Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Characterization factors for land use impacts on biodiversity in life cycle assessment based on direct measures of plant species richness in European farmland in the 'Temperate Broadleaf and Mixed Forest' biome

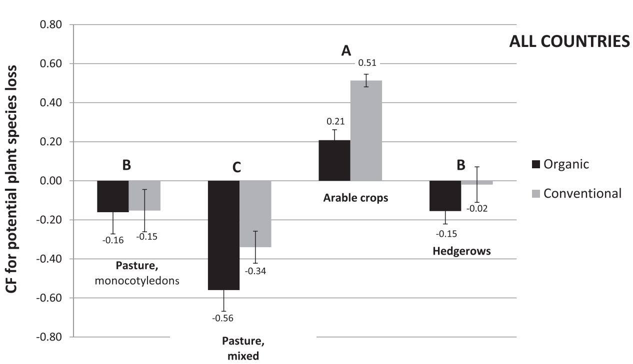
Marie Trydeman Knudsen [a,*], John E. Hermansen [a], Christel Cederberg [b], Felix Herzog [c], Jim Vale [j], Philippe Jeanneret [c], Jean-Pierre Sarthou [d,e], Jürgen K. Friedel [f], Katalin Balázs [g], Wendy Fjellstad [h], Max Kainz [i], Sebastian Wolfrum [i], Peter Dennis [j]

[a] *Dept. of Agroecology, Aarhus University, DK-8830 Tjele, Denmark*
[b] *Dept. of Energy and Environment, Chalmers University of Technology, 41296 Gothenburg, Sweden*
[c] *Agroscope, Institute for Sustainability Sciences ISS, Zurich CH-8046, Switzerland*
[d] *Toulouse University, ENSAT, UMR 1248 AGIR, Castanet-Tolosan F-31326, France*
[e] *INRA, UMR 1248 AGIR, Chemin de Borde-Rouge, Castanet-Tolosan F-31326, France*
[f] *University of Natural Resources and Life Sciences Vienna, Vienna A-1180, Austria*
[g] *Institute of Environmental and Landscape Management, MKK, Szent Istvan University, Pater K. u.1, Gödöllö H-2100, Hungary*
[h] *Norwegian Forest and Landscape Institute (NFLI), N-1431 Ås, Norway*
[i] *Munich Technical University, Freising D-85350, Germany*
[j] *Institute of Biological, Environmental and Rural Sciences, Penglais Campus, Aberystwyth University, UK-SY23 3DD, UK*

HIGHLIGHTS

- New characterization factors (CF) for land use impacts on biodiversity in LCA
- Provides CFs for different land use types and management (organic or conventional)
- Shows significant differences in CFs between organic and conventional fields
- Compares the new characterization factors with other studies
- Useful for assessing land use impacts on biodiversity in agricultural LCA studies

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form 23 November 2016
Accepted 24 November 2016
Available online xxxx

Editor: D. Barcelo

ABSTRACT

Life Cycle Assessment (LCA) is a widely used tool to assess environmental sustainability of products. The LCA should optimally cover the most important environmental impact categories such as climate change, eutrophication and biodiversity. However, impacts on biodiversity are seldom included in LCAs due to methodological limitations and lack of appropriate characterization factors. When assessing organic agricultural products the omission of biodiversity in LCA is problematic, because organic systems are characterized by higher species richness at field level compared to the conventional systems. Thus, there is a need for characterization factors to estimate land use impacts on biodiversity in life cycle assessment that are able to distinguish between organic and conventional agricultural land use that can be used to supplement and validate the few currently suggested

* Corresponding author at: Dept. of Agroecology, Aarhus University, Blichers Alle 20, P.O. BOX 50, DK-8830 Tjele, Denmark.
E-mail address: mariet.knudsen@agro.au.dk (M.T. Knudsen).

http://dx.doi.org/10.1016/j.scitotenv.2016.11.172

Keywords:
LCA
Organic agriculture
Conventional farming
Biodiversity damage potential
Potentially disappeared fraction of species
General habitat categories

characterization factors. Based on a unique dataset derived from field recording of plant species diversity in farmland across six European countries, the present study provides new midpoint occupation Characterization Factors (CF) expressing the Potentially Disappeared Fraction (PDF) to estimate land use impacts on biodiversity in the 'Temperate Broadleaf and Mixed Forest' biome in Europe. The method is based on calculation of plant species on randomly selected test sites in the biome and enables the calculation of characterization factors that are sensitive to particular types of management. While species richness differs between countries, the calculated CFs are able to distinguish between different land use types (pastures (monocotyledons or mixed), arable land and hedges) and management practices (organic or conventional production systems) across countries. The new occupation CFs can be used to supplement or validate the few current CF's and can be applied in LCAs of agricultural products to assess land use impacts on species richness in the 'Temperate Broadleaf and Mixed Forest' biome.

1. Introduction

Life Cycle Assessment (LCA) is a widely used tool to assess the potential environmental impacts of a given product to support decision making in production and consumption (ISO 14040:, 2006a, 2006b; ISO, 2006a, b) and is one of the preferred methods for estimating environmental impacts (Curran, 2013). LCA is integrated in EU's policy instruments and in private companies' environmental information systems (Souza et al., 2015). As part of implementing its strategy for *Building the Single Market for Green Products,* the European Commission has initiated the development of common life cycle based methods to measure and communicate the life cycle environmental performance of products (EC, 2015). In this work, a number of impact categories are included by default such as climate change, eutrophication, eco-toxicity etc., all midpoint impact categories. However, with regard to biodiversity, no midpoint characterization factor is present due to lack of an agreed methodology. This is problematic since biodiversity loss has become a major environmental concern high on the political agenda (Millennium Ecosystem Assessment, 2005; Earth Summit, 2012). Biodiversity is here defined as 'the variability among living organisms from all ecosystems and the ecological complexities of which they are part' (Millennium Ecosystem Assessment, 2005). One of the challenges of developing mid-point indicators for biodiversity is related to the fact that, while LCA is well suited to account for inflows and outflows from processes, such as emissions, it does not deal well with effects that are dynamic, scale-dependent, non-linear and hard to quantify (Curran et al., 2011) such as effects on biodiversity. Thus, inclusion of impacts on biodiversity poses a particular challenge to LCAs, due to ecological complexity and dynamics (Freidberg, 2013). Most studies use species richness and alpha diversity as the biodiversity indicator (Souza et al., 2015) and many studies are based on a single taxon, mainly vascular plants (e.g. Mueller et al., 2014; De Schryver et al., 2010; Schmidt, 2008). Other studies use approaches such as functional diversity (e.g. Souza et al., 2013), ecosystem scarcity (e.g. Coelho and Michelsen, 2014), combined species-area model with vulnerability indicators (Chaudhary et al., 2015) or expert system that combines a high level of detail regarding management options and their impact on a set of indicator species group (Jeanneret et al., 2014). Koellner et al. (2013b) published a UNEP (United Nations Environment Programme)-SETAC (Society of Environmental Toxicology and Chemistry) guideline on land use impact assessment on biodiversity in LCA, building on the earlier method of Milà i et al. (2007). This was followed up by a UNEP-SETAC initiative (Teixeira et al., 2016). The outcome of this initiative was a UNEP-SETAC consensus workshop (Pellston) and a review by Curran et al. (2016), where the model by Chaudhary et al. (2015) was provisionally recommended for hotspot analysis only, but not for comparative assertions and product labelling (Sala et al., 2016; Teixeira et al., 2016). However, even if this method can be used for hotspot analysis, it is not able to capture the effect of farm management practices or production systems on biodiversity such as differences between organic and conventional. Curran et al. (2016) also recognised this, and recommended that an optimal model should be able to differentiate extensive/intensive land management practices. However, most of the current LCA models are insufficient to determine the impacts of management options, production systems or field operations. They often deal with a limited set of land use classes in which "agriculture" is a bulk class, which is a consequence of using data-driven models that rely on secondary data sources. To determine CFs that are sensitive to management systems would require much more data. One of the main conclusions from the Pellston workshop was that further testing as well as development of CFs for further land use types is required before a method on land use impacts on biodiversity can be fully recommended and used in LCA (Frischknecht and Jolliet, 2016). Teixeira et al. (2016) recommended that the ideal biodiversity dataset should reflect changes in land management, and that species richness seems to be the best option for a start and that one of the crucial limitations was data availability. Similarly Souza et al. (2015) concluded from her review of approaches to assess biodiversity in relation to land use in LCA that it is crucial to broaden the range of experts developing methods, particular involving biologists and ecologists.

When assessing organic agricultural products using LCA, the omission of biodiversity is problematic, because organic systems are characterized by higher species richness at field level compared to the conventional systems (Hole et al., 2005; Bengtsson et al., 2005). Tuck et al. (2014) reviewed 184 observations from 94 studies and concluded that organic farming increases species richness at the field level by about 30% compared to conventional and that the result has been robust over the last 30 years of published studies. Thus, if land use impacts on biodiversity are not included in LCAs or are included without distinguishing between organic and conventional land use practices, the LCA results will not reflect the real impact of the product. Thus, it is essential to include land use impacts on biodiversity in LCA and to have valid CFs for that are also able to distinguish between organic and conventional farming practices, when performing LCA's of organic agricultural products.

In this respect, very few studies have provided CF's that distinguish whether land is used for organic or conventional production. De Schryver et al. (2010) provided detailed CF's for different agricultural land uses (arable or grass) and management practices (organic or conventional). Two limitations of this study are that the geographical coverage is only UK and that samples collected from the centre of fields were assumed to correspond to 'intensive' fields and samples from the field margin were assumed to correspond to 'organic' arable areas. Similarly, Jeanneret et al. (2014) is only valid for Swiss arable and grassland systems and adjacent regions. Koellner and Scholz (2008) and Mueller et al. (2014) are the only other studies found that provided CF's for organic and conventional production and are valid over a larger biome. One limitation of those studies is that it is based on literature reviews of different studies using different sampling methods. Souza et al. (2015) pointed to the need for CFs to be carefully validated against field data and local/national case studies. Thus, there is a need for CF's that are based on field data and local/national case studies using the same sampling method, that are valid over a larger biome, and that can be used to supplement and validate the current CF's.