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Accounting for land use in life cycle assessment: The value of NPP as a proxy indicator to assess land use impacts on ecosystems

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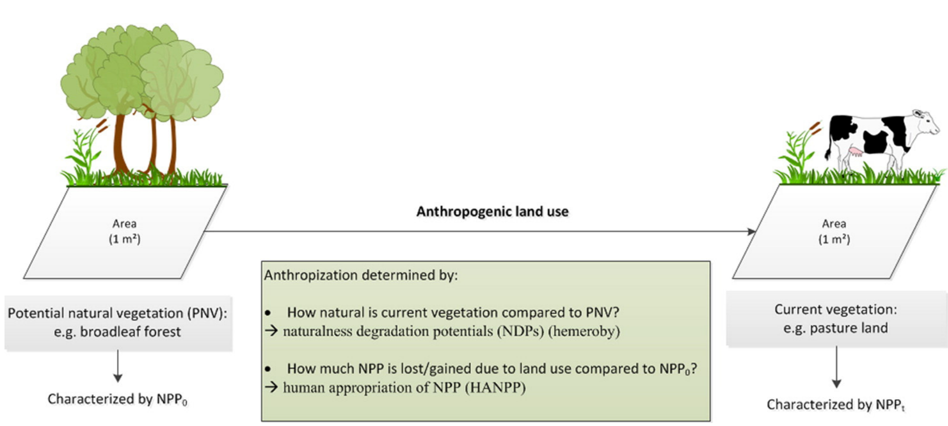
HIGHLIGHTS

- Land use can alter the amount of natural resources and/or ecosystem functioning.
- Identification of the cause–effect chain and review of land use LCIA indicators
- Introduction of two LCIA indicators for land use impacts on ecosystem health
- Characterization factors based on net primary production loss, used as a proxy
- Hemeroby and HANPP concepts used to address the remaining NPP after land use

GRAPHICAL ABSTRACT



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ABSTRACT

Terrestrial land and its resources are finite, though, for economic and socio-cultural needs of humans, these natural resources are further exploited. It highlights the need to quantify the impact humans possibly have on the environment due to occupation and transformation of land. As a starting point of this paper (1st objective), the land use activities, which may be mainly socio-culturally or economically oriented, are identified in addition to the natural land-based processes and stocks and funds that can be altered due to land use. To quantify the possible impact anthropogenic land use can have on the natural environment, linked to a certain product or service, life cycle assessment (LCA) is a tool commonly used. During the last decades, many indicators are developed within the LCA framework in an attempt to evaluate certain environmental impacts of land use. A second objective of this study is to briefly review these indicators and to categorize them according to whether they assess a change in the asset of natural resources for production and consumption or a disturbance of certain ecosystem processes, i.e. ecosystem health. Based on these findings, two enhanced proxy indicators are proposed

Abbreviations: AoP, area of protection; BDP, Biodiversity Damage Potential; BPP, biotic production potential; CF, characterization factor; CEENE, Cumulative Exergy Extraction from the Natural Environment; CSP, Carbon Sequestration Potential; EDP, Ecosystem Damage Potential; EF, ecosystem function; ERP, erosion regulation potential; FWRP, fresh water regulation potential; HANPP, human appropriation of net primary production; ISO, International Organization for Standardization; LANCA, Land Use Indicator Value Calculation; LCA, Life Cycle Assessment; LCC, life cycle costing; LCI, life cycle inventory; LCIA, life cycle impact assessment; LF, land function; LUF, land use function; MEA, Millennium Ecosystem Assessment; NDP, naturalness degradation potential; NPP, net primary production; PDF, Potentially Disappeared Fraction; PNV, potential natural vegetation; SAR, Species–Area Relationship; SED, Solar Energy Demand; SLCA, Social Life Cycle Assessment; SOC, soil organic carbon; WPP, water purification potential.

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Ecosystem health
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(3rd objective). Both indicators use net primary production (NPP) loss (potential NPP in the absence of humans minus remaining NPP after land use) as a relevant proxy to primarily assess the impact of land use on ecosystem health. As there are two approaches to account for the natural and productive value of the NPP remaining after land use, namely the Human Appropriation of NPP (HANPP) and hemeroby (or naturalness) concepts, two indicators are introduced and the advantages and limitations compared to state-of-the-art NPP-based land use indicators are discussed. Exergy-based spatially differentiated characterization factors (CFs) are calculated for several types of land use (e.g., pasture land, urban land).

1. Introduction

Today, a key question in policy, economics and science is: how to manage the use of our available natural resources in a sustainable way? It has become a pressing need to find answers to this question as we are facing global problems such as fossil fuel depletion and fresh water and metal scarcity. One of our most important and scarce natural resources is land, as humans have been using it for thousands of years to fulfill their needs for energy, food and accommodation (Beck et al., 2010). Competition for land among different uses is becoming acute and the pressure of a rising population is taking a huge toll on land quality and affects ecosystem resilience (FAO, 1999). Consequences of an intensified land use include, amongst others, soil degradation and erosion, shifts in ground water availability and loss of biodiversity (Koellner and Scholz, 2007). Therefore, humanity is forced to manage resources more efficiently and environmentally sustainably to limit a long-term environmental damage. In order to ensure land availability for future generations, a critical challenge and essential step involves incorporating a sustainable perspective into land management. As life cycle (impact) assessment (LC(I)A) methods try to evaluate environmental damages due to human activities, they should allow for the evaluation of land use impact on the natural environment. However, accounting for land use impacts in LCA is not straightforward yet due to difficulties in analyzing and modeling the effects on complex natural interactions. Moreover, the need for geographical differentiation in land use impact assessment and the lack of reliable data hinders the application of certain land use indicators in LCA (Teixeira et al., 2016). Consequently, there is still no clear consensus on what kind of land use impacts need to be quantified and, in addition, on the most suitable indicator (Finnveden et al., 2009). Therefore, the present study has three major objectives: (1) identifying the natural land-based processes (e.g., nutrient and water cycling) and its components (e.g., fossil resources) that can be altered due to economic or socio-cultural oriented human activities on land (Section 2), (2) discussing the possible impact pathways for land use within the LCA framework and reviewing currently existing LCIA indicators that either account for impact on ecosystem health or impact on the amount of natural resources due to land use (Section 3) and (3), proposing two enhanced proxy indicators (based on NPP) that primarily assess the impact of land use on ecosystem health and providing spatially differentiated CFs for different types of land occupation as development in this field is crucial to improve decision making (Section 4).

2. The use of land, consequences for natural land-based processes and components

One of the main challenges in monitoring, modeling and communicating land use impacts is identifying the relation between land cover, land use and the functions of land. Over the past years, land use is often confused with land cover. However, there is a clear difference between the two terms: land cover is defined as the observed (bio)-physical cover on the earth's surface (Di Gregorio, 2005), and comprises mainly vegetation and man-made features (incl. water surfaces), while land use most often refers to human activities on land of a certain cover type (Fig. 1). Land use is thus a functional dimension. Nevertheless, the relationship between both terms is strong because the dominant land use within a certain area is often related to the existing land cover type. The anthropogenic land use activities can include biotic (e.g., clearcutting of tropical rainforest) and abiotic resource extraction (e.g., mining), surface use for biotic production (e.g., agriculture) and non-biotic matters (e.g., housing, recreation). Land use change, often linked to these human activities, refers to the change from one land use type to another, which regularly leads to a change in land cover (Matilla et al., 2012). When there has been no land use (or it happened a considerable time ago) at a given location, the present land cover corresponds to the natural vegetation (e.g., natural forest). In contrast, land use by humans at present or in the recent past generally results in a land cover that is not natural for that specific location (Koellner et al., 2013a).

2.1. Land functions as defined in literature

To encourage more sustainable land-management practices, it is important to first consider the functions of land. Several attempts have been made in recent studies to identify different types of land functions that are associated with natural, semi-natural and man-made ecosystems. De Groot et al. (2002) defined ecosystem functions (EFs) as the capacity of natural processes and components to provide goods and services that satisfy humans, directly or indirectly. In total, 23 ecosystem functions were described and grouped in four primary categories: regulation, habitat, production and information (Table A.1 of Appendix A). Each function is a result of a natural process and it provides goods and/or services that are valued by humans. Only those goods and services that can be used on a sustainable basis are included, i.e. non-renewable natural resources such as oil and gold are excluded because extracting these resources could impair the integrity and proper functioning of certain ecosystem processes. In 2005, the Millennium Ecosystem Assessment (MEA) report provided a conceptual framework that can be used in land management. It determines the ecosystem goods and services (also referred to as our natural capital), defined as the benefits people obtain from ecosystems (Table A.1). Goods are material products resulting from ecosystem processes, such as fossil fuels, wood, minerals and fiber. Ecosystem services were grouped according to their value for humans into four main categories: 1) provisioning, such as the production of food and water; 2) regulating, such as the control of climate and erosion; 3) supporting, e.g., nutrient cycling and soil formation; and 4) cultural, such as ecotourism and spiritual and recreational values (Millennium Ecosystem Assessment, 2005). These categories roughly correspond to the regulation, habitat, production and information categories as defined by de Groot et al. (2002) (De Groot and Hein, 2007). According to the MEA report (Millennium Ecosystem Assessment, 2005), humans have substantially altered all 31 goods and services by exceeding the capabilities of ecosystems to provide the services.

It is clear that an anthropocentric perspective forms the basis of both concepts (Silva, 2011). Ecosystem functions and ecosystem goods and services were mainly focused on ecosystem processes and natural components (the environmental pillar of sustainability) in light of the benefits they can provide to human well-being. Both concepts were not considered to be sufficiently comprehensive to include the requirements for a full sustainability analysis of land use impacts (Silva, 2011). Therefore, within the SENSOR project, a land use functions (LUFs) framework was developed, based on the concepts of multifunctionality,