F O

Keywords:
Biodiversity
Life cycle assessment (LCA)
Life cycle impact assessment (LCIA)
Indicators
Pressures
Environment

A B S T R A C T

Purpose: For over 20 years the feasibility of including man-made impacts on biodiversity in the context of Life Cycle Assessment (LCA) has been explored. However, a comprehensive biodiversity impact assessment has so far not been performed. The aim of this study is to analyse how biodiversity is currently viewed in LCA, to highlight limitations and gaps and to provide recommendations for further research.
Method: Firstly, biodiversity indicators are examined according to the level of biodiversity they assess (genetic, species, ecosystem) and to their usefulness for LCA. Secondly, relevant pressures on biodiversity that should be included in LCA are identified and available models (in and outside of an LCA context) for their assessment are discussed. Thirdly, existing impact assessment models are analysed in order to determine whether and how well pressures are already integrated into LCA. Finally, suggestions on how to include relevant pressures and impacts on biodiversity in LCA are provided and the necessary changes in each LCA phase that must follow are discussed.
Results: The analysis of 119 indicators shows that 4% of indicators represent genetic diversity, 40% species diversity and 35% ecosystem diversity. 21% of the indicators consider further biodiversity-related topics. Out of the indicator sample, 42 indicators are deemed useful as impact indicators in LCA. Even though some identified pressures are already included in LCA with regard to their impacts on biodiversity (e.g. land use, carbon dioxide emissions etc.), other proven pressures on biodiversity have not yet been considered (e.g. noise, artificial light).
Conclusion: Further research is required to devise new options (e.g. impact assessment models) for integrating biodiversity into LCA. The final goal is to cover all levels of biodiversity and include all missing pressures in LCA. Tentative approaches to achieve this goal are outlined.

1. Introduction

The Convention on Biological Diversity (CBD) defines biological diversity (biodiversity) as a variety of living organisms. This means all types of terrestrial and aquatic ecosystems and includes their genetic diversity, their species diversity and their ecosystem diversity (also known as 'levels of biodiversity') (United Nations (UN), 1992). The term genetic diversity describes the variety within one gene pool. Species diversity is the variety of species in a given ecosystem. Ecosystem diversity implies the variety of ecosystems in a defined region, for example in a country. In past decades, biodiversity has been decreasing at an alarming rate (Butchart et al., 2010). Not only is the state of biodiversity deteriorating, but the pressures on biodiversity (i.e. the factors causing biodiversity loss) continue to intensify (Butchart et al., 2010). This is a dangerous development because firstly biodiversity ought to be protected for its intrinsic value and secondly its loss threatens the safe provision of so called 'ecosystem services' which our society depends on. These ecosystem services include a support function of e.g. nutrients or soil, a provisioning function such as the provision of food or fresh water, a regulating function such as that of climate regulation or water purification as well as cultural services (e.g. education or aesthetics) (Millennium Ecosystem Assessment (MEA), 2005). Moreover, the higher the biodiversity the higher the resistance of an ecosystem against climate change-induced effects (Isbell et al., 2015). As a counter measure against the loss of biodiversity, the CBD secretariat (SCBD) drafted and implemented in cooperation with the United Nations Environment Programme (UNEP) a strategic plan for the protection of biodiversity from 2011 to 2020 within the Global Biodiversity Outlook 4 (GBO 4). The strategy, referred to as *Strategic Plan for Biodiversity 2011–2020*, contains five major goals termed *Aichi Biodiversity Targets* (SCBD, 2014):

- Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
- Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use

* Corresponding author.
E-mail address: lisa.winter@campus.tu-berlin.de (L. Winter).

http://dx.doi.org/10.1016/j.eiar.2017.08.006
Received 26 October 2016; Received in revised form 14 July 2017; Accepted 18 August 2017
0195-9255/

- Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity
- Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services
- Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building

None of these five goals have been reached so far (SCBD, 2014). Besides these goals, the SCBD identified five main drivers[1] of biodiversity loss in the GBO 3 (2010). These are (SCBD, 2010):

- Habitat loss and degradation
- Climate change
- Pollution and nutrient load
- Overexploitation and unsustainable use and
- Invasive alien species

Each of these drivers of biodiversity loss can be subdivided into several environmental pressures (i.e. threats to biodiversity). Even though the distinction between pressures and drivers is not always clear, pressures on biodiversity can be assigned to superior drivers. For instance, habitat loss is a consequence of the pressures land use or water use and climate change is a consequence of greenhouse gas emissions (e.g. carbon dioxide) which lead to the pressure change in temperature. To reach the Aichi Biodiversity Targets these main drivers and the related pressures causing the loss of biodiversity need to be addressed and their relation to production processes needs to be determined.

Life Cycle Assessment (LCA) is a tool that allows to quantify the potential environmental impacts of a product over its full life cycle; from raw material extraction to end-of-life management (International Organization for Standardization (ISO), 2006a). Consequently, we suggest the LCA framework for estimating the impact of pressures arising from anthropogenic activities on biodiversity. LCA presents a practical tool to directly address *Strategic Goal B* of the Aichi Biodiversity Targets. By allowing us to identify hotspots (i.e. production processes with particularly high impacts) along the life cycle of a product, LCA enables decision-makers to develop more targeted solutions towards reducing adverse impacts on the environment, including on biodiversity. According to the ISO standards 14040/14044, an LCA consists of the following four phases: I. Definition of the goal and scope, II. Life cycle inventory analysis (LCI), III. Life cycle impact assessment (LCIA) and IV. Interpretation (ISO, 2006a, 2006b). In the LCI phase, data is collected for all inputs (e.g. kilowatt-hours of electricity) and outputs (e.g. kg emissions of greenhouse gases) of the studied product system. In the LCIA phase, the inventory data is transferred via impact assessment models into midpoint[2] impact indicator results for a specific midpoint impact category. For example, the absolute amount of greenhouse gases emitted by the analysed product system (inventory result) is translated into kg carbon dioxide equivalents (kg CO_2-Eq.) to express the contribution of the product system to the midpoint impact category ‘climate change’. Indicator results at the midpoint level can be translated additionally via impact assessment models into endpoint[2] impact indicator results (e.g. potential disappeared fraction (PDF)) for a specific endpoint category (e.g. ecosystem health). In this manner, impacts are assessed along an impact pathway, i.e. a series of effects from inventory data to midpoint impact result to endpoint impact result (Klöpffer and Grahl, 2014). Pressures on biodiversity (e.g. land use) can be represented as midpoint impact categories whereas biodiversity in general is an endpoint category, expressed as ecosystem health.

Research into the integration of biodiversity in LCA has been ongoing for more than 20 years. So far, the largest number of attempts to include biodiversity in LCA have been made for incorporating the impacts of land use as a pressure on biodiversity (see for instance Köllner, 2000 and Lindeijer, 2000) (Teillard et al., 2016). Despite the proliferation of research in the field, the impacts of pressures on biodiversity are still not comprehensively assessed in LCA – neither with regard to land use (Curran et al., 2016; Gabel et al., 2016; Souza et al., 2015) nor in general (Curran et al., 2011; Finkbeiner et al., 2014). Biodiversity impact assessment in LCA still suffers from a number of gaps and faces enduring challenges such as the inclusion of a spatial dimension.

This paper does not attempt to solve current gaps and challenges associated with the integration of biodiversity into LCA but to analyse them, to define open research questions and to present conceptual approaches, which could lead to future solutions. Therefore, this review study is divided into four parts:

1. Analysis and identification of indicators (addressing biodiversity)
2. Identification of pressures on biodiversity inside and outside of LCA
3. Analysis of impact assessment methods
4. Including biodiversity in LCA

This study aims to answer the following research questions: 1. Which indicators addressing biodiversity are available and which of them are suitable for integration into LCIA? 2. Which pressures on biodiversity have so far been identified? 3. Which impact assessment models exist and to what extent do they take into account effects on all levels of biodiversity? 4. How extensively are the identified pressures reflected in common impact categories in LCA? 5. How can biodiversity impact assessment be comprehensively incorporated in LCA, taking into account the answers to the preceding questions (regarding the available indicators, the existing pressures on biodiversity, the existing LCIA models and the implementation of the pressures in these LCIA models)? Answering the questions includes the presentation of the current status, the identification of gaps and challenges, as well as first recommendations. This study builds on Curran's and his colleagues' work (see Curran et al., 2011) while attempting to include new findings and address more recent gaps. Furthermore, we examine additional pressures on biodiversity, which require consideration within LCIA and explore approaches for their inclusion. Finally, the changes in each individual phase of LCA, which will inevitably ensue if biodiversity is to be adequately incorporated into LCIA, are presented. Thus, the main focus of this study is on LCIA, but the changes in the other phases of LCA are also considered. Even though more recent reviews concerning biodiversity in LCA have been published (e.g. Curran et al., 2016, Gabel et al. (2016)), they do not cover the scope of this study. They mainly focus on land use impact assessment models and do not address other important biodiversity pressures such as artificial light pollution. Therefore, they have not been considered as a basis for the present study. At the time of writing this review and to the best of our knowledge, no other reviews relevant to the work presented here have been published. The novelty of the current study lies in analysing the state of biodiversity impact assessment within LCA with a broader perspective that takes all three levels of biodiversity and all pressures on biodiversity into consideration as well as in discussing the implications of an improved assessment of biodiversity in all phases of LCA.

This paper is structured as follows. Section 2 presents the methods used for the different parts of this study, Section 3 displays the results and Section 4 is devoted to discussion. We conclude with a number of recommendations for further research in order to integrate missing pressures on biodiversity (and their associated impact pathways) into LCIA in the future and to adapt all other phases of LCA to the needs of such integration.

[1] In the following the term *driver* refers to the drivers published by the SCBD (2010).

[2] Midpoint categories are defined as problem-oriented (e.g. global warming potential), whereas endpoint categories are defined as damage-oriented (e.g. human health) (European Commission, 2010b).