Learning-by-doing: experience from 20 years of teaching LCA to future engineers

Purpose: In support of the sustainable development of our societies, future engineers should have elementary knowledge in sustainability assessment and use of life cycle assessment. Publications on pedagogical experience with teaching life cycle assessment (LCA) in high-level education are however scarce. Here, we describe and discuss 20 years of experience in teaching LCA at MSc level in an engineering university with the ambition to share our insights and inspire teaching of LCA as part of a university curriculum.

Methods: We detail the design of an LCA course taught at the Technical University of Denmark since 1997. The course structure relies on (i) a structured combination of theoretical teaching, practical assignments and hands-on practice on LCA case studies, and (ii) the conduct of real-life LCA case studies in collaboration with companies or other organisations. Through the semester-long duration of the course, students from different engineering backgrounds perform full-fledged LCA studies in groups, passing through two iterations—a screening LCA supporting a more targeted LCA. Results and discussion: The course design, which relies on a learning-by-doing principle, is transparently described to inspire LCA teachers among the readers. Historical evolution and statistics about the course, including its 192 case studies run in collaboration with 105 companies and institutions, are analysed and serve as basis to discuss the benefits and challenges of its different components, such as the theory acquisition, the assignment work, the LCA software learning, the conduct of case studies, the merits of industrial collaborations and grading approaches. Conclusions: We demonstrate the win-win situation created by the setting of the course, in which the students are actively engaged and learn efficiently how to perform an LCA while the collaborating companies often get useful insights into their analysed case studies. The course can also be an eye opener for companies unfamiliar with LCA, who get introduced to life cycle thinking and the potential benefits of LCA. We have no hesitation in recommending industries and LCA teachers to engage into such collaborations even in the fundamental teaching of LCA techniques.
A Framework for Development and Communication of Absolute Environmental Sustainability Assessment Methods: ASEA Method Framework

An absolute environmental sustainability assessment (AESA) addresses whether a production or consumption activity can be considered environmentally sustainable in an absolute sense. This involves a comparison of its environmental pressure to its allocated environmental carrying capacity. AESA methods have been developed in multiple academic fields, each using their own set of concepts and terms with little communication across the fields. A recent growing interest in using AESA methods for decision support calls for a better common understanding of the constituents of an AESA method and how it can be communicated to scientific peers and to potential users.

With this aim, we develop a framework for AESA methods, composed of a succession of four assessment steps and involving six methodological choices that must be made by the method developer or the user. We then use the framework to analyze and compare five selected AESA methods that focus on the release of phosphorus and nitrogen to the environment. In this manner, we show that the framework is able to systematically differentiate AESA methods that initially appear to be similar. Intended users of the framework include (1) method developers communicating new AESA methods to academic peers or potential method users and (2) researchers comparing a group of existing AESA methods and communicating their differences to their peers and to potential users looking for guidance on method selection.
Challenges of including human exposure to chemicals in food packaging as a new exposure pathway in life cycle impact assessment

Methods
The LCIA framework for human toxicity was extended for the first time to include consumer exposure to chemicals in food packaging through the product intake fraction (PiF) metric. The related exposure pathway was added to LCIA without other modifications to the existing toxicity characterization framework used by USEtox®, i.e., effect factor derivation. The developed method was applied to a high impact polystyrene (HIPS) container case study with the functional unit of providing 1 kg of yogurt in single servings. Various exposure scenarios were considered, including an evidence-based scenario using concentration data and a migration model. Human toxicity impact scores in comparative toxic units (CTUh) for the use stage were evaluated and then compared to human toxicity impact scores from a conventional LCIA methodology.

Results and discussion
Data allowed toxicity characterization of use stage exposure to only seven chemicals in HIPS out of forty-four identified. Data required were the initial concentration of chemicals in food packaging, chemical mass transfer from packaging into food, and relevant toxicity information. Toxicity characterization demonstrated that the combined CTUh for HIPS material acquisition, manufacturing, and disposal stages exceeded the toxicity scores related to consumer exposure to previously estimated concentrations of the seven characterizable chemicals in HIPS, by about two orders of magnitude. The CTUh associated with consumer exposure became relevant when migration was above 0.1% of the European regulatory levels. Results emphasize missing data for chemical concentrations in food contact materials and a need to expand the current USEtox method for effect factor derivation (e.g., to consider endocrine disruption, mixture toxicity, background exposure, and thresholds when relevant).

Conclusions
An LCIA method was developed to include consumer exposure to chemicals in food packaging. Further study is required to assess realistic scenarios to inform decisions and policies, such as circular economy, which can lead to trade-offs between environmental impacts and potentially toxic chemicals in packaging. To apply the developed method, data regarding occurrence, concentration, and toxicity of chemicals in food packaging are needed. Revisiting the derivation of effect factors in future work could improve the interpretation of human toxicity impact scores.

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Effect factors of terrestrial acidification in Brazil for use in Life Cycle Impact Assessment

Purpose: In Life Cycle Impact Assessment, atmospheric fate factors, soil exposure factors, and effect factors are combined to characterize potential impacts of acidifying substances in terrestrial environments. Due to the low availability of global data sets, effect factors (EFs) have been reported as the major contributors to statistical uncertainties of characterization factors and they are the focus of this study. We aim to develop spatially differentiated EFs taking Brazil as case and explore new methodological ways to derive them. Methods: EFs are calculated based on a comprehensive database reporting observations of approximately 30,000 plant species at biome and ecoregion levels. Species richness distributions as function of soil pH are developed and translated into potentially not occurring fraction (PNOF) of species, which can be equated to the more commonly used potentially disappeared fraction of species, to assess effects of changes in soil hydrogen ion concentration on terrestrial plant species. Potentially extinct fraction (PXF) of species is proposed as a complementary metric for LCIA models based on distributions of range-restricted species (species only occurring in one ecoregion of Brazil). Different approaches for determining EFs from the species richness distributions are evaluated. Area-weighted EFs are explored to determine potential effects when considering both acid and alkaline sides of species richness curves, thus integrating potentially positive effects of acidification on biodiversity. Results and discussion: Spatially differentiated EFs are provided for 6 biomes and 45 ecoregions composing Brazil. Comparisons with previous EFs demonstrate that data availability might significantly influence regression analyses, and the use of more representative data can lead to more consistent EFs. Moreover, consideration of the entire species richness curves yields positive and negative EFs. Adding acidifying substances onto specific soils in Brazilian ecoregions may therefore be associated with increased species richness if the pH approaches the optimum pH from the alkaline side of the curve. The meaningfulness of species richness as indicator of acidification stress is discussed based on this finding, as is the inclusion of the metric PXF, highlighting species whose loss could cause irreversible damages to the environment.

Conclusions: We recommend the calculation of area-weighted EFs to be integrated into characterization models for terrestrial acidification, and we therefore advocate that similar work be done for other regions in the world than Brazil to
enhance the consistency of the EFs and reduce their uncertainties. We additionally recommend that LCIA method developers further explore the application of PXF for other impact categories than acidification.

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Evaluating the monetary values of greenhouse gases emissions in life cycle impact assessment

It is commonly acknowledged that greenhouse gas (GHG) emissions from anthropogenic sources accelerate climate change impacts. Efforts are made by governments and companies to reduce GHG emissions via policies and actions. In order to determine which actions to prioritize among many options, benefits of emission reductions are often monetized, to compare with the costs of action or with benefits that can be obtained from other actions. Life cycle assessment (LCA) is a commonly used tool to assess the amount of GHGs emitted over the life cycle of a service, policy or product system. However, the damage modelling of GHGs in life cycle impact assessment (LCIA) and its monetary values have not been separately evaluated. This hinders the application of LCA in relevant decision contexts. This study evaluates the cause-effect chains and associated monetary values of GHG in three LCIA methods LIME2, EPS2015 and ReCiPe2016. Among these three, EPS2015 covers most damage categories, including the ones on human health, ecosystem and social assets. ReCiPe2016 does not include social assets damages and LIME2 does not consider ecosystem damages in climate change impact. Human health damages are well estimated in all three methods, contributing to 70–97% of the GHG monetary values. The lack of data is a clear obstacle across methods. Further research is needed to develop comprehensive and robust modelling approach for ecosystem damages, which are not well covered in current LCIA methods. Moreover, due to the scope of environmental LCA, there is a lack of consideration on socio-economic consequences, which may not be negligible for climate change. The resulting monetary value of GHG, expressed in per tonne CO2-eq are 16, 160 and 140 US$2017 respectively in LIME2, EPS2015 and ReCiPe 2016. These monetary values are reasonable for use in decision contexts where LCA is applied. Further research is, however, needed to reduce the current uncertainty of at least 1–2 orders of magnitude.

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IMPACT World+: a globally regionalized life cycle impact assessment method

This paper addresses the need for a globally regionalized method for life cycle impact assessment (LCIA), integrating multiple state-of-the-art developments as well as damages on water and carbon areas of concern within a consistent LCIA framework. This method, named IMPACT World+, is the update of the IMPACT 2002+, LUCAS, and EDIP methods. This paper first presents the IMPACT World+ novelties and results and then analyzes the spatial variability for each regionalized impact category.

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Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development

The aquaculture sector is anticipated to be a keystone in food production systems in the coming decades. However, it is associated with potentially important environmental damages caused by its contribution to eutrophication or climate change, for example. To comprehensively quantify those impacts, life cycle assessment (LCA) studies have been conducted on several seafood farming systems for the past 15 years. But, what major findings and common trends can we draw from this pool of studies? What can we learn to provide recommendations to decision and policymakers in the aquaculture sector? To address these questions, we performed a critical review of 65 LCA studies of aquaculture systems from the open literature. We conducted quantitative analyses to explore which impacts can be identified as dominating and to compare different types of aquaculture systems. Our results evidenced that the feed production is a key driver for climate change, acidification, cumulative energy use and net primary production use, while the farming process is a key driver for eutrophication. We also found that different aquaculture systems and technology components may exert considerably different environmental impacts. Based on identified patterns and comparisons, we therefore provided specific recommendations to aquaculture stakeholders for future policy and system development. Overall, the analysis of existing studies demonstrates that important insights can be gained by applying LCA to aquaculture systems, and, to move towards an environmentally sustainable aquaculture sector, we recommend its systematic use in the design of new aquaculture systems or policies, and/or in the evaluation and optimization of existing ones.
Overview and recommendations for regionalized life cycle impact assessment

Purpose
Regionalized life cycle impact assessment (LCIA) has rapidly developed in the past decade, though its widespread application, robustness, and validity still face multiple challenges. Under the umbrella of UNEP/SETAC Life Cycle Initiative, a dedicated cross-cutting working group on regionalized LCIA aims to provide an overview of the status of regionalization in LCIA methods. We give guidance and recommendations to harmonize and support regionalization in LCIA for developers of LCIA methods, LCI databases, and LCA software.

Methods
A survey of current practice among regionalized LCIA method developers was conducted. The survey included questions on chosen method’s spatial resolution and scale, the spatial resolution of input parameters, the choice of native spatial resolution and limitations, operationalization and alignment with life cycle inventory data, methods for spatial aggregation, the assessment of uncertainty from input parameters and model structure, and the variability due to spatial aggregation. Recommendations are formulated based on the survey results and extensive discussion by the authors.

Results and discussion
Survey results indicate that majority of regionalized LCIA models have global coverage. Native spatial resolutions are generally chosen based on the availability of global input data. Annual modeled or measured elementary flow quantities are mostly used for aggregating characterization factors (CFs) to larger spatial scales, although some use proxies, such as population counts. Aggregated CFs are mostly available at the country level. Although uncertainty due to input parameter, model structure, and spatial aggregation are available for some LCIA methods, they are rarely implemented for LCA studies. So far, there is no agreement if a finer native spatial resolution is the best way to reduce overall uncertainty. When spatially differentiated model CFs are not easily available, archetype models are sometimes developed.
Conclusions

Regionalized LCIA methods should be provided as a transparent and consistent set of data and metadata using standardized data formats. Regionalized CFs should include both uncertainty and variability. In addition to the native-scale CFs, aggregated CFs should always be provided and should be calculated as the weighted averages of constituent CFs using annual flow quantities as weights whenever available. This paper is an important step forward for increasing transparency, consistency, and robustness in the development and application of regionalized LCIA methods.

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Pollution levels of stormwater discharges and resulting environmental impacts

Stormwater carries pollutants that potentially cause negative environmental impacts to receiving water bodies, which can be quantified using life cycle impact assessment (LCIA). We compiled a list of 20 metals, almost 300 organic compounds, and nutrients potentially present in stormwater, and measured concentrations reported in literature. We calculated mean pollutant concentrations, which we then translated to generic impacts per litre of stormwater discharged, using existing LCIA characterisation factors. Freshwater and marine ecotoxicity impacts were found to be within the same order of magnitude (0.72, and 0.82 CTUe/l respectively), while eutrophication impacts were 3.2E-07 kgP-eq/l for freshwater and 2.0E-06 kgN-eq/l for marine waters. Stormwater discharges potentially have a strong contribution to ecotoxicity impacts compared to other human activities, such as human water consumption and agriculture. Conversely, contribution to aquatic eutrophication impacts was modest. Metals were identified as the main contributor to ecotoxicity impacts, causing >97% of the total impacts. This is in line with conclusions from a legal screening, where metals showed to be problematic when comparing measured concentrations against existing environmental quality standards.

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Quantification of environmental damage and benefit of four different stormwater management systems

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Relationships between plant species richness and soil pH at the level of biome and ecoregion in Brazil
Soil pH has been used to indicate how changes in soil acidity can influence species loss. The correlation between soil pH and plant species richness has mainly been studied in North America and Europe, while there is a lack of studies exploring Tropical florae. Here, our aim was therefore to investigate the relationships between terrestrial plant species richness and soil pH for the large Brazilian flora, with spatial differentiation into biomes and ecoregions. Data of plant species occurrences and soil pH in Brazil were compiled from public databases into a geo-referenced inventory of 29,712 terrestrial plants species with a harmonized nomenclature. Based on the pH range, over which each species had been observed, the species richness for each unit of soil pH was determined and plotted as a function of pH for the 6 biomes and 47 ecoregions of Brazil. Lognormal distributions were found for entire Brazil (R² = 0.999), the six biomes (R² > 0.955) and for 40 out of 45 ecoregions, for which a sufficient number of observations was available (R² of 0.830–1.000). Similar distribution patterns were observed when limiting the study scope to range-restricted species, i.e. species only occurring in a single ecoregion in Brazil. Species richness is an indicator of plant biodiversity and we recommend a combined use of species richness for all species and for range-restricted species to address the overall status of the terrestrial plant ecosystem as well as the potential loss of unique species within it, including endemic species. We additionally propose that the developed inventory and the observed sensitivity distributions serve as basis for life cycle impact assessment of terrestrial acidification.

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Scopus rating (2015): CiteScore 3.99 SJR 1.478 SNIP 1.727
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Web of Science (2014): Impact factor 3.444
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.63 SJR 1.347 SNIP 1.825
Web of Science (2013): Impact factor 3.23
ISI indexed (2013): ISI indexed yes
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BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.42 SJR 1.252 SNIP 1.845
Web of Science (2012): Impact factor 2.89
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 3.05 SJR 1.223 SNIP 1.73
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BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.26 SNIP 1.603
Web of Science (2010): Impact factor 2.967
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.059 SNIP 1.756
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.925 SNIP 1.518
Scopus rating (2007): SJR 0.783 SNIP 1.364
Scopus rating (2006): SJR 0.688 SNIP 0.947
Scopus rating (2005): SJR 0.466 SNIP 1.009
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About This Book
To reach the UN sustainable development goal, there is a need for comprehensive and robust tools to help decision-making identify the solutions that best support sustainable development. The decisions must have a system perspective, consider the life cycle, and all relevant impacts caused by the solution. Life Cycle Assessment (LCA) is a tool that has these characteristics and the ambition with this book is to offer a comprehensive and up-to-date introduction to the tool and its underlying methodological considerations and potential applications. The book consists of five parts. The first part introduces LCA. The second part is a text book aiming at university students from undergraduate to PhD level, and professionals from industry and within policy making. It follows ISO 14040/14044 structure, draws upon a variety of LCA methods published over the years, especially the ILCD, and offers prescriptions and recommendations for all the most important methodological choices that you meet when performing an LCA. The third part introduces applications of LCA and life cycle thinking by policy- and decision-makers in government and industry. The fourth part is a Cookbook guiding you through the concrete actions to undertake when performing an LCA. The fifth part contains some appendices. The book can be used as a text book, the chapter can be read as stand alone, and you can use the Cookbook as a manual on how to perform an LCA.

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A comparison of land use change accounting methods: seeking common grounds for key modeling choices in biofuel assessments
Five currently used methods to account for the global warming (GW) impact of the induced land-use change (LUC) greenhouse gas (GHG) emissions have been applied to four biofuel case studies. Two of the investigated methods attempt to avoid the need of considering a definite occupation -thus amortization period by considering ongoing LUC trends as a dynamic baseline. This leads to the accounting of a small fraction (0.8%) of the related emissions from the assessed LUC, thus their validity is disputed. The comparison of methods and contrasting case studies illustrated the need of clearly distinguishing between the different time horizons involved in life cycle assessments (LCA) of land-demanding products like biofuels. Absent in ISO standards, and giving rise to several confusions, definitions for the following time horizons have been proposed: technological scope, inventory model, impact characterization, amortization/occupation, plantation lifetime and harvesting frequency. It is suggested that the anticipated technical lifetime of biorefineries using energy crops as feedstock stands as the best proxy for the cut-off criterion of land's occupation period and the inventory modeling period. Top-down LUC models are suggested as a gross reference benchmark to evaluate LUC results from bottom-up models, since the former represent average GHG emissions from deforestation statistics at different spatial resolutions. Reporting LUC emissions per area and implementing a corporate accounting system that ascribes deforestation emissions to responsible companies could avoid the critical uncertainty related to yield estimations.

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Contributors: Hauschild, M. Z., Laurent, A., Molin, C.
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ASTA - A method for multi-criteria evaluation of water supply technologies to Assess the most SusTainable Alternative for Copenhagen
Utilities in larger cities have to make complex decisions planning future investments in urban water infrastructure. Changes are driven by physical water stress or political targets for environmental water flows e.g. through the implementation of the European water framework directive. To include these environmental, economic and social sustainability dimensions we introduce a novel multi-criteria assessment method for evaluation of water supply technologies. The method is presented and demonstrated for four alternatives for water supply based on groundwater, rain- & stormwater or seawater developed for augmenting Copenhagen's current groundwater based water supply. To identify the most sustainable technology, we applied rank order distribution weights to a multi-criteria decision analysis to combine the impact assessments of environment, economy and society. The three dimensions were assessed using 1)
life-cycle assessment, 2) cost calculations taking operation and maintenance into account and 3) the multi-criteria decision analysis method Analytical hierarchy process. Specialists conducted the life-cycle assessment and cost calculations and the multi-criteria decision analyses were based on a stakeholder workshop gathering stakeholders relevant for the specific case. The workshop reached consensus on three sets of ranked criteria. Each set represented stakeholder perspectives with first priority given to one of the three sustainability dimensions or categories. The workshop reached consensus and when the highest weight was assigned to the environmental dimension of sustainability then the alternative of 'Rain- & stormwater harvesting' was the most sustainable water supply technology; when the highest weight was assigned to the economy or society dimensions then an alternative with 'Groundwater abstraction extended with compensating actions' was considered the most sustainable water supply technology. Across all three sets of ranked weights, the establishment of new well fields is considered the least sustainable alternative.

**General information**

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BFI (2016): BFI-level 2  
Scopus rating (2016): CiteScore 5.09 SJR 1.652 SNIP 1.856  
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BFI (2015): BFI-level 2  
Scopus rating (2015): CiteScore 4.33 SJR 1.653 SNIP 1.648  
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Scopus rating (2013): CiteScore 3.73 SJR 1.527 SNIP 1.745  
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Scopus rating (2011): CiteScore 3.61 SJR 1.802 SNIP 1.676
Cradle to Cradle and LCA

Cradle to Cradle (C2C) offers a positive vision of a future, where products are radically redesigned to be beneficial to humans and the environment. The idea is not to reduce negative impacts (as in LCA), but to increase positive impacts. This chapter presents the C2C concept and its relationship with the circular economy, the C2C certification and examples of C2C certified or inspired products and systems. This is followed by a comparison of C2C with eco-efficiency and LCA. Because of their important differences, we conclude that care should be taken when combing C2C and LCA, e.g. using LCA to evaluate products inspired by C2C. We then provide an in-depth analysis of the conflicts between C2C and LCA and offer solutions. Finally, we reflect upon how LCA practitioners can learn from C2C in terms of providing a vision of a sustainable future, creating a sense of urgency for change and communicating results in an inspiring way.

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Contributors: Bjørn, A., Hauschild, M. Z.
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Development of a life-cycle impact assessment methodology linked to the Planetary Boundaries framework

To enable quantifying environmental performance of products and technologies in relation to Planetary Boundaries, there is a need for life-cycle impact assessment (LCIA) methods which allow for expressing indicators of environmental impact in metrics corresponding to those of the control variables in the Planetary Boundaries framework. In this study, we present such a methodology, referred to as PB-LCIA. Characterization factors for direct use in the LCIA phase of a life cycle assessment, or other life-cycle based assessment, were developed for a total of 85 elementary flows recognized as dominant contributors to transgressing specific Planetary Boundaries. Exception was made for “biosphere integrity” and “introduction of novel entities” where a Planetary Boundary is yet to be defined for the latter and characterization models are considered immature for the former. The PB-LCIA can be used to quantify the share of the “safe operating space” that human activities occupy, as was illustrated by calculating indicator scores for about 10,600 products, technologies and services exemplifying several sectors, including materials, energy, transport, and processing. The PB-LCIA can be used by companies interested in gauging their activities against the Planetary Boundaries to support decisions that help to reduce the risk of human activities moving the Earth System out of the Holocene state.

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Web of Science (2016): Impact factor 3.898
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BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.76 SJR 1.464 SNIP 1.974
Web of Science (2014): Impact factor 3.444
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Scopus rating (2013): CiteScore 3.63 SJR 1.347 SNIP 1.825
The purpose of our study is to analyse how urban lifestyles impact on the environment to offer knowledge based inspiration for effective environmental policies relating to contemporary Danish consumption patterns. The application of a Personal Metabolism (PM) coupled Life Cycle Assessment (LCA) approach supported by cluster analysis facilitated the identification of consumption-related clusters based on central demographic and life style parameters such as income, diet, transport, and age. The environmental performance of the assessed consumption patterns were calculated in a full life cycle perspective and covering all relevant environmental impacts both on midpoint and endpoint levels by applying the ReCiPe 2008 Life Cycle Impact Assessment (LCIA) methodology. The results of the contribution analysis revealed that climate change, particulate matter, human toxicity, fossil depletion and ionizing radiation contribute most to the three endpoints covered by ReCiPe 2008. Results of cluster analysis indicated that demographic parameters such as income level and age of the respondents has a strong influence on the environmental impacts. The influence of lifestyle aspects such as choice of diet, use of private car and household size was also investigated. These three parameters were found to significantly influence the consumption related environmental impacts of urban Danish residents. Overall our study identify drivers and focus points of consumption and provides a contemporary picture of Danish urban consumption-related environmental impacts.
Environmental screening of potential biomass for green biorefinery conversion

Green biorefinery (GBR) is a new biorefinery technology for the conversion of fresh biomass to value added products. In the present study, we combined a Process Flowsheet Simulation (PFS) and Life Cycle Assessment (LCA) of a small scale decentralized GBR to screen environmental impact profiles for potential biomass feedstocks for GBR conversion. Furthermore, we carried out hotspot and sensitivity analysis to identify where the largest impacts arise in the biorefining stage in order to provide recommendations and focus points for GBR technology developers. The GBR considered in this study produces a protein-rich feed for monogastric animals and an energy-rich feed from the press pulp and biogas from the GBR residues. The included biomass feedstocks are: alfalfa, grass-clover, festulolium and ryegrass. These biomasses were selected to accommodate variations in central biomass characteristics like: crop yields, rate of fertilizer application, chemical biomass compositions and related potential environmental implications. Among the studied crops, alfalfa provides the best overall environmental performance due to its high yield and low agricultural input demands. Results of the hotspot analysis further identified the coagulation and the drying as the processes that induce most of the environmental impacts in the biorefining stage. Conversion of green biomass for the production of feed and energy could provide environmental benefits compared to the production of conventional feed. However, the GBR technology have still room for optimization in order to further reduce the environmental impacts, across all impact categories, by decreasing energy consumption and increasing conversion efficiency. (C) 2018 Elsevier Ltd. All rights reserved.
Environmental sustainable decision making – The need and obstacles for integration of LCA into decision analysis

Decision analysis is often used to help decision makers choose among alternatives, based on the expected utility associated to each alternative as function of its consequences and potential impacts. Environmental impacts are not always among the prioritized concerns of traditional decision making. This has fostered the development of several environmental problems and is nowadays a reason of concern. Life Cycle Assessment (LCA) can assess an extensive
range of environmental impacts associated with a product or service system and support a life cycle perspective on the alternative products or service systems, revealing potential problem shifting between life cycle stages. Through the integration with traditional risk based decision analysis, LCA may thus facilitate a better informed decision process. In this study we explore how environmental impacts are taken into account in different fields of interest for decision makers to identify the need, potential and obstacles for integrating LCA into conventional approaches to decision problems. Three application areas are used as examples: transportation planning, flood management, and food production and consumption. The analysis of these cases shows that environmental impacts are considered only to a limited extent in traditional evaluation of transport and food projects. They are rarely, if at all, addressed in flood risk management. Hence, in each of the three cases studied, there is a clear need for the inclusion of a better and systematic assessment of environmental impacts. Some LCA studies have been conducted in all three research areas, mainly on infrastructures and production systems. The three cases show the potential of integrating LCA into existing decision analysis by providing the environmental profiles of the alternatives. However, due to different goals and scopes of LCA and other decision analysis approaches, there is a general lack of consistency in study system scoping in terms of considered elements and boundaries, in uncertainty treatment, and in applied metrics. In the present paper, we discuss the obstacles arising when trying to integrate LCA with conventional evaluation tools and we propose a research agenda to eventually make such integration feasible and consistent.

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Civil Engineering, Transport DTU, Transport Modelling, National Food Institute, Research group for Risk Benefit, Department of Applied Mathematics and Computer Science, Department of Environmental Engineering, Urban Water Systems, Research group for Genomic Epidemiology, Section for Structural Engineering
Contributors: Dong, Y., Miraglia, S., Manzo, S., Georgiadis, S., Sørup, H. J. D., Boriani, E., Hald, T., Thöns, S., Hauschild, M. Z.
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Web of Science (2017): Impact factor 3.826
Web of Science (2017): Indexed yes
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Scopus rating (2016): CiteScore 3.9 SJR 1.677 SNIP 1.581
Web of Science (2016): Impact factor 3.751
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.83 SJR 1.613 SNIP 1.467
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BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.02 SJR 1.812 SNIP 1.814
Web of Science (2014): Impact factor 3.018
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 4.08 SJR 1.687 SNIP 1.957
Web of Science (2013): Impact factor 3.514
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 3.35 SJR 1.505 SNIP 1.647
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Global guidance on environmental life cycle impact assessment indicators: impacts of climate change, fine particulate matter formation, water consumption and land use

Purpose: Guidance is needed on best-suited indicators to quantify and monitor the man-made impacts on human health, biodiversity and resources. Therefore, the UNEP-SETAC Life Cycle Initiative initiated a global consensus process to agree on an updated overall life cycle impact assessment (LCIA) framework and to recommend a non-comprehensive list of environmental indicators and LCIA characterization factors for (1) climate change, (2) fine particulate matter impacts on human health, (3) water consumption impacts (both scarcity and human health) and 4) land use impacts on biodiversity.

Methods: The consensus building process involved more than 100 world-leading scientists in task forces via multiple workshops. Results were consolidated during a 1-week Pellston Workshopâ"¢ in January 2016 leading to the following recommendations. Results and discussion: LCIA framework: The updated LCIA framework now distinguishes between intrinsic, instrumental and cultural values, with disability-adjusted life years (DALY) to characterize damages on human health and with measures of vulnerability included to assess biodiversity loss. Climate change impacts: Two complementary climate change impact categories are recommended: (a) The global warming potential 100 years (GWP 100) represents shorter term impacts associated with rate of change and adaptation capacity, and (b) the global temperature change potential 100 years (GTP 100) characterizes the century-scale long term impacts, both including climate-carbon cycle feedbacks for all climate forcers. Fine particulate matter (PM2.5) health impacts: Recommended characterization factors (CFs) for primary and secondary (interim) PM2.5 are established, distinguishing between indoor, urban and rural archetypes. Water consumption impacts: CFs are recommended, preferably on monthly and watershed levels, for two categories: (a) The water scarcity indicator "AWARE" characterizes the potential to deprive human and ecosystems users and quantifies the relative Available Water Remaining per area once the demand of humans and aquatic ecosystems has been met, and (b) the impact of water consumption on human health assesses the DALYs from malnutrition caused by lack of water for irrigated food production. Land use impacts: CFs representing global potential species loss from land use are proposed as interim recommendation suitable to assess biodiversity loss due to land use and land use change in LCA hotspot analyses. Conclusions: The recommended environmental indicators may be used to support the UN Sustainable Development Goals in order to quantify and monitor progress towards sustainable production and consumption. These indicators will be periodically updated, establishing a process for their stewardship.
How to bring absolute sustainability into decision-making: An industry case study using a Planetary Boundary-based methodology

The Planetary Boundaries concept has emerged as a framework for articulating environmental limits, gaining traction as a basis for considering sustainability in business settings, government policy and international guidelines. There is emerging interest in using the Planetary Boundaries concept as part of life cycle assessment (LCA) for gauging absolute environmental sustainability. We tested the applicability of a novel Planetary Boundaries-based life cycle impact assessment methodology on a hypothetical laundry washing case study at the EU level. We express the impacts corresponding to the control variables of the individual Planetary Boundaries together with a measure of their respective uncertainties. We tested four sharing principles for assigning a share of the safe operating space (SoSOS) to laundry washing and assessed if the impacts were within the assigned SoSOS. The choice of sharing principle had the greatest influence on the outcome. We therefore highlight the need for more research on the development and choice of sharing principles. Although further work is required to operationalize Planetary Boundaries in LCA, this study shows the potential to relate impacts of human activities to environmental boundaries using LCA, offering company and policy decision-makers information needed to promote environmental sustainability.

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BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.2 SJR 1.635 SNIP 1.843
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Scopus rating (2012): CiteScore 3.7 SJR 1.749 SNIP 1.82
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Web of Science (2011): Impact factor 3.286
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BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.576 SNIP 1.6
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.461 SNIP 1.489
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.393 SNIP 1.473
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.512 SNIP 1.586
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.439 SNIP 1.509
Web of Science (2005): Indexed yes
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Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.156 SNIP 1.35
Influence of substance coverage on impacts from the electricity sector

The electricity sector is a major source of emissions of greenhouse gas, but also heavy metals, dioxins or radioactive isotopes. However, most environmental assessments of the electricity sector at national or global scale focus solely on climate change and do not include other environmental impact categories such as particulate matter formation or toxic impacts on human health. At the national scale, the few available databases are limited to a narrow substance coverage. For example, official reports of pollutants emissions to the European Monitoring and Evaluation Programme (EMEP) should cover 23 substances in 51 countries, but they are not always complete. The Multi-Regional Input-Output database EXIOBASE includes environmental extensions emitted to air in 44 countries and 5 regions but only for 33 substances. In comparison, the database Ecoinvent provides emission data for hundreds of substances in the unit process inventories for electricity and heat generation. Here, we aim to develop a globally consistent and extensive dataset of airborne emissions from electricity production to get a more realistic coverage of toxicity impacts in large-scale life cycle assessments (LCAs). We thus built the Ecoinvent-based National Energy-related Emission Inventory (ENEEI) by upscaling processes from Ecoinvent 3.3 with national production volumes of electricity and complementing it with emission data from external sources. The resulting inventory ENEEI covers 229 substances, including 51 radioactive isotopes. By comparing inventories and databases at midpoint level, we show that LCAs using Ecoinvent may underestimate the toxicity impacts associated with electricity production by a factor ranging from 1.4 to 1.9, while Exiobase may cut them off by up to 4 orders of magnitude in some countries. This demonstrates the importance of having an extensive substance coverage to fully represent the environmental impacts of electricity production.

Integrating groundwater stress in life-cycle assessments – An evaluation of water abstraction

Understanding groundwater abstraction effects is vital for holistic impact assessments in areas depending on groundwater resources. The objective of our study was to modify the state-of-the-art AWaRe (available water remaining), freshwater impact assessment specifically for use in LCAs in areas dependent on groundwater resources. The new method, called “AGWaRe” (available groundwater remaining), reflects groundwater availability, based on a fraction of available groundwater remaining locally relative to a reference. Furthermore, our method increases spatial resolution beyond 1770km² grid cells and adjusts demarcations in order to improve the representation of the heterogeneity of groundwater catchments. The applicability of AGWaRe was demonstrated on three groundwater systems producing 5 million m³ water for the city of Copenhagen, namely Advanced Treatment of Groundwater, Simple Treatment of Groundwater and Infiltration of Reclaimed water. Results were normalised to compare with other effects of supplying water to an average Danish person. The normalised impacts for drinking water for one person ranged between 0.1 and 39PE (person equivalent) for the three systems, which indicates that effects on groundwater resources differ substantially between
systems. A comparative LCA of these groundwater systems shows that other impact categories range between 0 and 1 PE/person. Advanced Treatment of Groundwater generally has the lowest effect, for example <50% of the other groundwater systems in Global Warming Potential. The AGWaRe results indicate that freshwater impacts from Simple Treatment of Groundwater are up to 100 times greater than for Infiltration of Reclaimed water. Furthermore, AGWaRe exposes differences between the groundwater systems that AWaRe cannot evaluate, because one AWaRe cell covers two of the systems in question. These improvements are crucial for groundwater managers looking to include sustainability considerations in their analysis and decision-making.

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Scopus rating (2017): CiteScore 4.54 SJR 1.161 SNIP 1.705
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.28 SJR 1.161 SNIP 1.809
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.86 SJR 1.189 SNIP 1.712
Web of Science (2015): Impact factor 3.131
Web of Science (2015): Indexed yes
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Scopus rating (2014): CiteScore 3.62 SJR 1.228 SNIP 1.913
Web of Science (2014): Impact factor 2.723
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.84 SJR 1.203 SNIP 1.988
Web of Science (2013): Impact factor 3.188
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 4.01 SJR 1.354 SNIP 2.51
Web of Science (2012): Impact factor 3.057
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 3.66 SJR 1.212 SNIP 2.182
Web of Science (2011): Impact factor 3.245
ISI indexed (2011): ISI indexed yes
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Introduction to LCA Methodology
In order to offer the reader an overview of the LCA methodology in the preparation of the more detailed description of its different phases, a brief introduction is given to the methodological framework according to the ISO 14040 standard and the main elements of each of its phases. Emphasis is on the iterative nature of the LCA process with its many feedback loops between the different phases. It is explained how the integrated use of sensitivity analysis helps identify key assumptions and key data and thus ensure effectiveness by directing the focus of the LCA practitioner to those parts of the study where additional work contributes most to strengthen the results and conclusions of the study.

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Is green infrastructure more sustainable? Environmental life cycle assessment of four different stormwater management systems
LCA Cookbook

The LCA cookbook presents the provisions and actions from the ILCD Handbook that are central in the performance of an LCA. The selection is intended to cover all those activities that an LCA practitioner needs to undertake in a typical process-LCA, and the presentation follows the normal progression of the LCA work according to the ISO framework. For explanation of the reasoning behind the actions, the reader is referred to the presentation of the methodological elements in Part 2 of the book.

LCA History

The idea of LCA was conceived in the 1960s when environmental degradation and in particular the limited access to resources started becoming a concern. This chapter gives a brief summary of the history of LCA since then with a focus on the fields of methodological development, application, international harmonisation and standardisation, and dissemination. LCA had its early roots in packaging studies and focused mainly on energy use and a few emissions, spurring a largely un-coordinated method development in the US and Northern Europe. Studies were primarily done for companies, who used them internally and made little communication to stakeholders. After a silent period in the 1970s, the 1980s and 1990s saw an increase in methodological development and international collaboration and coordination in the scientific community and method development increasingly took place in universities. With the consolidation of the methodological basis, application of LCA widened to encompass a rapidly increasing range of products and systems with studies commissioned or performed by both industry and governments, and results were increasingly communicated through academic papers and industry and government reports. To this day, methodological development has continued, and increasing attention has been given to international scientific consensus building on central parts of the LCA methodology, and standardisation of LCA and related approaches.
LCA of Energy Systems

Energy systems are essential in the support of modern societies’ activities, and can span a wide spectrum of electricity and heat generation systems and cooling systems. Along with their central role and large diversity, these systems have been demonstrated to cause serious impacts on human health, ecosystems and natural resources. Over the past two decades, energy systems have thus been the focus of more than 1000 LCA studies, with the aim to identify and reduce these impacts. This chapter addresses LCA applications to energy systems for generation of electricity and heat. The chapter gives insight into the LCA practice related to such systems, offering a critical review of (i) central methodological aspects, including the definition of the goals and scopes of the studies, their coverage of the system life cycle and the environmental impacts, and (ii) key findings of the studies, particularly aimed at identifying environmental hotspots and impact patterns across different energy sources. Based on this literature review recommendations and guidelines are issued to LCA practitioners on key methodological aspects that are important for a proper conduct of LCA studies of energy systems and thus ensuring the reliability of the LCA results provided to decision- and policy-makers.

LCA of Solid Waste Management Systems

The chapter explores the application of LCA to solid waste management systems through the review of published studies on the subject. The environmental implications of choices involved in the modelling setup of waste management systems are increasingly in the spotlight, due to public health concerns and new legislation addressing the impacts from managing our waste. The application of LCA to solid waste management systems, sometimes called “waste LCA”, is distinctive in that system boundaries are rigorously defined to exclude all life cycle stages except from the end-of-life. Moreover, specific methodological challenges arise when investigating waste systems, such as the allocation of impacts and the consideration of long-term emissions. The complexity of waste LCAs is mainly derived from the variability of the object under study (waste) which is made of different materials that may require different treatments. This chapter attempts to address these challenges by identifying common misconceptions and by providing methodological guidance for alleviating the associated uncertainty. Readers are also provided with the list of studies reviewed and key sources for reference to implement LCA on solid waste systems.
LCA of Wastewater Treatment

The main purpose of wastewater treatment is to protect humans against waterborne diseases and to safeguard aquatic bio-resources like fish. The dominating environmental concerns within this domain are indeed still potential aquatic eutrophication/oxygen depletion due to nutrient/organic matter emissions and potential health impacts due to spreading of pathogens. Anyway, the use of treatment for micro-pollutants is increasing and a paradigm shift is ongoing — wastewater is more and more considered as a resource of, e.g. energy, nutrients and even polymers, in the innovations going on. The focus of LCA studies addressing wastewater treatment have from the very first published cases, been on energy and resource consumption. In recent time, the use of characterisation has increased and besides global warming potential, especially eutrophication is in focus. Even the toxicity-related impact categories are nowadays included more often. Application of LCA for comparing avoided against induced impacts, and hereby identifying trade-offs when introducing new technology, is increasingly used. A typical functional unit is the treatment of one cubic metre of wastewater which should be well defined regarding composition. Depending on the goal and scope of the study, all life cycle stages have the potential of being significant, though disposal of infrastructure seems to be the least important for the impact profile in many cases. No inventory data and none of the conventional impact categories (except stratospheric ozone depletion if emission of N2O is excluded) should be ruled out; but eutrophication and ecotoxicity are in many cases among the dominating ones.

Life cycle assessment in corporate sustainability reporting: Global, regional, sectoral, and company-level trends

Large companies now commonly release corporate sustainability (CS) reports in which they describe their approach to handle sustainability challenges. To guide environmental sustainability efforts in the industry, the life cycle assessment (LCA) methodology has been recognized as an important tool by researchers and policy makers. But to what extent has the LCA methodology been present in companies’ narratives through their CS reports up to now? To answer this question, we map references to the LCA methodology in CS reports over the past two decades at geographical, sectoral, and company levels through keyword searching within an extensive database (~45,000 CS reports), analyze trends, and highlight challenges, opportunities, and recommendations to strengthen the presence of LCA in CS reports. The results show that LCA generally remains weakly present in CS reporting, with some geographical and sectoral variations. Recommendations to strengthen LCA presence in CS reports are derived for method developers, policy makers, and companies.
Life cycle assessment of adic acid production from lignin
Lignin is a heterogeneous, aromatic polymer and one of the main components of plant biomass. Current lignocellulosic biorefineries primarily focus on polysaccharide conversion from biomass, and separate and combust the residual lignin for heat and power. By using lignin only as a fuel, this polysaccharide-centric approach potentially limits the valorization potential of biomass feedstocks. In this study, we performed a life cycle assessment (LCA) on an emerging lignin upgrading process, namely the production of bio-based adipic acid from lignin sourced from bioethanol production, relative to the conventional petrochemical production pathway. The LCA predicts an overall lower environmental impact for the bio-based route, primarily due to the utilization of a biorefinery side-stream as feedstock material and in the avoidance of nitrous oxide emissions. Bio-based adipic acid is predicted to lead to 4.87 kg CO2 eq. per kg(AA) for greenhouse gas emissions, which is a reduction of -62% to -78% compared to conventional adipic acid. Furthermore, results from the sensitivity analysis identify sodium hydroxide utilization and heating needs as the inputs that contribute the largest environmental burden in the bio-based process. Alternative lignin depolymerization processes and development of microbial strains that can tolerate low pH are possible optimization strategies to further improve the environmental profile of bio-based adipic acid. The effects of the LCA modeling assumptions on the environmental profile of bio-based adipic acid are also examined, demonstrating that the electricity footprint and the assumptions made to estimate the effects of diverting lignin from energy to material production play an important role in the model predictions. More broadly, this study highlights that partial lignin conversion to select chemicals in biorefineries may be more environmentally beneficial than solely producing bio-power through combustion, which is the current biorefinery paradigm for lignin utilization.

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Web of Science (2017): Impact factor 8.586
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.86 SJR 2.598 SNIP 2.021
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 8.21 SJR 2.452 SNIP 1.884
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 8.05 SJR 2.386 SNIP 1.989
Web of Science (2014): Impact factor 8.02
Web of Science (2014): Indexed yes
**Life Cycle Assessment - Theory and Practice**

This book is a uniquely pedagogical while still comprehensive state-of-the-art description of LCA-methodology and its broad range of applications. The five parts of the book conveniently provide: I) the history and context of Life Cycle Assessment (LCA) with its central role as quantitative and scientifically-based tool supporting society’s transitioning towards a sustainable economy; II) all there is to know about LCA methodology illustrated by a red-thread example which evolves as the reader advances; III) a wealth of information on a broad range of LCA applications with dedicated chapters on policy development, prospective LCA, life cycle management, waste, energy, construction and building, nanotechnology, agrifood, transport, and LCA-related concepts such as footprinting, ecolabelling, design for environment, and cradle to cradle. IV) A cookbook giving the reader recipes for all the concrete actions needed to perform an LCA. V) An appendix with an LCA report template, a full example LCA report serving as inspiration for students who write their first LCA report, and a more detailed overview of existing LCIA methods and their similarities and differences.

**General information**

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Life cycle engineering of lightweight structures

Lightweight structures are increasingly necessary to meet current engineering requirements. Weight reduction in diverse applications such as automobiles or machine tools is achieved either by using less material or by substituting material with a lighter one, which provides more functionality per unit of weight. To be an effective enabler for sustainability, lightweight structures should result in lower environmental impacts per functional unit when compared to conventional structures on a life cycle basis. However, applying new materials and manufacturing processes often leads to an increase in environmental impacts from the raw materials and production stage of the life cycle. Furthermore, end-of-life disassembly and recycling may become more difficult. In addition, the expected efficiency gains from the use of lightweight structures depend on how the overall market and technical systems respond to them. Consequently, the environmental evaluation of lightweight structures in engineering entails various methodological challenges. Organised around a life cycle engineering framework with a focus on eco-effectiveness, this paper provides a comprehensive review of lightweight structure applications and the challenges and opportunities they present in a life cycle engineering context.

General information

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Technical University of Braunschweig, KU Leuven, University of New South Wales, University of Michigan, Ann Arbor
Contributors: Herrmann, C., Dewulf, W., Hauschild, M., Kaluza, A., Kara, S., Skerlos, S.
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Web of Science (2017): Impact factor 3.333
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.93 SJR 2.055 SNIP 3.158
Web of Science (2016): Impact factor 2.893
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.83 SJR 2.088 SNIP 3.294
Web of Science (2015): Impact factor 2.492
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.39 SJR 3.123 SNIP 3.992
Life Cycle Impact Assessment
This chapter is dedicated to the third phase of an LCA study, the Life Cycle Impact Assessment (LCIA) where the life cycle inventory’s information on elementary flows is translated into environmental impact scores. In contrast to the three other
LCA phases, LCIA is in practice largely automated by LCA software, but the underlying principles, models and factors should still be well understood by practitioners to ensure the insight that is needed for a qualified interpretation of the results. This chapter teaches the fundamentals of LCIA and opens the black box of LCIA with its characterisation models and factors to inform the reader about: (1) the main purpose and characteristics of LCIA, (2) the mandatory and optional steps of LCIA according to the ISO standard, and (3) the science and methods underlying the assessment for each environmental impact category. For each impact category, the reader is taken through (a) the underlying environmental problem, (b) the underlying environmental mechanism and its fundamental modelling principles, (c) the main anthropogenic sources causing the problem and (d) the main methods available in LCIA. An annex to this book offers a comprehensive qualitative comparison of the main elements and properties of the most widely used and also the latest LCIA methods, to further assist the advanced practitioner to make an informed choice between LCIA methods.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Universite de Sherbrooke, IRSTEA ELSA-PACT, PRé Consultants B.V.
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Life Cycle Interpretation
The interpretation is the final phase of an LCA where the results of the other phases are considered together and analysed in the light of the uncertainties of the applied data and the assumptions that have been made and documented throughout the study. This chapter teaches how to perform an interpretation. The process of interpretation starts with identification of potentially significant issues in the previous stages of goal and scope definition, inventory analysis and impact assessment, and examples of potential significant issues are given for each phase. The significance is then determined by checking completeness, sensitivity and consistency for each of these identified issues. The outcome is used to inform previous stages on the needs for strengthening the data basis of the study, and where this is not possible to reconsider the goal and scope definition of the study. Finally, guidance is given on how to draw conclusions based on the previous steps of the interpretation, qualify the conclusions in terms of their robustness, and develop recommendations based on the results of the study.

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Contributors: Hauschild, M. Z., Bonou, A., Olsen, S. I.
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Life Cycle Inventory Analysis
The inventory analysis is the third and often most time-consuming part of an LCA. The analysis is guided by the goal and scope definition, and its core activity is the collection and compilation of data on elementary flows from all processes in the studied product system(s) drawing on a combination of different sources. The output is a compiled inventory of elementary flows that is used as basis of the subsequent life cycle impact assessment phase. This chapter teaches how to carry out this task through six steps: (1) identifying processes for the LCI model of the product system; (2) planning and collecting data; (3) constructing and quality checking unit processes; (4) constructing LCI model and calculating LCI results; (5) preparing the basis for uncertainty management and sensitivity analysis; and (6) reporting.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Transport DTU, Technical University of Denmark
Contributors: Bjørn, A., Moltesen, A., Laurent, A., Owsianiak, M., Corona, A., Birkved, M., Hauschild, M. Z.
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Life cycle targets applied in highly automated car body manufacturing – Method and algorithm
Automotive companies are striving for higher productivity, flexibility and more sustainable products to meet demands of central stakeholders (e.g. regulation, customers, investors). New drive systems or lightweight-design of cars often imply an environmental burden shifting from one life cycle stage to another, e.g. from the use-stage to the manufacturing stage. More products will be manufactured for an increasing population and higher efficiency effort may lead to increased consumption (rebound effect). An optimization of the manufacturing stage is thus increasingly important but it has to be done from the perspective of bringing the product's life cycle performance in accordance with sustainability requirements. In order to support the companies in finding effective solutions, the framework “Sustainability Cone” was applied and an algorithm developed guiding the definition of economic and environmental target states (TS) in automotive manufacturing. Especially during the early phase of planning, largest improvements can be achieved, however target states are not yet integrated in production simulation software (e.g. PLM tools). This paper describes the approach and its application in the planning of a body shop, being one of the most relevant and complex steps of car production. The approach addresses all relevant levels, e.g. a robot, a production cell and the entire production line. So-called life cycle targets (LCT) are introduced, which represent a specific share of the target state, reflecting the importance (i.e. activity-based) of each level. Using this approach, a product and production system can be planned holistically and any rebound effect factored in and sub-optimization can be avoided.

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Mapping of global plastic value chain and plastic losses to the environment: with a particular focus on marine environment

Plastics have become one of the most ubiquitous materials used globally, and global production has on average increased by about 9% per year since 1950. The plastic industry has become a major economic actor with revenue of about 1,722 billion Euros in 2015. The issue of plastics ending up in the oceans and harming marine lifeforms has been known since the 1970s. Research focusing on the impacts associated with exposure of organisms to marine microand macroplastics has been ongoing for years. However, studies linking the processes in the plastic value chain to plastics being released to the oceans are only starting to emerge. This report provides a comprehensive global mapping of plastic losses to the environment throughout the plastic value chain using 2015 as the reference year. This mapping covers plastics production and processing, use of plastics or plastic containing products, and disposal of the products. It differentiates 23 types of plastics and 13 plastic applications, including division between macro- and microplastics (incl. microbeads and microfibers). Global production was about 388 million tonnes (Mt) in 2015. Plastics are primarily produced and consumed in China, North America, and Western Europe. The majority of plastics are used for packaging (30%), building and construction (17%), and transportation (14%). The most used plastic polymers are polypropylene (PP; 16%), low density polyethylene & linear low density polyethylene (LDPE, LLDPE; 12%), polyvinylchloride (PVC; 11%), high density polyethylene (HDPE; 10%), and polyethylene terephthalate (PET; 5%) which in total account for more than 50% of total plastics usage. It was found that approximately 3.0 and 5.3 million tonnes of micro- and macroplastics, respectively, are annually lost to the environment. The largest sources of microplastic losses were from abrasion of tyres, and city dust, which include abrasion of plastics from e.g. shoe soles, exterior paints, and road markings. The primary sources of macroplastic losses stem from mismanaged municipal solid waste (i.e. open dumping and inadequate landfilling), accounting for about half of the macroplastics lost to the environment. Littering of plastic waste and loss of fishing gears and other equipment related to maritime activities were also major sources of macroplastic losses.

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Metal toxicity characterization factors for marine ecosystems: considering the importance of the estuary for freshwater emissions

The study develops site-dependent characterization factors (CFs) for marine ecotoxicity of metals emitted to freshwater, taking their passage of the estuary into account. To serve life cycle assessment (LCA) studies where emission location is often unknown, site-generic marine CFs were developed for metal emissions to freshwater and coastal seawater, respectively. The new CFs were applied to calculate endpoint impact scores for the same amount of metal emission to each compartment, to compare the relative ecotoxicity damages in freshwater and marine ecosystems in LCA.

Site-dependent marine CFs for emission to freshwater were calculated for 64 comparatively independent seas (large marine ecosystems, LMEs). The site-dependent CF was calculated as the product of fate factor (FF), bioavailability factor (BF), and effect factor (EF). USEtox modified with site-dependent parameters was extended with an estuary removal process to calculate FF. BF and EF were taken from Dong et al. Environ Sci Technol 50:269–278 (2016). Site-generic marine CFs were derived from site-dependent marine CFs. Different averaging principles were tested, and the approach representing estuary discharge rate was identified as the best one. Endpoint marine and freshwater metals CFs were developed to calculate endpoint ecotoxicity impact scores.

Marine ecotoxicity CFs are 1.5 orders of magnitude lower for emission to freshwater than for emission to seawater for Cr, Cu, and Pb, due to notable removal fractions both in freshwater and estuary. For the other metals, the difference is less than half an order of magnitude, mainly due to removal in freshwater. The site-dependent CFs generally vary within two orders of magnitude around the site-generic CF. Compared to USES-LCA 2.0 CFs (egalitarian perspective), the new site-
generic marine CFs for emission to seawater are 1–4 orders of magnitude lower except for Pb. The new site-generic marine CFs for emission to freshwater lie within two orders of magnitude difference from USES-LCA 2.0 CFs. The comparative contribution share analysis shows a poor agreement of metal toxicity ranking between both methods.

Accounting for estuary removal particularly influences marine ecotoxicity CFs for emission to freshwater of metals that have a strong tendency to complex-bind to particles. It indicates the importance of including estuary in the characterization modelling when dealing with those metals. The resulting endpoint ecotoxicity impact scores are 1–3 orders of magnitude lower in seawater than in freshwater for most metals except Pb, illustrating the higher sensitivity of freshwater ecosystems to metal emissions, largely due to the higher species density there.

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BFI (2014): BFI-level 2  
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Web of Science (2014): Impact factor 3.988  
Web of Science (2014): Indexed yes  
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Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978  
Web of Science (2013): Impact factor 3.089  
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Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707  
Web of Science (2012): Impact factor 2.773  
ISI indexed (2012): ISI indexed yes  
Web of Science (2012): Indexed yes  
BFI (2011): BFI-level 2  
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737  
Web of Science (2011): Impact factor 2.362
Seafood is a main diet component in many countries. Until recently, its production came predominantly from fisheries, but with a majority of fish stocks being now fished at full or unsustainable capacities, seafood production is turning to aquaculture (FAO 2016). However, seafood farming has several potential impacts on the environment and human health, such as eutrophication of surrounding water bodies, climate change, water consumption or land transformation (Naylor et al. 2000; Diana 2009). It is therefore important to ensure that aquaculture development takes place in a sustainable way.

In that context, life cycle assessment (LCA) has been widely applied to aquaculture production systems over the last decade. However, how has the LCA methodology been applied? Which methodological choices did the authors take, and to what extent were they appropriate to answer their research questions? To answer these questions, a critical literature review, new in its coverage of studies and depth of analysis was conducted, whose objectives were to analyze the relevance of methodological choices in relation to the research goals of the studies, and establish a set of recommendations for LCA practitioners to improve the quality and comparability of future studies.

**Methodological choices of LCA applied to aquaculture systems: A critical review & recommendations.**

Seafood is a main diet component in many countries. Until recently, its production came predominantly from fisheries, but with a majority of fish stocks being now fished at full or unsustainable capacities, seafood production is turning to aquaculture (FAO 2016). However, seafood farming has several potential impacts on the environment and human health, such as eutrophication of surrounding water bodies, climate change, water consumption or land transformation (Naylor et al. 2000; Diana 2009). It is therefore important to ensure that aquaculture development takes place in a sustainable way.

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Prospective Assessment of Steel Manufacturing Relative to Planetary Boundaries: Calling for Life Cycle Solution

Steel, as one of the largest consumed materials is a large contributor to climate change accounting for about 7% of annual human induced CO2 emissions. Using material in-use stock modelling and dynamic life-cycle assessment, this study predicted the share of the safe operating space for climate change that will be occupied by steel production between 2015 and 2100. Results show that if current practice is continued, steel manufacturing will occupy what corresponds to about 50% of the safe operating space for climate change by 2100, indicating an urgent need for impact reducing strategies to stay within the safe operating space.

Pursuing necessary reductions in embedded GHG emissions of developed nations: will efficiency improvements and changes in consumption get us there?

The COP21 summit in Paris led to a policy commitment of limiting the global temperature increase to 1.5–2.0 °C and this can be translated to a global annual greenhouse gas (GHG) emission budget that is shrinking rapidly throughout the 21st century. Here, we estimate the reductions in GHG emission intensities of technologies that will be required for the embedded GHG emissions of a developed nation to stay within its fair share of a global emission budget in the year 2050. The estimates are made for different conceivable developments in consumption patterns in the case of Denmark, based on a large survey of current consumption patterns. To evaluate whether the required emission intensity reductions are likely to be met, they are compared to historic time series of emission intensities and to projections for 2050, based on policies currently in place, for ten technologies that have a high contribution to current GHG emissions.

We estimate that emission intensities must be reduced by factors of 2–12 and 5–14, depending on the development in consumption, for the 2.0 and 1.5 °C climate goals, respectively. Of the ten selected technologies, only electricity supply is projected to, partially, meet the most strict reduction target, applying to a scenario where all inhabitants in 2050 consume as the most consuming inhabitants today.

The results indicate that both a change in "consumption as usual" and in "business as usual" is needed for developed nations to meet equitable climate targets. This has implications for national and international policies targeting GHG
emission intensities and may require a new orientation of policies to consider the societal structures around consumption.

**General information**

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- **Organisations:** Department of Management Engineering, Quantitative Sustainability Assessment, Indian Institute of Technology, Bombay, Aarhus University, Aalborg University, CIRAIG
- **Contributors:** Bjørn, A., Kalbar, P., Elsborg Nygaard, S., Kabins, S., Jensen, C. L., Birkved, M., Schmidt, J., Hauschild, M. Z.
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Quantifying sustainability – from better to good enough

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Review of environmental sustainability assessments of aquaculture systems: main findings and outlook.
Aquaculture has been growing quickly during the last decades and, albeit often regarded as sustainable by nature, this sector remains associated with several environmental impacts (e.g. aquatic eutrophication, ecotoxicity impacts in local ecosystems). To assess environmental sustainability of food production systems, one of the most commonly used tools is life cycle assessment (LCA), which quantifies the impacts of a system along its whole life cycle. Over the past decades, LCA has been applied to aquaculture systems, but what are the lessons we learn from them? To address this question, we performed an unprecedentedly comprehensive critical review encompassing 65 LCA studies of aquaculture systems published in peer-reviewed journals. We conducted a statistical meta-analysis of the results, and performed comparative analyses of the fish farms and practices, accounting for differences in intensity, technology, feed conversion ratio (FCR), and types of farmed species. Overall, we found that FCR, the species and the technology have a significant influence on the environmental impacts per produced output. The intensification of the aquaculture systems is usually associated with environmental burdens shifting from local to global impacts. Polyculture is a promising candidate for more sustainable aquaculture systems, especially integrated agriculture-aquaculture and aquaponics. Therefore, in the quest for more environmental-friendly aquaculture systems, we recommend to (1) focus on reducing the FCR and choose environmental-friendly diets (e.g. replacing fish meal and fish oil ingredients by crop ingredients); and (2) implement systems such as closed-systems or polyculture, that allow efficient management of nutrients without creating burden-shifting with energy demand.

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Role of manufacturing towards achieving circular economy: The steel case
Circular economy (CE) has been promoted worldwide as a strategy to reduce material use and to increase the material use efficiency by closing material loops at the societal level. The core concept of CE is to improve the circularity of material use through turning materials at the end of their service life into resources for others, however, there is very little information about the role of manufacturing in achieving CE. Using the concepts of dynamic material flow analysis and stock dynamics, this paper proposes a methodological approach to help understand the role of manufacturing in achieving...
CE. A number of other strategies such as material efficiency in conjunction with CE are also tested using the case of global steel use to draw conclusions.
**Scope Definition**

The scope definition is the second phase of an LCA. It determines what product systems are to be assessed and how this assessment should take place. This chapter teaches how to perform a scope definition. First, important terminology and key concepts of LCA are introduced. Then, the nine items making up a scope definition are elaborately explained: (1) Deliverables, (2) Object of assessment, (3) LCI modelling framework and handling of multifunctional processes, (4) System boundaries and completeness requirements, (5) Representativeness of LCI data, (6) Preparing the basis for the impact assessment, (7) Special requirements for system comparisons, (8) Critical review needs and (9) Planning reporting of results. The instructions relate both to the performance and reporting of a scope definition and are largely based on ILCD.

**General information**

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Spatially explicit fate factors of waterborne nitrogen emissions at the global scale

Purpose: Marine eutrophication impacts due to waterborne nitrogen (N) emissions may vary significantly with their type and location. The environmental fate of dissolved inorganic nitrogen (DIN) forms is essential to understand the impacts they may trigger in receiving coastal waters. Current life cycle impact assessment (LCIA) methods apply fate factors (FFs) with limited specificity of DIN emission routes, and often lack spatial differentiation and global applicability. This paper describes a newly developed method to estimate spatially explicit FFs for marine eutrophication at a global scale and river basin resolution. Methods: The FF modelling work includes DIN removal processes in both inland (soil and river) and marine compartments. Model input parameters are the removal coefficients extracted from the Global NEWS 2-DIN model and residence time of receiving coastal waters. The resulting FFs express the persistence of the fraction of the original DIN emission in the receiving coastal large marine ecosystems (LMEs). The method further discriminates three DIN emission routes, i.e., diffuse emission from soils, and direct point emissions to freshwater or marine water. Based on modelling of individual river basins, regionally aggregated FFs are calculated as emission-weighted averages. Results and discussion: Among 5772 river basins of the world, the calculated FFs show 5 orders of magnitude variation for the soil-related emission route, 3 for the river-related, and 2 for emissions to marine water. Spatial aggregation of the FFs at the continental level decreases this variation to 1 order of magnitude or less for all routes. Coastal water residence time was found to show inconsistency and scarcity of literature sources. Improvement of data quality for this parameter is suggested. Conclusions: With the proposed method and factors, spatial information of DIN emissions can be used to improve the environmental relevance and the discriminatory power of the assessment of marine eutrophication impacts in a geographically differentiated characterization model at a global scale.

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Supply chain collaboration in industrial symbiosis networks

A strategy supporting the development towards a circular economy is industrial symbiosis (IS). It is a form of collaborative supply chain management aiming to make industry more sustainable and achieve collective benefits based on utilization of waste, by-products, and excess utilities between economically independent industries. Based on an extensive analysis of published studies on existing IS collaborations and interviews with central stakeholders of a comprehensive IS, this paper investigates IS from a supply chain collaboration perspective. A theoretical framework is built and used to discuss how industrial symbiosis pursues sustainability and to identify the main collaboration aspects and performance impacts. This framework is then used in the analysis of selected published cases. Based on this, we derive propositions on the organizational and operational requirements for collaboration in the context of IS networks, related to the supply chain integration and coordination practices. As IS has only received little attention in the operations and supply chain management community, our propositions directly lead to future research directions. Furthermore, the analysis in this paper provides directions to increase the feasibility and resource efficiency of IS networks and can hence be used by
stakeholders involved in these networks.

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  - Scopus rating (2014): CiteScore 4.6 SJR 1.665 SNIP 2.481
  - Web of Science (2014): Impact factor 3.844
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  - BFI (2009): BFI-level 2
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Sustainability and LCA in Engineering Education - A Course Curriculum

Educating engineering students in sustainability is becoming increasingly important since engineering is expected to play a vital role in solving the sustainability challenges facing us. At the Technical University of Denmark this awareness is visible in the strategy where sustainability is expected to be an integrated part of all study programmes. The division for Quantitative Sustainability Assessment (QSA) aims to provide this competence to the DTU students. QSA focus mainly on Life Cycle Assessment based methods but have designed a course curriculum that can provide different levels of sustainability competences to students with a progression of complexity from the bachelor to the master or even PhD level. This role is unique since LCA is not systematically a component of engineering studies today. We present and discuss our experience with attempts to integrate LCA and life cycle thinking in an educational curriculum to teach sustainability broadly to engineering students at DTU. A main challenge is how to integrate the teaching into study programmes and eventually how to accommodate an increasing number of students on the individual courses.

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Target-Driven Life Cycle Engineering: Staying within the Planetary Boundaries

The definition of Life Cycle Engineering has evolved from a bottom up - to an integrated approach in order to steer the LCE activities towards achieving the goals of sustainability in absolute terms. The Lyngby Framework [9] was recently proposed in order to position Life Cycle Engineering in an absolute sustainability context and bring together the top-down and bottom-up approaches so that the technological solutions developed at the product and company level become target driven as determined by the planetary boundaries. Building further on the Lyngby Framework, this paper analyses means of operationalising the concept of absolute boundaries for environmental sustainability within a company's LCE activities and discusses a number of new tools and techniques for the LCE practitioner. (C) 2018 The Authors. Published by Elsevier B.V.

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Contributors: Kara, S., Hauschild, M. Z., Herrmann, C.
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Techno-environmental assessment of the green biorefinery concept: Combining process simulation and life cycle assessment at an early design stage

The Green biorefinery (GBR) is a biorefinery concept that converts fresh biomass into value-added products. The present study combines a Process Flowsheet Simulation (PFS) and Life Cycle Assessment (LCA) to evaluate the technical and environmental performance of different GBR configurations and the cascading utilization of the GBR output. The GBR configurations considered in this study, test alternatives in the three main steps of green-biorefining: fractionation, precipitation, and protein separation. The different cascade utilization alternatives analyse different options for press-pulp utilization, and the LCA results show that the environmental profile of the GBR is highly affected by the utilization of the press-pulp and thus by the choice of conventional product replaced by the press-pulp. Furthermore, scenario analysis of different GBR configurations shows that higher benefits can be achieved by increasing product yields rather than lowering energy consumption. Green biorefining is shown to be an interesting biorefining concept, especially in a Danish context. Biorefining of green biomass is technically feasible and can bring environmental savings, when compared to conventional production methods. However, the savings will be determined by the processing involved in each conversion stage and on the cascade utilization of the different platform products.

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Toward Harmonizing Ecotoxicity Characterization in Life Cycle Impact Assessment

Ecosystem quality is an important area of protection in life cycle impact assessment (LCIA). Chemical pollution has adverse impacts on ecosystems at the global scale. To improve methods for assessing ecosystem impacts, the Life Cycle Initiative hosted at the United Nations Environment Programme established a task force to evaluate the state-of-the-science in modelling chemical exposure of organisms and resulting ecotoxicological effects for use in LCIA. Outcome of the task force work will be global guidance and harmonization by recommending changes to the existing practice in exposure and effect modelling in ecotoxicity characterization. These changes reflect the current science and ensure stability of recommended practice. Recommendations must work within the needs of LCIA in terms of (a) operating on information from any inventory reporting chemical emissions with limited spatiotemporal information, (b) applying best estimates rather than conservative assumptions to ensure unbiased comparison with results for other impact categories, and (c) yielding results that are additive across substances and life cycle stages and allow a quantitative expression of damage to the exposed ecosystem. Here, we report the current framework as well as discuss research questions identified in a roadmap. Primary research questions relate to the approach for ecotoxicological effect assessment, the need to clarify the method's scope and interpretation of its results, the need to consider additional environmental compartments and impact pathways, and the relevance of effect metrics other than the currently applied geometric mean of toxicity effect data across species. Because they often dominate ecotoxicity results in LCIA, metals pose a specific focus, which includes consideration of their possible essentiality and changes in environmental bioavailability. We conclude with a summary of key questions along with preliminary recommendations to address them as well as open questions that require additional research efforts. This article is protected by copyright. All rights reserved.
An Integrated Framework for Life Cycle Engineering

Life Cycle Engineering (LCE) was introduced as a concept more than 24 years ago in order to address emerging concerns about environmental sustainability in engineering. A number of methods and tools have been introduced to operationalise the LCE concept, but since then, the scope of sustainability has broadened, and as a result, LCE has evolved in parallel with other disciplines with similar aims. Currently, in addition to LCE, there exist a number of concepts such as Industrial Ecology, Cleaner Production, Life Cycle Management (LCM), Industrial Symbiosis, and Circular Economy. As a result, orientation becomes challenging and a framework to integrate them is required. The paper aims to introduce an integrated framework for LCE defining the concept and its boundaries, and it argues for the need to reorientate LCE towards the environmental dimension of sustainability. Through an integrated top-down and bottom-up approach, the framework establishes a relationship between LCE and the other concepts and positions them relative to the planetary boundaries and the concept of absolute environmental sustainability. (C) 2017 The Authors. Published by Elsevier B.V.

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Can carbon footprint serve as proxy of the environmental burden from urban consumption patterns?

Carbon footprint (CFP) is widely applied as an indicator when assessing environmental sustainability of products and services. The objective of the present study is to evaluate the validity of CFP as overall environmental indicator for representing the environmental burden of residents from urbanized areas. Applying four different Life Cycle Impact Assessment (LCIA) methods environmental impact profiles were determined for the consumption patterns of 1281 Danish urban residents. Six main consumption components were distinguished including road transport, air travel, food, accommodation (covering consumption of materials for the construction of dwellings) and use of energy in terms of thermal energy, and electricity. The results for the individual consumption components showed a strong correlation between CFP and nearly all other impact indicators for all the applied LCIA methods. However, upon aggregation of the indicator results across consumption components, the impact indicators for the total consumption showed no significant correlation between CFP and the other impact scores for any of the four impact assessment methods. These findings suggest that while CFP can be a good indicator of the environmental burden associated with specific activities, this is not the case for more complex activities (such as consumption patterns related to urban life styles). This conclusion discourages the use of CFP as sustainability measure in relation to regulation of private or public consumption.
Characterization of waterborne nitrogen emissions for marine eutrophication modelling in life cycle impact assessment at the damage level and global scale

Current life cycle impact assessment (LCIA) methods lack a consistent and globally applicable characterization model relating nitrogen (N, as dissolved inorganic nitrogen, DIN) enrichment of coastal waters to the marine eutrophication impacts at the endpoint level. This paper introduces a method to calculate spatially explicit characterization factors (CFs) at endpoint and damage to ecosystems levels, for waterborne nitrogen emissions, reflecting their hypoxia-related marine eutrophication impacts, modelled for 5772 river basins of the world.

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BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
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Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
This paper examines some of the most common frameworks available to companies in implementing circular economy strategies, i.e. the Cradle-to-Cradle design protocol, the Material Circularity Indicator and the Life Cycle Sustainability Assessment framework intended as a combination of Life Cycle Assessment, Environmental Life Cycle Costing and Social Life Cycle Assessment. We focus on the packaging sector and use the case of closed-loop aluminium can supply to illustrate the benefits and limitations of combining some of these frameworks. Our recommendation is to use the Life Cycle Sustainability Assessment framework to evaluate circularity strategies, since it is the most comprehensive and still operational framework and best at preventing burden shifting between stakeholders in the value chain.

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Organisations: Department of Chemical and Biochemical Engineering, Department of Management Engineering, Quantitative Sustainability Assessment
Combining eco-efficiency and eco-effectiveness for continuous loop beverage packaging systems: learnings from the Carlsberg Circular Community

Eco-efficiency (i.e., increasing value while reducing resource use and pollution) can with advantage be combined with eco-effectiveness (i.e., maximizing the benefits to ecological and economical systems) to address the challenges posed by the circular economy in the design of circular industrial systems. We present a framework combining life cycle assessment (LCA) and the Cradle to Cradle® (C2C) certification program for the development of continuous loop packaging systems, which was conceived for aluminum cans in the context of the Carlsberg Circular Community. As a first step, the environmentally optimal beverage packaging life cycle scenario is identified, both in terms of defined use and reuse. Second, the limiting factors are identified for the continuous use of materials in multiple loops, meeting the two requirements in the C2C certification process that address the material level (i.e., "material health" and "material reutilization" criteria) and the "renewable energy" criterion. Then, alternative scenarios are built to meet C2C certification criteria, and LCA is used to quantify the environmental impacts of the resulting improvement strategies, for example, change in material composition, in order to guide the identification of the optimal scenario from an eco-efficiency point of view. Finally, the business perspective is addressed by assessing the potential for a green value network business model for a closed-loop supply. The outcome is a list of prioritized actions needed to implement the most efficient and effective "upcycling" strategy for the beverage packaging, both from an environmental and an economic point of view. In the case of the aluminum cans, the main recommendation from both the LCA and C2C perspective is to ensure a system that enables can-to-can recycling.
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Scopus rating (2011): CiteScore 2.13 SJR 1.042 SNIP 1.262
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BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.21 SNIP 1.397
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.265 SNIP 1.647
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Scopus rating (2007): SJR 1.229 SNIP 1.745
Scopus rating (2006): SJR 1.045 SNIP 1.575
Scopus rating (2005): SJR 0.623 SNIP 1.692
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.159 SNIP 1.982
Scopus rating (2003): SJR 0.637 SNIP 1.067
Scopus rating (2002): SJR 0.499 SNIP 1.14
Contributions of Local Farming to Urban Sustainability in the Northeast United States

Food consumption is an important contributor to a city’s environmental impacts (carbon emissions, land occupation, water use, etc.) Urban farming (UF) has been advocated as a means to increase urban sustainability by reducing food-related transport and tapping into local resources. Taking Boston as an illustrative Northeast U.S. city, we developed a novel method to estimate sub-urban, food-borne carbon and land footprints using multiregion input-output modeling and nutritional surveys. Computer simulations utilizing primary data explored UF’s ability to reduce these footprints using select farming technologies, building on previous city-scale UF assessments which have hitherto been dependent on proxy data for UF. We found that UF generated meagre food-related carbon footprint reductions (1.1−2.9% of baseline 2211 kg CO₂ equivalents/capita/annum) and land occupation increases (<1% of baseline 9000 m² land occupation/capita/annum) under optimal production scenarios, informing future evidence-based urban design and policy crafting in the region.

Notwithstanding UF’s marginal environmental gains, UF could help Boston meet national nutritional guidelines for vegetable intake, generate an estimated $160 million U.S. in revenue to growers and act as a pedagogical and community building tool, though these benefits would hinge on large-scale UF proliferation, likely undergirded by environmental remediation of marginal lands in the city.

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Massachusetts Institute of Technology
Contributors: Goldstein, B. P., Hauschild, M. Z., Fernandez, J. E., Birkved, M.
Number of pages: 10
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Publication information
Journal: Environmental Science and Technology
Volume: 51
Issue number: 13
ISSN (Print): 0013-936X
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.535 SNIP 1.941
Web of Science (2017): Impact factor 6.653
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.26 SJR 2.559 SNIP 1.902
Web of Science (2016): Impact factor 6.198
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 5.61 SJR 2.546 SNIP 1.838
Web of Science (2015): Impact factor 5.393
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Environmental impacts of barley cultivation under current and future climatic conditions

The purpose of this work is to compare the environmental impacts of spring barley cultivation in Denmark under current (year 2010) and future (year 2050) climatic conditions. Therefore, a Life Cycle Assessment was carried out for the production of 1 kg of spring barley in Denmark, at farm gate. Both under 2010 and 2050 climatic conditions, four subscenarios were modelled, based on a combination of two soil types and two climates. Included in the assessment were seed production, soil preparation, fertilization, pesticide application, and harvest. When processes in the life cycle resulted in co-products, the resulting environmental impacts were allocated between the main product and their respective by-products using economic allocation. Impact assessment was done using the ReCiPe (H) methodology, except for toxicity impacts, which were assessed using USEtox. The results show that the impacts for all impact categories, except human and freshwater eco-toxicity, are higher when the barley is produced under climatic circumstances representative for 2050. Comparison of the 2010 and 2050 climatic scenarios indicates that a predicted decrease in barley yields under the 2050 climatic conditions is the main driver for the increased impacts. This finding was confirmed by the sensitivity analysis. Because this study focused solely on the impacts of climate change, technological improvements and political measures to reduce impacts in the 2050 scenario are not taken into account. Options to mitigate the environmental impacts are discussed.
Environmental impacts of electricity self-consumption from organic photovoltaic battery systems at industrial facilities in Denmark

Organic photovoltaics (OPV) show promise of greatly improving the environmental and economic performance of PV compared to conventional silicon. Life cycle assessment studies have assessed the environmental impacts of OPV, but not under a self-consumption scheme for industrial facilities. We investigate the life cycle environmental impacts of electricity self-consumption from an OPV system coupled with a sodium/nickel chloride battery at an iron/metal industry in Denmark. Results show that an OPV system without storage could decrease the carbon footprint of the industry; installation of the battery increases climate change and human toxicity impacts. We discuss sensitive modelling parameters and provide recommendations.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, Quantitative Sustainability Assessment, Transport DTU, Department of Management Engineering
Contributors: Chatzisideris, M. D., Laurent, A., Hauschild, M. Z., Krebs, F. C.
Pages: 45-48
Publication date: 2017
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Publication information
Journal: C I R P Annals
Volume: 66
ISSN (Print): 0007-8506
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.09 SJR 2.034 SNIP 2.811
Web of Science (2017): Impact factor 3.333
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.93 SJR 2.055 SNIP 3.158
Web of Science (2016): Impact factor 2.893
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.83 SJR 2.088 SNIP 3.294
Web of Science (2015): Impact factor 2.492
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.39 SJR 3.123 SNIP 3.992
Web of Science (2014): Impact factor 2.542
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.87 SJR 2.598 SNIP 3.818
Web of Science (2013): Impact factor 2.541
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 3.04 SJR 2.088 SNIP 4.156
Web of Science (2012): Impact factor 2.251
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.81 SJR 2.117 SNIP 3.46
Web of Science (2011): Impact factor 1.708
ISI indexed (2011): ISI indexed yes
Environmental impacts of electricity self-consumption from organic photovoltaic battery systems at industrial facilities in Denmark

Organic photovoltaics (OPV) show promise of greatly improving the environmental and economic performance of PV compared to conventional silicon. Life cycle assessment studies have assessed the environmental impacts of OPV, but not under a self-consumption scheme for industrial facilities. We investigate the life cycle environmental impacts of electricity self-consumption from an OPV system coupled with a sodium/nickel chloride battery at an iron/metal industry in Denmark. Results show that an OPV system without storage could decrease the carbon footprint of the industry; installation of the battery increases climate change and human toxicity impacts. We discuss sensitive modelling parameters and provide recommendations.

General information
State: Published
Organisations: Department of Energy Conversion and Storage, Organic Energy Materials, Quantitative Sustainability Assessment, Transport DTU, Department of Management Engineering
Contributors: Chatzisideris, M. D., Laurent, A., Hauschild, M. Z., Krebs, F. C.
Publication date: 2017

Host publication information
Title of host publication: CIRP ANNALS 2017
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Electronic versions:
Marios_CIRP_pres_2017.pdf
URLs:
Environmental impacts of electricity self-consumption in residential buildings: Case study of organic photovoltaic battery systems in Denmark

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Chatzisideris, M. D., Laurent, A., Hauschild, M. Z., Krebs, F. C.
Publication date: 2017

Host publication information
Title of host publication: Proceedings of the 8th Life Cycle Management Conference
Source: PublicationPreSubmission
Source-ID: 160236527
Research output: Research - peer-review › Conference abstract in proceedings – Annual report year: 2018

Environmental impacts of stormwater management and pollutant discharges

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Brudler, S., Arnbjerg-Nielsen, K., Hauschild, M. Z., Rygaard, M.
Number of pages: 1
Publication date: 2017
Peer-reviewed: Yes
Event: Poster session presented at 9th biennial conference of the International Society for Industrial Ecology (ISIE) and the 25th annual conference of the International Symposium on Sustainable Systems and Technology (ISSST), Chicago, United States.
Electronic versions:
ISIE_ISSST_17_poster_sabr.pdf
Source: PublicationPreSubmission
Source-ID: 134332733
Research output: Research - peer-review › Poster – Annual report year: 2017

Environmental impacts of stormwater management and pollutant discharges
Stormwater management systems are necessary to protect people and assets from flooding and pollution, especially in densely built, sealed urban areas. The possible solutions range from underground pipes and basins, where rain water is often handled together with wastewater, to local and multi-functional solutions, e.g. rain beds or retention lakes. Ideally, these solutions are not only economically, but also environmentally sustainable. Risk assessments are sometimes carried out, e.g. to determine the effect of discharges during extreme events, but they lack a holistic perspective: While pollutants in runoff are one possible source of (local) environmental impacts, the stormwater management system itself is a source of emissions. Raw material extraction, construction, operation, renewal, and disposal all cause environmental impacts at a more regional or even global scale. These impacts can be quantified using life cycle assessment, which on the other hand usually neglects the impacts from local emissions, even though these may potentially be significant. By integrating local emissions into the assessment, we are able to quantify the total environmental impacts of stormwater management solutions.

We have tested the approach using a sub-catchment of Copenhagen. The existing stormwater management system has to be adapted to climatic changes to maintain existing flood safety levels. The environmental impacts from both local and global emissions over a period of 100 years have been quantified using life cycle assessment. The inventory for the assessment is based on an extensive literature research, planning documents and expert interviews. Here, we focus on the ecotoxicity impacts: The impact over the whole life cycle of the system, excluding local emissions, is 14 mio comparative toxic units (CTUe). This ecotoxicity impact is mainly caused by the emission of metals. Metals are, however, also important pollutants in stormwater runoff. In Copenhagen, the emission of stormwater pollutants from runoff are found to cause additional impacts of 19 mio CTUe when discharged directly to freshwater. If the water first infiltrates through soil, the impacts are significantly lower (10 mio CTUe). The stormwater system itself is passive, and mainly causes impacts during construction, while runoff goes through the system constantly over 100 years, which explains the large difference in impacts. The results are characterized by a high uncertainty, which is caused by large ranges in measured concentrations in literature (up to 5 orders of magnitude). Limiting these uncertainties is the subject of ongoing research.

Our results highlight the importance of including local emission of toxic compounds in stormwater management systems. Often, an increase in global emission, e.g. through the construction of treatment facilities, will lead to reduced local
impacts, and vice versa. By taking into account both local and global impacts, stormwater management systems can be optimized holistically to minimize environmental impacts and create more sustainable stormwater management systems.

**General information**

State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Brudler, S., Arnbjerg-Nielsen, K., Hauschild, M. Z., Rygaard, M.
Number of pages: 1
Publication date: 2017
Peer-reviewed: Yes
Event: Abstract from 9th biennial conference of the International Society for Industrial Ecology (ISIE) and the 25th annual conference of the International Symposium on Sustainable Systems and Technology (ISSST), Chicago, United States.
Electronic versions: ISIE_ISSST_17_sabr.pdf
Research output: Research - peer-review » Conference abstract for conference – Annual report year: 2017

**Environmental performance of gasified willow from different lands including land-use changes**

A life-cycle assessment (LCA) of a low-input, short rotation coppice (SRC) willow grown on different Danish lands was performed. Woodchips are gasified, producer gas is used for co-generation of heat and power (CHP) and the ash-char output is applied as soil amendment in the field. A hybrid model was developed for the estimation of greenhouse gas (GHG) emissions from indirect land-use changes (iLUC) induced by willow cropping on arable land. For this, area expansion results from a general equilibrium economic model were combined with global LUC trends to differentiate between land transformation (as additional agricultural expansion, in areas with historical deforestation) and occupation (as delayed relaxation, DR, in areas with historical land abandonment) impacts. A biophysical approach was followed to determine the iLUCfeed emissions factor from marginal grassland. Land transformation impacts were derived from latest world deforestation statistics, while a commercial feed mix of equivalent nutritive value was assumed to substitute the displaced grass as fodder. Intensification effects were included in both iLUC factors as additional N-fertilizer consumption. Finally, DR impacts were considered for abandoned farmland, as a relative C stock loss compared to natural regeneration. ILUC results show that area related GHG emissions are dominant (93% of iLUCfood and 80% of iLUCfeed), transformation being more important (82% of iLUCfood) than occupation (11%) impacts. LCA results show that CHP from willow emits 4,047 kg CO2-eq haoccup−1 (or 0.8 gCO2-eq MJ−1) when grown on arable land, while sequestering 43,745 kg CO2-eq haoccup−1−1 (or -10.4 gCO2-eq MJ−1) when planted on marginal pastureland, and 134,296 kg CO2-eq haoccup−1−1 (or -31.8 gCO2-eq MJ−1) when marginal abandoned land is cultivated. Increasing the bioenergy potential without undesirable iLUC effects, especially relevant regarding biodiversity impacts, requires that part of the marginally used extensive grasslands are released from their current use or energy cropping on abandoned farmland incentivized.

**General information**

State: Published
Organisations: Department of Environmental Engineering, Atmospheric Environment, Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Saez de Bikuna Salinas, K., Hauschild, M. Z., Pilegaard, K., Ibrom, A.
Pages: 756-769
Publication date: 2017
Peer-reviewed: Yes

**Publication information**

Journal: GCB Bioenergy
Volume: 9
Issue number: 4
ISSN (Print): 1757-1693
Ratings:

BFI (2019): BFI-level 1
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
Scopus rating (2017): CiteScore 5.01 SJR 1.816 SNIP 1.478
Web of Science (2017): Impact factor 5.415
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 4.52 SJR 1.775 SNIP 1.475
Web of Science (2016): Impact factor 4.655
Web of Science (2016): Indexed yes
Scopus rating (2015): CiteScore 5.14 SJR 1.962 SNIP 1.593
Exploring REACH as a potential data source for characterizing ecotoxicity in life cycle assessment

Toxicity models in life cycle impact assessment (LCIA) currently only characterize a small fraction of marketed substances, mostly because of limitations in the underlying ecotoxicity data. One approach to improve the current data situation in LCIA is to identify new data sources, such as the European Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) database. The present study explored REACH as a potential data source for LCIA based on matching reported ecotoxicity data for substances that are currently also included in the United Nations Environment Programme/Society for Environmental Toxicology and Chemistry (UNEP/SETAC) scientific consensus model USEtox for characterizing toxicity impacts. Data are evaluated with respect to number of data points, reported reliability, and test duration, and are compared with data listed in USEtox at the level of hazardous concentration for 50% of the covered species per substance. The results emphasize differences between data available via REACH and in USEtox. The comparison of ecotoxicity data from REACH and USEtox shows potential for using REACH ecotoxicity data in LCIA toxicity characterization, but also highlights issues related to compliance of submitted data with REACH requirements as well as different assumptions underlying regulatory risk assessment under REACH versus data needed for LCIA. Thus, further research is required to address data quality, pre-processing, and applicability, before considering data submitted under REACH as a data source for use in LCIA, and also to explore additionally available data sources, published studies, and reports.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, National Institute for Public Health and the Environment, Polytechnique Montreal
Contributors: Müller, N., de Zwart, D., Hauschild, M. Z., Kijko, G., Fantke, P.
Number of pages: 9
Pages: 492–500
Publication date: 2017
Peer-reviewed: Yes

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Journal: Environmental Toxicology and Chemistry
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ISSN (Print): 0730-7268
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 2.87 SJR 1.178 SNIP 1.018
Web of Science (2017): Impact factor 3.179
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.74 SJR 1.231 SNIP 1.021
Web of Science (2016): Impact factor 2.951
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3 SJR 1.433 SNIP 1.056
Web of Science (2015): Impact factor 2.763
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.89 SJR 1.501 SNIP 1.12
Web of Science (2014): Impact factor 3.225
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.88 SJR 1.656 SNIP 1.086
Web of Science (2013): Impact factor 2.826
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.81 SJR 1.639 SNIP 1.108
Web of Science (2012): Impact factor 2.618
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 3.05 SJR 1.947 SNIP 1.168
Web of Science (2011): Impact factor 2.809
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.715 SNIP 0.992
Web of Science (2010): Impact factor 3.026
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.616 SNIP 1.053
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.487 SNIP 1.036
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.694 SNIP 1.127
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.609 SNIP 1.142
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.534 SNIP 1.184
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.107 SNIP 1.397
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.747 SNIP 1.323
Purpose: The static functional unit definition in the current LCA framework has limitations in addressing the changing product functionality and associated environmental impact of constantly evolving product technologies. As a result, it overlooks the changes in consumer behaviour of increased consumption of products in provided services as well as in growing volumes. This article aims to present a new framework in defining a dynamic functional unit of product technologies that caters for changes in consumer behaviour and growing market. Methods: A new approach to defining the functional unit is proposed that caters for changes in consumer behaviour and the use of technology from a technical performance perspective. A dynamic approach to definition of the functional unit is proposed that is based on Kano’s model of product function and satisfaction. Results and discussion: The new approach is demonstrated on a case study in which the analysis of historical data for two TV product technologies—CRT and LCD—is used to show how the total environmental impact is increasing due to the increased functionality which triggers an increase in the volume of the market. Despite the efforts of improving product life cycle design, the society is still faced with increasing environmental impact from the product type overall. Conclusions: This article presents the challenges of using a static, single functional unit definition in an industrial culture with constant evolution of products that influences usage behaviour and demonstrates the vicious circle of improving product efficiency that leads to further consumption and environmental impact. To address this problem, a new framework of dynamic functional unit definition is put forward for performing comparative LCA to manage the development of product life cycle design that helps keep the total environmental impact of the company’s product portfolio within absolute boundaries.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, University of New South Wales
Contributors: Kim, S. J., Kara, S., Hauschild, M. Z.
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Peer-reviewed: Yes

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 22
Issue number: 8
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.62 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.288 SNIP 0.954
Scopus rating (2001): SJR 0.49 SNIP 1.456
Scopus rating (2000): SJR 0.413 SNIP 1.862
Scopus rating (1999): SJR 0.442 SNIP 1.283

Original language: English
How does the long-term aging in the soil change terrestrial ecotoxic impacts of anthropogenic metal emissions?

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, University of Copenhagen
Contributors: Owsianiak, M., Holm, P. E., Fantke, P., Christiansen, K. S., Borggaard, O., Hauschild, M. Z.
Number of pages: 1
Publication date: 2017
Peer-reviewed: Yes
Research output: Research - peer-review » Conference abstract for conference – Annual report year: 2017

If bio-based plastics is the answer, what was the question?

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Hauschild, M. Z.
Number of pages: 1
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Publisher: Technical University of Denmark (DTU)
Article number: P-2
Electronic versions:
SustainAbstracts2017c.compressed_136.pdf
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Improved comparative toxicity potentials of 23 metallic elements in soils: addressing solid- and liquid-phase speciation in environmental fate, exposure, and effects

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Radboud University Nijmegen
Contributors: Owsianiak, M., Huijbregts, M., Hauschild, M. Z.
Number of pages: 1
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Bibliographical note
Pg. 30
Research output: Research - peer-review » Conference abstract for conference – Annual report year: 2017

Improving substance information in usetox®, part 1: discussion on data and approaches for estimating freshwater ecotoxicity effect factors
The scientific consensus model USEtox® is recommended by the European Commission as the reference model to characterize life cycle chemical emissions in terms of their potential human toxicity and freshwater aquatic ecotoxicity
impacts in the context of the International Reference Life Cycle Data System (ILCD) Handbook and the Environmental Footprint pilot phase looking at products (PEF) and organisations (OEF). Consequently, this model has been systematically used within the PEF/OEF pilot phase by 25 EU industry sectors, which manufacture a wide variety of consumer products. This testing phase has raised some questions regarding the derivation of and the data used for the chemical-specific freshwater ecotoxicity effect factor in USEtox®. For calculating the potential freshwater aquatic ecotoxicity impacts, USEtox® bases the effect factor on the chronic hazard concentration (HC50) value for a chemical calculated as the arithmetic mean of all logarithmized geometric means of species-specific chronic lethal (or effect) concentrations (LC50). We investigated the dependency of the USEtox® effect factor on the selection of ecotoxicological data source and toxicological endpoints, and we found that both influence the ecotoxicity ranking of chemicals and may hence influence the conclusions of a PEF/OEF study. We furthermore compared the average measure (HC50) to other types of ecotoxicity effect indicators like the lowest species EC50 or NOEC, frequently used in regulatory risk assessment, and demonstrated how they may also influence the ecotoxicity ranking of chemicals. We acknowledge that these indicators represent different aspects of a chemical’s ecotoxicity potential and discuss their pros and cons for a comparative chemical assessment as performed in LCA and in particular within the PEF/OEF context. This article is protected by copyright. All rights reserved.

**General information**

State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, European Commission - Joint Research Center
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 2.87 SJR 1.178 SNIP 1.018
Web of Science (2017): Impact factor 3.179
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.74 SJR 1.231 SNIP 1.021
Web of Science (2016): Impact factor 2.951
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3 SJR 1.433 SNIP 1.056
Web of Science (2015): Impact factor 2.763
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.89 SJR 1.501 SNIP 1.12
Web of Science (2014): Impact factor 3.225
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.88 SJR 1.656 SNIP 1.086
Web of Science (2013): Impact factor 2.826
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.81 SJR 1.639 SNIP 1.108
Improving substance information in useTox®, part 2: Data for estimating fate and ecosystem exposure factors

The scientific consensus model USEtox® is developed since 2003 under the auspices of the UNEP-SETAC Life Cycle Initiative as a harmonized approach for characterizing human and freshwater toxicity in life cycle assessment (LCA) and other comparative assessment frameworks. Using physicochemical substance properties, USEtox® quantifies potential human toxicity and freshwater ecotoxicity impacts by combining environmental fate, exposure and toxicity effects information, considering multimedia fate and multi-pathway exposure processes. The main source to obtain substance properties for USEtox® 1.01 and 2.0 is the Estimation Program Interface (EPI SuiteTM ) from the U.S. Environmental Protection Agency. However, since the development of the original USEtox® substance databases, new chemical regulations have been enforced in Europe such as the REACH and the Plant Protection Products regulations. These regulations require that a chemical risk assessment for humans and the environment is performed before a chemical is placed on the European market. Consequently, additional physicochemical property data and new toxicological end-points are now available for thousands of chemical substances. The aim of the present study is to explore to which extent the
new available data can be used as input for USEtox® - especially for application in Environmental Footprint studies - and to discuss how this would influence the quantification of fate and exposure factors. Initial results show that the choice of data source and the parameters selected can greatly influence fate and exposure factors leading to potentially different rankings and relative contributions of substances to overall human toxicity and ecotoxicity impacts. Moreover, it is crucial to discuss the relevance of exposure factor for freshwater ecotoxicity impacts particularly for persistent highly adsorbing and bio-accumulating substances. This article is protected by copyright. All rights reserved.
Indicators for environmental sustainability
Decision making on sustainable consumption and production requires scientifically based information on sustainability. Different environmental sustainability targets exist for specific decision problems. To observe how well these targets are met, relevant environmental indicators are needed. In this study, we reviewed indicators applied in life cycle assessment (LCA), planetary boundary framework (PB), and Sustainable Development Goals (SDGs) developed under United Nation. The aim is to 1) identify their applications and relevant decision context; 2) Review their indicators and categorize them into Drivers-Pressures-States-Impacts-Responses scheme for comparison and; 3) provide suggestions for indicator system choice and important aspects to consider when choosing.

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Integrating environmental impacts into cost-benefit analysis: The value of environmental pollutants

Is Earth recognized as a finite system in corporate responsibility reporting?

Companies are increasingly encouraged to frame their sustainability activities and communication around ecological limits, as captured by concepts such as planetary boundaries, climate tipping points or regenerative capacity. Ecological limits may serve as scientific basis for defining environmental sustainability targets at the company level and, moreover, inspire companies to align their product portfolios with emerging societal needs related to sustainable transformations. Although corporate environmental reporting is widely researched, little attention has, hitherto, been given to company use of the ecological limits concepts in stakeholder communication. This study presents a comprehensive review of references made to ecological limits in corporate responsibility (CR) reports in 2000-2014. An exhaustive list of terms related to ecological limits was developed and used to search the CorporateRegister database, which contained approximately 40,000 CR reports from this time period. For every identified reference, we analyzed the context in which the ecological limit term was used in the CR report. We found a 10-fold increase in the number of references made to ecological limits in CR reports during the period 2000-2014. The number of CR reports published in this time period has also increased at a similar rate. Hence, the proportion of companies referring to ecological limits in their CR reports has over the years remained stable; roughly 5%. The most commonly invoked ecological limits were related to climate change and references to “2°C” were by far the most frequent. The vast majority of companies referring to ecological limits did so without specific references to ongoing or planned changes in their activities as a consequence of recognizing these limits. Only a small percentage, predominately high-tech companies (31 in total), explicitly used ecological limits to define targets for resource consumption, emissions reductions and/or as a stated reason for adjusting their product portfolio. In defining targets for resource consumption or emissions, only a few CR reports dealt explicitly with the issue of allocating resource and emission rights within ecological limits amongst companies and other actors. A longitudinal study of three companies showed that these did not directly report progress towards planned changes based on ecological limits and offered explanations as to why some companies abandoned planned changes altogether. Our findings provide novel insights into the current use of the ecological limits concept by companies and may be useful for actors trying to motivate companies to align their activities with the finite nature of Earth's natural systems.
LCIA framework and cross-cutting issues guidance within the UNEP-SETAC Life Cycle Initiative

Increasing needs for decision support and advances in scientific knowledge within life cycle assessment (LCA) led to substantial efforts to provide global guidance on environmental life cycle impact assessment (LCIA) indicators under the auspices of the UNEP-SETAC Life Cycle Initiative. As part of these efforts, a dedicated task force focused on addressing several LCIA cross-cutting issues as aspects spanning several impact categories, including spatiotemporal aspects, reference states, normalization and weighting, and uncertainty assessment. Here, findings of the cross-cutting issues task force are presented along with an update of the existing UNEP-SETAC LCIA emission-to-damage framework. Specific recommendations are provided with respect to metrics for human health (Disability Adjusted Life Years, DALY) and ecosystem quality (Potentially Disappeared Fraction of species, PDF). Additionally, we stress the importance of transparent reporting of characterization models, reference states, and assumptions, in order to facilitate cross-comparison between chosen methods and indicators. We recommend developing spatially regionalized characterization models, whenever the nature of impacts shows spatial variability and related spatial data are available. Standard formats should be used for reporting spatially differentiated models, and choices regarding spatiotemporal scales should be clearly communicated. For normalization, we recommend using external normalization references. Over the next two years, the task force will continue its effort with a focus on providing guidance for LCA practitioners on how to use the UNEP-SETAC LCIA framework as well as for method developers on how to consistently extend and further improve this framework.
Measuring and increasing the sustainability of biochemicals: contrasting feedstock’s, biorefinery processes, and upscaling

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Quantifying the importance of comprehensive life cycle and impact coverage for photovoltaic systems

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Contributors: Chatzisideris, M. D., Laurent, A., Hauschild, M. Z., Krebs, F. C.
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Recent developments in USEtox: a global consensus model for characterization of human toxicity and ecotoxicity in life cycle impact assessment

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Response to Comment on "Weighting and Aggregation in Life Cycle Assessment: Do Present Aggregated Single Scores Provide Correct Decision Support ?”

General information
Sustainability assessment of stormwater management systems
We quantify ecotoxicity impacts caused by different solutions to manage stormwater using life cycle assessment. As a novelty, we include emissions of a wide range of pollutants present in runoff. These emissions turn out to be of great importance, especially in decentralized, above surface systems.

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Organisations: Department of Environmental Engineering, Urban Water Systems, Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Brudler, S., Arnbjerg-Nielsen, K., Ammitsøe, C., Hauschild, M. Z., Rygaard, M.
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The Challenges of Applying Planetary Boundaries as a Basis for Strategic Decision-Making in Companies with Global Supply Chains
The Planetary Boundaries (PB) framework represents a significant advance in specifying the ecological constraints on human development. However, to enable decision-makers in business and public policy to respect these constraints in strategic planning, the PB framework needs to be developed to generate practical tools. With this objective in mind, we analyse the recent literature and highlight three major scientific and technical challenges in operationalizing the PB approach in decision-making: first, identification of thresholds or boundaries with associated metrics for different geographical scales; second, the need to frame approaches to allocate fair shares in the ‘safe operating space’ bounded by the PBs across the value chain and; third, the need for international bodies to co-ordinate the implementation of the measures needed to respect the Planetary Boundaries. For the first two of these challenges, we consider how they might be addressed for four PBs: climate change, freshwater use, biosphere integrity and chemical pollution and other novel entities. Four key opportunities are identified: (1) development of a common system of metrics that can be applied consistently at and across different scales; (2) setting ‘distance from boundary’ measures that can be applied at different scales; (3) development of global, preferably open-source, databases and models; and (4) advancing understanding of the interactions between the different PBs. Addressing the scientific and technical challenges in operationalizing the planetary boundaries needs be complemented with progress in addressing the equity and ethical issues in allocating the safe operating space between companies and sectors.

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Organisations: Department of Environmental Engineering, Department of Management Engineering, Quantitative Sustainability Assessment, University of Surrey, Unilever, Radboud University Nijmegen, Unilever R&D, CIRAIG, Stanford University, Humboldt University of Berlin, Columbia University, University of Bayreuth, Stockholm University, United Nations Environment Programme, University of Technology Sydney
Toward meaningful evaluation of climate change impacts in sustainability assessment of bioplastics

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USEtox® 2.0 Documentation (Version 1.00)
This document represents the official Documentation of USEtox, the United Nations Environment Programme (UNEP) / Society of Environmental Toxicology and Chemistry (SETAC) scientific consensus model for characterizing human and ecotoxicological impacts of chemical emissions in life cycle assessment. Main output of USEtox is a database of «recommended» and «indicative» characterization factors for human toxicity and freshwater ecotoxicity, based on modelling of environmental fate, exposure, and effect parameters for the substances. Due to deficiencies in the model or the available substance data, the «indicative» factors are accompanied by a higher uncertainty than the «recommended» factors, which should be considered when applying the factors and interpreting the results.
The latest official release version of USEtox is available at http://usetox.org

Weighting and Aggregation in Life Cycle Assessment: Do Present Aggregated Single Scores Provide Correct Decision Support?
This study investigates the prevailing practice of obtaining single scores in life cycle assessment (LCA) and identifies potential lacunas in impact assessment methodology related to the results of aggregation into endpoints and single scores. In order to conduct this investigation, a detailed approach was adopted to facilitate identification of three main problems related to the single-score calculation approach. The prevailing ReCiPe single-score calculation method does not account for either the effect of so-called dominating alternatives (i.e., alternatives having high values across all endpoints) or the interdependency of the indicators being aggregated. It was also found that the simple linear weighted sum method, presently used for obtaining single scores, is not capable of accounting for the effect of weighting schemes and thus cannot realistically represent stakeholders’ perspectives. Finally, we propose a distance-based multiple attribute decision-making method for use in obtaining single scores. This method was found to be more suitable, given that it takes into account the weighting schemes and types of indicators in the process of estimating single scores. The new single-score calculation method proposed here is considered ideal for environmental decision-making problems in the context of life cycle sustainability assessment. Thus, it is also ideal for situations in which more-complex decision-making situations will emerge by combining LCA indicators (midpoints or endpoints) with other indicators representing the performance of a system from economic and social perspectives.
Advancing absolute sustainability assessments of products with a new Planetary Boundaries based life-cycle impact assessment methodology

The Planetary Boundaries (PB)-framework introduced quantitative boundaries for a set of biophysical Earth System processes. The PBs delimit a ‘safe operating space’ for humanity to act within to keep Earth in a Holocene-like state (Rockström et al 2009). The concept has gained strong interest from companies that want to assess and communicate the environmental sustainability of their products relative to the PBs. However, consistent methods for assessing environmental impacts of products and systems based on the PBs have, to date, not been developed (Ryberg et al 2016).

In this study, we developed an operational life-cycle impact assessment (LCIA) methodology where the definition of the impact categories is based on the control variables as defined in the PB-framework by Steffen et al (2015). This included the development and calculation of characterization factors for the Earth System processes considered in the PB-framework. The characterization factors cover environmental flows contributing to impacts on the Earth System processes (e.g. CO2 and its precursors contributing to ocean acidification) and are expressed in the units of the PB framework’s control variables (e.g. change in the aragonite saturation state per unit CO2 emission for ocean acidification). The use of these characterization factors for evaluating the environmental impacts of products in LCA ensures impact scores that are compatible with the PB framework. The impact scores can be related to either the full PBs or an allocated safe operating space. The latter reflect the share of the safe operating space the assessed products can be considered entitled to, thereby, allowing for quantifying the absolute environmental sustainability of the products.

This new Planetary Boundaries based LCIA methodology provides additional and complementary insights which cannot be achieved with traditional LCIA methodologies. The key added value is the ability to relate the impacts of a product to the Planetary Boundaries. This can be used for communicating a product’s environmental performance and for setting reduction targets based on absolute environmental boundaries, thereby, advancing absolute sustainability assessments.

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A proposal to measure absolute environmental sustainability in lifecycle assessment

Environmental monitoring indicates that progress towards the goal of environmental sustainability in many cases is slow, non-existing or negative. Indicators that use environmental carrying capacity references to evaluate whether anthropogenic systems are, or will potentially be, environmentally sustainable are therefore increasingly important. Such absolute indicators exist, but suffer from shortcomings such as incomplete coverage of environmental issues, varying data quality and varying or insufficient spatial resolution. The purpose of this article is to demonstrate that life cycle assessment (LCA) can potentially reduce or eliminate these shortcomings. We developed a generic mathematical framework for the
use of carrying capacity as environmental sustainability reference in spatially resolved life cycle impact assessment models and applied this framework to the LCA impact category terrestrial acidification. In this application carrying capacity was expressed as acid deposition (eq. mol H+ ha−1 year−1) and derived from two complementary pH related thresholds. A geochemical steady-state model was used to calculate a carrying capacity corresponding to these thresholds for 99,515 spatial units worldwide. Carrying capacities were coupled with deposition factors from a global deposition model to calculate characterisation factors (CF), which expresses space integrated occupation of carrying capacity (ha year) per kg emission. Principles for calculating the entitlement to carrying capacity of anthropogenic systems were then outlined, and the logic of considering a studied system environmentally sustainable if its indicator score (carrying capacity occupation) does not exceed its carrying capacity entitlement was demonstrated. The developed CFs and entitlement calculation principles were applied to a case study evaluating emission scenarios for personal residential electricity consumption supplied by production from 45 US coal fired electricity plant. Median values of derived CFs are 0.16–0.19 ha year kg−1 for common acidifying compounds. CFs are generally highest in Northern Europe, Canada and Alaska due to the low carrying capacity of soils in these regions. Differences in indicator scores of the case study emission scenarios are to a larger extent driven by variations in pollution intensities of electricity plants than by spatial variations in CFs. None of the 45 emission scenarios could be considered environmentally sustainable when using the relative contribution to GDP or the grandfathering (proportionality to past emissions) valuation principles to calculating carrying capacity entitlements. It is argued that CFs containing carrying capacity references are complementary to existing CFs in supporting decisions aimed at simultaneously reducing environmental impacts efficiently and maintaining or achieving environmental sustainability. We have demonstrated that LCA indicators can be modified from being relative to being absolute indicators of environmental sustainability. Further research should focus on quantifying uncertainties related to choices in indicator design and on reducing uncertainties effectively. © 2015 Elsevier Ltd. All rights reserved.
Area of Concern: A new paradigm in life cycle assessment for the development of footprint metrics

As a class of environmental metrics, footprints have been poorly defined, have shared an unclear relationship to life cycle assessment (LCA), and the variety of approaches to quantification have sometimes resulted in confusing and contradictory messages in the marketplace. In response, a task force operating under the auspices of the UNEP/SETAC Life Cycle Initiative project on environmental life cycle impact assessment (LCIA) has been working to develop generic guidance for developers of footprint metrics. The purpose of this paper is to introduce a universal footprint definition and related terminology as well as to discuss modelling implications. The task force has worked from the perspective that footprints should be based on LCA methodology, underpinned by the same data systems and models as used in LCA. However, there are important differences in purpose and orientation relative to LCA impact category indicators. Footprints have a primary orientation toward society and nontechnical stakeholders. They are also typically of narrow scope, having the purpose of reporting only in relation to specific topics. In comparison, LCA has a primary orientation toward stakeholders interested in comprehensive evaluation of overall environmental performance and trade-offs among impact categories. These differences create tension between footprints, the existing LCIA framework based on the area of protection paradigm and the core LCA standards ISO14040/44. In parallel to area of protection, we introduce area of concern as the basis for a universal footprint definition. In the same way that LCA uses impact category indicators to assess impacts that follow a common causeeffect pathway toward areas of protection, footprint metrics address areas of concern. The critical difference is that areas of concern are defined by the interests of stakeholders in society rather than the LCA community. In addition, areas of concern are stand-alone and not necessarily part of a framework intended for comprehensive environmental performance assessment. The area of concern paradigm is needed to support the development of footprints in a way that fulfils their distinctly different purpose. It is also needed as a mechanism to extricate footprints from some of the provisions of ISO 14040/44 which are not considered relevant. Specific issues are identified in relation to double counting, aggregation and the selection of relevant indicators. The universal footprint definition and related terminology introduced in this paper create a foundation that will support the development of footprint metrics in parallel with LCA.

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Assessing environmental performance of hydrothermal carbonization of wet biomass at industry-relevant scales

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
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Assessment of Metal Toxicity in Marine Ecosystems: Comparative Toxicity Potentials for Nine Cationic Metals in Coastal Seawater

This study is a first attempt to develop globally applicable and spatially differentiated marine Comparative Toxicity Potentials (CTPs) or ecotoxicity characterization factors for metals in coastal seawater for use in Life Cycle Assessment. The toxicity potentials are based exclusively on marine ecotoxicity data and take account of metal speciation and bioavailability. CTPs were developed for nine cationic metals (Cd, Cr(III), Co, Cu(II), Fe(III), Mn, Ni, Pb and Zn) in 64 Large Marine Ecosystems (LMEs) covering all coastal waters in the world. The results showed that the CTP of a specific metal varies 3-4 orders of magnitude across LMEs, largely due to different seawater residence time. Therefore the highest toxicity potential for metals was found in the LMEs with the longest seawater residence times. Across metals, the highest CTPs were observed for Cd, Pb and Zn. At the concentration levels occurring in coastal seawaters, Fe acts not as a toxic agent but an essential nutrient and thus has CTPs of zero.
Challenges in implementing a Planetary Boundaries based Life-Cycle Impact Assessment methodology

Impacts on the environment from human activities are now threatening to exceed thresholds for central Earth System processes, potentially moving the Earth System out of the Holocene state. To avoid such consequences, the concept of Planetary Boundaries was defined in 2009, and updated in 2015, for a number of processes which are essential for maintaining the Earth System in its present state. Life-Cycle Assessment was identified as a suitable tool for linking human activities to the Planetary Boundaries. However, to facilitate proper use of Life-Cycle Assessment for non-global environmental management based on the Planetary Boundaries, there is a need for linking non-global activities to impacts on a planetary level. In this study, challenges related to development and operationalization of a Planetary Boundary based Life-Cycle Impact Assessment method are identified and the feasibility of resolving the challenges and developing such methodology is discussed. The challenges are related to technical issues, i.e., modelling and including the Earth System processes and their control variables as impact categories in Life-Cycle Impact Assessment and to theoretical considerations with respect to the interpretation and use of Life-Cycle Assessment results in accordance with the Planetary Boundary framework. The identified challenges require additional research before a Planetary Boundaries based Life-Cycle Impact Assessment method can be developed. Research on modelling the impacts on Earth System processes and on allocation of and entitlement to the 'safe operating space' appear to be most urgent for operationalizing a Planetary Boundaries based Life-Cycle Impact Assessment method. The results of a Planetary Boundaries based Life-Cycle Impact Assessment would be highly relevant and could provide novel insights on the environmental performance and sustainability of products and systems.

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Effect factors for marine eutrophication in LCIA based on species sensitivity to hypoxia

Hypoxia is an important environmental stressor to marine species, especially in benthic coastal waters. Increasing anthropogenic emissions of nutrients and organic matter contribute to the depletion of dissolved oxygen (DO). Biotic sensitivity to low levels of DO is determined by the organisms' ability to use DO as a respiratory gas, a process depending on oxygen partial pressure. A method is proposed to estimate an indicator of the intensity of the effects caused by hypoxia on exposed marine species. Sensitivity thresholds to hypoxia of an exposed ecological community, modelled as lowest-observed-effect-concentrations (LOEC), were compiled from literature for 91 demersal species of fish, crustaceans, molluscs, echinoderms, annelids, and cnidarians, and converted to temperature-specific benthic (100 m depth) LOEC values. Species distribution and LOEC values were combined using a species sensitivity distribution (SSD) methodology to estimate the DO concentration at which the potentially affected fraction (PAF) of the community's species having their LOEC exceeded is 50% (HC50LOEC). For the purpose of effect modelling in Life Cycle Impact Assessment (LCIA), effect factors (EF, [(PAF) m3 kgO2 -1]) were derived for five climate zones (CZ) to represent the change in effect due to a
variation of the stressor intensity, or \( \text{EF} = \frac{\Delta \text{PAF}}{\Delta \text{DO}} = 0.5/\text{HC50}_{\text{LOEC}} \). Results range from 218 (PAF) m\(^3\) kgO\(_2\)\(^{-1}\) (polar CZ) to 306 (PAF) m\(^3\) kgO\(_2\)\(^{-1}\) (tropical CZ). Variation between CZs was modest so a site-generic global EF of 264 (PAF) m\(^3\) kgO\(_2\)\(^{-1}\) was also estimated and may be used to represent the average impact on a global ecological community of marine species exposed to hypoxia. The EF indicator is not significantly affected by the major sources of uncertainty in the underlying data suggesting valid applicability in characterisation modelling of marine eutrophication in LCIA.

**General information**

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Effect factors for terrestrial acidification in Brazil

To support the increased use of existing Life Cycle Impact Assessment (LCIA) methodologies across the world, new methodological elements have been developed towards spatially resolved impact assessment. Spatially resolved methods could better capture the differences of regional environmental conditions, which is an essential approach considering countries like Brazil, with high biodiversity. Previous studies have assessed the impacts of terrestrial acidification from the estimations of the potential losses of vascular plants species richness as a result of exposure to acidifying substances for 13 biomes, with 2409 species addressed for whole world. In this context this work aims to provide spatially-differentiated effect factors (EF) for terrestrial acidification in Brazil and support the development of spatially-differentiated characterization factors for Brazil. In order to maintain compatibility with existing LCIA methods the effect factors were developed using the framework adopted by LC-Impact and Impact World+ methods. Soil pH was used as an indicator of soil acidity to predict plant occurrences. From the number of plant species occurring at each 0.1 pH unit response relationships of species richness and soil pH were developed. The species richness in each ecoregion were transformed into an empirical potentially not occurring fraction, which is a zero-to-one measure used to represent the presence or absence of species. The set of data consists of 976345 records of plants occurrences in Brazil, represented by 33167 species, indicating that this is a comprehensive study. Maps of soil pH in Brazil were extracted at 1-km resolution and pH values were extracted for the depth range of 0-30cm. For each ecoregion, species richness was plotted against soil pH and the exposure-response curves for acidification described the behavior of plant species in a certain region when it is exposed to acidic conditions. From these curves it was possible to derive the effect factors for terrestrial acidification. The results of this work show that spatial differentiation is meaningful when it is possible to combine fine spatial resolutions and highly representative data and this approach can be applied for other impact categories and regions, and contribute to the development of spatial differentiated LCIA methodologies.

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Environmental impacts of flood control measures in climate change adaptation strategies

Because of climatic changes, large investments are needed to keep flood risk at an acceptable level in urban areas. Increasing dimensions of underground sewer systems and retention basins are increasingly supplemented with multi-functional approaches, aimed at managing water locally and/or route it on the surface without harming assets. When evaluating different adaptation approaches, a cost assessment is typically carried out, while environmental impacts usually are not considered. To close this gap, a Life Cycle Assessment (LCA) based method is developed, which allows to quantify environmental impacts of different storm water management strategies. It is tested with two different adaptation
strategies for the Nørrebro catchment in Copenhagen, Denmark: A Cloudburst Management Plan (CMP), which uses a multi-functional approach and combines green infrastructure with subsurface pipes, and a Subsurface scenario (SSA), which uses only pipes and underground retention basins. To ensure comparability, flood safety levels for different rain events are defined, which have to be met in both scenarios. The environmental impacts are calculated for eight different categories, including climate change, resource depletion, eutrophication and acidification. The case study shows significantly lower impacts for the multi-functional, green infrastructure CMP, compared to the SSA. Among the installations, those measures which are installed to ensure no water on the surface during rain events with a return period of 10 years and handling small events with a return period of up to 0.2 years cause by far the largest share of the total environmental impacts in both scenarios (up to 96% for the CMP, and up to 84% for the SSA). In contrast, measures aimed at handling extreme events with a return period of up to 100 years only contribute up to 4% of the environmental impacts for the CMP and less than 1% for the SSA. Our method helps explain how the handling of everyday events and extreme rain events affect the environmental sustainability of climate change adaptation and it enables cities to consider the environmental sustainability of climate change adaptation solutions in the planning process.

Environmental performance of hydrothermal carbonization of four wet biomass waste streams at industry-relevant scales

Hydrothermal carbonization (HTC) of green waste, food waste, organic fraction of municipal solid waste (MSW), and digestate is assessed using life cycle assessment as a potential technology to treat biowaste. Water content of the biowaste and composition of the resulting hydrochar are important parameters influencing environmental performance. Hydrochar produced from green waste performs best and second best in respectively 2 and 10 out of 15 impact categories, including climate change, mainly due to low transportation needs of the biowaste and optimized pumping efficiency for the feedstock. By contrast, hydrochar produced from the organic fraction of MSW performs best in 6 impact categories, but has high potential impacts on human health and ecosystems caused by emissions of toxic elements through ash disposal. The greatest potential for environmental optimization for the HTC technology is in the use of heat and electricity with increasing plant size, but its overall environmental performance is largely influenced in a given geographic location by the incumbent waste management system that it replaces. Impact scores are within the range of existing alternative treatment options, suggesting that despite being relatively immature technology, and depending on the geographic location of the plant, HTC may be an attractive treatment option for biowaste.
Global guidance on environmental life cycle impact assessment indicators: Progress and case study

Purpose The life cycle impact assessment (LCIA) guidance flagship project of the United Nations Environment Programme (UNEP)/Society of Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative aims at providing global guidance and building scientific consensus on environmental LCIA indicators. This paper presents the progress made since 2013, preliminary results obtained for each impact category and the description of a rice life cycle assessment (LCA) case study designed to test and compare LCIA indicators.

Methods The effort has been focused in a first stage on impacts of global warming, fine particulate matter emissions, water use and land use, plus cross-cutting issues and LCA-based footprints. The paper reports the process and progress and specific results obtained in the different task forces (TFs). Additionally, a rice LCA case study common to all TF has been developed. Three distinctly different scenarios of producing and cooking rice have been defined and underlined with life cycle inventory data. These LCAs help testing impact category indicators which are being developed and/or selected in the harmonisation process. The rice LCA case study further helps to ensure the practicality of the finally recommended impact category indicators.

Results and discussion The global warming TF concludes that analysts should explore the sensitivity of LCA results to metrics other than GWP. The particulate matter TF attained initial guidance of how to include health effects from PM2.5 exposures consistently into LCIA. The biodiversity impacts of land use TF suggest to consider complementary metrics besides species richness for assessing biodiversity loss. The water use TF is evaluating two stress-based metrics, AWaRe and an alternative indicator by a stakeholder consultation. The cross-cutting issues TF agreed upon maintaining disability-adjusted life years (DALY) as endpoint unit for the safeguard subject "human health". The footprint TF defined main attributes that should characterise all footprint indicators. "Rice cultivation" and "cooking" stages of the rice LCA case study contribute most to the environmental impacts assessed.

Conclusions The results of the TF will be documented in white papers and some published in scientific journals. These white papers represent the input for the Pellston workshop ™, taking place in Valencia, Spain, from 24 to 29 January 2016, where best practice, harmonised LCIA indicators and an update on the general LCIA framework will be discussed and agreed on. With the diversity in results and the multi-tier supply chains, the rice LCA case study is well suited to test candidate recommended indicators and to ensure their applicability in common LCA case studies.
How much biochar does gasification energy need to be carbon neutral?

Indirect land use changes (iLUC) from bioenergy emerge whenever an energy crop is planted in arable land. Due to their overarching magnitude from a life-cycle perspective, they have been repeatedly recommended to be included in bioenergy’s greenhouse gas (GHG) accountings, despite their challenging quantification and inherent uncertainties. Marginal or abandoned lands have been often quoted as the solution to avoid these undesired effects from bioenergy. However, land abandonment and marginalization is to a large extent a socio-economic process, and thus heavily depends on specific, constantly changing socio-political context and economic circumstances in place. We suggest a carbon negative bioenergy system that compensates for potential iLUC emissions and losses in soil organic carbon (SOC). A consequential life cycle assessment on willow bioenergy has been performed, distinguishing marginal and arable land scenarios. Specific soil types and their estimated SOC changes have been considered [9], as well as iLUC emissions for the arable case. Taking the study case of a willow plantation combined with a medium-scale gasification plant in Denmark, we illustrate the biochar needed from the process in order to remain carbon neutral. The time scopes assessed are 20 and 100 years and it is assumed a fossil fuel (FF) free Denmark beyond 2050 as targeted by government (no FF displacement occurs after 2050). Results show that willow on marginal land remains carbon negative (4% biochar fraction) for the short term, while as much as 31.8% of biochar (or 0.95 Mg C ha-1 yr-1) would be necessary in 100 years to be carbon neutral (taking natural vegetation as reference baseline). As for arable land willow, a biochar fraction of 34.1% (or 2.32 Mg C ha-1 yr-1) would be necessary in the short term to compensate for iLUC emissions, while a 4% would suffice to make it carbon negative in the long term, as iLUC “dilutes” over 100 years. To achieve such high biochar fractions (>10%), lower process temperatures are needed, which affect negatively the long-term stability of biochar. This can put at risk the claimed GWP reduction benefits. This study did not consider impacts on other environmental aspects as ecosystem services and biodiversity, which are deemed to be rather important and significant for iLUC.

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How to consistently make your product, technology or system more environmentally-sustainable?

Human activities are currently unsustainable, causing many damages to ecosystems, human health and natural resources. In this setting, the development of new products and technologies has been increasingly required to relate to sustainability and ensure that such development goes hand-in-hand with low environmental impacts, low-carbon emissions, low environmental footprints or more sustainability as a whole. To enable a scientifically-sound and consistent documentation of such sustainable development, quantitative assessments of all environmental impacts are needed. Life cycle assessment (LCA) is recognized as the most holistic tool to address that need. LCA has two main strengths: (1) the ability to quantify all relevant environmental impacts – not just climate change, but also metal depletion, water use, toxicity exerted by pollutants on ecosystems and human health, etc.; and (2) making the assessment of the product/technology in a life cycle perspective, from the extraction of raw materials through production and use/operation of the product up to its final disposal. Fully embracing these 2 features enables to minimize the risk of burden-shifting, e.g. if impacts on climate change are being reduced while increasing other relevant environmental impacts or if impacts are shifted from the use stage of a product to the manufacturing stage as a result of a change in the product composition. Here, we provide a glimpse at how LCA can help for eco-design purposes, moving towards the use of low-impact materials, identifying environmental hotspots parts of the life cycle with largest environmental impacts), making prospective simulations through scenario analyses, comparing and selecting most environmentally-friendly product/technology alternatives, reporting on the environmental performances of the system. We rely on state-of-the-art science in the food sector, the aquaculture sector and the energy sector to showcase and illustrate the potential of LCA to undertake the environmental sustainability challenge and support product/technology/system development.

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Integrating LCA and Risk Assessment for Decision Support

The study aims at developing a methodology using decision analysis theory and tools to find the optimal policy (or design) of the studied system, to ensure both sustainability and meanwhile manage risks.

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Land Use in LCIA: an absolute scale proposal for Biotic Production Potential

Environmental impacts caused by land occupation and transformation have been bypassed in many LCA studies due to soils’ multifunctionality and the interconnectedness between the ecosystem services they provide. These inherent modelling complexities have traditionally forced LCA practitioners to content with a mere quantification of Land Use (LU), as surface area and duration (in m² or ha and years) appropriated by humans, without further analysis of the impact pathways derived from those land uses. Milà i Canals established the first comprehensive, basic framework for taking soil quality aspect into LCIA that reached acceptance among the LCA community. Through contributions from UNEP-SETAC’s special task force on LU, great progress has ensued in developing further such LCIA. Building on the latest proposal by Koellner et al. and with the aim of developing the Planetary Boundaries thinking into LCA, the present study proposes a single absolute scale for the midpoint impact category (MIC) of Biotic Production Potential (BPP). It is hypothesized that, for an ecosystem in equilibrium (where NPP equals decay), such an ecosystem has reached the maximum biotic
throughput subject to site-specific conditions and no externally added inputs. The original ecosystem (or Potential Natural Vegetation) of a certain land gives then the maximum BPP with no additional, downstream or upstream, impacts. This Natural BPP is proposed as the maximum BPP in a hypothetical Absolute Scale for LCA’s Land Use framework. It is argued that this maximum BPP is Nature’s optimal solution through evolution-adaptation mechanisms, which provides the maximum matter throughput subject to the rest of environmental constraints (without further impacts). As a consequence, this scale rises a Land Use Optimality Point that suggests the existence of a limit regarding the maximization of divergent objectives with bioenergy. It will be attempted to model that beyond this point, and for the land available within a country, if the objective of Climate Change mitigation through bioenergy is further maximized, then the Fossil Fuel displacing objective will decrease, and vice versa.

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**Life cycle assessment for policy-making: Case of the human health impacts from national NMVOC emissions in the EU-27 between 2000 and 2010**

**General information**

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**Life cycle assessment of stormwater management in the context of climate change adaptation**

Expected increases in pluvial flooding, due to climatic changes, require large investments in the retrofitting of cities to keep damage at an acceptable level. Many cities have investigated the possibility of implementing stormwater management (SWM) systems which are multi-functional and consist of different elements interacting to achieve desired safety levels. Typically, an economic assessment is carried out in the planning phase, while environmental sustainability is given little or no attention. In this paper, life cycle assessment is used to quantify environmental impacts of climate change adaptation strategies. The approach is tested using a climate change adaptation strategy for a catchment in Copenhagen, Denmark. A stormwater management system, using green infrastructure and local retention measures in combination with planned routing of stormwater on the surfaces to manage runoff, is compared to a traditional, sub-surface approach. Flood safety levels based on the Three Points Approach are defined as the functional unit to ensure comparability between systems. The adaptation plan has significantly lower impacts (3-18 person equivalents/year) than the traditional alternative (14-103 person equivalents/year) in all analysed impact categories. The main impacts are caused by managing rain events with return periods between 0.2 and 10 years. The impacts of handling smaller events with a return period of up to 0.2 years and extreme events with a return period of up to 100 years are lower in both alternatives. The uncertainty analysis shows the advantages of conducting an environmental assessment in the early stages of the planning process, when the design can still be optimised, but it also highlights the importance of detailed and site-specific data.

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Life cycle assessment of stormwater management in the context of climate change

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Limitations and opportunities of combining Cradle to Grave and Cradle-to-Cradle approaches to support the circular economy

Both Life Cycle Assessment (LCA) with its “Cradle to Grave” approach and the Cradle to Cradle®(C2C) design framework based on the eco-effectiveness concept can support the implementation of circular economy. Based on the insights gained in the packaging sector, we perform a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the combined use of LCA and “C2C tools”, i.e. the C2C design protocol and the C2C certified TM product standard, in the implementation of circularity strategies at the product level. Moreover, we discuss the challenges which need to be addressed in order to move from a relative to an absolute environmental sustainability perspective at the company level, and define a framework for implementing circularity strategies at the company level, considering an absolute environmental sustainability perspective and the business dimension.

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Mainstreaming life cycle thinking through a consistent approach to footprints

Over recent years, footprints have emerged as an important means of reporting environmental performance. Some individual footprints have become quite sophisticated in their calculation procedures. However, as an overall class of environmental metrics they have been poorly defined, having a variety of conceptual foundations and an unclear relationship to LCA. The variety and sometimes contradictory approaches to quantification have also led to confusing and contradictory messages in the marketplace which have undermined their acceptance by industry and governments. In response, a task force operating under the auspices of the UNEP/SETAC Life Cycle Initiative project on environmental Life Cycle Impact Assessment has been working to develop generic guidance for developers of footprint metrics. The initial work involved forming a consensual position on the difference between footprints and existing LCA impact category indicators.

In short, footprints are deemed to have a primary orientation toward society and nontechnical stakeholders and report only on selected topics of concern. On the other hand, LCA impact category indicators have a primary orientation toward technical stakeholders and report in relation to a larger framework designed for comprehensive evaluation of environmental performance and trade-offs. The task force has also developed a universal footprint definition. In parallel to Area of Protection, we introduce Area of Concern. In the same way that LCA uses impact category indicators to assess impacts that follow a common cause-effect pathway toward Areas of Protection, footprint metrics address Areas of Concern. The critical difference is that Areas of Concern are defined by the interests of stakeholders in society rather than the LCA community. In addition, Areas of Concern are stand-alone and not part of a framework intended for comprehensive environmental performance assessment. Accordingly, footprints are universally defined as metrics used to report life cycle assessment results addressing an Area of Concern.

Natural fibre selection for composite eco-design

Natural fibre composites (NFC) are gaining interest in manufacturing because they address some of the environmental problems of traditional composites: use of non-renewable resources, and large impacts related to their production and disposal. Since natural fibres are not yet optimized for composite production, it is crucial to identify the most appropriate applications, and determine the optimal fibre/matrix ratio. A methodology is proposed for early-stage decisions support on selection of bio-composite materials. Results help identify the application with the largest reduction in environmental burden and show that the fibre/matrix combination with the lowest environmental burden also has the best mechanical properties.
On the need for integrating LCA into decision making

The need for sustainable solutions has gained attention both in academia and industry research due to increasing demands of human beings, which are incompatible with limitations in resources availability. Several methods, such as Life Cycle Assessment (LCA), were developed in the past decades to assess the environmental profile of products and services. However, when decision makers have several alternatives at hand to solve a problem, environmental performance is not the only criterion for choosing the best alternative. Other criteria such as risks and economical costs and benefits that are associated with the alternatives will also influence the final choice. Sometimes the most environmentally sustainable alternative may not be the safest or cheapest one. How to make a balanced decision considering environmental performance together with other criteria is not straightforward.

Decision analysis is broadly used to help decision makers identify the best solution among alternatives. The decision is based on expected utility generation, which incorporates consequences (or impacts) associated with each alternative. Depending on the research field and goal of the study, the included consequences can be e.g. environmental impacts, property damages from natural hazards and/or human health impacts. We examined the current decision analysis practice as it is applied in different research fields. The review shows that generally environmental impacts are considered less often than the other consequences. Meanwhile, LCA has been applied in many research fields to assess a wide range of environmental impacts associated with products or services. There is a huge potential for integrating LCA into other decisions analysis tools to include assessments of the environmental profile of alternatives. This will provide the possibility of systematical inclusion of environmental considerations in the decision making process, thus facilitating a more holistic decision. However, due to different scopes and purposes of LCA and other decision analysis tools, the integration is not straightforward. The lack of consistency in e.g. system boundaries and handling of uncertainty needs to be carefully managed.

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Sensitivity analysis of the use of Life Cycle Impact Assessment methods: a case study on building materials

The main aim of this research is to perform a sensitivity analysis of a Life Cycle Assessment (LCA) case study to understand if the use of different Life Cycle Impact Assessment (LCIA) methods may lead to different conclusions by decision makers and stakeholders. A complete LCA was applied to non-load-bearing external climate walls for comparative purposes. The LCIA phase of the case study was performed using five different Impact Assessment Methods: EDIP 97/2003 (midpoint), CML 2001 (midpoint), Impact 2002+ (endpoint and midpoint), ReCiPe (endpoint and midpoint) and the ILCD recommended practices for LCIA (midpoint). The endpoint results were compared aggregately, and the midpoint categories concerning similar potential impacts were compared individually for the analysis of possible deviations. The observations and comparisons involved mostly the decision maker's point of view and not the differences among the characterization models. The endpoint LCIA showed that the only two methods which applied such an approach (Impact 2002+ and ReCiPe) provided different results and led to different conclusions. For midpoint LCIA, the results were completely consistent for the following impact categories: General Eutrophication, Aquatic and Freshwater Ecotoxicity, Ionizing Radiation, Particulate Matter Formation, and Resources Depletion. Global Warming, Terrestrial Ecotoxicity, Human Toxicity (except for the Non-carcinogens impact category) and Land Use (except for Natural Land Transformation) showed partially consistent results and pointed out to the same worst environmental alternative, but with a slightly different impact profile among the other alternatives. Ozone Layer depletion and Photochemical Oxidant Formation categories showed discrepant results and the impact profile differences between the older and newer methods were notable. Acidification, Terrestrial and Aquatic Eutrophication, Marine Ecotoxicity and Water Depletion showed substantially inconsistent results. (C) 2015 Elsevier Ltd. All rights reserved.
Testing the environmental performance of urban agriculture as a food supply in northern climates

The past decade has seen a renaissance of urban agriculture in the world’s wealthy, northern cities. The practice of producing food in and around cities is championed as a method to reduce environmental impacts of urban food demands (reducing distance from farm to fork - ‘food miles’) whilst conferring a number of ancillary benefits to host cities (runoff...
attenuation, urban heat island mitigation) and ex-urban environments (carbon sequestration). Previous environmental assessments have found urban agriculture to be more sustainable than conventional agriculture when performed in mild climates, though opposite findings emerge when external energy inputs are significant. In this study we perform an environmental life cycle assessment of six urban farms in Boston, US producing lettuce and tomatoes, with conventional counterparts across six impact categories. Performance of urban agriculture was system dependent and no farm provided superior performance to conventional for all indicators. High-yield, heated, greenhouse production of tomatoes has potentially higher environmental burdens than conventional methods in terms of climate change (267–369%) and non-renewable resource depletion (108–239%), driven primarily by external energy inputs. Heated lettuce production systems showed similar trends. Low-tech, empty-lot farming appears to hold some advantages in terms of climate change burdens and resource use, though water and land usage was found to be elevated relative to conventional lettuce and tomatoes. Open rooftop farming apparently provides benefits if high yield crops (e.g. tomatoes) are cultivated, otherwise significant capital inputs detrimentally affect environmental performance. In general, the benefits of reduced food miles may be overwhelmed by energy inputs and inefficient use of production inputs. A comparison of urban agriculture and solar panels showed that the latter would confer greater benefits to mitigate climate change per unit area. Thus, urban agriculture may not be the optimal application of space in northern cities to improve urban environmental performance.

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The development of an operational LCIA-methodology with impact categories based on the control variables in the Planetary Boundaries framework

This study presents a first attempt at an operational LCIA-methodology basing the definition of the impact categories on the control variables as defined in the Planetary Boundaries (PB) framework. The PB-framework introduced a set of biophysical Earth system processes and defined quantitative PBs that have to be respected for Earth to remain in the Holocene state. The concept is attracting a strong interest from industry as companies seek to assess and communicate the environmental performance of their products relative to the PBs. The PB-framework has previously been attempted included in LCA as part of normalization and weighting. The limitations of both attempts are the lack of spatial differentiation for spatially differentiated PBs and the requirement for harmonizing the control variables with indicators already used in life-cycle impact assessment (LCIA). A way to overcome these limitations is to directly use the control variables in the PB-framework as impact categories in LCIA, which is also the objective of this study. This work defines a mathematical framework for a LCIA-methodology where Characterization Factors (CFs) are included for all Earth system processes in the PB-framework, for all substances contributing to effects on the Earth system processes and expressed in the units of the control variables. Except for novel entities and biosphere integrity which are currently excluded from the LCIA-methodology because the former is lacking a planetary boundary metric while a full understanding of the cause-effect chain is missing for the latter. The CFs were estimated by
identifying the environmental models
needed to model the control variables of the PB-framework and adapting these to fit the LCIA-framework. This work
provides a full set of CFs for all the Earth
system processes in the PB-framework. The new LCIA-methodology provides
additional and complementary insights which cannot be achieved with raditional
LCIA-methodologies. The results provide information on the environmental
impacts of the assessed products and solves previous problems with approximative links between control variables in the
PB-framework and current
LCIA impact categories. The new insights can be used for communicating the
product’s environmental performance and to support definitions of absolute
reduction targets relative to the PBs.

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The role of manufacturing in affecting the social dimension of sustainability
Manufacturing affects all three dimensions of sustainability: economy, environment, and society. This paper addresses the
last of these dimensions. It explores social impacts identified by national level social indicators, frameworks, and
principles. The effects of manufacturing on social performance are framed for different stakeholder groups with associated
social needs. Methodology development as well as various challenges for social life cycle assessment (S-LCA) are further
examined. Efforts to integrate social and another dimension of sustainability are considered, with attention to globalization
challenges, including offshoring and reshoring. The paper concludes with a summary of key takeaways and promising
directions for future work.

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Urban versus conventional agriculture, taxonomy of resource profiles: a review

Urban agriculture appears to be a means to combat the environmental pressure of increasing urbanization and food demand. However, there is hitherto limited knowledge of the efficiency and scaling up of practices of urban farming. Here, we review the claims on urban agriculture’s comparative performance relative to conventional food production. Our main findings are as follows: (1) benefits, such as reduced embodied greenhouse gases, urban heat island reduction, and storm water mitigation, have strong support in current literature. (2) Other benefits such as food waste minimization and ecological footprint reduction require further exploration. (3) Urban agriculture benefits to both food supply chains and urban ecosystems vary considerably with system type. To facilitate the comparison of urban agriculture systems we propose a classification based on (1) conditioning of the growing space and (2) the level of integration with buildings. Lastly, we compare the predicted environmental performance of the four main types of urban agriculture that arise through the application of the taxonomy. The findings show how taxonomy can aid future research on the intersection of urban food production and the larger material and energy regimes of cities (the “urban metabolism”).

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Advances in assessing terrestrial toxicity of metal emissions for improved sustainability characterization of technologies

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A marine eutrophication impacts assessment method in LCIA coupling coastal ecosystems exposure to nitrogen and species sensitivity to hypoxia

Characterisation modelling in Life Cycle Impact Assessment (LCIA) aims at quantifying potential impacts of anthropogenic emissions. It delivers substance-specific Characterisation Factors (CF) expressing ecosystem responses to marginal increments in emitted quantities. Nitrogen (N) emissions from e.g. agriculture and industry enrich coastal marine ecosystems. Excessive algal growth and dissolved oxygen (DO) depletion typify the resulting marine eutrophication. LCIA modelling frameworks typically encompass fate, exposure and effect in the environment. The present novel method couples relevant marine biological processes of ecosystem’s N exposure (Exposure Factor, XF) with the sensitivity of select species to hypoxia (Effect Factor, EF). The XF converts N-inputs into a sinking carbon flux from planktonic primary production and DO consumed by bacterial respiration in bottom waters, whereas EF builds on probabilistic Species Sensitivity Distribution (SSD) methodologies to quantify potential species losses from hypoxia. Results show 2 orders of magnitude global spatial differentiation on a Large Marine Ecosystems (LME) spatial resolution. Adding an N-fate model completes CFs for anthropogenic N-forms, thus producing comparative environmental sustainability indicators of human activities as applied in Life Cycle Assessment (LCA) of product systems.

Assessing comparative terrestrial ecotoxicity of Cd, Co, Cu, Ni, Pb, and Zn: The influence of aging and emission source

Metal exposure to terrestrial organisms is influenced by the reactivity of the solid-phase metal pool. This reactivity is thought to depend on the type of emission source, on aging mechanisms that are active in the soil, and on ambient conditions. Our work shows, that when controlling for soil pH or soil organic carbon, emission source occasionally has an effect on reactivity of Cd, Co, Cu, Ni, Pb and Zn emitted from various anthropogenic sources followed by aging in the soil from a few years to two centuries. The uncertainties in estimating the age prevent definitive conclusions about the influence of aging time on the reactivity of metals from anthropogenic sources in soils. Thus, for calculating comparative toxicity potentials of man-made metal contaminations in soils, we recommend using time-horizon independent accessibility factors derived from source-specific reactive fractions.
Better – But is it Good Enough? On the Need to Consider Both Eco-efficiency and Eco-effectiveness to Gauge Industrial Sustainability

Sustainability is gaining prominence among the priorities of large companies, and engineers have taken on the eco-efficiency challenge, optimizing the functionality and minimizing the negative environmental impacts of our products and technologies. Although impressive improvements in efficiency can be demonstrated in many local cases, increases in population, affluence and consumption create an opposite trend that we need to factor in when we address sustainability of our technological developments in an absolute sense. The paper discusses absolute boundaries for environmental sustainability, metrics for gauging our solutions against these boundaries and the need and possibilities of expanding our focus from efficiency to effectiveness.

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Coupling ecosystems exposure to nitrogen and species sensitivity to hypoxia: modelling marine eutrophication in LCIA
Characterisation modelling in Life Cycle Impact Assessment (LCIA) quantifies impacts of anthropogenic emissions by applying substance-specific impact potentials, or Characterisation Factors (CF), to the amount of substances emitted. Nitrogen (N) emissions from human activities enrich coastal marine ecosystems and promote planktonic growth that may lead to marine eutrophication impacts. Excessive algal biomass and dissolved oxygen (DO) depletion typify the ecosystem response to the nutrient input. The present novel method couples a mechanistic model of coastal biological processes that determines the ecosystem response (exposure) to anthropogenic N enrichment (eXposure Factor, XF [kgO2·kgN-1]) with
the sensitivity of species exposed to oxygen-depleted waters (Effect Factor, EF \([\text{IPAF} \cdot \text{m}^3 \cdot \text{kgO}_2^{-1}]\), expressed as a Potentially Affected Fraction (PAF) of species). Thus, the coupled indicator \((X^*E^F, \text{[(PAF) \cdot m}^3 \cdot \text{kgN}^{-1}]\)) represents the potential impact on benthic and demersal marine species caused by N inputs. Preliminary results range from 2 \((\text{PAF}) \cdot \text{m}^3 \cdot \text{kgN}^{-1}\) (Central Arctic Ocean) to 94 \((\text{PAF}) \cdot \text{m}^3 \cdot \text{kgN}^{-1}\) (Baltic Sea). Comparative contributions per country or watersheds can also be obtained. Further adding environmental fate modelling of N emissions completes the CF for eutrophying emissions making it a useful contribution for sustainability assessment of human activities, as applied in Life Cycle Assessment (LCA).

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**Eco-efficient production of spring barley in a changed climate: A Life Cycle Assessment including primary data from future climate scenarios**

The paper has two main objectives: (i) to assess the eco-efficiency of spring barley cultivation for malting in Denmark in a future changed climate (700 ppm \([\text{CO}_2]\) and +5 °C) through Life Cycle Assessment (LCA) and (ii) to compare alternative future cultivation scenarios, both excluding and including earlier sowing and cultivar selection as measures of adaptation to a changed climate. A baseline scenario describing the current spring barley cultivation in Denmark was defined, and the expected main deviations were identified (differences in pesticide treatment index, modifications in nitrate leaching and change in crop yield). The main input data originate from experiments, where spring barley cultivars were cultivated in a climate phytotron under controlled and manipulated treatments. Effects of changed climate on both crop productivity and crop quality were represented, as well as impacts of predicted extreme events, simulated through a long heat-wave. LCA results showed that the changed climatic conditions will likely increase the negative impacts on the environment from Danish spring barley cultivation, since all environmental impact categories experienced increased impact for all investigated scenarios, except under the very optimistic assumption that the pace of yield improvement by breeding in the future will be the same as it was in the last decades. The main driver of the increased environmental impact was identified as the reduction in crop yield. Therefore, potential adaptation strategies should mainly focus on maintaining or improving crop productivity. The LCA also showed that selection of proper cultivars for future climate conditions including the challenge from extreme events is one of the most effective ways to reduce future environmental impacts of spring barley. Finally, if yield measurements are based on relative protein content, the negative effects of the future climate seem to be reduced. © 2015 Elsevier Ltd. All rights reserved.

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Experimental determinations of soil copper toxicity to lettuce (Lactuca sativa) growth in highly different copper spiked and aged soils

Accurate knowledge about factors and conditions determining copper (Cu) toxicity in soil is needed for predicting plant growth in various Cu-contaminated soils. Therefore, effects of Cu on growth (biomass production) of lettuce (Lactuca sativa) were tested on seven selected, very different soils spiked with Cu and aged for 2 months at 35 °C. Cu toxicity was
expressed as pEC50(Cu2+), i.e., the negative logarithm of the EC50(Cu2+) activity to plant growth. The determined pEC50(Cu2+) was significantly and positively correlated with both the analytically readily available soil pH and concentration of dissolved organic carbon [DOC] which together could explain 87 % of the pEC50(Cu2+) variation according to the simple equation: pEC50(Cu2+) = 0.98 × pH + 345 × [DOC] − 0.27. Other soil characteristics, including the base cation concentrations (Na+, K+, Ca2+, Mg2+), the cation exchange capacity at soil pH (ECEC), and at pH 7 (CEC7), soil organic carbon, clay content, and electric conductivity as well as the distribution coefficient (Kd) calculated as the ratio between total soil Cu and water-extractable Cu did not correlate significantly with pEC50(Cu2+). Consequently, Cu toxicity, expressed as the negative log of the Cu2+ activity, to plant growth increases at increasing pH and DOC, which needs to be considered in future management of plant growth on Cu-contaminated soils. The developed regression equation allows identification of soil types in which the phytotoxicity potential of Cu is highest.

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Exploring the planetary boundary for chemical pollution

Rockström et al. (2009a, 2009b) have warned that humanity must reduce anthropogenic impacts defined by nine planetary boundaries if "unacceptable global change" is to be avoided. Chemical pollution was identified as one of those boundaries for which continued impacts could erode the resilience of ecosystems and humanity. The central concept of the planetary boundary (or boundaries) for chemical pollution (PBCP or PBCPs) is that the Earth has a finite assimilative capacity for chemical pollution, which includes persistent, as well as readily degradable chemicals released at local to regional scales, which in aggregate threaten ecosystem and human viability. The PBCP allows humanity to explicitly address the increasingly global aspects of chemical pollution throughout a chemical's life cycle and the need for a global response of internationally coordinated control measures. We submit that sufficient evidence shows stresses on ecosystem and human health at local to global scales, suggesting that conditions are transgressing the safe operating space delimited by a PBCP. As such, current local to global pollution control measures are insufficient. However, while the PBCP is an important conceptual step forward, at this point single or multiple PBCPs are challenging to operationalize due to the extremely large number of commercial chemicals or mixtures of chemicals that cause myriad adverse effects to innumerable species and ecosystems, and the complex linkages between emissions, environmental concentrations, exposures and adverse effects. As well, the normative nature of a PBCP presents challenges of negotiating pollution limits amongst societal groups with differing viewpoints. Thus, a combination of approaches is recommended as follows: develop indicators of chemical pollution, for both control and response variables, that will aid in quantifying a PBCP(s) and gauging progress towards reducing chemical pollution; develop new technologies and technical and social approaches to mitigate global chemical pollution that emphasize a preventative approach; coordinate pollution control and sustainability efforts; and facilitate implementation of multiple (and potentially decentralized) control efforts involving scientists, civil society, government, non-governmental organizations and international bodies.
Exposure factors for marine eutrophication impacts assessment based on a mechanistic biological model

Emissions of nitrogen (N) from anthropogenic sources enrich marine waters and promote planktonic growth. This newly synthesised organic carbon is eventually exported to benthic waters where aerobic respiration by heterotrophic bacteria results in the consumption of dissolved oxygen (DO). This pathway is typical of marine eutrophication. A model is proposed to mechanistically estimate the response of coastal marine ecosystems to N inputs. It addresses the biological processes of nutrient-limited primary production (PP), metazoan consumption, and bacterial degradation, in four distinct sinking routes from primary (cell aggregates) and secondary producers (faecal pellets, carcasses, and active vertical transport). Carbon export production (PE) and ecosystems eXposure Factors (XF), which represents a nitrogen-to-oxygen ‘conversion’ potential, were estimated at a spatial resolution of 66 large marine ecosystem (LME), five climate zones, and site-generic. The XF obtained range from 0.45 (Central Arctic Ocean) to 15.9kgO2kgN⁻¹ (Baltic Sea). While LME resolution is recommended, aggregated PE or XF per climate zone can be adopted, but not global aggregation due to high variability. The XF is essential to estimate a marine eutrophication impacts indicator in Life Cycle Impact Assessment (LCIA) of anthropogenic-N emissions. Every relevant process was modelled and the uncertainty of the driving parameters considered low suggesting valid applicability in characterisation modelling in LCIA.

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From nitrogen enrichment to oxygen depletion: a mechanistic model of coastal marine ecosystems response

Nitrogen (N) emissions from anthropogenic sources may enrich coastal waters and lead to marine eutrophication impacts. Processes describing N-limited primary production (PP), zooplankton grazing, and bacterial respiration of sinking organic carbon, were modelled to quantify the potential dissolved oxygen (DO) consumption as a function of N input. Such indicator is the basis for an exposure factor (XF) applied in Life Cycle Impact Assessment (LCIA) to estimate impacts from N enrichment. The Large Marine Ecosystems (LME) biogeographical classification system was adopted to address the spatial variation of the modelled parameters and to characterise spatially differentiated N-emissions. Preliminary XF results range from 0.5 kgO2·kgN-1 in the Central Arctic Ocean to 16 kgO2·kgN-1 in the Baltic Sea, out of a total of 66 LME-dependent XFs. All the relevant processes were included in a mechanistic model and the uncertainty of the driving parameters is considered low. The presented XF estimation method contributes with a central component for site-dependent characterization factors (CFs) for marine eutrophication, to be coupled with environmental fate of N emissions and effects of oxygen depletion on biota.

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Abstract

From species sensitivity to hypoxia to effect factors modelling in life cycle impact assessment (LCIA)

Nutrient enrichment of coastal waters fuels planktonic growth. The subsequent sinking of this organic matter and its aerobic respiration by heterotrophic bacteria in bottom waters results in the consumption of dissolved oxygen (DO) there. If excessive amounts of organic carbon reach the benthic layer DO depletion may drop it down to hypoxic or anoxic levels. Acute and chronic effects on biota may then be expected. The sensitivity of relevant demersal (benthic and benthopelagic) species (n=91) to DO levels, as lowest-observed-effect-levels (LOEL), was used to estimate the community’s sensitivity in five climate zone (polar, subpolar, temperate, subtropical, tropical). Species Sensitivity Distribution (SSD) curves combining DO concentrations and Potentially Affected Fractions (PAF) of species were plotted to estimate hazard concentrations (HC50LOEL) per climate zone, and Effect Factors (EF, [(PAF)·m3·kgO2-1]). Preliminary EF results range from 220 (PAF)·m3·kgO2-1 (polar zone) to 310 (PAF)·m3·kgO2-1 (tropical zone). A site-generic value of 260 (PAF)·m3·kgO2-1 is useful when no relevant spatial differentiation is to consider. The proposed method for effects modelling contributes with an essential component in the characterisation of eutrophying emissions in Life Cycle Impact Assessment (LCIA) and is applicable in a global assessment framework of marine eutrophication impacts.

General information
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How to implement the circular economy in the beer packaging sector through eco-efficiency- and eco-effectiveness- based solutions

According to Verghese et al. (2012) sustainable packaging should be: effective in delivering its functional requirements, efficient in its use of materials, energy, and water throughout its life cycle, cyclic in its use of renewable materials and recoverability at end-of-life, and safe for people and the natural environment. Companies in the packaging sector have traditionally been using the Life Cycle Assessment (LCA) methodology to fulfill these requirements. However, being inspired by the eco-efficiency principle, LCA aims to reduce the negative environmental footprint of human activities by optimizing product system individually, without considering multiple future uses of resources in continuous loops (Bjørn and Hauschild, 2013). A broader approach oriented towards product quality and innovation is the Cradle to Cradle® (C2C) design framework. C2C aims to increase the positive footprint of products by designing “eco-effective” solutions, i.e. maximizing the benefit to ecological systems. C2C is based on three key principles “waste equal food”, “use solar energy income” and “celebrate diversity” (McDonough and Braungart, 2002). The first principle calls for eliminating the concept of waste and challenges production systems to use materials in continuous loops through the “up-cycling” approach, which consists in improving the quality of materials or systems for recycling materials. From a company point of view, LCA and C2C are complementary approaches to implement the circular economy and develop sustainable and innovative solutions for packaging. We will illustrate the challenges and opportunities emerging from the case study of Carlsberg Circular Community, a cooperation platform where Carlsberg and some global partners are joining forces to reduce the reliance on raw materials, and support the circular economy by improving quality and purity of packaging. We will consider the case of aluminium cans and discuss how both approaches can be combined within the circular economy framework. From an LCA perspective, the Life Cycle Inventory of aluminium products is currently based on a pure aluminium flow, neglecting the presence of alloying elements. However an aluminium can is composed of two main components, the body and the lid, which are made of two different wrought alloys. This aspect needs to be taken into account while addressing the use of aluminium in continuous loops, even in a closed product loop recycling. Therefore, we will discuss how upcycling can be defined for aluminium cans, including both eco-efficiency- and eco-effectiveness- inspired considerations, i.e. both from a C2C and LCA point of view.
How to manage uncertainty in future Life Cycle Assessment (LCA) scenarios addressing the effect of climate change in crop production

When Life Cycle Assessment (LCA) is used to provide insights on how to pursue future food demand, it faces the challenge to describe scenarios of the future in which the environmental impacts occur. In the case of future crop production, the effects of climate change should be considered. In this context, the objectives of this paper are two-fold: (i) to recommend an approach to deal with uncertainty in scenario analysis for LCA of crop production in a changed climate, when the goal of the study is to suggest strategies for adaptation of crop cultivation practices towards low environmental impacts, and (ii) to implement the suggested approach to spring barley cultivation in Denmark. First, the main implications of climate change for future crop cultivation are analyzed, and the factors which should be included when modeling the climate change effects on crops through LCA are introduced, namely climate, soil, water loss and production parameters. Secondly, the handling of these factors in the inventory modeling is discussed and finally implemented in the case study. Our approach follows a 3-step procedure consisting of: (1) definition of a baseline scenario at the Life Cycle Inventory (LCI) level for the selected crop and performance of Life Cycle Impact Assessment (LCIA) including normalization and contribution analysis, in order to identify the focus points in terms of impact categories, unit processes and substances; (2) identification of the main deviations from the baseline scenario for these key parameters in alternative future scenarios; (3) comparison of the different scenarios including quantification of the uncertainty at inventory level. The procedure presented was successfully implemented to assess the consequences of the changed climate on Danish spring barley cultivated under future climate conditions. The LCA results, obtained using mainly primary data from phytotron experiments mimicking a future Danish climate, emphasized that adaptation strategies should prioritize the development of resilient and stable cultivars, i.e. robust to the expected extremes of the future climate and offering a reasonable yield under different climatic conditions.
Introducing carrying capacity-based normalisation in LCA: framework and development of references at midpoint level

There is currently a weak or no link between the indicator scores quantified in life cycle assessment (LCA) and the carrying capacity of the affected ecosystems. Such a link must be established if LCA is to support assessments of environmental sustainability and it may be done by developing carrying capacity-based normalisation references. The purpose of this article is to present a framework for normalisation against carrying capacity-based references and to develop average normalisation references (NR) for Europe and the world for all those midpoint impact categories...
Carrying capacity was in this context defined as the maximum sustained environmental intervention a natural system can withstand without experiencing negative changes in structure or functioning that are difficult or impossible to revert. A literature review was carried out to identify scientifically sound thresholds for each impact category. Carrying capacities were then calculated from these thresholds and expressed in metrics identical to midpoint indicators giving priority to those recommended by ILCD. NR was expressed as the carrying capacity of a reference region divided by its population and thus describes the annual personal share of the carrying capacity. The developed references can be applied to indicator results obtained using commonly applied characterisation models in LCIA. The European NR are generally lower than the global NR, mainly due to a relatively high population density in Europe. The NR were compared to conventional normalisation references (NR′) which represent the aggregated interventions for Europe or the world in a recent reference year. For both scales, the aggregated intervention for climate change, photochemical ozone formation and soil quality were found to exceed carrying capacities several times. The developed carrying capacity-based normalisation references offer relevant supplementary reference information to the currently applied references based on society’s background interventions by supporting an evaluation of the environmental sustainability of product systems on an absolute scale. Challenges remain with respect to spatial variations to increase the relevance of the normalisation references for impact categories that function at the local or regional scale. The sensitivity of NR to different choices, e.g. threshold value, should be quantified with the aim of understanding and managing uncertainties of NR. For complete coverage of the midpoint impact categories, normalisation references based on sustainability preconditions should be developed for those categories that link to the areas of protection human health and natural resources.

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Introducing Life Cycle Impact Assessment

This chapter serves as an introduction to the presentation of the many aspects of life cycle impact assessment (LCIA) in this volume of the book series 'LCA Compendium'. It starts with a brief historical overview of the development of life cycle impact assessment driven by numerous national LCIA methodology projects and presents the international scientific discussions and methodological consensus attempts in consecutive working groups under the auspices of the Society of Environmental Toxicology and Chemistry (SETAC) as well as the UNEP/SETAC Life Cycle Initiative, and the (almost) parallel standardisation activities under the International Organisation for Standardisation (ISO). A brief introduction is given on the purpose and structure of LCIA. As a common background for the 11 chapters dealing with the characterisation modelling of the most common impact categories, the chapter concludes with an introduction of the general principles and features of characterisation.
Introducing life cycle thinking in product development – A case from Siemens Wind Power

How can use of LCA improve the environmental sustainability of wind industry products? An analysis of a case study from Siemens Wind Power identifies the knowledge offered by LCA that is relevant to each step of the product development process (PDP). The study illustrates the difference that this knowledge can make to the decision making in the PDP and to the environmental sustainability of the product. Based on these findings, the study concludes with a discussion of barriers for LCA integration in the PDP of complex products and possible measures to overcome them.
LCA as a decision support tool in policy making: the case study of Danish spring barley production in a changed climate

Life Cycle Assessment (LCA) can support policy makers in the choice of the most effective measures to adapt to climate change in crop production. A case study involving spring barley cultivation in Denmark under changed climate conditions has been performed using primary data from future climate scenarios. We developed and applied a 3-step procedure based on combined contribution, scenario and uncertainty analyses. This approach can be useful to deal with uncertainty in scenario analysis for LCA of crop production in a changed climate, when the goal of the study is to suggest strategies for adaptation of crop cultivation practices towards low environmental impacts.

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Necessidade de uma metodologia de Avaliação de Impacto do Ciclo de Vida espacialmente diferenciada para o Brasil

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Opportunities and challenges for including Planetary Boundaries in Life-Cycle Assessment

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Power generation from chemically cleaned coals: do environmental benefits of firing cleaner coal outweigh environmental burden of cleaning?

Power generation from high-ash coals is a niche technology for power generation, but coal cleaning is deemed necessary to avoid problems associated with low combustion efficiencies and to minimize environmental burdens associated with emissions of pollutants originating from ash. Here, chemical beneficiation of coals using acid and alkali–acid leaching procedures is evaluated as a potential coal cleaning technology employing life cycle assessment (LCA). Taking into account the environmental benefits from firing cleaner coal in pulverized coal power plants and the environmental burden of the cleaning itself, it is demonstrated that for a wide range of cleaning procedures and types of coal, chemical cleaning generally performs worse than combustion of the raw coals and physical cleaning using dense medium separation. These findings apply for many relevant impact categories, including climate change. Chemical cleaning can be optimized with regard to electricity, heat and methanol use for the hydrothermal washing step, and could have environmental impact comparable to that of physical cleaning if the overall resource intensiveness of chemical cleaning is reduced by a factor 5 to 10, depending on the impact category. The largest potential of the technology is observed for high-ash lignites, with initial ash content above 30%, for which the environmental benefits from firing cleaner coal can outweigh the environmental burden of cleaning for some impact categories. Overall, we recommend to policy makers that coal cleaning using acid or alkali–acid leaching procedures should not be considered for direct implementation as a coal beneficiation technology. We encourage further research on chemical cleaning and its optimization, however, as chemical cleaning has advantages that might make it attractive for cleaning of difficult to treat coals when compared to the less efficient option of physical cleaning.
Preparing the ground for an operational handling of long-term emissions in LCA

Currently, there is no meaningful methodology for the estimation of environmental impacts from long-term heavy metal emissions in a life cycle assessment (LCA) context, when an assessment of landfill and mining technologies is performed. In this paper, the aims are to investigate the main issues hindering the standardisation of a methodology to account for potential impacts from long-term metal emissions, and to describe the characteristics of a robust framework for an
operational impact assessment methodology. In order to demonstrate the issues around potential impacts from long-term emissions in LCA and derive a scientific basis for developing an adequate LCA methodology to address these impacts, a two-part review on long-term metal emissions is performed that (a) identifies a suitable time-dependent life cycle inventory (LCI) while underlining the problems in existing emission prediction attempts and (b) describes the existing LCA approaches for accounting of toxic potential impacts from these emissions while explaining the reason that the identified proposals have not been adopted from the LCA community. These approaches are then compared upon the basis of a common LCI and their differences are highlighted. A suitable dynamic LCI is identified for landfill emissions, which calculates Ni, Zn, Cd and Pb emissions as a function of time, based on assumed developments of the leachate pH. The results of the application of the different impact assessment methods on that LCI differ by up to 8 orders of magnitude. Therefore, the decision-making process supported by an LCA becomes very confusing. None of the approaches consider future changes in the receiving environment and are accompanied with any uncertainty considerations. In order to move towards a robust environmental assessment of long-term emissions, it is necessary to (i) represent future potential impacts more accurately by estimating time-dependent characterisation factors (CFs) corresponding to changing environmental conditions, (ii) develop more robust estimations by addressing uncertainty and (iii) refer to actual potential impacts, by taking into account the current and future background concentrations.

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Quantifying spatially derived carrying capacity occupation: Framework for characterisation modelling and application to terrestrial acidification

The popularity of the ecological footprint method and the planetary boundaries concept shows an increasing interest among decision makers in comparing environmental impacts to carrying capacities of natural systems. Recently carrying capacity-based normalisation references were developed for impact categories at midpoint level in LCA. These references are operational and their meaning can easily be communicated to practitioners and decision makers. Yet they do not capture potentially important spatial variations in carrying capacities. To overcome this weakness we propose to integrate carrying capacity in characterisation factors (CFs) as an alternative to using carrying capacity as reference information in normalisation references. We developed a generic mathematical expression for a spatially differentiated CF, which allows expressing impact scores as occupation of carrying capacity in units of km²·year. This metric resembles that of the ecological footprint method and may be compared to the availability of land or water. The framework was applied to the terrestrial acidification impact category. The geochemical steady-state model PROFILE was used to quantify carrying capacities as deposition levels corresponding to an acceptable change of natural pH, at a 2.0x2.5° resolution at the global scale. Carrying capacities were then combined with atmospheric fate factors of acidifying emissions to derive CFs. These were applied to an average emission inventory for the annual electricity consumption of a household in 100 random global locations. To evaluate the consequence of using the CFs in a comparative assessment the 100 impact scores were ranked and compared to the corresponding ranking when using existing CFs based on marginal impacts above carrying
capacity on the same inventory. The difference in ranking reflects the different natures of the two sets of CFs: The existing CFs are aligned with consequential thinking and concerned with marginal changes above carrying capacity, while our derived CFs are aligned with attributional thinking and concerned with the occupation of carrying capacity. This work shows the viability of spatially derived absolute sustainability assessment, i.e. assessments where impacts are compared to sustainable levels of impacts. This can become an important supplement to the predominant relative environmental assessments, where impacts of different product systems are compared. SETAC
Sustainability in highly automated production systems: Methodology and algorithm for assessing production lines in the planning phase

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Rödger, J., Dijkman, T. J., Hauschild, M. Z., Bey, N.
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Testing the assertion that urban agriculture is sustainable

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Massachusetts Institute of Technology
Contributors: Goldstein, B., Birkved, M., Fernandez, J., Hauschild, M. Z.
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The need for an established allocation method when assessing absolute sustainability on a product level

Assessment of absolute sustainability within life cycle assessment (LCA) framework is operational on the country scale. However, it is difficult to apply the existing approaches to products, which are typically the scope of LCAs. How should we assess whether a chair is (absolutely) sustainable? If we assess the life cycle and relate the impact scores to the remaining capacity available for impacts, there is a risk that all products are seen absolutely sustainable. In addition, how should we decide on who can use the remaining capacity? To address these issues an allocation method is proposed for dividing the remaining capacity between and within product groups. The method is a two-step method developed based on the annual consumption pattern of an average person in the country and share of product sub-groups in the group. For example, in the first allocation step, the remaining capacity share allocated to furniture should correspond to the share of an average person’s income that is spent on furniture. In this way the impact of the chair is related to the remaining capacity allocated to this particular product group. In the second step, allocation is done between product sub-groups using allocation keys specific to each product group, e.g. mass for furniture, or economic revenue for IT. The proposed method facilitates assessment of absolute sustainability of products within the LCA framework.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
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The potential contribution to climate change mitigation from temporary carbon storage in biomaterials

While lasting mitigation solutions are needed to avoid climate change in the long term, temporary solutions may play a positive role in terms of avoiding certain climatic target levels, for preventing the crossing of critical and perhaps irreversible climatic tipping points. While the potential value of temporary carbon storage in terms of climate change mitigation has been widely discussed, this has not yet been directly coupled to avoiding climatic target levels representing predicted climatic tipping points. This paper provides recommendations on how to model temporary carbon storage in products in life cycle assessment (LCA), in order to include the potential mitigation value relative to crossing critical climatic target levels. Further, estimates are made on potential magnitude of this value, highlighting the importance of including this aspect in climate change impact assessment of biomaterials. The recently developed approach for quantifying the climate tipping potential (CTP) of emissions is used, with some adaption, to account for the value of temporary carbon storage. CTP values for short-, medium- and long-term carbon storage in chosen biomaterials are calculated for two possible future atmospheric greenhouse gas (GHG) concentration development scenarios. The potential magnitude of the temporary carbon storage in biomaterials is estimated by considering the global polymer production being biobased in the future. Both sets of CTP values show the same trend; storage which releases the carbon again before the climatic target level is reached increases the CTP value of the product compared to a situation with no storage of the product, whereas storage extending beyond the time where the climatic target level is predicted to be crossed according to the GHG concentration scenarios contributes with negative CTP values, which means mitigation. The longer the duration of the storage, the larger the mitigation potential. Temporary carbon storage in biomaterials has a potential for contributing to avoid or postpone the crossing of a climatic target level of 450 ppm CO2e, depending on GHG concentration development scenario. The potential mitigation value depends on the timing of sequestration and re-emission of CO2. The suggested CTP approach enables inclusion of the potential benefit from temporary carbon storage in the environmental profile of biomaterials. This should be seen as supplement to the long-term climate change impacts given by the global warming potential which does not account for temporary aspects like benefits from non-permanent storage in terms of avoiding a critical climatic target level.
The USEtox story: A survey of model developer visions and user requirements

Purpose USEtox is a scientific consensus model for assessing human toxicological and ecotoxicological impacts that is widely used in life cycle assessment (LCA) and other comparative assessments. However, how user requirements are met has never been investigated. To guide future model developments, we analyzed user expectations and experiences and compared them with the developers’ visions.

Methods We applied qualitative and quantitative data collection methods including an online questionnaire, semistructured user and developer interviews, and review of scientific literature. Questionnaire and interview results were analyzed in an actor-network perspective in order to understand user needs and to compare these with the developers’ visions. Requirement engineering methods, more specifically function tree, system context, and activity diagrams, were iteratively applied and structured to develop specific user requirements-driven recommendations for setting priorities in future USEtox development and for discussing general implications for developing scientific models.

Results and discussion The vision behind USEtox was to harmonize available data and models for assessing toxicological impacts in LCA and to provide global guidance for practitioners. Model developers show different perceptions of some underlying aspects including model transparency and expected user expertise. Users from various sectors and geographic regions apply USEtox mostly in research and for consulting. Questionnaire and interview results uncover various user requests regarding USEtox usability. Results were systematically analyzed to translate user requests into recommendations to improve USEtox from a user perspective and were afterwards applied in the further USEtox development process.

Conclusions We demonstrate that understanding interactions between USEtox and its users helps guiding model development and dissemination. USEtox-specific recommendations are to (1) respect the application context for different user types, (2) provide detailed guidance for interpreting model and factors, (3) facilitate consistent integration into LCA software and methods, (4) improve update/testing procedures, (5) strengthen communication between developers and users, and (6) extend model scope. By generalizing our recommendations to guide scientific model development in a broader context, we emphasize to acknowledge different levels of user expertise to integrate sound revision and update procedures and to facilitate modularity, data import/export, and incorporation into relevant software and databases during model design and development. Our fully documented approach can inspire performing similar surveys on other LCA-related tools to consistently analyze user requirements and provide improvement recommendations based on scientific user analysis methods.
Viewpoint: Making Sense of the Minefield of Footprint Indicators

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Commonwealth Scientific and Industrial Research Organisation, Swiss Federal Institute of Technology Zurich, University of Texas, Norwegian University of Science and Technology, United Nations Environmental Programme, Western Sydney University, Oxford Brookes University, European Commission - Joint Research Center, University of New South Wales, United States Environmental Protection Agency, Polytechnique Montreal, treeze Ltd., University of Michigan, Ann Arbor, University of California at Berkeley

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20 years of LCA applied to waste management systems: what can we learn?

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Contributors: Laurent, A., Clavreul, J., Bernstad, A., Bakas, I., Niero, M., Gentil, E., Christensen, T., Hauschild, M. Z.
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Assessment of urgent impacts of greenhouse gas emissions—the climate tipping potential (CTP)
The impact of anthropogenic greenhouse gas (GHG) emissions on climate change receives much focus today. This impact is however often considered only in terms of global warming potential (GWP), which does not take into account the need for staying below climatic target levels, in order to avoid passing critical climate tipping points. Some suggestions to include a target level in climate change impact assessment have been made, but with the consequence of disregarding
impacts beyond that target level. The aim of this paper is to introduce the climate tipping impact category, which represents the climate tipping potential (CTP) of GHG emissions relative to a climatic target level. The climate tipping impact category should be seen as complementary to the global warming impact category. The CTP of a GHG emission is expressed as the emission’s impact divided by the ‘capacity’ of the atmosphere for absorbing the impact without exceeding the target level. The GHG emission impact is determined as its cumulative contribution to increase the total atmospheric GHG concentration (expressed in CO2 equivalents) from the emission time to the point in time where the target level is expected to be reached, the target time. The CTP of all the assessed GHGs increases as the emission time approaches the target time, reflecting the rapid decrease in remaining atmospheric capacity and thus the increasing potential impact of the GHG emission. The CTP of a GHG depends on the properties of the GHG as well as on the chosen climatic target level and background scenario for atmospheric GHG concentration development. In order to enable direct application in life cycle assessment (LCA), CTP characterisation factors are presented for the three main anthropogenic GHGs, CO2, CH4 and N2O. The CTP metric distinguishes different GHG emission impacts in terms of their contribution to exceeding a short-term target and highlights their increasing importance when approaching a climatic target level, reflecting the increasing urgency of avoiding further GHG emissions in order to stay below the target level. Inclusion of the climate tipping impact category for assessing climate change impacts in LCA, complimentary to the global warming impact category which shall still represent the long-term climate change impacts, is considered to improve the value of LCA as a tool for decision support for climate change mitigation.
Beyond Safe Operating Space: Finding Chemical Footprinting Feasible

Environmental overshoot occurs when human demands exceed the biosphere’s regenerative capacities. Earth Overshoot Day (EOD) marks the day that humanity’s footprint exhausts the Earth’s annual regenerative capacity. The EOD of 2013, on August 20th, was memorable for the first author as it fell on his mother’s 89th birthday. Each EOD, falling earlier every year, confronts us with urgent environmental problems, some of which are poorly defined. One such example is chemical pollution, which threatens the Earth’s capacities. Rockström et al. listed chemical pollution as an important but yet undefined boundary in their selection of planetary boundaries delineating the “safe operating space for humanity”. Can we use the well-known concept of “ecological footprints” to express a chemical pollution boundary aimed at preventing the overshoot of the Earth’s capacity to assimilate environmental pollution? Current literature is replete with ideas on this, and shows the benefits of trans-disciplinary collaborations. Borrowing our subtitle from Don Mackay’s seminal paper that introduced fugacity-based modeling for quantifying the environmental distribution of chemicals, we now see the development of chemical footprinting that is feasible, relevant, and necessary for expressing the overshoot of the Earth’s capacity. With widespread “chemical overshoot” leading to adverse effects of pollution, we argue for implementing a solution-focused assessment paradigm: Chemical footprinting helps identify scenarios that allow us to avoid “chemical overshoot” beyond the Earth’s safe operating space.
Can carbon footprint be an acceptable indicator of environmental sustainability?

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Chemical footprint assessment: presentation of method and application to a case study involving different spatial scales

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Chemical Footprint Method for Improved Communication of Freshwater Ecotoxicity Impacts in the Context of Ecological Limits

The ecological footprint method has been successful in communicating environmental impacts of anthropogenic activities in the context of ecological limits. We introduce a chemical footprint method that expresses ecotoxicity impacts from anthropogenic chemical emissions as the dilution needed to avoid freshwater ecosystem damage. The indicator is based on USEtox characterization factors with a modified toxicity reference point. Chemical footprint results can be compared to the actual dilution capacity within the geographic vicinity receiving the emissions to estimate whether its ecological limit has been exceeded and hence whether emissions can be expected to be environmentally sustainable. The footprint method was illustrated using two case studies. The first was all inventoried emissions from European countries and selected metropolitan areas in 2004, which indicated that the dilution capacity was likely exceeded for most European countries and all landlocked metropolitan areas. The second case study indicated that peak application of pesticides alone was likely to exceed Denmark's freshwater dilution capacity in 1999-2011. The uncertainty assessment showed that better spatially differentiated fate factors would be useful and pointed out other major sources of uncertainty and some opportunities to reduce these.

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Chemical Footprints: Thin Boundaries Support Environmental Quality Management

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, National Institute of Public Health and the Environment, Radboud University Nijmegen, University of Toronto
Confronting Uncertainty in Life Cycle Assessment Used for Decision Support: Developing and Proposing a Taxonomy for LCA Studies

The aim of this article is to help confront uncertainty in life cycle assessments (LCAs) used for decision support. LCAs offer a quantitative approach to assess environmental effects of products, technologies, and services and are conducted by an LCA practitioner or analyst (AN) to support the decision maker (DM) in making the best possible choice for the environment. At present, some DMs do not trust the LCA to be a reliable decision support tool—often because DMs consider the uncertainty of an LCA to be too large. The standard evaluation of uncertainty in LCAs is an ex-post approach that can be described as a variance simulation based on individual data points used in an LCA.

This article develops and proposes a taxonomy for LCAs based on extensive research in the LCA, management, and economic literature. This taxonomy can be used ex ante to support planning and communication between an AN and DM regarding which type of LCA study to employ for the decision context at hand. This taxonomy enables the derivation of an LCA classification matrix to clearly identify and communicate the type of a given LCA. By relating the LCA classification matrix to statistical principles, we can also rank the different types of LCA on an expected inherent uncertainty scale that can be used to confront and address potential uncertainty. However, this article does not attempt to offer a quantitative approach for assessing uncertainty in LCAs used for decision support.

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Coupling habitat exposure to nitrogen and species sensitivity to hypoxia – LCIA methodology applied to marine eutrophication

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Development of characterization factors for metals in coastal seawater

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Development of Comparative Toxicity Potentials of 14 cationic metals in freshwater

Site-dependent and site-generic Comparative Toxicity Potentials (CTPs) (also known as Characterization Factors (CFs)) were calculated for 14 cationic metals (Al(III), Ba, Be, Cd, Co, Cr(III), Cs, Cu(II), Fe(II), Fe(III), Mn(II), Ni, Pb, Sr and Zn), to be applied in Life Cycle Impact Assessment. CTPs were calculated for 7 EU-archetypes, taking bioavailability and speciation pattern into account. The resulting site-dependent CTPs showed up to 2.4–6.5 orders of magnitude variation across archetypes for those metals that form stable hydroxyl compounds in slightly alkaline waters (Al(III), Be, Cr(III), Cu(II) and Fe(III)), emphasizing the importance of using site-dependent CTPs for these metals where possible. For the other metals, CTPs stayed within around 0.9 orders of magnitude, making spatial differentiation less important. In acidic waters (pH < 6.4), Al(III) and Cu(II) had the highest CTPs, while Cd ranked highest in other waters. Based on the site-dependent CTPs, site-generic CTPs were developed applying different averaging principle. Emission weighted average of 7 EU-archetype CTPs was recommended as site-generic CTP for use in LCA studies, where receiving location is unclear. Compared to previous studies by Gandhi et al. (2010, 2011a), new site-dependent CTPs were similar or slightly higher for Cd, Co, Ni, Pb and Zn, but 1–2 orders of magnitude higher for Cu. Compared to the default site-generic CTPs in the frequently used characterization models USES-LCA and USEtox, new site-generic CTPs were mostly higher or similar, within up to ~2 orders of magnitude difference.

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Elucidating differences in metal absorption efficiencies between terrestrial soft-bodied and aquatic species

It is unknown whether metal absorption efficiencies in terrestrial soft-bodied species can be predicted with the same metal properties as for aquatic species. Here, we developed models for metal absorption efficiency from the dissolved phase for terrestrial worms and several aquatic species, based on 23 metal physicochemical properties. For the worms, the absorption efficiency was successfully related to 7 properties, and is best predicted with the ionic potential. Different properties (8 in total) were found to be statistically significant in regressions predicting metal absorption in aquatic species, with the covalent index being the best predictor. It is hypothesized that metal absorption by soft-bodied species in soil systems is influenced by the rate of metal supply to the membrane, while in aquatic systems accumulation is solely determined by metal affinity to membrane bound transport proteins. Our results imply that developing predictive terrestrial bioaccumulation and toxicity models for metals must consider metal interactions with soil solids. This may include desorption of a cation bound to soil solids through ion exchange, or metal release from soil surfaces involving breaking of metal–oxygen bonds. © 2014 Published by Elsevier Ltd.

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Enabling optimization in LCA: from "ad hoc" to "structural" LCA approach—based on a biodiesel well-to-wheel case study

Purpose Applied life cycle assessment (LCA) studies often lead to a comparison of rather few alternatives; we call this the "ad hoc LCA approach." This can seem surprising since applied LCAs normally cover countless options for variations and derived potentials for improvements in a product life cycle. In this paper, we will suggest an alternative approach to the ad hoc approach, which more systematically addresses the many possible variations to identify the most promising. We call it the "structural LCA approach." The goals of this paper are (1) to provide basic guidelines for the structural approach, including an easy expansion of the LCA space; (2) to show that the structural LCA approach can be used for different types of optimization in LCA; and (3) to improve the transparency of the LCA work.

Methods The structural approach is based on the methodology "design of experiments" (Montgomery 2005). Through a biodiesel well-to-wheel study, we demonstrate a generic approach of applying explanatory variables and corresponding impact categories within the LCA methodology. Explanatory variables are product system variables that can influence the environmental impacts from the system. Furthermore, using the structural approach enables two different possibilities for optimization: (1) single-objective optimization (SO) based on response surface methodology (Montgomery 2005) and (2) multiobjective optimization (MO) by the hypervolume estimation taboo search (HETS) method. HETS enables MO for more than two or three objectives.

Results and discussion Using SO, the explanatory variable “use of residual straw from fields” is, by far, the explanatory variable that can contribute with the highest decrease of climate change potential. For the respiratory inorganics impact category, the most influencing explanatory variable is found to be the use of different alcohol types (bioethanol or petrochemical methanol) in biodiesel production. Using MO, we found the Pareto front based on 5 different life cycle pathways which are nondominated solutions out of 66 different analyzed solutions. Given that there is a fixed amount of resources available for the LCA practitioner, it becomes a prioritizing problem whether to apply the structural LCA approach or not. If the decision maker only has power to change a single explanatory variable, it might not be beneficial to apply the structural LCA approach. However, if the decision maker (such as decision makers at the societal level) has power to change more explanatory variables, then the structural LCA approach seems beneficial for quantifying and comparing the potentials for environmental improvement between the different explanatory variables in an LCA system and identifying the overall most promising product system configurations among the chosen PWs.

Conclusions The implementation of the structural LCA approach and the derived use of SO and MO have been successfully achieved and demonstrated in the present paper. In addition, it is demonstrated that the structural LCA approach can lead to more transparent LCAs since the potentially most important explanatory variables which are used to model the LCAs are explicitly presented through the structural LCA approach. The suggested structural approach is a new approach to LCA and it seems to be a promising approach for searching or screening product systems for environmental optimization potentials. In the presented case, the design has been a rather simple full factorial design. More complicated problems or designs, such as fractional designs, nested designs, split plot designs, and/or unbalanced data, in the context of LCA could be investigated further using the structural approach.
**Environmental assessment of biomass based materials: With special focus on the climate effect of temporary carbon storage**

**Goal and scope**

The goal of this PhD project is to contribute to a more consistent methodology for life cycle assessment (LCA) of biomaterials and to address the environmental performance and perspectives of biomaterials. In particular, it is the goal to develop an approach for dealing with temporary carbon storage in biomaterials, in a way that quantifies the potential climate change benefit in relation to avoiding crossing near-term climatic targets.

The geographical scope in this PhD project is global, as the focus is on methodology development and assessment of biomaterials at a global level. The temporal scope is defined by the impact category considered. The technological scope includes both current environmental performance of biomaterials and a discussion of future perspectives, including potentials for future change in their environmental impacts compared to fossil based materials.

**Background**

The society today is highly dependent on fossil oil and gas for producing fuels, chemicals and materials, however many of those can alternatively be produced from biomass. The potential of biomaterials to substitute fossil based materials receives increased attention, and their global production is increasing. As the demand for biomaterials increases, so does the need for knowledge about their environmental performance – both in absolute terms and relative to the petrochemical counterparts that they may replace. LCA is a commonly used tool for assessing environmental sustainability of products and systems, accounting for the environmental impacts during their entire lifecycle. However, there are still important gaps in the methodology for LCAs of biomaterials.

One such gap is the handling of the potential climate change mitigation value of the temporary storage of carbon that takes place in biomaterials, on which there is currently no consensus. Other important environmental aspects related to biomaterials that are currently not generally included in LCAs are land use and land use change (LULUC) related impacts, such as changes in biogenic carbon stocks (especially including soil organic carbon), surface albedo and biodiversity, as well as potential indirect land use changes (ILUC) of biomaterial production.

**Potential value of (temporary) carbon storage**

Due to the existence of climate tipping points, expected to induce dangerous and potentially irreversible changes in the climate system if crossed, temporary carbon storage may have a potential for contributing to mitigating climate change.

This potential is in terms of either avoiding the crossing of such expected tipping points (assuming the mitigation scenario RCP3PD, where the atmospheric CO2 concentration peaks within the coming decades) or substantially postpone the crossing (assuming the medium stabilization level scenario RCP6 with a continuous growth in the atmospheric CO2 concentration towards year 2100).

Besides the value of the temporary carbon storage in single products, resulting stock changes are expected if petrochemical materials are substituted with biomaterials. These stock changes are more long-term or even permanent, leading to a reduction of carbon fluxes from fossil resources, while potentially increasing fluxes from the atmosphere to the biosphere and via this to the anthroposphere. This leads to a decrease in atmospheric carbon stock and increase in biosphere carbon stock, as well as an increase of biogenic carbon storage in the anthroposphere. This is a trend that will be permanent as long as the biomaterial production is not decreased or phased out again.

**The CTP approach**

The general used metric in LCA for assessing climate change, the GWP, does not take into account the need for staying below climatic target levels, and it does not reflect the increased importance of short-lived GHGs in terms of near-term target levels.

An approach has been developed in this PhD project for inclusion of the urgency of avoiding crossing dangerous climatic tipping points in the assessment of GHG emissions – the Climatic Tipping Potential (CTP). This approach assesses impacts of GHG emissions up until the potential crossing of a predefined climatic target level. This impact is expressed as a fraction of the atmospheric ‘capacity’ for absorbing the impact without exceeding the target level. The CTP should be seen as complementary to GWP, which should still account for long-term climate change impacts.

The CTP method has been further developed to consider the aspect of temporary carbon storage, and illustrate the potential mitigation value of this in relation to avoid crossing dangerous climatic target levels. CTP characterization factors for several GHG development scenarios and a number of other important model parameters are given, making the approach operational for direct inclusion in LCA.

**Influence of selected non-standard impacts from land use and land use change (LULUC)**

Some of the impacts associated with LULUC for biomass production, which are often not addressed in LCAs have been addressed through a theoretic case study in this PhD project. These impacts are changes in surface albedo, biogenic carbon fluxes (including SOC) and biodiversity. All three impacts are here found to be potentially important for the environmental performance of the biobased production. Further, potential tradeoffs are found between these impacts. This supports the need for including the best possible assessment of these impacts in LCA, in order to get a realistic picture of the overall impacts from a biomass feedstock crop establishment, and thus downstream products. However, there is a challenge in terms of e.g. the preliminary state of methods, and the requirements to availability of local data.

**Available biomass potential**

When discussing the environmental preference of biomaterials relative to fossil-based materials, an important aspect is the sustainable availability of biomass for the production of the biomaterials. It is estimated that there will be enough biomass feedstock available for future biomaterial production without competing with food for the land, even if the entire global need for organic chemicals (including polymers) is based on biomass in the future. However, there is likely to be a
competition with bioenergy, including biofuels, for the biomass. Environmental performance of biomaterials
Biomaterials generally perform better than equivalent petrochemical materials in terms of fossil fuel savings and reductions in GHG emissions. However in other impact categories they often perform worse, e.g. in terms of eutrophication and acidification, while also entailing land use and related environmental impacts. If using second generation biomass, some of those aspects are likely to improve. It is important to understand that the group of biomaterials is very diverse, both in terms of life cycle pathways and end-products. This gives different environmental profiles within the group, and one should thus be careful with a 'one profile fits all' mindset when it comes to environmental assessment of biomaterials.

Future perspectives
As biomaterials are often based on new, and hence immature, technologies, large improvement potentials are expected for those technologies relative to the competing petrochemical technologies, which are rather mature. Further, potential future shifts in feedstock for both biomaterials and fossil based materials may change their relative environmental performance.
Global guidance on environmental life cycle impact assessment indicators: findings of the scoping phase

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How does the choice of ILCD recommended practice for characterization modelling change the assessment of environmental impacts in LCA of products?

The European Commission has launched a recommended set of characterization methods for application in life cycle impact assessment (LCIA). However, it is not known yet whether the choice of the recommended practice, referred to as the ILCD, over existing LCIA methodologies matters for interpretation of LCA results. Here, we compare the ILCD with two of the most frequently used LCIA methodologies, IMPACT 2002+ and ReCiPe 2008, focusing on characterization at midpoint, by applying them on a case study comparing four window design options. First, to see whether the choice of ILCD matters for identification of product with the lowest environmental burden, ranking of the four window options was done for each impact category within each of the three methodologies. Next, impact scores calculated using each of the
three methodologies were converted into common metrics for each impact category to see whether the choice of ILCD matters for total impact scores. Results show that apart from toxic impacts on human health and ecosystems, all three methodologies consistently identify the same window option as having the lowest and the highest total environmental impact. This is mainly because production of heat dominates the total impacts and there is large difference in demand for heat between the compared options. Yet, there were significant differences in impact scores for some of the impact categories after conversion to common metrics: above 3 orders of magnitude for impacts from ionizing radiation on human health and impacts from land use on natural environment; between 1 and 3 orders of magnitude for metal depletion and for toxicity-related impact categories; and within 1 order of magnitude for the remaining impact categories. These differences are caused by the differences in underlying characterization models and/or substance coverage, depending on the impact category. In summary, we showed that different LCIA methods, including the ILCD, are likely to point to the same conclusion with respect to identifying the product with the lowest environmental burden, if one process is driving environmental impacts and there is large difference in demand for output from that process between the compared options. Nevertheless, the choice of ILCD matters the most for assessment of impacts from ionizing radiation, land use, resource depletion (minerals), and all toxicity-related impact categories, where differences between ILCD and alternative methodologies are large.

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IMPACT 2002+, ReCiPe 2008 and ILCD’s recommended practice for characterization modelling in life cycle impact assessment: a case study-based comparison

**Purpose** The European Commission has launched a recommended set of characterization models and factors for application in life cycle impact assessment (LCIA). However, it is not known how this recommended practice, referred to as the ILCD 2009, performs relative to some of the most frequently used alternative LCIA methodologies. Here, we compare the ILCD 2009 with IMPACT 2002+ and ReCiPe 2008, focusing on characterization at midpoint based on a case study comparing four window design options for use in a residential building.

**Methods** Ranking of the four window options was done for each impact category within each methodology. To allow comparison across the methodologies both in terms of total impact scores and contribution patterns for individual substances, impact scores were converted into common metrics for each impact category.

**Results and discussion** Apart from toxic impacts on human health and ecosystems, all studied methodologies consistently identify the same window option as having the lowest and the highest environmental impact. This is mainly because few processes, associated with production of heat, dominate the total impacts, and there is a large difference in demand for heat between the compared options. Despite this general agreement in ranking, differences in impact scores are above 3 orders of magnitude for human health impacts from ionizing radiation and ecosystem impacts from land use, and they lie between 1 and 3 orders of magnitude for metal depletion and for toxicity-related impact categories. The differences are somewhat smaller (within 1 order of magnitude) for the impact categories respiratory inorganics and photochemical ozone formation, and are within a factor of 3 for the remaining impact categories. The differences in impact scores in our case study are brought about by the differences in underlying characterization models and/or substance coverage, depending on the impact category.

**Conclusions** In spite of substantial differences in impact scores for the individual impact categories, we find that the studied LCIA methods point to the same conclusion with respect to identifying the alternative with the lowest environmental burden and ascribe this to the fact that few processes are driving the main environmental impacts, and there is large differences in demand for output from these processes between the compared options. Even though the overall conclusions remain the same for our case study, the choice of the ILCD’s recommended practice over the existing alternatives does matter for the impact categories ionizing radiation and land use and all toxicity-related impact categories.
Impacts of NMVOC emissions on human health in European countries for 2000-2010: Use of sector-specific substance profiles

Non-methane volatile organic compounds (NMVOC) are known to cause damages to human health via two main pathways, viz. the direct toxic effects exerted by certain substances (termed here human toxicity) and their indirect effects related to photochemical ozone formation (POF). To comprehensively assess the damages at national level and thus
define adequate air pollution abatement policies, substance breakdowns are needed. However, these are not readily available as total NMVOC emissions are only reported at sector level. In this study, we developed a reproducible methodology that combines available speciation profiles, i.e. distributions of substances emitted per type of sources, and sectoral NMVOC information to reach country-specific, substance-specific emission profiles. Annual emission inventories, including 270 single substances and 52 unrefined groups of substances, were determined for 31 European countries within the period 2000e2010. Using life cycle impact assessment methods for POF and human toxicity, impacts on human health were quantified. The results indicated that a strong linear correlation exists between POF impacts and the total NMVOC emissions, suggesting that air pollution abatement policies could use total NMVOC emissions as a proxy for reducing these impacts. Despite underlying uncertainties, the results also demonstrated that the POF impacts from NMVOC are negligible compared to their direct toxic impacts. The analysis of the results revealed that the toxic impacts (i) are caused by few substances, such as formaldehyde, acrolein and furan, (ii) primarily stem from transportation sectors and from residential sources, and (iii) are found not to correlate with total NMVOC emissions. Our findings therefore suggest the need for supporting air pollution abatement strategies with comprehensive impact assessments, which, in addition to complementing emission- and concentration-based indicators, should allow identifying country-specific improvement potentials at substance and sector levels.

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Integrating planetary boundaries into the life cycle assessment framework for assessing absolute environmental sustainability of products and systems

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Large Marine Ecosystems and coastal water archetypes implemented in LCIA methods for marine eutrophication and metals ecotoxicity

The marine eutrophication (MEu) and marine ecotoxicity (MEc) indicators in Life Cycle Impact Assessment (LCIA) respectively express the eutrophying impact of nitrogen (N) and the toxic impact of metals emissions to the marine environment. Characterisation Factors (CF) are calculated to translate the emissions into impact potentials. For consistency in the characterisation modelling across impact categories, the same modelling framework was applied including Fate Factors of N or metals (FF), habitat Exposure Factor (XF) in MEu or Bioavailability Factor of metals (BF) in MEc, and Factors for the Effect on biota (EF). In both impact categories there is a need for spatial differentiation according to the receiving ecosystems, and the parameterisation of the characterisation models requires the adoption of suitable spatial units out of the global receiving coastal marine ecosystem. The Large Marine Ecosystems (LME) biogeographical classification system identifies 64 spatial units of coastal marine waters and it was adopted for both MEu and MEc. The applicability of 13 alternative zonation systems was compared before choosing the LME classification. The hydraulic residence time (RT) of the receiving LMEs expressing the system’s flushing through local hydrodynamics is required for the parameterisation of the FF term to estimate the loss of N or metals from the LME through advection. The RT was found in literature for 36% of the LMEs, whereas 4 archetypes were built for the remaining, for which no data was found (47%) or to settle high variability of found sources (17%). The 4 archetypes were defined by the exposure to currents and regional marine circulation, depth and profile of the continental shelf, and stratification. Archetype 1 (high dynamics and exposure) with estimated RT=3 months, Archetype 2 (medium dynamics and exposure) with RT=2 yr, Archetype 3 (low dynamics) with RT=25 yr, and Archetype 4 (very low dynamics, embayed, often stratified) with RT=90 yr. It is assumed that the system dynamics is determining the RT of both N and metals in the photic zone in each LME. The LME classification system was chosen for its data availability, modelling feasibility, and adequacy of size and number of spatial units considering the needs of LCIA. The application of the archetypical RTs was useful for the parameterisation of the fate models. The spatial differentiation of the resulting CFs was found essential to increase the discriminatory power of the models.
Life cycle assessment applied to nanomaterials in solid waste management: Focus on human health impact assessment

While the generation of solid waste is globally increasing, much effort is concentrated to minimise the environmental impacts related to their management. With respect to nanoproducts (products containing nanomaterials), a growing amount of ‘nanowaste’ can be expected to enter the waste streams, thus potentially posing problems on human health, e.g. through occupational exposure to engineered nanoparticles. In that setting, through its holistic quantification of environmental impacts, life cycle assessment (LCA) can be a useful decision support tool for managing environmental sustainability of solid waste management systems as well as that of nanoproducts. But how has LCA generally been applied to both fields of solid waste management and nanotechnology until now? In particular, what are the current shortcomings for assessing impacts of released engineered nanoparticles? Is it possible to derive useful preliminary results from currently available data? And, if so, what could be the occupational impacts of engineered nanoparticles taken through the life cycle of nanoproducts including their end-of-life? The answers to these questions form the red thread of the thesis, which is composed by several pieces of work.

Critical reviews were performed to evaluate the current state of LCA application to solid waste management systems and to nanoproducts. The former revealed that, out of 222 reviewed studies, several limitations were identified in the types of LCA application, with a narrow focus on specific waste types and waste management systems, all primarily reflecting situations in economically developed countries. At the same time, methodological practice was found in many studies not to be compliant with current reference guidance, such as the ISO standards and the ILCD Handbook. Likewise, in the application of LCA to nanoproducts, important inconsistencies and shortcomings were noted. While some of them could be prevented by a proper application of the LCA methodology, others were strongly related to the data paucity, particularly with regard to the lack of emission data and characterisation factors for assessing engineered nanoparticles.

To support the impact assessment of engineered nanoparticles in the life cycle of nanoproducts and in solid waste management systems, a comprehensive review of toxicological data for nanosilver and titanium dioxide (TiO2) particles was conducted and it enabled to investigate the influence of some of the physicochemical properties of the particles on their toxic effects. This led to quantify relationships between the primary size and the toxic effects of nanosilver and TiO2 particles that ultimately could be used for deriving consistent, size-dependent no-observed-adverse-effect levels and effect factors applicable in risk assessment and life cycle impact assessment, respectively. The developed effect factors for TiO2 and Ag particles were applied on two simplified LCA case studies, namely the annual consumption of food containing TiO2 nanoparticles in the United Kingdom and a T-shirt embedded with nanosilver. Although highly uncertain because of lack of data, this preliminary assessment suggested that the manufacturing stage may lead to larger occupational impacts from engineered nanoparticles than the disposal stage, and that the occupational exposure to engineered nanoparticles may be negligible when compared to other contributions to human health impacts in the nanoproduct life cycle.

More than the results themselves, these case studies, along with the developed methodology for investigating the relationships between the physicochemical properties of the particles and their toxic effects, served to pinpoint the data required to perform proper assessment of the impacts of exposure to engineered nanoparticles. In particular, detailed emission data matching the actual processes in both the manufacturing and disposal stages, full characterisations of exposure situations, and the generation of more reliable and relevant toxicological data are highly needed and should urgently be addressed. Integrating these information into LCA practice, for which detailed recommendations are also provided in this thesis, should allow the conduct of consistent LCA studies of waste management systems and nanoproducts, and accurately evaluate the relevance of engineered nanoparticles in the total human health impacts.
Life Cycle Engineering and Sustainable Manufacturing

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Long term impacts of international outsourcing of manufacturing on sustainability

International outsourcing seems to be a cost efficient way of production. However, there are serious concerns about its long term impacts on the environmental, social and economic sustainability. This paper aims to quantify these impacts by using input output analysis, linear programming and system dynamics in a case study including European electrical industry (outsourcer), Chinese electrical industry (outsourcer) and their main suppliers. Results depict the differences related to the total CO2 emissions, the number of employees and the gross value added of these two regions between a 10% international outsourcing scenario and the baseline scenario due to their differences in production technologies. © 2014 CIRP.

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Scopus rating (2015): CiteScore 3.83 SJR 2.088 SNIP 3.294
Web of Science (2015): Impact factor 2.492
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.39 SJR 3.123 SNIP 3.992
Web of Science (2014): Impact factor 2.542
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.87 SJR 2.598 SNIP 3.818
Web of Science (2013): Impact factor 2.541
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 3.04 SJR 2.088 SNIP 4.156
Web of Science (2012): Impact factor 2.251
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.81 SJR 2.117 SNIP 3.46
Web of Science (2011): Impact factor 1.708
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 2.12 SNIP 3.449
Web of Science (2010): Impact factor 1.684
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.652 SNIP 2.219
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.056 SNIP 1.645
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.119 SNIP 1.55
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.892 SNIP 1.96
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.988 SNIP 1.904
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 1.591 SNIP 2.376
Web of Science (2004): Indexed yes
Managing human health impacts from chemical emissions: Learnings from analysis of national NMVOC emissions and impacts in the EU-27 in 2000-2010

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Laurent, A., Hauschild, M. Z.
Publication date: 2014
Peer-reviewed: Yes
Event: Abstract from Sustainability Science Congress 2014 , Copenhagen, Denmark.

Bibliographical note
Oral presentation
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2014

Proposal for a new normalization reference in LCA based on "safe operating space": presentation of framework and global factors at midpoint level
Planetary boundaries have been suggested for a range of environmental impacts, such as climate change, eutrophying nutrients and land use. The boundaries demarcate the safe operating space of humanity: Staying within the space ensures environmental sustainability, while exceeding it risks pushing ecosystems into alternative regimes, leading to adverse effects for humanity. Planetary boundaries can be applied as policy targets. To promote a societal development in the direction of these targets, an indicator system is needed that measures the fraction of the safe operating space that a given activity occupies. We propose that such an indicator system can be applied in life cycle assessment (LCA) by integrating planetary boundaries via the normalization step. We present the framework of integration, a literature review of quantified boundaries and resulting normatively consistent global average normalization factors in units compatible with characterized results at midpoint level in LCA. Our suggested framework allows expressing normalized results in units of "sustainable person years". Normalization factors are derived by dividing the safe operating space by the global population. The proposed normalization factors were compared with existing normalization factors that are based on global impacts currently taking place. The impact categories climate change, land use and terrestrial acidification were found to have their safe operating space exceeded on average globally, while the opposite was true for the remaining six categories assessed. Additional research is needed with respect to spatial differentiation since the derived global normalization factors have reduced environmental relevance for impact categories operating at the regional or local scale. Nevertheless the developed normalization factors represent an important first step in enabling LCA to help guiding society in the direction of staying within the safe operating space.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Bjørn, A., Hauschild, M. Z.
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Put numbers on the sustainability

Sustainability is about meeting the needs of the present without compromising the possibilities for our future generations to meet their needs and is commonly perceived as comprising three dimensions – a social, an economic and an environmental dimension, e.g. in the triple bottom line thinking applied in many companies today. As engineers we need methods to analyze the sustainability performance of the technologies that we develop in order to create value for society. Quantitative methods allow us to benchmark alternative solutions against each other, to prioritize improvements and to document the sustainability performance. In this presentation the focus will be on the environmental dimension of sustainability and on methods for quantifying the environmental performance of products and technical systems. A product may cause environmental impacts when it is brought to use, but also when it is produced and disposed of at its end of life. The assessment therefore needs to take a life cycle perspective comprising all relevant activities from the extraction of resources over production, distribution and use, to the disposal and possible recycling of its constituents in new products (Figure 1).

Figure 1. Product life cycle

Environmental sustainability encompasses multiple types of environmental impact ranging from the global scale like climate change and stratospheric ozone depletion over regional impacts associated with air pollution impacts causing acidification, photochemical ozone formation and particle exposure of humans, to the local impacts associated with physical transformation of land and extraction of water. Chemicals can cause toxic impacts to humans and ecosystems on all scales. All these impacts need to be quantified if we want to put numbers on sustainability. The life cycle perspective on products and systems and the coverage of all relevant environmental impacts are combined in Life cycle assessment (LCA) which is introduced in the talk as the tool to put numbers on environmental sustainability. The basics of LCA are introduced, current applications are presented and a discussion of its possibilities and limitations in assessment of sustainability in relative and absolute terms is given.

Review of LCA studies of solid waste management systems – Part II: Methodological guidance for a better practice

Life cycle assessment (LCA) is increasingly used in waste management to identify strategies that prevent or minimise negative impacts on ecosystems, human health or natural resources. However, the quality of the provided support to decision- and policy-makers is strongly dependent on a proper conduct of the LCA. How has LCA been applied until now? Are there any inconsistencies in the past practice? To answer these questions, we draw on a critical review of 222 published LCA studies of solid waste management systems. We analyse the past practice against the ISO standard requirements and the ILCD Handbook guidelines for each major step within the goal definition, scope definition, inventory analysis, impact assessment, and interpretation phases of the methodology. Results show that malpractices exist in several aspects of the LCA with large differences across studies. Examples are a frequent neglect of the goal definition, a frequent lack of transparency and precision in the definition of the scope of the study, e.g. an unclear delimitation of the system boundaries, a truncated impact coverage, difficulties in capturing influential local specificities such as representative waste compositions into the inventory, and a frequent lack of essential sensitivity and uncertainty analyses. Many of these aspects are important for the reliability of the results. For each of them, we therefore provide detailed recommendations to practitioners of waste management LCAs.

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Review of LCA studies of solid waste management systems – Part I: Lessons learned and perspectives

The continuously increasing solid waste generation worldwide calls for management strategies that integrate concerns for environmental sustainability. By quantifying environmental impacts of systems, life cycle assessment (LCA) is a tool, which can contribute to answer that call. But how, where and to which extent has it been applied to solid waste management systems (SWMSs) until now, and which lessons can be learnt from the findings of these LCA applications? To address these questions, we performed a critical review of 222 published LCA studies of SWMSs. We first analysed the geographic distribution and found that the published studies have primarily been concentrated in Europe with little application in developing countries. In terms of technological coverage, they have largely overlooked application of LCA to waste prevention activities and to relevant waste types apart from household waste, e.g. construction and demolition waste. Waste management practitioners are thus encouraged to abridge these gaps in future applications of LCA. In addition to this contextual analysis, we also evaluated the findings of selected studies of good quality and found that there is little agreement in the conclusions among them. The strong dependence of each SWMS on local conditions, such as waste composition or energy system, prevents a meaningful generalisation of the LCA results as we find it in the waste hierarchy. We therefore recommend stakeholders in solid waste management to regard LCA as a tool, which, by its ability of capturing the local specific conditions in the modelling of environmental impacts and benefits of a SWMS, allows identifying critical problems and proposing improvement options adapted to the local specificities.

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Spatially differentiated comparative toxicity potentials of metals in global coastal seawater

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Dong, Y., Rosenbaum, R. K., Hauschild, M. Z.
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Event: Abstract from SETAC Europe 24th Annual Meeting, Basel, Switzerland.
Electronic versions:
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Research output: Research - peer-review • Conference abstract for conference – Annual report year: 2014

Spatially-explicit LCIA model for marine eutrophication as a tool for sustainability assessment

The increasing emissions from human activities are overrunning the ecosystems’ natural capacity to absorb them. Nutrient emissions, mostly nitrogen- and phosphorus-forms (N, P) from e.g. agricultural runoff and combustion processes, may lead to social-economic impacts and environmental quality degradation. Life Cycle Assessment (LCA) is as a tool to comparatively quantify the environmental impacts from product systems throughout their life cycle. Marine eutrophication is one of the LC Impact Assessment (LCIA) categories and it is still lacking an overall model linking nutrients over-enrichment to impacts on marine ecosystems. Emitted nitrogen reaches marine coastal waters where it promotes the growth of phytoplankton biomass in the surface photic zone from where it eventually sinks to bottom waters. This downward flux of organic matter is respired there by bacteria resulting in the consumption of dissolved oxygen. An excessive depletion of oxygen affects the exposed organisms and loss of species diversity may be expected. A model framework was built to estimate the potential impacts arising from N-emissions (see figure). It combines the fate of N in rivers and coastal waters, the exposure of receiving ecosystem to the N enrichment, and the effects of oxygen depletion on relevant species. The estimated impacts are quantified by means of substance-specific factors that translate the emission into potential impacts, i.e. Characterization Factors (CFs). These express the impacts to the ecosystem quality as potentially affected fraction of species (PAF) per mass of N emitted to the environment, volume and time integrated, or (PAF·)[m³·yr·kg⁻¹]. Preliminary results present spatially differentiated CFs for 214 country-to-ecosystem combinations and for 143 countries. Such CFs can be implemented into impact assessment methods in LCA to help characterizing the eutrophication impact of product systems related to agricultural production or involving combustion processes, and ultimately to assess the environmental sustainability of human activities.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Cosme, N. M. D., Hauschild, M. Z.
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Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Research output: Research - peer-review • Conference abstract in proceedings – Annual report year: 2014

Towards a more robust fate modeling of metals' long-term emissions in an LCIA context

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Residual Resource Engineering, Lawrence Berkeley National Laboratory, Irstea
Contributors: Bakas, I., McKone, T., Astrup, T. F., Hauschild, M. Z., Rosenbaum, R.
Number of pages: 1
Publication date: 2014
Peer-reviewed: Yes
Event: Poster session presented at SETAC Europe 24th Annual Meeting, Basel, Switzerland.
Urban agricultural typologies and the need to quantify their potential to reduce a city's environmental 'foodprint'

Presently, the supply chain supporting urban food consumption is placing stress on the environment at the planetary, regional and local scales. Despite the urban origin of global food demands, cities supply little of their own food, and are susceptible to disruptions across the global supply chain. One possible mitigation strategy to these issues is increasing food production in and around cities using urban agriculture (UA).

Through a literature review, we found claims surrounding UA as a way to attenuate a cornucopia of environmental burdens due to urban food needs, but that their veracity remains inconclusive. A comprehensive analysis of the environmental performance of dominant UA forms is therefore needed. However, the review also found paucity in meaningful systematics that described UA systems based on attributes important to environmental performance. We addressed this by developing a system that categorizes UA into five broad types that are optimized for comparing environmental performance.

Will organic photovoltaic technology render benefits in a 30-year horizon?

The cradle-to-cradle (C2C) concept has emerged as an alternative to the more established eco-efficiency concept based on life cycle assessment (LCA). The two concepts differ fundamentally in that eco-efficiency aims to reduce the negative environmental footprint of human activities while C2C attempts to increase the positive footprint. This article discusses the strengths and weaknesses of each concept and suggests how they may learn from each other. The eco-efficiency concept involves no long-term vision or strategy, the links between resource consumption and waste emissions are not well related to the sustainability state, and increases in eco-efficiency may lead to increases in consumption levels and hence overall impact. The C2C concept's disregard for energy efficiency means that many current C2C products will likely not perform well in an LCA. Inherent drawbacks are restrictions on the development of new materials posed by the ambition of continuous loop recycling, the perception that human interactions with nature can benefit all parts of all ecosystems, and the hinted compatibility with continued economic growth. Practitioners of eco-efficiency can benefit from the visions of C2C.
to avoid a narrow-minded focus on the eco-efficiency of products that are inherently unsustainable. Moreover, resource
efficiency and positive environmental effects could be included more strongly in LCA. Practitioners of C2C on the other
hand should recognize the value of LCA in addressing trade-offs between resource conservation and energy use. Also,
when designing a "healthy emission" it should be recognized that it will often have an adverse effect on parts of the
exposed ecosystem. © 2012 by Yale University.
A critical review of life cycle assessment applied to solid waste management systems

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Residual Resource Engineering
Publication date: 2013

Addressing Geographic Variability in the Comparative Toxicity Potential of Copper and Nickel in Soils

Comparative toxicity potentials (CTP), in life cycle impact assessment also known as characterization factors (CF), of copper (Cu) and nickel (Ni) were calculated for a global set of 760 soils. An accessibility factor (ACF) that takes into account the role of the reactive, solid-phase metal pool in the soil was introduced into the definition of CTP. Geographic differences in fate, accessibility, bioavailability, and terrestrial toxicity were assessed by combining the USEtox characterization model, empirical regression models, and terrestrial biotic ligand models. The median CTPs for Cu and Ni with 95% geographic variability intervals are $1.4 \times 10^3 (1.7 \times 102$ to $2.0 \times 104$) and $1.7 \times 10^3 (2.1 \times 102$ to $1.1 \times 104)$ m$^3$/kg·day, respectively. The geographic variability of 3.5 orders of magnitude in the CTP of Cu is mainly associated with the variability in soil organic carbon and pH. They largely influence the fate and bioavailability of Cu in soils. In contrast, the geographic variability of 3 orders of magnitude in the CTP of Ni can mainly be explained by differences in pore water concentration of magnesium (Mg$^{2+}$). Mg$^{2+}$ competes with Ni$^{2+}$ for binding to biotic ligands, influencing the toxicity. Our findings stress the importance of dealing with geographic variability in the calculation of CTPs for terrestrial ecotoxicity of metals.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Radboud University Nijmegen
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Approaching the planetary boundary for chemical pollution through a chemical footprint indicator – exploring feasibility via two case studies

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, University of Toronto
Contributors: Bjørn, A., Hauschild, M. Z., Birkved, M., Diamond, M.
Number of pages: 1
Pages: 399
Publication date: 2013

Assessing Environmental Sustainability of Remediation Technologies in a Life Cycle Perspective is Not So Easy

Integrating sustainability into remediation projects has attracted attention from remediation practitioners, and life cycle assessment (LCA) is becoming a popular tool to address the environmental dimension. The total number of studies has reached 31 since the first framework for LCA of site remediation was published in 1999,1 and has almost doubled compared to number of studies in two reviews published in 2010.2,3 However, our analysis shows an increasing frequency of examples with serious methodological problems (compared to requirements in ISO standards or authoritative guidelines). Figure 1 shows that numerous studies have no or an incomplete definition of the functional unit, omit an appropriate quantification of primary impacts, or fail to include all relevant secondary impact categories. We will illustrate how ignoring these methodological challenges can lead to a misleading conclusion about the environmental sustainability of remediation technologies.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Water Resources Engineering
Contributors: Owsianiak, M., Lemming, G., Hauschild, M. Z., Bjerg, P. L.
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Challenges in LCA-based decision making involving heavy metals long-term emissions from landfills

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Residual Resource Engineering
Contributors: Bakas, I., Astrup, T. F., Hauschild, M. Z., Rosenbaum, R. K.
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Development of characterization factors for metals in 7 EU water archetypes
Toxicity potential of most metals in the freshwater are estimated in current life cycle impact assessment (LCIA) models without taking the spatial differentiated speciation behavior of the metals into consideration. Using a novel approach developed by Gandhi and Diamond (Gandhi et al. 2010), new characterization factors (CF) representing freshwater ecotoxicity potentials are calculated for metals (e.g. Cr, Be and Ba) in 7 EU water types, taking into account the influence of speciation behavior on metal bioavailability and metal fate in seven different EU water types.

USEtox is used to model the fate of the metals, WHAM 7.0 is used to model the metal speciation, Kd values and bioavailability, while the Free Ion Activity Model (FIAM) is used to model the ecotoxicity effect. The resulting archetype-specific CFs show up to ~4 orders of magnitude difference for Cr and Be. This indicates that the toxicity potential of these two metals is strongly dependent on differences in water chemistry. In comparison, Ba shows a constant bioavailability ratio and toxicity effect across the modeled water chemistries. Thus CFs are strongly correlated with fate, which results in a more narrow range of CFs. The differences in water chemistry not only changes the absolute values of the CFs for the individual metals, but also their ranking in terms of freshwater ecotoxicity potential, illustrating the relevance of taking water chemistry into account when modeling metal ecotoxicity potential in LCIA. In order to support LCIA in the frequent situation where no information is available of the specific water type into which the metal emission occurs, site generic average factors are also calculated and different approaches to averaging across archetypes are investigated and discussed.

General information
Drivers and barriers for implementation of environmental strategies in manufacturing companies

In order for environmental strategies to come into effect in industry practice, they need to be implemented and applied in daily business routines. Based on a dedicated comprehensive international survey in product developing and manufacturing companies, this paper identifies major current drivers for implementing product life cycle oriented environmental strategies but also barriers and obstacles that need to be addressed. On this basis it provides a number of recommendations for manufacturing companies as well as policy makers to consider for a successful implementation of strategic environmental goals in manufacturing industry.

**General information**

State: Published  
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Mechanical Engineering, Engineering Design and Product Development  
Contributors: Bey, N., Hauschild, M. Z., McAloone, T. C.  
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BFI (2015): BFI-level 2  
Scopus rating (2015): CiteScore 3.83 SJR 2.088 SNIP 3.294  
Web of Science (2015): Impact factor 2.492  
Web of Science (2015): Indexed yes  
BFI (2014): BFI-level 2  
Scopus rating (2014): CiteScore 4.39 SJR 3.123 SNIP 3.992  
Web of Science (2014): Impact factor 2.542  
Web of Science (2014): Indexed yes  
BFI (2013): BFI-level 2
Endpoint characterisation modelling for marine eutrophication in LCIA

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Cosme, N. M. D., Larsen, H. F., Hauschild, M. Z.
Endpoint characterisation modelling for marine eutrophication in LCIA

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Contributors: Cosme, N. M. D., Larsen, H. F., Hauschild, M. Z.
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Location: Glasgow, United Kingdom

Environmental challenges of anthropogenic metals flows and cycles
This report from the UNEP-hosted International Resource Panel, Environmental Risk and Challenges of Anthropogenic Metals Flows and Cycles, gives a clear picture of the potential environmental impacts of metals at different stages of the life-cycle while linking with other areas of resource use such as water, food production and energy.

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Research output: Research › Report – Annual report year: 2012

Fate process modelling in LCI: improving inventory quality or double counting?

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Dijkman, T. J., Birkved, M., Hauschild, M. Z.
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Host publication information
Final evaluation of the newly developed characterisation and normalisation factors in an LCA case study - Paper production and printing

Identifying best existing practice for characterization modeling in life cycle impact assessment

Purpose: Life cycle impact assessment (LCIA) is a field of active development. The last decade has seen prolific publication of new impact assessment methods covering many different impact categories and providing characterization factors that often deviate from each other for the same substance and impact. The LCA standard ISO 14044 is rather general and unspecific in its requirements and offers little help to the LCA practitioner who needs to make a choice. With the aim to identify the best among existing characterization models and provide recommendations to the LCA practitioner, a study was performed for the Joint Research Centre of the European Commission (JRC). Methods Existing LCIA methods were collected and their individual characterization models identified at both midpoint and endpoint levels and supplemented with other environmental models of potential use for LCIA. No new developments of characterization models or factors were done in the project. From a total of 156 models, 91 were short listed as possible candidates for a recommendation within their impact category. Criteria were developed for analyzing the models within each impact category. The criteria addressed both scientific qualities and stakeholder acceptance. The criteria were reviewed by external experts and stakeholders and applied in a comprehensive analysis of the short-listed characterization models (the total number of criteria varied between 35 and 50 per impact category). For each impact category, the analysis concluded with identification of the best among the existing characterization models. If the identified model was of sufficient quality, it was recommended by the JRC. Analysis and recommendation process involved hearing of both scientific experts and stakeholders.

Results and recommendations: Recommendations were developed for 14 impact categories at midpoint level, and among these recommendations, three were classified as "satisfactory" while ten were "in need of some improvements" and one was so weak that it has "to be applied with caution." For some of the impact categories, the classification of the recommended model varied with the type of substance. At endpoint level, recommendations were only found relevant for three impact categories. For the rest, the quality of the existing methods was too weak, and the methods that came out best in the analysis were classified as "interim," i.e., not recommended by the JRC but suitable to provide an initial basis for further development.

Discussion, conclusions, and outlook: The level of characterization modeling at midpoint level has improved considerably over the last decade and now also considers important aspects like geographical differentiation and combination of midpoint and endpoint characterization, although the latter is in clear need for further development. With the realization of the potential importance of geographical differentiation comes the need for characterization models that are able to produce characterization factors that are representative for different continents and still support aggregation of impact scores over the whole life cycle. For the impact categories human toxicity and ecotoxicity, we are now able to recommend a model, but the number of chemical substances in common use is so high that there is a need to address the substance data shortage and calculate characterization factors for many new substances. Another unresolved issue is the need for quantitative information about the uncertainties that accompany the characterization factors. This is still only adequately addressed for one or two impact categories at midpoint, and this should be a focus point in future research. The dynamic character of LCIA research means that what is best practice will change quickly in time. The characterization methods presented in this paper represent what was best practice in 2008–2009.
Inclusion of Climatic Tipping Potential in LCA

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Novozymes AS, University of Michigan, Ann Arbor, Polytechnique Montreal, University of California, Institute of Wetland and Water Research
Contributors: Jørgensen, S. V., Hauschild, M. Z., Nielsen, P.
Number of pages: 1
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Keeping USEtox up-to-date: What is coming and how you can contribute

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, University of Michigan, Ann Arbor, Polytechnique Montreal, University of California, Institute of Wetland and Water Research
Number of pages: 1
Key issues and options in accounting for carbon sequestration and temporary storage in life cycle assessment and carbon footprinting

Purpose: Biological sequestration can increase the carbon stocks of non-atmospheric reservoirs (e.g. land and landbased products). Since this contained carbon is sequestered from, and retained outside, the atmosphere for a period of time, the concentration of CO2 in the atmosphere is temporarily reduced and some radiative forcing is avoided. Carbon removal from the atmosphere and storage in the biosphere or anthroposphere, therefore, has the potential to mitigate climate change, even if the carbon storage and associated benefits might be temporary. Life cycle assessment (LCA) and carbon footprinting (CF) are increasingly popular tools for the environmental assessment of products, that take into account their entire life cycle. There have been significant efforts to develop robust methods to account for the benefits, if any, of sequestration and temporary storage and release of biogenic carbon. However, there is still no overall consensus on the most appropriate ways of considering and quantifying it.

Method: This paper reviews and discusses six available methods for accounting for the potential climate impacts of carbon sequestration and temporary storage or release of biogenic carbon in LCA and CF. Several viewpoints and approaches are presented in a structured manner to help decision-makers in their selection of an option from competing approaches for dealing with timing issues, including delayed emissions of fossil carbon.

Results: Key issues identified are that the benefits of temporary carbon removals depend on the time horizon adopted when assessing climate change impacts and are therefore not purely science-based but include value judgments. We therefore did not recommend a preferred option out of the six alternatives presented here.

Conclusions: Further work is needed to combine aspects of scientific and socio-economic understanding with value judgements and ethical considerations.
LCA as a support tool for forecasting scenarios: the case study of Danish spring barley production in a changing climate

General information
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Organisations: Department of Chemical and Biochemical Engineering, Department of Management Engineering, Quantitative Sustainability Assessment, Ecosystems Programme
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Peer-reviewed: Yes
Event: Abstract from SETAC Europe 19th LCA Case Study Symposium, Rome, Italy.
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LCA_as_a_support_tool_.pdf
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Source-ID: 96463385
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Life-cycle and freshwater withdrawal impact assessment of water supply technologies
Four alternative cases for water supply were environmentally evaluated and compared based on the standard environmental impact categories from the life-cycle assessment (LCA) methodology extended with a freshwater withdrawal category (FWI). The cases were designed for Copenhagen, a part of Denmark with high population density and relatively low available water resources. FWI was applied at local groundwater catchments based on data from the national implementation of the EU Water Framework Directive. The base case of the study was the current practice of groundwater abstraction from well fields situated near Copenhagen. The 4 cases studied were: Rain & stormwater harvesting from several blocks in the city; Today's groundwater abstraction with compensating actions applied in the affected freshwater environments to ensure sufficient water flow in water courses; Establishment of well fields further away from the city; And seawater desalination. The standard LCA showed that the Rain & stormwater harvesting case had the lowest overall environmental impact (81.9 μPET/m3) followed by the cases relying on groundwater abstraction (123.5–137.8 μPET/m3), and that desalination had a relatively small but still important increase in environmental impact (204.8 μPET/m3). Rain & stormwater harvesting and desalination had a markedly lower environmental impact compared to the base case, due to the reduced water hardness leading to e.g. a decrease in electricity consumption in households. For a relevant comparison, it is therefore essential to include the effects of water hardness when comparing the environmental impacts of water systems of different hardness. This study also emphasizes the necessity of including freshwater withdrawal respecting the relevant affected geographical scale, i.e. by focusing the assessment on the local groundwater catchments rather than on the regional catchments. Our work shows that freshwater withdrawal methods previously used on a regional level can also be applied to local groundwater catchments and integrated into the standard LCA as an impact category. When standard LCA is extended to include impacts of freshwater withdrawal, rain & stormwater and seawater (0.09–0.18 compared to 11.45–17.16 mPET/m3) were the resources resulting in least overall environmental impact.

General information
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Organisations: Department of Environmental Engineering, Urban Water Engineering, Department of Management Engineering, Quantitative Sustainability Assessment, HOFOR A/S
Contributors: Godskesen, B., Hauschild, M. Z., Rygaard, M., Zambrano, K., Albrechtsen, H.
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Mapping and characterization of LCA networks

Purpose: The aims of this study were to provide an up-to-date overview of global, regional and local networks supporting life cycle thinking and to characterize them according to their structure and activities.

Methods: Following a tentative life cycle assessment (LCA) network definition, a mapping was performed based on (1) a literature search, (2) a web search and (3) an inquiry to stakeholders distributed via the two largest LCA fora. Networks were characterized based on responses from a survey.

Results and discussion: We identified 100 networks, of which 29 fulfilled all six criteria composing our tentative network definition (the remaining fulfilled four to five criteria). The networks are mainly located in Europe and the USA, whilst Africa, the Middle East and Central Asia are less covered regions. The survey results (from 25 network responses) indicate that LCA networks appear to be primarily small- to medium-sized (<100 members) and to include a large proportion of academia and industries, including small- and mediumsized enterprises, with much less involvement of authorities and non-governmental organisations. Their major activities relate to knowledge sharing and communication, support of case studies, and development of life cycle inventories and impact assessment methods. Networks in developing economies have different structures and activities than networks in developed economies and, for instance, more frequently have members from non-governmental organisations. Globally, an increasing trend in the formation of LCA networks over time is observed, which tends to correlate with the number of LCA scientific publications over the same time period. Continental distributions of networks also show a correlation with the number of LCA publications from the same region.

Conclusions: The provided list of LCA networks is currently the most comprehensive, publicly available mapping. We believe that the results of this mapping can serve as a basis for deciding where priorities should be set to increase the dissemination and development of LCA worldwide. In this aim, we also advocate the creation of an online, regularly updated database of LCA networks supplemented by an online platform that could facilitate network communication and knowledge sharing.
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
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ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.288 SNIP 0.954
Scopus rating (2001): SJR 0.49 SNIP 1.456
Scopus rating (2000): SJR 0.413 SNIP 1.862
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Modelling of pesticide emissions for Life Cycle Inventory analysis: Model development, applications and implications

The work presented in this thesis deals with quantification of pesticide emissions in the Life Cycle Inventory (LCI) analysis phase of Life Cycle Assessment (LCA). The motivation to model pesticide emissions is that reliable LCA results not only depend on accurate impact assessment models, but also good emission inventories. Recent LCA studies of agricultural products that take toxicity impacts into account show that pesticide emissions considerably contribute to toxicity impacts. At the same time, such conclusions are derived using a simplified approach to quantify pesticide emissions.

The research presented in this thesis centers around PestLCI 2.0, a model to calculate pesticide emissions to air, surface water and groundwater for use in LCI. PestLCI2.0 is an updated and expanded version of the PestLCI model, released in 2006. The boundaries between ecosphere and technosphere in the model are defined by a ‘technosphere box’, which includes the arable land where the pesticide is applied, the field soil up to 1 meter of depth and the air column above the field up to 100 meter. When a pesticide leaves this box, it is considered an emission. The model works with a primary distribution, where the pesticide is deposited on the crop, on soil or emitted due to wind drift, followed by secondary processes that determine the pesticides’ fate.

In PestLCI 2.0, most fate process modelling has been updated, most notably the modelling of pesticide volatilization from leaves and pesticide runoff. The model was expanded by the inclusion of macropore flow, which leads to pesticide emissions to groundwater. Moreover, PestLCI 2.0 databases with active ingredients, climates and soils were updated, broadening the applicability of the model to European circumstances. A case study showed that emissions vary with variations in the climates and soils present in Europe.

Emissions of pesticides to surface water and groundwater calculated by PestLCI 2.0 were compared with models used for risk assessment. Compared to the MACRO module in SWASH 3.1 model, which calculates surface water emissions by runoff and drainage, pesticide emissions to surface water calculated by PestLCI 2.0 were generally higher, which was attributed to differences in the modelling approach between the two models. The model comparison for emissions to groundwater showed that PestLCI 2.0 calculated higher emissions than FOCUSPEARL 4.4.4 (modelling chromatographic flow of water through the soil), which was attributed to the omission of emissions via macropore flow in the latter model.

The comparison was complicated by the fact that the scenarios used were not fully identical. In order to quantify the implications of using PestLCI 2.0, human toxicity and freshwater ecotoxicity impacts obtained with two inventory approaches were compared. The first approach was PestLCI 2.0, the second was the currently prevalent approach (the Ecoinvent approach), which assumes that 100% of the applied mass is emitted to agricultural soil. For both impact categories it was found that the PestLCI approach results in impacts that on average are three orders of magnitude lower. This conclusion was found to be valid for characterization of the impacts with both USEtox and US-ES-LCA 2.0 characterization factors.

The difference observed between these approaches will have implications for the comparison of toxicity impacts between conventional and organic agriculture. However, the difference in pesticide use and the corresponding environmental impacts is only one of the many aspects that are relevant to assess when discussing sustainability of both types of agriculture. A second implication from these findings is that the contribution of pesticide emissions to the overall toxicity impacts of agricultural products may be lower than what is currently found in LCA studies.

Since the PestLCI and Ecoinvent approaches differ in both their ecosphere-technosphere boundary setting and in the modelling of fate processes within the technosphere, a hybrid approach was also used to calculate toxicological impacts. This approach combined the fate modelling of the PestLCI approach with the technosphere boundaries of the Ecoinvent approach. The toxicological impacts of this approach showed that it is the technosphere boundaries, rather than the in- or exclusion of fate processes, that determine the differences observed between the PestLCI and Ecoinvent approaches. This technosphere-ecosphere boundary is impossible to define objectively in the case of LCAs of agricultural products: it depends on the practitioners’ values what is environment and what is man-made production system. Therefore it is advisable to discuss what LCA should aim to protect, instead of where the boundary should be located.

The first of the two applications of PestLCI 2.0 presented in this thesis is the case of pesticide emissions in conventional kiwifruit cultivation in the Western Bay of Plenty district in New Zealand. For nine scenarios, based on different combinations of local soils and climates, pesticide emissions were calculated with PestLTCI 2.0 and subsequently characterized with characterization factors obtained using USEtox. The emissions to air showed little variation between the nine assessed scenarios. Emissions to surface water and groundwater showed larger variations. Despite this, the differences in the freshwater ecotoxicity and human toxicity for the nine scenarios were small. In an LCA context, when considering uncertainties in emission modelling and impact assessment, these differences probably are not relevant. For all nine scenarios, it was found that emissions of cyan-amide dominated the toxicological impacts.

A second application of PestLCI 2.0 was in the comparison of the environmental impacts of barley cultivation in Denmark under current (2010) and future (2050) climatic circumstances. The functional unit of this study was 1 kg of barley at the farm gate. Using an attributional approach, impacts of co-products were handled by economic allocation. Impact assessment was done with ReCiPe (hierarchich perspective), except for toxicity impacts, which were characterized using USE-tox. The differences between four scenarios, based on combinations of wet and dry climates, and sandy and sandy loam soils, for barley cultivation under current climatic conditions were found to be small. Differences in impacts between cultivation in current and future climatic conditions were concluded to be mainly driven by differences in grain yield. The use of economic allocation was found to be a key issue, since the price levels of 2050 can’t be predicted with any reasonable certainty.

Although PestLCI has been updated and expanded, further improvements are still possible. A number of improvements and suggestions to increase the model’s applicability are discussed. These suggestions focus on both the fate modelling (for example wind drift, degradation and volatilization from leaves) and the boundary setting of the model.
Need for relevant timescales when crediting temporary carbon storage

Purpose: Earth faces an urgent need for climate change mitigation, and carbon storage is discussed as an option. Approaches for assessing the benefit of temporary carbon storage in relation to carbon footprinting exist, but many are based on a 100-year accounting period, disregarding impacts after this time. The aim of this paper is to assess the consequences of using such approaches that disregard the long timescale on which complete removal of atmospheric CO2 occurs. Based on these findings, an assessment is made on what are relevant timescales to consider when including the value of temporary carbon storage in carbon footprinting.

Methods: Implications of using a 100-year accounting period is evaluated via a literature review study of the global carbon cycle, as well as by analysing the crediting approaches that are exemplified by the PAS 2050 scheme for crediting temporary carbon storage.

Results and discussion: The global carbon cycle shows timescales of thousands of years for the transport of carbon from the atmosphere to pools beyond the near-surface layers of the Earth, from where it will not readily be re-emitted as a response to change in near-surface conditions. Compared to such timescales, the use of the 100-year accounting period appears hard to justify. We illustrate how the use of the 100-year accounting period can cause long-term global warming impacts to be hidden by short-term storage solutions that may not offer real long-term climate change mitigation. Obtaining long-term climatic benefits is considered to require storage of carbon for at least thousand years. However, it has been proposed that there may exist tipping points for the atmospheric CO2 concentration beyond which irreversible climate changes occur. To reduce the risk of passing such tipping points, fast mitigation of the rise in atmospheric greenhouse gas concentration is required and in this perspective, shorter storage times may still provide climatic benefits. Conclusions: Both short- and long-term perspectives should be considered when crediting temporary carbon storage, addressing both acute effects on the climate and the longterm climate change. It is however essential to distinguish between short- and long-term mitigation potential by treating them separately and avoid that short-term mitigation is used to counterbalance long-term climate change impacts from burning of fossil fuels.
Potential for optimized production and use of rapeseed biodiesel. Based on a comprehensive real-time LCA case study in Denmark with multiple pathways

Purpose: Several factors contribute to the current increased focus on alternative fuels such as biodiesel, including an increasing awareness of the environmental impact of petrochemical (PC) oil products such as PC diesel, the continuously increasing price of PC oil, and the depletion of PC oil. For these reasons, the European Union has enacted a directive requiring each member state to ensure that the share of energy from renewable sources in transport be at least 10 % of the final consumption of energy by 2020 (The European Parliament and the Council 2009). This LCA study assesses the specific environmental impacts from the production and use of biodiesel as it is today (real-time), based on rapeseed oil and different types of alcohols, and using technologies that are currently available or will be available shortly. Different options are evaluated for the environmental improvement of production methods. The modeling of the LCA is based on a specific Danish biodiesel production facility.

Methods: The functional unit is “1,000 km transportation for a standard passenger car.” All relevant process stages are included, such as rapeseed production including carbon sequestration and N2O balances, and transportation of products used in the life cycle of biodiesel. System expansion has been used to handle allocation issues.

Results and discussion: The climate change potential from the production and use of biodiesel today is 57 kg CO2-eq/1,000 km, while PC diesel is 214 kg CO2-eq/1,000 km. Options for improvement include the increased use of residual straw from rapeseed fields for combustion in a power plant where carbon sequestration is considered, and a change in transesterification from a conventional process to an enzymatic process when using bioethanol instead of PC methanol. This research also evaluates results for land use, respiratory inorganics potential, human toxicity (carc) potential, ecotoxicity (freshwater) potential, and aquatic eutrophication (N) potential. Different sources for uncertainty are evaluated, and the largest drivers for uncertainty are the assumptions embedded into the substitution effects. The results presented should not be interpreted as a blueprint for the increased production of biodiesel but rather as a benchmarking point for the present, actual impact in a well-to-wheels perspective of biodiesel, with options for improving production and use.

Conclusions: Based on this analysis, we recommend investigating additional options and incentives regarding the increased use of rape straw, particularly considering the carbon sequestration issues (from the perspective of potential climate change) of using bioalcohol instead of PC alcohol for the transesterification process.

General information
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Organisations: Department of Management Engineering, Systems Analysis, DTU Climate Centre, Quantitative Sustainability Assessment, University of Copenhagen
Contributors: Herrmann, I. T., Jørgensen, A., Bruun, S., Hauschild, M. Z.
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Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Quantification of urban metabolism through coupling with the life cycle assessment framework: concept development and case study: Letter

Cities now consume resources and produce waste in amounts that are incommensurate with the populations they contain. Quantifying and benchmarking the environmental impacts of cities is essential if urbanization of the world’s growing population is to occur sustainably. Urban metabolism (UM) is a promising assessment form in that it provides the annual sum material and energy inputs, and the resultant emissions of the emergent infrastructural needs of a city’s sociotechnical subsystems. By fusing UM and life cycle assessment (UM–LCA) this study advances the ability to quantify environmental impacts of cities by modeling pressures embedded in the flows upstream (entering) and downstream (leaving) of the actual urban systems studied, and by introducing an advanced suite of indicators. Applied to five global cities, the developed UM–LCA model provided enhanced quantification of mass and energy flows through cities over earlier UM methods. The hybrid model approach also enabled the dominant sources of a city’s different environmental footprints to be identified, making UM–LCA a novel and potentially powerful tool for policy makers in developing and monitoring urban development policies. Combining outputs with socioeconomic data hinted at how these forces influenced the footprints of the case cities, with wealthier ones more associated with personal consumption related impacts and poorer ones more affected by local burdens from archaic infrastructure.

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Scopus rating (2017): CiteScore 4.83 SJR 2.436 SNIP 1.538
Web of Science (2017): Impact factor 4.541
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.74 SJR 2.71 SNIP 1.624
Web of Science (2016): Impact factor 4.404
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 4.51 SJR 2.704 SNIP 1.535
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.91 SJR 2.177 SNIP 1.446
Web of Science (2014): Impact factor 3.906
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 4.06 SJR 2.304 SNIP 1.671
Web of Science (2013): Impact factor 4.09
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
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Web of Science (2012): Impact factor 3.582
ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 3.51 SJR 1.897 SNIP 1.503
Web of Science (2011): Impact factor 3.631
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.732 SNIP 1.299
Web of Science (2010): Impact factor 3.049
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.854 SNIP 1.274
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Scopus rating (2008): SJR 0.73 SNIP 1.208
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.402 SNIP 0.197
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Quantification_of_urban_metabolism_through_coupling_with_the_life_cycle_assessment_framework_concept_development_and_case_study.pdf
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Source: dtu
Source-ID: n::oai:DTIC-ART:iop/389961511::30931
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Recommended assessment framework, method and characterisation and normalisation factors for ecosystem impacts of eutrophying emissions: phase 3 (report, model and factors)

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
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Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Cosme, N. M. D., Larsen, H. F., Hauschild, M. Z.
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Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures

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Spatially_explicit_LCIA.pdf
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http://www.york.ac.uk/conferences/allatsea/index.html
Research output: Research › Sound/Visual production (digital) – Annual report year: 2013

Supply chain coordination in industrial symbiosis
Industrial symbiosis (IS) is a form of supply chain cooperation in industrial networks in order to achieve collective benefits by leveraging each other’s by-products and sharing services and utilities. This paper investigates the concept of IS from the perspective of supply chain coordination (SCC). For this purpose a theoretical framework is built based on SCC aspects, which is subsequently used to analyze a case study. We conclude that research is scant on operational issues and trade-offs as well as on challenges in terms of logistical integration. Also small-scale examples are barely studied or modeled.

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Organisations: Department of Management Engineering, Management Science, Production and Service Management, Quantitative Sustainability Assessment, Technische Universität München
Contributors: Herczeg, G., Akkerman, R., Hauschild, M. Z.
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Supply_chain_coordination.pdf
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Sustainability of abrasive processes
This paper presents an overview of research on sustainability of abrasive processes. It incorporates results from a round robin study on "energy-efficiency of abrasive processes" which has been carried out within the scientific technical committee “abrasive processes” (STC G) of CIRP, the content of technical presentations in STC G, and the results of a comprehensive literature study. The approach to sustainability includes environmental, social, and economic sustainability in accordance with the definition proposed in the Brundtland Report of the United Nations [156]. The main focus is on environmental and social sustainability. Economic sustainability will be considered as manufacturing productivity. © 2013 CIRP.
Can carbon footprint serve as a comprehensive tool for assessing and managing environmental sustainability?

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Laurent, A., Olsen, S. I., Hauschild, M. Z.
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Title of host publication: Proceedings
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Challenges in life cycle assessments of waste application to agricultural land

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, University of Turin, University of Copenhagen
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Location: Fiera Del Levante, Bari, Italy
Electronic versions:
Challenges_in_life_cycle_assessments.pdf
Source: dtu
Source-ID: u::6895
Research output: Research › Sound/Visual production (digital) – Annual report year: 2013

Defining and mapping LCA networks: Initial results

General information
Evaluation of spatial variability of metal bioavailability in soils using geostatistics

Soil properties show significant spatial variability at local, regional and continental scales. This is a challenge for life cycle impact assessment (LCIA) of metals, because fate, bioavailability and effect factors are controlled by environmental chemistry and can vary orders of magnitude for different soils. Here, variography is employed to analyse spatial variability of bioavailability factors (BFs) of metals at the global scale. First, published empirical regressions are employed to calculate BFs of metals for 7180 topsoil profiles. Next, geostatistical interpretation of calculated BFs is performed using ArcGIS Geostatistical Analyst. Results show that BFs of copper span a range of 6 orders of magnitude, and have significant spatial variability at local and continental scales. The model nugget variance is significantly higher than zero, suggesting the presence of spatial variability at lags smaller than those in the data set. Geostatistical analyses indicate however, that BFs exhibit no significant spatial correlation at a range beyond 3200 km. Because BF is spatially correlated, its values at unsampled locations can be predicted, as demonstrated using ordinary krigging method. Similar approach can be employed for analyzing spatial variability of terrestrial ecotoxicity characterization factors of metals. Predicted maps can be used to provide a set of regionalized factors at spatial scales that are both scientifically relevant and practically feasible in LCIA.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Owsianiak, M., Hauschild, M. Z., Rosenbaum, R. K.
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Abstractbook1_Part1.pdf
Research output: Research › Conference abstract in proceedings – Annual report year: 2012

Exploring the feasibility of chemical footprint assessment - the case of eco-toxicological impacts on freshwater from pesticide use in Denmark

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Bjørn, A., Birkved, M., Hauschild, M. Z.
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programme_abstracts_book_31102012_v2.pdf
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Helhedsorienteret miljøvurdering af teknologier i et livscyklusperspektiv

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Contributors: Hauschild, M. Z.
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Including urgency in global warming assessment in LCA

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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Novozymes AS
Contributors: Jørgensen, S. V., Hauschild, M. Z., Nielsen, P. H., Kløverpris, J. H.
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Learning by doing - bringing real-life case studies into the classroom

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Life cycle assessment of central softening of very hard drinking water
Many consumers prefer softened water due to convenience issues such as avoidance of removing limescale deposits from household appliances and surfaces, and to reduce consumption of cleaning agents and laundry detergents leading to lower household expenses. Even though central softening of drinking water entailed an increased use of energy, sand and chemicals at the waterworks, the distributed and softened drinking water supported a decrease in consumption of energy and chemical agents in the households along with a prolonged service life of household appliances which heat water. This study used Life Cycle Assessment (LCA) to quantify the environmental impacts of central softening of drinking water considering both the negative effects at the waterworks and the positive effects imposed by the changed water quality in the households. The LCA modeling considered central softening of drinking water from the initial hardness of the region of study (Copenhagen, Denmark) which is 362 mg/L as CaCO(3) to a final hardness as CaCO(3) of 254 (a softening depth of 108) mg/L or 145 (a softening depth of 217) mg/L. Our study showed that the consumer preference can be met together with reducing the impact on the environment and the resource consumption. Environmental impacts decreased by up to 3 mPET (milli Personal Equivalent Targeted) and the break-even point from where central softening becomes environmentally beneficial was reached at a softening depth of only 22 mg/L as CaCO(3). Both energy-related and chemically related environmental impacts were reduced as well as the consumption of resources. Based on scarcity criteria, nickel was identified as the most problematic non-renewable resource in the system, and savings of up to 8 mPR (milli Person Reserve) were found.

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Organisations: Urban Water Engineering, Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering, Københavns Energi A/S
Limitations of Carbon Footprint as Indicator of Environmental Sustainability

Greenhouse gas accountings, commonly referred to with the popular term carbon footprints (CFP), are a widely used metric of climate change impacts and the main focus of many sustainability policies among companies and authorities. However, environmental sustainability concerns not just climate change but also other environmental problems, like chemical pollution or depletion of natural resources, and the focus on CFP brings the risk of problem shifting when reductions in CFP are obtained at the expense of increase in other environmental impacts. But how real is this risk? Here, we model and analyze the life cycle impacts from about 4000 different products, technologies, and services taken from several sectors, including energy generation, transportation, material production, infrastructure, and waste management. By investigating the correlations between the CFP and 13 other impact scores, we show that some environmental impacts, notably those related to emissions of toxic substances, often do not covary with climate change impacts. In such situations, carbon footprint is a poor representative of the environmental burden of products, and environmental management focused exclusively on CFP runs the risk of inadvertently shifting the problem to other environmental impacts when products are optimized to become more “green”. These findings call for the use of more broadly encompassing tools to assess and manage environmental sustainability.
Mapping and characterization of LCA networks

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Methodology for systematic analysis and improvement of manufacturing unit process life-cycle inventory (UPLCI)—CO2PE! initiative (cooperative effort on process emissions in manufacturing). Part 1: Methodology description
This report proposes a life-cycle analysis (LCA)-oriented methodology for systematic inventory analysis of the use phase of manufacturing unit processes providing unit process datasets to be used in life-cycle inventory (LCI) databases and libraries. The methodology has been developed in the framework of the CO2PE! collaborative research programme (CO2PE! 2011a) and comprises two approaches with different levels of detail, respectively referred to as the screening approach and the in-depth approach. The screening approach relies on representative, publicly available data and engineering calculations for energy use, material loss, and identification of variables for improvement, while the in-depth approach is subdivided into four modules, including a time study, a power consumption study, a consumables study and an emissions study, in which all relevant process in- and outputs are measured and analysed in detail. The screening approach provides the first insight in the unit process and results in a set of approximate LCI data, which also serve to guide the more detailed and complete in-depth approach leading to more accurate LCI data as well as the identification of potential for energy and resource efficiency improvements of the manufacturing unit process. To ensure optimal reproducibility and applicability, documentation guidelines for data and metadata are included in both approaches. Guidance on definition of functional unit and reference flow as well as on determination of system boundaries specifies the generic goal and scope definition requirements according to ISO 14040 (2006) and ISO 14044 (2006). The proposed methodology aims at ensuring solid foundations for the provision of high-quality LCI data for the use phase of manufacturing unit processes. Envisaged usage encompasses the provision of high-quality data for LCA studies of products using these unit process datasets for the manufacturing processes, as well as the in-depth analysis of individual manufacturing unit processes. In addition, the accruing availability of data for a range of similar machines (same process, different suppliers and machine capacities) will allow the establishment of parametric emission and resource use estimation models for a more streamlined LCA of products including reliable manufacturing process data. Both approaches have already provided useful results in some initial case studies (Kellens et al. 2009; Duflou et al. (Int J Sustain Manufacturing 2:80–98, 2010); Santos et al. (J Clean Prod 19:356–364, 2011); UPLCI 2011; Kellens et al. 2011a) and the use will be illustrated by two case studies in Part 2 of this paper (Kellens et al. 2011b).
Methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI) CO2PE! initiative (cooperative effort on process emissions in manufacturing). Part 2: case studies

This report presents two case studies, one for both the screening approach and the in-depth approach, demonstrating the application of the life cycle assessment-oriented methodology for systematic inventory analysis of the machine tool use phase of manufacturing unit processes, which has been developed in the framework of the CO2PE! collaborative research programme (CO2PE! 2011) and is described in part 1 of this paper (Kellens et al. 2011). The screening approach, which provides a first insight into the unit process and results in a set of approximate LCI data, relies on representative industrial data and engineering calculations for energy use and material loss. This approach is illustrated by means of a case study of a drilling process. The in-depth approach, which leads to more accurate LCI data as well as the identification of potential for environmental improvements of the manufacturing unit processes, is subdivided into four modules, including a time study, a power consumption study, a consumables study and an emissions study, in which all relevant process in- and outputs are measured and analysed in detail. The procedure of this approach, together with the proposed CO2PE! template, is illustrated by means of a case study of a laser cutting process. The CO2PE! methodology aims to provide high-quality LCI data for the machine tool use phase of manufacturing unit processes, to be used in life cycle inventory databases and libraries, as well as to identify potential for environmental improvement based on the in-depth analysis of individual manufacturing unit processes. Two case studies illustrate the applicability of the methodology.

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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, KU Leuven, Wichita State University
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Modelling health effects from inhalation of nano-objects

General information
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PestLCI 2.0: a second generation model for estimating emissions of pesticides from arable land in LCA

The spatial dependency of pesticide emissions to air, surface water and groundwater is illustrated and quantified using PestLCI 2.0, an updated and expanded version of PestLCI 1.0. PestLCI is a model capable of estimating pesticide emissions to air, surface water and groundwater for use in life cycle inventory (LCI) modelling of field applications. After calculating the primary distribution of pesticides between crop and soil, specific modules calculate the pesticide's fate, thus determining the pesticide emission pattern for the application. PestLCI 2.0 was developed to overcome the limitations of the first model version, replacement of fate calculation equations and introducing new modules for macropore flow and effects of tillage. The accompanying pesticide database was expanded, the meteorological and soil databases were extended to include a range of European climatic zones and soil profiles. Environmental emissions calculated by PestLCI 2.0 were compared to results from the risk assessment models SWASH (surface water emissions), FOCUSPEARL (groundwater via matrix leaching) and MACRO (groundwater including macropore flow, only one scenario available) to partially validate the updated model. A case study was carried out to demonstrate the spatial variation of pesticide emission patterns due to dependency on meteorological and soil conditions. Compared to PestLCI 1.0, PestLCI 2.0 calculated lower emissions to surface water and higher emissions to groundwater. Both changes were expected due to new pesticide fate calculation approaches and the inclusion of macropore flow. Differences between the SWASH and FOCUSPEARL and PestLCI 2.0 emission estimates were generally lower than 2 orders of magnitude, with PestLCI generally calculating lower emissions. This is attributed to the LCA approach to quantify average cases, contrasting with the worst-case risk assessment approach inherent to risk assessment. Compared to MACRO, the PestLCI 2.0 estimates for emissions to groundwater were higher, suggesting that PestLCI 2.0 estimates of fractions leached to groundwater may be slightly conservative as a consequence of the chosen macropore modelling approach. The case study showed that the distribution of pesticide emissions between environmental compartments strongly depends on local climate and soil characteristics. PestLCI 2.0 is partly validated in this paper. Judging from the validation data and case study, PestLCI 2.0 is a pesticide emission model in acceptable accordance with both state-of-the-art pesticide risk assessment models. The case study underlines that the common pesticide emission estimation practice in LCI may lead to misestimating the toxicity impacts of pesticide use in LCA.

Environmental implications of the whole supply-chain of products, both goods and services, their use, and waste management, i.e., their entire life cycle from "cradle to grave" have to be considered to achieve more sustainable production and consumption patterns. Progress toward environmental sustainability requires enhancing the methodologies for quantitative, integrated environmental assessment and promoting the use of these methodologies in different domains.

In the context of Life Cycle Assessment (LCA) of products, in recent years, several methodologies have been developed for Life Cycle Impact Assessment (LCIA). The Joint Research Center of the European Commission (EC-JRC) led a "science to decision support" process which resulted in the International Reference Life Cycle Data System (ILCD) Handbook, providing guidelines to the decision and application of methods for LCIA. The Handbook is the result of a comprehensive process of evaluation and selection of existing methods based on a set of scientific and stakeholder acceptance criteria and involving review and consultation by experts, advisory groups and the public. In this study, we report the main features of the ILCD LCIA recommendation development highlighting relevant issues emerged from this "from science to decision support" process in terms of research needs and challenges for LCIA. Comprehensiveness of the assessment, as well as acceptability and applicability of the scientific developments by the stakeholders, are key elements for the design of new methods and to guarantee the mainstreaming of the sustainability concept.

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Organisations: Department of Management Engineering, European Commission - Joint Research Center
Contributors: Sala, S., Pant, R., Hauschild, M. Z., Pennington, D.
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Towards energy and resource efficient manufacturing: A processes and systems approach

This paper aims to provide a systematic overview of the state of the art in energy and resource efficiency increasing methods and techniques in the domain of discrete part manufacturing, with attention for the effectiveness of the available options. For this purpose a structured approach, distinguishing different system scale levels, is applied: starting from a unit process focus, respectively the multi-machine, factory, multi-facility and supply chain levels are covered. Determined by the research contributions reported in literature, the de facto focus of the paper is mainly on energy related aspects of manufacturing. Significant opportunities for systematic efficiency improving measures are identified and summarized in this area.

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Stichting Katholieke Universiteit, Purdue University, University of California, Technical University of Braunschweig, Queen's University Kingston, University of New South Wales

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Valg af afværge med inddragelse af livscyklusvurdering (LCA)

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Organisations: Water Resources Engineering, Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering, Polytechnique Montreal
Contributors: Lemming, G., Chambon, J. C. C., Binning, P. J., Bjerg, P. L., Hauschild, M. Z., Margni, M., Bulle, C.
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Validation of PestLCI 2.0, an updated and expanded model to estimate pesticide emissions for use in LCI

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Dijkman, T. J., Birkved, M., Hauschild, M. Z.
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A bright future for addressing chemical emissions in life cycle assessment

General information
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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, University of Michigan, Ann Arbor, Radboud University Nijmegen
Contributors: Hauschild, M. Z., Jolliet, O., Huijbregts, M. A.
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Accounting for the potential value of temporary carbon storage: The issue of choosing relevant time horizons

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Contributors: Jørgensen, S. V., Hauschild, M. Z.
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Addressing Speciation in the Effect Factor for Characterisation of Freshwater Ecotoxicity: The case of copper

Purpose: Determination of the ecotoxicity effect factor (EF) in LCIA is based on test data reporting the total dissolved concentration of a substance. In spite of the recognized influence of chemical speciation and physico-chemical characteristics of the aquatic systems on toxicity of dissolved metals, these properties are not considered when calculating characterization factors (CFs) for metals. It is hypothesized that the main cause of the variation in reported EC50 values of Cu among published test results lies in different speciation patterns for Cu in the test media, and that the toxicity of Cu is predominantly caused by the free Cu2+ ion. Hence, the free Cu2+ ion concentration should substitute the total dissolved metal concentration when determining the EF. Methods: The study was based on a review of published ecotoxicity studies reporting acute and chronic EC50 data for Cu to Daphnia magna and to different species of fish and algae. The speciation pattern of Cu in the different media applied in the studies was calculated using the Visual Minteq model. EFs were
calculated according to the expression applied in the USEtox™ characterization model. Results and Discussion: Reported EC50 values for Cu show variations of one to several orders of magnitude for the same organism, but the study indicates that the large variation is caused by differences in water chemistry of the test media influencing the metal speciation. The relationship between the calculated free Cu2+ ion concentration and reported EC50-values indicates that the aquatic ecotoxicity of Cu to D. magna can be predicted from the free ion concentration. Other results confirm that the free Cu2+ ion concentration depends on the [Cu]/[DOC] ratio since the majority of the total dissolved Cu is present as Cu-DOC complexes when the media contains more than 1 mg/L of DOC, and since Cu in such complexes has limited availability to the test organisms. Conclusions: These results suggest that speciation should be taken into account in the modelling of both EFs and fate factors (FF) for LCIA, and the EF for Cu in the aquatic environment should be based on the concentration of the free Cu2+ ion.

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A Methodology for Inclusion of Terrestrial Ecotoxic Impacts of Metals in Life Cycle Impact Assessment

Terrestrial ecotoxicity is in most cases not addressed or to a very limited extent in life cycle assessment (LCA). We are developing a new method for calculating terrestrial ecotoxicity characterization factor (CF) of metals for application in life cycle impact assessment (LCIA). The method takes into account metal speciation and interactions with soil organic constituents, because these mechanisms control metal bioavailability and influence their toxic properties. Transfer functions and geochemical speciation models are employed to calculate reactive and available fractions of metals in 1300 soils spanning a wide range of properties and pore water chemistry. Site-specific fate factors (FF), bioavailability factors (BF) and effect factors (EF) are then calculated for these soils. The biggest variability is observed for BF, which can vary from 2 to 6 orders of magnitude for the cases of Ni and Cu, respectively. These variations are a result of variability in soil properties such as pH, organic carbon or clay content. Published terrestrial biotic ligand models (TBLM) and free ion activity models (FIAM) are next employed in order to derive terrestrial ecotoxicity EFs. Median EFs predicted with TBLMs for Cu and Ni correspond to average ecotoxicity (range) of 12.4 (6.6 – 364) and 1194 (62 – 42164) μg/L, respectively. EFs derived with FIAMs turn out to be 6.5 (Cu) and 7.5 (Ni) times higher than these derived with TBLMs. The ecotoxicity ratio of Cu to Ni is accurately predicted with both models and the contribution of EF to the CF is within the same order of magnitude or lower comparing to that of the BF. Us, FIAMs can be employed to calculate EFs for metals for which TBLMs are not available. From a set of spatially explicit CFs, site-generic CFs can be derived at global or continental scales. For applications in LCIA, the trade-off between the level of geographical detail and the level of uncertainty in both spatially explicit and site-generic CFs remains to be investigated. The method highlights the importance of taking into account variability of soil properties in deriving operational characterization factors for terrestrial ecotoxicity of metals.

General information

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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Contributors: Owsianiak, M., Rosenbaum, R. K., Hauschild, M. Z.
An improved model for estimating pesticide emissions for agricultural LCA

Credible quantification of chemical emissions in the inventory phase of Life Cycle Assessment (LCA) is crucial since chemicals are the dominating cause of the human and ecotoxicity-related environmental impacts in Life Cycle Impact Assessment (LCIA). When applying LCA for assessment of agricultural products, off-target pesticide emissions need to be quantified as accurately as possible because of the considerable toxicity effects associated with chemicals designed to have a high impact on biological organisms like for example insects or weed plants. PestLCI was developed to estimate the fractions of the applied pesticide that is emitted from a field to the surrounding environmental compartments: air, surface water, and ground water. However, the applicability of the model has been limited to 1 typical Danish soil type and 1 climatic profile obtained from the national Danish meteorological station. To overcome these limitations, a reworked and updated version of PestLCI is presented here. The new model includes 16 European climate types and 6 mean European soil characteristic profiles covering all dominant European soil types to widen the geographical scope and to allow contemporary (varying site and or climate condition) and future (change climate condition of a location) differentiation. In addition, the tillage frequency is now incorporated as an input parameter. The tillage frequency has an impact on the soil permeability through its relation to the occurring frequency of macro pores in the top soil, and thus the initial leaching rate of pesticide through preferential flow. A third improvement of the updated model is a simplified user interface which makes the model easier to evaluate and operate. The updated PestLCI model is demonstrated on cases involving different climatic circumstances and locations presenting the resulting variations in pesticide emission patterns.

Are Free Ion Activity Models Sufficient Alternatives to Biotic Ligand Models in Evaluating Metal Toxic Impacts in Terrestrial Environments?

Metal partitioning between solid and aqueous phases and speciation in soil pore water control the bioavailability of toxic forms of metals, while protons and base cations can mitigate metal ecotoxicity by competitive interactions with biotic ligands. Employment of BLMs to evaluate toxicity potential of metals in soils results in site-specific toxicity scores due to large variability of soil properties and differences in ionic composition. Unfortunately, terrestrial BMLs are available only for few metals and few organisms, thus their applicability to hazard ranking or toxic impact assessment is low and alternatives must be found. In this study, we compared published terrestrial BLMs and their potential alternatives such as free ion activity models (FIAM), for applicability in addressing metal toxic impacts in terrestrial environments. A set of 1300 soils representative for the whole world is employed to calculate EC50 and thereafter hazardous concentration HC50 (geometric mean of all EC50) for these terrestrial organisms, for which both TBLMs and FIAMs are available. Results showed that median HC50 for all soils predicted with BLMs range 2 and 3 orders of magnitude for copper and nickel, respectively. In all cases, predictions of FIAMs fall within the range of values predicted with BLMs, and toxicity ratio of copper to nickel is accurately predicted with both models. us, both models are able to distinguish between the two metals in terms of their average toxicity. Given that the calculated toxicity scores show large variability even for soils located in close proximity to each other, selection of FIAMs is also justified in deriving soil quality criteria. It remains to be investigated at what spatial scale the FIAMs are a good alternative to TBLMs in evaluating metal toxic impacts in terrestrial environments.
Assessing the impacts of industrial water use in Life Cycle Assessment

Use of freshwater gives rise to important environmental impacts to consider in the sustainability analysis of an industry or a product. Water use impacts are highly dependent on the local or regional conditions, and apart from the quantity that is extracted and used, the impact of the freshwater use also depends on the local sensitivity to freshwater extraction, and the change in the quality from water intake to discharge of the used water. A methodology is presented catering to these characteristics of the water use issue and demonstrated on an industrial case study from the biotech industry.
Assessing the most Sustainable Alternative for Production of drinking water - ASTA a decision support system

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Assessing the most sustainable alternative for production of drinking water – ASTA a decision support system alternatives fulfilling the EU-Water Framework Directive

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Atmospheric fate of non volatile and ionizable compounds
A modified version of the Multimedia Activity Model for Ionics MAMI, including two-layered atmosphere, air–water interface partitioning, intermittent rainfall and variable cloud coverage was developed to simulate the atmospheric fate of ten low volatility or ionizable organic chemicals. Probabilistic simulations describing the uncertainty of substance and environmental input properties were run to evaluate the impact of atmospheric parameters, ionization and air–water (or air–ice) interface enrichment. The rate of degradation and the concentration of OH radicals, the duration of dry and wet periods, and the parameters describing air–water partitioning (KA/W and temperature) and ionization (pKa and pH) are the key parameters determining the potential for long range transport. Wet deposition is an important removal process, but its efficiency is limited, primarily by the duration of the dry period between precipitation events. Given the underlying model assumptions, the presence of clouds contributes to the higher persistence in the troposphere because of the capacity of cloud water to accumulate and transport non-volatile (e.g. 2,4-D) and surface-active chemicals (e.g. PFOA). This limits the efficiency of wet deposition from the troposphere enhancing long-range transport.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Environmental Chemistry, Unilever, University of Michigan, Ann Arbor
Contributors: Franco, A., Hauschild, M. Z., Jolliet, O., Trapp, S.
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Can freshwater toxicity models (FIAM and BLM) be applicable to marine ecosystem?

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Climate change damage functions in LCA: – (2) data availability and selection of indicators
Emissions of greenhouse gases among other things lead to increasing atmospheric CO2 concentrations, increasing temperatures, changed precipitation patterns and thus multi-factorial changes in the growth environment (1). Primary producers in both terrestrial and aquatic ecosystems and consumers in the food web will experience ecophysiological changes as a consequence of this. To date, only very few truly multi-factorial ecophysiological experiments at the field scale exist. Results from these suggest that the sensitivities of species and ecosystems towards a changing growth environment will be variable (2). Modeling exercises suggest large-scale range shifts of the major biomes of the world (1). The unknown magnitude of future GHG emissions and the complexity of the climate-carbon system induce large uncertainties in the projected changes. A changed climate may result in new interactions and new directions of ecosystem change due to differing adaptive capacities and new species assemblages. Within the framework ‘ecosystem services’ both marketed and non-marketed utilities of the natural environment are formulated (3). Provisioning, cultural, supporting, and regulating ecosystem services have been described. How will these services be affected by the increasing atmospheric GHG concentrations? How can the changes be expressed in a damage model for LCIA? For the area of protection ‘Natural environment’ both sensitive and robust responses to climate change may be foreseen for different species within ecosystems and between ecosystems. A common metric may thus show high variability. Plural metrics may be needed to adequately describe the variety of different ecosystem services in different regional settings. By evaluation of available data from e.g. global monitoring initiatives of ecosystem services such as UN’s Food and Agriculture Organisation (FAO), UN-REDD (reducing emissions from deforestation and forest degradation in developing countries), and other available sources (e.g. the Global Biodiversity Information Facility), we discuss the selection of indicators for different environmental services from the natural environment, how these can be related to life cycle inventory results for GHG emissions and what would be appropriate metrics for the resulting damage to the area of protection ‘Natural environment’. References [1] Fischlin A, Midgley JT et al 2007. Chapter 4 Ecosystems, their properties, goods and services. In: Climate change 2007. Cambridge, Cambridge University Press, p. 211-272. [2] Mikkelsen TN, Beier C, et al. (2008) Experimental design of multifactor climate change experiments with elevated CO2, warming and drought – the CLIMAIITE project. Functional Ecology, 22, 185-195. [3] Millennium Ecosystem Assessment, 2005. Ecosystems and
Climate change damage functions in LCA – (1) from global warming potential to natural environment damages

Energy use often is the most significant contributor to the impact category ‘global warming’ in life cycle impact assessment. However, the potential global warming effects on the climate at regional level and consequential effects on the natural environment are not thoroughly described within LCA methodology. The current scientific understanding of the extent of climate change impacts is limited due to the immense complexity of the multi-factorial environmental changes and unknown adaptive capacities at process, species and ecosystem level. In the presentation we argue that the global warming impacts from a product system being studied in an LCA must be seen in context with the changing future background situation. This background situation is among other things affected by e.g. cumulative atmospheric greenhouse gas emissions of yet unknown magnitude. Here, we define climate change damage on the natural environment as climate change driven environmental changes. The man-made environment such as cultivated land, infrastructure and urban areas is not considered. Hypothetical climate change damage functions representing both sensitive and robust responses were analyzed in relation to cumulative greenhouse gas emissions. An attempt was made to link these hypothetical damage functions with current experimental evidence of biological and biogeochemical responses to a changing growth environment. Each LCA stage involves uncertainty due to e.g. choice, modeling, sampling and measurement errors apart from natural variation. Error propagation throughout the stages of the LCA is thus needed. The relative uncertainty (expressed as the coefficient of variation) of the product related emission, of the background situation and of the natural environment responses were compared. It seemed that the overall relative uncertainty of a characterization factor for climate change might be at least 64%-152% indicating a large variability around the unknown mean climate change damage.
to characterise thousands of substances, but the limitation of the available data calls for reliable indicators suitable for extrapolation from the limited data that is available. Indeed, free metal ion concentration has in some cases been shown to be a sufficient indicator of metal toxicity for both aquatic and terrestrial species. With the aim of deriving extrapolations to predict terrestrial toxic impacts of metals from aquatic effect data, we compared copper toxicity of aquatic organisms with that of terrestrial organisms, testing the hypothesis that the free metal ion is an appropriate "general" descriptor of metal toxicity. Results for 128 laboratory tests on Daphnia magna exposed to copper ions (Cu2+) in water show that variation of several orders of magnitude are observed between the toxicity tests. These variations may be a result of the inability of the free metal ion concentration to reflect toxicity, as the presence of protons and other cations reacting with biological binding sites has been shown to affect the toxicity of copper to D. magna. Similar patterns, albeit with smaller variations, are observed for terrestrial organisms. Up to three orders of magnitude difference occur for the extreme case of barley (Hordeum vulgare). Given the scarcity of terrestrial effect data compared to aquatic data, reliable and transparent, mechanistic-based predictions of terrestrial toxic impacts from aquatic effect data would be an important step ahead in the context of LCIA or comparative risk. Here we demonstrate that the overall ability of the free metal ion to reflect toxicity of metals for aquatic and terrestrial organisms is limited. This has consequences if potential terrestrial toxic effects are based on extrapolations from aquatic data, because the use of more sophisticated models such as the Biotic Ligand Model (BLM) would be required. However, extrapolation models based on an improved free ion approach might still be a good proxy, particularly when the comparative nature of life cycle assessment is taken into account.

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Cradle to Cradle and LCA – is there a conflict?
The Cradle to Cradle (C2C) approach to eodesign has been gaining increasing interest among industries, authorities and consumers over the last years. With its focus on resource conservation through closing loops, use of solar-based energy sources, avoidance of certain chemicals and the stated aim to create good rather than just avoid doing too much evil, it appeals more to industry than traditional LCA-based eodesign. What are the real differences between the two approaches, and is there a conflict? Potential points of divergence between C2C and LCA are identified and the ability of C2C to support a sustainable development is discussed.

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Environmental impacts and timeframes of remediation scenarios for chloroethene-contaminated sites

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Importance of linkage between LCA methodology developments and their applications in practice

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Contributors: Laurent, A., Olsen, S. I., Hauschild, M. Z.
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Improved model for estimating pesticide emissions for agricultural LCA: PestLCI2.0: Climate, soil and chemical specificity in LCI modelling

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LCA as an environmental technology development performance indicator of engineered nano-materials and their application in polymers

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Contributors: Miseljic, M., Olsen, S. I., Hauschild, M. Z.
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LCA as an environmental technology development performance indicator of engineered nano-materials and their application in polymers
Engineered nano-material (ENM) application in products has in recent years developed to an important market segment but with rising environmental concerns, as the environmental life cycle impacts, especially toxicity of nanoparticles, are not assessed. Life cycle assessment (LCA) is a holistic tool to assess products and systems, but current knowledge about the development of ENM's environmental impacts is too scarce to be included for application within the LCA framework. In the EUFP7 project MINANO the aim is to develop an efficient, continuous method of large-scale, low cost synthesis of ENM's with functionalities of flame retardancy, UV protection and antimicrobial properties through functionalized Mg(OH)₂, ZnO and Ag nanoparticles. The aim is also to apply the ENM's in plastic and wood-plastic matrixes and thereby develop products that have a new and improved way of attaining these properties, compared to the conventional ways of attaining these in the polymer product industry. To assure environmental sustainability LCA will be performed within the MINANO project and more precisely comparing the new ENM technology and the conventional technology approach to attain the same functionalities. The LCA in the MINANO project is aimed to be holistic and thereby include the entire life cycle of the nano-polymer products and not be like the current frequently applied nano-material LCA case study approaches where the life cycle is reduced and system boundaries substantially limited. In order to perform accurate assessments LCA needs to be further developed and adjusted according to this material class as there is currently a large uncertainty related to the chemical and biological interactions and toxicological properties of ENM's during their life cycle.

LCA of contaminated site remediation – integration of site-specific impact assessment of local toxic impacts

The environmental impacts from remediation can be divided into primary and secondary impacts. Primary impacts cover the local impacts associated with the on-site contamination, whereas the secondary impacts are impacts on the local, regional and global scale generated by the remediation activities. Although two different remediation methods reach the same remedial target with time, their timeframes can be substantially different and lead to a difference in the local toxic impacts over time. By including primary impacts in the LCA of remediation this quality difference is accounted for. Primary impacts have typically been assessed using site-generic characterization models representing a continental scale and excluding the groundwater compartment. Soil contaminants have therefore generally been assigned as emissions to surface soil or surface water compartments. However, such site-generic assessments poorly reflect the fate of frequent soil contaminants such as chloroethenes as they exclude the groundwater compartment and assume that the main part escapes to the atmosphere. Another important limitation of the generic impact assessment models is that they do not include the formation of metabolites during biodegradation of chlorinated ethenes, of which particularly vinyl chloride is problematic due to its toxic and carcinogenic effects. In this study, the assessment of local toxic impacts with the USEtox model was therefore combined with site-specific reactive transport modeling of the contaminant mass discharge to groundwater. The exposure via contaminated groundwater was subsequently estimated using exposure parameters representing the local groundwater body. The developed methodology for a site-specific impact assessment of primary impacts is tested on two case localities contaminated with chlorinated solvents. Secondary and primary impacts of a
number of remediation options for the two sites are evaluated and compared. The results show that especially vinyl chloride, which is an intermediate product during biodegradation of trichloroethene, contributes significantly to the human toxicity of bioremediation scenarios (86-98 % of the human toxicity impacts at Site 1). The inclusion of primary impacts in the environmental assessment of remediation alternatives gives a more complete basis for comparison of technologies with substantially different timeframes and efficiencies.

**LC-IMPACT Deliverable 2.1. Terrestrial ecotoxicity**

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**Life Cycle Assessment Combined with Remedial Performance Modeling for Assessment of the Environmental Impacts of Remediation Technologies for TCE-Contaminated Sites**

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Organisations: Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering, Interuniversity Research Centre for the Life Cycle of Products, Processes and Services
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**Metal impact in the marine system**

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Normalization in EDIP97 and EDIP2003: updated European inventory for 2004 and guidance towards a consistent use in practice

Purpose: When performing a life cycle assessment (LCA), the LCA practitioner faces the need to express the characterized results in a form suitable for the final interpretation. This can be done using normalization against some common reference impact—the normalization references—which require regular updates. The study presents updated sets of normalization inventories, normalization references for the EDIP97/EDIP2003 methodology and guidance on their consistent use in practice. Materials and methods: The base year of the inventory is 2004; the geographical scope for the non-global impacts is limited to Europe. The emission inventory was collected from different publicly available databases and monitoring bodies. Where necessary, gaps were filled using extrapolations. A new approach for inventoring specific groups of substances—non-methane volatile organic compounds and pesticides—was also developed. The resulting inventory was combined with the most updated sets of characterization factors for each impact category in the EDIP methodologies. Results and discussion: Normalization references are provided for global and non-global impact categories for the year 2004, and causes of variations compared to previous versions are identified. For the non-toxic impact categories, they mainly reflect demographic evolution or change in emission intensities. For the toxic impact categories, they are strongly dependent on improvements in the characterization models as well as on the inventory analysis. Differentiation of substance groups into individual substance emissions is an important source, which leads to identification of inconsistencies in the current practice and guidance to ensure compatibility between LCI and LCIA. Uncertainties are not quantified but are mainly expected to lie in the toxic substance inventories, which are known not to encompass all potentially harmful chemicals released in Europe, e.g. omitting some toxic metals. Conclusions: The present study provides the most updated set of publicly available normalization references for the EDIP methodology and emission inventories for Europe that may also serve for the calculation of normalization references for other impact categories. It is believed to be the best estimate available for Europe and is thus recommended for use along with the guidance provided in this study.
Normalization references for Europe and North America for application with USEtox™ characterization factors

Purpose: In life cycle impact assessment, normalization can be a very effective tool for the life cycle assessment practitioner to interpret results and put them into perspective. The paper presents normalization references for the recently developed USEtox™ model, which aims at calculating globally applicable characterization factors. Normalization references for Europe and North America are determined, and guidance for expansions to other geographical regions is provided. Materials and methods The base years of the European and North American inventories are 2004 and 2002/2008, respectively. Emission data were extracted from two literature sources referring to each of the considered regions. The inventory for North America was adapted to avoid extrapolation of data from other regions and thus bring consistency with the emission inventory for Europe. In spite of different inventory assumptions, a similar coverage of substances was obtained for both regions with relatively high representation of metals and a number of organic compounds, mainly consisting of non-methane volatile organic compounds and pesticides. The two inventory sets were eventually characterized with the characterization factors (CFs) calculated with the version 1.0 of the USEtox™ model and substance database; both interim and recommended CFs were used. Results and discussion: Normalization references are provided for Europe and North America for the three USEtox™ toxic impact categories; ratios between the normalization references for the two regions in all cases lie below a factor of 3. Causes for the observed discrepancies are found to be different inventory assumptions as well as variations in the type and intensity of actual emissions between the two regions. Additional causes are inventories that only cover a limited number of substances, and the characterization model, which can only provide interim factors for certain substances like metal compounds. Based on these causes and on a review of recent studies on normalization references, a list of substances to be prioritized when collecting emission data was built, demonstrating the importance of metals. Conclusions: In the perspective of further refining the presented normalization references and of calculating new references for other regions, guidance is provided including a list of priority substances that should be considered when building emission inventories for normalization references.

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Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
Normalization references for USEtox™-based toxic impact categories: North American and European economic systems

As an optional step of the life cycle impact assessment (LCIA) phase in the ISO standards, normalization aims to express the magnitude of the impacts by comparing the characterized results against a common reference situation - the normalization references. In this study, we used inventories of two economic regions, North America and Europe, to calculate normalization references for the three currently-modelled USEtox™-based impact categories, i.e. freshwater ecotoxicity, human toxicity, divided into cancer effects and non-cancer effects. Base years for the references are 2004 for Europe and 2006 for North America. The normalization references have been calculated using recommended factors as well as with interim factors, as needed. It is found that, in spite of different inventory assumptions, the normalization references fall within the same order of magnitude for both North America and Europe. By analysing the most contributing substances, metals turn out to dominate the impacts in both regions. This may be explained by the interim status of the characterization factors (CFs) for metals, which might be overestimated in the current model. Part of the explanation may also lie in the incomplete coverage of organics in both the inventory and the CF databases. With respect to the intended...
global character of the USEtox™ model, different approaches to determine normalization references of other economic systems (e.g. Asia or world) are discussed in relation to these findings. Overall, we thus recommend the use of the provided set of normalization references for USEtox™, but we also advocate 1) to perform an update as soon as a more comprehensive inventory can be obtained and as soon as characterization factors for metals are revised; 2) to consider extension to other economic systems in order to allow normalization in USEtox™ to be used on a global scale.

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Site specific pesticide emission patterns: Influence of site specific emissions patterns on pesticide impact potential

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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Contributors: Dijkman, T. J., Birkved, M., Hauschild, M. Z.
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USEtox fate and ecotoxicity factors for comparative assessment of toxic emissions in Life Cycle Analysis: Sensitivity to key chemical properties

The USEtox model was developed in a scientific consensus process involving comparison of and harmonization between existing environmental multimedia fate models. For freshwater ecosystem toxicity, it covers the entire impact pathway, i.e., transforming a chemical emission into potential impacts based on quantitative modeling of fate, exposure, and ecotoxicity effects. Taken together, these are represented as chemical-specific characterization factors (CFs). Through analysis of freshwater CFs for approximately 2500 organic chemicals, with special focus on a subset of chemicals with characteristic properties, this work provides understanding of the basis for calculations of CFs in USEtox. In addition, it offers insight into the chemical properties and critical mechanisms covering the continuum from chemical emission to freshwater ecosystem toxicity. For an emission directly to water, the effect factor, which is obtained from laboratory measurements of substance toxicity to different phyla, strongly controls freshwater ecotoxicity, with a range of up to 10 orders of magnitude. Chemical-specific differences in multimedia transfer influence the CF for freshwater emissions by less than two orders of magnitude. However, for an emission to air or soil, differences in chemical properties may decrease the CF by up to 10 orders of magnitude, as a result of intermedia transfer and degradation. This result brings new clarity to the relative contributions of fate and freshwater ecotoxicity to the overall characterization factor.

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USEtox human exposure and toxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties

Purpose
The aim of this paper is to provide science-based consensus and guidance for health effects modelling in comparative assessments based on human exposure and toxicity. This aim is achieved by i) describing the USEtoxTM exposure and toxicity models representing consensus and recommended modelling practice, ii) identifying key mechanisms influencing human exposure and toxicity effects of chemical emissions, iii) extending substance coverage.

Methods
The methods section of this paper contains a detailed documentation of both the human exposure and toxic effects models of USEtoxTM, to determine impacts on human health per kg substance emitted in different compartments. These are considered as scientific consensus and therefore recommended practice for comparative toxic impact assessment. The framework of the exposure model is described in details including the modelling of each exposure pathway considered (i.e. inhalation through air, ingestion through i) drinking water, ii) agricultural produce, iii) meat and milk, and iv) fish). The calculation of human health effect factors for cancer and non-cancer effects via ingestion and inhalation exposure respectively is described. This section also includes discussions regarding parameterisation and estimation of input data needed, including route-to-route and acute-to-chronic extrapolations. Results and discussion
For most chemicals in USEtoxTM, inhalation, above-ground agricultural produce, and fish are the important exposure pathways with key driving factors being the compartment and place of emission, partitioning, degradation, bioaccumulation and bioconcentration, and dietary habits of the population. For inhalation, the population density is the key factor driving the intake, thus the importance to differentiate emissions in urban areas, except for very persistent and mobile chemicals that are taken in by the global population independently from their place of emission. The analysis of carcinogenic potency (TD50) when volatile chemicals are administrated to rats and mice by both inhalation and an oral route suggests that results by one route can reasonably be used to represent another route. However, we first identify and mark as interim chemicals for which observed tumours are directly related to a given exposure route (e.g. for nasal or lung, or gastrointestinal cancers) or for which absorbed fraction by inhalation and by oral route differ greatly. Conclusions
A documentation of the human exposure and toxicity models of USEtoxTM is provided, and key factors driving the human health characterisation factor are identified. Approaches are proposed to derive human toxic effect factors and expand the number of chemicals in USEtoxTM, primarily by extrapolating from an oral route to exposure in air (and optionally acute-to-chronic). Some exposure pathways (e.g. indoor inhalation, pesticide residues, dermal exposure) will be included in a later stage. USEtoxTM is applicable in various comparative toxicity impact assessments and not limited to LCA.
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
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Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
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BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
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BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
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Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
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Scopus rating (2005): SJR 0.648 SNIP 1.777
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Ability of carbon footprint to reflect the environmental burden of a product or service – an empirical study

In the context of a global awareness of the climate change, carbon footprint (CFP) has recently become extensively used as a simple way to sensitize not only consumers in their purchasing behaviours but also public opinion in general. However, limitations in its environmental representativeness arise if one decides to expand the outlook to include other environmental impacts, which are commonly evaluated in Life Cycle Assessments (LCA). In that perspective, over 500 products/services and two concrete cases are investigated, using the EDIP-methodology and the USEtox-based toxicity-related impacts, each one updated with the latest set of characterization factors and with normalization references for the emission year 2004. Outcome of the study shows that carbon footprinting coincides well with the LCA-based global warming assessment, though divergences rise whenever NMVOC show a significant contribution in the inventory. Among other impact categories, especially the toxicity-related impacts do not correlate and show significant differences to carbon footprint results. Despite the fact that carbon footprint is a first step towards a more "environmental friendly" policy, its implications shall therefore be nuanced as they might overlook other environmentally-relevant impacts and lead to possible misinterpretations, if for instance a product presenting low CO2 emissions is qualified as "green", even though its true environmental burden is high due to the contribution of other impacts (e.g. human toxicity).

Assessing the validity of impact pathways for child labour and well-being in Social Life Cycle Assessment

Background, aim and scope Assuming that the goal of social life cycle assessment (SLCA) is to assess damage and benefits on its ‘area of protection’ (AoP) as accurately as possible, it follows that the impact pathways, describing the cause effect relationship between indicator and the AoP, should have a consistent theoretical foundation so the inventory results can be associated with a predictable damage or benefit to the AoP. This article uses two concrete examples from the work on SLCA to analyse to what extent this is the case in current practice. One considers whether indicators included in SLCA approaches can validly assess impacts on the well-being of the stakeholder, whereas the other example addresses whether the ‘incidence of child labour’ is a valid measure for impacts on the AoPs. Materials and methods The theoretical basis for the impact pathway between the relevant indicators and the AoPs is analysed drawing on research from relevant scientific fields. Results The examples show a lack of valid impact pathways in both examples. The first example shows that depending on the definition of ‘well-being’, the assessment of impacts on well-being of the stakeholder cannot be performed exclusively with the type of indicators which are presently used in SLCA approaches. The second example shows that the mere fact that a child is working tells little about how this may damage or benefit the AoPs, implying that the normally used indicator; ‘incidence of child labour’ lacks validity in relation to predicting damage or benefit on the AoPs of SLCA. Discussion New indicators are proposed to mitigate the problem of invalid impact pathways. However, several problems arise relating to difficulties in getting data, the usability of the new indicators in management...
situations, and, in relation to example one, boundary setting issues. Conclusions The article shows that it is possible to assess the validity of the impact pathways in SLCA. It thereby point to the possibility of utilising the same framework that underpins the environmental LCA in this regard. It also shows that in relation to both of the specific examples investigated, the validity of the impact pathways may be improved by adopting other indicators, which does, however, come with a considerable ‘price’. Recommendations and perspectives It is argued that there is a need for analysing impact pathways of other impact categories often included in SLCA in order to establish indicators that better reflect actual damage or benefit to the AoPs.

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Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
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Carbon footprint as environmental performance indicator for the manufacturing industry

With the current focus on our climate change impacts, the embodied CO2 emission or "Carbon footprint" is often used as an environmental performance indicator for our products or production activities. The ability of carbon footprint to represent other types of impact like human toxicity, and hence the overall environmental impact is investigated based on life cycle assessments of several materials of major relevance to manufacturing industries. The dependence of the carbon footprint on the assumed scenarios for generation of thermal and electrical energy in the life cycle of the materials is analyzed, and the appropriateness of carbon footprint as an overall indicator of the environmental performance is discussed.

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Characterisation of social impacts in LCA. Part 1: Development of indicators for labour rights

Background, Aim and Scope The authors have earlier suggested a framework for life cycle impact assessment (LCIA) to form the modelling basis of Social LCA. In this framework the fundamental labour rights were pointed out as obligatory issues to be addressed, and protection and promotion of human dignity and well-being as the ultimate goal and area of protection of Social LCA. The intended main application of this framework for Social LCA was to support management decisions in companies who wish to conduct business in a socially responsible manner, by providing information about the potential social impacts on people caused by the activities in the life cycle of a product. Environmental LCA normally uses quantitative and comparable indicators to provide a simple representation of the environmental impacts from the product lifecycle. This poses a challenge to the Social LCA framework because due to their complexity, many social impacts are difficult to capture in a meaningful way using traditional quantitative single-criterion indicators. A salient example is the violation of fundamental labour rights (child labour, discrimination, freedom of association, and right to organise and collective bargaining, forced labour). Furthermore, actual violations of these rights somewhere in the product chain are very difficult to substantiate and hence difficult to measure directly. Materials and Methods Based on a scorecard, a multi-criteria indicator model has been developed for assessment of a number of social impact categories. The multi-criteria indicator assesses the effort (will and ability) of a company to manage the individual issues and it calculates a score reflecting the company’s performance in a form which allows aggregation over the life cycle of the product. The multi-criteria indicator model is presented with labour rights as an example, but the underlying principles make it suitable for modelling of other social issues with similar complexity and susceptibility to a management approach. Results The outcome of the scorecard is translated for each impact category through a number of steps into a company performance score which is translated into a risk of social impacts actually occurring. This translation of the scorecard results into a company risk score constitutes the characterisation of the developed Social LCA methodology. The translation from performance score to risk involves assessment of the context of the company in terms of geographical location and industry and of the typical level of social impacts that these entail, and interpretation of the company’s management effort in the light of this context. Discussion The developed indicators in Social LCA are discussed in terms of their ability to reflect impacts within the four obligatory impact categories representing the labour rights according to the conventions of the International Labour Organisation, ILO, covering: Forced labour, Discrimination, Restrictions of freedom of association and collective bargaining, and Child labour. Also their feasibility and the availability of the required data is discussed. Conclusions It is concluded that it is feasible to develop indicators and characterisation methods addressing impacts related to the four obligatory impact categories representing the labour rights. The developed indicators are judged to be both feasible and relevant but this remains to be further investigated in a separate paper in which they are implemented and tested in six separate industrial case studies. Recommendations and Perspectives The suitability of multi-criteria assessment methods to cover other social impacts than the obligatory ILO-based impacts is discussed, and it is argued that the combination of indirect indicators measuring a risk of impacts and direct indicators giving a direct measure of the impacts requires an explicit weighting before interpretation and possible aggregation.
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Characterisation of social impacts in LCA. Part 2: implementation in six company case studies

Abstract Background, Aim and Scope A characterisation model based on multi-criteria indicators has been developed for each of four impact categories representing the labour rights according to the conventions of the International Labour Organisation, ILO, covering: Forced labour, Discrimination, Restrictions of freedom of association and collective bargaining, and Child labour (Dreyer et al, 2009a). These impact categories are considered by the authors to be among the obligatory impact categories in a Social LCA. The characterisation models combine information about the way a company manages its behaviour towards some of its important stakeholders, its employees, with information about the geographical location ad branch of industry of the company and the risk of violations of these workers’ rights inherent in the setting of the company. The result is an indicator score which for each impact category represents the risk that violations occur in the company. In order to test the feasibility and relevance of the developed methodology, it is tested on real cases. Materials and Methods The developed characterisation models are applied to six cases representing individual manufacturing companies from three different continents. Five of the case companies are manufacturing companies while the sixth is a knowledge company. The application involves scoring the management efforts of the case company in a multi-criteria scorecard and translating the scores into an aggregated performance score, which represents the effort of the management in order to prevent violations of the workers’ rights to occur in the company. The company performance score is multiplied by a contextual adjustment score which reflects the risk of violations taking place in the context (in terms of geographical location or industrial branch or sector) of the company. The resulting indicator score represents the risk that violations take place of the labour right represented by the impact category. Results The social impact characterisation is performed for each of the six case studies using the methodology earlier developed. The procedure and outcome are documented through all the intermediary results shown for all four obligatory impact categories for each of the six case studies. Discussion The results are judged against the risk which was observed during visits and interviews at each of the six case companies, and their realism and relevance are discussed. They are found to be satisfactory for all four impact categories for the manufacturing companies, but there are some problems for two of the impact categories in the case company which represents knowledge work, and it is discussed how these problems may be addressed through change of the underlying scorecard or the way in which the scoring is translated into a company performance score. Conclusions It is concluded that it is feasible to perform a characterisation of the impacts related to the four obligatory impact categories representing the labour rights according to the conventions of the International Labour Organisation, ILO, covering: Forced labour, Discrimination, Restrictions of freedom of association and collective bargaining, and Child labour. When compared to the observed situation in the companies, the results are also found to be relevant and realistic. Recommendations and Perspectives The proposed characterisation method is rather time-consuming and can not realistically be applied to all companies in the product system. It must therefore be combined with less time-requiring screening methods which can help identify the key companies in the life cycle for which a detailed analysis is required. The possibility to apply country- or industry sector-based information is discussed, and while it is found useful to identify low-risk companies and eliminate them from more detailed studies, the ability of the screening methods to discriminate between companies located in medium and high risk contexts is questionable.

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Defining the baseline in social life cycle assessment

A relatively broad consensus has formed that the purpose of developing and using the social life cycle assessment (SLCA) is to improve the social conditions for the stakeholders affected by the assessed product's life cycle. To create this effect, the SLCA, among other things, needs to provide valid assessments of the consequence of the decision that it is to support. The consequence of a decision to implement a life cycle of a product can be seen as the difference between the decision being implemented and 'non-implemented' product life cycle. This difference can to some extent be found using the consequential environmental life cycle assessment (ELCA) methodology to identify the processes that change as a consequence of the decision. However, if social impacts are understood as certain changes in the lives of the stakeholders, then social impacts are not only related to product life cycles, meaning that by only assessing impacts related to the processes that change as a consequence of a decision, not all changes in the life situations of the stakeholders will be captured by an assessment following the consequential ELCA methodology. This article seeks to identify these impacts relating to the non-implemented product life cycle and establish indicators for their assessment. A conceptual overview of the non-implemented life cycle situation is established, and the impacts which may be expected from this situation are identified, based on theories and empirical findings from relevant fields of research. Where possible, indicators are proposed for the measurement of the identified impacts. In relation to the workers in the life cycle, the non-implemented life cycle situation may lead to increased levels of unemployment. Unemployment has important social impacts on the workers; however, depending on the context, these impacts may vary significantly. The context can to some extent be identified and based on this, indicators are proposed to assess the impacts of unemployment. In relation to the product user, it was not possible to identify impacts of the non-implemented life cycle on a generic basis. The assessment of the non-implemented life cycle situation increases the validity of the SLCA but at the same time adds a considerable extra task when performing an SLCA. It is therefore discussed to what extent its assessment could be avoided. It is argued that this depends on whether the assessment will still meet the minimum criterion for validity of the assessment, that the assessment should be better than random in indicating the decision alternative with the most favourable social impacts. Based on this, it is concluded that the assessment of the non-implemented life cycle cannot be avoided since an assessment not taking into account the impacts of the non-implemented life cycle will not fulfilling this minimum criterion. To mitigate the task of assessing the impacts of the non-implemented life cycle, new research areas are suggested, relating to simpler ways of performing the assessment as well as to investigations of whether the effect of SLCA can be created through other and potentially simpler assessments than providing an assessment of the consequences of a decision as addressed here.
EASEWASTE-life cycle modeling capabilities for waste management technologies

Background, Aims and Scope The management of municipal solid waste and the associated environmental impacts are subject of growing attention in industrialized countries. EU has recently strongly emphasized the role of LCA in its waste and resource strategies. The development of sustainable solid waste management systems applying a life-cycle perspective requires readily understandable tools for modelling the life cycle impacts of waste management systems. The aim of the paper is to demonstrate the structure, functionalities and LCA modelling capabilities of the PC-based life cycle oriented waste management model EASEWASTE, developed at the Technical University of Denmark specifically to meet the needs of the waste system developer with the objective to evaluate the environmental performance of the various elements of existing or proposed solid waste management systems. Materials and methods The EASEWASTE model supports a full life cycle assessment of any user defined residential, bulky waste or garden waste management system. The model focuses on the major components of the waste and reviews each component in terms of the available waste management options, including bio-gasification and composting, thermal treatment incineration, use-on-land, material sorting and recycling, bottom and fly ash handling, material and energy utilization and landfilling. In order to allow the use of the model in an early stage where local data may be limited, default data sets are provided for waste composition and quantities as well as for the waste technologies mentioned above. The model calculates environmental impacts and resource consumptions and allows the user to trace all impacts to their source in a waste treatment processes or in a specific waste material fraction. In addition to the traditional impact indicators, EASEWASTE incorporates impact categories on stored eco-toxicity, specifically developed for representation of the long term impacts of persistent pollutants in land filled waste. The model reports data at any stage of the LCA and supports identification of most sensitive parameters as well as overall sensitivity analysis and material balances for all substances passing through the system.

Results and Discussion The structure of the model is presented and its functionalities are demonstrated on a hypothetical case study based on waste data from a large Danish municipality. The aim of the case is to demonstrate new waste treatment technologies and their modelling capabilities as well as the LCA modelling capabilities in EASEWASTE to identify the most important impact categories and the main sources of contributions to these in the system for treating the waste. Based on the results, the modelling features, user flexibility and transparency of the EASEWASTE model are discussed. Conclusion EASEWASTE is demonstrated to be a versatile and detailed (engineering) model with a strong differentiation of individual fractions, but it requires an engineering background to use all the features. The model is especially developed for the modelling of the handling of municipal solid wastes and therefore it does not support other wastes such as demolition and large commercial waste. The model is useful for an iterative approach to waste system modelling; its database access supports a quick primary calculation of the impacts from a designed waste system using default data, and based on this, a gradually refined focusing on the parts which contribute the most to the total impacts. The EASEWASTE model allows the user to supply detailed data for waste generation, waste composition including material fractions and chemical properties, sorting efficiencies, waste collection and waste treatment technologies. More generic LCA modelling tools developed for LCA of products do not support these steps of the modelling to the same extent, and also the creation and evaluation of waste collection, waste transportation and waste treatment technology individually or in a designed scenario is much easier in EASEWASTE. Recommendation and Outlook EASEWASTE has been used in the modelling of a number of real case studies and much data have been incorporated into it. Several research projects are currently underway under the Danish 3R (Residual Resources Recovery) research school in support of its further development. There are, however still many issues that have to be improved significantly to facilitate application by other users than model developers. The improvements in consideration are to provide data for more treatment and disposal technologies, and more flexibility. The current version of the model supports the environmental assessment (environmental impacts and resource consumption) of household and small commercial business units waste treatment systems in a Danish context, but it is the ambition that future versions of the model shall support the inclusion of other waste types as well as economic evaluation and that the geographical coverage shall be extended to other countries.

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Environmental Impacts of Remediation of a Trichloroethene-Contaminated Site: Life Cycle Assessment of Remediation Alternatives

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From emission to ecotoxicity: comparative assessment of fate and ecotoxicity in LCA using USEtox

The USEtox model was developed in a scientific consensus process involving comparison of and harmonization between existing environmental multimedia fate models. For life cycle impact assessment, USEtox may be used as a comparative
tool for ecosystem and human toxicity. As a characterization model, it covers the entire impact pathway transforming a chemical emission into potential impacts on freshwater ecosystems based on quantitative modeling of fate, exposure and ecotoxicity effects. Taken together, these are represented as chemical-specific characterization factors (CFs). In the case of freshwater ecotoxicity, impacts are measured as potentially affected or disappeared species [PAF m3-day / kg emitted]. Through analysis of the freshwater CFs of over three thousand organic chemicals, this work provides insight into the chemical properties that most strongly influence freshwater ecosystem toxicity for a variety of emission scenarios. Furthermore, the analysis addresses the influence of chemical properties along the emission-fate-exposure-impact chain of events. The main trends are identified using results for the entire dataset of chemicals, and typical patterns are illustrated for a small selection of chemicals with characteristic combinations of properties. For an emission directly to water, the effect factor, which is obtained from laboratory measurements of substance toxicity to different trophic levels, strongly controls toxicity. Multimedia transfer affects the CF for these emissions by less than two orders of magnitude. However, for emission to air or soil, intermedia transfer and degradation may decrease the CF by up to 10 orders of magnitude. This result shows the importance of the Henry's law constant, the organic carbon and octanol-water partitioning coefficient, the degradation half-life in various media, and the treatment of intermittent rain in the model. The interplay between these parameters and the model, which assumes a typical ratio of water to land surface area, shows that direct air to water transfer is less important for many hydrophilic chemicals than might be suspected. As a result, for some compounds, second-order transfers, eg., from air to soil to water, are relatively more important. USEtox addresses some of the pressing problems in current life cycle impact assessment of chemical emissions by providing a consensus model that can calculate transparent chemical-specific characterization factors.

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LCA as decision support for evaluation of environmental impacts of site remediation scenarios

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Life cycle assessment (LCA) as a decision-support tool for the evaluation of environmental impacts of site remediation on the global, regional and local scale
Life cycle assessment (LCA) was used to compare the environmental impacts of three alternatives for remediating a TCE-contaminated site: (i) enhanced reductive dechlorination (ERD); (ii) in situ thermal desorption (ISTD) and (iii) excavation with off-site soil treatment. In addition, the remediation alternatives were compared to a no action scenario, where only monitoring and natural attenuation takes place. A numerical reactive fracture model was used to predict the timeframes for the ERD and the no action scenarios. Moreover, the model was used to estimate the mass discharge of TCE and degradation products leaching to the drinking water aquifer during these timeframes. These local toxic impacts, referred to as primary impacts, were included in the LCA together with impact on the local, regional and global scale caused by the remediation itself – the termed secondary impacts. The results of the LCA showed that of the three remediation methods compared, the ERD had the lowest total environmental impacts, even though it had significant primary impacts due to its long timeframe. The environmental impacts of ERD were comparable or only slightly higher than those of the no action scenario. ISTD had the highest global warming potential of the three remediation technologies, but excavation proved worse than ISTD in most of the remaining impact categories, e.g. eutrophication, ozone formation, ecotoxicity and human toxicity.

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Life cycle assessment of soil and groundwater remediation technologies: literature review
Background, aim, and scope Life cycle assessment (LCA) is becoming an increasingly widespread tool in support systems for environmental decision-making regarding the cleanup of contaminated sites. In this study, the use of LCA to compare the environmental impacts of different remediation technologies was reviewed. Remediation of a contaminated site reduces a local environmental problem, but at the same time, the remediation activities may cause negative environmental impacts on the local, regional, and global scale. LCA can be used to evaluate the inherent trade-off and to compare remediation scenarios in terms of their associated environmental burden. Main features An overview of the assessed remediation technologies and contaminant types covered in the literature is presented. The LCA methodologies of the 12
reviewed studies were compared and discussed with special focus on their goal and scope definition and the applied impact assessment. The studies differ in their basic approach since some are prospective with focus on decision support while others are retrospective aiming at a more detailed assessment of a completed remediation project. Literature review The literature review showed that only few life cycle assessments have been conducted for in situ remediation technologies aimed at groundwater-threatening contaminants and that the majority of the existing literature focuses on ex situ remediation of contaminated soil. The functional unit applied in the studies is generally based on the volume of contaminated soil (or groundwater) to be treated; this is in four of the studies combined with a cleanup target for the remediation. While earlier studies often used more simplified impact assessment models, the more recent studies based their impact assessment on established methodologies covering the conventional set of impact categories. Ecotoxicity and human toxicity are the impact categories varying the most between these methodologies. Many of the reviewed studies address the importance of evaluating both primary and secondary impacts of site remediation. Primary impacts cover the local impacts related to residual contamination left in the subsurface during and after remediation and will vary between different remediation technologies due to different cleanup efficiencies and cleanup times. Secondary impacts are resource use and emissions arising in other stages of the life cycle of the remediation project. Discussion Among the reviewed literature, different approaches for modeling the long-term primary impacts of site contamination have been used. These include steady state models as well as dynamic models. Primary impacts are not solely a soil contamination or surface water issue, since many frequently occurring contaminants, such as chlorinated solvents, have the potential to migrate to the groundwater as well as evaporate to ambient air causing indoor climate problems. Impacts in the groundwater compartment are not included in established impact assessment methodologies; thus, the potential groundwater contamination impacts from residual contamination are difficult to address in LCA of site remediation. Due to the strong dependence on local conditions (sensitivity of groundwater aquifer, use for drinking water supply, etc.) a more site-specific impact assessment approach than what is normally applied in LCA is of relevance. Conclusions, recommendations, and perspectives The inclusion of groundwater impacts from soil contaminants requires the definition of an impact category covering human toxicity via groundwater or the inclusion of these impacts in the human toxicity impact category and the associated characterization models and normalization procedures. When evaluating groundwater impacts, attention should also be paid to potentially degradable contaminants forming metabolites of higher human toxic concern than the parent compound.
Livscyklusvurdering (LCA) som beslutningsstøtte ved valg af afværgemetoder

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Models for waste life cycle assessment: Review of technical assumptions

A number of waste life cycle assessment (LCA) models have been gradually developed since the early 1990s, in a number of countries, usually independently from each other. Large discrepancies in results have been observed among different waste LCA models, although it has also been shown that results from different LCA studies can be consistent. This paper is an attempt to identify, review and analyse methodologies and technical assumptions used in various parts of selected waste LCA models. Several criteria were identified, which could have significant impacts on the results, such as the functional unit, system boundaries, waste composition and energy modelling. The modelling assumptions of waste management processes, ranging from collection, transportation, intermediate facilities, recycling, thermal treatment, biological treatment, and landfilling, are obviously critical when comparing waste LCA models. This review infers that some of the differences in waste LCA models are inherent to the time they were developed. It is expected that models developed later, benefit from past modelling assumptions and knowledge and issues. Models developed in different countries furthermore rely on geographic specificities that have an impact on the results of waste LCA models. The review concludes that more effort should be employed to harmonise and validate non-geographic assumptions to strengthen waste LCA modelling.
Quantifying sustainability of genetically modified crops

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Scopus rating (2013): CiteScore 3.39 SJR 1.815 SNIP 2.413
Web of Science (2013): Impact factor 3.157
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 2.91 SJR 1.59 SNIP 2.18
Web of Science (2012): Impact factor 2.485
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.99 SJR 1.694 SNIP 2.071
Web of Science (2011): Impact factor 2.428
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.553 SNIP 1.821
Web of Science (2010): Impact factor 2.358
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.519 SNIP 1.919
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.375 SNIP 2.145
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.998 SNIP 1.785
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.021 SNIP 1.819
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.065 SNIP 1.653
Scopus rating (2004): SJR 1.271 SNIP 1.911
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.853 SNIP 1.234
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.498 SNIP 0.903
Scopus rating (2001): SJR 0.45 SNIP 0.731
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.328 SNIP 0.444
Scopus rating (1999): SJR 0.26 SNIP 0.541
Original language: English
DOIs:
10.1016/j.wasman.2010.06.004
Source: orbit
Source-ID: 268093
Research output: Research - peer-review › Journal article – Annual report year: 2010

Quantifying sustainability of genetically modified crops

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Simplified methodology for inclusion of climate parameters in chemical prioritization as applied in life cycle impact assessment and risk assessment – PBT(+C) prioritization

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Aarhus University
Publication date: 2010
Peer-reviewed: Yes
Event: Poster session presented at 20th SETAC Europe Annual Meeting, Sevilla, Spain.
Research output: Research - peer-review › Poster – Annual report year: 2010

The clearwater consensus: the estimation of metal hazard in fresh water

Background, aim, and scope Task Force 3 of the UNEP/SETAC Life Cycle Initiative has been working towards developing scientifically sound methods for quantifying impacts of substances released into the environment. The Clearwater Consensus follows from the Lausanne (Jolliet et al. Int J Life Cycle Assess 11:209–212, 2006) and Apeldoorn (Apeldoorn Int J Life Cycle Assess 9(5):334, 2004) statements by recommending an approach to and identifying further research for quantifying comparative toxicity potentials (CTPs) for ecotoxicological impacts to freshwater receptors from nonferrous metals. The Clearwater Consensus describes stages and considerations for calculating CTPs that address inconsistencies in assumptions and approaches for organic substances and nonferrous metals by focusing on quantifying the bioavailable fraction of a substance. Methods A group of specialists in Life Cycle Assessment, Life Cycle Impact Assessment, metal chemistry, and ecotoxicology met to review advances in research on which to base a consensus on recommended methods to calculate CTPs for metals. Conclusions and recommendations Consensus was reached on introducing a bioavailability factor (BF) into calculating CTPs where the BF quantifies the fraction of total dissolved chemical that is truly dissolved, assuming that the latter is equivalent to the bioavailable fraction. This approach necessitates calculating the effects factor, based on a HC50EC50, according to the bioavailable fraction of chemical. The Consensus recommended deriving the BF using a geochemical model, specifically WHAM VI. Consensus was also reached on the need to incorporate into fate calculations the speciation, size fractions, and dissolution rates of metal complexes for the fate factor calculation. Consideration was given to the characteristics of the evaluative environment defined by the multimedia model, which is necessary because of the dependence of metal bioavailability on water chemistry.

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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
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BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.288 SNIP 0.954
Scopus rating (2001): SJR 0.49 SNIP 1.456
Scopus rating (2000): SJR 0.413 SNIP 1.862
Scopus rating (1999): SJR 0.442 SNIP 1.283
Original language: English
Keywords: Nonferrous metals, Life cycle impact assessment, Comparative toxicity potentials, Metal bioavailability, Freshwater ecotoxicity
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http://dx.doi.org/10.1007/s11367-009-0140-2
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Research output: Research - peer-review › Journal article – Annual report year: 2010

Bæredygtig biodiesel med enzymer

General information
State: Published
Organisations: Department of Chemical and Biochemical Engineering, Center for BioProcess Engineering, Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Nordblad, M., Xu, Y., Herrmann, I. T., Hauschild, M. Z., Jensen, T., Brask, J., Woodley, J.
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Publication date: 2009
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Journal: Dansk Kemi
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ISI indexed (2013): ISI indexed no
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Web of Science (2007): Indexed yes
Web of Science (2004): Indexed yes
Original language: Danish
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Research output: Communication › Journal article – Annual report year: 2009

C balance, carbon dioxide emissions and global warming potentials in LCA-modeling of waste management systems

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Organisations: Residual Resource Engineering, Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering
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Journal: Waste Management and Research
Volume: 27
Issue number: 8
ISSN (Print): 0734-242X
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BFI (2019): BFI-level 1
Deliverable 4.2: Methodology for including specific biological effects and pathogen aspects into LCA

As described in deliverable 4.1 (Larsen et al. 2007) NEPTUNE is using two main types of life cycle impact assessment (LCIA) methodologies when doing LCA studies on the waste water treatment technologies included. The basic methodology is the well known existing EDIP97 methodology (Wenzel et al. 1997, Hauschild and Wenzel 1998) for which the impact assessment on toxicity is PNEC based. However, in order to include the newest development on especially best available practice as regards ecotoxicity a new revised and updated EDIP 200X LCIA methodology has been developed. A first draft of this methodology is presented here. Furthermore, special issues related to waste water have been addressed by including novel development on LCIA methodology for possible impact from pathogens and whole effluent toxicity. Special focus is also allocated to micropollutants with specific toxic mode of action (i.e. endocrine disruptors) and the possibilities and relevance of including impact categories on land use and site-specific assessments have been addressed. Further, the special problems on how to deal with land fill and how to do normalization and weighting of impact potentials are also dealt with. The problem with possible bias in normalization references is especially addressed.
Effects of Globalisation on Carbon Footprints of Products.

Outsourcing of production from the industrialised countries to the newly industrialised economies holds the potential to increase wealth in both places, but what are the environmental costs of the globalised manufacturing systems? This paper looks into the changes in carbon footprint of manufactured products when production is moved from United Kingdom or Denmark to China and uses environmental input-output analysis to calculate the carbon footprint in the bilateral trade between these countries. The results show that differences between the European and Chinese production systems can lead to substantial increases in the carbon footprint of the traded products, even without including the CO2 emissions from the associated transportation.
Due to their generally positive carbon dioxide balance, biofuels are seen as one of the energy carriers in a more sustainable future transportation energy system, but how good is their environmental sustainability, and where lie the main
potentials for improvement of their sustainability? Questions like these require a life cycle perspective on the biofuel - from the cradle (production of the agricultural feedstock) to the grave (use as fuel). An environmental life cycle assessment is performed on biodiesel to compare different production schemes including chemical and enzymatic esterification with the use of methanol or ethanol. The life cycle assessment includes all processes needed for the production, distribution and use of the biodiesel (the product system), and it includes all relevant environmental impacts from the product system, ranging from global impacts like climate change and loss of non-renewable resources over regional impacts like acidification, eutrophication and photochemical ozone to more local impacts like ecotoxicity and physical impacts like land use, to allow judging on the overall environmental sustainability of the biodiesel and to support identification of the main focus points for improvement of the environmental sustainability.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Herrmann, I. T., Hauschild, M. M. Z., Birkved, M.
Publication date: 2009

Event information
Event: The American Oil Chemists' Society Conference
Location: Orlando, Florida, USA
Electronic versions:
AOCS presentation016.ppt
Source: orbit
Source-ID: 246131
Research output: Research › Sound/Visual production (digital) – Annual report year: 2009

LCA as decision support for remediation of contaminated sites: Assessment of groundwater impacts

General information
State: Published
Organisations: Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering
Contributors: Lemming, G., Hauschild, M. Z., Chambon, J. C. C., Binning, P. J., Bjerg, P. L.
Publication date: 2009

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Place of publication: Allerød
Publisher: Niras
Source: orbit
Source-ID: 253057
Research output: Research › Conference abstract in proceedings – Annual report year: 2009

Lifecycle assessment of fuel ethanol from sugarcane in Brazil
This paper presents the lifecycle assessment (LCA) of fuel ethanol, as 100% of the vehicle fuel, from sugarcane in Brazil. The functional unit is 10,000 km run in an urban area by a car with a 1,600-cm³ engine running on fuel hydrated ethanol, and the resulting reference flow is 1,000 kg of ethanol. The product system includes agricultural and industrial activities, distribution, cogeneration of electricity and steam, ethanol use during car driving, and industrial by-products recycling to irrigate sugarcane fields. The use of sugarcane by the ethanol agribusiness is one of the foremost financial resources for the economy of the Brazilian rural area, which occupies extensive areas and provides far-reaching potentials for renewable fuel production. But, there are environmental impacts during the fuel ethanol lifecycle, which this paper intents to analyze, including addressing the main activities responsible for such impacts and indicating some suggestions to minimize the impacts. This study is classified as an applied quantitative research, and the technical procedure to achieve the exploratory goal is based on bibliographic revision, documental research, primary data collection, and study cases at sugarcane farms and fuel ethanol industries in the northeast of São Paulo State, Brazil. The methodological structure for this LCA study is in agreement with the International Standardization Organization, and the method used is the Environmental Design of Industrial Products. The lifecycle impact assessment (LCIA) covers the following emission-related impact categories: global warming, ozone formation, acidification, nutrient enrichment, ecotoxicity, and human toxicity. The results of the fuel ethanol LCI demonstrate that even though alcohol is considered a renewable fuel because it comes from biomass (sugarcane), it uses a high quantity and diversity of nonrenewable resources over its lifecycle. The input of renewable resources is also high mainly because of the water consumption in the industrial phases, due to the sugarcane washing process. During the lifecycle of alcohol, there is a surplus of electric energy due to the cogeneration activity. Another focus point is the quantity of emissions to the atmosphere and the diversity of the substances emitted. Harvesting is the unit process that contributes most to global warming. For photochemical ozone formation, harvesting is also the activity with the strongest contributions due to the burning in harvesting and the emissions from using diesel fuel.
The acidification impact potential is mostly due to the NOx emitted by the combustion of ethanol during use, on account of the sulfuric acid use in the industrial process and because of the NOx emitted by the burning in harvesting. The main consequence of the intensive use of fertilizers to the field is the high nutrient enrichment impact potential associated with this activity. The main contributions to the ecotoxicity impact potential come from chemical applications during crop growth. The activity that presents the highest impact potential for human toxicity (HT) via air and via soil is harvesting. Via water, HT potential is high in harvesting due to lubricant use on the machines. The normalization results indicate that nutrient enrichment, acidification, and human toxicity via air and via water are the most significant impact potentials for the lifecycle of fuel ethanol. The fuel ethanol lifecycle contributes negatively to all the impact potentials analyzed: global warming, ozone formation, acidification, nutrient enrichment, ecotoxicity, and human toxicity. Concerning energy consumption, it consumes less energy than its own production largely because of the electricity cogeneration system, but this process is highly dependent on water. The main causes for the biggest impact potential indicated by the normalization is the nutrient application, the burning in harvesting and the use of diesel fuel. The recommendations for the ethanol lifecycle are: harvesting the sugarcane without burning; more environmentally benign agricultural practices; renewable fuel rather than diesel; not washing sugarcane and implementing water recycling systems during the industrial processing; and improving the system of gases emissions control during the use of ethanol in cars, mainly for NOx. Other studies on the fuel ethanol from sugarcane may analyze in more details the social aspects, the biodiversity, and the land use impact.

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State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
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Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 14
Issue number: 3
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
Life cycle assessment of offset printed matter with EDIP97: – how important are emissions of chemicals?

Existing product life cycle assessment (LCA) studies on offset printed matter all point at paper as the overall dominating cause of environmental impacts. All studies focus on energy consumption and the dominating role of paper is primarily based on the energy-related impact categories global warming, acidification and nutrient enrichment. Ecotoxicity and human toxicity, which are related to emissions of chemicals etc., are only included to a limited degree or not at all. In this paper we include the impacts from chemicals emitted during the life cycle of sheet fed offset printed matter. This is done by making use of some of the newest knowledge about emissions from the production at the printing industry combined with knowledge about the composition of the printing materials used. In cases with available data also upstream emissions from the production of printing materials are included. The results show that inclusion of the chemical emission-related impacts makes the EDIP97 impact profile of sheet fed offset products much more varied, as well for the normalised profiles as for the profiles weighted by distance to political environmental targets. Especially the ecotoxicity impact potential related to the production stage may contribute significantly, and the use of paper no longer becomes the overall dominating factor driving the environmental impacts.
Recent developments in Life Cycle Assessment

Life Cycle Assessment is a tool to assess the environmental impacts and resources used throughout a product’s life cycle, i.e., from raw material acquisition, via production and use phases, to waste management. The methodological development in LCA has been strong, and LCA is broadly applied in practice. The aim of this paper is to provide a review of recent developments of LCA methods. The focus is on some areas where there has been an intense methodological development during the last years. We also highlight some of the emerging issues. In relation to the Goal and Scope definition we especially discuss the distinction between attributional and consequential LCA. For the Inventory Analysis, this distinction is relevant when discussing system boundaries, data collection, and allocation. Also highlighted are developments concerning databases and Input–Output and hybrid LCA. In the sections on Life Cycle Impact Assessment we discuss the characteristics of the modelling as well as some recent developments for specific impact categories and weighting. In relation to the Interpretation the focus is on uncertainty analysis. Finally, we discuss recent developments in relation to some of the strengths and weaknesses of LCA.

General information

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Journal: Journal of Environmental Management
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.54 SJR 1.161 SNIP 1.705
Web of Science (2017): Impact factor 4.005
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 4.28 SJR 1.161 SNIP 1.809
Web of Science (2016): Impact factor 4.01
Relevance and feasibility of Social Life Cycle Assessment from a Company Perspective

Methodology development should reflect demands from the intended users: what are the needs of the user group and what is feasible in terms of requirements involving data and work? Mapping these questions of relevance and feasibility is thus a way to facilitate a higher degree of relevance of the developed methodology. For the emerging area of social life cycle assessment (SLCA), several different potential user groups may be identified. This article addresses the issues of relevance and feasibility of SLCA from a company perspective through a series of interviews among potential company users. The empirical basis for the survey is a series of eight semi-structured interviews with larger Danish companies, all of which potentially have the capacity and will to use comprehensive social assessment methodologies. SLCA is not yet a well-defined methodology, but still it is possible to outline several potential applications of SLCA and the tasks a company must be able to perform in order to make use of these applications. The interviews focus on the companies’ interest in these potential applications and their ability and willingness to undertake the required work. Based on these interviews, three hypotheses are developed relating to these companies’ potential use of SLCA, viz.: (1) needs which may be supported by SLCA relate to three different applications, being comparative assertions, use stage assessments, and weighting of social impacts; (2) assessing the full life cycle of a product or service is rarely possible for the companies; and (3) companies see their social responsibility in the product chain as broader than dictated by the product perspective of SLCA. Trends for these three hypotheses developed on the basis of the opinions of the interviewees. Also, factors influencing the generalization of the results to cover other industries are analyzed. Full comparative assertions as known from environmental life cycle assessment (LCA) may be difficult in a company context due to several difficulties in assessing the full life cycle. Furthermore, the comparative assertion may potentially be hampered by differences in how companies typically allocate responsibility along the product chain and how it is done in SLCA, creating a boundary setting issue. These problems do, only in a limited degree, apply for both the use stage assessment and the tool for weighting social issues. Despite these difficulties, it is concluded that all three applications of SLCA may be possible for the interviewed companies, but it seems the tendency is to demand assessment tools with very limited life cycle perspective, which to some extent deviate from the original thought behind the LCA tools as being holistic decision aid tools. It is advocated that there is a need to focus more on questions regarding the relevance and feasibility of SLCA from several different perspectives to direct the future methodology development.
The influence of speciation on the ecotoxic effects of heavy metals in aquatic systems

The fate, bioavailability and exposure of aquatic organisms to potentially toxic metals are strongly influenced by the speciation of the metal ions in the medium. Metal speciation is mainly controlled by pH, ionic strength, and presence of ligands ranging from small ions (e.g. citrate, EDTA) to highly complex compounds such as dissolved organic matter, DOM. In the concept of Life Cycle Impact Assessment (LCIA) the Characterisation Factor (CF) expresses the relative hazard of a chemical as the product of a Fate Factor (FF) and an Effect Factor (EF): $CF = FF \times EF$. CFs has been developed for the total chemical mass emitted into the environment. In this study we show that by means of the metal speciation, EF can be
corrected in such a way that the resulting CF becomes more accurate for each metal in the LCIA. The chemical speciation in various media was calculated by Visual Minteq ver. 2.56. Calculations showed that the speciation is very dependent on the metal concentration and the composition of the media. A large variation in heavy metal toxicity for the same test organism was found for a given metal in different media. Our main hypothesis is that this is due to differences in speciation and that if we correct for this we will find the same EC50 for the free metal ion species for Daphnia magna in both natural waters and synthetic media. This should be applied to correct the EF influence on CF in LCIA when the speciation for the metal is known. The hypothesis has been tested by comparing studies carried out in natural waters and in synthetic test media and analysing correlations between the free metal concentration and acute as well as chronic toxicity reported for Cd, Cu and Zn.

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Department of Environmental Science and Engineering, University of Copenhagen
Contributors: Jensen, K. S., Borggaard, O. K., Hauschild, M. Z., Holm, P. E.
Number of pages: 355
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Peer-reviewed: No
Source: orbit
Source-ID: 253192
Research output: Research » Poster – Annual report year: 2009

Use of LCA as decision support for the selection of remedial strategies for remediation of contaminated soil and groundwater: Abstract TU 245

General information
State: Published
Organisations: Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering
Contributors: Lemming, G., Hauschild, M. Z., Bjerg, P. L.
Number of pages: 204
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Volume: Abstract Book
Place of publication: Brussels
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Source: orbit
Source-ID: 244375
Research output: Research - peer-review » Conference abstract in proceedings – Annual report year: 2009

Use of LCA as decision support for the selection of remedial strategies for remediation of contaminated soil and groundwater

Groundwater is the dominant source of drinking water in Denmark and the general policy is to maintain the groundwater as a clean source of drinking water. The risk of groundwater contamination is therefore often the prime reason for remediating a contaminated site. Chlorinated solvents are among the contaminants most frequently found to be threatening the groundwater quality in Denmark and worldwide. Life cycle assessment has recently been applied as part of decision support for contaminated site management and subsurface remediation techniques. Impacts in the groundwater compartment have only gained little attention in established life cycle impact assessment methodologies. Often groundwater is included in a general freshwater compartment, is simply disregarded, or is only functioning as a sink for contaminant emissions. When applying LCA for decision support for contaminated site remediation, there is a trade-off between obtaining local beneficial effects from the remediation and generating environmental impacts on the regional and global scale due to the remedial actions. Therefore there is a need for including the impact of soil contaminants that will potentially leach to the groundwater, e.g. chlorinated solvents, in the LCA. The poster discusses possible ways to assess the risk for contaminating the groundwater with chlorinated solvents within the LCA framework. This can be used to assess the potential groundwater impact of residual contamination when remediation techniques with different remedial efficiencies are compared or when a no-action scenario is compared to a remedial action scenario. The groundwater impact is evaluated for a case study comparing a number of remedial scenarios to a no-action scenario.

General information
State: Published
Assessing social impacts in a life cycle perspective - Lessons learned

In our globalised economy, important stakeholder groups nowadays hold companies responsible for the social impacts they cause in their product chain through activities like child labour, corruption or discrimination of employees. Many companies thus see themselves in need of a tool which can help them make informed decisions about their social impacts throughout the life cycle of their products. The paper presents lessons learned from four years of work with industry on development of a methodology for social Life Cycle Assessment and implementation in the industrial product chain. The Social LCA methodology supplements the traditional environment-oriented LCA and the life cycle costing tools in support of sustainability management addressing all three pillars of sustainability: people, planet and profit.
Biogenic carbon accounting in LCA-modelling: Comparison of different criteria

General information
State: Published
Organisations: Residual Resource Engineering, Department of Environmental Engineering, Innovation and Sustainability, Department of Management Engineering
Contributors: Christensen, T. H., Gentil, E., Boldrin, A., Larsen, A. W., Hauschild, M. Z.
Pages: 311
Publication date: 2008
Building a model based on scientific consensus for Life Cycle Impact Assessment of chemicals: The Search for Harmony and Parsimony

Achieving consensus among scientists is often a challenge - particularly in model development. In this article we describe a recent scientific consensus-building process for Life Cycle Impact Assessment (LCIA) models applied to chemical emissions - including the strategy, execution, and results of a process that used model comparison to achieve parsimony. This process has succeeded in establishing a transparent LCIA consensus model. We present the lessons that may be adapted by similar consensus processes in other fields.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering, Quantitative Sustainability Assessment
Contributors: Hauschild, M. Z., Huijbregts, M., Jolliet, O., MacLeod, M., Margni, M., van de Meent, D., Rosenbaum, R. K., McKone, T.
Pages: 7032-7037
Publication date: 2008
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BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.535 SNIP 1.941
Web of Science (2017): Impact factor 6.653
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.26 SJR 2.559 SNIP 1.902
Web of Science (2016): Impact factor 6.198
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 5.61 SJR 2.546 SNIP 1.838
Web of Science (2015): Impact factor 5.393
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.5 SJR 2.777 SNIP 2.003
Web of Science (2014): Impact factor 5.33
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 5.52 SJR 2.952 SNIP 2.102
Web of Science (2013): Impact factor 5.481
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
C balance, carbon dioxide emissions and global warming potentials in LCA-modelling of waste management systems

General information
State: Published
Organisations: Residual Resource Engineering, Department of Environmental Engineering, Innovation and Sustainability, Department of Management Engineering
Contributors: Christensen, T. H., Gentil, E., Boldrin, A., Larsen, A. W., Hauschild, M. Z.
Publication date: 2008

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Development of a recommended Life Cycle Impact Assessment methodology - a European step towards a worldwide method

General information
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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Number of pages: 7
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Development of recommended characterisation factors for primary and secondary particulate matter

General information
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Source-ID: 264161
Research output: Research › Conference abstract in proceedings – Annual report year: 2008

Gone… but not away: Addressing the problem of long-term impacts from landfills in LCA
Background, aim and scope: Land filling of materials with content of toxic metals or highly persistent organic compounds has posed a problem for life cycle assessment (LCA) practitioners for many years. The slow release from the landfill entails a dilution in time, which is dramatic compared to other emissions occurring in the life cycle, and with its focus on the emitted mass, LCA is poorly equipped to handle this difference. As a consequence, the long-term emissions from landfills occurring over thousands of years are often disregarded, which is unacceptable to many stakeholders considering the quantities of toxic substances that can be present. On the other hand, inclusion of all future emissions (over thousands of years) in the inventories potentially dominates all other impacts from the product system. The paper aims to present a pragmatic approach to address this dilemma. Materials and methods: Two new impact categories are introduced representing the stored ecotoxicity and stored human toxicity of the contaminants remaining in the landfill after a ‘foreseeable’ time period of 100 years. The impact scores are calculated using the normal characterisation factors for the ecotoxicity and human toxicity impact categories, and they represent the toxicity potentials of what remains in the landfill after 100 years (hence the term ‘stored’ (eco)toxicity). Normalisation references are developed for the stored toxicity categories based on Danish figures to support comparison with indicator scores for the conventional environmental impact categories. In contrast to the scores for the conventional impact categories, it is uncertain to what extent the stored toxicity scores represent emissions, which will occur at all. Guidance is given on how to reflect this uncertainty in the weighting and interpretation of the scores. Results and discussion: In landfills and road constructions used to deposit residuals from incinerators, less than 1% of the content of metals is leached within the first 100 years. The stored toxicity scores are therefore much higher than the conventional impact scores that represent the actual emissions. Several examples are given illustrating the use and potential significance of the stored toxicity categories. Conclusions and perspectives: The methodology to calculate stored human and ecotoxicity is a simple and pragmatic approach to address LCA’s problem of treating the slow ‘long-term emissions at very low concentrations appropriately. The problem resides in the inventory analysis and the impact assessment, and the methodology circumvents the problem by converting it into a weighting and
interpretation issue accommodating the value-based discussion of how to weight potential effects in the far future.
Identification of best practice: Development of basis for a recommended LCIA methodology for the European Commission

General information
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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
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Peer-reviewed: Yes
Event: Abstract from SETAC Europe 18th Annual Meeting, Warsaw, Poland.
Source: orbit
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Research output: Research - peer-review › Journal article – Annual report year: 2008

Identification of best practice: Development of basis for a recommended LCIA methodology for the European Commission

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Publication date: 2008
Peer-reviewed: Yes
Event: Abstract from InLCA Seattle, September 2008, Seattle, United States of America.
Source: orbit
Source-ID: 264130
Research output: Research - peer-review › Conference abstract for conference – Annual report year: 2008

International consensus model for comparative assessment of chemical emissions in LCA
Under the UNEP-SETAC Life Cycle Initiative the six most commonly used characterisation models for toxic impacts from chemicals were compared and harmonised through a sequence of workshops removing differences which were unintentional or unnecessary. A parsimonious (as simple as possible but as complex as needed) and transparent consensus model, USEtox, was created producing characterisation factors that fall within the range of factors from the
harmonised existing characterisation models. The USEtox model together with factors for several thousand substances are currently under review to form the basis of the recommendations from the UNEP-SETAC Life Cycle Initiative in this field.

**General information**

State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, European Institute for Energy Research, Radboud University Nijmegen, University of Michigan, Ann Arbor, Swiss Federal Institute of Technology, Polytechnique Montreal, University of California at Berkeley, Universidad Rovira i Virgili
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Source: orbit
Source-ID: 264163
Research output: Research › Conference abstract in proceedings – Annual report year: 2008

**Market Forces and the need to design for the environment**

**General information**

State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Jeswiet, J., Hauschild, M. Z.
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BFI (2017): BFI-level 1
Scopus rating (2017): SJR 0.31 SNIP 0.639
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.79 SJR 0.251 SNIP 1.008
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 0.35 SJR 0.155 SNIP 0.23
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 0.65 SJR 0.187 SNIP 0.285
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 0.39 SJR 0.153 SNIP 0.281
ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 0.5 SJR 0.282 SNIP 0.632
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 1.66 SJR 0.664 SNIP 1.471
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.359 SNIP 1.143
Methodologies for Social Life Cycle Assessment: A review

Goal, Scope and Background. In recent years several different approaches towards Social Life Cycle Assessment (SLCA) have been developed. The purpose of this review is to compare these approaches in order to highlight methodological differences and general shortcomings. SLCA has several similarities with other social assessment tools, but in order to limit the review, only claims to address social impacts from an LCA-like framework is considered. Main Features. The review is to a large extent based on conference proceedings and reports of which some are not easily accessible, since very little has been published on SLCA in the open literature. The review follows the methodological steps of the environmental LCA (ELCA) known from the ISO 14044 standard. Results. The review reveals a broad variety in how the approaches address the steps in the ELCA methodology, particularly in the choice and formulation of indicators. The indicators address a wide variety of issues; some approaches focus on impacts created in the very close proximity of the processes included in the product system, whereas others focus on the more remote societal consequences. Only very little focus has been given to the use stage in the product life cycle. Another very important difference among the proposals is their position towards the use of generic data. Several of the proposals argue that social impacts are connected to the conduct of the company leading to the conclusion that each individual company in the product chain has to be assessed, whereas others claim that generic data can give a sufficiently accurate picture of the associated social impacts. Discussion. The SLCA approaches show that the perception of social impacts is very variable. An assessment focussing on social impacts created in the close proximity of the processes included in the product system will not necessarily point in the same direction as an assessment that focuses on the more societal consequences. This point towards the need to agree on the most relevant impacts to include in the SLCA in order to include the bulk of the situation. Regarding the use of generic data as a basis for the assessment, this obviously has an advantage over using site specific data in relation to practicality, however many authors behind the SLCA approaches claim that reasonable accuracy can only be gained through the use of site specific data. However, in this context it is important to remember that the quality of site specific data is very dependent on the auditing approach and therefore not necessarily of high accuracy and that generic data might be designed to take into account the location, sector, size and maybe ownership of a company and thereby in some cases give a reasonable impression of the social impacts that can be expected from the company performing the assessed process. Conclusions. This review gives an overview of the present development of SLCA by presenting the existing approaches to SLCA and discussing how they address the methodological aspects in the ISO standardised ELCA framework. The authors found a multitude of different approaches with regards to nearly all steps in the SLCA methodology reflecting that this is a very new and immature field of LCA. Recommendations and Perspectives. SLCA is at an early stage of development where consensus building still has a long way. Nevertheless, some agreement regarding which impacts are most relevant to include in the SLCA in order to cover the field sufficiently seems paramount if the SLCA is to gain any weight as a decision support tool. Furthermore, some assessment of the difference between site specific and generic data could give valuable perspectives on whether a reasonable accuracy can be gained from using generic data or whether the use of site specific data is mandatory, and if so where it is most important.
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.288 SNIP 0.954
Scopus rating (2001): SJR 0.49 SNIP 1.456
Scopus rating (2000): SJR 0.413 SNIP 1.862
Milestone 4.1 • First draft on complemented LCA methodology

As described in deliverable 4.1, D4.1 (Larsen et al. 2007) NEPTUNE is using two main types of life cycle impact assessment (LCIA) methodologies when doing LCA studies on the waste water treatment technologies included. The basic methodology is the well known existing EDIP97 methodology (Wenzel et al. 1997, Hauschild and Wenzel 1998) for which the impact assessment on toxicity is PNEC based. However, in order to include the newest development on especially best available practice as regards ecotoxicity a new revised and updated EDIP 200X LCIA methodology has been developed. A first draft of this methodology is presented here. Special issues of waste water have been addressed by including novel development on LCIA methodology for possible impact from pathogens and whole effluent toxicity. Special focus is also allocated to micropollutants with specific toxic mode of action (i.e. endocrine disruptors) and the possibilities and relevance of including impact categories on land use and site-specific assessments have been addressed. Further, the special problems on how to deal with land fill and how to do normalisation and especially weighting of impact potentials are also dealt with. This report is a first draft and in principle only outlines the different issues but is more or less detailed in many cases.

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Contributors: Larsen, H. F., Olsen, S. I., Hauschild, M. Z.
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Research output: Research › Report – Annual report year: 2008

REVIEW OF EXISTING LCA STUDIES ON WASTE WATER TREATMENT TECHNOLOGIES

The EU research project “NEPTUNE” is related to the EU Water Framework Directive and focused on the development of new waste water treatment technologies (WWTT) for municipal waste water. The sustainability of these WWTTs is going to be assessed by the use of life cycle assessment (LCA). New life cycle impact assessment methods on pathogens, whole effluent toxicity and micropollutants will be developed within the project. As part of this work a review of more than 20 previous LCA studies on WWTTs has been done and the findings are summarised on this poster. The review is focused on the relative importance of the different life cycle stages and the individual impact categories in the total impact from the waste water treatment, and the degree to which micropollutants, pathogens and whole effluent toxicity have been included in earlier studies. The results show that more than 30 different WWTT (and even more treatment trains/scenarios) have already been the subject of more or less detailed LCAs. All life cycle stages may be important and all impact categories (except stratospheric ozone depletion) typically included in LCAs may show significance depending on the actual scenario. Potential impacts of pathogens and whole effluent toxicity have not been included in any study, and only a few studies have included micropollutants (in total less than 20 different micropollutants).

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State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Larsen, H. F., Hauschild, M. Z.
Publication date: 2008
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Keywords: LCA, Review, LCIA, Waste water treatment technologies
Source: orbit
Source-ID: 231987
Review of methodologies for Social LCA

During the last years the interest for including social impacts in LCA has grown steadily, resulting in several preliminary Social LCA (SLCA) methodology proposals. A review of 12 methodological proposals has been made covering the most of what has been proposed as Social LCA until now focusing on their approaches to the goal and scope definition, inventory, and impact assessment phases of LCA. The review concludes that a main methodical difference lies in the definition of impact categories to be included in the assessment as well as in the formulation of indicators. Another challenging aspect is the data collection. Some SLCA proposals opinion that the use of generic process data is not feasible in SLCA, because social impacts are claimed not to be process specific but rather company specific. This change could easily imply a strong need for site-specific data leading to a very demanding data collection process. The review shows that the field of SLCA is still being framed, and that there is presently limited consensus on the approaches and that a fully developed method to support a full SLCA applying calculation procedures as known from LCA is not yet available.

General information
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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Innovation and Sustainability
Contributors: Jørgensen, A., Hauschild, M. Z.
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Event: Poster session presented at SETAC Europe 18th Annual Meeting, Warsaw, Poland.
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Research output: Research - peer-review › Poster – Annual report year: 2008

Standardisation Efforts to Measure Greenhouse Gases and 'Carbon Footprinting' for Products

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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
The role of heavy metal speciation in the determination of toxicity in aquatic systems

**General information**

State: Published

Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, University of Copenhagen
USEtox - The UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment

Background, Aim and Scope. In 2005 a comprehensive comparison of LCIA toxicity characterisation models was initiated by the UNEP-SETAC Life Cycle Initiative, directly involving the model developers of CalTOX, IMPACT 2002, USES-LCA, BETR, EDIP, WATSON, and EcoSense. In this paper we describe this model-comparison process and its results—in particular the scientific consensus model developed by the model developers. The main objectives of this effort were (i) to identify specific sources of differences between the models’ results and structure, (ii) to detect the indispensable model components, and (iii) to build a scientific consensus model from them, representing recommended practice. Methods. A chemical test set of 45 organics covering a wide range of property combinations was selected for this purpose. All models used this set. In three workshops, the model comparison participants identified key fate, exposure and effect issues via comparison of the final characterisation factors and selected intermediate outputs for fate, human exposure and toxic effects for the test set applied to all models. Results. Through this process, we were able to reduce inter-model variation from an initial range of up to 13 orders of magnitude down to no more than 2 orders of magnitude for any substance. This led to the development of USEtox, a scientific consensus model that contains only the most influential model elements. These were, for example, process formulations accounting for intermittent rain, defining a closed or open system environment, or nesting an urban box in a continental box. Discussion. The precision of the new characterisation factors (CFs) is within a factor of 100-1000 for human health and 10-100 for freshwater ecotoxicity of all other models compared to 12 orders of magnitude variation between the CFs of each model respectively. The achieved reduction of inter-model variability by up to 11 orders of magnitude is a significant improvement. Conclusions. USEtox provides a parsimonious and transparent tool for human health and ecosystem CF estimates. After a process of consensus building among stakeholders on a broad scale as well as several improvements regarding a wider and easier applicability of the model, USEtox will become available to practitioners for the calculation of further CFs.
Assessing the social impacts of the biofuel lifecycle

In order to assess the social impacts of the biofuel lifecycle, Social Life Cycle Assessment (SLCA) may be a promising tool. However, as this review study points out, several problems are still to be solved. SLCA can be defined as a tool for assessing a product’s or service’s total impact on human health and well-being throughout its life cycle. During the recent years several different approaches towards SLCA have been developing. This review reveals a broad variety in how the SLCAs address all methodological steps. One of the main differences is in the choice and formulation of social indicators. The indicators address a wide variety of issues; some approaches focus on impacts created in the very close proximity of the processes included in the product system, whereas others focus on the more remote societal consequences. The perception of social impacts is thus very varying. An assessment focussing on social impacts created in the close proximity of the processes included in the product system will not necessarily point in the same direction as an assessment that focuses on the more societal consequences. This point towards the need to agree on the most relevant impacts to include in the SLCA in order to include the bulk of the situation. Another very important difference among the proposals is their position towards data quality. Several of the proposals argue that each individual company in the product chain has to be assessed, whereas others claim that generic data can give a sufficiently accurate picture of the associated social impacts. The use of generic data as a basis for the assessment obviously has an advantage over using site specific data in relation to practicality, still many authors behind the SLCA approaches claim that reasonable accuracy can only be gained through the use of site specific data. However, in this context it is important to remember that that the quality of site specific data is very dependent on the auditing approach and therefore not necessarily of high accuracy and that generic data might be designed to take into account the location, sector, size and maybe ownership of a company and thereby in some cases give a reasonable impression of the social impacts that can be expected from the company performing the assessed process. SLCA is in an early stage of development where consensus building seems premature. Nevertheless,
some agreement regarding which impacts are most relevant to include in the SLCA in order to cover the field sufficiently seems paramount if the SLCA is to gain any weight as a decision support tool. Furthermore, some assessment of the difference between site specific and generic data could give valuable perspectives on whether a reasonable accuracy can be gained from using generic data or whether the use of site specific data is mandatory, and if so where it is most important.

Course Content for Life Cycle Engineering and EcoDesign

There is a need to create an awareness of Life Cycle Engineering and EcoDesign in Engineering students. Topics covered in an LCE/EcoDesign course will create an awareness of environmental impacts, especially in other design course projects. This paper suggests that an awareness of product impact upon the environment must be created at an early stage in undergraduate education. Deciding what to include in an LCE/EcoDesign Course can be difficult because there are many different views on the subject. However, there are more similarities than differences. All LCE/ EcoDesign Engineering courses have the ultimate objective of decreasing the environmental impact of a design. It has been observed that 70% of product costs are decided at the design stage. This can be extended to environmental impact, where it can be observed that, the design is correct, at the beginning, the environmental impact can be reduced by an estimated 70%. An LCE course does not need a high mathematical content and can give undergraduate students exposure to information that can be used in product design courses as they progress through university. The general content of such a course is suggested in this paper.
In order to do a life cycle assessment (LCA) of a waste water treatment technique, a system to handle the mapped inventory data and a life cycle impact assessment (LCIA) method/model is needed. Besides NEPTUNE, another EU-funded project has the same methodology need namely INNOWATECH (contract No. 036882) running in parallel with NEPTUNE but focusing on industrial waste water. With the aim of facilitating cooperation between the two projects a common LCA methodology framework has been worked out and is described in the following. This methodology work has been done as a joint effort between NEPTUNE WP4 and INNOWATECH WP4 represented by the WP4 lead partner IVL. The aim of the co-operation is to establish common methodologies and/or LCA models and/or tools in order to achieve a homogenous approach in INNOWATECH and NEPTUNE. Further, the aim is to facilitate possibilities of data exchange between the two projects and eventually normalise the final output. A coordination/working group with representatives from INNOWATECH (WP4) and NEPTUNE (WP4) has been set up. It consists of the following representatives from the two projects: NEPTUNE: Henrik Fred Larsen (DTU/IPU), Michael Hauschild (DTU), Henrik Wenzel (SDU). INNOWATECH: Mats Almemark (IVL), Christian Junestedt (IVL). In support of this work and as a starting point for especially NEPTUNE WP4, a review of existing LCA studies on waste water treatment technologies has been done by DTU and is included as an Appendix.

**Deliverable 4.1 Homogeneous LCA methodology agreed by NEPTUNE and INNOWATECH**

In order to do a life cycle assessment (LCA) of a waste water treatment technique, a system to handle the mapped inventory data and a life cycle impact assessment (LCIA) method/model is needed. Besides NEPTUNE, another EU-funded project has the same methodology need namely INNOWATECH (contract No. 036882) running in parallel with NEPTUNE but focusing on industrial waste water. With the aim of facilitating cooperation between the two projects a common LCA methodology framework has been worked out and is described in the following. This methodology work has been done as a joint effort between NEPTUNE WP4 and INNOWATECH WP4 represented by the WP4 lead partner IVL. The aim of the co-operation is to establish common methodologies and/or LCA models and/or tools in order to achieve a homogenous approach in INNOWATECH and NEPTUNE. Further, the aim is to facilitate possibilities of data exchange between the two projects and eventually normalise the final output. A coordination/working group with representatives from INNOWATECH (WP4) and NEPTUNE (WP4) has been set up. It consists of the following representatives from the two projects: NEPTUNE: Henrik Fred Larsen (DTU/IPU), Michael Hauschild (DTU), Henrik Wenzel (SDU). INNOWATECH: Mats Almemark (IVL), Christian Junestedt (IVL). In support of this work and as a starting point for especially NEPTUNE WP4, a review of existing LCA studies on waste water treatment technologies has been done by DTU and is included as an Appendix.
Development of Brazilian normalization references from the combined study of emissions data and Brazilian energy matrix

General information
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Erratum: Evaluation of Ecotoxicity Effect Indicators for Use in LCIA: Eq. 8 was lacking on p. 32, No. 1, Vol. 12, 2007

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Contributors: Larsen, H. F., Hauschild, M. Z.
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Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.288 SNIP 0.954
Scopus rating (2001): SJR 0.49 SNIP 1.456
Scopus rating (2000): SJR 0.413 SNIP 1.862
Scopus rating (1999): SJR 0.442 SNIP 1.283

Original language: English

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Source: orbit
Source-ID: 210343
Research output: Research - peer-review; Journal article – Annual report year: 2006
Evaluation of Ecotoxicity Effect Indicators for Use in LCIA

Goal, Scope and Background. The paper describes different ecotoxicity effect indicator methods/approaches. The approaches cover three main groups, viz. PNEC approaches, PAF approaches and damage approaches. Ecotoxicity effect indicators used in life cycle impact assessment (LCIA) are typically modelled to the level of impact, indicating the potential impact on 'ecosystem health'. The few existing indicators, which are modelled all the way to damage, are poorly developed, and even though relevant alternatives from risk assessment exist (e.g. recovery time and mean extinction time), these are unfortunately at a very early stage of development, and only few attempts have been made to include them in LCIA. Methods. The approaches are described and evaluated against a set of assessment criteria comprising compatibility with the methodological requirements of LCIA, environmental relevance, reproducibility, data demand, data availability, quantification of uncertainty, transparency and spatial differentiation. Results and Discussion. The results of the evaluation of the two impact approaches (i.e. PNEC and PAF) show both pros and cons for each of them. The assessment factor-based PNEC approach has a low data demand and uses only the lowest data (e.g. lowest NOEC value). Because it is developed in tiered risk assessment, and hence makes use of conservative assessment factors, it is not optimal, in its present form, to use in the comparative framework of LCIA, where best estimates are sought. The PAF approaches have a higher data demand but use all data and can be based on effect data (PNEC is no-effect-based), thus making these approaches non-conservative and more suitable for LCIA. However, indiscriminate use of ecotoxicity data tends to make the PAF-approaches no more environmentally relevant than the assessment factor-based PNEC approaches. The PAF approaches, however, can at least in theory be linked to damage modelling. All the approaches for damage modelling which are included here have a high environmental relevance but very low data availability, apart from the 'media recovery- approach', which depends directly on the fate model. They are all at a very early stage of development. Conclusion, Recommendations and Outlook. An analysis of the different PAF approaches shows that the crucial point is according to which principles and based on which data the hazardous concentration to 50% of the included species (i.e. HC50) is estimated. The ability to calculate many characterisation factors for ecotoxicity is important for this impact category to be included in LCIA in a proper way. However, the access to effect data for the relevant chemicals is typically limited. So, besides the coupling to damage modelling, the main challenge within the further development and improvement of ecotoxicity effect indicators is to find an optimal method to estimate HC50 based on little data.
Experience with the use of LCA-modelling (EASEWASTE) in waste management

General information
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Web of Science (2019): Indexed yes
BFI (2018): BFI-level 1
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Scopus rating (2017): CiteScore 1.78 SJR 0.519 SNIP 0.92
Web of Science (2017): Impact factor 1.631
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.76 SJR 0.673 SNIP 1.091
Web of Science (2016): Impact factor 1.803
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 1.53 SJR 0.623 SNIP 0.893
Web of Science (2015): Impact factor 1.338
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 1.28 SJR 0.733 SNIP 1.097
Web of Science (2014): Impact factor 1.297
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 1.17 SJR 0.58 SNIP 0.925
Web of Science (2013): Impact factor 1.114
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 1.4 SJR 0.874 SNIP 1.053
Web of Science (2012): Impact factor 1.047
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 1.33 SJR 1.028 SNIP 0.858
Web of Science (2011): Impact factor 1.193
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.662 SNIP 0.957
Web of Science (2010): Impact factor 1.222
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.869 SNIP 1.251
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.537 SNIP 0.967
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.359 SNIP 0.697
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.317 SNIP 0.759
Fate and Distribution Modelling of Metals in Life Cycle Impact Assessment

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering, FORCE Technology, University of Copenhagen
Contributors: Strandesen, M., Birkved, M., Holm, P. B., Hauschild, M. Z.
Pages: 327-338
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Journal: Ecological Modelling
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Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 2.69 SJR 1.084 SNIP 1.088
Web of Science (2017): Impact factor 2.507
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.43 SJR 0.967 SNIP 1.09
Web of Science (2016): Impact factor 2.363
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 2.43 SJR 1.082 SNIP 1.097
Web of Science (2015): Impact factor 2.275
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.7 SJR 1.132 SNIP 1.341
Web of Science (2014): Impact factor 2.321
Web of Science (2014): Indexed yes
GM-troph – a low data demand ecotoxicity effect indicator for use in LCIA

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Larsen, H. F., Hauschild, M. Z.
Pages: 79-91
Publication date: 2007
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International consensus model for comparative assessment of chemicals

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Publication date: 2007
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Research output: Research » Poster – Annual report year: 2007

Life Cycle Assessment LCA of Waste Management Systems - LCA Oriented Solid Waste Management Model - EASEWASTE

General information
State: Published
Organisations: Department of Management Engineering, Residual Resource Engineering, Department of Environmental Engineering, Quantitative Sustainability Assessment
Contributors: Bhander, G. S., Christensen, T. H., Hauschild, M. Z., Das, T.
Publication date: 2007
Peer-reviewed: No
Source: orbit
Source-ID: 264510
Research output: Research » Conference abstract for conference – Annual report year: 2007

Life cycle assessment of disposal of residues from municipal solid waste incineration: Recycling of bottom ash in road construction or landfilling in Denmark evaluated in the ROAD-RES model

Two disposal methods for MSWI bottom ash were assessed in a new life cycle assessment (LCA) model for road construction and disposal of residues. The two scenarios evaluated in the model were: (i) landfilling of bottom ash in a coastal landfill in Denmark and (ii) recycling of bottom ash as subbase layer in an asphalted secondary road. The LCA included resource and energy consumption, and emissions associated with upgrading of bottom ash, transport, landfilling processes, incorporation of bottom ash in road, substitution of natural gravel as road construction material and leaching of heavy metals and salts from bottom ash in road as well as in landfill. Environmental impacts associated with emissions to air, fresh surface water, marine surface water, groundwater and soil were aggregated into 12 environmental impact categories: Global Warming, Photochemical Ozone Formation, Nutrient Enrichment, Acidification, Stratospheric Ozone Depletion, Human Toxicity via air/water/soil, Ecotoxicity in water/soil, and a new impact category, Stored Ecotoxicity to water/soil that accounts for the presence of heavy metals and very persistent organic compounds that in the long-term might leach. Leaching of heavy metals and salts from bottom ash was estimated from a series of laboratory leaching tests. For both scenarios, Ecotoxicity(water) was, when evaluated for the first 100 yr, the most important among the twelve impact categories involved in the assessment. Human Toxicity(soil) was also important, especially for the Road scenario. When the long-term leaching of heavy metals from bottom ash was evaluated, based on the total content of heavy metals
in bottom ash, all impact categories became negligible compared to the potential Stored Ecotoxicity, which was two orders of magnitudes greater than Ecotoxicity(water) was the constituent that gave the strongest contributions to the ecotoxicities. The most important resources consumed were clay as liner in landfill and the groundwater resource which was potentially spoiled due to leaching of salts from bottom ash in road. The difference in environmental impacts between landfilling and utilization of bottom ash in road was marginal when these alternatives were assessed in a life cycle perspective. (c) 2007 Elsevier Ltd. All rights reserved.

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Management Engineering, Innovation and Sustainability
Contributors: Birgisdottir, H., Bhander, G. S., Hauschild, M. Z., Christensen, T. H.
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Publication date: 2007
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.94 SJR 1.456 SNIP 2.059
Web of Science (2017): Impact factor 4.723
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4 SJR 1.407 SNIP 2.159
Web of Science (2016): Impact factor 4.03
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 4.33 SJR 1.732 SNIP 2.263
Web of Science (2015): Impact factor 3.829
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.43 SJR 1.763 SNIP 2.49
Web of Science (2014): Impact factor 3.22
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.39 SJR 1.815 SNIP 2.413
Web of Science (2013): Impact factor 3.157
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 2.91 SJR 1.59 SNIP 2.18
Web of Science (2012): Impact factor 2.485
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.99 SJR 1.694 SNIP 2.071
Web of Science (2011): Impact factor 2.428
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Life cycle assessment of the wave energy converter: Wave Dragon

Any power production technology should be able to demonstrate that it's able to comply with current and future environmental regulation and that it demonstrates a considerable surplus in the energy balance being a part of the entire power system. This means that the energy used throughout all the lifecycle stages; from provision of materials over manufacturing of components and assembly, to deployment and use and eventually the disposal stage, is considerably less than the energy produced by the devise during its use/production stage.

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Wave Dragon ApS, University of Copenhagen
Contributors: Hans Chr., S., Stefan, N., Stefan, A., Hauschild, M. Z.
Publication date: 2007
Peer-reviewed: No
Event: Poster session presented at Conference in Bremerhaven,
Electronic versions:
WaveDragon.pdf
Source: orbit
Source-ID: 251441
Research output: Research › Poster – Annual report year: 2007

Modelling of environmental impacts of solid waste landfilling within the life-cycle analysis program EASEWASTE

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Management Engineering, Innovation and Sustainability
New methodology in life cycle impact assessment (LCIA) of waste water treatment

General information
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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Publication date: 2007
Peer-reviewed: No
Event: Poster session presented at SETAC Europe 17th Annual Meeting: Multiple stressors for the environment and human health - present and future challenges and perspectives, Porto, Portugal, 20-24 May,

Research output: Research › Poster – Annual report year: 2007

The UNEP/SETAC recommended characterisation factors for human health and aquatic ecotoxicity: results and future

Over the last two years, the developers of seven toxicity characterization models collaborated to carry out a comprehensive model comparison as part of the UNEP/SETAC Life Cycle Initiative. The models in this evaluation included CalTOX, IMPACT 2002, USES-LCA, BETR, EDIP, WATSON, and EcoSense. This paper summarizes and draws lessons from this model evaluation process. The main objectives of this effort were to 1) identify specific sources of differences in model results, 2) define common and indispensable model components, and 3) use the selected models to build a "scientific consensus" model, called USEtox, to serve as a repository for recommended practice. USEtox is a parsimonious and transparent tool that currently provides human-health characterisation factors (CFs) for some 1000 chemicals and aquatic ecotoxicity CFs for more than 2000 substances. The accuracy of these factors relative to other models remains within 1-3 orders of magnitude compared to 12 orders of magnitude variation among the chemicals. The main task of model development is complete, but the following future activities are foreseen for the upcoming second phase of the UNEP/SETAC Life Cycle Initiative: 1) increase of substance coverage and quality assurance of substance data; 2) accommodation of metals; 3) inclusion of terrestrial and marine ecotoxicity; 4) incorporation of indoor emissions; 5) including parameter uncertainty in the uncertainty estimates on the CFs; 6) publication of model documentation 7) development and distribution of a user-friendly version of USEtox; 8) industry/stakeholder workshops on comparative assessment of chemicals and training courses in USEtox. The promising scientific results now need to be transferred into
daily LCA practice, which is the main goal of these activities, aiming at a broad acceptance and consideration of the toxicity impact categories.

**Towards a consensus model in chemical characterisation modelling for LCA: comparison and harmonisation of models for fate and ecotoxicity effects**

**General information**

**State:** Published

**Organisations:** Quantitative Sustainability Assessment, Department of Management Engineering

**Contributors:** van de Meent, D., Bachmann, T., Hauschild, M. Z., Huijbregts, M., Jolliet, O., Koehler, A., Larsen, H. F., Margni, M., McKone, T., McLeod, M., Rosenbaum, R. K., Schuhmacher, M.,

**Publication date:** 2007

**Peer-reviewed:** No

**Event:** Poster session presented at SETAC Europe 17th Annual Meeting: Multiple stressors for the environment and human health - present and future challenges and perspectives, Porto, Portugal, 20-24 May.

**Research output:** Research › Poster – Annual report year: 2007

**USEtox: The UNEP-SETAC consensus model for life-cycle impacts on human health and ecosystems**

Life cycle impact assessment (LCIA) characterizes emissions for the life-cycle assessment (LCA) of a product by translating these emissions into their potential impacts on human health, ecosystems, global climate and other resources. This process requires substance-specific characterization factors (CFs) that represent the relative potential of specific chemical emissions to impact human disease burden and ecosystem health. Within the Life Cycle Initiative, a joint initiative of the United Nations Environment Program (UNEP) and of the Society of Environmental Toxicology and Chemistry (SETAC), a consensus model called USEtox was established to develop internationally harmonized CFs. In 2005 the LCI initiated an international comparison of six models used to make CF calculations. In this paper we describe this model-comparison process and its results, in particular the consensus model. The comparison focused on model differences both in terms of results and model structure. In three workshops, the model comparison participants identified crucial fate, exposure and effect issues for which the models differed. This process identified important sensitivities, differences in assumptions, and model structures that could be harmonized among the different models. Through this process, we were able to reduce inter-model variation. This process also led to the development of a consensus model that contained only the most influential model elements. The consensus model provided a parsimonious and transparent tool for making human health and ecosystem CF estimates. The consensus model has now been used to calculate CFs for several thousand substances and is intended to form the basis of the recommendations from UNEP-SETAC’s Life Cycle Initiative regarding characterization of toxic impacts in Life Cycle Assessment.
Using a life cycle assessment methodology for the analysis of two treatment systems of food-processing industry wastewaters

Feasibility evaluation of wastewater treatment plants' designs & operation strategies is nowadays done in a plant-wide perspective. Environmental concerns regarding energy consumption and sludge disposal are the main drivers to consider pre/post-treatment units in these evaluations. Existing criteria involve sludge disposal strategies and electrical energy consumption. However, there is a need to develop a systematic methodology to quantify relevant environmental indicators; comprising information of the wastewater treatment system in a life cycle perspective. Also, to identify which are the parameters that have the greatest influence on the potential environmental impacts of the systems analyzed. In this study, we present a systematic methodology for the analysis of the operation of two modern wastewater treatment technologies: Biological removal of nitrogen and organic matter by activated sludge (Scenario 1), and anaerobic removal of organic matter by a continuous stirred tank reactor (Scenario 2). Both technologies were applied to wastewater coming from a fish meals industry and a pet food industry discharging about 250 to 260 thousand cubic meters of wastewater per year. The methodology comprises three major steps: (i) Data gathering regarding wastewater characteristics and discharge, (ii) Simulation of the wastewater treatment plant’s operation by dedicated process engineering models in Matlab/Simulink, (iii) Classification and calculation of life cycle inventory data: removal efficiencies, area occupied, ancillaries consumption, energy balances, sludge production, and effluent characteristics by a Matlab script. The classified data is then fed into a generic model developed in GaBi software v.4.1 SP 8 where production of ancillaries, energy production grids, and production of fertilizers are balanced, normalized & weighted using EDIP 97. The functional unit was defined as an annual averaged volumetric person equivalent (P.E.=0,2 m3 d-1). Person equivalent is a term which results more familiar to wastewater engineers and many plant designs are expressed in that unit. The system boundaries were limited from the influent entering the wastewater treatment plant until the disposal of the effluents generated, i.e. wastewater, sludge, and biogas (for Scenario 2). Main differences between Scenario 1 & Scenario 2 were: (i) Effluent quality was 65% better when pet food wastewater was fed into the anaerobic tank whilst for fish meals wastewater was 83% better when fed into nutrients removal plant. (ii) Energy balance turned favorable only for the fish meals wastewater by anaerobic treatment producing 0,06 kWh PE-1 after energy for mixing has been utilized. (iii) Area occupied by nutrient removal tanks was bigger by at least 10 times in order of magnitude to area occupied by anaerobic tank. It was observed that in most of the weighted environmental impacts, fish meals wastewater turned into higher values. This may be due to high nitrogen concentrations in the influent which increases electricity consumption, causing higher global warming, acidification & nutrients enrichment impacts. We also noticed that sludge volumes and sludge quality were related to nitrogen and suspended solids concentrations in the influents simulated. Therefore, the sensitivities of different influent parameters over the weighted environmental impacts were investigated and quantified.
A design-based model for the life cycle assessment of different process configurations for treatment of food processing wastewater: MO2/Y2/P03

A framework for social life cycle impact assessment

Goal, Scope and Background. To enhance the use of life cycle assessment (LCA) as a tool in business decision-making, a methodology for Social life cycle impact assessment (LCIA) is being developed. Social LCA aims at facilitating companies to conduct business in a socially responsible manner by providing information about the potential social impacts on people caused by the activities in the life cycle of their product. The development of the methodology has been guided by a business perspective accepting that companies, on the one hand, have responsibility for the people affected by their business activities, but, on the other hand, must also be able to compete and make profit in order to survive in the marketplace. Methods. A combined, bottom-up and top-down approach has been taken in the development of the Social LCIA. Universal consensus documents regarding social issues as well as consideration for the specific business context of companies has guided the determination of damage categories, impact categories and category indicators. Results, Discussion, and Conclusion. The main results are the following: (1) Impacts on people are naturally related to the conduct of the companies engaged in the life cycle rather than to the individual industrial processes, as is the case in Environmental LCA. Inventory analysis is therefore focused on the conduct of the companies engaged in the life cycle. (2) Boundaries of the product system are determined with respect to the influence that the product manufacturer exerts over the activities in the product chain. (3) A two-layer Social LCA method with an optional and an obligatory set of impact categories is suggested to ensure both societal and company relevance of the method. The obligatory set of impact categories encompasses the minimum expectations to a company conducting responsible business. (4) A new area of protection, Human dignity and Well-being, is defined and used to guide the modelling of impact chains. (5) The Universal Declaration of Human Rights serves as normative basis for Social LCA, together with local or country norms based on socio-economic development goals of individual countries. The International Labour Organisation's Conventions and Recommendations, and the Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policy, support development of the impact pathway top-down, starting from the normative basis. (6) The obligatory part of Social LCA addresses the main stakeholder groups, employees, local community and society.
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
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BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
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Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731

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Contributors: McKone, T. E., A.D., K., Olsen, S. I., Hauschild, M. Z.
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Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
Ecolabelling of printed matter. Part II: Life cycle assessment of model sheet fed offset printed matter

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State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Contributors: Larsen, H. F., Hauschild, M. Z., Hansen, M. S.
Number of pages: 142
Publication date: 2006

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Ecolabelling_of_printed_matter_2.pdf
Research output: Research › Report – Annual report year: 2006

Environmental assessment of roads constructed with and without bottom ash from municipal solid waste incineration

**General information**
State: Published
Organisations: Department of Environmental Engineering, Department of Management Engineering, Innovation and Sustainability
Environmental assessment of solid waste systems and technologies: EASEWASTE

A new model has been developed for evaluating the overall resource consumption and environmental impacts of municipal solid waste management systems by the use of life cycle assessment. The model is named EASEWASTE (Environmental Assessment of Solid Waste Systems and Technologies) and is able to compare different waste management strategies, waste treatment methods and waste process technologies. The potential environmental impacts can be traced back to the most important processes and waste fractions that contribute to the relevant impacts. A model like EASEWASTE can be used by waste planners to optimize current waste management systems with respect to environmental achievements and by authorities to set guidelines and regulations and to evaluate different strategies for handling of waste. The waste hierarchy has for decades been governing waste management but the ranking of handling approaches may not always be the most environmentally friendly. The EASEWASTE model can identify the most environmentally sustainable solution, which may differ among waste materials and regions and can add valuable information about environmental achievements from each process in a solid waste management system.
Evaluation of environmental impacts from municipal solid waste management in the municipality of Aarhus, Denmark (EASEWASTE)

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Management Engineering, Innovation and Sustainability
Experiences on the use of LCA-modeling (EASEWASTE) in waste management

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Management Engineering, Innovation and Sustainability
Publication date: 2006

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Proceedings
Volume: CD-ROM
Place of publication: Copenhagen
Publisher: The International Solid Waste Association
Source: orbit
Source-ID: 192675
Research output: Research › Article in proceedings – Annual report year: 2006

From Pressures to Impacts: - Life Cycle Impact Assessment
Life cycle assessment (LCA) has been developed as a tool for assessment of the environmental impacts which are caused by the pressures from products or systems, viewed in a life cycle perspective, i.e. covering all stages of the life cycle of the product or system from the extraction of raw materials over manufacture or construction through use to disposal or decommissioning and recycling. It is a holistic tool in the sense that it models all relevant environmental impacts from the global (like climate change and ozone depletion) to the local (like land use) and also the loss of resources. The framework for LCA has been standardised by the International Standards Organisation, ISO, which identifies four phases – Goal and scope definition, where the goal is defined, the service to be provided by the studied system is quantified in terms of the functional unit of the study, and the product system is defined, Inventory analysis where data for the physical flows to and from all processes in the life cycle is collected and related to the functional unit, Impact assessment, where the physical flows are translated into impacts on the environment and resource base, and Interpretation where the outcomes of the earlier phases are interpreted in relation to the goal of the LCA. LCA is typically used for comparisons, and in order to facilitate the comparison of the rather diverse environmental impacts which are comprised by the Life Cycle Impact Assessment (LCIA) methodology, procedures have been developed for normalisation and valuation which support aggregation and comparison across the different impacts. The resulting impact scores are seen as representing potential impacts rather than real effects due to: - The lack of knowledge about geographical conditions of most of the processes in the product system and the background conditions of the receiving environment - the aggregation of emissions over time and space - the fact that the emissions in the inventory represent the impacts from a functional unit, which for products often constitutes a minute fraction of the total output from the manufacturing stage. For waste management systems, it is pointed out, that these aspects may be less of a problem than for the typical product systems for which LCA was originally developed, since the environmental impacts from waste management systems are
typically dominated by one or a few central waste treatment processes for which both the location, receiving environments
and temporal emission profiles can be well known. The emissions of persistent pollutants from landfills does, however,
pose special problems to LCIA due to an emission pattern characterised by a very long duration and very low
concentrations of the emissions, which is quite different from the typical emission patterns from other processes in the life
cycle, and which really requires a more risk-oriented assessment procedure than what is normally applied in LCIA. Finally,
some of the topical discussions within the LCIA method development community are introduced, including questions like -
How large a part of the environmental mechanism should we model? - For waste management systems (particularly for
landfills), it is relevant to include site-specific information in the assessment - is it also possible? - (When) can we develop
global recommendations for the life cycle impact assessment?

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Hauschild, M. Z.
Number of pages: 11
Publication date: 2006

Host publication information
Title of host publication: Waste site stories : ISWA Annual Congress 2006
Volume: CD ROM proceedings
Publisher: The International Solid Waste Association
Source: orbit
Source-ID: 194306
Research output: Research - peer-review › Article in proceedings – Annual report year: 2006

LCA Center Denmark: - status and perspectives for dissemination of IPP and Life cycle thinking in Industry
As the first country in Europe Denmark established an official centre for Life Cycle Assessments and life cycle approaches
as an element of the national IPP (Integrated Product Policy), three years ago. The aim of the centre is to promote and
support the use of Life Cycle Assessment and other product-oriented environmental tools in companies, to ensure that the
LCA efforts is based on a solid and scientific basis, and to maintain the well-established co-operation between all
important actors in the LCA field in Denmark. A status is given on the achievements of LCA Center Denmark, and the
learning that other countries can draw in support of IPP and dissemination of life cycle thinking in industry.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Hauschild, M. Z., Frydendal, J.
Pages: 37-42
Publication date: 2006

Host publication information
Title of host publication: LCE 2006 - Towards a closed loop economy
Volume: 1
Electronic versions:
173_hauschild.pdf
Source: orbit
Source-ID: 194289
Research output: Research - peer-review › Article in proceedings – Annual report year: 2006

Life cycle assessment of residue use in road construction (ROAD-RES)

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Management Engineering, Innovation and
Sustainability
Contributors: Christensen, T. H., Birgisdottir, H., Bhander, G. S., Hauschild, M. Z.
Pages: 617-627
Publication date: 2006

Host publication information
Title of host publication: WASCON 2006. Sixth International Conference on the Environmental and Technical Implications
of Construction with Alternative Materials, May 30 - June 2, 2006, Belgrade
Place of publication: Utrecht, NL
Publisher: ISCOWA
PestLCI - a model for estimating field emissions of pesticides in agricultural LCA
Life cycle assessment (LCA) involves assessment of resource consumption and emissions caused by the provision of a given service over the whole life cycle of the products it involves, from the cradle to the grave. The quantification of exchanges with the environment during the life cycle of a product or service is a specific element of LCA termed life cycle inventory (LCI). Estimation of chemical emissions in agricultural LCA is typically based on standard emission factors which at best are determined by a few physical-chemical substance properties and the use scenario of the chemical compound. Dynamic and realistic models capable of predicting compartment specific mode of entry fractions for various chemicals and uses under specific temporal and use circumstances are scarce. This lack of appropriate models to estimate emission fractions results in a lower accuracy when accounting for one of the major corner stones in any LCA, chemical emissions, and it inevitably influences the outcome of the impact assessment, where the environmental impacts are normally assumed proportional to the emissions in LCA.

PestLCI is a modular model for estimation of pesticide emissions from field application to the different environmental compartments. It estimates the fractions of the applied quantity which is emitted to the air, surface water, and groundwater compartment based on information which will normally be available to the model user about: type and time of application, crop species and development stage, geological and meteorological conditions and the area of application, and properties of the active ingredients of the pesticide. The use and capability of the model is illustrated through two realistic Danish case studies, but the modular structure of the model will allow adaptation to conditions valid for other regions of the world. (c) 2006 Elsevier B.V. All rights reserved.
Scoping must be done in accordance with the goal definition, also in Social LCA

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Dreyer, L. C., Hauschild, M. Z.
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Peer-reviewed: No

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Journal: International Journal of Life Cycle Assessment
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Spatial differentiation in life cycle impact assessment - a decade of method development to increase the environmental realism of LCIA

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Potting, J., Hauschild, M. Z.
Pages: 11-13
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Peer-reviewed: Yes

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Journal: International Journal of Life Cycle Assessment
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Spatial differentiation in the characterisation of photochemical ozone formation: – The EDIP2003 methodology

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Hauschild, M. Z., Potting, J., Hertel, O., Schöpp, W., Bastrup-Birk, A.
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Volume: 11
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BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
Towards consensus in chemical characterization modeling for LCA: comparison and harmonization of models for human exposure and toxicity

A comprehensive LCIA characterization model comparison is being undertaken in the UNEP/SETAC Life Cycle Initiative, focusing on toxicity impacts and directly involving the developers of all models included. The main objective is to identify where differences come from, what indispensable model components are and if there can be a consensus model built from them, leading towards recommended practice in chemical characterization for LCIA. The models were selected in an open process inviting all models identified to be capable of characterizing a chemical in terms of environmental fate, human exposure, human toxicity and ecotoxicity. The invitation was accepted by the developers of CalTOX, IMPACT 2002, USES-LCA, EDIP, WATSON, and EcoSense. A consistent chemical test set comprising 66 organic (generic, amphiphilic and dissociating) and inorganic (metals, salts) compounds was selected representing a wide range of substance property combinations. All compared models showed correlation for human health endpoints for generic organics, with high variations on individual chemicals, typically with high Kow. For the other organics and inorganics, less agreement was observed. Influential processes and assumptions were identified and agreed upon to implement in all models for harmonization. These were, e.g., an urban box nested in a continental box with fixed surfaces and populations, consistent biotransfer and –concentration factors from experiments or one source/model, vegetation as an exposure pathway is determined by air-plant and soil-plant BCF correlations. For human toxicity, safety factors are avoided, directly using the TD50 benchmark dose with an applied slope on the dose response curve. Human data are preferred and animal-human extrapolation is done using allometrically based factors. Route-to-route extrapolation options were also explored.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering, Swiss Federal Institute of Technology Lausanne, Radboud University Nijmegen, University of Michigan, Ann Arbor, Polytechnique Montreal, University of California at Berkeley, National Institute of Public Health and the Environment, Universidad Rovira i Virgili, Swiss Federal Institute of Technology Zurich
Contributors: Rosenbaum, R., Hauschild, M. Z., Bachmann, T., Huijbregts, M., Jolliet, O., Larsen, H. F., Margni, M., McKone, T., van de Meent, D., Schuhmacher, M., Köhler, A., MacLeod, M.
Number of pages: 12
Publication date: 2006

Host publication information
Title of host publication: Global Environment and Sustainability: Sound Science in a world of diversity : Proceedings of the 27th annual meeting of SETAC North America
Source: orbit
Source-ID: 194291
Towards consensus in comparative chemical characterization modeling for LCIA: Efforts within the UNEP/SETAC Life Cycle Initiative

The Task Force on Toxic Impacts under the UNEP/SETAC Life Cycle Initiative is developing recommendations on characterization models and characterization factors for human toxicity and ecotoxicity impacts in Life Cycle Impact Assessment (LCIA). Building on experience from earlier model development work within, for instance, the OECD, and guidance from a series of expert workshops held between 2002 and 2005, preliminary guidelines focusing on chemical fate, and human and ecotoxic effects were established. For further elaboration of the fate-, exposure- and effect-sides of the modeling, six models were compared, focusing on their structure and results in terms of characterization factors. Through three workshops, modelers identified crucial fate, exposure and effect issues for which the presently available models differ. Between the workshops, the models were harmonized, removing identified unnecessary differences. Based on the adapted set of models and their outcomes, and on the earlier guidelines for fate modeling, overall guidelines for toxicity modeling in LCIA were developed. In line with these overall guidelines, a simple consensus model was developed. This model is collectively owned by the Task Force and the model providers. While the compared models and their differences are important tools to further advance LCA science, the consensus model is intended to provide a generally agreed and scientifically sound method to calculate consistent characterization factors for use in LCA practice and to be the basis of the “recommended practice” for calculation of characterization factors for chemicals under authority of the UNEP/SETAC Life Cycle Initiative.

Assessing environmental impacts in a life cycle perspective

What are the environmental impacts from an armchair or a cellular phone or a steak, if you take into account all the activities needed to produce, maintain, use or consume and eventually dispose of it? Life cycle impact assessment is the part of life cycle assessment (LCA) where the inventory of material flows in the life cycle of a product are translated into environmental impacts and consumption of resources, and questions like these are given an answer. The environmental impacts may range from very local (e.g. land use) to global (like climate change). As an environmental analysis tool, LCA is focused on the product system which comprises all the processes which the product and its components meet
throughout their lives- from the extraction of raw materials via manufacture, use and waste management to final disposal, or in short from the cradle to the grave (see Figure 1). The focus on the product system sets the frame for life cycle impact assessment (LCIA), and the bearings it has on current LCIA methodology are described in this paper together with the newest developments within this discipline.

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- **State**: Published
- **Organisations**: Innovation and Sustainability, Department of Management Engineering
- **Contributors**: Hauschild, M. Z.
- **Pages**: 81-88
- **Publication date**: 2005
- **Peer-reviewed**: Yes

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- **Journal**: Environmental Science and Technology
- **Volume**: 39(4)
- **ISSN (Print)**: 1382-3124
- **Ratings**:
  - Web of Science (2019): Indexed yes
  - Web of Science (2018): Indexed yes
  - Web of Science (2017): Indexed yes
  - ISI indexed (2013): ISI indexed no
  - ISI indexed (2012): ISI indexed no
  - ISI indexed (2011): ISI indexed no
  - Web of Science (2005): Indexed yes
  - Web of Science (2004): Indexed yes
  - Web of Science (2001): Indexed yes
  - Web of Science (2000): Indexed yes
- **Original language**: English
- **Keywords**: Risk assessment, Life cycle impact assessment, Life Cycle Assessment, ERA, LCIA
- **Source**: orbit
- **Source-ID**: 187383
- **Research output**: Research - peer-review › Journal article – Annual report year: 2005

**EcoDesign and future environmental impacts**
This paper describes the relation between EcoDesign and Life Cycle Engineering; both include Product Engineering as a focal point. Product Engineering includes both product design and manufacture, two fields which are changing quickly. In addition, this paper shows where future changes can be expected in Life Cycle Engineering and EcoDesign.

**General information**
- **State**: Published
- **Organisations**: Innovation and Sustainability, Department of Management Engineering, Queen's University Kingston
- **Contributors**: Jeswiet, J., Hauschild, M. Z.
- **Pages**: 629-634
- **Publication date**: 2005
- **Peer-reviewed**: Yes

**Publication information**
- **Journal**: J. of Materials & Design
- **Volume**: 26(7)
- **Original language**: English
- **Source**: orbit
- **Source-ID**: 187382
- **Research output**: Research - peer-review › Journal article – Annual report year: 2005

**From life cycle assessment to sustainable production: Status and perspectives**
The paper reviews the current state of Life Cycle Assessment (LCA) introducing the central elements of the methodology and the latest developments in assessment of the environmental, economic and social impacts along the product chain. The central role of LCA in Integrated Product Policy (IPP) is substantiated describing the different tools of the IPP. An overview is given on Design for Environment (DFE), presenting central findings from the latest decade of research and reviewing different DFE tools which have been developed. Describing the DFX’s of Design for environment, a specific focus is devoted to the tools for design for disassembly. Life Cycle Engineering is defined, and a systematic hierarchy is presented for the different levels at which environmental impacts from industry can be addressed by the engineer in order
to improve the eco-efficiency of the industry. The role of industry in meeting the sustainability challenge to our societies is
discussed, and it is concluded that industry must include not only the eco-efficiency but also the product's environmental
justification and the company ethics in a life cycle perspective in order to become sustainable. In the outlook it is
concluded that current drivers seem insufficient to create a strong move of particularly the small and medium-sized
enterprises in the direction of sustainability, and the need for stronger legislation and particularly for education and attitude
building among future citizens and engineers is identified.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering, Queen's University Kingston
Contributors: Hauschild, M. Z., Jeswiet, J., Alting, L.
Pages: 535-554
Publication date: 2005
Peer-reviewed: Yes

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Journal: CIRP Annals : Manufacturing Technology
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ISSN (Print): 0007-8506
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.09 SJR 2.034 SNIP 2.811
Web of Science (2017): Impact factor 3.333
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.93 SJR 2.055 SNIP 3.158
Web of Science (2016): Impact factor 2.893
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.83 SJR 2.088 SNIP 3.294
Web of Science (2015): Impact factor 2.492
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.39 SJR 3.123 SNIP 3.992
Web of Science (2014): Impact factor 2.542
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.87 SJR 2.598 SNIP 3.818
Web of Science (2013): Impact factor 2.541
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 3.04 SJR 2.088 SNIP 4.156
Web of Science (2012): Impact factor 2.251
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.81 SJR 2.117 SNIP 3.46
Web of Science (2011): Impact factor 1.708
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
LCA-tool for disposal of MSWI residues: Recycling in road construction and landfilling

General information
State: Published
Organisations: Department of Environmental Engineering, Innovation and Sustainability, Department of Management Engineering
Contributors: Birgisdottir, H., Christensen, T. H., Bhander, R., Hauschild, M. Z.
Publication date: 2005

Host publication information
Title of host publication: Sardinia 2005: Proceedings of the Tenth International Waste Management and Landfill Symposium
Volume: CD-ROM
Place of publication: Cagliari, Italy
Publisher: CISA, Environmental Sanitary Engineering Centre
Editors: Cossu, R., Stegmann, R.
Source: orbit
Source-ID: 183537
Research output: Research › Article in proceedings – Annual report year: 2005

Modelling the influence of intermittent rain events on long-term fate and transport of organic air pollutants
The deposition of particles and substances in air is under strong influence of the precipitation patterns of the atmosphere. Most multimedia models, like type III Mackay models, treat rain as a continuous phenomenon. This may cause severe overestimation of the substance removal from the atmosphere through wet deposition, and an underestimation of travel distances, leading to the following questions: How strong is the influence of the intermittent character of rain on concentrations, residence times, deposited fractions and characteristic transport distances of different substances in air? Is there an expression which can provide an accurate approximation to be used in steady state multimedia models?
Assuming a periodically intermittent rain, the mass of an emitted substance which is present in the air compartment is calculated as a function of the deposition rate constants during dry and wet periods, and the durations of these periods. In this paper results for 300 different organic chemicals are presented and illustrated in more detail for four typical substances, showing that: 1) Deposition velocities can be up to four orders of magnitude higher during rain events than during dry periods, especially for persistent substances with low Henry constant. 2) For substances with a short reaction time (residence time as determined by atmospheric degradation alone), e.g. acephate, the assumption of continuous rain may lead to an underestimation of the atmospheric residence time and travel distance by up to 3 orders of magnitude. For this group of substances, the residence time during dry period provides a good estimate of the overall atmospheric residence time. 3) For substances with reaction times close to the duration of the dry period, the behaviour is driven by the length of the time interval between two rain events, as e.g. for methomyl. 4) For very persistent substances such as pentachloronitrobenzene or carbon tetrachloride, the continuous rain approximation provides a good estimate. Based on these findings, an accurate but simple approximation is provided for the incorporation of intermittent rain behaviour in steady state multimedia models.

General information
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Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Jolliet, O., Hauschild, M. Z.
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Publication date: 2005
Peer-reviewed: Yes

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Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
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BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.535 SNIP 1.941
Web of Science (2017): Impact factor 6.653
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.26 SJR 2.559 SNIP 1.902
Web of Science (2016): Impact factor 6.198
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 5.61 SJR 2.546 SNIP 1.838
Web of Science (2015): Impact factor 5.393
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.5 SJR 2.777 SNIP 2.003
Web of Science (2014): Impact factor 5.33
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 5.52 SJR 2.952 SNIP 2.102
Web of Science (2013): Impact factor 5.481
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.17 SJR 3.115 SNIP 2.043
Web of Science (2012): Impact factor 5.257
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Progresses in Life Cycle Impact Assessment within the UNEP/SETAC Life Cycle Initiative

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Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Jolliet, O., Dubreuil, A., Gloria, T., Hauschild, M. Z.
Pages: 447-448
Publication date: 2005
Peer-reviewed: Yes

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Journal: International Journal of Life Cycle Assessment
Volume: 10(6)
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes

Original language: English
Keywords: Life cycle impact assessment, Fate and exposure modelling, LCIA
Source: orbit
Source-ID: 187678
Research output: Research - peer-review › Journal article – Annual report year: 2005
Use of life cycle assessment (LCA) and environmental risk assessment (ERA) as tools for design and optimization of a wastewater treatment system for effluents from the food processing industry

Aquatic ecotoxicological indicators in life cycle assessment

This paper compares available options for the aquatic ecotoxicological effect factor component in life cycle assessment (LCA). The effect factor is expressed here as the change in risk per unit change in cumulative exposure, \( \Delta \text{Effect}/\Delta \text{Exposure} \). The comparison is restricted to approaches linked, implicitly as well as explicitly, to species sensitivity distributions (SSDs). This draws on recent insights for chemical mixtures and identifies the implications of different model choices. In spite of the many options, assumptions, and areas for further research, it is concluded that a single effect factor basis represents the best available practice for use in LCA at this time, \( \Delta \text{PAFms}/\Delta C = 0.5/\text{HC50} \); where \( \Delta \text{PAFms} \) is the change in the (Potentially Affected) Fraction (PAF) of species that experiences an Increase in exposure above a specified effect level, accounting for the presence of complex background mixtures (ms), \( \Delta C \) is the change in cumulative exposure concentration of the chemical of interest, and HC50 is the median, chronic Hazardous Concentration for regional, multiple species systems. The resultant aquatic effect factors are risk-based and can be readily estimated for many chemicals using available methods, without the need to describe the entire SSDs and without the need for additional data. For example, the octanol-water partitioning coefficient provides a sufficient estimation basis for about 50% of existing chemicals that have a narcosis mode of action. This is also relevant in LCA for more chemicals that are at low concentrations in the environment; concentrations below biological thresholds at which more specific modes of action would be of relevance.
Web of Science (2017): Impact factor 3.179
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 2.74 SJR 1.231 SNIP 1.021
Web of Science (2016): Impact factor 2.951
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3 SJR 1.433 SNIP 1.056
Web of Science (2015): Impact factor 2.763
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 2.89 SJR 1.501 SNIP 1.12
Web of Science (2014): Impact factor 3.225
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 2.88 SJR 1.656 SNIP 1.086
Web of Science (2013): Impact factor 2.826
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.81 SJR 1.639 SNIP 1.108
Web of Science (2012): Impact factor 2.618
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 3.05 SJR 1.947 SNIP 1.168
Web of Science (2011): Impact factor 2.809
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.715 SNIP 0.992
Web of Science (2010): Impact factor 3.026
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.616 SNIP 1.053
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.487 SNIP 1.036
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.694 SNIP 1.127
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.609 SNIP 1.142
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.534 SNIP 1.184
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 2.107 SNIP 1.397
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.747 SNIP 1.323
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 1.815 SNIP 1.385
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 1.75 SNIP 1.365
Web of Science (2001): Indexed yes
Background for spatial differentiation in life cycle impact assessment. The EDIP2003 methodology

The code of practice of the Society of Environmental Toxicology and Chemistry and the recent international standards and technical reports from ISO are widely accepted as general frameworks for Life Cycle Assessment (LCA) but they are not detailed methodological references, since international agreement is limited to main lines and methodology has not yet been fully developed. A major problem to be solved is the poor accordance between impact as calculated in LCA and the expected occurrence of actual impact. Until recently, Life Cycle Impact Assessment (LCIA) typically focused on substance properties and left out information about the location of the emission and characteristics of transport to the receiving environment. Thus LCIA ignored those fate and exposure characteristics which were specified according to the conditions at the relevant locations. Here lies a source of discrepancy between modelled impact and the occurrence of actual impact. This technical report aims to contribute to a solution of the poor accuracy of the assessed impact in typical LCA resulting from the present disregard of spatial information in LCA.

Bringing Science and Pragmatism together - a Tiered Approach for Modelling Toxicological Impacts in LCA

Goal, Scope and Background. The EU 5th framework project OMNIITOX will develop models calculating characterisation factors for assessing the potential toxic impacts of chemicals within the framework of LCA. These models will become accessible through a web-based information system. The key objective of the OMNIITOX project is to increase the coverage of substances by such models. In order to reach this objective, simpler models which need less but available data, will have to be developed while maintaining scientific quality. Methods. Experience within the OMNIITOX project has taught that data availability and quality are crucial issues for calculating characterisation factors. Data availability determines whether calculating characterisation factors is possible at all, whereas data quality determines to what extent the resulting characterisation factors are reliable. Today, there is insufficient knowledge and/or resources to have high data availability as well as high data quality and high model quality at the same time. Results. The OMNIITOX project is developing two inter-related models in order to be able to provide LCA impact assessment characterisation factors for toxic releases for as broad a range of chemicals as possible: 1) A base model representing a state-of-the-art multimedia model and 2) a simple model derived from the base model using statistical tools. Discussion. A preliminary decision tree for using the OMNIITOX information system (IS) is presented. The decision tree aims to illustrate how the OMNIITOX IS can assist an LCA practitioner in finding or deriving characterisation factors for use in life cycle impact assessment of toxic releases. Conclusions and Outlook. Data availability and quality are crucial issues when calculating characterisation factors for the toxicity impact categories. The OMNIITOX project is developing a tiered model approach for this. It is foreseen that a first version of the base model will be ready in late summer of 2004, whereas a first version of the simple base model is expected a few months later.
Calculation of site specific characterisation factors for metal ecotoxicity using decoupled multi species fate and exposure modelling

Calculation of characterisation factors (CF’s) for metal ecotoxicity typically involves fate and exposure modelling of metals in multi-media models developed for assessment of organic compounds. Metals do not follow the fate patterns of organic chemicals, and the results will therefore most likely misrepresent the exposure concentration of metals. However, using multiple versions of such models for individual metal species within each model region and linking these to databases containing information on speciation pattern and fate properties of the individual metal species enables the assessment of metals taking into account the speciation pattern under e.g. specific pH, DOM and salinity conditions. The study presented here indicates that CF’s calculated using the traditional assessment method known as single species assessment of metals, under realistic conditions differs significantly, due to the part of the metal species present as complexes which is very hard to account for in single species assessment. Preliminary results on the CF’s based on single species assessment and decoupled multi species assessment will be presented for 4 common metals.

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Comparison between three different LCIA methods for aquatic ecotoxicity and a product Environmental Risk Assessment – Insights from a Detergent Case Study within OMNIITOX

Background and Objective. In the OMNIITOX project 11 partners have the common objective to improve environmental management tools for the assessment of (eco)toxicological impacts. The detergent case study aims at: i) comparing three Procter & Gamble laundry detergent forms (Regular Powder-RP, Compact Powder-CP and Compact Liquid-CL) regarding their potential impacts on aquatic ecotoxicity, ii) providing insights into the differences between various Life Cycle Impact Assessment (LCIA) methods with respect to data needs and results and iii) comparing the results from Life Cycle Assessment (LCA) with results from an Environmental Risk Assessment (ERA). Material and Methods. The LCIA has been conducted with EDIP97 (chronic aquatic ecotoxicity) [1], USES-LCA (freshwater and marine water aquatic ecotoxicity, sometimes referred to as CML2001) [2, 3] and IMPACT 2002 (covering freshwater aquatic ecotoxicity) [4]. The comparative product ERA is based on the EU Ecolabel approach for detergents [5] and EUSES [6], which is based on the Technical Guidance Document (TGD) of the EU on Environmental Risk Assessment (ERA) of chemicals [7]. Apart from the Eco-label approach, all calculations are based on the same set of physico-chemical and toxicological effect data to enable a better comparison of the methodological differences. For the same reason, the system boundaries were kept the same in all cases, focusing on emissions into water at the disposal stage. Results and Discussion. Significant differences between the LCIA methods with respect to data needs and results were identified. Most LCIA methods for freshwater ecotoxicity and the ERA see the compact and regular powders as similar, followed by compact liquid. IMPACT 2002 (for freshwater) suggests the liquid is equally as good as the compact powder, while the regular powder comes out worse by a factor of 2. USES-LCA for marine water shows a very different picture seeing the compact liquid as the clear winner over the powders, with the regular powder the least favourable option. Even the LCIA methods which result in the same product
ranking, e.g. EDIP97 chronic aquatic ecotoxicity and USES-LCA freshwater ecotoxicity, significantly differ in terms of most contributing substances. Whereas, according to IMPACT 2002 and USES-LCA marine water, results are entirely dominated by inorganic substances, the other LCIA methods and the ERA assign a key role to surfactants. Deviating results are mainly due to differences in the fate and exposure modelling and, to a lesser extent, to differences in the toxicological effect calculations. Only IMPACT 2002 calculates the effects based on a mean value approach, whereas all other LCIA methods and the ERA tend to prefer a PNEC-based approach. In a comparative context like LCA the OMNIITOX project has taken the decision for a combined mean and PNECbased approach, as it better represents the ‘average’ toxicity while still taking into account more sensitive species. However, the main reason for deviating results remains in the calculation of the residence time of emissions in the water compartments. Conclusion and Outlook. The situation that different LCIA methods result in different answers to the question concerning which detergent type is to be preferred regarding the impact category aquatic ecotoxicity is not satisfactory, unless explicit reasons for the differences are identifiable. This can hamper practical decision support, as LCA practitioners usually will not be in a position to choose the ‘right’ LCIA method for their specific case. This puts a challenge to the entire OMNIITOX project to develop a method, which finds common ground regarding fate, exposure and effect modelling to overcome the current situation of diverging results and to reflect most realistic conditions.

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Design for the environment - do we get the focus right?

Sometimes, products resulting from design for environment (DFE) endeavours are sub-optimisations from an environmental perspective, because the tool determines the process and not vice versa. For a more systematic way of getting the focus right, a hierarchy of focusing is introduced: 1. What is the function provided and what is the optimal way of providing it while making a business out of it? Which product should the company then produce? 2. Where are the "environmental hot spots" in the life cycle of this product? 3. Which DFE tool supports optimisation of the product by reducing these hot spots?

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Ecotoxicity Effect Indicator for use in the OMNITOX Base Model

The ecotoxicity effect indicator (EFI) is used together with the input results from the fate modelling when calculating characterisation factors for ecotoxicity within life-cycle impact assessment (LCIA). A number of methods have been proposed and used in recent years involving different approaches for the estimation of the EFI. However none of these methods are found to be adequately robust and/or able to work on the low data input defined by the OMNITOX Base Model (BM), i.e. a minimum of three acute EC50 values. Given the fact that the BM should be applicable to a significant number of chemicals, this requirement follows from the current and the most likely future data availability as defined by the proposed EU chemicals policy REACH. In this paper, a theoretical elaboration of effect-based average approaches (arithmetic mean, geometric mean and median) and the non-effect based approach (PNEC) is made focusing on their statistical robustness. Considerations about the possibility to relate the effect indicator to damage on the endpoint, the ecosystem, are also included. The effect-based approaches are tested for their robustness in estimating an HC50 in a practical test on datasets from eleven different substances representing seven different toxic modes of action (TMoA). On the basis of the theoretical elaboration and the practical tests it is recommended for the EFI to use the GM-trophic calculated as the geometric mean of three EC50 values, one from each of the three trophic levels, primary producers, primary consumers and secondary consumers comprising three different taxa, i.e. algae, crustacean (invertebrates) and fish. If more than three useable EC50 are available then the geometric means within each trophic level are used as input data to the final calculation.

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Estimating pesticide emissions for life cycle assessment of agricultural products
As the first country in Europe Denmark almost 2 years ago established an official center for Life Cycle Assessments and life cycle approaches as an element of the national IPP (Integrated Product Policy). The Danish EPA lends financial support to this important initiative, the aim of which is to: 1. promote the use of Life Cycle Assessment and other product-oriented environmental tools in companies, 2. support companies and other in using environmental assessment of products and services, 3. ensure that the effort in the LCA area is based on a solid and scientific basis, and 4. maintain the well-established co-operation between all important actors in the LCA field in Denmark. LCA Center Denmark was presented at the SETAC Europe conference in Hamburg in 2003 where it had just been launched. This presentation will follow up on the progress and activities of the center and report from an independent evaluation finished in September 2004. Important learnings for all who are engaged in dissemination of life cycle thinking in industry will be presented.
Evaluation of selection methods for toxicological impacts in LCA. Recommendations for OMNIITOX.

Goal, Scope and Background. The aim of this study has been to come up with recommendations on how to develop a selection method (SM) within the method development research of the OMNIITOX project. An SM is a method for prioritization of chemical emissions to be included in a Life Cycle Impact Assessment (LCIA) characterisation, in particular for (eco)toxicological impacts. It is therefore designed for pre-screening to support a characterisation method. The main reason why SMs are needed in the context of LCIA is the high number of chemical emissions that potentially contribute to the impacts on ecosystems and human health. It will often not be feasible to cover all emissions with characterisation factors and therefore there exists a real need to focus the effort on the most significant chemical emissions in the characterisation step. Until now not all LCA studies include toxicity related impact categories, and when they do there are typically many gaps. This study covers the only existing methods explicitly designed as SMs (EDIP-selection, Priofactor and CPM-selection), the dominating Chemical Ranking and Scoring (CRS) method in Europe (EURAM) and in USA (WMPT) that can be adapted for this purpose, as well as methods presenting novel approaches which could be valuable in the development of improved SMs (CART analysis and Hasse diagramme). Methods. The included methods are described. General guidance principles established for CRS systems are applied to SMs and a set of criteria for good performance of SMs is developed. The included methods are finally evaluated against these criteria. Results and Discussion. Two of the most important performance criteria include providing consistent results relative to the more detailed, associated characterisation methods and the degree of data availability to ensure broader chemical coverage. Applicability to different chemical groups, user friendliness, and transparency are also listed amongst the important criteria. None of the evaluated methods currently fulfil all of the proposed criteria to a degree that excludes the need for development of improved selection methods. Conclusion and Recommendations. For the development of SMs it is recommended that the general principles for CRS systems as applied to SMs are taken into account. Furthermore, special attention should be paid to some specific issues, i.e. the emitted amount should be included, data availability should enable broad chemical coverage, and when identifying priority chemicals for the characterisation, the developed SM should generate few false positives (chemical emissions classified wrongly as being of high concern) and no (significant) false negatives (classified wrongly as being of low concern) as compared to the associated characterisation method. These recommendations are not only relevant for a stand alone SM, but also valuable when dealing with simple characterisation methods associated with a higher tier characterisation method. Outlook. There are several questions that need to be answered before an optimal SM can be developed, inter alia: Is it optimal to use simple measured data with high availability or are QSAR estimates of more complex and relevant data better? Which key parameters to include and how? Is a statistical approach, like linear regression of characterisation factors or CART analysis, the best solution?
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BFI (2009): BFI-level 2
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Web of Science (2009): Indexed yes
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Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.517 SNIP 1.731
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Implementation of the ecotoxicological effects module

The goal of this report is to come up with recommendations on how to calculate the ecotoxicity effect indicator (termed ecotox effect indicator) for use in the OMNIIITOX base model (BM). The ecotox effect indicator is used together with the input from the fate modelling to calculate a characterisation factor for the chemical in question. Within the OMNIIITOX project consortium it has been decided that the ecotox effect indicator for the BM should be able to work on minimum three measured EC50 acute laboratory test data. The main reason for this decision is that the BM should be able to work on a significant number of chemicals today and be in accordance with the most likely data availability in the near future as defined by the proposed EU chemicals policy REACH. The focus in this report is therefore on an ecotox effect indicator that is able to work on only three EC50 values and only the freshwater pelagic compartment is dealt with here. For about a year discussions have been going on within the ecotox task force established within the OMNIIITOX consortium, especially about which estimation principle to chose, i.e. whether it should be no-effect based (PNEC) or effect based (e.g. median or geometric mean). As a starting point existing approaches used within LCIA has been described and evaluated. Reports on these two issues (estimation principle and evaluation of existing approaches) are enclosed with this report as possible sources for background information. In this report further theoretical elaboration of effect based average approaches (arithmetic mean, geometric mean and median) and the non-effect based approach (PNEC, here only as lowest EC50 in the dataset) are done focusing on their statistical robustness and the possibility to relate the effect indicator (based on a measure of effect rather than a no-effect measure) to damage on the endpoint, the ecosystem. The approaches are also tested for their robustness in estimating HC50 in a practical test on datasets from eleven different substances comprising seven different toxic modes of action (TMoA). On the basis of the theoretical considerations and the results of the practical test of the different approaches, the following recommendations are given for the estimation principle of the ecotox effect indicator: • The indicator is based on the GM-trophic calculated as the geometric mean (HC50) of three EC50 values, one from each of the three trophic levels, primary producers, primary consumers and secondary consumers comprising three different taxa, i.e. algae, crustacean (invertebrates) and fish. • If more than one EC50 value from each trophic level is available then the GM-trophic is calculated on the basis of the geometric means for each trophic level (GM-trophic-levels). The lower limit values around the GM-trophic are based on the geometric means of the geometric means at the genus level (GM-genuses) which again are calculated as the geometric means of the geometric means at species level (GM-species). The estimated GM-species is calculated as the geometric mean of the single EC50 values for each species. • As limit values around the GM-trophic, the lowest EC50 value is used as the lower limit and the highest EC50 value as the upper limit in datasets with only three EC50’s values, i.e. one from each trophic level. • If more than one EC50 value from each trophic level is available then the limit values around the GM-trophic are based on the three GM-trophic-level values, i.e. the lowest GM-trophic-level value is used as the lower limit and the highest GM-trophic-level value as the upper limit. It is recommended to use EC50chronic values when possible but as only acute data will be available in most cases, the use of best estimate assessment factors are recommended to extrapolate from acute to chronic values. Even though there is a need for research in this area, an acute to chronic ratio of 10 between HC50acute and HC50chronic is recommended as a starting point. For several reasons (i.a. the fact that one of the main applications of the ecotox effect indicator is LCIA where the results are used in a comparison between substances), it is recommended only to use test results from laboratory tests, fulfilling certain standard conditions, e.g. standard organism and test duration restrictions. The ability of a geometric mean to represent the toxicity of very toxic substances and very sensitive species has not been dealt with yet, and further research is needed here. However, it may be anticipated on the basis of the results from the practical tests of different average approaches on substances with different TMoA, that the GM-trophic with its limit values at least to some degree accounts for very toxic substances if representative toxicity data are available.

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Including chemical-related impact categories in LCA on printed matter does it matter?

Introduction Existing product Life Cycle Assessments (LCA)s on offset printed matter all point at paper as the overall dominating contributor to the impacts from the life-cycle of this category of products. This dominating role of paper is primarily founded in the energy-related impact categories global warming, acidification and nutrification. The studies focus on energy consumption including the emissions and impact categories related to energy. The chemical-related impact categories comprising ecotoxicity and human toxicity are not included at all or only to a limited degree. In this paper we include these chemical-related impact categories by making use of some of the newest knowledge about emissions from the production at the printing industry combined with knowledge about the composition of the printing materials used during the production of offset printed matter. This paper is based on the report (§3) Life Cycle Assessment of generic printed matter from a fictitious sheet fed printing industry;” [1] which is going to be published by the Danish EPA as part of the project §Ecolabelling of printed matter”. Goal and scope The goal of the study is to identify the distribution of potential environmental impacts and consumption of resources along the life cycle of a generic printed matter produced on a fictitious sheet feed offset printing industry in Europe. The results are to be used for developing ecolabelling criteria. Main activities at all stages in the life cycle are covered. However special focus is on the production stage but upstream emissions assessed to be of possible significant importance are included (e.g. estimated emissions from pigment production) or handled in the sensitivity analysis. The functional unit is 1 ton of sheet feed offset produced printed matter, i.e. printed communication covering books, pamphlets etc. As time scope for the production stage 1990 – 2002 is chosen and as technological scope mainly modern technology (not state-of-the-art) used at least in Northern Europe is used. Marginal approaches are used for production of electricity (natural gas) and paper production (virgin fibres) as the main approach i.e. in the reference scenario. In all other cases an average approach is used. The consumption of raw materials at the fictitious printing industry is mainly based on average values for 10 – 70 Swedish and Danish offset printing industries. The range in the consumption of the most important raw materials is typically well below or just above a factor of about 10. Method The EDIP method is used [2]. The impact assessment comprises classification, characterisation, normalisation and weighting. Danish/global normalisation references and weighting factors (Wenzel et al. 1997) are used in the reference scenario and European/global ones [3] are used for sensitivity analysis. The weighting factors for the impact categories are based on political reduction targets. Conclusion §1 The distribution of potential environmental impacts along the life cycle of a generic printed matter produced on a fictitious sheet feed offset printing industry in Europe has been identified and shown in Figure 1 (light bars). §2 The effect of including the chemical related impact categories is substantial as shown in Figure 1, e.g. the importance of paper is reduced from 67% to 31% and the importance of printing increased from 10% to 41%. §3 On the basis of sensitivity analysis it is concluded that the results of this LCA study is valuable for ecolabelling of offset printed matter (especially sheet fed) at both a Nordic scale (Swan labelling) and a European scale (Flower labelling). Furthermore, on the basis of the alternative scenarios and sensitivity analysis done it is concluded that the strength for use in ecolabelling of printed matter of the LCA approach used here is not only the exact LCA profile of the reference scenario based upon average values but to a high degree the possibilities to use sensitivity analysis based upon known or theoretical ranges within values on consumption, emissions or other parameters. By doing sensitivity analysis we get an indication on how sensitive the distribution of the potential impact within the life cycle of the printed matter is to variation in the parameter in question and thereby guidance in how much weight to put on the parameter in the development of ecolabelling criteria. References [1] Larsen, H.F., Hansen, M.S., Hauschild, M. (2004). Life Cycle Assessment of generic printed matter from a fictitious sheet fed printing industry. DRAFT April 2004. Part of the project §Ecolabelling of printed matter” which is going to be published by the Danish EPA in summer 2004. [2] Wenzel, H., Hauschild, M., & Alting, L. (1997) Environmental Assessment of Products, Vol. 1. First edn. Chapman & Hall [3] Stranddorff, H.K., Hoffmann, L., Schmidt, A. (2004). LCA Guideline: Update on impact categories, normalisation and weighting in LCA. Selected EDIP97-data. Final draft February 2004. To be published as an Environmental Project by the Danish EPA. Figure 1 Comparison of weighted LCA profiles with or without chemical related impact categories included (percentage of total, milli-person-equivalents-targeted, mPET). For §Total paper (net)” the avoided energy consumptions and emissions due to incineration and recycling of paper is allocated to paper.
Including social impacts in LCIA

Sustainability management in industries is often defined by measuring the performance against the triple bottom-line, People, Planet and Profit in business decisions. The product chain perspective inherent in LCA is very suitable for sustainability management but LCA methodology only considers environmental impacts and, therefore, recommendations based on LCA fail to address both social and economic concerns. This has raised questions about LCA’s ability to support sustainable development decisions. In a research project carried out at Brødrene Hartmann A/S and the Technical University of Denmark a framework for social LCA is currently being developed. The project quantifies social impacts and makes them operational in the traditional LCIA framework by developing measurable indicators. These indicators are selected to provide a meaningful and sufficient overall description of social impacts of all activities in the product life cycle. Workers’ fundamental rights, as defined by the ILO, are used as baseline in the method, and as a consequence, some of the issues addressed by the method are: child labour, discrimination, right to organise, and forced labour.

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Including social impacts in LCIA

Sustainability management in industries is often defined by measuring the performance against the triple bottom-line, People, Planet and Profit in business decisions. The product chain perspective inherent in LCA is very suitable for sustainability management but LCA methodology only considers environmental impacts and, therefore, recommendations based on LCA fail to address both social and economic concerns. This has raised questions about LCA’s ability to support sustainable development decisions. In a research project carried out at Brødrene Hartmann A/S and the Technical University of Denmark a framework for social LCA is currently being developed. The project quantifies social impacts and makes them operational in the traditional LCIA framework by developing measurable indicators. These indicators are selected to provide a meaningful and sufficient overall description of social impacts of all activities in the product life cycle. Workers’ fundamental rights, as defined by the ILO, are used as baseline in the method, and as a consequence, some of the issues addressed by the method are: child labour, discrimination, right to organise, and forced labour.

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Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
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BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
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Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
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Web of Science (2011): Indexed yes
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Scopus rating (2010): SJR 1.447 SNIP 1.826
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BFI (2009): BFI-level 2
Modelling pesticide emission patterns in agricultural life cycle inventories using a modular approach: Case study of apple production in New Zealand

In the Life Cycle Assessment (LCA) of field crops, the system description and inventory analysis provides information about the identities and quantities of pesticide applied, the form and the pattern of application. The field itself is seen as part of the technosphere, the ecosphere beginning outside the boundaries of the field or below the ploughing zone. To determine emissions of pesticide ingredients, we need to model their fate in the field system in order to quantify the fractions which cross its boundaries entering into the ecosphere. A modular framework for the calculation of organic pesticide fractions reaching the different environment compartments is used for the application of LCA to apple production in New Zealand. The approach has been developed to be used in the life cycle inventory (LCI) of agricultural systems. This framework allows the consideration of site-dependent parameters and farmers, habits in the calculation procedure, and is therefore very useful to increase the sophistication of agricultural LCA. The approach requires few parameters of the pesticides (Koc, vapour pressure, half-lives in soil and on the plant), and of the site (soil type and rainfall), and its modularity allows to include more sophistication in the different modules as required. For instance, in New Zealand a complex mechanistic model exists for the prediction of pesticide leaching, as well as field data on farmers’ habits’ effect on pesticide drift, so this was included in the calculations. The effect of pesticide parameters, site conditions and farmers’ habits on the pesticide emission patterns has been described for some pesticides. The feasibility and practicality of the model is discussed in relation to other, more complex, models.

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Contributors: Mila i Canals, L., Hauschild, M. Z., Domenech, X.
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Research output: Research – Poster – Annual report year: 2004

OMNIITOX - operational life-cycle impact assessment models and information tools for practitioners
This article is the preamble to a set of articles describing initial results from an on-going European Commission funded, 5th Framework project called OMNIITOX, Operational Models and Information tools for Industrial applications of eco/TXicological impact assessments. The different parts of this case study-driven project are briefly presented and put in relation to the aims of contributing to an operational life cycle-impact assessment (LCIA) model for impacts of toxicants.
The present situation has been characterised by methodological difficulties, both regarding choice of the characterisation model(s) and limited input data on chemical properties, which often has resulted in the omission of toxicants from the LCIA, or at best focus on well characterised chemicals. The project addresses both problems and integrates models, as well as data, in an information system – the OMNIITOX IS. There is also a need for clarification of the relations between the (environmental) risk assessments of toxicants and LCIA, in addition to investigating the feasibility of introducing LCA into European chemicals legislation, tasks that also were addressed in the project.

**General information**

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Organisations: Innovation and Sustainability, Department of Management Engineering, Volvo Car Corporation, P&G, Puig S.A., Chalmers University of Technology
Contributors: Molander, S., Lidholm, P., Schowanek, D., Recasens, M., Fullana, P., Christensen, F. M., Guinée, J., Hauschild, M. Z., Jolliet, O., Carlson, R.
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BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
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PestLCI - an inventory model estimating pesticide emissions from the field for LCA of agriculture products

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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Contributors: Hauschild, M. Z., Birkved, M.
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Simplified fate, exposure and effect modelling of chemical compounds in the case of lacking complete assessment data sets
Within the EU 5th framework OMNIITOX project a simple base model (SBM) is currently being developed to calculate characterisation factors for life cycle impact assessment of toxic releases. This SBM will be derived from a multi-media base model (BM) using statistical techniques combined with mechanistic insights in fate and effect relationships. The SBM must be able to cover a much higher number of substances than the BM and hence it must be based on fewer and more available substance properties than the BM. Preparatory work has been performed to gain insight into the structure of the BM e.g. in terms of how the input parameters enter the regression equation. In the absence of a final OMNIITOX BM a model of similar complexity USES-LCA, has been used as surrogate BM. We have applied partial least square of latent structure regression (PLSR) and combined insights from this with knowledge on data availability limitations to select key parameters that explain much of the variance and at the same time are relatively easily available. Further, PLSR was used to derive linear SBM models. In further investigations multiple linear regression (MLR) will be used to derive predictive equations for SBM characterisation factors. The result of this will be tested on common sense and environmental knowledge and a mechanistically understandable SBM will be developed by rounding off the coefficients of the regression equations. Preliminary results including PLSR derived linear SBM's of this work is presented.
Spatial differentiation in characterisation modelling – what difference does it make?
In the life cycle of a product, emissions take place at many different locations. The location of the sources and its surrounding condition influence the fate of the emission and the exposure it leads to but this source of variation is currently neglected in life cycle impact assessment, although it is well known that the impacts predicted by site-generic LCIA in some cases differ significantly from the actual impacts. Indeed, there are eloquent examples where the spatially determined variation in impact for one substance clearly exceeds the variation in impact between different substances. Recent results from the Danish LCA Methodology Development and Consensus Creation Project address this issue and provides a framework for spatially differentiated characterisation modelling together with easily applicable site-dependent factors for each European country and normalisation references for those impact categories commonly addressed in LCA (EDIP2003 methodology). The site-dependent factors are backed by site-generic factors to be used for those processes of the life cycle where the location of emission is unknown. Compared to traditional midpoint characterisation modelling, this novel approach is spatially resolved and comprises a larger part of the cause-effect chain including exposure assessment and in some cases exceeding of threshold values, which positions it closer to endpoint modelling. Examples are given where conclusions are reversed when the site-dependent characterisation modelling is used instead of the conventional site-generic modelling.

Spatial differentiation in life cycle impact assessment - the EDIP-2003 methodology. Guidelines from the Danish EPA
Guideline on the accordance between the environmental impact predicted in the life cycle assessment and the expected occurrence of actual impact.

The Progress of LCA Center Denmark After Almost Two Years of Service
As the first country in Europe Denmark almost 2 years ago established an official center for Life Cycle Assessments and life cycle approaches as an element of the national IPP (Integrated Product Policy). The Danish EPA lends financial support to this important initiative, the aim of which is to: 1. promote the use of Life Cycle Assessment and other product-
oriented environmental tools in companies, 2. support companies and other in using environmental assessment of products and services, 3. ensure that the effort in the LCA area is based on a solid and scientific basis, and 4. maintain the well-established co-operation between all important actors in the LCA field in Denmark. LCA Center Denmark was presented at the SETAC Europe conference in Hamburg in 2003 where it had just been launched. This presentation will follow up on the progress and activities of the center and report from an independent evaluation finished in September 2004. Important learnings for all who are engaged in dissemination of life cycle thinking in industry will be presented.

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Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99. Does it matter which one you choose
Goal, Scope and Background. A number of impact assessment methodologies are available to the LCA practitioner. They differ, and often there is not one obvious choice among them. The question therefore naturally arises: 'Does it make any difference to my conclusions which method I choose?' To investigate this issue, a comparison is performed of three frequently applied life cycle impact assessment methods. Methods. The three life cycle impact assessment methods EDIP97 (1), CML2001 (2) and Eco-indicator 99 (3) are compared on their performance through application to the same life cycle inventory from a study of a water-based UV-lacquer. EDIP97 and CML2001 are both midpoint approaches and hence quite similar in their scope and structure, and this allows a comparison during both characterisation and normalisation. The third impact assessment method Eco-indicator 99 is an endpoint method and different in scope and structure from the other two. A detailed comparison can not be done but a comparative analysis of the main contributors to the Eco-indicator 99 results and the weighted and aggregated EDIP97 results is performed. Results and discussion. Following a translation into common units of the EDIP97 and CML2001 output, differences up to two orders of magnitude are found for some of the indicator results for the impact categories describing toxicity to humans and ecosystems, and there is little similarity in the patterns of major contributors among the two methods. For human toxicity the CML2001 score is dominated by contribution from metals while the EDIP97 score is caused by a solvent and nitrogen oxides. For aquatic ecotoxicity, metals are the main contributors for both methods but while it is vanadium for CML2001, it is strontium for EDIP97. After normalisation, the differences are reduced but still considerable. For the other impact categories, the two methods show only minor differences. The comparison of the main contributors to the Eco-indicator 99 results and the weighted and aggregated EDIP97 results identifies nitrogen oxides as the main contributor for both methods. It is, however, much more dominant for Eco-indicator 99 while the EDIP97 score represents important contributions from a number of different substances, and furthermore, the analysis reveals that the aggregated scores for the two methods come from different impacts. It is thus difficult to extend the findings for these two methods to other inventories. Conclusion. For EDIP97 and CML2001, it mainly matters which method is used if the chemical impacts on human health and ecosystem health are important for the study. For the other impact categories, the differences are minor for these two methodologies. For EDIP97 and Eco-indicator 99, the patterns of most important contributors to the weighted and aggregated impact scores are rather different, and considering the known differences in the underlying framework and models, the results of the two methods may well go in opposite directions for some inventories even if the conclusion is the same for the inventory studied in this paper. Recommendations and outlook. Particularly for the impact categories representing toxic impacts from chemicals the study demonstrates the need for more a detailed analysis of the causes underlying the big differences revealed between the methods.

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Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
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Scopus rating (2010): SJR 1.447 SNIP 1.826
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Scopus rating (2009): SJR 1.247 SNIP 1.644
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Web of Science (2007): Indexed yes
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Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
Web of Science (2004): Indexed yes
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Education and training in LCA and life-cycle thinking experience and needs

This paper discusses experience and needs for education and training in LCA and life-cycle thinking based on project carried out for the Environmental Protection Agency in Denmark. An approach was chosen where both quantitative and qualitative facts and records were collected. The quantitative data was gathered by means of a survey among providers and users of education and training in this field, while the qualitative data was established in the course of a dialogue meeting to which particular interested individuals, selected among those who had returned the questionnaire, were invited. The questionnaire for providers was returned by 20 institutions, describing 47 educational offers and the questionnaire for users of education was filled by 41 companies and 16 consultancies. Most of the companies and consultancies that participated in the survey have experience with LCA and/or life cycle thinking. The target group for the educational offers are students of both short and long term higher education, primarily engineering students of various disciplines. However, teaching within LCA and life cycle thinking also takes place in curricula for designers, architects and production technicians. The target group for the training are in most cases companies, and participants are in mostly employees from the environmental department, but there are also offers for governmental authorities and unemployed. Both education and further training mainly convey qualifications on a “knowing about”-level in the form of basic principles of LCA and the applications of LCA. The competence regarding LCA and life cycle thinking is predominantly built-up by individuals who work in the environmental field. This applies to both companies and consultancies. The preferred means to strengthen competence in the future is to send employees on external courses, while internal courses lead by own employees also are attractive, especially for manufacturing companies with a certain degree of experience in applying LCA.

Engineering for Sustainable Development - An obligatory Skill of the Future Engineer

The LCE-seminar in Copenhagen 2003 succeeds a long line of LCE-seminars under the auspices of CIRP. The seminar proceedings 2003 comprises topics as Eco-design, Life Cycle Management, LCA-application, LCA-education, Integrated Product Policy, and software demonstrations. Within the topics there are keynotes from Delft University of Technology & Environmental Competence Centre, Philips Consumer Electronics (The Netherlands), from Aarhus School of Business, Department of Accounting and Auditing, (Denmark). From The Swedish Environmental Protection Agency, and from European Commission DG RTD- G2, Bruxelles (Belgium). Department of Manufacturing Engineering and Management hosted a mini-tutorial on Courses and Curricula in Sustainable Development and Environmental Management at the Technical University of Denmark. The proceedings comprise papers from universities and institutions in many countries and in a number, which fully substantiates the commitment and the engagement in the LCE- disciplines all over the industrialized world.
Evaluation of Selection Methods for use in Life Cycle Impact Assessment

Today very few LCA studies include ecotoxicity and human toxicity in the impact assessment and if they do it is typically highly incomplete. The reason for this seems to be that in many cases an extremely high number of chemical emissions from the inventory potentially contribute to the toxicity related impact categories and only for a small part of them there are characterisation factors provided by the applied impact assessment method. This calls for a method that is able to select/prioritise those chemical emissions that contribute significantly to the toxicity related impact categories. Such a method is called a selection method and its overall aim is to focus the effort on significant chemical emissions when Life Cycle Impact Assessment is done on toxic releases. Today experience from application of the few existing selection methods is very sparse and the need for research within this area therefore seems urgent. This paper will present the result of a comparison between different selection methods (e.g. CPM-selection and priofactor) including a partial order ranking method called Hasse diagram technique. Furthermore a characterisation method (EDIP) is included in order to compare the ranking of the selection methods with the results of a characterisation. The data used for this comparison comprises a test set of around 80 different substances covering all relevant combinations of different substance properties through representatives of different substance groups, i.e. non-dissociating organics, dissociating organics, amphiphilics, metals and other inorganics. This test set has been developed within the EU project OMNIITOX for a structured comparison of characterisation methods and selection methods. The comparison includes an identification of differences in ranking between the different methods and an analysis of the causes to the observed differences.

Implementation of Life Cycle Assessment (LCA) in the early stages of product development

The paper aims to outline the problems for the designer in evaluating the environmental benignity of the product from the outset and to provide the designer with a framework for decision support based on the performance evaluation at different stages of the design process. The overall aim of the paper is to provide an understanding of the environmental issues involved in the early stages of product development and the capacity of life cycle assessment techniques to address these issues. An Environmentally Conscious Design method is introduced and trade-offs are presented between design degrees of freedom and environmental solutions. Life cycle design frameworks and strategies are addressed. The paper collects experiences and ideas around the state-of-the-art in eco-design, from literature and personal experience and further provides eco-design life cycle assessment strategies. The result of the paper is a definition of the requirements for performance measurement techniques and a performance measurement environment necessary to support life cycle evaluation throughout the evaluation of early stages of a product system.
Implementing Life Cycle Assessment in systems development.

Today's industry is being forced to consider the environmental performance of its products concurrently with traditional requirements such as quality, price or functional performance. The Life Cycle Assessment (LCA) technique has been identified as a powerful tool to calculate environmental impacts derived from products and system, and calculate resource consumptions. However, the complexity of LCA poses restrictions to its use in current product and system development given the need for a reduction in product development cycle time which is needed to meet the increasing competitive pressures and the rapid changes in markets for many products. The overall aim of the paper is to provide an understanding of the environmental issues involved in the early stages of product development and the capacity of life cycle assessment techniques to address these issues. The paper aims to outline the problems for the designer in evaluating the environmental benignity of the product from the outset and to provide the designer with a framework for decision support based on the performance evaluation at different stages of the design process. The overall aim of this paper is to produce an in-depth understanding of the barriers to implementation of LCA by developers of products, and of the opportunities for introducing environmental criteria in the design process through meeting the information requirements of the designer on the different life cycle stages, producing an in-depth understanding of the attitudes of practitioners among product developers to the subject area, and an understanding of possible future directions for product development. An Environmentally Conscious Design method is introduced and trade-offs are presented between design degrees of freedom and environmental solutions. It also discusses a number of possibilities which can be introduced in the design stage comparable to the other life cycle stages of the product system. The paper collects experiences and ideas around the state-of-the-art in eco-design, from literature and personal experience and further provides eco-design life cycle assessment strategies. The paper reviews the current environmental evaluation practices with respect to product life cycles. As a number of deficiencies in LCA are identified, strategies are presented to provide a solution to many of the deficiencies. The result of the paper is a definition of the requirements for performance measurement techniques and a performance measurement environment necessary to support life cycle evaluation throughout the evaluation of early stages of a product system.

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Contributors: Bhander, G. S., Hauschild, M. Z., McAloone, T. C.
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Learning by doing – creating competences in engineering students on how and when to perform and use life cycle assessments

The course Life cycle assessment of products and systems has been given for eight consecutive years at the Technical University of Denmark. From the beginning, the course has been targeted on life cycle assessment with a strong emphasis on the performance and use of life cycle assessment as decision support to industry and authorities. While different applications of life cycle assessments are introduced in lectures during the course, the main focus is on how to do an LCA.

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Life cycle assessment of the reuse of waste incineration residues in road construction

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Life Cycle Engineering – from methodology to enterprise culture
As part of a sustainable development, the environmental efficiency of industry must increase by a factor four to ten. This engenders attention to the environmental impact of products and technical systems over their entire life cycle. The last decade has seen the development of a number of methodologies and tools for life cycle assessment and development of more eco-efficient products, from complex to simplified, catering to the needs of especially small and medium-sized enterprizes. The tools and data are in place, but dissemination lacks behind. Propagation of life cycle thinking and life cycle engineering to larger parts of industry is attempted by strengthening the market pull through integrated product policy measures, and at the same time pushing through information activities, training and dissemination of tools. Experience hitherto shows that these forces are insufficient and that stronger legislation is warranted.

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PestLCI - A new model for estimation of inventory data for pesticide applications
PestLCI is a new, modular model for estimation of pesticide emissions from field application to the different environmental compartments. It calculates emission fractions to the air, water, soil and groundwater compartments of the environment based on generally available information about: Type and time of application, crop species and development stage, and properties of the pesticide active ingredients. The required physical-chemical information on the 69 organic pesticides approved for field-use in Denmark is included in the model as a data base. So is the relative leaf area for 28 common European crops on 2-5 development stages together with meteorological data for 12 stations in Denmark. The use and capability of the model is illustrated through Danish case studies but the modular structure of the model will allow its adaptation to conditions valid for other regions.
PESTLCI – A PESTICIDE DISTRIBUTION MODEL FOR LCA

The aim of the presented work is to develop a model for distribution of pesticides into the environment following application to the field. Based on input of required substance characteristics and applied quantities for the pesticides, the model will estimate the emissions to the air, water, soil and groundwater compartments for use in life cycle inventory analysis of agricultural product systems. The model is called PESTLCI and it builds on an already existing model by Hauschild, 2000 /2/ to which a number of amendments are introduced inspired by existing work on hazard and risk characterisation and assessment of pesticide applications. The report therefore starts with a review of the work reported by the CAPER project as described in /1/ in order to locate new methods amenable for: 1. Handling of pesticide screening in LCA 2. Distribution modelling of pesticides in LCA 3. Evaluation of human exposure in LCA. Following the review of existing methods, a number of modifications and new modules are developed and integrated into the existing method for pesticide distribution modelling to arrive at PESTLCI. Finally, PESTLCI is tested on three pesticide applications and the results compared to the results obtained with the old model. PESTLCI is available as a Excel® spreadsheet (Danish Xp version) model.

Sustainable Environment and Health for 21st Century.

The overall aim of the paper is to provide an understanding of the issues involved in implementation of life cycle assessment/costing in product and system development. The paper aims to produce an in-depth understanding of the barriers to implementation of LCA by developers of products and systems, and opportunities for introducing environmental criteria; produce an in-depth understanding of information requirements for the designer, and improvement potentials and resources in product manufacturing, use, recycle and end-of-life process; produce an in-depth understanding of the attitudes of practitioners among product and system developers to the subject area, and an understanding of possible future directions for product development; participate actively in development and documentation of methods for Improvement Assessments in LCA internationally; integrate CAD-LCA systems in the early stages of the product development; develop a methodology for aggregating environmental impact scores and resource consumption scores into a single score based on the EDIP methodology and Actual Life Cycle Costing.
Estimation of pesticide emissions for LCA of agricultural products

Inventory data for the use of pesticides in agricultural or forestry product systems are typically based on the applied dose and the contents of different ingredients in the commercial pesticide product. Normally in LCA, the field is considered as part of the technosphere, and then the emissions from the system are only those fractions of the applied dose which reach the environment surrounding the field. The routes of emission may be direct through wind drift or indirect through evaporation, leaching, or surface run-off. Based on existing tools for hazard or risk assessment of pesticides, a model is presented developed, allowing estimation of emission factors based on characteristics of application and substance, which are normally available.

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Fate and exposure in the Life Cycle Impact Assessment of Toxicity

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Indicators for ecotoxicity in life cycle impact assessment.

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Inventory and classification of LCA characterisation methods for assessing toxic releases.

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Inventory of LCIA selection methods for assessing toxic releases. Methods and typology report part B
This report describes an inventory of Life Cycle Impact Assessment (LCIA) selection methods for assessing toxic releases. It consists of an inventory of current selection methods and other Chemical Ranking and Scoring (CRS) methods assessed to be relevant for the development of (a) new selection method(s) in Work package 8 (WP8) of the OMNIITOX project. The selection methods and the other CRS methods are described in detail, a set of evaluation criteria are developed and the methods are evaluated against these criteria. This report (Deliverable 11B (D11B)) gives the results from task 7.1d, 7.1e and 7.1f of WP 7 for selection methods. The other part of D11 (D11A) is reported in another report and deals with characterisation methods. A selection method is a method for prioritising chemical emissions to be included in an LCIA characterisation of toxic releases, i.e. calculating indicator scores by a characterisation method for the impact categories covering ecotoxicity and human toxicity. A selection method is therefore not a characterisation method like the "simple base method" and the "base method" that are going to be developed within WP8 but the purpose of a selection method is to focus the effort within characterisation. Selection methods are used within LCIA to select those chemical emissions (mapped in the inventory part of the LCA in question) that are expected to contribute significantly to the characterisation and exclude the insignificant ones. In this way only significant emissions (i.e. the selected ones) are included in the typically more data demanding and more time demanding characterisation step.

LCA-uddannelse – en analyse af nuværende udbud og fremtidige behov for LCA-uddannelse

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Research output: Research › Report – Annual report year: 2002
LCIA selection methods for assessing toxic releases

Characterization of toxic emissions in life cycle impact assessment (LCIA) is in many cases severely limited by the lack of characterization factors for the emissions mapped in the inventory. The number of substances assigned characterization factors for (eco)toxicity included in the dominating LCA methods in use today (e.g. Eco-indicator 99 and EDIP) is in the range of 40 – 330 and often they only cover a minor part of the substances in the inventory. The user of the LCA method should in principle be able to calculate any missing factors (if needed substance data are available which is often not fulfilled) but this task is at best very time consuming and often not possible. There seems to be a need for an easy in use and less time consuming selection/screening method based on readily available substance data. The aim of such a selection method is to prioritise those emissions (chemicals) from the inventory that contribute significantly to the impact categories on ecotoxicity and human toxicity to focus the characterisation work. The reason why the selection methods are more important for the chemical-related impact categories than for other impact categories is the extremely high number of substances potentially contributing to these categories. This paper will present the results from an inventory study on the few existing selection methods (i.e. EDIP-selection and priofactor) and a number of relevant candidates (e.g. EURAM, WMPT, Hasse diagram) as basis for developing new selection methods. The methods are evaluated against a set of predefined criteria (comprising consistency with characterization and data requirement) and applied to case studies and a test set of chemicals. The reported work is part of the EU-project OMNITOX.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Larsen, H. F., Birkved, M., Hauschild, M. Z.
Publication date: 2002

Host publication information
Title of host publication: LCIA selection methods for assessing toxic releases
Place of publication: Brussels
Publisher: SETAC Europe
Keywords: Chemicals, ecotoxicology, Selection methods, life cycle impact assessment, Human toxicity
Source: orbit
Source-ID: 63269
Research output: Research - peer-review › Article in proceedings – Annual report year: 2002

Life Cycle Impact Assessment: Striving towards best practice

The publication focuses on furthering the development of a technical framework, offers an overview of existing data and methods for different impact categories and explores evaluation criteria, including scientific validity, transparency, environmental relevance, feasibility and links with life-cycle inventory.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Number of pages: 249
Publication date: 2002

Host publication information
Title of host publication: Proceedings
Place of publication: Pensacola, Florida
Publisher: SETAC Press
ISBN (Print): 1.880611.54-6
Keywords: Life cycle impact assessment
Source: orbit
Source-ID: 63307
Research output: Research › Conference abstract in proceedings – Annual report year: 2002

Two tools for environmentally conscious designers and product developers of electrical & electronic equipment (EEE)

The paper presents the two tools 1) "Product families - short cuts to environmental knowledge" and 2) "Eco-conscious design of electrical & electronic equipment (EEE)". Tool 1) comes in form of a handbook. The purpose of this handbook is to ease the work with developing more environmentally sound products, thus giving guidelines for development of new products without the companies themselves having to perform an LCA. The handbook describes 5 productfamilies: mobile phones, vacuum cleaners, industrial valves with electronic controls, lighting, ventilation. Tool 2) comes in form of a software tool with built in training, guidance, references, calculator and database. The tool provides the basic understanding of how EEE-products in general interact with the environment. The tool gives an overview of the tasks and
responsibilities involved in Eco-Design, and examples of how to choose and quantify environmental metrics.

**General information**
State: Published
Organisations: Department of Management Engineering, Innovation and Sustainability, Dansk Toksikologi Center
Publication date: 2002

**Host publication information**
Title of host publication: Euro Environment 2002 Papers
Publisher: Euro Environment
Keywords: Eco-design, Environmental assessment, electronic equipment, product families, case study
Source: orbit
Source-ID: 63353
Research output: Research - peer-review › Article in proceedings – Annual report year: 2002

**Waste related emissions scenarios for risk assessment of chemicals. Report to Danish Environmental Protection Agency**

**General information**
State: Published
Organisations: Department of Environmental Engineering, Environmental Chemistry, Residual Resource Engineering, Quantitative Sustainability Assessment, Department of Management Engineering
Publication date: 2002

**Publication information**
Place of publication: Kgs. Lyngby
Publisher: Environment & Resources DTU. Technical University of Denmark
Original language: English
Source: orbit
Source-ID: 43334
Research output: Research › Report – Annual report year: 2002

**2000 Annual report NATO/CCMS Pilot Study, Clean Products and Processes (Phase I).**
The NATO/Committee on the Challenges of Modern Society third Pilot Study meeting on Clean Products and Processes was held in Copenhagen, Denmark on May 7-12, 2000. This meeting maintained the momentum generated during the of the first two years of the pilot study, focusing on progress made on several pilot projects being implemented by participating nations and continuing to build a program of collaborative endeavors. This meeting featured a special topical seminar titled, Product Oriented Environmental Measures, which focused participants’ attention on advances in product design and use. The meeting featured several guest lectures on significant developments in government programs, academic research and industrial applications. The report presents the ideas and views shared by the delegates and invited participants at the Copenhagen meeting. The full report can be viewed on the US EPA homepage.

**General information**
State: Published
Organisations: Department of Management Engineering, Innovation and Sustainability
Publication date: 2001

**Host publication information**
Title of host publication: 2000 Annual report NATO/CCMS Pilot Study, Clean Products and Processes (Phase I).
Place of publication: Cincinnati, OH
Publisher: United States Environmental Protection Agency
Editor: W. H. M. C. H. M. A. K. H. (.
Keywords: Clean products and processes - Product Oriented En
Source: orbit
Source-ID: 63312
Research output: Research › Conference abstract in proceedings – Annual report year: 2001

**Increasing the environmental relevance of life cycle impact assessment. In From basic science to decision-making**

**General information**
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Indicators for Ecotoxicity in LCIA – position paper for SETAC WIA2 Task group on ecotoxicity.

**General information**
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Pennington, D., Hauschild, M. Z.
Publication date: 2001

**Host publication information**
Title of host publication: 9th Annual Meeting of SETAC-North America, Baltimore
Place of publication: Pensacola, Florida
Publisher: SETAC Press
Keywords: indicators for ecotoxicity in Life cycle impact as
Source: orbit
Source-ID: 63317
Research output: Research - peer-review › Article in proceedings – Annual report year: 2001

Life Cycle Assessment and Risk Assessment: A Methodological Comparison.
Life Cycle Assessment and Risk Assessment are two different tools in environmental management. The paper identifies harmonies, discrepancies and relations between the two tools exemplified by the risk assessment principles of the European Commission (EC) and the LCA method ‘EDIP’ (En-vironmental Design of Industrial Products) developed in Denmark, respectively. A very important feature of LCA is the relative assessment due to the use of a functional unit. Risk assessment on the other hand is an absolute assessment, which may require very specific and detailed information on e.g. the exposure conditions. It is concluded that the conceptual background and the purpose of the tools are different but that there are overlaps where they may benefit from each other and they do complement each other in an overall environmental effort.

**General information**
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Pages: 385-404
Publication date: 2001
Peer-reviewed: Yes

**Publication information**
Journal: Environmental Impact Assessment Review
Volume: 21
ISSN (Print): 0195-9255
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 3.59 SJR 1.071 SNIP 1.754
Web of Science (2017): Impact factor 3.054
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.98 SJR 1.404 SNIP 1.888
Web of Science (2016): Impact factor 3.094
Livscyklusvurderinger - en kommenteret oversættelse af ISO 14040 til 14043

General information
State: Published
Organisations: Department of Management Engineering
Contributors: Jerland, J., Christiansen, K., Weidema, B., Jensen, A., Hauschild, M. Z.
Number of pages: 97
Publication date: 2001

Publication information
Place of publication: Charlottenlund
Publisher: Dansk Standard
Original language: Danish
URLs:
http://www.ipl.dtu.dk/publikation/7375/dk/
OMNIITOX – operational models and information tools for industrial applications of eco/toxicological impact assessments

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Publication date: 2001

Host publication information
Title of host publication: In From basic science to decision-making: "The environmental odyssey"
Place of publication: Brussels
Publisher: SETAC Europe
Keywords: eco/toxicological impact assessment LCA industria
Source: orbit
Source-ID: 63315
Research output: Research - peer-review › Article in proceedings – Annual report year: 2001

SETAC Europe working group on best available practice in life cycle impact assessment. In From basic science to decision-making

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Udo de Haes, H., Lindeijer, E., Müller-Wenk, E., Potting, J., Jolliet, O., Krewitt, W., Hauschild, M. Z., Finnveden, G.
Publication date: 2001

Host publication information
Title of host publication: In From basic science to decision-making: "The environmental odyssey"
Place of publication: Brussels
Publisher: SETAC Europe
Keywords: Life cycle impact assessment best available pract
Source: orbit
Source-ID: 63316
Research output: Research - peer-review › Article in proceedings – Annual report year: 2001

The European Person Equivalent: Measuring the personal environmental space

The European person equivalent (PE) is a quantification of the environmental impact caused annually by the activities of an average European. It comprises contributions to all the major environmental impacts from global to local as well as our consumption of resources. Similarly, the targeted European person equivalent is a quantification of the average person’s environmental impact in a near future according to the current politically set environmental targets. In addition to expressing the current societal priorities in pollution reduction, the targeted PE expresses the environmental space available to all of us according to the current environmental policy. Both concepts were developed in the mid-nineties for use in life cycle impact assessment to help comparisons across different environmental impact categories. Since then they have shown their value as a pedagogic tool in the presentation and interpretation of environmental impacts from all kinds of man-made activities, technologies and systems. The paper presents the determination of the person equivalents for different impact categories and consumption of resources. Its relation to the sustainability-based ecological space and its use as a common yardstick for industry in the presentation and comparison of environmental impact are discussed.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Contributors: Hauschild, M. Z., Wenzel, H.
Publication date: 2001

Host publication information
Place of publication: Cincinnati, OH
Waste related emission scenarios for risk assessment of chemicals. A background document for revision of the EU Technical Guidance Document on risk assessment of new and existing substances

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Publication date: 2001

Estimating pesticide emissions for LCA of agricultural products
Emission data for pesticides from agricultural product systems may be based on national and international pesticide usage statistics, but these only provide information on the applied dose. When the field is considered as part of the technosphere, the emissions from the system are those quantities, which reach the environment surrounding the field. The routes of emission may be direct through wind drift or indirect through evaporation, leaching, or surface run-off. Models are presented that will allow estimation of emission factors based on substance characteristics normally available for pesticide ingredients.

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z.
Pages: 64-79
Publication date: 2000

Levels of sophistication in life cycle impact assessment of acidification: Points of discussion additional to the presentation

General information
State: Published
Organisations: Department of Manufacturing Engineering, International Institute for Applied Systems Analysis, Utrecht University
Contributors: Potting, J. M. B., Schöpp, W., Blok, K., Hauschild, M. Z.
Publication date: 2000

Host publication information
Title of host publication: International workshop on life cycle impact assessment sophistication
Place of publication: Bayreuth
Publisher: Eco-Informa Press
Editors: Bare, J. C., Udo de Haes, H. A., Pennington, D.
In life cycle assessment (LCA) the environmental impacts from a product are assessed throughout the entire life-cycle of the product, i.e., from the extraction of the raw materials from which the product is made through manufacture and use of the product to the final disposal of the product and possible recycling thereof. The assessment is based on an inventory of inputs and outputs (resource/material consumption and generation of energy and emissions) for all the processes that occur as part of the product life-cycle. A model is developed to estimate the inputs and outputs associated with the disposal of a product through waste incineration. Based on knowledge of the material composition of the product and the
technology applied in the waste incineration plant, the model estimates input of energy and auxiliary materials required for
the incineration of the product and generation of energy and output of emissions to the environment caused by the
incineration. The work has been performed as part of the EUREKA project EUROENVIRON 1296: LCAGAPS, sponsored
by the Danish Agency for Industry and Trade.

**General information**

**State:** Published  
**Organisations:** Department of Management Engineering  
**Contributors:** Erichsen, H., Hauschild, M. Z.  
**Number of pages:** 36  
**Publication date:** 2000

**Publication information**

**Publisher:** Institut for Produktion og Ledelse, DTU  
**Original language:** English  
**URLs:**  
http://www.ipl.dtu.dk/publikation/7663/dk/  
**Source:** orbit  
**Source-ID:** 187238  
**Research output:** Research - peer-review > Report – Annual report year: 2000

**UK: Levels of sophistication in life cycle impact assessment of acidification**

**General information**

**State:** Published  
**Organisations:** Department of Manufacturing Engineering  
**Contributors:** Potting, J., Hauschild, M. Z.  
**Publication date:** 2000

**Host publication information**

**Title of host publication:** An international workshop on life cycle impact assessment sophistication. EPA/600/R-00/023, Washington  
**Publisher:** US EPA  
**Source:** orbit  
**Source-ID:** 176926  
**Research output:** Research - peer-review > Article in proceedings – Annual report year: 2000

**UK: Technical data for waste incineration background for modelling of product-specific emissions in a life cycle
assessment context**

**General information**

**State:** Published  
**Organisations:** Department of Management Engineering  
**Contributors:** Hauschild, M. Z.  
**Number of pages:** 38  
**Publication date:** 2000

**Publication information**

**Publisher:** IPL  
**Original language:** Danish  
**URLs:**  
http://www.ipl.dtu.dk/publikation/420/dk/  
**Source:** orbit  
**Source-ID:** 186739  
**Research output:** Research - peer-review > Report – Annual report year: 2000

**A new concept for fate modelling in life cycle toxicity assessment: Development and validation of the air module**

**General information**

**State:** Published  
**Organisations:** Department of Manufacturing Engineering, Swiss Federal Institute of Technology Lausanne  
**Contributors:** Jolliet, O., Hauschild, M. Z.  
**Number of pages:** 77  
**Publication date:** 1999
Best available practice regarding impact categories and category indicators in life cycle impact assessment

General information
State: Published
Organisations: Department of Manufacturing Engineering, Leiden University, Swiss Federal Institute of Technology Lausanne, Stockholm University, University of Stuttgart, University of St. Gallen
Contributors: Udo de Haes, H., Jolliet, O., Finnveden, G., Hauschild, M. Z., Krewitt, W., Müller-Wenk, R.
Pages: 1-15
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 4
Issue number: 2
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Comparison of LCA with risk characterisation according to the principles of EU technical guidance document

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Olsen, S., Hauschild, M. Z.
Number of pages: 86
Publication date: 1999

Host publication information
Title of host publication: Quality of Life and Environment in Cultured Landscapes. Proceedings from the 9th Annual Meeting of SETAC-EUROPE, Leipzig, 25-29 May, 1999
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry
Source: orbit
Source-ID: 175540
Research output: Research › Article in proceedings – Annual report year: 1999

Environmental Design of Industrial Products (EDIP), anchoring of the life cycle concept in industry and society

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Alting, L., Wenzel, H., Hauschild, M. Z.
Pages: 370-379
“Less is better” and “only above threshold”: Two incompatible paradigms for human toxicity in life cycle assessment

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Potting, J. M. B., Hauschild, M. Z., Christensen, H. W.
Pages: 16-24
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 4
Issue number: 1
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Life cycle assessment

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z., Wenzel, H.
Pages: 155-189
Publication date: 1999

Host publication information
Title of host publication: Jørgensen, S.E. (ed.): A Systems Approach to the Environmental Analysis of Pollution Minimization
Place of publication: Boca Raton
Publisher: Lewis
Source: orbit
Source-ID: 175533
Research output: Research - peer-review › Book chapter – Annual report year: 1999

Life cycle assessment (LCA) - Danish contributions to the development of the methodology

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z.
Number of pages: 13
Publication date: 1999
Life Cycle Assessment, risk assessment and environmental impact assessment;: complementary tools supporting different decision-contexts

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Potting, J. M. B., Hauschild, M. Z.
Number of pages: 87
Publication date: 1999

Host publication information
Title of host publication: Quality of Life and Environment in Cultured Landscapes. Proceedings from the 9th Annual Meeting of SETAC-EUROPE, Leipzig, 25-29 May, 1999
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry
Source: orbit
Source-ID: 175537
Research output: Research › Article in proceedings – Annual report year: 1999

Life Cycle Design - a Route to the Sustainable Industrial Culture?

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z., Wenzel, H., Alting, L.
Pages: 393-396
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: C I R P Annals
Volume: 1
Issue number: 1
ISSN (Print): 0007-8506
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.09 SJR 2.034 SNIP 2.811
Web of Science (2017): Impact factor 3.333
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.93 SJR 2.055 SNIP 3.158
Web of Science (2016): Impact factor 2.893
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.83 SJR 2.088 SNIP 3.294
Web of Science (2015): Impact factor 2.492
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Life cycle impact assessment - Danish recommendations

General information
State: Published
Site-dependent life cycle impact assessment of human toxicity from air emissions

General information
State: Published
Organisations: Department of Manufacturing Engineering, University of Stuttgart, Utrecht University
Number of pages: 87
Publication date: 1999

Host publication information
Title of host publication: Quality of Life and Environment in Cultured Landscapes. Proceedings from the 9th Annual Meeting of SETAC-EUROPE
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry
Source: orbit
Source-ID: 175536
Research output: Research › Article in proceedings – Annual report year: 1999

The need and feasibility of inclusion of spatial information in characterisation of ecotoxicity

General information
State: Published
Organisations: Department of Manufacturing Engineering, Water Quality Institute, Denmark, Science Park Aarhus
Contributors: Tørslev, J., Hauschild, M. Z., Rasmussen, D.
Number of pages: 78
Publication date: 1999

Host publication information
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry
Source: orbit
Source-ID: 175538
Research output: Research › Article in proceedings – Annual report year: 1999

The structure of life cycle impact assessment

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Potting, J. M. B., Hauschild, M. Z.
Pages: 4-6
Publication date: 1999
Peer-reviewed: Yes

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 4
Issue number: 1
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.65 SJR 1.726 SNIP 1.78
Web of Science (2014): Impact factor 3.988
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 3.35 SJR 1.672 SNIP 1.978
Web of Science (2013): Impact factor 3.089
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 2.89 SJR 1.529 SNIP 1.707
Web of Science (2012): Impact factor 2.773
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 2.82 SJR 1.595 SNIP 1.737
Web of Science (2011): Impact factor 2.362
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.447 SNIP 1.826
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.247 SNIP 1.644
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.885 SNIP 1.397
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.813 SNIP 1.222
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.573 SNIP 1.339
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.648 SNIP 1.777
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.653 SNIP 1.437
A generic method for location-dependent assessment and comparison of the acidifying impact from individual sources

Assessing Toxicological Impacts in Life-Cycle Assessment

Comparison of the acidifying impact from emissions with different regional origin in life-cycle assessment
Elements in a new sustainable industrial culture - Environmental assessment in product development

In the last few years the environmental focus in the manufacturing industry has shifted from the manufacturing processes to the products themselves, as these are accountable for the environmental impacts in all life cycle phases. The paper describes for three industrial cases how a newly developed LCA methodology can assist the product developer in development of more environmentally friendly products. Finally, common experience gained will be discussed. (C) 1998 Published by Elsevier Science Ltd. All rights reserved.

General information
State: Published
Organisations: Department of Manufacturing Engineering, Institute for Product Development
Contributors: Alting, L., Hauschild, M. Z., Wenzel, H.
Pages: 429-439
Publication date: 1998
Peer-reviewed: Yes

Publication information
Journal: Robotics and Computer-Integrated Manufacturing
Volume: 14
Issue number: 5-6
ISSN (Print): 0736-5845
Ratings:
BFI (2019): BFI-level 1
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 4.11 SJR 1.041 SNIP 2.681
Web of Science (2017): Impact factor 3.464
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.13 SJR 1.275 SNIP 2.73
Web of Science (2016): Impact factor 2.846
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 3.86 SJR 1.435 SNIP 3.027
Web of Science (2015): Impact factor 2.077
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.66 SJR 1.689 SNIP 3.424
Web of Science (2014): Impact factor 2.305
BFI (2013): BFI-level 1
Elements in a new sustainable industrial culture - Environmental assessment in product development

General information
State: Published
Organisations: Department of Manufacturing Engineering, Institute for Product Development
Contributors: Alting, L., Wenzel, H., Hauschild, M. Z.
Publication date: 1998

Host publication information
Title of host publication: Proceedings - Life Cycle Design '98
Place of publication: Stockholm
Publisher: Kungl. Tekniska Högskolan
Source: orbit
Source-ID: 172034
Research output: Research - peer-review › Article in proceedings – Annual report year: 1998

Environmental Assessment of Products, Volume 2: Scientific Background

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z., Wenzel, H.
Environmental considerations in product development

General information
State: Published
Organisations: Institute for Product Development, Department of Management Engineering
Contributors: Olesen, J., Hauschild, M. Z.
Number of pages: 24
Publication date: 1998

Publication information
Place of publication: London
Publisher: Chapman & Hall
Original language: English
Source: orbit
Source-ID: 166961
Research output: Research - peer-review › Book – Annual report year: 1998

Estimation of product specific emissions from municipal solid waste landfills for the inventory phase in LCA

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Nielsen, P. H., Hauschild, M. Z.
Pages: 127-128
Publication date: 1998

Host publication information
Title of host publication: Third Swedish landfill research symposia 1998
Place of publication: Stockholm
Publisher: AFR
Source: orbit
Source-ID: 171631
Research output: Research - peer-review › Article in proceedings – Annual report year: 1998

Human toxicity as a criterion in the environmental assessment of products

As part of a life cycle assessment methodology methods are developed for the semiquantitative screening and for the quantitative assessment of potential contributions to toxicity towards human beings through exposure in the environment to emissions occurring during the life cycle of a product. The assessment proceeds through the steps of classification, characterization, normalization and valuation. In the classification step attention is focused on intrinsic toxicity, low biodegradability and potential for bioconcentration as properties that predispose a substance for ecotoxicity. No concrete values are given but a semiquantitative screening method is proposed as tool for the classification. In the characterization the potential contribution to ecotoxicity from the compound is quantified in three compartments of the environment: Air, water, groundwater and soil. A characterization method is developed involving an analysis of the generic fate of the substance in the environment, its transfer efficiency to human beings and its potential effects. The fate analysis involves the passage of a wastewater treatment plant, redistribution through evaporation, deposition and biodegradation in the environment. The transfer efficiency is modelled in a standard scenario for indirect exposure of human beings through intake of fish, plants, meat and dairy products. The effect analysis consists in the determination of the highest oral dose or air concentration that is expected to cause no effects in human beings through a lifelong exposure. For all four compartments characterization factors are presented that express the toxicity potential of the substance in terms of a volume of the considered compartment. For normalization of the characterized emissions three different reference scenarios are suggested representing the situations of non exceedence of: ? The carrying capacity anywhere within Denmark or the European Union. ? The existing Danish political reduction targets for toxicity scaled to the year 2000 and applied to present Danish emissions. ? The presently occurring emissions within Denmark. The normalization references derived for each of these scenarios are presented as personal equivalents for citizens in the considered region. Valuation
Applying the "distance to target principle to the present Danish political reduction targets for toxicity a weighting factor is derived to be used in the quantitative weighing of the potential contribution to toxicity against the potential contributions to other environmental effect types.

General information
State: Published
Organisations: Department of Management Engineering
Contributors: Hauschild, M. Z., Olsen, S. I., Wenzel, H.
Pages: 315-444
Publication date: 1998

Host publication information
Title of host publication: Environmental Assessment of products. Volume 2: Scientific background
Publisher: Chapman & Hall
Editor: M. H. A. H. W.
URLs:
http://www.ipl.dtu.dk/publikation/7508/dk/
Source: orbit
Source-ID: 187115
Research output: Research - peer-review › Book chapter – Annual report year: 1998

Industrial ecology starting with the product perspective: experience at the Technical University of Denmark

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z., Alting, L.
Pages: 89-102
Publication date: 1998

Host publication information
Title of host publication: Industrial ecology and curriculum, Proceedings of the 3rd Industrial Ecology Seminar and Workshop
Place of publication: Trondheim
Publisher: NTVA
Source: orbit
Source-ID: 175519
Research output: Research - peer-review › Article in proceedings – Annual report year: 1998

Product specific emissions from municipal solid waste landfills: 2. Presentation and verification of the computer tool LCA-LAND

This paper presents and verifies the computer tool LCA-LAND for estimation of emissions from specific waste products disposed in municipal solid waste landfills in European countries for use in the inventory analysis of LCA. Examples of input data (e.g., distribution of the waste product in different countries, composition of the product and physical/chemical/biological properties of waste product components) and output data (e.g., estimated emissions to atmosphere and water) are given for a fictive waste product made of representative types of components (toluene, cellulose, polyvinylchloride (PVC), copper and chloride). Since waste products from different processes in the product system may be disposed at different landfills where they are mixed with waste originating outside the product system, the estimated emissions from specific waste products cannot be compared with measured emissions from true landfills. Hence, the computer tool is verified in terms of mass balances and sensitivity analyses. The mass balances agree exactly and the sensitivity analyses show that different types of waste product components behave differently in different types of landfills. Emission of e.g., toluene is significantly reduced in the presence of landfill top-cover, landfill gas combustion units and leachate treatment units. Generally, the sensitivity analysis shows good agreement between the relative proportions of various types of emissions (based on properties of the waste and properties of landfills) and good agreement with emission levels that would be expected based on a general understanding of landfill processes.

General information
State: Published
Organisations: Department of Manufacturing Engineering, Department of Management Engineering, ECOS Umwelt Nord GmbH, IMSA Amsterdam
Contributors: Nielsen, P. H., Exner, S., Jørgensen, A., Hauschild, M. Z.
Pages: 225-236
Publication date: 1998
Peer-reviewed: Yes
Product specific emissions from municipal solid waste landfills: 1. Landfill model

For the inventory analysis of environmental impacts associated with products in LCA there is a great need for estimates of emissions from waste products disposed at municipal solid waste landfills (product specific emissions). Since product specific emissions can not be calculated or measured directly at the landfills, they must be estimated by modelling of landfill processes. This paper presents a landfill model based on a large number of assumptions and approximations concerning landfill properties, waste product properties and characteristics of various kinds of environmental protection systems (e.g. landfill gas combustion units and leachate treatment units). The model is useful for estimation of emissions from waste products disposed in landfills and it has been made operational in the computer tool LCA-LAND presented in a following paper. In the model, waste products are subdivided into five groups of components: general organic matter (e.g. paper), specific organic compounds (e.g. organic solvents), inert components (e.g. PVC), metals (e.g. cadmium), and inorganic non-metals (e.g. chlorine,) which are considered individually. The assumptions and approximations used in the model are as far as possible scientifically based, but where scientific information has been missing, qualified estimates have been made to fulfill the aim of a complete tool for estimation of emissions. Due to several rough simplifications and missing links in our present understanding of landfills, the uncertainty associated with the model is relatively high.

General information
State: Published
Organisations: Department of Manufacturing Engineering, Department of Management Engineering
Contributors: Nielsen, P. H., Hauschild, M. Z.
Pages: 158-168
Publication date: 1998
Peer-reviewed: Yes

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 3
Issue number: 3
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.49 SJR 1.53 SNIP 1.579
Reducing the discrepancy between predicted impacts and actual impacts in LCA

General information
State: Published
Site-dependent life-cycle impact assessment of acidification

The lack of spatial differentiation in current life-cycle impact assessment (LCIA) affects the relevance of the assessed impact. This article first describes a framework for constructing factors relating the region of emission to the acidifying impact on its deposition areas. Next, these factors are established for 44 European regions with the help of the RAINS model, an integrated assessment model that combines information on regional emission levels with information on long-range atmospheric transport to estimate patterns of deposition and concentration for comparison with critical loads and thresholds for acidification, eutrophication via air; and tropospheric ozone formation. The application of the acidification factors in LCIA is very straightforward. The only additional data required, the geographical site of the emission, is generally provided by current life-cycle inventory analysis. The acidification factors add resolving power of a factor of 1,000 difference between the highest and lowest ratings, while the combined uncertainties in the RAINS model are canceled out to a large extent in the acidification factors as a result of the large number of ecosystems they cover. The framework presented is also suitable for establishing similar factors for eutrophication and tropospheric ozone formation for regions outside Europe as well.
Electrohydraulic control unit from Danfoss A/S

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Stenstoft, K., Erichsen, H., Hauschild, M. Z.
Publication date: 1997

Host publication information
Title of host publication: Environmental assesement of products. Vol.1 - Methodology, tools, techniques and case studies
Place of publication: United Kingdom
Publisher: Chapman & Hall
Source: orbit
Source-ID: 176174
Research output: Research - peer-review › Book chapter – Annual report year: 1997

Elements in a new sustainable industrial culture - Environmental assessment in product development
In the last few years the environmental focus in the manufacturing industry has shifted from the manufacturing processes to the products themselves, as these are accountable for the environmental impacts in all life cycle phases. The paper describes for 3 industrial cases how a newly developed LCA methodology can assist the product developer in development of more environmentally friendly products. Finally, common experience gained will be discussed.

General information
State: Published
Organisations: Department of Manufacturing Engineering, Institute for Product Development
Contributors: Alting, L., Hauschild, M. Z., Wenzel, H.
Pages: 523-531
Publication date: 1997

Host publication information
Title of host publication: 1st International Conference on Managing Enterprises - Stakeholders, Engineering, Logistics, and Achievement (ME-SELA 97) : Conference Theme: Sustainable Manufacturing for Global Business
Publisher: Mechanical Engineering Publications Limited
ISBN (Print): 1-86058-066-1
Keywords: sustainable industrial culture, environmental assessment, product development
Source: orbit
Source-ID: 167706
Research output: Research - peer-review › Article in proceedings – Annual report year: 1997
Environmental Assessment of Products, Volume 1: Methodology, tools and case studies in product development

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Wenzel, H., Hauschild, M. Z., Alting, L.
Number of pages: 543
Publication date: 1997
Publication information
Place of publication: London
Publisher: Chapman & Hall
Original language: English
Source: orbit
Source-ID: 166960
Research output: Research - peer-review › Book – Annual report year: 1997

Predicted environmental impact and expected occurrence of actual environmental impact. Part I.: The linear nature of environmental impact from emissions in life cycle assessment.

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Potting, J. M. B., Hauschild, M. Z.
Pages: 171-177
Publication date: 1997
Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 2
Issue number: 3
ISSN (Print): 0948-3349
Ratings:
BFI (2019): BFI-level 2
Web of Science (2019): Indexed yes
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 3.71 SJR 1.268 SNIP 1.454
Web of Science (2017): Impact factor 4.195
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.386 SNIP 1.517
Web of Science (2016): Impact factor 3.173
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Predicted environmental impact and expected occurrence of actual environmental impact. Part II: Spatial differentiation in life cycle assessment via the site-dependent characterisation of environmental impact from emissions.
Refrigerator from Gram A/S

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Mose, A., Wenzel, H., Hauschild, M. Z.
Publication date: 1997

Host publication information
Title of host publication: Environmental assessment of products. Vol. 1 - Methodology, tools, techniques and case studies
Place of publication: United Kingdom
Publisher: Chapman & Hall
Source: orbit
Source-ID: 176173
Research output: Research - peer-review › Book chapter – Annual report year: 1997

Site-dependent life-cycle impact assessment of acidification.

General information
State: Published
Organisations: Department of Manufacturing Engineering, International Institute for Applied Systems Analysis, Utrecht University
Contributors: Potting, J. M. B., Schöpp, W., Blok, K., Hauschild, M. Z.
Pages: 149-154
Publication date: 1997

Host publication information
Title of host publication: Ale, B.J.M., M.P.M. Janssen and M.J.M. Pruppers (eds.). Book of papers. Proceedings of RISK97, the international conference on environmental risks and risk comparison, 21-24 October 1997 in Amsterdam
Place of publication: Bilthoven, Nehterlands
Publisher: RIVM
Source: orbit
Source-ID: 175546
Research output: Research › Article in proceedings – Annual report year: 1997

Background for the environmental assessment of products, (in Danish)

General information
Discussion of general principles and guidelines for practical use

General information
State: Published
Organisations: Department of Manufacturing Engineering, Leiden University, IMSA, Krüger Veolia Water Technologies, Swedish Environmental Research Institute, Swiss Federal Institute of Technology, dk-TEKNIK A/S, Swiss Federal Institute of Technology Lausanne, IVAM, PIRA Consultants, Inc., Procter and Gamble, University of St. Galien
Pages: 7-31
Publication date: 1996

Host publication information
Title of host publication: Towards a methodology for life cycle impact assessment
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry - Europe
Source: orbit
Source-ID: 175551
Research output: Research - peer-review › Article in proceedings – Annual report year: 1996

Environmental Assessment Methods

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z.
Pages: 73-113
Publication date: 1996

Host publication information
Title of host publication: Selected Topics in Environmental Management. UNESCO Series of Learning Materials in Engineering Sciences
Place of publication: Paris
Publisher: UNESCO
Source: orbit
Source-ID: 167419
Research output: Research - peer-review › Book chapter – Annual report year: 1996

Environmental assessment of products

General information
State: Published
Organisations: Department of Manufacturing Engineering, Technical University of Denmark
Contributors: Christensen, H. W., Hauschild, M. Z., Rasmussen, E.
Number of pages: 336
Publication date: 1996

Publication information
Place of publication: Copenhagen
Environmental Design

General information
State: Published
Organisations: Department of Manufacturing Engineering, KRTA Ltd.
Contributors: Thom, D., Hauschild, M. Z.
Pages: 292-316
Publication date: 1996

Host publication information
Title of host publication: Selected Topics in Environmental Management. UNESCO Series of Learning Materials in Engineering Sciences
Place of publication: Paris
Publisher: UNESCO
Source: orbit
Source-ID: 167423
Research output: Research - peer-review › Book chapter – Annual report year: 1996

Global warming as assessment criterion in environmental assessment of products

General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z., Wenzel, H.
Pages: 11-84
Publication date: 1996

Host publication information
Title of host publication: Background for environmental assessment of products
Place of publication: Copenhagen
Publisher: Miljø- og Energimisteriet og Dansk Industri
Source: orbit
Source-ID: 167427
Research output: Research - peer-review › Book chapter – Annual report year: 1996

Impact assessment of human and ecotoxicity in life cycle assessment

General information
State: Published
Organisations: Department of Manufacturing Engineering, Swiss Federal Institute of Technology Lausanne, IMSA, Swedish Environmental Research Institute, Leiden University, Swiss Federal Institute of Technology
Pages: 49-61
Publication date: 1996

Host publication information
Title of host publication: Towards a methodology for life cycle impact assessment
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry - Europe
Source: orbit
Source-ID: 175552
Research output: Research - peer-review › Article in proceedings – Annual report year: 1996

Impact assessment of non toxic pollution in life cycle assessment.

General information
Host publication information
Title of host publication: Towards a methodology for life cycle impact assessment
Place of publication: Brussels
Publisher: Society of Environmental Toxicology and Chemistry - Europe
Source: orbit
Source-ID: 167415
Research output: Research - peer-review › Article in proceedings – Annual report year: 1996

Life-Cycle Assessment
General information
State: Published
Organisations: Department of Manufacturing Engineering
Contributors: Hauschild, M. Z.
Pages: 114-148
Publication date: 1996

Host publication information
Title of host publication: Selected Topics in Environmental Management. UNESCO Series of Learning Materials in Engineering Sciences
Place of publication: Paris
Publisher: UNESCO
Source: orbit
Source-ID: 167422
Research output: Research - peer-review › Book chapter – Annual report year: 1996

Spatial aspects of human toxicity in life cycle impact assessment
General information
State: Published
Organisations: Department of Manufacturing Engineering, Department of Management Engineering
Publication date: 1996

Host publication information
Title of host publication: Proceedings from the 17th annual meeting of SETAC/US
Publisher: Society of Environmental Toxicology and Chemistry
Source: orbit
Source-ID: 176162
Research output: Research › Article in proceedings – Annual report year: 1996

The Dobris assessment of the state of the environment in Europe
General information
State: Published
Organisations: Department of Management Engineering
Contributors: Hauschild, M. Z.
Pages: 64-65
Publication date: 1996
Peer-reviewed: No

Publication information
Journal: Dansk Kemi
Volume: 77
Issue number: 8
ISSN (Print): 0011-6335
Ratings:
ISI indexed (2013): ISI indexed no
Environmental tools in product development
A precondition for design of environmentally friendly products is that the design team has access to methods and tools supporting the introduction of environmental criteria in product development. A large Danish program, EDIP, is being carried out by the Institute for Product Development, Technical University of Denmark, in cooperation with 5 major Danish companies aiming at the development and testing of such tools. These tools are presented in this paper

Projects:
REACH-4-USEtox
The overall objective of the REACH-4-USEtox project is to assess REACH registration data for use in the global scientific consensus model USEtox and apply USEtox to identify sensitive input parameters for characterizing the fate of chemical substances released to the environment and for characterizing related human and ecosystem exposures.
Fantke, P., PI, Department of Management Engineering, Quantitative Sustainability Assessment
Hauschild, M. Z., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
Aurisano, N., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
01/01/2018 → 30/06/2018
Keywords: REACH, USEtox, Chemicals
Collaborators: European Chemicals Agency
Project: Research

The objective of the GLAM project is to run a global process aiming at global guidance and consensus building on a limited number of environmental life cycle impact category indicators developed within a consistent framework, and to identify the related research agenda. The deliverable would be a global guidance publication with a supporting web system that includes the limited number of 6 to 10 life cycle assessment (LCA) based environmental impact category indicators and the characterization factors (for various regions). It may also include guidance on how to best establish a particular regional impact category indicator in case global consensus on characterization factors cannot be achieved or makes no sense.
Fantke, P., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
Hauschild, M. Z., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
Laurent, A., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
Owsianiak, M., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
Aurisano, N., Project Participant, Quantitative Sustainability Assessment, Department of Management Engineering
01/05/2013 → 31/07/2020
Keywords: UNEP, Life Cycle Impact Assessment
Collaborators: United Nations Environmental Programme
Project: Research

Assessing the absolute environmental sustainability of products and systems
Vea, E. B., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Ryberg, M., Supervisor
15/11/2018 → 14/11/2021
Project: PhD

Sustainability Impact Assessment for Circular Economy
Kravchenko, M., PhD Student, Department of Mechanical Engineering
McAloone, T. C., Main Supervisor
Pigosso, D. C. A., Supervisor
Hauschild, M. Z., Supervisor
Hildenbrand, J., Supervisor
Samfinansieret - Andet
01/12/2017 → 30/11/2020
Award relations: Sustainability Impact Assessment for Circular Economy
Project: PhD

Climate tipping indicators for improved environmental sustainability assessment of bioplastics
Fabbri, S., PhD Student, Department of Management Engineering
Owsianiak, M., Main Supervisor
Hauschild, M. Z., Supervisor
Samfinansieret - Andet
01/09/2017 → 17/11/2020
Award relations: Climate tipping indicators for improved environmental sustainability assessment of bioplastics
Project: PhD

Environmental Sustainability Assessment of Advanced Agricultural Waste Technologies and Agricultural Territories
Sohn, J., PhD Student, Department of Management Engineering
Olsen, S. I., Main Supervisor
Birkved, M., Supervisor
Goldstein, B. P., Supervisor
Hauschild, M. Z., Supervisor
Kalbar, P., Supervisor
Anden EU-finansiering
01/05/2017 → 13/08/2020
Award relations: Environmental Sustainability Assessment of Advanced Agricultural Waste Technologies and Agricultural Territories
Project: PhD

Environmental Sustainability Assessment of Advanced Agricultural Waste Technologies and Agricultural Territories
Vega, G. C., PhD Student, Department of Management Engineering
Olsen, S. I., Main Supervisor, Department of Management Engineering
Birkved, M., Supervisor, Department of Management Engineering
Uellendahl, H., Supervisor, Rise National Laboratory for Sustainable Energy
Hauschild, M. Z., Supervisor, Department of Management Engineering
Uellendahl, H., Supervisor, Rise National Laboratory for Sustainable Energy
Bruun, S., Supervisor
Samfinansieret - Andet
01/05/2017 → 30/04/2020
Award relations: Environmental Sustainability Assessment of Advanced Agricultural Waste Technologies and Agricultural Territories
Project: PhD
Environmental sustainability assessment of the aquaculture sector at global and national scales
Bohnes, F. A., PhD Student, Department of Management Engineering
Laurent, A., Main Supervisor
Hauschild, M. Z., Supervisor
Schlundt, J., Supervisor
Technical University of Denmark
15/12/2016 → 14/12/2019
Award relations: Environmental sustainability assessment of the aquaculture sector at global and national scales
Project: PhD

Hybrid Life-cycle-assessment-urban-metabolism model as a framework for quantifying the contributions of urban agriculture to the sustainability of urban food system
Goldstein, B. P., PhD Student, Department of Management Engineering
Birkved, M., Main Supervisor
Fernandez, J. E., Supervisor
Hauschild, M. Z., Supervisor
Nielsen, P. S., Examiner
Dalgaard, T., Examiner
Newell, J. P., Examiner
Technical University of Denmark
01/12/2013 → 23/03/2017
Award relations: Hybrid Life-cycle-assessment-urban-metabolism model as a framework for quantifying the contributions of urban agriculture to the sustainability of urban food system
Project: PhD

Afværgestrategier for in-situ oprensning af chlorerede opløsningsmidler - udvikling af ramme for livscyklusvurdering og cost-effectiveness nalyse
Søndergaard, G. L., PhD Student, Department of Environmental Engineering
Bjerg, P. L., Main Supervisor
Hauschild, M. Z., Supervisor
Finkel, M., Examiner
DTU-lønnet stipendie
01/10/2006 → 22/09/2010
Award relations: Afværgestrategier for in-situ oprensning af chlorerede opløsningsmidler - udvikling af ramme for livscyklusvurdering og cost-effectiveness nalyse
Project: PhD

Bæredygtig produktion - vurdering af den sociale og miljømæssige dimension
Jørgensen, A., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Jørgensen, M. S., Supervisor
Olsen, S. I., Examiner
Benolf, C., Examiner
Griesshammer, R., Examiner
DTU-lønnet stipendie
01/09/2006 → 30/06/2010
Award relations: Bæredygtig produktion - vurdering af den sociale og miljømæssige dimension
Project: PhD

Inddragelse af sociale, sundheds- og sikkerhedsmæssige aspekter i livscyklusvurdering af produkter og servideydelses
Dreyer, L. C., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Schierbeck, J., Supervisor
Wangel, A., Examiner
Griesshammer, R., Examiner
Olsen, M., Examiner
ErhvervsPhD-ordningen VTU
01/02/2003 → 02/12/2009
Award relations: Inddragelse af sociale, sundheds- og sikkerhedsmæssige aspekter i livscyklusvurdering af produkter og servideydelses
Project: PhD
**Miljøvurdering af restprodukters genanvendelse**
Birgisdottir, H., PhD Student, Department of Environmental Engineering  
Christensen, T. H., Main Supervisor  
Hauschild, M. Z., Supervisor  
Kjeldsen, P., Examiner  
Finnveden, G., Examiner  
Gardner, K. H., Examiner  
DTU-lønnest stipendie  
01/09/2001 → 23/12/2005  
Award relations: Miljøvurdering af restprodukters genanvendelse  
Project: PhD

**Kemikalieorienteret produktmiljøvurdering**
Birkved, M., PhD Student, Department of Management Engineering  
Hauschild, M. Z., Main Supervisor  
Jørgensen, S. E., Examiner  
McKone, T. E., Examiner  
Sørensen, P., Examiner  
Eksternt EU-finansieret  
01/08/2001 → 18/05/2005  
Award relations: Kemikalieorienteret produktmiljøvurdering  
Project: PhD

**Modeller til miljøvurdering af affaldssystemer**
Kirkeby, J. S., PhD Student, Department of Environmental Engineering  
Christensen, T. H., Main Supervisor  
Hauschild, M. Z., Supervisor  
Mikkelsen, P. S., Examiner  
Bilitewski, B., Examiner  
Nielsen, P. H., Examiner  
DTU-lønnest stipendie  
01/02/2001 → 18/05/2005  
Award relations: Modeller til miljøvurdering af affaldssystemer  
Project: PhD

**Absolut miljømæssig bæredygtighed af industrielle aktiviteter**
Bjørn, A., PhD Student, Department of Management Engineering  
Hauschild, M. Z., Main Supervisor  
Rapke, I., Supervisor  
Olsen, S. I., Examiner  
Richardson, K., Supervisor  
Goedkoop, M., Examiner  
Cornell, S. E., Examiner  
Offentlig finansiering  
15/12/2011 → 24/09/2015  
Award relations: Absolut miljømæssig bæredygtighed af industrielle aktiviteter  
Project: PhD

**Development of environmental footprints for large-scale systems**
Leclerc, A. S. C., PhD Student, Department of Management Engineering  
Laurent, A., Main Supervisor  
Hauschild, M. Z., Supervisor  
Wood, R., Supervisor  
Technical University of Denmark  
15/09/2016 → 31/01/2020  
Award relations: Development of environmental footprints for large-scale systems  
Project: PhD

**Effective Implementation of Sustainability Approaches**
Stewart, R. M. M., PhD Student, Department of Management Engineering
**Life-cycle assessment of climate adaption technologies for stormwater management**

Brudler, S., PhD Student, Department of Environmental Engineering  
Rygaard, M., Main Supervisor  
Arnbjerg-Nielsen, K., Supervisor  
Hauschild, M. Z., Supervisor  
Damgaard, A., Examiner  
Jensen, M. B., Examiner  
Stokes-Draut, J. R., Examiner  
Ammitsøe, C., Supervisor  
Industrial PhD  
15/08/2015 → 21/02/2019  
Award relations: Life-cycle assessment of climate adaption technologies for stormwater management  
Project: PhD

**Integrating Supply Chain Hot Spot Analysis and Business Risk Management**

Colley, T. A., PhD Student, Department of Management Engineering  
Hauschild, M. Z., Main Supervisor  
Birkved, M., Supervisor  
Olsen, S. I., Supervisor  
Privatist  
15/02/2015 → 14/08/2019  
Award relations: Integrating Supply Chain Hot Spot Analysis and Business Risk Management  
Project: PhD

**Water Supplies' Water Footprint**

Gejl, R. N., PhD Student, Department of Environmental Engineering  
Rygaard, M., Main Supervisor  
Bjerg, P. L., Supervisor  
Hauschild, M. Z., Supervisor  
Henriksen, H. J., Supervisor  
Rasmussen, J., Supervisor  
Industrial PhD  
15/12/2014 → 31/05/2019  
Award relations: Water Supplies' Water Footprint  
Project: PhD

**Integration of boundaries for selected planetary threads into life cycle assessment**

Ryberg, M., PhD Student, Department of Management Engineering  
Hauschild, M. Z., Main Supervisor  
Owsianiak, M., Supervisor  
Olsen, S. I., Examiner  
Sala, S., Examiner  
Richardson, K., Supervisor  
Cornell, S. E., Examiner  
Technical University of Denmark  
15/12/2014 → 30/09/2018  
Award relations: Integration of boundaries for selected planetary threads into life cycle assessment  
Documents:  
Morten Ryberg_PhDthesis_Putting life-cycle indicators on an absolute scale  
Project: PhD
Environmental sustainability assessment of bio-products based on agricultural crop and crop residue feedstocks
Corona, A., PhD Student, Department of Management Engineering
Birkved, M., Main Supervisor
Hauschild, M. Z., Supervisor
Bey, N., Examiner
Bruun, S., Examiner
Sonesson, U., Examiner
Samfinansieret - Andet
01/09/2014 → 16/04/2018
Award relations: Environmental sustainability assessment of bio-products based on agricultural crop and crop residue feedstocks
Project: PhD

Eco-design 2.0 - Quantitative Eco-design within Drives and Automation Technologies
Auer, J., PhD Student, Department of Management Engineering
Bey, N., Main Supervisor
Hauschild, M. Z., Supervisor
Wegener, D., Supervisor
Olsen, S. I., Examiner
Herrmann, C., Examiner
Herrmann, C., Examiner
Privatist
01/06/2014 → 25/09/2017
Award relations: Eco-design 2.0 - Quantitative Eco-design within Drives and Automation Technologies
Project: PhD

Sustainable Management of Water Treatment Technologies
Bonou, A., PhD Student, Department of Management Engineering
Olsen, S. I., Main Supervisor
Hauschild, M. Z., Supervisor
Bey, N., Examiner
Boks, C., Examiner
Finkbeiner, M., Examiner
ErhvervsPhD-ordningen VTU
01/10/2011 → 25/11/2016
Award relations: Sustainable Management of Water Treatment Technologies
Project: PhD

Environmental assessment of biomass based materials
Jørgensen, S. V., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Birkved, M., Examiner
Ortiz, I. M., Examiner
Cowie, A., Examiner
ErhvervsPhD-ordningen VTU
15/11/2010 → 26/05/2014
Award relations: Environmental assessment of biomass based materials
Project: PhD

Arealanvendelse og toksikologi i konsekvens-LCA
Kløverpris, J. H., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Nielsen, J., Supervisor
Olsen, S. I., Examiner
Mila i Canals, L., Examiner
Ekvall, T. I., Examiner
ErhvervsPhD-ordningen VTU
01/01/2005 → 21/11/2008
Award relations: Arealanvendelse og toksikologi i konsekvens-LCA
Project: PhD
Integration of Environmental Life Cycle Information Into Cad-Systems for Support of Design for Environment
Bhander, G. S., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Christensen, T. H., Supervisor
Mikkelsen, P. S., Examiner
Finnveden, G., Examiner
Nielsen, P. H., Examiner
Friplads
01/12/2001 → 31/03/2006
Award relations: Integration of Environmental Life Cycle Information Into Cad-Systems for Support of Design for Environment
Project: PhD

Development of a Flexible Bioprocess for Handling and Recycling Seasonal Industrial Wastewaters
Maya Altamira, L., PhD Student, Department of Environmental Engineering
Schmidt, J. E., Main Supervisor
Baun, A., Supervisor
Hauschild, M. Z., Supervisor
Eilersen, A. M., Examiner
Alves, M. M. D. S., Examiner
Petersen, G., Examiner
Privatist
15/04/2004 → 04/07/2008
Award relations: Development of a Flexible Bioprocess for Handling and Recycling Seasonal Industrial Wastewaters
Project: PhD

Development of a Life Cycle Impact Assessment methodology for Brazil
Crespo Mendes, N., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Laurent, A., Supervisor
Olsen, S. I., Examiner
Bruun, S., Examiner
Ugaya, C. M. L., Examiner
Science Without Borders, Brasi
15/12/2013 → 08/06/2018
Award relations: Development of a Life Cycle Impact Assessment methodology for Brazil
Project: PhD

Development of a methodology for inclusion of terrestrial ecotoxic impacts of metals in life cycle impact assessment
Owsianiak, M., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Rosenbaum, R. K., Supervisor
Olsen, S. I., Examiner
Diamond, M. L., Examiner
Lützhøft, H. H., Examiner
Anden EU-finansiering
01/04/2010 → 12/12/2013
Award relations: Development of a methodology for inclusion of terrestrial ecotoxic impacts of metals in life cycle impact assessment
Project: PhD

Supply chain modelling for professionally prepared meals
Wang, Y., PhD Student, Department of Management Engineering
Akkerman, R., Main Supervisor
Grunow, M., Supervisor
Hauschild, M. Z., Examiner
Li, D., Examiner
Sonesson, U., Examiner
Offentlig finansiering
01/08/2008 → 31/01/2013
Award relations: Supply chain modelling for professionally prepared meals
**Kemikalieorienteret produktvurdering**
Larsen, H. F., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Kusk, K. O., Examiner
Chapman, P. M., Examiner
Molander, S., Examiner
Anden sektorministeriel finans
01/01/2001 → 11/02/2005
Award relations: Kemikalieorienteret produktvurdering
Project: PhD

**An integrated Multi-level Framework for Life Cycle Sustainability Assessment Case study: Production of High-grade Concrete from Construction and Demol**
Bozhilova-Kisheva, K. P., PhD Student, Department of Management Engineering
Olsen, S. I., Main Supervisor
Hauschild, M. Z., Supervisor
Bey, N., Examiner
Petersen, E. E., Examiner
Zamagni, A., Examiner
Institut, samfinansiering
15/02/2011 → 19/01/2017
Award relations: An integrated Multi-level Framework for Life Cycle Sustainability Assessment Case study: Production of High-grade Concrete from Construction and Demol
Project: PhD

**New high-quality mined nanomaterials mass produced for plastic and wood-plastic nanocomposites**
Miseljic, M., PhD Student, Department of Management Engineering
Olsen, S. I., Main Supervisor
Hauschild, M. Z., Supervisor
Birkved, M., Examiner
Hansen, S. F., Examiner
Hischier, R., Examiner
Institut, samfinansiering
01/01/2011 → 19/03/2015
Award relations: New high-quality mined nanomaterials mass produced for plastic and wood-plastic nanocomposites
Project: PhD

**Life cycle assessment applied to nanomaterials in solid waste management - Focus on human health impact assessment**
Laurent, A., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Hellweg, S., Supervisor
Birkved, M., Examiner
Hansen, S. F., Examiner
Walser, T., Examiner
1/3 DTU-stip, 2/3 FUR/andet
01/05/2010 → 24/03/2014
Award relations: Life cycle assessment applied to nanomaterials in solid waste management - Focus on human health impact assessment
Project: PhD

**Waste Management Strategies of the Future: A Consistent European and National Technology Platform**
Gentil, E., PhD Student, Department of Environmental Engineering
Christensen, T. H., Main Supervisor
Hauschild, M. Z., Supervisor
Astrup, T., Examiner
Fischer, C., Examiner
Wilson, D. C., Examiner
1/3 DTU-stip, 2/3 FUR/andet
01/10/2006 → 02/03/2011
Award relations: Waste Management Strategies of the Future: A Consistent European and National Technology Platform
Livscyklus- og risikoanalyse af alternative teknologier og ressourcer til drikkevandsforsyningen
Godskesen, B., PhD Student, Department of Environmental Engineering
Albrechtsen, H., Main Supervisor
Hauschild, M. Z., Supervisor
Rygaard, M., Supervisor
Zambrano, K. C., Supervisor
Astrup, T., Examiner
Lindgaard-Jørgensen, P., Examiner
Lundie, S., Examiner
ErhvervsPhD-ordningen VTU
01/05/2009 → 06/02/2013
Award relations: Livscyklus- og risikoanalyse af alternative teknologier og ressourcer til drikkevandsforsyningen
Project: PhD

Life cycle impact assessment of long-term emissions from landfills
Bakas, I., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Astrup, T. F., Supervisor
Rosenbaum, R. K., Supervisor
Olsen, S. I., Examiner
Finnveden, G., Examiner
Henderson, A. D., Examiner
Technical University of Denmark
15/12/2011 → 22/06/2015
Award relations: Life cycle impact assessment of long-term emissions from landfills
Project: PhD

Development and application of a standardized methodology for the PROspective Sustainabilty assessment of Technologies
Dong, Y., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Rosenbaum, R. K., Supervisor
Birkved, M., Examiner
Lützhøft, H. H., Examiner
Henderson, A. D., Examiner
Technical University of Denmark
15/11/2010 → 23/02/2015
Award relations: Development and application of a standardized methodology for the PROspective Sustainabilty assessment of Technologies
Project: PhD

Modelling of pesticide emissions for Life Cycle Inventory analysis: model development, applications and implications
Dijkman, T. J., PhD Student, Department of Management Engineering
Birkved, M., Main Supervisor
Hauschild, M. Z., Supervisor
Olsen, S. I., Examiner
Bruun, S., Examiner
Zelm, R. V., Examiner
Technical University of Denmark
01/09/2010 → 21/02/2014
Award relations: Modelling of pesticide emissions for Life Cycle Inventory analysis: model development, applications and implications
Project: PhD

Sustainable assessment of full chain bioenergy production
Saez de Bikuna Salinas, K., PhD Student, Department of Environmental Engineering
Ibrom, A., Main Supervisor
Hauschild, M. Z., Supervisor
Pilegaard, K., Supervisor
Damgaard, A., Examiner
Development of a Sustainability Assessment method for robotic manufacturing systems
Rödger, J., PhD Student, Department of Management Engineering
Bey, N., Main Supervisor
Hauschild, M. Z., Supervisor
Olsen, S. I., Examiner
Dewulf, W., Examiner
Anden EU-finansiering
15/12/2013 → 07/12/2017
Award relations: Development of a Sustainability Assessment method for robotic manufacturing systems
Project: PhD

Formation of Life Cycle Inventory (LCI) Database for Crude Palm Oil Production and Palm Oil Based Bio-diesel Refining in Malaysia
Hansen, S. B., PhD Student, Department of Management Engineering
Olsen, S. I., Main Supervisor
Hauschild, M. Z., Supervisor
Wangel, A., Supervisor
Birkved, M., Examiner
Finkbeiner, M., Examiner
Bruun, S., Examiner
Technical University of Denmark
01/09/2009 → 24/04/2013
Award relations: Formation of Life Cycle Inventory (LCI) Database for Crude Palm Oil Production and Palm Oil Based Bio-diesel Refining in Malaysia
Project: PhD

Environmental Sustainability Assessment of Biodiesel Production
Herrmann, I. T., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Olsen, S. I., Examiner
Mortensen, J. B., Examiner
Rydberg, T. V., Examiner
Technical University of Denmark
01/01/2009 → 20/09/2012
Award relations: Environmental Sustainability Assessment of Biodiesel Production
Project: PhD

Quantifying the Sustainability of Consumer Products: Focusing on Chemical Exposures
Ernstoff, A., PhD Student, Department of Management Engineering
Fantke, P., Main Supervisor
Hauschild, M. Z., Supervisor
Rosenbaum, R. K., Supervisor
Trier, X., Supervisor
Olsen, S. I., Examiner
Hellweg, S., Examiner
Jolliet, O., Supervisor
Egeghy, P. P., Examiner
Technical University of Denmark
15/12/2013 → 23/03/2017
Award relations: Quantifying the Sustainability of Consumer Products: Focusing on Chemical Exposures
Project: PhD
Impacts of waterbone nitrogen emissions to hypoxia-driven marine eutrophication: modelling of damage to ecosystems in life cycle impact assessment (LC IA)
Cosme, N. M. D., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Birkved, M., Supervisor
Rosenbaum, R. K., Supervisor
Laurent, A., Examiner
Verones, F., Examiner
Henderson, A. D., Examiner
Technical University of Denmark
15/12/2012 → 01/09/2016
Award relations: Impacts of waterbone nitrogen emissions to hypoxia-driven marine eutrophication: modelling of damage to ecosystems in life cycle impact assessment (LC IA)
Project: PhD

Advanced planning approaches for small- and medium-sized enterprises
Herczeg, G., PhD Student, Department of Management Engineering
Hauschild, M. Z., Main Supervisor
Akkerman, R., Supervisor
Jacobsen, P., Supervisor
Jensen, P. L., Supervisor
Hvam, L., Examiner
Olhager, J. E., Examiner
Govindan, K., Examiner
Technical University of Denmark
01/12/2011 → 04/07/2016
Award relations: Advanced planning approaches for small- and medium-sized enterprises
Project: PhD

Dynamic optimization of total value and environmental performance: Use of real time property data for improved Facilities Management
Maslesa, E., PhD Student, Department of Management Engineering, Systems Analysis
Nielsen, S. B., Main Supervisor, Department of Management Engineering, Centre for Facilities Management, Systems Analysis
Birkved, M., Supervisor, Department of Management Engineering, Quantitative Sustainability Assessment
Hauschild, M. Z., Supervisor, Department of Management Engineering, Quantitative Sustainability Assessment
Hultén, J., Supervisor, KMD A/S
01/02/2016 → 31/01/2019
Collaborators: KMD A/S
Documents:
PhD poster - KMD
Project: Research

AREUS: Automation and Robotics for EUropean Sustainable Manufacturing
Bey, N., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Rödger, J., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Dijkman, T. J., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Hauschild, M. Z., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Molin, C., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Alting, L., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment, Department of Mechanical Engineering, Manufacturing Engineering
FP7 Contract ID: Agreement No. 609391
Project ID: 81375
01/09/2013 → 31/08/2016
Project: Research

Hauschild, M. Z., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Rosenbaum, R. K., Project Participant
Larsen, H. F., Project Participant
Fantke, P., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Owsianiak, M., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Assessment of sustainable wastewater handling in sewerless settlment.
The purpose is to develop a method for comparative assessment of solutions for sustainable handling of wastewater in the open land. The perspective is transparency and a better agreement between different stakeholders perception of what sustainable wastewater handling is. The assessment method will be incorporated in a generally accessible and practicable computer-based decision support system for use in planning and quality control of projects. The basic premise of the method is that no specific technologies are inherently sustainable, or ecological, but that the sustainability of the total system of technologies for a settlement in a given location must be assessed in a holistic and transparent manner. The method brings wastewater handling into focus, but related waste streams and stormwater is included in the assessments, when their handling are directly coupled with the handling of wastewater. Settlements without traditional sewer systems are covered, e.g. farm houses, summer cottages, garden allotments, villages and ecological settlements planned with specific reference to avoiding sewers. These types of settlements have very different natural and manmade preconditions and the method thus rests on site-analyses of local conditions. The project will involve external stakeholders through case-studies where solutions for existing or planned settlements are assessed to test and illustrate the assessment method.

Henze, M., Project Manager, Department of Environmental Science and Engineering
Mikkelsen, P. S., Project Participant, Department of Environmental Science and Engineering
Eilersen, A. M., Project Participant, Department of Environmental Science and Engineering
Gabriel, S., Project Participant, Department of Environmental Science and Engineering
Rauch, W., Project Participant, Department of Environmental Science and Engineering
Tjell, J. C., Project Participant, Department of Environmental Science and Engineering
Hauger, M. B., Project Participant, Department of Environmental Science and Engineering
Christensen, K., Project Participant, Department of Planning
Elle, M., Project Participant, Department of Planning
Nielsen, S. B., Project Participant, Department of Planning
Hoffmann, B., Project Participant, Department of Planning
Hauschild, M. Z., Project Participant, Department of Planning
Ukendt: DKK2,312,000.00
01/10/1998 → 31/12/2000
Award relations: Assessment of sustainable wastewater handling in sewerless settlment.
Project: Research

LCA-method development and consensus creation - inclusion of spatial information in life cycle impact assessment
This part of the general method development and consensus programme covers investigations of the possibilities for inclusion of spatial information in the life cycle impact assessment of non-global impact categories (photochemical ozone formation, acidification, nutrient enrichment, ecotoxicity, human toxicity, noise).
Hauschild, M. Z., Project Manager, Department of Management Engineering
Potting, J. M. B., Project Participant, Department of Management Engineering
Schmidt, A., Project Participant, dk-TEKNIK A/S
Christensen, F. M., Project Participant, Dansk Toksikologi Center
Terslev, J., Project Participant, Vandkvalitetsinstituttet, VKI
Ølgaard, H., Project Participant, Danish Technological Institute
Ukendt: DKK1,800,000.00
01/09/1997 → 01/07/2001
Award relations: LCA-method development and consensus creation - inclusion of spatial information in life cycle impact assessment
Project: Research
**LCAGAPS - Development and application of complementary components to the existing detailed life cycle assessment methodology**

In cooperation between University, Consultants and Industry the project develops solutions to remediate identified lacks and shortcomings of existing life cycle assessment (LCA) methods to arrive at a full LCA-method. Focus of the project will be on the handling of waste treatment processes in the inventory component of the LCA, on treatment of toxicity and land use in the impact assessment component, on development of European normalization references and the setting of weighting factors in the evaluation component and on statistical treatment of uncertainties in LCA. Based on the outcome of the project suggestions for guidelines will be developed and introduced into the international LCA society.

Hauschild, M. Z., Project Manager, Department of Manufacturing Engineering
Erichsen, H. K. L., Project Participant, Department of Manufacturing Engineering
Potting, J. M. B., Project Participant, Department of Manufacturing Engineering
Nielsen, P. H., Project Participant, Institute for Product Development
Mortensen, B., Project Participant, Institute for Product Development
Weidema, B. P., Project Participant, Institute for Product Development
Bracke, R., Project Participant, ECOS Umwelt Nord GmbH

Ukendt: DKK5,084,000.00
01/09/1995 → 01/09/2001
Collaborators: ECOS Umwelt Nord GmbH
Award relations: LCAGAPS - Development and application of complementary components to the existing detailed life cycle assessment methodology
Project: Research

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**ESTO-WASTE: Waste prevention, waste policy and innovation**

Jørgensen, U., Project Participant, Department of Manufacturing Engineering
Jørgensen, M. S., Project Participant, Department of Manufacturing Engineering
Olsen, S. I., Project Participant, Department of Manufacturing Engineering
Knudsen, H. H., Project Manager, Department of Manufacturing Engineering
Lauridsen, E. H., Project Participant, Department of Manufacturing Engineering
Hauschild, M. Z., Project Participant, Department of Manufacturing Engineering

Fors. EU - Andre EU-midler: DKK1,500,000.00
01/11/2005 → 30/08/2006
Award relations: Waste prevention, waste policy and innovation
Project: Research

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**ECO-QSA: Climate damage modeling in LCA – quantitative sustainability assessment of future technologies**

Climate change is a global threat to ecosystems and vast resources are invested to develop new climatically sustainable technologies. However, the assessments of such climatic sustainability are generally hindered by the absence of appropriate assessment tools of sufficiently broad scope. In the project we will develop "a concept for quantitative environmental sustainability assessment of technologies (e.g. renewable energy) from a climate change and climate protection point of view". Financed by the Villum Kann Rasmussen Foundation

Callesen, I., Project Manager, Department of Management Engineering, Quantitative Sustainability Assessment
Beier, C., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Olsen, S. I., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Hauschild, M. Z., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment
Bagger Jørgensen, R., Project Participant, Department of Management Engineering, Quantitative Sustainability Assessment

Project ID: 81110
Gaver, Private danske Fonde: DKK1,000,000.00
01/03/2010 → 28/02/2012
Keywords: climate change, ecosystem damage modeling, LCA
Award relations: Climate damage modeling in LCA – quantitative sustainability assessment of future technologies
Project: Research

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**LCA and residual products**

Life cycle inventory modelling for residual products from waste incineration
Hauschild, M. Z., Project Participant, Department of Management Engineering
Olsen, S. I., Project Participant, unknown organisation

01/12/2000 → 01/12/2002
Collaborators: unknown organisation
Project: Research
**Pesticide dispersion model**
Development of LCA inventory model for pesticide emissions from cultivation of field crops
Hauschild, M. Z., Project Manager, Department of Management Engineering
Ukendt
01/12/2001 → 01/12/2002
Award relations: Pesticide dispersion model
Project: Research

**LCA method development and consensus**
Development of spatially differentiated characterisation model for all non-global impact categories. To be published as an update, EDIP200, of the existing EDIP97 LCIA methodology. LCA-method development and consensus creation - inclusion of exposure in life cycle impact assessment. This part of the general method development and consensus programme covers investigations of the possibilities for inclusion of exposure in the life cycle impact assessment of non-global impact categories (photochemical ozone formation, acidification, nutrient enrichment, ecotoxicity, human toxicity, noise).
Hauschild, M. Z., Project Manager, Department of Management Engineering
01/12/1997 → 01/12/2002
Project: Research

**LCA Malaysia**
Implementation of life cycle assessment in Malaysian industry
Jensen, A. H., Project Manager
Hauschild, M. Z., Project Participant, Department of Management Engineering
Poll, C., Project Participant
01/12/2000 → 01/12/2002
Project: Research

**LCA-center Denmark**
LCA Center Denmark is a knowledge centre for life cycle assessments (LCA) and the life cycle approach. The centre promotes product-orientated environmental strategies in private and public companies by assisting them in implementing life cycle thinking. LCA Center Denmark is partly funded by the Danish Environmental Protection Agency and is managed by Institute for Product Development (IPU), COWI and dk-TEKNIK ENERGY & ENVIRONMENT. The aims of LCA Center Denmark are: * To assist companies that have a need for environmental assessment of products in a life cycle perspective. * To secure that the development of tools and methods for the life cycle approach in Denmark builds on a solid and scientific basis. * To promote product-orientated environmental work in companies (Life Cycle Assessments and other Environmental Management Systems). * To maintain the existing cooperation between Danish LCA stakeholders.
Hauschild, M. Z., Project Manager, Department of Management Engineering
01/12/2001 → 01/12/2005
Project: Research

**Spatial differentiation in life cycle assessment**
Promotor: prof. dr. Johanna van Eijndhoven, Utrecht University, the Nederlands, co-promotor dr. Michael Hauschild, Technical University of Denmark. Spatial differentiation in life cycle impact assessment: A framework, and site-dependents factors to assess acidification and human exposure by Jose Potting. Brief abstract: Life cycle assessment is a fairly new tool to evaluate the environmental performance of products. SETAC's code of practice and international standard ISO 14040 and others in this series are widely accepted as general framework for life cycle assessment. However, the methodology is not yet fully developed. One of the problems to be solved, is the poor accordance between impacts as predicted in the LCA and the expected occurrence of actual impacts. The objective of the thesis is to contribute to a solution of the poor accuracy of the assessed impact in LCA that results from the present disregard of spatial information in LCA.
Hauschild, M. Z., Project Manager, Department of Management Engineering
Potting, J., Project Participant, unknown organisation
Ukendt
01/05/1996 → 01/03/2000
Collaborators: unknown organisation
Award relations: Spatial differentiation in life cycle assessment
Project: Research

**LCAGAPS**
LCA-Gaps - Development and application of complementary components to the existing detailed life cycle assessment methodology. In cooperation between University, Consultants and Industry this EUREKA project develops solutions to remediate identified lacks and shortcomings of existing life cycle assessment (LCA) methods to arrive at a full LCA-method. Focus of the project will be on the handling of waste treatment processes in the inventory component of the LCA, on treatment of toxicity in the impact assessment component, on development of European normalization references and
the setting of weighting factors in the evaluation component and on statistical treatment of uncertainties in LCA. Based on the outcome of the project suggestions for guidelines will be developed and introduced into the international LCA society.

Hauschild, M. Z., Project Manager, Department of Management Engineering
01/12/1994 → 01/12/2000
Project: Research

Operational Models and Information tools for Industrial applications of eco/TOXicological impact assessments
OMNIITOX is a EU-project under the "Competitive and Sustainable Growth"-programme, running from 2001 to 2004. OMNIITOX will facilitate decision making regarding potentially hazardous compounds by improving methods and developing information tools necessary for impact assessment of toxic chemicals within Life Cycle Assessment (LCA) and (Environmental) Risk Assessment (ERA).

Hauschild, M. Z., Project Manager, Department of Management Engineering
Larsen, H. F., Project Participant, Department of Management Engineering
Birkved, M., Project Participant, Department of Management Engineering
Olsen, S. I., Project Participant, Department of Management Engineering

Forsk. EU - Rammeprogram: DKK2,700,000.00
01/04/2001 → 01/01/2005
Award relations: Operational Models and Information tools for Industrial applications of eco/TOXicological impact assessments
Project: Research

Activities:

Operationalize Planetary Boundaries in LCA Workshop
Period: 13 Dec 2018
Morten Ryberg (Invited speaker)
Michael Zwicky Hauschild (Invited speaker)
Quantitative Sustainability Assessment
Department of Management Engineering

Related external organisation
European Commission's Joint Research Centre
Activity: Talks and presentations » Conference presentations

Pellston(TM) workshop on "Global guidance on environmental life cycle impact assessment indicators, 2nd round"
Period: 24 Jun 2018 → 29 Jun 2018
Alexis Laurent (Participant)
Michael Zwicky Hauschild (Participant)
Peter Fantke (Participant)
Mikolaj Owsianiak (Participant)
Quantitative Sustainability Assessment
Department of Management Engineering

Description
UNEP/SETAC Pellston WorkshopTM to Support Development of "Global Guidance for Life Cycle Impact Assessment Indicators and Methods, Phase 2" (GLAM)
Degree of recognition: International

Related event
Pellston(TM) workshop on "Global guidance on environmental life cycle impact assessment indicators, 2nd round"
24/06/2018 → 29/06/2018
Valencia, Spain
Activity: Attending an event » Participating in or organising workshops, courses, seminars etc.

25th CIRP Life Cycle Engineering (LCE) Conference
Period: 30 Apr 2018 → 2 May 2018
Christine Molin (Organizer)
Alexis Laurent (Organizer)
Alexandra Segolene Corinne Leclerc (Organizer)
Carlos Manuel Moraleda Melero (Organizer)
Malene Emilie Vinding (Organizer)
Mikolaj Owsianiak (Organizer)
Peter Fantke (Organizer)
Leo Alting (Chairman)
Michael Zwicky Hauschild (Chairman)
Quantitative Sustainability Assessment
Department of Management Engineering

Description
Degree of recognition: International

Related event

Interactive Session on "How can the Life Cycle Engineering community contribute to meet the UN’s Sustainable Development Goals?"
Period: 30 Apr 2018
Christine Molin (Organizer)
Mikolaj Owsianiak (Organizer)
Peter Fantke (Organizer)
Alexis Laurent (Organizer)
Sami Kara (Organizer)
Christoph Herrmann (Organizer)
Wim Dewulf (Organizer)
Michael Zwicky Hauschild (Organizer)
Quantitative Sustainability Assessment
Department of Management Engineering

Description
Interactive Session aimed at identifying solutions (tools, concrete actions, etc.) that the LCE community can offer in addressing the challenges in order to meet the UN Sustainable Development Goals and some of their underlying targets.
Degree of recognition: International

Related event

Interactive Session on "How can the Life Cycle Engineering community contribute to meet the UN’s Sustainable Development Goals?"
30/04/2018 → 30/04/2018
Copenhagen, Denmark
Activity: Attending an event › Participating in or organising a conference

Marine Plastics Value Chain Mapping, Plastic Losses, and Hotspots
Period: 15 Feb 2018
Alexis Laurent (Invited speaker)
Morten Ryberg (Invited speaker)
Michael Zwicky Hauschild (Invited speaker)
Quantitative Sustainability Assessment
Related event

UN Environment multi-stakeholder consultation workshop on a systemic approach to marine plastics
15/02/2018 → 16/02/2018
Paris, France
Activity: Talks and presentations › Talks and presentations in private or public companies and organisations

**Better but is it good enough? Absolute sustainability requirements and how they challenge the food sector**

**Period:** 1 Nov 2017 → 2 Nov 2017

Yan Dong (Guest lecturer)
Michael Zwicky Hauschild (Guest lecturer)

**Department of Management Engineering**

**Quantitative Sustainability Assessment**

**Description**

In a world with a rapidly growing population, increasing standards of living and pressing needs to reduce human impacts on environment and climate UN’s member states have agreed on a global sustainable development agenda towards 2030. A sustainable development calls for vast improvements in the eco-efficiency of our food production systems (more people fed with considerably less environmental impact), and Life cycle assessment (LCA) is introduced as a tool to measure eco-efficiency and help gauge the environmental dimension of sustainability. The presentation gives an introduction to life cycle assessment as a tool to determine eco-efficiency of our technologies and help optimizing their functionality and minimizing their negative environmental impacts. It discusses the sustainability challenge that faces food production in the future and demonstrates the need to go beyond eco-efficiency, and goes on to discuss absolute boundaries for environmental sustainability, metrics for gauging our solutions against these boundaries. Possible conflicts between food safety and sustainability are discussed together with ways to address them based on a combined assessment of risk and sustainability.

Related event

**11th Annual China International Food Safety & Quality Conference**

**Period:** 01/11/2017 → 02/11/2017

Beijing, China
Activity: Talks and presentations › Conference presentations

**Sustainability assessment of stormwater management systems and the importance of pollutants in runoff**

**Period:** 11 Oct 2017

Sarah Brudler (Guest lecturer)
Karsten Ambjerg-Nielsen (Other)
Christian Ammitsøe (Other)
Michael Zwicky Hauschild (Guest lecturer)
Martin Rygaard (Guest lecturer)

**Department of Environmental Engineering**

**Urban Water Systems**

**Department of Management Engineering**

**Quantitative Sustainability Assessment**

**Degree of recognition:** International

Related event

**15th Nordic Wastewater Conference**

10/10/2017 → 12/10/2017
Aarhus, Denmark
Activity: Talks and presentations › Conference presentations
Learning by doing – Experience from 20 years of teaching LCA to future engineers
Period: 7 Sep 2017
Alexis Laurent (Invited speaker)
Nuno Miguel Dias Cosme (Invited speaker)
Michael Zwicky Hauschild (Invited speaker)
Christine Molin (Invited speaker)
Ralph K. Rosenbaum (Invited speaker)
Quantitative Sustainability Assessment
Department of Management Engineering
Degree of recognition: International

Related event
FSLCI Workshop on "Life Cycle Education"
07/09/2017 → 07/09/2017
Luxembourg, Luxembourg
Activity: Talks and presentations › Talks and presentations in private or public companies and organisations

Integrating environmental impacts into cost-benefit analysis- The value of environmental pollutants
Period: 26 Jun 2017
Yan Dong (Speaker)
Stefano Manzo (Other)
Michael Zwicky Hauschild (Other)
Department of Management Engineering
Quantitative Sustainability Assessment
Transport DTU
Transport Modelling
Degree of recognition: International
Documents:
Abstract_Final version
Links:
http://programme.exordo.com/isie2017/delegates/presentation/13/

Related event
9th biennial conference of the International Society for Industrial Ecology (ISIE) and the 25th annual conference of the International Symposium on Sustainable Systems and Technology (ISSST)
25/06/2017 → 29/06/2017
Chicago, United States
Activity: Talks and presentations › Conference presentations

Integrating environmental impacts into cost-benefit analysis- The value of environmental pollutants
Period: 25 Jun 2017 → 29 Jun 2017
Yan Dong (Guest lecturer)
Stefano Manzo (Guest lecturer)
Michael Zwicky Hauschild (Guest lecturer)
Department of Management Engineering
Quantitative Sustainability Assessment
Transport DTU
Transport Modelling

Description
Sustainable Development Goals (SDGs) have raised the attention of the global society to apply environmental friendly solutions to solve problems. Cost Benefit Analysis (CBA) has been broadly used in different contexts and disciplines to facilitate decision makers in choosing among alternatives. CBA assumes that for each alternative there is a set of consequences, divided between costs and benefits that can be expressed in monetary terms. The preferred alternative is
the one with the higher benefit cost ratio or Net Present Value (NPV). The considered consequences vary depending on the decision context. For example, the consequences that are covered in conventional transport projects include, among others, financial costs, travel time savings, variation in distance traveled, and the so called externalities, including number of accidents, noise impacts and some air pollutants (e.g. CO2, NOx, SOx, CO and HC from fuel consumption). With respect to the air pollutants, monetary values are provided by CBA guidelines for transport as well as for other disciplines. However, CBA overlooks the full life cycle of infrastructures and vehicles, and the full set of environmental impacts, due to the lack of methodology to quantify the comprehensive impacts and the lack of monetary values of those impacts. Life Cycle Assessment (LCA) is a robust methodology that assesses environmental profiles of products and services through their whole life cycles. For a given solution to a decision problem, LCA can quantify environmental pollutants and resource consumptions that are associated with the physical elements in the solution (e.g. infrastructures and vehicles). Note that LCA provides an inventory that covers a comprehensive list of pollutants and resource consumptions, which can also be translated into damages on the protected area, namely ecosystem health, human health and resources availability, via life cycle impact assessment (LCIA). This gives possibilities of monetizing environmental impacts either on the inventory level, or on the damage level. Nevertheless, the monetizing values of different pollutants and resources should be consistent with the damages (and thus the monetizing values of the damages) that they may cause on the protected area.

This research aims to 1) investigate the monetary values of environmental pollutants in the chosen application disciplines; 2) understand if those values are consistent with the monetized damages calculated by LCA methods and; 3) compare CBA with and without LCA, considering the uncertainty, using a transport case study. Our study shows that the monetized damages calculated by LCA methods lie within the range of values reviewed in transport and waste treatment studies. The variation of pollutant prices can vary up to 2-3 orders of magnitude depending on the chosen methodology. The results from the transport case study show that including the monetized LCA result in the traditional CBA doubles the NPV. This suggests that the price assigned to particularly CO2 can change the NPV dramatically, which can influence the decision when more options are available. In sum, integrating monetized LCA results into current CBA is a feasible way of including environmental impacts in decision making, increasing the environmental relevance of the decision support.

Degree of recognition: International
Links:
http://isie-issst2017.uic.edu/

**Related event**

**ISIE 2017: Science for Sustainable and Resilient Communities**
25/06/2017 → 29/06/2017
Chicago, United States
Activity: Talks and presentations › Conference presentations

**Applying LCA in decision making- the need and the future perspective**
Period: 10 May 2017
Yan Dong (Speaker)
Simona Miraglia (Other)
Stefano Manzo (Other)
Stylianos Georgiadis (Other)
Hjalte Jomo Danielsen Sarup (Other)
Elena Boriani (Other)
Tine Hald (Other)
Sebastian Thöns (Other)
Michael Zwicky Hauschild (Other)
Department of Management Engineering
Quantitative Sustainability Assessment
Centre for oil and gas – DTU
Transport DTU
Transport Modelling
Department of Applied Mathematics and Computer Science
Statistics and Data Analysis
Department of Environmental Engineering
Urban Water Systems
Description

There is nowadays a need of including sustainable considerations in the policy and decision making. Sound decision making requires evidence-based support, i.e. decision analysis to help decision makers in identifying the best alternative based on the associated impacts. Decision analysis includes four steps: 1) structure decision problem; 2) assess possible impacts associated with alternatives; 3) determine stakeholder preferences and 4) evaluate alternatives. Decision analysis can be performed applying different tools, such as cost-benefit analysis (CBA), risk assessment, and life cycle assessment (LCA).

LCA is a decision analysis tool that focuses on environmental impacts. One limit is that LCA is based on defined impact categories and therefore does not provide information for those impacts and consequences out of the LCA scope. However, the LCA framework closely follows the decision analysis scheme and has the potential to be integrated with other decision analysis tools to enhance their assessment of environmental impacts.

To understand why LCA is needed in the policy decision context, we looked into the decision support for policy in several disciplines. Taking sustainable transport policy as an example, the traditional decision analysis tool for choosing the best
alternative is CBA. CBA mainly analyses socio-economic impacts, such as travel time savings and costs, while only some environmental impacts are considered; i.e. the damage costs of greenhouse gas emissions, particulate matters, SOx, NOx and noise. Therefore, current transport policy making rarely reflect a full environmental profile of the suggested alternatives. Making decisions based on incomplete information may lead to sub-optimal solutions, especially where the environment is a major concern. There is a growing attention of conducting LCA in transport. Some identified environmental hotspots, such as consumer and household behavior, which may be the focus for future policies. Others assess the environmental impacts associated with building infrastructures and vehicle use. These studies verify that LCA can successfully quantify the environmental profile of alternatives in transport policy, if the relevant physical changes, e.g. vehicle travel distance and new infrastructures, are well-defined. However, before integrating LCA with other decision analysis methods for decision support, the study system, objectives, scopes, evaluation metrics and uncertainty handling need to be aligned.

Degree of recognition: International
Links:
https://brussels.setac.org/

Related event

SETAC Europe: 27th Annual Meeting – Environmental Quality Through Transdisciplinary Collaboration
07/05/2017 → 13/07/2017
Brussels, Belgium
Activity: Talks and presentations › Conference presentations