Introduction to Part III: Application of LCA in Practice

While Part II of this book presents the theoretical foundation and methodology of LCA, Part III is dedicated to a comprehensive discussion of how this methodology has been adapted and applied in practice. The chapters of Part III provide an easily readable and accessible introduction to different fields of LCA application with their specific decision situations, user competences and stakeholder needs, and associated methodological challenges and adaptations.

LCA of Electromobility

Private transportation is increasingly responsible for a significant share of GHG emissions. In this context, electric vehicles (EVs) are considered to be a key technology to reduce the environmental impact caused by the mobility sector. While EVs do offer an opportunity to decrease the production of greenhouse gases radically by avoiding the generation of tailpipe emissions, different technological challenges must be overcome. On the one side, the production of the battery system is of significant importance as it is reckoned to be responsible for around 40–50% of the total CO2-eq. emissions of the vehicle’s manufacturing stage. Moreover, the additional requirements for metals like copper and aluminium for the battery system as well as rare earth metals for the production of electric motors might lead to shifting the problem to other life cycle stages or areas of impact. On the other side, the source of the energy used to power an EV has an ultimate influence on the environmental impact caused during the vehicle’s use stage. The life cycle assessment methodology is
normally used to measure the environmental impact of electric vehicles and to identify potential problem shifting. In this chapter, we present an overview of the application of the methodology within the electric mobility sector.

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 Thinking and the Use of LCA in Policies Around the World
The chapter explains what Sustainable Consumption and Production (SCP) is about, why it is about taking a life cycle approach and shows that SCP-related policies have been developed at the intergovernmental level and in different regions of the world. A key element at the international level is the 10-Year Framework of Programmes on SCP adopted in 2012 and the global agreements on the Sustainable Development Goals (SDGs) adopted in 2015. Life cycle thinking has
become mature, moving from its academic origins and limited uses, primarily in-house in large companies, to more powerful approaches that can support the provision of more sustainable goods and services through efficient use in product development, external communications, in support of customer choice, and in public debates. Now governments can use LCA for SCP policies. For this purpose LCA databases are needed. LCA is in particular relevant for policies focusing on design for sustainability, sustainable consumer information, sustainable procurement and waste management, minimization and prevention as well as sector-specific policies like sustainable energy and food supply. Examples of life cycle thinking and the use of LCA in policies are provided for numerous countries around the world but with a certain focus on the European Union. It can be expected that the use of LCA in policies for the sustainability assessment of products will further increase, also slowly covering more means of implementation such as incentives and legislative obligations.

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Organisational LCA
The most applied and widespread approaches for environmental assessments at the organisation level have only recently extended their view beyond the factory gates. Even if they now consider the full value chain, they still mostly concentrate on a single environmental aspect like greenhouse gases (GHGs). While LCA was originally developed for products, its benefits and potential can be extended to the assessment of organisations. Organisational LCA is built on the principles, requirements and guidelines of ISO 14040 and ISO 14044, but requires some adaptations in the scope and inventory phases, when the unit of analysis and the system boundaries are defined. Also, the approach for data collection needs to be fixed. Organisational LCA is a compilation and evaluation of the inputs, outputs and potential environmental impacts of the activities associated with the organisation adopting a life cycle perspective. It includes not only the facilities of the organisation itself, but also the activities upstream and downstream the value chain. This methodology is capable of serving multiple goals at the same time, like identifying environmental hotspots throughout the value chain, tracking environmental performance over time, supporting strategic decisions, and informing corporate sustainability reporting. Several initiatives are on the way for the LCA of organisations: the UNEP/SETAC Life Cycle Initiative published the ‘Guidance on organisational LCA’, using ISO/TS 14072 as a backbone; moreover, the European Commission launched a guide for the organisation environmental footprint.
Overview of Existing LCIA Methods—Annex to Chapter 10
The chapter gives an overview and a systematic comparison of a selection of the most used Life Cycle Impact Assessment (LCIA) methods, focusing on methods that have been implemented and made available in LCA software. Currently available midpoint and endpoint characterisation methodologies are presented and their specific properties are qualitatively compared in detailed tables.

Use of Input–Output Analysis in LCA
Input–output analysis can be used as a tool for complementing the traditionally process-based life cycle assessment (LCA) with macroeconomic data from the background systems. Properly used, it can result in faster and more accurate LCA. It also provides opportunities for streamlining the LCA inventory collection and focusing resources. This chapter reviews the main uses of input–output analysis (IO) to ensure consistent system boundaries, to evaluate the completeness of an LCA study and to form a basis for in-depth inventory collection. The use of IO as a data source for social and economic sustainability metrics is also discussed, as are the limitations of the approach. All aspects are demonstrated through examples and references both to recent scientific literature and publicly available datasets are provided. The aim of the chapter is to present the basic tools for applying IO in practical LCA studies.

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 textbook 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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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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Critical Review
Manipulation and mistakes in LCA studies are as old as the tool itself, and so is its critical review. Besides preventing misuse and unsupported claims, critical review may also help identifying mistakes and more justifiable assumptions as well as generally improve the quality of a study. It thus supports the robustness of an LCA and increases trust in its results and conclusions. The focus of this chapter is on understanding what a critical review is, how the international standards define it, what its main elements are, and what reviewer qualifications are required. It is not the objective of this chapter to learn how to conduct a critical review, neither from a reviewer nor from a practitioner perspective. The foundation of this chapter and the basis for any critical review of LCA studies are the International Standards ISO 14040:2006, ISO 14044:2006 and ISO TS 14071:2014.
Future-Oriented LCA

LCA is often applied for decision-making that concerns actions reaching near or far into the future. However, traditional life cycle assessment methodology must be adjusted for the prospective and change-oriented purposes, but no standardised way of doing this has emerged yet. In this chapter some challenges are described and some learnings are derived. Many of the future-oriented LCAs published so far perform relatively short-term prediction of simple comparisons. But for more long-term time horizons foresight methods can be of help. Scenarios established by qualified experts about future technological and economic developments are indispensable in future technology assessments. The uncertainties in future-oriented LCAs are to a large extent qualitative and it is important to emphasise that LCA of future technologies will provide a set of answers and not 'the' answer.

Goal Definition

The goal definition is the first phase of an LCA and determines the purpose of a study in detail. This chapter teaches how to perform the six aspects of a goal definition: (1) Intended applications of the results, (2) Limitations due to methodological choices, (3) Decision context and reasons for carrying out the study, (4) Target audience, (5) Comparative studies to be disclosed to the public and (6) Commissioner of the study and other influential actors. The instructions address both the conduct and reporting of a goal definition and are largely based on the ILCD guidance document (EC-JRC in European Commission—Joint Research Centre—Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook—General Guide for Life Cycle Assessment—Detailed Guidance. Publications Office of the European Union, Luxembourg 2010).
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Illustrative Case Study: Life Cycle Assessment of Four Window Alternatives
This report serves as an example report on how to perform an LCA according to the guidance given in Chap. 37 and how to structure the report according to the reporting template in Chap. 38. The goals of the LCA were (i) to perform a benchmarking of a prototype wood/composite (W/C) window made out of glass fibre against three alternative window types currently offered in the market (made of wood (W), wood/aluminium (W/ALU), and PVC) and (ii) to identify environmental hotspots for each window system.

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LCA of Nanomaterials
Application of nanomaterials in products has led to an increase in number of nanoproducts introduced to the consumer market. However, along with new and improved products, there is a concern about the potential life cycle environmental impacts. Life cycle assessment is able to include a wide range of environmental impacts but, due to data limitations, it is commonly applied with focus on the cradle-to-gate part of the nanoproducts life cycle, neglecting use and disposal of the products. These studies conclude that nanomaterials are more energy demanding and have an inferior environmental profile than conventionally used materials, but functional units of these comparisons need to consider the use stage benefits attained through nanomaterials. A particular assessment challenge is the lack of understanding of the toxicological mechanisms related to potential release, fate and effects of nanomaterials when penetrating into living organisms. This is especially relevant for the freshwater compartment, as it is a common recipient.

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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 phases 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.

Renewable Energy and Carbon Management in the Cradle-to-Cradle Certification: Limitations and Opportunities
As part of the Cradle to Cradle® (C2C) certification program, the C2C certification criterion, Renewable Energy and Carbon Management (RE&CM), focuses on use of electricity from renewable energy (RE) and direct greenhouse gas offsets in the manufacturing stage and, to a limited extent, on the cradle to gate only at the highest level of certification. The aim of this study is to provide decision makers with a quantified overview of possible limitations of that C2C certification requirement and potential gains by introducing a full lifecycle assessment (LCA) perspective to the scheme.
Scenario analysis was used to perform an LCA of an aluminum can system representing different levels of the C2C certification criterion, RE&CM, considering different strategies to achieve 100% RE in the manufacturing stage. The adoption of a broader life cycle RE perspective was considered through the implementation of electricity from renewable sources from cradle to grave. Our results show that compliance with the current RE&CM certification framework offers limited benefits, that is, significant reduction for climate change, but negligible reductions for other environmental impacts (e.g., particulate matter and acidification). However, increasing the share of RE in the primary aluminum production from a full life cycle perspective can greatly increase the environmental benefits brought up by the C2C certification not only for climate change, but also for the broader range of impact categories. In our striving toward environmental sustainability, which often cannot be approximated by climate-change impacts alone, we therefore recommend decision makers in industries to combine the C2C certification with LCA when they define strategies for the selection of RE and raw materials suppliers.
**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.


Measuring the sustainability of goods and services in a systematic and objective manner has become an issue of paramount importance. Life cycle sustainability assessment (LCSA) is a holistic methodology whose aim is to integrate into a compatible format the analysis of the three pillars of sustainability, namely, economy, environment, and society. Social life cycle assessment (S-LCA) is a novel methodology still under development, used to cover the social aspects of sustainability within LCSA. The aim of this article is to provide additional discussion on the practical application of S-LCA by suggesting a new classification and characterization model that builds upon previous methodological developments. The structure of the social analysis has been adapted to maintain coherence with that of standard LCA. The application of this methodology is demonstrated using a case study—the analysis of power generation in a concentrated solar power plant in Spain. The inventory phase was completed by using the indicators proposed by the United Nations Environment Program/Society for Environmental Toxicology and Chemistry (UNEP/SETAC) Guidelines on S-LCA. The impact assessment phase was approached by developing a social performance indicator that builds on performance reference points, an activity variable, and a numeric scale with positive and negative values. The social performance indicator obtained (+0.42 over a range of −2 to +2) shows that the deployment of the solar power plant increases the social welfare of Spain, especially in the impact categories of socioeconomic sustainability and fairness of relationships, whose results were 1.38 and 0.29, respectively.
The current use of fossil fuels is problematic for both environmental and economic reasons and biofuels are regarded as a potential solution to current energy issues. This study analyzes the energy balances and greenhouse gas emissions of 24 different technology scenarios for the production of algal biodiesel from Nannochloropsis cultivated at industrial scale in photobioreactors in Denmark. Both consolidated and pioneering technologies are analyzed focusing on strengths and weaknesses which influence the performance. Based on literature data, energy balance and greenhouse gas emissions are determined in a comparative ‘well-to-tank’ Life Cycle Assessment against fossil diesel. Use of by-products from biodiesel production such as glycerol obtained from transesterification and anaerobic digestion of residual biomass are included. Different technologies and methods are considered in cultivation stage (freshwater vs. wastewater; synthetic
CO2 vs. waste CO2), harvesting stage (flocculation vs. centrifugation) and oil extraction stage (hexane extraction vs. supercritical CO2 extraction). The choices affecting environmental performance of the scenarios are evaluated. Results show that algal biodiesel produced through current conventional technologies has higher energy demand and greenhouse gas emissions than fossil diesel. However, greenhouse gas emissions of algal biodiesel can be significantly reduced through the use of ‘waste’ flows (nutrients and CO2) but there are still technical difficulties with both microalgae cultivation in wastewater as well as transportation and injection of waste CO2. In any way, a positive energy balance is still far from being achieved. Considerable improvements must be made to develop an environmentally beneficial microalgae biodiesel production on an industrial scale. In particular, different aspects of cultivation need to be enhanced, such as the use of wastewater and CO2–rich flue gas from industrial power plants.
Circular economy: To be or not to be in a closed product loop? A Life Cycle Assessment of aluminium cans with inclusion of alloying elements

Packaging, representing the second largest source of aluminium scrap at global level, deserves a key role in the transition towards the circular economy. Life Cycle Assessment (LCA) of aluminium products has been typically based on one life cycle considering pure aluminium flows and neglecting the presence of alloying elements and impurities. However, this simplification undermines the potentials of using LCA to quantify the environmental performances of products in multiple loops, as required in the circular economy. This study aims to investigate the effects of including the actual alloy composition in the LCA of aluminium can production and recycling, in order to understand whether a can-to-can (i.e. closed product loop) recycling should be promoted or not. Mass balance of the main alloying elements (Mn, Si, Cu, Fe) was carried out at increasing levels of recycling rate, corresponding to a temporal interval of five years. Different aluminium packaging scrap sources were considered: mixed packaging aluminium scrap and used beverage can scrap. The outcomes of the mass balance were used to quantify the amount of Mn and primary Al that needs to be reintegrated in each scenario according to the recycling rate and this information was further used to perform an LCA of 30 loops of aluminium can production and recycling, based on the actual alloy composition. The LCA revealed that the closed product loop option (considering used beverage can scrap) has lower climate change impacts over the other recycling scenario using mixed Al packaging scrap. The main recommendation from an LCA methodological point of view is to include the idea of multiple co-functions in the functional unit definition. To further improve the environmental performances of the aluminium beverage can sector towards circular economy implementation the key actions are: to reduce the weight of the lid, to develop methods to separate the body and lid at the point of collection, and to investigate the potentials of a closed supply chain loop for aluminium cans in terms of combined environmental and economic value creation.
Despite their different scopes, both the Life Cycle Assessment (LCA) methodology and the Cradle to Cradle (C2C) Certified™ Product Standard can support companies in the implementation of circular economy strategies. Considering the case of aluminum cans, the objectives of this paper are twofold: (i) to compare the environmental impact associated with different levels of two C2C certification requirements by using LCA; and (ii) to identify the main challenges and drawbacks in the combined use of LCA and C2C for packaging within the circular economy framework. Twenty different scenarios were developed and compared, according to three C2C certification levels, in terms of % renewable energy and % recycled content. The results show that increasing the recycled content provides more improvements to environmental impacts than increasing renewable energy usage. Furthermore, receiving a higher certification level does not necessarily mean environmental burden reduction in LCA sense. From a methodological point of view, the main challenge for LCA is to address the continuous loop of materials and account for the benefits from recycling in a consistent way. Meanwhile for C2C the challenge is to guarantee a proper translation of the C2C principles into the C2C certification program, avoiding burden shifting and to find a balance between the different certification requirements.
Comparative environmental and economic assessment of production, use and recycling of aluminium cans: Bologna vs Copenhagen

Circularity strategies need to be assessed both in terms of environmental and economic impacts, by performing full chain analysis, including the perspectives of producers, users and waste management operators. This study considered two different aluminium beverage can systems: Bologna and Copenhagen. We performed a combined Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) analysis of the purchasing, production and waste management of beer aluminium cans, with the aim to compare the environmental and economic performances of the two systems and to identify potential misalignment in the integrated LCA-LCC analysis. The comparative analysis of aluminium cans production, use, collection and recycling in the two systems showed that the best option from an environmental point of view is also leading to higher costs and trade-offs need to be considered in the decision making process.

Ecodesign framework for developing wind turbines

Despite a wind turbines perceived environmental benefits, there are still many improvements that can be made in the product development process to improve its environmental performance across life cycles. This is especially important as the wind power industry continues to grow, both in volume and size, in response to increasing global market demands. Planning, implementing, monitoring, documenting and communicating product related environmental activities of wind turbines in a life cycle management context is the focal point of this article. The development and application of an ecodesign framework specific to the organizational context of Siemens Wind Power is described. The framework was developed using an iterative, action research design approach which relied on the participation of cross-functional employees. Five iterations occurred over a four year time frame and methods such as workshops, pilots, interviews and life cycle assessment were applied. The ecodesign framework was aligned with the company's formal product lifecycle management process. When combined with life cycle assessment, the framework can identify potential environmental improvements and contribute to coherent and transparent environmental target setting. Examples of this are demonstrated at the technological, organizational and societal levels of the company. Lessons learned obtained during the design iterations call for assigned responsibility through key performance indicators at project and functional levels; adaptive learning approaches to ecodesign based on continuous improvements; and additional capacity building amongst employees in life cycle thinking. The article proposes that a life cycle based ecodesign framework can be a driver for sustainable innovations in components, product systems, technologies and business models.
Greenhouse gas emissions and energy balance of biodiesel production from microalgae cultivated in photobioreactors in Denmark: a life-cycle modeling

The current use of fossil fuels is problematic for both environmental and economic reasons and biofuels are regarded as a potential solution to current energy issues. This study analyzes the energy balances and greenhouse gas emissions of 24 different technology scenarios for the production of algal biodiesel from Nannochloropsis cultivated at industrial scale in photobioreactors in Denmark. Both consolidated and pioneering technologies are analyzed focusing on strengths and weaknesses which influence the performance. Based on literature data, energy balance and greenhouse gas emissions are determined in a comparative 'well-to-tank' Life Cycle Assessment against fossil diesel. Use of by-products from biodiesel production such as glycerol obtained from transesterification and anaerobic digestion of residual biomass are included. Different technologies and methods are considered in cultivation stage (freshwater vs. wastewater; synthetic CO2 vs. waste CO2), harvesting stage (flocculation vs. centrifugation) and oil extraction stage (hexane extraction vs. supercritical CO2 extraction). The choices affecting environmental performance of the scenarios are evaluated. Results show that algal biodiesel produced through current conventional technologies has higher energy demand and greenhouse gas emissions than fossil diesel. However, greenhouse gas emissions of algal biodiesel can be significantly reduced through the use of 'waste' flows (nutrients and CO2) but there are still technical difficulties with both microalgae cultivation in wastewater as well as transportation and injection of waste CO2. In any way, a positive energy balance is still far from being achieved. Considerable improvements must be made to develop an environmentally beneficial microalgae biodiesel production on an industrial scale. In particular, different aspects of cultivation need to be enhanced, such as the use of wastewater and CO2-rich flue gas from industrial power plants. (C) 2015 Elsevier Ltd. All rights reserved.

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Life Cycle Assessment of Functionally Enhanced Polymers-Engineered Nanomaterials or Conventional Additives?

Engineered nanomaterials, where at least one dimension is within 1-100 nm, are produced and used in many consumer products, with the purpose of enhancing specific material properties (e.g., in plastic products). Conventionally, organic and inorganic non-engineered nanomaterial additives are also used to enhance material properties. The aim of this study is to perform life cycle assessments (LCAs) on 5 polymer products (polypropylene air-conditioner part for cars, polypropylene garden chair, polypropylene small electrical box for houses, polyvinylchloride-wood outdoor flooring and polystyrene insulation panels for buildings). Antibacterial, ultraviolet ray protection or flame retardancy properties of these products have been improved through the addition of either Ag, ZnO or Mg(OH)$_2$ engineered nanomaterials, or conventional organic/inorganic polymer additives. The study also presents new industrial production inventories of the considered engineered nanomaterials as well as the quantification of potential changes in impacts when the LCA functional unit is adjusted according to material functionality (antibacterial, ultraviolet-protection and flame retardancy). The LCA results show that in all cases the products with engineered nanomaterials generate higher potential environmental impacts than products with conventional additives. However, when considering the improved material functionality results differ more. The polyvinylchloride-wood outdoor flooring and polystyrene insulation panels for buildings with engineered nanomaterials perform better than with the use of conventional additives, while the polypropylene products with engineered nanomaterials have slightly higher environmental impacts than products with conventional additives. In the case of polypropylene small electrical box the needed large content of micro-Mg(OH)$_2$ makes the engineered nanomaterial case far less favourable, but if Mg(OH)$_2$ substitutes halogenated flame retardants the potential toxicological impacts are shown to be significantly lower. This study shows that the consideration of enhanced material functionality in LCA can favour some of the engineered nanomaterial based products, versus conventional additives, by reflecting the potential increase in use quality and potentially the use time. Also in this study, based on assumed release amounts, freshwater ecotoxicity caused by engineered nanomaterial release from products is quantified showing a novel
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- BFI (2010): BFI-level 1
- Scopus rating (2010): SJR 0.571 SNIP 0.524
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- Scopus rating (2009): SJR 0.675 SNIP 0.589
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- BFI (2008): BFI-level 1
- Scopus rating (2008): SJR 0.835 SNIP 0.653
- Web of Science (2008): Indexed yes
- Scopus rating (2007): SJR 0.843 SNIP 0.69
- Scopus rating (2006): SJR 0.996 SNIP 0.731
- Web of Science (2006): Indexed yes
- Scopus rating (2005): SJR 1.073 SNIP 0.774
- Scopus rating (2004): SJR 0.99 SNIP 0.668
- Web of Science (2004): Indexed yes
- Scopus rating (2003): SJR 0.891 SNIP 0.887
- Scopus rating (2002): SJR 1.161 SNIP 1.081

Original language: English
Life Cycle Assessment, Engineered Nanomaterials, Impact Assessment, Nanoproducts, Manufacturing, Polymers, Additives
Life cycle assessment of onshore and offshore wind energy - from theory to application
This study aims to assess the environmental impacts related to the provision of 1 kWh to the grid from wind power in Europe and to suggest how life cycle assessment can inform technology development and system planning. Four representative power plants onshore (with 2.3 and 3.2 MW turbines) and offshore (4.0 and 6.0 MW turbines) with 2015 state-of-the-art technology data provided by Siemens Wind Power were assessed. The energy payback time was found to be less than 1 year for all technologies. The emissions of greenhouse gases amounted to less than 7 g CO2-eq/kWh for onshore and 11 g CO2-eq/kWh for offshore. Climate change impacts were found to be a good indicator for overall hotspot identification however attention should also be drawn to human toxicity and impacts from respiratory inorganics. The overall higher impact of offshore plants, compared to onshore ones, is mainly due to larger high impact material requirements for capital infrastructure. In both markets the bigger turbines with more advanced direct drive generator technology is shown to perform better than the smaller geared ones. Capital infrastructure is the most impactful life cycle stage across impacts. It accounts for more than 79% and 70% of climate change impacts onshore and offshore respectively. The end-of-life treatment could lead to significant savings due to recycling, ca. 20-30% for climate change. In the manufacturing stage the impacts due to operations at the case company do not exceed 1% of the total life cycle impacts. This finding highlights the shared responsibility across multiple stakeholders and calls for collaborative efforts for comprehensive environmental management across organizations in the value chain. Real life examples are given in order to showcase how LCA results can inform decisions, e.g. for concept and product development and supply chain management. On a systems level the results can be used by energy planners when comparing with alternative energy sources. (C) 2016 Elsevier Ltd. All rights reserved.

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Authors: Bonou, A. (Intern), Laurent, A. (Intern), Olsen, S. I. (Intern)
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Scopus rating (2016): CiteScore 7.78 SJR 3.058 SNIP 2.573
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.912 SNIP 2.61 CiteScore 6.4
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 3.254 SNIP 3.28 CiteScore 6.93
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 3.164 SNIP 3.377 CiteScore 6.59
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 2.854 SNIP 3.108 CiteScore 5.69
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
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.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Niero, M. (Intern), Hauschild, M. Z. (Intern), Olsen, S. I. (Intern)
Pages: 439-446
Publication date: 2016
A teaching and communication tool based on DPSIR and LCIA indicator for marine eutrophication

The Drivers-Pressures-State-Impacts-Responses (DPSIR) is an adaptive environmental management approach that integrates environmental, social, and economic aspects into a common framework. Life Cycle Impact Assessment (LCIA) indicators aim at modelling the P-S-I components and provide background to understand D-R. The DPSIR approach was applied to the LCIA indicator for marine eutrophication to communicate sustainability assessment to graduate students. Broadly, this science-based educational example is useful to predict impacts, communicate knowledge, and support decisions. It assesses the high demand for fixation of reactive nitrogen (D) to support socioeconomic secondary drivers. Nitrogen exported to marine ecosystems (P) induces changes in the environmental conditions (S) including dissolved oxygen depletion that cause effects on biota (I). These, stimulate society into designing actions (R) to modify D, reduce P, and restore S. LCIA indicators also support a precautionary approach acting earlier on D-P and promoting sustainability. LCIA-based DPSIR seems a useful tool for sustainability teaching and communication purposes, bridging science and management while promoting a good conceptual understanding of sustainable development in practical educational applications. Other LCIA indicators may be adapted to fit similar purposes.

Challenges and opportunities in using Life Cycle Assessment and Cradle to Cradle® for biodegradable bio-based polymers: a review

Both Life Cycle Assessment (LCA) and Cradle to Cradle® (C2C) approaches can provide operative insights in the design of biodegradable bio-based polymers. Some of the challenges shared by both LCA and C2C that need further investigation are the use of laboratory scale data versus primary data from established technologies and the identification of the best option for...
the end of use stage, e.g. for use as packaging. We consider the case of a natural fiber-based composite material obtained from barley straw and present some insights from both LCA and C2C perspectives in the identification of the best option for its end of use.

**General information**

State: Published

Organisations: Department of Chemical and Biochemical Engineering, Department of Management Engineering, Quantitative Sustainability Assessment, Carlsberg Laboratory

Authors: Niero, M. (Intern), Manat, R. (Ekstern), Møller, B. L. (Ekstern), Olsen, S. I. (Intern)

Pages: 347-350

Publication date: 2015

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Publisher: ENEA

Editors: Scalbi, S., Loprieno, A. D., Sposato, P.

Main Research Area: Technical/natural sciences

Conference: International conference on Life Cycle Assessment as reference methodology for assessing supply chains and supporting global sustainability challenges, Stresa and Milano, Italy, 06/10/2015 - 06/10/2015

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LCA2015

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**Freshwater ecotoxicity characterisation factor for metal oxide nanoparticles: A case study on titanium dioxide nanoparticle**

The Life Cycle Assessment (LCA) methodology is widely applied in several industrial sectors to evaluate the environmental performance of processes, products and services. Recently, several reports and studies have emphasized the importance of LCA in the field of engineered nanomaterials. However, to date only a few LCA studies on nanotechnology have been carried out, and fewer still have assessed aspects relating to ecotoxicity. This is mainly due to the lack of knowledge in relation to human and environmental exposure and effect of engineered nanoparticles (ENPs). This bottleneck is continued when performing Life Cycle Impact Assessment, where characterization models and consequently characterization factors (CFs) for ENPs are missing. This paper aims to provide the freshwater ecotoxicity CF for titanium dioxide nanoparticles (nano-TiO2). The USEtox™ model has been selected as a characterisation model. An adjusted multimedia fate model has been developed which accounts for nano-specific fate process descriptors (i.e. sedimentation, aggregation with suspended particle matter, etc.) to estimate the fate of nano-TiO2 in freshwater. A literature survey of toxicity tests performed on freshwater organism representative of multiple trophic levels was conducted, including algae, crustaceans and fish in order to collect relevant EC50 values. Then, the toxic effect of nano-TiO2 was computed on the basis of the HC50 value. Thus, following the principle of USEtox™ model and accounting for nano-specific descriptors a CF for the toxic impact of freshwater ecotoxicity of 0.28PAFdaym3kg-1 is proposed.

**General information**

State: Published

Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, University of Bologna

Authors: Salieri, B. (Ekstern), Righi, S. (Ekstern), Pasteris, A. (Ekstern), Olsen, S. I. (Intern)

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Main Research Area: Technical/natural sciences

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Scopus rating (2016): CiteScore 5.09 SJR 1.621 SNIP 1.849

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BFI (2015): BFI-level 2

Scopus rating (2015): SJR 1.674 SNIP 1.642 CiteScore 4.33

Web of Science (2015): Indexed yes

BFI (2014): BFI-level 2

Scopus rating (2014): SJR 1.635 SNIP 1.847 CiteScore 4.2
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.

**General information**

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Organisations: Department of Chemical and Biochemical Engineering, Department of Management Engineering, Quantitative Sustainability Assessment, Carlsberg Breweries AS
Authors: Niero, M. (Intern), Boas, S. H. (Ekstern), Hauschild, M. Z. (Intern), Olsen, S. I. (Intern)
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Main Research Area: Technical/natural sciences

**Bibliographical note**

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Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2015

**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.

**General information**

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Authors: Bonou, A. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
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Life Cycle Management in wind energy technologies and planning - a case from Siemens Wind Power

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
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Poster presentation

Merging marine eutrophication, LCA and DPSIR into a learning tool for sustainability

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Cosme, N. M. D. (Intern), Olsen, S. I. (Intern)
Number of pages: 1
Publication date: 2015
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Main Research Area: Technical/natural sciences
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Providing sustainability competences to all engineering students at DTU?

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Olsen, S. I. (Intern)
Number of pages: 1
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C2_DTU_Sustain_2015.pdf
Teaching sustainable solutions in engineering

The increasing societal and industrial emphasis on sustainability requests that the next generation engineers needs to be trained in the context of sustainability. One of the means to address students at DTU is the establishment of a course aimed at bachelor students from all of the university's study lines. The objectives of the course 'Sustainability in engineering solutions', is for the participants to understand the basic concept of sustainability and its three dimensions (people, profit, planet), as well as to analyse problems and synthesise solutions that are sustainable throughout their life cycle. The course runs over a full time 3-week period and employs project-based learning with several sub-projects/-problems. This paper takes an in-depth discussion of the considerations concerning how to teach such a complicated subject to students of widely differing backgrounds, and reflects both the teachers’ and the students’ experiences with the course.

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State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Production and Service Management, Centre for Facilities Management, Systems Analysis, DTU Climate Centre, Energy Systems Analysis, Department of Mechanical Engineering, Engineering Design and Product Development, Technical University of Denmark
Authors: Olsen, S. I. (Intern), Nielsen, S. B. (Intern), Ejlertsen, M. (Ekstern), McAloone, T. C. (Intern)
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BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.229 SNIP 0.254 CiteScore 0.51
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Scopus rating (2015): SJR 0.24 SNIP 0.386 CiteScore 0.6
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.264 SNIP 0.538 CiteScore 0.56
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.243 SNIP 0.444 CiteScore 0.6
ISI indexed (2013): ISI indexed no
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.23 SNIP 0.527 CiteScore 0.6
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.267 SNIP 0.333 CiteScore 0.6
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.257 SNIP 0.533
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.354 SNIP 0.52
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.278 SNIP 0.4
Scopus rating (2007): SJR 0.247 SNIP 0.219
Scopus rating (2006): SJR 0.163 SNIP 0.094
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Olsen_et_al._2015_IJSD_postprint_version.pdf
The Hamlet dilemma for aluminium cans in the circular economy: to be or not to be in a closed loop

In the context of circular economy the focus is not only on recycling from a quantitative point of view, but also on improving the quality of materials. We considered the case of aluminium cans, and quantified the influence of alloying elements on the overall environmental performances of aluminium can recycling. We performed a Life Cycle Assessment (LCA) comparing different sources of aluminium: primary aluminium and mixed scraps, Used Beverage Can (UBC) scrap, mixed aluminium packaging scrap and building scrap. The preliminary LCA results show that the lowest environmental impacts come from the use of UBC scraps. This suggests that in a circular economy context for aluminium cans it is better to be in a closed loop.

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Organisations: Department of Chemical and Biochemical Engineering, Department of Management Engineering, Quantitative Sustainability Assessment, Carlsberg Breweries AS
Authors: Niero, M. (Intern), Boas, S. H. (Ekstern), Langen, H. (Ekstern), Olsen, S. I. (Intern)
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A collaborative quest for sustainability at DTU

General information
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Organisations: Campus Service, Department of Management Engineering, Quantitative Sustainability Assessment, Production and Service Management, Centre for Facilities Management
Can carbon footprint be an acceptable indicator of environmental sustainability?

Carbon balance impacts of land use changes related to the life cycle of Malaysian palm oil-derived biodiesel

The area of oil palm plantations in Malaysia is expanding by approximately 0.14 million hectare per year, and with the increasing demand for palm oil worldwide, there is no sign of the expansions slowing down. This study aims to identify the greenhouse gas emissions associated with land conversion to oil palm, in a life cycle perspective. LCA methodology is applied to existing land use change data. The assessment includes the issue of temporary carbon storage in the plantations. Through quantification of emissions from state forest reserve and rubber plantation conversions, the average Malaysian palm oil-related land use changes are calculated. The results show that there are high emissions associated with the conversion of Malaysian state forest reserve to oil palm, whereas the conversion of rubber leaves a less significant carbon debt when indirect land use change is not included. Looking at the average Malaysian land use changes associated with oil palm shows that land use change emissions are responsible for approximately half of the total conventional biodiesel production emissions. The sensitivity analysis shows that the results could be significantly influenced by data variations in indirect land use changes, peat soils, and state forest reserve carbon stock. The relatively extensive conversions of the state forest reserve must be reversed and preferably with a shift toward conversion of degraded land in order for the average Malaysian land use changes to have less impact on the production life cycle of palm oil and biodiesel.
Carlsberg, the fourth largest global brewer in the world, and a selection of global suppliers have created the Carlsberg Circular Community (CCC), a cooperation platform aiming at rethinking the design and production of traditional packaging material. The ambition of the CCC is to develop products that are optimized for recycling and reuse, while retaining their quality and their value. CCC will contribute to reduce the reliance on raw materials, involve consumers and customers, as
Engineered nanomaterials (ENMs) have in recent time received substantial attention, both in scientific and consumer circles, as these materials are introduced to a steadily increasing number of consumer products. This has led to environmental concerns on how this new material class behaves in the environment, at which concentrations organisms are exposed to the materials and what effects these materials may have on the environment. In relation to metal-oxide engineered nanomaterials (ENMs), as is the general case for ENMs, many environmental aspects are still unknown and/or hence not properly scientifically mapped. One approach that has not been given much attention in relation to environmental assessment of ENM, more precisely the fate, exposure and effect modelling of metal-oxide ENMs is the application of adapted characterization modelling (ACM) and hence application of characterisation models designed for single (chemical) compound assessment e.g. the USEtox™ model for characterisation of ENM effect potentials.

The purpose of this study is therefore to evaluate if existing characterisation model such as the USEtox™ model can be applied for characterisation modelling of ENMs applying the principles of ACM. The primarily principle of adapted characterisation modelling relies on the recognition of the fact that nano-materials do not behave like single chemical compounds in the environment. The second principle of ACM relies on the fact that existing chemical characterisation can be applied to model hypothetical representatives for effect causing emissions such as groups of chemicals (i.e. equivalence approaches applied to model mercury by). In this study the approach taken was therefore to consider if USEtox™ characterisation of ENMs is possible and appropriately valid. The characterisation was done by relating nanomaterial properties to chemical properties and hence model the nano-material as a chemical with representative fate and exposure patterns.

In the case study in-volatile ENM’s (metal-oxides) were characterised in USEtox™ applying adapted characterisation modelling. The result obtained indicates that with some limitations the approach is considered valid – the characterisation factors are considered uncertain relating to several facts such as lack of environmental studies on ENMs making is hard to assess the general environmental behaviour of ENMs and hence relate this environmental behaviour to similar “chemical behaviour”.

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**General information**

**State:** Published

**Organisations:** Department of Management Engineering, Quantitative Sustainability Assessment, Carlsberg Breweries AS

**Authors:** Niero, M. (Intern), Boas, S. (Ekstern), Olsen, S. I. (Intern)

**Number of pages:** 2

**Pages:** 47-48

**Publication date:** 2014
Improvement of methodological and data background for life cycle assessment of nano-metaloxides

Engineered nanomaterials (ENMs) introduction into consumer products and the increasing amount of ENM product has led to concerns. Based on this, an all-inclusive environmental assessment method of the potential impacts from these is needed. Life cycle assessment (LCA) is an assessment method that considers the whole life cycle of a product or system and is able to quantify impacts from a wide range of impact categories. In theory LCA is the needed tool, but still there is a limited amount of LCAs performed on ENM products and there are concerns raised on how to apply such a tool on an emerging technology.

The aim of the PhD project was to investigate the status and improvement potential of LCA of ENMs. This was done through three sub-aims: • Review current possibilities and limitations of applying LCA on ENM products. • Improve the limitation in ENM production data inventory by presenting novel data from an industrial case study of metal (-oxide) ENM products. • Improve the LCA limitation of ecotoxicity assessment by developing freshwater ecotoxicity characterisation factors for chosen metal (-oxide) ENMs. By reviewing the scientifically published LCA studies of ENMs it was concluded that there are several challenges. Firstly the LCAs are limited to the first part of the life cycle, the cradle-to-gate. The main reason for this is that the data and approaches for assessing the remainder of the life cycle are not there. Industrial data inventories are missing, e.g. the data for production of ENMs is often from lab-scale testing and also being reused in different LCA studies. This means that a too limited amount of data is publicly available. Further, issues are also seen on the functional unit setting, as the ENM enhanced functionalities in products are to a lesser extent included. This provides an unfair comparison, as production of ENM products leads to higher environmental impacts than conventional products. The potential release of ENMs from a product is commonly not dealt with in the reviewed LCAs, mainly due to the missing (eco-) toxicity LCA characterisation factors and actual release measurements from products. Based on the review a central part of the improvement could be done by addressing the functional unit, data inventory and ENM freshwater ecotoxicity CFs.

In order to derive freshwater (European continent) ecotoxicity CFs, at midpoint level, of metal (-oxide) ENMs a fate and effect model was setup. The fate was based on peri-kinetic aggregation (Brownian motion), ortho-kinetic aggregation (fluid motion), differential settling (sedimentation), resuspension and dissolution of ENMs. The effect part was based on three freshwater trophic levels (algae, daphnia and fish), as in standardized toxicity testing. The results for the engineered nanoparticle (ENP) geometric mean ranges of 1-100 nm and 801-1000 nm in nominal diameter sizes, were 4.81E+01 (1-100 nm, α=0.01) to 2.05E-02 (801-1000 nm, α=1), 1.48E-01 (1-100 nm, α=0.01) to 6.27E-05 (801-1000 nm, α=1), and 7.49E+00 (1-100 nm, α=0.01) to 3.20E-03 (801-1000 nm, α=1) PAF·m³·day/kg for Ag, TiO2, and ZnO ENMs, respectively. In terms of toxicity level the derived CFs show that Ag>ZnO>TiO2. The CFs can be applied, but should be considered interim.

A LCA case study was performed on five ENM products, where novel industrial production data was presented along with showing the result differences when applying different functional unit approaches. The LCA case study comparison was based on whether to use ENM or conventional additives (e.g. to enhance the antibacterial properties of a product). The functional units were set according to products equality and to targeted enhanced functionality/property. Results of the study showed that by setting the functional unit according to the targeted functionality some ENM products can environmentally outperform the conventional based products, in terms of predicted environmental impacts. In the end, a 1 % ENM products release to freshwater was assumed in the case study. The results showed that the ENM release freshwater ecotoxicity contributes with a low impact in relation to the current conventional aquatic ecotoxicity assessment in LCA that does not consider ENM release.

In conclusion, the project showed that LCA needs overhauling and particularly in relation to the issues broached in this project. By not addressing these, the reliability of one’s LCA of ENMs would be significantly compromised.

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Authors: Miseljic, M. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
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Main Research Area: Technical/natural sciences
Publication: Research › Ph.D. thesis – Annual report year: 2015
Life-cycle assessment of engineered nanomaterials: A literature review of assessment status

The potential environmental impacts of engineered nanomaterials (ENMs), and their engineered nanoparticles (ENPs), have, in recent years, been a cause of concern. Life-cycle assessment (LCA) is a highly qualified tool to assess products and systems and has an increasing extent been applied to ENMs. However, still only 29 case studies on LCA of ENMs have been published in journals and this article investigates these studies. Generally, data on production of ENMs as well as the coverage of the life cycle are limited. In particular, within use and disposal stages data are scarce due to many unknowns regarding the potential release and fate of ENMs/ENPs to and in the environment. This study investigates the sensitivity of case studies with respect to ecotoxicity impacts through a quantification of the potential ecotoxicity impacts to algae, daphnia and fish as a result of direct release of Ag and TiO$_2$ ENPs (mainly...
Sustainable packaging: from eco-efficiency to eco-effectiveness

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. 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 by designing systems where waste and emissions can be taken up as nutrients by other processes instead of reducing the amount of waste as eco-efficiency advocates. From a company point of view, LCA and C2C are complementary approaches to develop sustainable and innovative solutions for packaging, see Figure 1. 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, involving consumers and customers, and creating new types of cooperation among partners to generate resource effective products.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Carlsberg Breweries AS
Authors: Niero, M. (Intern), Boas, S. H. (Ekstern), Olsen, S. I. (Intern)
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Main Research Area: Technical/natural sciences
Conference: DTU Sustain Conference 2014, Lyngby, Denmark, 17/12/2014 - 17/12/2014
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2014

Teaching sustainability in engineering solutions with Campus Service as case
Engineers potentially influence the sustainability of technological solutions significantly. At DTU Management Engineering we aim to address sustainability to all engineering students at DTU. One of the means to address students throughout DTU is the establishment of a course aimed at bachelor students on all study lines. The objectives of the course is for the participants to acquire an understanding of the basic concept of sustainability and its three dimensions as well as getting an overview of a number of tools for analysis and synthesis of solutions that are sustainable throughout their life cycle and acquire the skills to use the most central of the tools. Furthermore, they should understand the engineer’s role and responsibility in the development of sustainable solutions. Examples of learning outcomes are:

Explain that each sustainability dimension is multifactorial and that trade-offs exist within and between them
The course runs over the June three week period. It employs project based problem oriented learning and is organized around a theme within which there are several subprojects/problems that the students work on in groups of 4-5 persons. Different themes have been used but especially “The Sustainable Campus” in cooperation with CAS has been successful. CAS frequently has to choose between different solutions for DTU Campus - but how to choose the most sustainable? The students get engaged since DTU Campus is part of their everyday life and they get a real opportunity to influence how CAS operate. The general outline of the course is that theory lectures and exercises are given in the morning whereas the afternoons are fully devoted to project work applying the theory learned in the morning. However, app. half of the days are fully devoted to project work with supervision. Several milestones for the project are defined at which the student presented their work. The students were evaluated on their presentations, their final report and a multiple choice questionnaire.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Mechanical Engineering, Engineering Design and Product Development, Production and Service Management, Centre for Facilities Management
Authors: Olsen, S. I. (Intern), McAloone, T. C. (Intern), Nielsen, S. B. (Intern)
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The DPSIR approach applied to marine eutrophication in LCIA as a learning tool
The Drivers-Pressures-State-Impacts-Responses (DPSIR) is an adaptive environmental management approach that integrates environmental, social and economic aspects into a common framework. It deals with the Drivers (D) that generate the Pressures (P) e.g. from human interventions, that modify the State (S) of the ecosystem, causing the Impacts (I) on these, and contributing to the management strategies and Responses R. The latter are designed to modify the drivers, minimise the pressures and restore the state of the receiving ecosystem. In our opinion the DPSIR provides a good conceptual understanding that is well suited for sustainability teaching and communication purposes. Life Cycle Impact Assessment (LCIA) indicators aim at modelling the P-S-I parts and provide a good background for understanding D and R. As an example, the DPSIR approach was applied to the LCIA indicator marine eutrophication. The goal is to promote an educational example of environmental impacts assessment through science-based tools to predict the impacts, communicate knowledge and support decisions. The example builds on the (D) high demand for fixation of reactive nitrogen that supports several socio-economic secondary drivers. The nitrogen exported to marine coastal ecosystems (P), after point and nonpoint source emissions, promote changes in the environmental conditions (S) such as low dissolved oxygen levels that cause the (I) effects on biota. These, stimulate society into designing actions R to modify D, reduce P, and restore S. Concrete responses can be technical (e.g. increasing sewage treatment coverage), regulatory (e.g. EC Nitrate Directive) or guidance (e.g. fertilisers formulation or best practices for application). These should consider six basic tenets for environmental management: environmentally sustainable, technologically feasible, economically viable, socially desirable, legally permissible, and administratively achievable. Specific LCIA indicators may provide preliminary information to support a precautionary approach to act earlier on D-P and contribute to sustainability. Impacts assessment and response design ultimately benefit from spatial differentiation in the results. DPSIR based on LCIA seems a useful tool to improve communication and learning, as it bridges science and management while promoting the basic elements of sustainable development in a practical educational application. Other LCIA indicators can also be adapted to fit similar purposes.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Cosme, N. M. D. (Intern), Olsen, S. I. (Intern)
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Main Research Area: Technical/natural sciences
A comparative study on life cycle assessment of micro and macro components

Micro manufacturing is an extremely demanding technological field where very special materials are used, extreme production condition like clean room, super high temperature, toxic chemicals, etc. are employed. Due to these facts, micro products can be environmentally damaging even after their smaller dimensional scale. So performing of LCA for micro products is equally important as it is for macro products. Keeping this motivation in mind, current paper systematically performs the LCA of a micro Socket used in hearing aids. The analysis makes a guide line about how to use the conventional knowledge about LCA and tools for the efficient LCA analysis of the micro parts. A comparative study is made in the paper by comparing two different sockets of hearing aid and it shows well how to make a comparative study for LCA when the manufacturer makes a new product to replace an old one. Another comparative study is made in the paper for micro and macro which shows that scaled up effect of the micro product compared to macro counterpart. The critical finding of this comparative study shows that the relative environmental damage done by micro product is higher than the macro product and that is confirmed by the net impact analysis. Finally, the LCA procedure presented in the paper, and the knowledge documented can be a valuable source of information for the researchers and scientists who work with the LCA of micro and macro products.

General information
State: Published
Organisations: Department of Mechanical Engineering, Manufacturing Engineering, Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Omidvarnia, F. (Intern), Islam, A. (Intern), Hansen, H. N. (Intern), Olsen, S. I. (Intern)
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.858 SNIP 1.274 CiteScore 1.8
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.084 SNIP 1.879 CiteScore 2.03
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.133 SNIP 2.117 CiteScore 2.26
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.982 SNIP 2.091 CiteScore 1.75
ISI indexed (2012): ISI indexed yes
Challenges in environmental sustainability assessment of metal nanomaterials

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Centro de Investigacion en Materiales Avanzados
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Comparison of Algal Biodiesel Production Pathways Using Life Cycle Assessment Tool
The consideration of algal biomass in biodiesel production increased very rapidly in the last decade. A life cycle assessment (LCA) study is presented to compare six different biodiesel production pathways (three different harvesting techniques, i.e., aluminum as flocculent, lime flocculent, and centrifugation, and two different oil extraction methods, i.e., supercritical CO2 (sCO2) and press and co-solvent extraction). The cultivation of Nannochloropsis sp. considered in a flat-panel photobioreactor (FPBPR). These algal biodiesel production systems were compared with the conventional diesel in a EURO 5 passenger car used for transport purpose (functional unit 1 person km (pkm). The algal biodiesel production systems provide lesser impact (22–105 %) in comparison with conventional diesel. Impacts of algal biodiesel on climate change were far better than conventional diesel, but impacts on human health, ecosystem quality, and resources were
higher than the conventional diesel. This study recommends more practical data at pilot-scale production plant with maximum utilization of by-products generated during the production to produce a sustainable algal biodiesel.

General information
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Authors: Singh, A. (Ekstern), Olsen, S. I. (Intern)
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Series: Green Energy and Technology
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Book chapter – Annual report year: 2013

Complementary use of life cycle assessment and risk assessment for engineered nanomaterials: Lessons learned from chemicals?
Successful strategies to handle the potential health and environmental risks of engineered nanomaterials (ENM) often rely upon the well-established frameworks of life cycle assessment (LCA) and risk assessment (RA). However, current research and specific guidance on how to actually apply these two frameworks are still very much under development. Through an in-depth review, this study evaluates how research efforts have applied LCA and RA together for ENM with a particular emphasis on past "lessons learned" from applying these frameworks to chemicals. Among other results, it appears that current scientific research efforts have taken into account some key lessons learned from past experiences with chemicals at the same time that many key challenges remain to applying these frameworks to ENM. In that setting, two main proposed approaches to use LCA and RA together for ENM are identified: i) LC-based RA, similar to traditional RA applied in a life cycle perspective, and ii) RA-complemented LCA, similar to conventional LCA supplemented by RA in specific life cycle steps. This study finds that these two approaches for using LCA and RA together for ENM are similar to those made for chemicals, and hence, there does not appear to be much progress made specifically for ENM. We therefore provide specific recommendations for applying LCA and RA to ENM, for which the need to establish proper dose metrics within both methods is identified as an important requirement.

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State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Environmental Chemistry
Authors: Grieger, K. D. (Ekstern), Laurent, A. (Intern), Miseljic, M. (Intern), Christensen, F. (Ekstern), Baun, A. (Intern), Olsen, S. I. (Intern)
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Singh, A. (Intern), Olsen, S. I. (Intern)
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Importance of Life Cycle Assessment of Renewable Energy Sources

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Life Cycle Assessment of Renewable Energy Sources

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
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Publisher: Springer
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Original language: English
Series: Green Energy and Technology
Main Research Area: Technical/natural sciences
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Publication: Research - peer-review › Book – Annual report year: 2013

Sustainability assessment of functionally enhanced polymers – engineered nanomaterials or conventional additives?

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Centro de Investigacion en Materiales Avanzados
Number of pages: 2
Publication date: 2013

Host publication information
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Main Research Area: Technical/natural sciences
Electronic versions: Sustainability_assessment.pdf

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Source-ID: 99356910
Publication: Research - peer-review › Article in proceedings – Annual report year: 2014
Teaching sustainability in engineering solutions as a generic bachelor course

Engineers have the potential to significantly influence the sustainability of technological solutions. At DTU we aim to address sustainability to all engineering students at DTU. One of the means to address students throughout DTU is the establishment of a course aimed at bachelor students from all of the university’s study lines. The objectives of the course, which is named “Sustainability in engineering solutions”, is for the participants to acquire an understanding of the basic concept of sustainability and its three dimensions (people, profit, planet), as well as to get an overview of a number of tools for the analysis of problems and the synthesis of solutions that are sustainable throughout their life cycle. The course ensures that the participants acquire the skills to use the most central of the tools introduced. Furthermore, the participants should understand the engineer’s role and responsibility in the development of sustainable solutions. Examples of learning outcomes are:

• Describe the three dimensions of sustainability
• Explain that each dimension is multifactorial and discuss the trade-offs that exist within and between them
• Illustrate how companies can work towards the development of sustainable solutions
• Know and use various simplified tools for use in sustainability assessment
• Be able to relate critically to the results of various tools.

The course runs over a three week period, where the students work full time on the course. It employs project-based learning and is organised around a theme, within which there are several subprojects/problems that the students work on in groups of 4-5 persons. The theme in 2011 was “everyday appliances”, in 2012 “the sustainable primary school”, and in 2013 “the sustainable campus”. In 2012 the students worked together with a primary school interested in improving their environmental performance and in which they could do some empirical work. Several sub-projects were suggested and 5 were chosen: heating, water use/supply, use of electronics, cleaning, and ventilation. Similarly in 2013 they worked with DTU Campus service who defined a number of projects. The general outline of the course (especially in the beginning) is that theory lectures and exercises are given in the morning and the afternoons are fully devoted to project work, applying the theory learned in the morning. As the course progresses and after the front-loading of large amounts of the course material, a number of the days are fully devoted to project work with supervision. Several milestones for the project are defined, where the students should present their work. The students are evaluated on their project presentations and final report, plus a multiple-choice examination, to test their theoretical understanding.

This paper takes an in-depth discussion of the considerations concerning how to teach such a complicated subject to students of widely differing backgrounds, and reflects both the teachers’ and the students’ experiences with the course.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Production and Service Management, Centre for Facilities Management, Department of Mechanical Engineering, Engineering Design and Product Development, Technical University of Denmark
Authors: Olsen, S. I. (Intern), Nielsen, S. B. (Intern), Ejlertsen, M. (Ekstern), McAloone, T. C. (Intern)
Number of pages: 8
Pages: Paper 72
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Title of host publication: Proceedings of Engineering Education for Sustainable Development EESD13
Publisher: University of Cambridge
Main Research Area: Technical/natural sciences
Electronic versions:
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Analysis of current research addressing complementary use of life-cycle assessment and risk assessment for engineered nanomaterials: have lessons been learned from previous experience with chemicals?

While it is generally agreed that successful strategies to address the health and environmental impacts of engineered nanomaterials (NM) should consider the well-established frameworks for conducting life-cycle assessment (LCA) and risk assessment (RA), scientific research, and specific guidance on how to practically apply these methods are still very much under development. This paper evaluates how research efforts have applied LCA and RA together for NM, particularly reflecting on previous experiences with applying these methods to chemicals. Through a literature review and a separate analysis of research focused on applying LCA and RA together for NM, it appears that current research efforts have taken into account some key “lessons learned” from previous experience with chemicals while many key challenges remain for practically applying these methods to NM. We identified two main approaches for using these methods together for NM: “LC-based RA” (traditional RA applied in a life-cycle perspective) and “RA-complemented LCA” (conventional LCA supplemented by RA in specific life-cycle steps). Hence, the latter is the
only identified approach which genuinely combines LC- and RA-based methods for NM-risk research efforts to date as the former is rather a continuation of normal RA according to standard assessment procedures (e.g., REACH). Both these approaches along with recommendations for using LCA and RA together for NM are similar to those made previously for chemicals, and thus, there does not appear to be much progress made specific for NM. We have identified one issue in particular that may be specific for NM when applying LCA and RA at this time: the need to establish proper dose metrics within both methods.

**General information**
- State: Published
- Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Department of Environmental Engineering, Environmental Chemistry, European Commission - Joint Research Center
- Authors: Grieger, K. D. (Intern), Laurent, A. (Intern), Miseljic, M. (Intern), Christensen, F. (Ekstern), Baun, A. (Intern), Olsen, S. I. (Intern)
- Number of pages: 23
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- Main Research Area: Technical/natural sciences

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  - Web of Science (2016): Indexed yes
  - BFI (2015): BFI-level 1
  - Scopus rating (2015): SJR 0.569 SNIP 0.689 CiteScore 1.97
  - Web of Science (2015): Indexed yes
  - BFI (2014): BFI-level 1
  - Scopus rating (2014): SJR 0.663 SNIP 0.868 CiteScore 2.17
  - Web of Science (2014): Indexed yes
  - BFI (2013): BFI-level 1
  - Scopus rating (2013): SJR 0.749 SNIP 1.013 CiteScore 2.54
  - ISI indexed (2013): ISI indexed yes
  - BFI (2012): BFI-level 1
  - Scopus rating (2012): SJR 0.855 SNIP 1.03 CiteScore 2.56
  - ISI indexed (2012): ISI indexed yes
  - Web of Science (2012): Indexed yes
  - BFI (2011): BFI-level 1
  - Scopus rating (2011): SJR 1.09 SNIP 1.44 CiteScore 3.52
  - ISI indexed (2011): ISI indexed yes
  - Web of Science (2011): Indexed yes
  - BFI (2010): BFI-level 1
  - Scopus rating (2010): SJR 0.966 SNIP 1.248
  - Web of Science (2010): Indexed yes
  - BFI (2009): BFI-level 1
  - Scopus rating (2009): SJR 0.977 SNIP 1.053
  - Web of Science (2009): Indexed yes
  - BFI (2008): BFI-level 1
  - Scopus rating (2008): SJR 0.989 SNIP 1.138
  - Scopus rating (2007): SJR 0.873 SNIP 1.082
  - Scopus rating (2006): SJR 0.862 SNIP 1.242
  - Scopus rating (2005): SJR 0.805 SNIP 1.174
  - Scopus rating (2004): SJR 0.805 SNIP 1.332
  - Scopus rating (2003): SJR 0.564 SNIP 0.87
An integrated life cycle inventory for demolition processes in the context of life cycle sustainability assessment

According to the Life Cycle Assessment in Building and Construction: State-of-the-Art Report (2003), the dismantling and demolition stage of the building life cycle is only sometimes included in the Life Cycle Inventory (LCI) when doing Life Cycle Assessments (LCA). The reason that it is less inventoried in a traditional LCA maybe because this stage is expected to have a negligible environmental impact comparing to other stages in the life cycle of the buildings. When doing a life cycle sustainability assessment considering not only environmental but also economic and social impacts, the impacts of the labor-intensive dismantling and demolition stage may not be possible to disregard anymore, due to the related process costs, health and safety of workers and the influence on the quality of the demolition materials, determining their suitability for high grade recycling. Currently, LCIs of dismantling and demolition processes are rare and reflect only the impacts to the environment and do not include data on economic and social impacts. The present study gives case specific environmental, economic and social LCI data for two demolition processes.

Bioelectrochemical systems (BES) for sustainable energy production and product recovery from organic wastes and industrial wastewaters

Bioelectrochemical systems (BESs) are unique systems capable of converting the chemical energy of organic waste including low-strength wastewaters and lignocellulosic biomass into electricity or hydrogen/chemical products in microbial fuel cells (MFCs) or microbial electrolysis cells (MECs) respectively, or other products formed at the cathode by an electrochemical reduction process. As compared to conventional fuel cells, BESs operate under relatively mild conditions, use a wide variety of organic substrates and mostly do not use expensive precious metals as catalysts. The recently discovered use of BES for product synthesis via microbial electrosynthesis have greatly expanded the horizon for these systems. Newer concepts in application as well as development of alternative materials for electrodes, separators, and catalysts, along with innovative designs have made BESs very promising technologies. This article discusses the recent developments that have been made in BESs so far, with an emphasis on their various applications beyond electricity generation, resulting performances and current limitations. © 2012 The Royal Society of Chemistry.
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
Authors: Laurent, A. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
Publication date: 2012

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Main Research Area: Technical/natural sciences
Conference: 4th International EcoSummit 2012, Columbus, OH, United States, 30/09/2012 - 30/09/2012
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Challenges in Implementing Life Cycle Sustainability Assessment (LCSA) and in an LCSA-based Decision-making

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Bozhilova-Kisheva, K. P. (Intern), Olsen, S. I. (Intern)
Number of pages: 2
Publication date: 2012
Conceptual Model for Life Cycle Sustainability Assessment

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Bozhilova-Kisheva, K. P. (Intern), Olsen, S. I. (Intern)
Number of pages: 1
Publication date: 2012
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Main Research Area: Technical/natural sciences
Electronic versions:
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Source-ID: u::8829
Publication: Research - peer-review › Poster – Annual report year: 2013

Construction Waste Recycling Technologies: How to Define and Assess Their Economic, Environmental and Social Effects by the use of Input-Output Analysis

Concrete is one of the most important building materials and it entails a big environmental impact making recycling relevant from an environmental perspective. Recycling of construction and demolition waste (CDW) containing concrete is being performed in the Netherlands resulting in recycled aggregates that due to the less quality are used mainly in road construction and less in buildings. Within the EU FP7 project Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste (C2CA), an innovative technology for CDW recycling to clean aggregates for use in buildings is being developed and its impacts assessed under different scenarios.

The assessment of the impacts, though, depends on how they are defined: is it only environmental impacts and economic profit, which are assessed? Does concrete recycling have other impacts, e.g. social, and on the basis of what indicators are these impacts assessed?

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State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Bozhilova-Kisheva, K. P. (Intern), Olsen, S. I. (Intern)
Number of pages: 12
Publication date: 2012
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Publication: Research - peer-review › Conference article – Annual report year: 2013
Environmental impacts and improvement prospects for environmental hotspots in the production of palm oil derived biodiesel in Malaysia

Palm oil is the largest and fastest growing vegetable oil on the world market and the prospects of biodiesel production will further spur the expansion. In order to contribute to the knowledge base on current environmental impacts and potential improvements in the palm oil industry this study sets out to generate LCI data for central, yet underexplored elements in the production of biodiesel with a focus on greenhouse gasses (GHG).

The research follows an attributional modelling framework, but does include system expansion to account for the use of residues from the palm oil production. The reference flow of the study is 1 MJ palm oil derived biodiesel, which has been chosen to facilitate comparisons of the results to fossil diesel and other biodiesels.

The impact focus is on global warming potential with extensive quantification of GHG emissions and potential reduction. Other impact categories are included mainly with the purpose of documenting whether the proposed GHG reduction initiatives result in problem shifting. Land use changes (LUC) are the most controversial aspect of palm oil production with large potential GHG emissions and impacts on biodiversity. With global warming and extinction of animals and plants in tropical areas being easily communicated to the public, palm oil has been the target of numerous scare campaigns. Conversely, the palm oil industry is adamant that palm oil and oil palm plantations are sequestering carbon and supporting a wide range of flora and fauna.

Through critical selection of literature data, field studies and application of state-of-the-art LCA methodology, this study is quantifying the GHG emissions from palm oil related LUC for the two most common previous land uses in Malaysia, namely logged-over forest and rubber plantations. In order to be able to assess the impacts from average palm oil production in Malaysia, a Malaysian average LUC scenario was set up and assessed.

Solid residues from the production of palm oil constitute two tons dry weight organic matter per ton palm oil produced. Current use of this potential resource is limited to mulching of plantation residues and empty fruit bunches (EFB) from the mills and use of press fibre and kernel shells in the mill boilers. The mill wastewater called palm oil mill effluent (POME) is treated anaerobically in open lagoons emitting large amounts of methane. In recent years it is becoming more popular to sell kernel shells for use in industrial boilers, and biogas plants with methane capture for the POME treatment are slowly making their entry, but the potential uses and environmental benefits of such uses have only been sporadically explored.

Residue energy recovery for substitution of fossil fuels is explored here through application of biomass power plants, pyrolysis and biogas production.

Modelling the results of the LUC study and the residue use study into a GaBi model, various scenarios were set up to test the environmental potentials of management decisions in respect to LUC choices, yield optimization and residue use. The study also includes an assessment of the management practices of corporations and smallholders and an economic feasibility study to assess financial aspect of environmental improvements.

The results show that biodiesel production from conventionally produced palm oil with national average LUC emissions emits only marginally less GHG than the life cycle emissions of fossil diesel. This study, however, shows that significant environmental improvements are available with currently available technologies to bring the impacts well below the fossil diesel emissions, and do so with economic profitability.

Residue use shows a big potential for improvement. The conventional residue management causes net GHG emissions where the prospective fossil fuel substitutions through residue energy recovery alone is so significant that net GHG emissions from the PME production process can become close to CO2 neutral when not including LUC.

An added bonus for the palm oil industry is that such improvements are likely to result in a net income through sales of residues and/or residue use products.

LUC emissions can potentially result in so large GHG emissions when high-carbon stock land is converted to oil palm that no environmental improvements or management strategies will be able to make the produced palm oil sustainable. On the other hand, conversion of low-carbon stock land or land with a temporary carbon stock can result in low or even negative LUC emissions thus giving PME carbon neutral potentials when combined with environmental initiatives in the production. A methodological choice made in this study of focusing on the Malaysian average LUC emissions results in LUC contributions of app.

40% of the total conventional biodiesel production emissions of 70 g CO2/MJ.

The impacts from LUC as well as the biodiesel production process can, however, be improved through management strategies. Increasing yields have a direct correlation with lower LUC emissions per MJ biodiesel and with potentials of up to 75% yield increases from the plantations, Malaysian average LUC emissions could thus be reduced by about 50%, which in combination with residue use would lower the overall PME emissions by 80%.

Such a scenario would require an optimization of the production system, which may be possible from a few dedicated producers, but is very unlikely as a Malaysian average scenario in a foreseeable future. However, the two future scenarios set up in this study show that the GHG emissions from biodiesel are likely to drop by almost 15% in 2015 and close to 65% by 2020 thus putting biodiesel on track to meet the sustainability criteria.

Assessing other impact categories than global warming potential (GWP) shows that all impact categories experience reduced impacts due to the proposed environmental improvements in the management scenarios set up in this study. Thus, even though most other impact categories experience lower reductions that GWP, it can be concluded that the proposed improvements do not result in problem shifting.

Through the data collection process in this study it has become evident that many holes in life cycle inventory data for palm oil production still exist. Thus, this study recommends extensive further studies within areas like biodiversity, nitrogen emissions, water footprint and many more as well as further studies on LUC and residue use.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Greenhouse gas reductions through enhanced use of residues in the life cycle of Malaysian palm oil derived biodiesel
This study identifies the potential greenhouse gas (GHG) reductions, which can be achieved by optimizing the use of residues in the life cycle of palm oil derived biodiesel. This is done through compilation of data on existing and prospective treatment technologies as well as practical experiments on methane potentials from empty fruit bunches. Methane capture from the anaerobic digestion of palm oil mill effluent was found to result in the highest GHG reductions. Among the solid residues, energy extraction from shells was found to constitute the biggest GHG savings per ton of residue, whereas energy extraction from empty fruit bunches was found to be the most significant in the biodiesel production life cycle. All the studied waste treatment technologies performed significantly better than the conventional practices and with dedicated efforts of optimized use in the palm oil industry, the production of palm oil derived biodiesel can be almost carbon neutral.

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State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, University of Technology Malaysia
Authors: Hansen, S. B. (Intern), Olsen, S. I. (Intern), Ujang, Z. (Ekstern)
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Key issues to consider in microalgae based biodiesel production

All nations have been confronted with the energy crisis due to depletion of finite fossil fuels reserves, which results an increasing global demand of biofuels for energy security, economic stability and reduction in climate change effects, and generate the opportunity to explore new biomass sources. The production of sustainable bioenergy is a challenging task in the promotion of biofuels for replacing the fossil based fuels to mitigate challenges of fossil based energy consumption. Algae might be a very promising source of biomass in this context as it sequesters a significant quantity of carbon from atmosphere and industrial gases and is also very efficient in utilizing the nutrients from industrial effluents and municipal wastewater. If developed sustainably, the algae biofuel industry may be able to provide large quantities of biofuels with potentially minimal environmental impacts. However, in order to realize this, a complete analysis of full life cycle impact of algal biofuel production in the context of issues such as water resource management, land use impact, energy balance and air emissions are very necessary. The commercial-scale production of algae requires careful consideration of many issues that can be broadly categorized into four main areas: selecting algae species that produce high oil levels and grow well in specified environments, algae growth methods, water sources and related issues, and nutrient and growth inputs.

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LCA of metal nanomaterial production

The use of engineered nanomaterials (ENMs) in commercial product has reached a new stage, where consumers in their daily life are frequently encountered with products containing this new material class. Metal and metal-oxide nanomaterials are among the most commonly used ENMs in products. Potential life cycle impacts arise from all life cycle stages of the ENM products. Currently there are many unknowns related to the inputs and outputs from production of ENMs and the potential impacts that arise from that and we need to better understand and map the impacts that arise from the raw material extraction and manufacturing of ENM products. Further in the life cycle, i.e. the use and disposal, additional difficulties are observed in accounting for potential impacts e.g. the potential health impacts related to release of nanoparticles. This case study considers the production of ENM (Ag, ZnO and Mg(OH)2 applied as additives in polypropylene (PP), and the production of PP with conventional additives that provide similar properties as the ENMs. Different scenarios of nanoproducts consisting of metal ENMs and PP were compared with current use of additives in PP products through a detailed cradle-to-gate LCA study. The results showed that the ENMs do not contribute substantially to the impact profile of nanoproducts, but the PP plastic has the main responsibility. The main reason is the rather low amounts of ENM added. Further the comparison showed that nanoproducts have less impacts associated to them compared to the PP products containing conventional additives due to the improved material functionality and properties that ENMs contribute to.

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LCIA and fate of metal-oxide engineered nanomaterials in freshwater

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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.

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Web of Science (2006): Indexed yes
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Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 2.545 SNIP 2.071
Web of Science (2003): Indexed yes
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Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 2.419 SNIP 1.977
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Modelling health effects from inhalation of nano-objects

General information
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Authors: Laurent, A. (Intern), Hauschild, M. Z. (Intern), Olsen, S. I. (Intern), Li, D. (Ekstern), Jolliet, O. (Intern)
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Potential environmental benefits of improving recycling of polyolefines – LCA of Magnetic density separation (MDS) developed in the EU FP7 funded project W2Plastic
The core of the EU FP7 funded project W2Plastic is development of a magnetic density separation (MDS) of polyolefines in order to improve the sorting efficiency of these polymer types in different waste fractions. As part of the project a life cycle assessment is performed in order to firstly identify eco-design criteria for the development and secondly to document the potential environmental improvement of polyolefin recycling using the MDS technology. A preliminary study focusing solely on the carbon footprint benefits of recycling plastic waste compared to virgin production of polymers showed that there are large benefits to recycling. However, including other uses of the waste illustrates that the benefits to a large extent depend on that the recycled plastic have such high quality that it can actually replace virgin plastic and also to some extent depends on which energy systems e.g. energy recovery from incineration substitutes.

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Teaching sustainability: Paving the way to a common understanding and meaningful actions

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A critical review of biochemical conversion, sustainability and life cycle assessment of algal biofuels

The increasing global demand of biofuels for energy security and reduction in climate change effects generate the opportunity to explore new biomass sources. Algae is a very promising source of biomass in this context as it sequester a significant quantity of carbon from atmosphere and industrial gases and is also very efficient in utilizing the nutrients from industrial effluents and municipal wastewater. Therefore cultivation of algal biomass provide dual benefit, it provides biomass for the production of biofuels and also save our environment from air and water pollution. The life cycle assessment (LCA) of algal biofuels suggests them to be environmentally better than the fossil fuels but economically it is not yet so attractive.

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In recent years research activities are intensively focused on renewable fuels in order to fulfill the increasing energy demand and to reduce the fossil fuels consumption and external oil dependency either in order to provide local energetic resources and or as a means for reducing greenhouse gases (GHG) emissions to reduce the climate change effects. Among the various renewable energy sources algal biofuels is a very promising source of biomass as algae sequester huge quantities of carbon from atmosphere and are very efficient in utilizing the nutrients from the industrial effluent and municipal wastewater. Algae capture CO2 from atmosphere and industrial flue gases and transform it in to organic biomass that can be used for the production of biofuels. Like other biomass, algal biomass is also a carbon neutral source for the production of bioenergy. Therefore cultivation of algal biomass provides dual benefits; while being able to utilize nutrients in waste water thus reducing impacts on inland waters it produce biomass for the production of biofuels. However, reaching commercial scale production of algal biofuels is difficult. The main drawbacks include the harvesting of dry biomass and higher capital investment. The harvested algal biomass and its extracts can be efficiently converted to different biofuels such as bioethanol, biodiesel, biogas and biohydrogen by implementation of various process technologies. Comprehensive life cycle assessments (LCA) of algal biofuels illustrating environmental benefits and impacts can be a tool for policy decisions and for technology development.
A viable technology to generate third-generation biofuel

First generation biofuels are commercialized at large as the production technologies are well developed. However, to grow the raw materials, there is a great need to compromise with food security, which made first generation biofuels not so much promising. The second generation of biofuels does not have direct competition with food but requires several energy intensive processes to produce them and also increase the land use change, which reduces its environmental and economical feasibility. The third generation biofuels production avoids issues with first and second generation biofuels, viz. food-fuel competition, land use change, etc., resulting in being considered as a viable alternative energy resource. On all dimensions of sustainability (environmental, social and economical), a life cycle assessment approach is most relevant to avoid issues in problem shifting. The utilization of organic waste and carbon dioxide in flue gases for the production of biomass further increases the sustainability of third generation biofuels, as it does minimize greenhouse gases emission and disposal problems.
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),

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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 consequent 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 green house 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.

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

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Improving Energy Efficiency in Industrial Solutions – Walk the Talk
This paper describes the outline of the energy efficiency and environmental care policy and management at Siemens Industry Solutions Division. This environmental policy coherently embraces strategic planning, eco-design of energy-efficient industrial processes and solutions, design evaluation and finally communication of both environmental and economic performance of solutions to customers. One of the main tools supporting eco-design and evaluation & controlling of derived design solutions is the so called "Eco-Care-Matrix" (ECM). The ECM simply visualizes the eco-efficiency of solutions compared to a given baseline. In order to prevent from "green washing" criticism and to ensure "walk the talk" attitude the ECM should be scientifically well-founded using appropriate and consistent methodology. The vertical axis of an ECM illustrates the environmental performance and the horizontal axis describes the economical customer benefit of one or more green solutions compared to a defined reference solution. Different scientific approaches for quantifying the environmental performance based on life cycle assessment methodology are discussed especially considering the ISO standards 14040/14044:2006. Appropriate ECM application is illustrated using the example of the Siemens MEROS® technology (Maximized Emission Reduction of Sintering) for the steel industry. MEROS® is currently the most modern and powerful system for cleaning off-gas in sinter plants. As an environmental technology MEROS® is binding and removing sulfur dioxide and other acidic gas components present in the off-gas stream by using dry absorbents and additional electrical power. Advantage in the impact category of acidification potential (by desulfurization) is a trade-off to disadvantages in global warming and resource depletion potential caused by use of electricity. Representing different impacts, indicator results for impact categories with different tendencies have to be compared category by category and therefore should not be aggregated to a single-score result. Results communicated in the form of a self-declared environmental claim (type II environmental labeling, ISO 14021) for MEROS® are presented.

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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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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.

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Life Cycle Assessment in Nanotechnology – Issues in Impact Assessment and case studies

General information
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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Authors: Olsen, S. I. (Intern), Miseljic, M. (Intern)
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Event: Abstract from Safety Issues of Nanomaterials along their Life Cycle, Barcelona, Spain.
Main Research Area: Technical/natural sciences
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 inventorizing 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.

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Authors: Laurent, A. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
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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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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 1.504 SNIP 1.554 CiteScore 3.49
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Scopus rating (2014): SJR 1.736 SNIP 1.738 CiteScore 3.65
Web of Science (2014): Indexed yes
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Scopus rating (2013): SJR 1.666 SNIP 1.979 CiteScore 3.35
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.515 SNIP 1.701 CiteScore 2.89
ISI indexed (2012): ISI indexed yes
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Scopus rating (2011): SJR 1.581 SNIP 1.716 CiteScore 2.82
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
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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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Authors: Laurent, A. (Intern), Lautier, A. (Ekstern), Rosenbaum, R. K. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
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Main Research Area: Technical/natural sciences
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\textsuperscript{TM}-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 CO\textsubscript{2} emissions is qualified as “green”, even though its true environmental burden is high due to the contribution of other impacts (e.g. human toxicity).

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Authors: Laurent, A. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
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environmental burden, USEtox, representativeness, Carbon footprint

A Strategy For Teaching Sustainability Assessment

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Authors: Olsen, S. I. (Intern)
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ISEE2010\_Binder[1].pdf
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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 CO\textsubscript{2} 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.
Ecoefficiency indicators for development of nano-composites

The EU FP7 funded project “NanCore” aims to develop foam nano composites. One WP addresses the environmental aspects using Life Cycle Assessments. A preliminary assessment, based on literature sources, aims to provide inputs for the further technology development in terms of eco-indicators. Four nanocomposites (5 wt%-nanofiller) were investigated; PU/CNT (in-situ polymerization), PP/CNT (in-situ polymerization), PU/clay (bulk polymerization), and PP/clay nanocomposites (bulk polymerization). Due to of lack of information, only the material stages (extraction of materials) and the production of the nanocomposites were evaluated, i.e. so-called “cradle to gate” assessment. Overall, the study emphasises the CNT production as a main cause of impact. Variations occur depending on the type of technology considered (HiPco, FBCVD). However, acid production (for purification process), electricity production, and production of catalysts are identified as main contributors to the impacts. Regarding nano clay the main contributors to impacts on environment are the foaming process as well as the production of the reactants and the catalysts (e.g. polyol, propylene). Nano clay does not contribute significantly. Eco-indicators thus high-light the CNT production, but also foaming processes etc. as focus areas for further technology development. Potential release of nano particles during the life cycle is also a particular issue to devote consideration.

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Environmental benefits from reusing clothes

Background, aim, and scope Clothes are often discarded when much of their potential lifetime is left. Many charitable organizations therefore collect used clothing and resell it as second-hand clothes for example in Eastern Europe or Africa. In this connection, the question arises whether reusing clothes actually results in a decrease of the environmental burden of the life cycle of clothing. The environmental burden of clothing has been studied in several studies. However, most of these studies focus solely on the energy consumption aspects and pay little attention to the potential benefits of diverting used clothing from the waste stream. The aim of the study was to assess the net environmental benefits brought by the disposal of used clothing through charities who return them for second-hand sales assuming that second hand clothes (SHC) to some extent replace the purchase of new clothes. Materials and methods The extent to which SHC introduces such a replacement was investigated applying a methodology in which a questionnaire-based survey was conducted on more than 200 consumers in second-hand shops. The survey was done in Sweden and Estonia and Africa was included by estimation. Based on the identification of the different profiles of the consumers questioned, a methodology was developed to get a quantitative evaluation of the replacement of new clothes enabled by second-hand clothing consumption. A Life cycle Assessment was conducted based on the EDIP methodology. The life cycle impacts of clothes that are directly disposed of by incineration were compared with the life cycle impacts of clothes that are collected and sorted after consumer use in order to be reused. Two products were assessed: a cotton T-shirt and a pair of polyester
Results Based on the survey result and the methodology applied, the purchase of 100 second-hand garments would save between 60 and 85 new garments dependent of the place of reuse. Based on information about the second-hand clothing activities conducted by Humana People to People in Sweden and Estonia, it was assumed that over 100 collected items 60 would be reused, 30 recycled in other ways and 10 go to final disposal. Using these inputs, the LCA showed that the collection, processing and transport of second-hand clothing has insignificant impacts on the environment in comparison to the savings that are achieved by replacing virgin clothing. The reduction of impacts resulting from collecting 100 garments for reuse range from 14% decrease of global warming for the cotton T-shirt to 45% reduction of human toxicity for the polyester/cotton trousers.

Discussion The approach applied is a fair way of establishing the net benefits from introducing clothes reuse. Indeed, it enables to take into consideration all the activities connected to reusing clothes, including, for instance, recycling and disposal of the collected clothes not suitable for reuse. In addition, the routes followed by the collected clothes have been determined based on real figures. A main assumption concerns the estimation of avoided production of new clothes brought by clothes reuse. The method used, based on questionnaires, could be further developed but still suggests an approach on an issue that had not been investigated so far. Conclusions The results of the study show that clothes reuse can significantly contribute to reducing the environmental burden of clothing. Recommendations and perspectives It would be beneficial to apply other methods for estimating the avoided production of new clothes in order to check the validity and reliability of the results obtained in the current study. Such a further work could include the possible difference in the lifetime of second-hand clothes compared to new clothes.
Life Cycle Assessment and Risk Assessment

Life Cycle Assessment (LCA) is a tool for environmental assessment of product and systems – over the whole life cycle from acquisition of raw materials to the end-of-life of the product – and encompassing all environmental impacts of emissions and resource usage, e.g. global warming, acidification and toxicity. Whereas Risk Assessment (RA) aims to identify absolute risks, LCA assess potential or relative impacts. LCA is readily applicable to nanotechnologies and several studies have been carried out, but LCA faces large problems when addressing toxic impacts of nanomaterials emitted during the life cycle. The models for assessing toxic impacts in LCA are to a large extent based on those developed for RA, e.g. EUSES, and require basic information about the inherent properties of the emissions like solubility, LogKow, ED50 etc. Additionally, it is a prerequisite to know how to characterize the emissions, how should they be defined and classified and what should be measured? LCA have many of these issues in common with RA. There is a need to understand which properties of nanomaterials are crucial for the assessment of their potential transformation and fate as well as their ability to cause adverse effects on target organisms or systems. If we want to be able to assess toxic impacts both in LCA and in RA these issues need to be addressed by the RA community and the LCA community must follow closely the progress made.

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Authors: Olsen, S. I. (Intern)
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Life Cycle Concepts for the Development of Safe Nanoproducts: State of the art, existing gaps and

Whilst the global industry is rapidly moving forward to take advantage of the new opportunities and prospects offered by nanotechnologies, it is imperative that such developments take place in a safe and sustainable manner. The increasing use of engineered nanomaterials (ENMs) in consumer products has raised certain concerns over their safety to human health and the environment. There are currently a number of major uncertainties and knowledge gaps in regard to behavior, chemical and biological interactions and toxicological properties of ENMs. As this will need generation of some new basic knowledge, it is unlikely that the uncertainties will be resolved in the immediate future. Considering the whole
life cycle of nanoproducts ensures that possible impacts can be systematically discovered, when assessing the risk of ENMs. For example, life cycle assessment (LCA) - a formalized life cycle concept - may be used to assess the relative environmental performance of nanoproducts in comparison with their conventional equivalents. Other less formalized life cycle concepts may uncover further detailed and prospective knowledge for human and environmental exposure to ENMs throughout the life cycle of nanoproducts and reveal systematically other risks such as cross product contamination or increasing waste production. The combination of different life cycle concepts with the current knowledge on risk assessment can provide an early basis for informed decision making by the industry and regulators.

General information
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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Som, C. (Ekstern), Berges, M. (Ekstern), Chaudry, Q. (Ekstern), Dusinska, M. (Ekstern), Fernandes, T. F. (Ekstern), Olsen, S. I. (Intern), Nowack, B. (Ekstern)
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Scopus rating (2010): SJR 1.205 SNIP 1.173
Web of Science (2010): Indexed yes
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Scopus rating (2009): SJR 1.147 SNIP 1.189
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Scopus rating (2008): SJR 1.002 SNIP 1.219
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.051 SNIP 1.269
Scopus rating (2006): SJR 1.028 SNIP 1.358
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.007 SNIP 1.224
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Scopus rating (2004): SJR 0.962 SNIP 1.14
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Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefins from Waste: Social Life Cycle Assessment - Methodology

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Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
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W2Plastics SLCA methodology report.doc
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Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefins from Waste: Social Life Cycle Assessment - Results

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Sustainability of Micro-Manufacturing Technologies

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Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Quantitative Sustainability Assessment, Department of Management Engineering, Institute for Product Development
Authors: De Grave, A. (Intern), Olsen, S. I. (Intern), Hansen, H. N. (Intern), Arentoft, M. (Intern)
Number of pages: 432
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Publication date: 2010
The importance of life cycle concepts for the development of safe nanoproducts

Whilst the global players in industry are rapidly moving forward to take advantage of the new opportunities and prospects offered by nanotechnologies, it is imperative that such developments take place in a safe and sustainable manner. The increasing use of engineered nanomaterials (ENMs) in consumer products has raised certain concerns over their safety to human health and the environment. There are currently a number of major uncertainties and knowledge gaps in regard to behavior, chemical and biological interactions and toxicological properties of ENMs. As dealing with these uncertainties will require the generation of new basic knowledge, it is unlikely that they will be resolved in the immediate future. One has to consider the whole life cycle of nanoproducts to ensure that possible impacts can be systematically discovered. For example, life cycle assessment (LCA) – a formalized life cycle concept – may be used to assess the relative environmental sustainability performance of nanoproducts in comparison with their conventional equivalents. Other less formalized life cycle concepts in the framework of prospective technology assessment may uncover further detailed and prospective knowledge for human and environmental exposure to ENMs during the life cycle of nanoproducts. They systematically reveal impacts such as cross product contamination or dissipation of scarce materials among others. The combination of different life cycle concepts with the evolving knowledge from toxicology and risk assessment can mitigate uncertainties and can provide an early basis for informed decision making by the industry and regulators.
Literature data show that in general, plastics produced through the mechanical recycling route involve less carbon dioxide emission than when produced from crude oil. A review of readily available data shows that road transport of untreated waste plastics account for a significant portion of the carbon dioxide emission generated during recycling. Therefore, much carbon dioxide emission can be saved by optimizing the logistics in the recycling of plastics. On the example of polyolefins originating from household packaging waste, this paper attempts to compare two different scenarios of mechanical recycling to the production of plastics from crude oil as a reference. The first scenario deals with packaging waste from selective collection, in which data from the current practice of the German DSD system were translated for the Dutch situation. In the second scenario, plastic packaging recovered from household waste using mechanical separation techniques is considered. It is assumed in the second scenario that the plastics are separated from the rest of the household waste and processed further to a compound close to the site at which the rest of the waste is disposed of, e.g. at an incinerator plant or landfill site. This scenario is assumed to involve the least of road transport of existing recycling options. The data presented in this paper represent the results of a preliminary study.
Comprehensive Approach to Energy and Environment in the EcoCare Program for Design, Engineering and Operation of Siemens Industry Solutions

This paper intends to describe the outline of the Eco Care Program (ECP) at the Siemens-Division Industry Solutions and its implementation. ECP aims to embrace and to coordinate main activities within the product lifecycle management (PLM) process considering both economic targets in terms of overall lifecycle costs as well as energy efficiency and other important environmental issues in the innovation management for industrial solutions. ECP consists of adapted methods for assessing the environmental and financial impacts of industrial solutions (plants, processes, single technologies or even services) and tools which helps to derive reliable assessment results. Life Cycle Assessment (LCA) is a suitable method for assessing environmental impacts of products and solutions over their entire lifecycle focusing on those lifecycle phases which may contribute significantly to environmental burdens or benefits. To meet these requirements the main challenge is to simplify the assessment methodology as far as reliability and accuracy of results is preserved. To present results in both dimensions of economical performance and environmental impact the paper introduces the concept of the “eco care matrix” (ECM). Environmental sound industrial solutions have advantages in both “eco" dimensions (economic + eco-logical). The analytical approach presented is further on implemented in two complementary and independent industrial application fields: in order to exemplify usability of the approach in quite complex process technology different hot metal producing technologies (blast furnace route vs. smelting reduction routes COREX / FINEX). The second pilot application is targeted on the assessment of infrastructure solutions especially focusing on the comparison of environmental and financial effects of different technologies and payment schemes of electronic city tolling systems for London and Copenhagen. Experienced results derived from these two pilot applications to put ECP in place are evaluated and presented.

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Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Siemens, Technical University of Berlin, Siemens Corporate Technology
Authors: Wegener, D. (Ekstern), Finkbeiner, M. (Ekstern), Geiger, D. (Ekstern), Olsen, S. I. (Intern), Walachowicz, F. (Ekstern)
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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 micropolitants 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.

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Authors: Larsen, H. F. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern), Laurent, A. (Intern)
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Main Research Area: Technical/natural sciences
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EcoDesign and LCA approach toward sustainable micro products development

Historically LCA has mainly been applied to products; however, it can be very useful in assisting the whole product development by identifying more sustainable options in process selection, design and optimisation. Using LCA it is believed that one can aim at identifying issues of environmental importance in the design of micro/nano products and of downscaled production pathways. In addition, the topic of EcoDesign, which has been used for a long time now in so-called “macro size”, is explained and the panel of tools used for designing products taking care of the environment will be investigated in the context of micro technology. Ecodesign and LCA take into account environmental impact of production of micro and nano products, but another important issue to include is the impact of such applications on human health. A particular focus has been put on the human health risks of nanoparticles.

General information
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Organisations: Manufacturing Engineering, Department of Mechanical Engineering, Quantitative Sustainability Assessment, Department of Management Engineering
Authors: De Grave, A. (Intern), Olsen, S. I. (Intern), Hansen, H. N. (Intern)
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EcoDesign
Source: orbit
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Integrating LCA and EHS expertise in the assessment of nanoparticles

DTU with their expertise in LCA have joined forces with IOM in two nanotechnology-related projects, one of which additionally involves and is lead by FERA. The first project, Nancore, includes the evaluation of health risks and environmental impacts over the life cycle concurrently with the development of new production technology for lightweight materials used in e.g. wind turbine blades. As the new technology involves the use of nanoparticles, the health and safety workpackage is needed to examine the potential exposure and effects of these particles. An LCA is also performed to evaluate the overall environmental impacts of the technology. Through the concurrent assessments, the strengths of the two tools are combined to provide a more qualified assessment of both the health and safety aspects and the life cycle impacts. The overall aim of the second project, sponsored by Defra, is to identify products containing CNT and evaluate the potential for inhalation exposure of a representative subset of products. As part of this study, we are investigating how a standardized Life Cycle Assessment can contribute to the analysis. Simplified LCAs will be performed for a few products. In particular, the issue of improving the estimates of health impacts across the life cycle, through the concurrent exposure and health effect analysis, will be addressed. The presentation will introduce the approach underpinning our approach in the Nancore project and present preliminary results from the second project.

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State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, Institute of Occupational Medicine, The Food and Environment Research Agency
Authors: Olsen, S. I. (Intern), Hankin, S. (Ekstern), Chaudry, Q. (Ekstern)
Publication date: 2009
Event: Poster session presented at 1st NanoImpactNet Conference for a Healthy Environment in a Future with Nanotechnology, Lausanne, Switzerland.
Main Research Area: Technical/natural sciences
Electronic versions:
NIN Poster Lausanne 090326.pdf
Source: orbit
Source-ID: 251035
Publication: Research › Poster – Annual report year: 2009

Nanolifecycle: A Lifecycle Assessment Study Of The Route And Extent Of Human Exposure Via Inhalation For Commercially Available Products And Applications Containing Carbon Nanotubes.

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Authors: Olsen, S. I. (Intern)
Number of pages: 81
Publication date: 2009

Publication information
Place of publication: York, UK
Publisher: FERA, UK
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
CNT-LCA, Final Report.pdf
Source: orbit
Source-ID: 265562
Publication: Research › Report – Annual report year: 2009

Categorizing Nanomaterials

General information
State: Published
Organisations: Environmental Chemistry, Department of Environmental Engineering, Theoretical Atomic-scale Physics, Department of Physics, Innovation and Sustainability, Department of Management Engineering
Authors: Hansen, S. F. (Intern), Larsen, B. H. (Intern), Olsen, S. I. (Intern), Baun, A. (Intern)
Publication date: 2008

Host publication information
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.
Integration of LCA in Micro/Nano products and production pathways

General information
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering, Manufacturing Engineering, Department of Mechanical Engineering
Authors: Olsen, S. I. (Intern), De Grave, A. (Intern)
Publication date: 2008
Event: Poster session presented at SETAC Europe 18th Annual Meeting, Warsaw, Poland.
Main Research Area: Technical/natural sciences

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
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 EDIP200X 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.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Authors: Larsen, H. F. (Intern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
Number of pages: 40
Publication date: 2008

Publication information
Publisher: DTU MAN (EU FP6 project)
Original language: English

Series: Milestone
Number: M4.1
Main Research Area: Technical/natural sciences
LCA, NEPTUNE, LCIA methodology, Waste water, EDIP200X
Source: orbit
Source-ID: 231979
Publication: Research › Report – Annual report year: 2008

Nanomaterialer i miljøet - hvor lille er risikoen?

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering, Environmental Chemistry, Innovation and Sustainability, Department of Management Engineering
Authors: Baun, A. (Intern), Hansen, S. F. (Intern), Hartmann, N. I. B. (Intern), Olsen, S. I. (Intern)
Pages: 127-137
Publication date: 2008

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Title of host publication: Vintermøde om jord- og grundvandsforurening, Vingstedcentret 4.-5. marts 2008
Volume: Bind 2
Place of publication: Kgs. Lyngby
Publisher: ATV Jord og Grundvand
Main Research Area: Technical/natural sciences
Conference: Vintermøde om jord- og grundvandsforurening, Vingstedcentret 4.-5. marts 2008, 01/01/2008
Source: orbit
Source-ID: 211667
Publication: Research › Article in proceedings – Annual report year: 2008

Nanomaterialer - muligheder og risici

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering, Environmental Chemistry, Innovation and Sustainability, Department of Management Engineering, National Food Institute
Authors: Baun, A. (Intern), Hansen, S. F. (Intern), Hartmann, N. I. B. (Intern), Olsen, S. I. (Intern), Binderup, M. (Intern), Lam, H. R. (Intern)
Pages: 195-221
Publication date: 2008

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Title of host publication: Nanoteknologiske horisonter
Volume: Kapitel 13
Categories of nanomaterials and their environmental hazards

General information
State: Published
Organisations: Department of Environmental Engineering, Innovation and Sustainability, Department of Management Engineering, Department of Physics
Authors: Baun, A. (Intern), Hansen, S. F. (Intern), Olsen, S. I. (Intern), Larsen, B. H. (Intern)
Number of pages: 130
Publication date: 2007

Host publication information
Title of host publication: NANOMAT conference 2007 and the satellite meetings, Bergen 4-9 June 2007 : Abstract Book
Place of publication: Oslo
Publisher: The Research Council of Norway
Main Research Area: Technical/natural sciences
Conference: NANOMAT conference 2007 and the satellite meetings, Bergen 4-9 June 2007, 01/01/2007
Source: orbit
Source-ID: 201430
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2007

Categorization framework to aid hazard identification of nanomaterials
The physical, chemical and biological properties of various nanomaterials differ substantially - as do the potential risks they pose. We argue that nanomaterials must be categorized based on the location of the nanoscale structure in the system/material before their hazards can be assessed and propose a categorization framework that enables scientists and regulators to identify the categories of nanomaterials systematically. The framework is applied to a suggested hazard identification approach aimed at identifying causality between inherent physical and chemical properties and observed adverse effects reported in the literature. We tested the workability of the proposed procedure using nanoparticles as an illustrative case study. A database was generated noting the reported inherent physical and chemical properties of the nanoparticles tested and the main effects observed. 428 studies were noted in the database reporting on a total of 965 nanoparticles. We found that although a limited number of studies have been reported on ecotoxicity, more than 120 and 270 have been reported on mammalian toxicity and cytotoxicity, respectively. In general there was a lack of characterization of the nanoparticles studied and it was not possible to link specific properties of nanoparticles to the observed effects. Our study shows that future research strategies must have a strong focus on characterization of the nanoparticles tested.

General information
State: Published
Organisations: Environmental Chemistry, Department of Environmental Engineering, Theoretical Atomic-scale Physics, Department of Physics, Innovation and Sustainability, Department of Management Engineering
Authors: Hansen, S. F. (Intern), Larsen, B. H. (Intern), Olsen, S. I. (Intern), Baun, A. (Intern)
Pages: 243-250
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Nanotoxicology
Volume: 1
ISSN (Print): 1743-5390
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes


**LCA of Nanotechnological Products: What's the issue?**

**General information**
State: Published
Organisations: Quantitative Sustainability Assessment, Department of Management Engineering
Authors: Olsen, S. I. (Intern)
Publication date: 2007
Event: Poster session presented at SETAC 17th annual Meeting, Porto, Portugal.
Main Research Area: Technical/natural sciences

**Electronic versions:**
SETAC LCA of Nanotechnological product, Olsen 2007.pdf
Source: orbit
Source-ID: 251039
Publication: Research › Poster – Annual report year: 2007

The number of nanotechnological products (NPs) on the market are steadily increasing but environmental aspects of their life cycle are still to a large extent disregarded presumably due to lack of data and a neglect from the nanoresearchers. Although essentially comparable, LCAs of NPs does involve some specificities compared to LCAs of traditional products. There is a need for reiteration of our common ground understanding of what may be of significant environmental importance in the life cycle. All parts of the LCA framework may require special consideration when the object is a NP. Through a number of product examples from both micro- and nanotechnology the specificities of LCAs of NPs are identified. The product may introduce entirely new functionalities and system boundaries may need to include production facilities. Development of new methods of characterising the toxic impacts from nanoparticles is necessary – this also have implication for the inventory. Scarce resources may be a more important issue than for other types of products. Although the object of LCA is a functional unit impacts due to rebound effects should also be considered.

**General information**
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Life Cycle Assessment of micro manufacturing process chains - Application to the micro factory concept

General information
State: Published
Organisations: Department of Management Engineering, Innovation and Sustainability
Authors: De Grave, A. (Intern), Olsen, S. I. (Intern), Hansen, H. N. (Intern)
Publication date: 2007

Host publication information
Title of host publication: Proceedings of the 3rd International Conference on multi-material micro manufacturing
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 203189
Publication: Research - peer-review › Article in proceedings – Annual report year: 2007

Limits and prospects of the “incremental approach” and the European legislation on the management of risks related to nanomaterials
Scientific uncertainty involved in evaluating potentially harmful properties of engineered nanoparticles complicates and hampers the implementation of proportionate regulative measures by legislators. The European Commission has adopted a so-called “incremental approach”, which focuses on adapting existing laws to regulate nanotechnologies, and therefore this paper aims to test the effectiveness of the “incremental approach”. Three commercially available products containing fullerenes (C60 and carbon nanotubes) were analysed in a life cycle perspective in order to (1) map current applicable regulations, (2) analyse their applicability to nanomaterials, (3) identify their gaps, and (4) suggest proper solutions. After mapping the life cycle of the three products, we analysed applicable regulations in the order in which they became relevant in their life cycle, i.e.: • The Safety at Workplace Directives, • Directive 61/1996 on the Integrated Pollution Prevention and Control, • The European Union’s Directive on the Registration, Evaluation, Authorization and Restriction of Chemicals, and • The Waste Management Directives. It was found that the applicability of environmental laws is limited due to difficulties in generating sufficient data on the nanomaterials residing in the products according to their life cycles. Further, metrology tools are unavailable; thresholds are not tailored to the nanoscale; and toxicological data and occupational exposure limits cannot be established with existing methodologies. We conclude that the “incremental approach” can only be applicable with the implementation of due amendments.

General information
State: Published
Organisations: Environmental Chemistry, Department of Environmental Engineering, Quantitative Sustainability Assessment, Department of Management Engineering, Center for Nanoteknologi, University of Padua
Authors: Franco, A. (Intern), Hansen, S. F. (Intern), Olsen, S. I. (Intern), Butti, L. (Ekstern)
Pages: 171-183
Publication date: 2007
Main Research Area: Technical/natural sciences

Publication information
Journal: Regulatory Toxicology and Pharmacology
Volume: 48
Issue number: 2
ISSN (Print): 0273-2300
Ratings:
BFI (2017): BFI-level 1
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Scopus rating (2016): CiteScore 2.15 SJR 0.699 SNIP 0.927
BFI (2015): BFI-level 1
Limits and prospects of the "incremental approach" and the European legislation on the management of risks related to nanomaterials

General information
State: Published
Organisations: Department of Environmental Engineering, Innovation and Sustainability, Department of Management Engineering
Authors: Franco, A. (Intern), Hansen, S. F. (Intern), Olsen, S. I. (Intern), Butti, L. (Ekstern)
Number of pages: 1
Pages: 77-77
Publication date: 2007

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Title of host publication: Nanotoxicology Conference, San Servolo Servizi, Venice, Italy, 19-21 April 2007 : Abstract Book
Place of publication: London, UK
Nanotechnology and Life Cycle Assessment. A systems approach to Nanotechnology and the environment: Synthesis of Results Obtained at a Workshop Washington, DC 2-3 October 2006

This report summarizes the results of "Nanotechnology and Life Cycle Assessment," a two-day workshop jointly convened by the Woodrow Wilson Center Project on Emerging Nanotechnologies; the United States Environmental Protection Agency Office of Research and Development; and the European Commission, RTD.G4 "Nano S&T: Converging Science and Technologies." Held in October 2006, the workshop involved international experts from the fields of Life Cycle Assessment (LCA) and nanotechnology. The main program of the workshop consisted of introductory lectures, group discussions and a final plenary session. A writing group prepared the initial draft of this report based on workshop discussions, and the final report was reviewed by all workshop participants and outside experts. The contents are based on the results of the group discussions. The structure of this report follows the main topics identified and discussed by the groups. The purpose of the workshop was to determine whether existing LCA tools and methods are adequate to use on a new technology. This document provides an overview of LCA and nanotechnology, discusses the current state of the art, identifies current knowledge gaps that may prevent the proper application of LCA in this field and makes recommendations on the application of LCA for assessing the potential environmental impacts of nanotechnology, nanomaterials, and nanoproducts. For the purposes of this report, "nanoproducts" are defined as products containing nanomaterials. A short version of this report will be published in an appropriate LCA journal or a technical nanotechnology journal. The following presents a summary of the main conclusions and recommendations identified by the workshop participants and presented in this report. Main Conclusions: There is no generic LCA of nanomaterials, just as there is no generic LCA of chemicals. The ISO-framework for LCA (ISO 14040:2006) is fully suitable to nanomaterials and nanoproducts, even if data regarding the elementary flows and impacts might be uncertain and scarce. Since environmental impacts of nanoproducts can occur in any life cycle stage, all stages of the life cycle of nanoproducts should be assessed in an LCA study. While the ISO 14040 framework is appropriate, a number of operational issues need to be addressed in more detail in the case of nanomaterials and nanoproducts. The main problem with LCA of nanomaterials and nanoproducts is the lack of data and understanding in certain areas. While LCA brings major benefits and useful information, there are certain limits to its application and use, in particular with respect to the assessment of toxicity impacts and of large-scale impacts. Within future research, major efforts are needed to fully assess potential risks and environmental impacts of nanoproducts and materials (not just those related to LCA). There is a need for protocols and practical methodologies for toxicity studies, fate and transport studies and scaling approaches. International cooperation between Europe and the United States, together with other partners, is needed in order to address these concerns. Further research is needed to gather missing relevant data and to develop user-friendly eco-design screening tools, especially ones suitable for use by small and medium-sized enterprises. Key Recommendations 1. Case-studies/prioritizing efforts With limited resources, a case-study research approach could be adopted to significantly enhance knowledge on environmental impacts of nanomaterials and nanoproducts. 2. LCA studies and presentations of results Any LCA study on nanoproducts and nanomaterials most likely suffers from high uncertainty issues. Therefore, the report recommends: Do not wait to have near-perfect data. Be modest about uncertainties; clearly state relevant uncertainty aspects and assumptions. Draw conclusions in the case of major or significant improvements; otherwise, state that the nanoproducts and the conventional product are equivalent. At this early stage, studies should focus on protecting humans and the environment. Separate the category indicators, grouping them by relevance/uncertainty. Avoid overselling the benefits of the new nanoproduct, since assessment methodologies will improve and might show "problems" in the future. Work with toxicologists and other scientists (geographical and socio-economic impacts) to review data and bound the issue. Make disaggregated data available for future LCA comparisons. 3. Approaches Critical review should always be done to ensure credibility of LCA studies. An independent review should be made by an expert panel with balanced representation and wide range of expertise. Data for the critical review or other supporting data should be published. Panels of interested parties should be formed to establish rules for LCA of nanomaterials and nanoproducts. 4. Actions from stakeholders Different stakeholders/authorities can potentially support the application and use of LCA for nanoproducts and nanomaterials through a large set of actions. Government actions could include: Setting up research frameworks and programs for the methodology development of LCA in the field of nanotechnology and with nanoproducts. R&D activities, with special emphasis on multinational cooperation in fields related to health and environmental safety. Use of LCA results to design adapted economic instruments. Using LCA to help develop green purchasing and integrate nanotechnology criteria in green purchasing. Allocating a portion of current nano research funding to nano/LCA research to make it more attractive to the private sector for further R&D. Providing independent, standardized and reviewed LCA information that might be used by industry and other stakeholders. Covering different nanotechnologies' flows of substances (air emissions, water releases etc.) into the European Commission's "European Reference Life Cycle Data System" (ELCD), and the US Life Cycle Impact database. Working toward an international LCI database for nanomaterials. Improving data coordination among different government agencies, e.g., agencies responsible for product consumer safety evaluations, workplace safety evaluations and environmental issues. Academia can potentially support the application and use of LCA to nanoproducts and nanomaterials through a large set of actions, including: Setting up databases for LCA case studies on nanotechnology and nanoproducts. Providing scholarships to the universities to hire Ph.D. students specifically for nano/LCA research. Carrying out research in LCA methods applied to nanotechnology and nanoproducts. Industry can potentially support the application and use of LCA to nanoproducts.
and nanomaterials through a large set of actions, including: · Undertake R&D activities. · Use of LCA results to design improved products. · Co-funding research on developing LCA methods, impact characterization metrics specific to nanotechnologies. · Co-funding research on toxic effects of specific nanomaterials. · Co-funding social science research on public concerns about nanotechnology and on developing effective risk-communication strategies using LCA data. · Actively creating mechanisms for sharing confidential data without compromising competitiveness. The report also notes that the insurance industry should play a leading role in assessing life cycle risk assessments of nanoproducts. NGO and Consumer Associations can potentially support the application and use of LCA to nanoproducts and nanomaterials through a large set of actions, including: · Communicating LCA study results to the public to inform consumers. · Educating themselves and promoting LCA as a tool to assess nanotechnology.

**General information**

State: Published

Organisations: Innovation and Sustainability, Department of Management Engineering, International Journal of Life Cycle Assessment, National Risk Management Research Laboratory, Ambiente Italia, Leiden University, Eidgenössische Technische Hochschule

Authors: Klöpffer, W. (Ekstern), Curran, M. A. (Ekstern), Frankl, P. (Ekstern), Heijungs, R. (Ekstern), Köhler, A. (Ekstern), Olsen, S. I. (Intern)

Number of pages: 37

Publication date: 2007

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Publisher: European Commission, DG Research, jointly with the Woodrow Wilson International Center for Scholars

Original language: English

Main Research Area: Technical/natural sciences

Electronic versions:

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Links:


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Publication: Research › Report – Annual report year: 2007

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**Nanotechnology/Health effects of nanoparticles**

**General information**

State: Published

Organisations: Department of Environmental Engineering, Innovation and Sustainability, Department of Management Engineering, Lab-on-a-Chip, Department of Micro- and Nanotechnology

Authors: Hansen, S. F. (Intern), Rasmussen, R. (Ekstern), Sørensen, S. (Ekstern), Baun, A. (Intern), Olsen, S. I. (Intern), Melhave, K. (Intern)

Publication date: 2007

**Host publication information**

Title of host publication: Nanotechnology

Publisher: Wikibooks

Editor: Melhave, K.

Main Research Area: Technical/natural sciences

Links:


Source: orbit

Source-ID: 208308

Publication: Research › Book chapter – Annual report year: 2007

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**Challenging the sustainability of micro products development**

Environmental aspects are one of the biggest concerns regarding the future of manufacturing and product development sustainability. Furthermore, micro products and micro technologies are often seen as the next big thing in terms of possible mass market trend and boom. Many questions are raised regarding the impact of size for recycling or environment. Indeed micro production is often seen as environmental friendly thanks to the small amount of material used. Such a statement can be misleading. In this article EcoDesign or Design for Environment (DFE) and Life Cycle Assessment (LCA) will be presented, together with some tools used in order to implement the concepts into design activities. Micro injection moulded components and MEMS are used as examples. Specificities of micro products will be investigated through a categorization in three levels: the end products, the whole production chain and the intermediate parts which can be in-process created. Possible future trends for micro products development scheme involving environmental concerns are given.

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Authors: McKone, T. E. (Ekstern), A.D., K. (Ekstern), Olsen, S. I. (Intern), Hauschild, M. Z. (Intern)
Pages: 137-140
Publication date: 2006
Main Research Area: Technical/natural sciences

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 11
Issue number: 2
ISSN (Print): 0948-3349
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.43 SJR 1.328 SNIP 1.423
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.504 SNIP 1.554 CiteScore 3.49
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.736 SNIP 1.738 CiteScore 3.65
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.666 SNIP 1.979 CiteScore 3.35
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.515 SNIP 1.701 CiteScore 2.89
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.581 SNIP 1.716 CiteScore 2.82
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Environmental Assessment of Micro/Nano Production in a Life Cycle Perspective

The concept of life cycle assessment (LCA) is build upon the object of assessment, namely the functional unit, i.e. all impacts etc. are related to a specific service or function in the society. In a LCA context, the assessment of emerging technologies like Nanotechnology is challenging due to a number of knowledge gaps. It may not be known exactly what is the function (or functional unit) or what the technology may substitute and production may still be at an experimental level, raising questions about technology or materials choice. For prospective LCA studies methodologies like “consequential LCA” may be useful because future changes are taken into account. However, it still does not suffice for emerging technologies. In a recent “Green Technology Foresight” project a methodology was developed based on five elements: Life-cycle thinking, systems approach, a broad dialogue based understanding of the environment, precaution as a principle and finally, prevention as preferred strategy. When assessing emerging technologies three levels should be considered. First order effects are connected directly to production, use and disposal. Second order are effects from interaction with other parts of the economy from more intelligent design and management of processes, products, services, product chains etc. and the effect on the stocks of products. An example could be dematerialisation. Rebound effects may be considered as third order effects, like when efficiency gains stimulate new demands, which balances or overcompensates the savings. In the Micro/Nano Production area a range of new possibilities arise both within applications, production technology and materials. The Department of Manufacturing Engineering and Management at The Technical University of Denmark has staked on a joint effort in manufacturing engineering and environmental assessment for eco efficiency improvement. A review of knowledge and studies on environmental assessments in the micro/nano technology area is performed and will be used to further detail the general framework for assessment outlined above to be more specific for micro/nano production.

General information
State: Published
Organisations: Department of Management Engineering, Innovation and Sustainability
Authors: Olsen, S. I. (Intern), Jørgensen, M. S. (Intern)
Number of pages: 8
Publication date: 2006

Host publication information
Title of host publication: Materials Research Society Symposium Proceeding : Life-Cycle Analysis Tools for "Green" Materials and Process Selection
Volume: 895
Publisher: Materials Research Society
Environmental risk assessment of nanotechnology: categories of nanomaterials: WE1/MI/1

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Physics, Innovation and Sustainability, Department of Management Engineering
Number of pages: 48
Publication date: 2006

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Title of host publication: Controversies and solutions in environmental sciences: SETAC Europe 16th annual meeting, The Hague, The Netherlands, 7-11 May 2006
Volume: Abstracts
Place of publication: Brussels
Publisher: SETAC
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 189224
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2006

Green Technology Foresight about Environmentally Friendly Products and Materials - Challenges from Nanotechnology, Biotechnology and ICT

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering, Innovation Systems and Foresight, CICT, Department of Informatics and Mathematical Modeling, Risø National Laboratory for Sustainable Energy
Publication date: 2006

Publication information
Publisher: Danish Environmental Protection Agency
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 187875
Publication: Research - peer-review › Book – Annual report year: 2006

Nanotechnology and toxicology

General information
State: Published
Organisations: Department of Management Engineering, Innovation and Sustainability
Authors: Olsen, S. I. (Intern)
Pages: 23-28
Publication date: 2006

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Title of host publication: The ethical aspects of nanomedicine: Proceeding of the roundtable debate organised by the European group on ethics
Place of publication: Brussels
Publisher: European Commission
ISBN (Print): 92-79-02365-9
Main Research Area: Technical/natural sciences
Regulering af miljø- og sundhedsaspekter ved nanoteknologiske produkter og processer: Rapport og anbefalinger fra projektet "Tokskologi og nanoteknologi"

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering
Authors: Olsen, S. I. (Intern)
Number of pages: 36
Publication date: 2006

Sustainability of Products Based on Micro and Nano Technologies

General information
State: Published
Organisations: Department of Management Engineering, Innovation and Sustainability
Authors: De Grave, A. (Intern), Hansen, H. N. (Intern), Olsen, S. I. (Intern)
Number of pages: 297
Pages: 40-45
Publication date: 2006

Waste prevention, waste policy and innovation

General information
State: Published
Organisations: Innovation and Sustainability, Department of Management Engineering, National Environmental Research Institute, Regional Environmental Center for Central and Eastern Europe, Danish Topic Centre on Waste
Number of pages: 228
Publication date: 2006

Electronic versions:
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.
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 PNEC-based 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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Implementation of the OMNIITOX Simplified Base Model.: Contribution to Work-package 7 of the OMNIITOX Project as part B of appropriate deliverable D41

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The potential role of life cycle assessment in regulation of chemicals in the European Union

Scope and Background. This paper presents the preliminary results from an ongoing feasibility study, investigating potential application of elements from the life cycle assessment (LCA) framework in European chemicals' policy. Many policy areas affect manufacturing, marketing and use of chemicals. This article focuses on the general chemical legislation, especially issues related to regulatory risk assessment and subsequent decisions on risk reduction measures.

Method. Current and upcoming chemical regulation has been reviewed and empirical knowledge has been gained from an ongoing case study and from dialogues with various stakeholders. Results and Discussion. LCAs are comparative and more holistic in view as compared to chemical risk assessments for regulatory purposes. LCAs may therefore potentially improve the basis for decisions between alternatives in cases where a risk assessment calls for risk reduction. In this process, LCA results might feed into a socio-economic analysis having similar objectives, but some methodological aspects related to system boundaries need to be sorted out. Life cycle impact assessment (LCIA) of toxic effects has traditionally been inspired by the more regulatory-orientated risk assessment approaches. However, the increasing need for regulatory priority setting and comparative/cumulative assessments might in the future convey LCIA principles into the regulatory framework. The same underlying databases on inherent properties of chemicals are already applied in both types of assessment. Similarly, data on the use and exposure of chemicals are needed within both risk assessments and LCA, and the methodologies might therefore benefit from a joint 'inventory' database.

Outlook. The final outcome of the feasibility study will be an implementation plan suggesting incorporation of core findings in future chemical regulation and related policy areas.

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The potential role of Life Cycle Assessment in regulation of chemicals in the European Union

The regulation of chemicals in EU is undergoing substantial changes these years with implementation of the “REACH” system. Simultaneously, the concepts of LCA and Integrated Product Policy (IPP) are becoming increasingly integrated in European standardisation and regulatory activities. As a logical consequence, the European Chemicals Bureau (ECB) has enrolled in the OMNIITOX project with the clear aim of investigating possible applications of LCA in future EU regulation of chemicals. Implementation of REACH will expand and change the activities and services currently delivered by ECB as the focal point for data and assessment procedures on dangerous chemicals. One change is the inclusion of socio-economic assessments as decision support to regulation of substances, which are undesirable from a risk assessment point of view. Comparative LCA’s have similarities with and may serve as good input to socio-economic analyses, because LCA’s attempt to: 1. cover all emissions (including intermediates), 2. assess all potential environmental impacts, 3. assess the average situation (including uncertainty analyses). Contrary, risk assessments are based on substance approaches and conservative assumptions. Other potential uses of LCA could be in overall priority setting (including non-chemical products) of environmental product policy and in standardisation work related to products/processes releasing chemicals to the environment. A number of methodological interactions between regulatory risk assessment and LCA as well as perspectives for integration of information systems dealing with substance and product related information will also be presented along with findings from a case study, which has shown that the well-known functional unit approach in LCA may be just as relevant for comparative risk assessments.

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Indicators for human toxicity in Life Cycle Impact Assessment

The main objectives of this task group under SETAC-Europe’s Second Working Group on Life Cycle Impact Assessment (LCIA-WIA2) were to identify and discuss the suitability of toxicological impact measures for human health for use in characterization in LCIA. The current state of the art of defining health indicators in LCIA is summarized in this document, promising approaches are addressed in further detail under the two headings of potency and severity, and then the suitability of the approaches is discussed with the aid of selected criteria. Toxicological potency factors are based on test data such as No Observed Effect Levels (NOEL), NOELs, and similar data, are determined in laboratory studies using rodents and are then extrapolated to more relevant human measures. Many examples also exist of measures and methods beyond potency-based indicators that attempt to account for differences in expected severity, as well as potency. Quantitative severity-based indicators yield measures in terms of Years of Life Lost (YOLL), Disability Adjusted Life Years (DALY), Quality Adjusted Life Years (QALY) and other similar measures. DALYs and QALYs are examples of approaches that attempt to account for both years of life lost (mortality) and years of impaired life (morbidity). Qualitative severity approaches tend to arrange potency-based indicators in categories, avoiding the need to quantitatively express differences in severity. Based on the proposed criteria and current state of the knowledge, toxicological potency indicators are pre-selected as a minimum default. Addressing accuracy and ensuring consistency, particularly when extrapolating data, are seen as some of the key issues that are beginning to be addressed in LCIA. While associated approaches are still in their infancy, it is encouraged to take into account relative severity whenever possible using qualitative and/or quantitative approaches.

Interim LCA comparison of metal working fluids with and without Chlorinated paraffins

The present report constitutes deliverable D 19 and D 23 of the OMNIITOX project and is the life cycle assessment part of the ECB case study (work package 5). The objectives of the case study have been to deliver empirical knowledge for the feasibility study carried out as part of WP5 and to deliver data and inspiration to other work packages (WP 7, 8 and 9). Specifically for this part of the case study (life cycle assessment part), the aims have been to apply LCA for comparing the
use of different alternative substances in a specific application and to make a basis for comparison with the EU risk assessment approach for assessing the same substances. In the other part of the case study (Deliverable 9; Christensen & Olsen, 2002), the results of the Risk Assessments are summarised. In the original problem definition focus were on the use of SCCP and as an alternative MCCP in metal working fluids (MWF), however since SCCP is largely substituted this was not possible. The LCA therefore focus on a comparison between a MWF containing MCCP and an alternative MWF containing sulphurised compounds. The product studied for the LCA is chosen by the cooperating company (company identity presently considered confidential) and it is a product for which it is necessary to use an extreme pressure metal working fluid (which is the main use of MCCP). The product chosen for study object is stainless steel tubes for use in e.g. heat exchangers. The functional unit of this study is 1 tonne stainless steel tube with an outer diameter of 19.5 mm and material thickness of 1.65 mm (corresponding to approx. 1340 m tube). The tube is used as a heat-exchanger tube and the quality named 2205. The study has focused on European based operations since most known processes in the product system takes place in Western Europe. All background processes, such as electricity production, are based on average technology. This is also valid for most processes upstream the supplier of metal working fluid, for which LCA data to a high degree has been estimated on the basis of available LCA data on comparable processes/products. To a certain extent the suppliers of raw materials have delivered data but not specific LCA data for their materials. As far as possible the study traces back all materials to elementary inputs (i.e. inputs from the nature) but estimates are used to a great extent. Transport has only been estimated for the MWF raw materials to the producer of MWF. Transport from MWF supplier to the company is assumed to be identical for the two alternatives. All energy data has been taken from the LCAiT database, so e.g. electricity is European average from 1994. The MWFs used are produced in Sweden and data has been supplied concerning the production and the use of raw materials. Information on the composition and in some case modest information on production of raw materials has been gathered. Many of the raw materials are based on some fatty acid esters and data for these esters are estimated from the production of rape seed oil methyl ester. Additionally data for detergent grade chemicals has been included as estimates for some of the components of the MWFs. Data on steel production and on electricity and transport are taken from the LCAiT data base. The tube manufacturing company was not able to provide process data. These have therefore been estimated from comparable processes in other data bases. They could however provide an estimate of the additional energy and steel required when using the alternative MWF (metal working fluids) as well as an estimate of the amount of MWF used per tonne of steel. The use and disposal stages of the steel tubes have been omitted since they are identical for both alternatives. The inventory results calculated using the software tool LCAiT are given in the appendices. Impact assessment has been performed using the CML method with current available characterisation factors. However for a selection of compounds in the inventory, the impact categories ecotoxicity and human toxicity have further been evaluated by several methods (EDIP, USES-LCA (CML), CALTOX, and Impact 2002) as an input to WP7 after a gathering of substance data for calculation of (eco)toxicity characterisation factors. The results of the impact assessment show that there are only minor differences between the two alternative systems. The differences are due to a slightly larger use of energy and steel in the production of tubes when using the non-chlorinated alternative to MCCP based MWF, i.e. a slightly less environmental impact from the MCCP containing MWF. However, differences in energy use etc. depend highly on the energy estimates which may be somewhat uncertain. Furthermore, the results show that, impacts from electricity and steel production and consumption during MWF application (the pilgering process) dominates over the impacts related to the production of the MWF itself, which is only a minor contributor to the total life cycle impact. Although the MWFs in themselves only contribute slightly to the overall life cycle impacts, it was found relevant to compare the production of these. It is seen that their impacts do not differ significantly. The assessment of selected substances with several methods for LCIA toxicity assessment did not introduce any other significant environmental differences between the two alternative MWFs. It can be concluded that the small differences between the two systems studied cannot be interpreted as significant. The lack of difference between productions of MWFs was to some degree expected since most raw material data has been estimated using the same background data. One of the main objectives of the LCA case study was to examine the possible higher energy consumption in metal working processes using the non-chlorinated alternative. The preliminary results in this report suggest that these differences are insignificant. However, due to the limited amount of specific data, this conclusion should be considered carefully. Better data for energy and steel consumption will be searched for and possibly included in the final report. In Risk Assessment of chlorinated paraffins, a risk has been associated with the emissions of MWFs from metal working operations. Since the actual company collects spent MWFs and incinerate these, emissions are not expected to occur except from diffuse losses. The diffuse emissions have not been estimated but could give rise to a higher toxic impact from the MCCP containing MWF. A sensitivity analysis of this will be made in the final report.

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Risk assessment of Short and Medium Chain Chlorinated Paraffin's (SCCP and MCCP)

The present report constitutes deliverable D9 of the OMNIIOTOX project and is the risk assessment part of the ECB case study (work package 5). The objectives of the case study have been to deliver empirical knowledge for the feasibility study carried out as part of WP5 and to deliver data and inspiration to other work packages (WP 7, 8 and 9). Specifically for this part of the case study (risk assessment part), the aims have been to illustrate the EU risk assessment scheme and to make a basis for comparison with an LCA approach for assessing the same substances. This report presents the main findings of the Short Chain Chlorinated Paraffin (SCCP) and the draft Medium Chain Chlorinated Paraffin (MCCP) risk assessments. The political actions taken as a consequence of the assessments are also described. The risk assessments have been prepared according to the EU Technical Guidance Document (TGD), which therefore is briefly introduced.

SCCP and MCCP are chemically similar and the risk assessments have shown that this is also the case for their applications and properties. Consequently the risk assessments end up with comparable conclusions as to where the substances pose risks and where risk reduction measures should be taken. It should be mentioned that there are still a few issues pending in the preparation of the MCCP report, which is therefore currently only in a draft version. The current report therefore fulfils the aim of illustrating the scientific and political aspects of the EU risk assessment scheme. The aim of delivering a basis for comparison with the LCA results has however not been completely met. The initial part of the case study showed that SCCP has already to a large extent been substituted from metal working fluids (which is a main application of CP’s). For this reason, it has been necessary to focus the LCA part of the case study on a metal working fluid with MCCP and an alternative without CP’s. In order to make a reasonable comparison between LCA and risk assessment evaluations, it would therefore be advantageous to also have a risk assessment of the alternative. However, metal working fluids cannot be modified by simple “drop in” substitution of MCCP. Comparable risk assessments would therefore have to be made on the entire metal working fluid products in order to make sense. These considerably more difficult assessments will be approached by co-operation with an ongoing Danish project dealing with substitution of MCCPs from metal working fluids. The results from that project will become available in the spring of 2003 and where relevant and possible be included in deliverables 40, 47 and/or 49, which are all to some extent dealing with comparison of LCA and risk assessment methods. An important conclusion at this stage of the project is however that risk assessments comparing alternatives cannot always be made at the substance level. It is necessary to take the function that the substances deliver into account. Interestingly this is the default approach in life cycle assessments in which the functional unit is the basis for comparison.

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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 product families: 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.

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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.

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Assessment of chemicals in construction products

The building sector uses a lot of products (several thousands) and many of these contain chemicals, some of which have harmful effects on human and environmental health. Due to the restricted knowledge of data, the impacts of chemicals can be overlooked e.g. in eco-profiles of building elements. The reasons for that are lacks of product-specific emissions by manufacturing of chemical products, e.g. waterproofing systems and sealants. Besides, most LCA-models do not include assessments of emissions in working environment, in indoor environment or from disposal processes. It was therefore in the project Assessment of Chemicals in Construction Products decided to adapt an existing score method for assessing the chemicals. As the European countries had agreed on a score Method for Risk Ranking chemicals (EURAM), it was decided to use this method to assess chemicals in construction products for two LCA phases, indoor environment and disposal phase. The score method was used on two water-proofing systems. Waterproofing systems are used for making a water-impermeable layer in a bathroom wall. Results from the score method for indoor environment were compared to results from a screening method. Due to lack of data the screening method could not be used for the disposal phase.

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**Green development within Product families**

From 1991 to 1996 the EDIP-methodology (Environmental Design of Industrial Products) was developed. One experience from the EDIP-project is that environmental assessment of products must give simple and operational conclusions, which can be acknowledged in the product development and by other decision makers throughout the product life cycle. The EDIP-project has demonstrated that it is possible to identify “the ten most important environmental hot spots”. The documentation achieved by the environmental assessment shows where the most serious environmental impacts in the product life cycle occur, and uncover where the improvement potentials are in the product. The environmental knowledge obtained in this context will be valid for a number of years, and both the producer and other interested parties can use this information for setting priorities in their future planning. However, it can be very time consuming to perform an environmental Life Cycle Assessment (LCA), and it would be an advantage if a number of similar products - product families - could be handled in one and the same LCA as a whole. The project has presently developed a method for selecting and forming product families, based on environmental and economical importance as well as the existence of several producers. Using this method, five families have been selected, namely mobile phones, vacuum cleaners, industrial valves with electronic controls, lighting and ventilation. Collaboration with 5 industrial companies has subsequently been established and environmental assessments (LCA) including diagnosis (the pointing out of hot spots) have been performed.

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**LCA versus RA - an introduction**

Risk Assessment (RA) of chemicals is an environmental management tool used to assess the risk of specific chemicals, which are harmful to man or the environment under certain circumstances of use or in certain environmental recipients. Life Cycle Assessment (LCA) or environmental assessment of products is another environmental management tool that gains more and more ground, and which is often thought of as universal due to its basic holistic philosophy. As the environmental impacts of one product can only be seen in relation to the impacts of other products providing the same functions, LCA is a comparative tool. The primary purpose of this article is to identify harmonies, discrepancies and relations between the two tools, exemplified by the risk assessment principles of the European Commission (EC) as stated in ‘Technical Guidance Document’ (EC, 1996) and the LCA method ‘EDIP’ (Environmental Design of Industrial Products) developed in Denmark (Wenzel et al., 1997), respectively. The interactions between the two tools can be viewed from two different angles: 1. As a general reflection of how the tools supplement each other in the total environmental effort. 2. As an assessment of coincidences and discrepancies in the principles of assessing the potential for ecotoxicological and toxicological effects. The aim here is to compare the two tools to each other and relate the development/use of the two tools to possibilities for integration etc. As the Technical Guidance Document (TGD) (see chapter on Principles and Methods for Hazard and Risk Assessment) focuses on an assessment of the toxicological and ecotoxicological risks, the focus of this article’s comparison of assessment principles, data requirements etc. will be on the assessment of toxicity and ecotoxicity in EDIP’s impact assessment methodology (see chapter on Principles and Methods for LCA). In this connection, it should be mentioned that toxicity assessments belong to a group of impacts (the local impact categories) for which there is at present no prospect of consensus either in SETAC or in ISO. This is due to the fact that the scopes of LCA do not permit a realistic assessment of actual effects (see chapter on Principles and Methods for LCA). The assessment is therefore limited to comprising potential impacts, and for local impacts in particular it can be difficult to assess the probability of the realisation of the potentials. However, several methods have been developed to assess the impact potentials within these categories (Guinée et al., 1996; Jolliet, 1994; Jolliet & Crettaz, 1996), among these EDIP (Hauschild et al., 1998a and 1998b). The assessment of impacts in the work environment in the EDIP methodology operates on another theoretical basis than the other impact categories. Therefore, the work environment will not be included in this paper even though exposures and effects in the work environment are included in TGD’s assessments.

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Survey on the Use of LCA in European Chemical Industry

During 1997 a questionnaire was sent to 40 European chemical manufacturers representing different positions in the supply chain. 25 companies (62.5%) responded, of which 23 had been involved in LCA to some degree. The questionnaire consisted of 30 questions divided into four parts dealing with: the company's general attitude to environmental matters, to which degree they had been involved in LCA and their opinions on LCA as a tool, which methodological choices they had taken when using LCA, and how LCA results were presented e.g. to ensure confidentiality. In general, the European chemical industry has taken up the LCA methodology and is testing its applicability for their purposes, although they still feel the methodology is a bit immature. The resources devoted to LCA depends to a great extent on the company's position in the supply chain and on the size of the company. Many of the LCA's have been undertaken to comply with customers' requirements for LCA data, but also process development and marketing were important purposes of the work. Interestingly, in about 40% of the companies the LCA's actually revealed results that would not have been anticipated without doing the LCA. In general the results were interpreted directly from the inventory, but more than half of the respondents have either been testing or actually use some kind of impact assessment methodology, often also including local impacts. Further development seems to be desirable to support the use of LCA in
decision making and for reaching consensus on impact assessment. Additionally, the companies think that it is important that LCA methodologies are replicable, and easy and fast to perform. To reach these last goals, the industry plays a very important part themselves because we need experience and data.

Assessing Toxicological Impacts in Life-Cycle Assessment

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.

Life Cycle assessment of basic chemicals
The present report results as part of a ph.d. project aiming at developing general rules for LCA of basic chemicals. Part 1 reviews the state of the art framework for life-cycle assessment and part 2 relates that framework to the chemical industry and gives some proposals for LCAs of basic chemicals. A survey of the use of LCA in the European chemical industry has been conducted and is reported in appendix 1. Life cycle assessment (LCA) is a tool/process to evaluate the potential environmental impacts of a system (most often a product) through its whole life cycle by collecting input and output data (together interventions) from all unit processes in the system and assessing the potential environmental impact of these interventions. The LCA framework comprise four phases which are iteratively interlinked:

- **Goal and scope definition**
- **Inventory**
- **Impact assessment**
- **Interpretation**

In the goal definition the purpose of the study is defined. The intended application of the results is very important to determine the extent of the study. The scope definition concerns defining how the study is to be performed, e.g. how is the function of the system defined, what part of the system should be included or excluded, which parameter should be evaluated, how should the study be validated etc. The inventory analysis is the phase where all the needed data are collected and it is the most laborious phase. Preferably data from the actual process should be used, but the data are most often collected from a variety of sources and will constitute a mix of actual measurements, literature data and estimates. Actually, during the case studies and from other studies, data availability was identified as a major problem. Therefore, data sources for process data from the chemical industry were investigated. The primary data sources are technical chemical encyclopaedias. However, as these works rarely include emissions, a review of several methodologies to estimate emission were made and some of the approaches tested in the case studies. It was found that in general the emission factors provided by these sources provided a good, although at times somewhat conservative estimate of the emissions. A special problem occurs when there are two or more product produced in the same process, a situation frequently encountered in chemical manufacturing. In such cases the environmental interventions of the process have to be allocated between the products from that process. In the chemical industry this is most often done in relation to the mass of the products. To provide a reliable result of the LCA it is further important to analyse the uncertainties of the study. However, most often the data does not support a quantitative uncertainty analysis and a sensitivity analysis must be performed as a check for validity. The impact assessment aims to evaluate the contribution of the interventions to different environmental impact categories, e.g. global warming, toxicity to humans, acidification etc. The assessment of toxicological impacts have been given special attention because the chemical industry typically will be significant contributor to this impact category. Several aspect of the LCA framework inflict the possibilities the assess actual impacts and especially for local impacts like toxicity this is a cause of limited accordance between the potential impact predicted in the LCA and the occurrence of actual impacts. The interpretation phase of the LCA checks the completeness and consistency of the results in relation to the goal and scope. LCA is mainly applied for internal purposes in the chemical industry. Typically, the most important application are in research and development to improve the environmental performance of processes and products, and as support for strategic decision making. However, the coherence between LCA and decision making needs to be addressed more specifically because most companies in the survey did not think LCA is sufficiently fit to support strategic decision making. Because, the chemical industry is a major supplier to other product systems the major incentive to perform LCAs has been to comply with customer requirements. An LCA may not always need to be very detailed to fulfil the goal, a simplified approach may in some cases serve as well. However, because of the diverse nature of chemical manufacturing it was not possible to establish general rules for simplification. Therefore a simplification procedure is suggested, where a semiquantitative principle is used to identify focal point for simplified LCAs.
Livscyklusvurdering af basiskemikalier

General information
State: Published
Organisations: Department of Management Engineering
Authors: Olsen, S. I. (Intern)
Pages: [25 pp.]
Publication date: 1998
Main Research Area: Technical/natural sciences

Projects:

Assessing Life Cycle Impacts of Bio-plastics from Dicarboxylic Acids
Novo Nordisk Foundation Center for Biosustainability
Applied Metabolic Engineering
Quantitative Sustainability Assessment
Department of Management Engineering
Period: 01/11/2015 → 30/11/2018
Number of participants: 4
Phd Student:
Ögmundarson, Ólafur (Intern)
Supervisor:
Fantke, Peter (Intern)
Förster, Jochen (Intern)
Olsen, Stig Irving (Intern)
Project

Using Integrated Sustainable Product Development for the development of a Green Fibre Bottle for Carlsberg
Department of Mechanical Engineering
Period: 01/08/2015 → 31/07/2018
Number of participants: 5
Phd Student:
Meijer, Ellen Brilhuis (Intern)
Supervisor:
Pigosso, Daniela Cristina Antelmi (Intern)
Howard, Thomas J. (Intern)
Olsen, Stig Irving (Intern)
Main Supervisor:
McAloone, Tim C. (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet

**Relations**
Activities:
Integrating Product and Technology Development: A Proposed Reference Model for Dual Innovation
Project: PhD

**Eco-design 2.0 - Quantitative Eco-design within Drives and Automation Technologies**
Department of Management Engineering
Period: 01/06/2014 → 25/09/2017
Number of participants: 7
Phd Student:
Auer, Johannes (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Wegener, Dieter (Ekstern)
Main Supervisor:
Bey, Niki (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Herrmann, Constantin (Ekstern)
Herrmann, Christoph (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Privatist
Project: PhD

**Development of a Sustainability Assessment method for robotic manufacturing systems**
Department of Management Engineering
Period: 15/12/2013 → 03/07/2017
Number of participants: 6
Phd Student:
Rödger, Jan-Markus (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Main Supervisor:
Bey, Niki (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Dettmer, Tina (Ekstern)
Dewulf, Wim (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

**Quantifying the Sustainability of Consumer Products: Focusing on Chemical Exposures**
Department of Management Engineering
Period: 15/12/2013 → 23/03/2017
Number of participants: 9
Phd Student:
Ernstoff, Alexi (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Jolliet, Olivier (Ekstern)
Rosenbaum, Ralph K. (Intern)
Trier, Xenia (Intern)
Main Supervisor:
Fantke, Peter (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Egeghy, Peter Paul (Ekstern)
Hellweg, Stefanie (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Lean & Green: Complementary and contradictory aspects within smart industrial automation of factories
Department of Management Engineering
Period: 01/10/2013 → 30/09/2015
Number of participants: 3
Phd Student:
Walachowicz, Frank (Ekstern)
Supervisor:
Wegener, Dieter (Intern)
Main Supervisor:
Olsen, Stig Irving (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet
Project: PhD

Qualitative and Quantitative Methods for Evaluation of Human Exposure to Nanomaterials
Department of Environmental Engineering
Period: 01/06/2012 → 17/11/2016
Number of participants: 7
Phd Student:
Liguori, Biase (Intern)
Supervisor:
Hansen, Steffen Foss (Intern)
Jensen, Keld Alstrup (Ekstern)
Main Supervisor:
Baun, Anders (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Riediker, Michael (Ekstern)
Tongeren, Martie Van (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.

Relations
Publications:
Occupational Exposure Assessment of Nanomaterials using Control Banding Tools
Absolut miljømæssig bæredygtighed af industrielle aktiviteter

Department of Management Engineering
Period: 15/12/2011 → 24/09/2015
Number of participants: 7
Phd Student: Bjørn, Anders (Intern)
Supervisor: Richardson, Katherine (Ekstern)
Røpke, Inge (Intern)
Main Supervisor: Hauschild, Michael Zwicky (Intern)
Examiner: Olsen, Stig Irving (Intern)
Cornell, Sarah Elisabeth (Ekstern)
Goedkoop, Mark (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD

Life cycle impact assessment of long-term emissions from landfills

Department of Management Engineering
Period: 15/12/2011 → 22/06/2015
Number of participants: 7
Phd Student: Bakas, Ioannis (Intern)
Supervisor: Astrup, Thomas Fruegaard (Intern)
Rosenbaum, Ralph K. (Intern)
Main Supervisor: Hauschild, Michael Zwicky (Intern)
Examiner: Olsen, Stig Irving (Intern)
Finnveden, Göran (Ekstern)
Henderson, Andrew D. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Sustainable Management of Water Treatment Technologies

Department of Management Engineering
Period: 01/10/2011 → 25/11/2016
Number of participants: 6
Phd Student: Bonou, Alexandra (Intern)
Supervisor: Hauschild, Michael Zwicky (Intern)
Main Supervisor: Olsen, Stig Irving (Intern)
Examiner: Bey, Niki (Intern)
Boks, Casper (Ekstern)
An integrated Multi-level Framework for Life Cycle Sustainability Assessment Case study: Production of High-grade Concrete from Construction and Demol

Department of Management Engineering
Period: 15/02/2011 → 19/01/2017
Number of participants: 6
Phd Student:
Bozhilova-Kisheva, Kossara Petrova (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Main Supervisor:
Olsen, Stig Irving (Intern)
Examiner:
Bey, Niki (Intern)
Petersen, Elisabeth Ekener (Ekstern)
Zamagni, Alessandra (Ekstern)

New high-quality mined nanomaterials mass produced for plastic and wood-plastic nanocomposites

Department of Management Engineering
Period: 01/01/2011 → 19/03/2015
Number of participants: 6
Phd Student:
Miseljic, Mirko (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Main Supervisor:
Olsen, Stig Irving (Intern)
Examiner:
Birkved, Morten (Intern)
Hansen, Steffen Foss (Intern)
Hischier, Roland (Ekstern)

Life cycle assessment of energy technologies and energy systems

Department of Environmental Engineering
Period: 01/09/2010 → 04/06/2014
Number of participants: 5
Phd Student:
Turconi, Roberto (Intern)
Main Supervisor:
Astrup, Thomas Fruergaard (Intern)
Examiner:
Scheutz, Charlotte (Intern)
Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Modelling of pesticide emissions for Life Cycle Inventory analysis: model development, applications and implications
Department of Management Engineering
Period: 01/09/2010 → 21/02/2014
Number of participants: 6
Phd Student:
Dijkman, Teunis Johannes (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Main Supervisor:
Birkved, Morten (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Bruun, Sander (Ekstern)
Zelm, Rosalie van (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Development of a methodology for inclusion of terrestrial ecotoxic impacts of metals in life cycle impact assessment
Department of Management Engineering
Period: 01/04/2010 → 12/12/2013
Number of participants: 6
Phd Student:
Owsianiak, Mikolaj (Intern)
Supervisor:
Rosenbaum, Ralph K. (Intern)
Main Supervisor:
Hauschild, Michael Zwicky (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Diamond, Miriam Leah (Ekstern)
Lützhøft, Hans-Christian Holten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Anden EU-finansiering
Project: PhD

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

Quantitative Sustainability Assessment
Department of Management Engineering
Risø National Laboratory for Sustainable Energy
Period: 01/03/2010 → 28/02/2012
Number of participants: 5
climate change, ecosystem damage modeling, LCA
Acronym: ECO-QSA
Project ID: 81110
Project participant:
Beier, Claus (Intern)
Olsen, Stig Irving (Intern)
Hauschild, Michael Zwicky (Intern)
Bagger Jørgensen, Rikke (Intern)
Project Manager, organisational:
Callesen, Ingeborg (Intern)

Financing sources
Source: Gaver, Private danske Fonde
Name of research programme: Gaver, Private danske Fonde
Amount: 1,000,000.00 Danish Kroner

Formation of Life Cycle Inventory (LCI) Database for Crude Palm Oil Production and Palm Oil Based Bio-diesel Refining in Malaysia
Department of Management Engineering
Period: 01/09/2009 → 24/04/2013
Number of participants: 7
Phd Student:
Hansen, Sune Balle (Intern)
Supervisor:
Hauschild, Michael Zwicky (Intern)
Wangel, Arne (Intern)
Main Supervisor:
Olsen, Stig Irving (Intern)
Examiner:
Birkved, Morten (Intern)
Bruun, Sander (Ekstern)
Finkbeiner, Matthias (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Life cycle assessment of waste management: Assessing technical externalities
Department of Environmental Engineering
Period: 01/09/2009 → 18/09/2013
Number of participants: 5
Phd Student:
Brogaard, Line Kai-Sørensen (Intern)
Main Supervisor:
Christensen, Thomas Højlund (Intern)
Examiner:
Scheutz, Charlotte (Intern)
Eriksson, Ola Norman (Ekstern)
Olsen, Stig Irving (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD
This study is aimed at analysing the likely route and extent of human exposure to carbon nanotubes (CNTs) via inhalation for a set of representative CNT-containing products in a lifecycle perspective. The study has been conducted by the Safety of Nanomaterial Interdisciplinary Research Centre (SnIRC), led for this study by the Food and Environment Research Agency, with participation of other Academic and Industrial Experts. As part of the study, a review of all available CNT-containing products was carried out, and a representative subset of the products was identified for exposure analysis. The three CNT-containing products selected for the study included lithium-ion batteries, epoxy adhesive resins, and textiles. The study assessed the suitability of current lifecycle assessment (LCA) protocols for assessing inhalation exposure from CNT and other nano-products. The relevance and adequacy of the relevant ISO protocols was assessed in relation to nanotechnology products (especially CNT-containing products), and any inadequacies have been highlighted. The study also analysed the possibility of exposure to CNTs arising via inhalation during all stages of the life cycles of the selected study products. The findings of the study indicate that: 6a)LCA is not a tool for exposure assessment. On the contrary, exposure assessments can provide information to LCA that is relevant for impact assessment of CNT releases. LCA is, however, useful in identifying the stages in the lifecycle during which exposure may be relevant. 6b)There is an almost complete lack of data to enable both a full-scale LCA, or a quantitative exposure assessment. Due to unavailability of the required data, a simplified LCA approach is adopted in this study, focusing on the potential inhalation exposure during the lifecycle of the selected CNT-containing products. Also, the exposure assessment is limited to qualitative analysis because of the lack of data necessary for a quantitative assessment. 7Both LCA and exposure analysis have shown that the material synthesis stage (both for CNT materials, and CNT-containing products) is prone to giving rise to inhalation exposure to CNTs. However, the few studies carried out so far have generally shown that nanoparticle emissions during synthesis can be effectively controlled through appropriate engineering measures. Significant inhalation exposure to CNT material at this stage should be preventable provided such processes are carried out under appropriate emission control and waste management procedures. The main emphasis from the exposure point of view, therefore, needs to be on other stages/processes in the lifecycle of products, where any sophisticated emission control measures are not likely to exist, e.g. during handling, transportation, accidental release, and use and disposal of the relevant materials and products. 8Using the currently available level of scientific evidence, those stages in the lifecycle of each study product have been highlighted where inhalation exposure to CNT is possible. 9In brief, the study has indicated that during post-production lifecycle stages: 9a)CNT-containing batteries will carry a risk of inhalation exposure during use only if the batteries are physically cut open. The main likelihood of exposure exists during accidental release (e.g. fire), and during recycling and disposal stages. People likely to be exposed will be those working at the recycling or waste disposal premises, or in the immediate vicinity. 9b)The use of the textiles, to which CNT is added on the outer surface of the yarn in a post-production coating process, is likely to pose a greater potential for exposure to CNT than any of the other processes studied. This is the only case where a significant consumer exposure during use stage seems plausible. Other lifecycle stages where there is a likelihood of exposure include recycling (shredding and milling of worn-out textiles), and disposal through incomplete incineration. Thus those likely to be exposed would include those working at the recycling or waste disposal premises, or in the immediate vicinity. 9c)CNT-containing epoxy adhesive resins may carry a risk of inhalation exposure during use only if there are conditions that lead to formation of aerosols. The main likelihood of exposure will be during disposal through incomplete incineration. It is also of note that epoxy resins generally have a relatively short shelf life (9 months in the case of the study product). There is therefore a need to develop a mechanism for appropriate disposal of the unused (unhardened, liquid) epoxy resin for appropriate disposal. 10)Common to all the three product types studied is the need for mechanisms for appropriate end-of-life
(e.g. separate collection of (spent) CNT-containing batteries, recycling of CNT-containing batteries and textiles under controlled conditions, and processes that ensure complete incineration of CNT in the disposed of products).

11) Urgent research is needed to address the almost total lack of exposure data for CNT-containing consumer products, and the appropriateness of end-of-life treatments. The findings of the research would also enable the manufacturers to develop safer products through better designs that are aimed at minimising the likelihood of exposure to CNTs (and/or other nanomaterials) during subsequent stages in the lifecycle.

**Quantitative Sustainability Assessment**

Department of Management Engineering

The Food and Environment Research Agency

Period: 01/04/2009 → 30/09/2009
Number of participants: 2
Project ID: 81073
Contact person:
Chaudry, Qasim (Ekstern)
Project Manager, organisational:
Olsen, Stig Irving (Intern)

**Financing sources**

Source: Indtægtsdækket virksomhed UK 90
Name of research programme: Indtægtsdækket virksomhed UK 90
Amount: 59,000.00 Danish Kroner

**Environmental Sustainability Assessment of Biodiesel Production**

Department of Management Engineering

Period: 01/01/2009 → 20/09/2012
Number of participants: 5
Phd Student:
Herrmann, Ivan Tengbjerg (Intern)
Main Supervisor:
Hauschild, Michael Zwicky (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Mortensen, Jørgen Birk (Ekstern)
Rydberg, Tomas Vilhelm (Ekstern)

**Financing sources**

Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

**Microcellular nanocomposite for substitution of Balsa wood and PVC core material**

Quantitative Sustainability Assessment

Department of Management Engineering

Period: 01/12/2008 → 30/06/2012
Number of participants: 1
Acronym: NanCore
Project ID: 80952
Project Manager, organisational:
Olsen, Stig Irving (Intern)

**Financing sources**

Source: Forsk. EU - Rammeprogram
Name of research programme: Forsk. EU - Rammeprogram
Amount: 1,000,000.00 Danish Kroner
Project
**Environmental Care : City Toll Systems**

The project assumed a Road Pricing scheme is to be implemented in a major city, and will then offer support as to which scheme will yield the most benefit to that particular city. (exemplified for Copenhagen). In short, the objective of this project is to construct a tool (hereafter referred to as ‘the Tool’). This incorporates the development of a methodology which allows the comparison of economical and ecological effects of a road pricing scheme. The tool that can be used to evaluate a set of different Road Pricing schemes based on various parameters and then answer the following three questions: from a customer’s point of view: 1. What Road Pricing scheme will yield the best results for the city? 2. What are the effects of the Road Pricing schemes compared to a given situation (which could be the current situation? or a situation in future)? 3. What are the answers to the above two questions in a near future scenario? (2 to 5 years)? The Tool will answer the above three questions with KPI’s within the areas pollution, revenue and traffic. Pollution will primarily be measured by airborne pollutants (incl. CO2 and particulate matter). Revenue will be the income from road users’ payments to the Road Pricing scheme minus the cost of establishing and maintaining the scheme. Traffic will be primarily measured by average speed and congestion. A future scenario is defined by the input parameters. As such there is no limit as to how far into the future the tool can be used, but the results are of course dependent on the accuracy of the input. The Tool will initially be able to evaluate three different Road Pricing schemes: 1. Distance based Road Pricing where the pricing is a function of the distance driven within a zone. In this case the Road Pricing scheme is based on GPS in possible combination with a secondary technology for enforcement such as camera or RFID. 2. Fixed zone based Road Pricing where there is a fixed price for entering a zone. The technology here can be GPS, RFID, camera or another stationary technology. 3. Flexible zone based Road Pricing where the price for entering a zone is dependent on the time of day the zone is entered. Technology can be as in (2), but additional displays informing of the price might be needed. The baseline scenario that will be used when evaluating the above three Road Pricing schemes will be the KPI’s from running the Tool with a no pricing strategy. The results showed that a mixed base pricing (mixed by 1 and 2 above) provides the best results in terms of increased average speed and less congestion as well as in terms of reduction of CO2 emissions (4.5% reduction) and human health impacts in the inner city.

**Quantitative Sustainability Assessment**

Department of Management Engineering

Siemens Corporate Technology

Period: 30/06/2008 → 30/06/2009
Number of participants: 2
Project ID: 80928
Contact person:
Walachowicz, Frank (Ekstern)
Project Manager, organisational:
Olsen, Stig Irving (Intern)

**Financing sources**

Source: Indtægtsdækket virksomhed virksomhed UK 90
Name of research programme: Indtægtsdækket virksomhed UK 90
Amount: 770,000.00 Danish Kroner
Project

**Bæredygtig produktion - vurdering af den sociale og miljømæssige dimension**

Department of Management Engineering
Environmentally Sustainable Utilization of Waste Resources for Energy Production

Department of Environmental Engineering
Period: 01/08/2006 → 21/04/2010
Number of participants: 5
Phd Student: 
Fruegaard, Thilde (Intern)
Main Supervisor: 
Christensen, Thomas Højlund (Intern)
Examiner:
Schuetz, Charlotte (Intern)
Olsen, Stig Irving (Intern)
Tillman, Anne-Marie (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønnet stipendie
Project: PhD

Waste prevention, waste policy and innovation

Department of Manufacturing Engineering
Department of Management Engineering
Period: 01/11/2005 → 30/08/2006
Number of participants: 6
Acronym: ESTO-WASTE
Project participant:
Jørgensen, Ulrik (Intern)
Jørgensen, Michael Segaard (Intern)
Olsen, Stig Irving (Intern)
Lauridsen, Erik Hagelskjær (Intern)
Hauschild, Michael Zwicky (Intern)
Project Manager, organisational:
Knudsen, Hans Henrik (Intern)

Financing sources
Source: Forsk. EU - Andre EU-midler
Name of research programme: Forsk. EU - Andre EU-midler
Amount: 1,500,000.00 Danish Kroner
Project
Activities:

Arealanvendelse og toksikologi i konsekvens-LCA

Department of Management Engineering
Period: 01/01/2005 → 21/11/2008
Number of participants: 6
PhD Student:
Kløverpris, Jesper Hedal (Intern)
Supervisor:
Nielsen, Jens (Intern)
Main Supervisor:
Hauschild, Michael Zwicky (Intern)
Examiner:
Olsen, Stig Irving (Intern)
Canals, Llorenc Milá i (Ekstern)
Ekvall, Tomas Ingemar (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

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 (E)RA.

Department of Management Engineering
Period: 01/04/2001 → 01/01/2005
Number of participants: 4
Project participant:
Larsen, Henrik Fred (Intern)
Birkved, Morten (Intern)
Olsen, Stig Irving (Intern)
Project Manager, organisational:
Hauschild, Michael Zwicky (Intern)

Financing sources
Source: Forsk. EU - Rammeprgram
Name of research programme: Forsk. EU - Rammeprgram
Amount: 2,700,000.00 Danish Kroner
Project

Livscyklusvurdering af basiskemikalier

Department of Environmental Science and Engineering
Period: 01/09/1994 → …
Number of participants: 3
PhD Student:
Olsen, Stig Irving (Intern)
Supervisor:
Alting, Leo (Intern)
Main Supervisor:
Bro-Rasmussen, Finn (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Erhvervsforskerordningen
Project: PhD

Activities:
Ethics as guiding principles in environmentally friendly product design?: The case of "Environmental improvements through product development, McAlone and Bey 2009
Period: 18 Nov 2015 → 20 Nov 2015
Stig Irving Olsen (Other)
Department of Management Engineering
Quantitative Sustainability Assessment

Description
Co-author
Documents:
ScAim2015_version19nov2015

Related event
3rd Scandinavian Conference Industrial Engineering and Management
18/11/2015 → 20/11/2015
Lyngby, Denmark
Activity: Talks and presentations › Conference presentations

2nd DIRE Working Group Meeting
Period: 27 Sep 2012
Stig Irving Olsen (Keynote speaker)
Department of Management Engineering
Quantitative Sustainability Assessment

Description
Strengths, weaknesses and opportunities of LCA and life cycle-based methods for the sustainability assessment of nanotechnologies
DIRE - Development and Improvement of LCA methodology: Research and Exchange of experiences - Working Group of the Italian Network on LCA.

Related event
2nd DIRE Working Group Meeting: What is sustainable technology? The role of Life Cycle-based methods in addressing the challenges of sustainability assessment of technologies
27/09/2012 → …
Rome, Italy
Activity: Talks and presentations › Conference presentations

Symposium on Nanosafety
Period: 4 May 2011 → 5 May 2011
Stig Irving Olsen (Invited speaker)
Department of Management Engineering
Quantitative Sustainability Assessment

Description
Life Cycle Assessment in nanotechnology Issues in impact assessment and case studies

Related event
Safety Issues of Nanomaterials along their Life Cycle: Symposium on Nanosafety 2011
04/05/2011 → 05/05/2011
Barcelona, Spain
Activity: Talks and presentations › Conference presentations
Nanotoxicology 2010
Period: 4 Jun 2010
Stig Irving Olsen (Keynote speaker)
Department of Management Engineering
Quantitative Sustainability Assessment

Description
Life Cycle Assessment (and Risk Assessment) in nanotechnology Issues in impact assessment and case studies

Related event
Nanotoxicology 2010
02/06/2010 → 04/06/2010
Edinburgh, United Kingdom
Activity: Talks and presentations › Conference presentations