Environmental impacts of barley cultivation under current and future climatic conditions

The purpose of this work is to compare the environmental impacts of spring barley cultivation in Denmark under current (year 2010) and future (year 2050) climatic conditions. Therefore, a Life Cycle Assessment was carried out for the production of 1 kg of spring barley in Denmark, at farm gate. Both under 2010 and 2050 climatic conditions, four subscenarios were modelled, based on a combination of two soil types and two climates. Included in the assessment were seed production, soil preparation, fertilization, pesticide application, and harvest. When processes in the life cycle resulted in co-products, the resulting environmental impacts were allocated between the main product and their respective by-products using economic allocation. Impact assessment was done using the ReCiPe (H) methodology, except for toxicity impacts, which were assessed using USEtox. The results show that the impacts for all impact categories, except human and freshwater eco-toxicity, are higher when the barley is produced under climatic circumstances representative for 2050. Comparison of the 2010 and 2050 climatic scenarios indicates that a predicted decrease in barley yields under the 2050 climatic conditions is the main driver for the increased impacts. This finding was confirmed by the sensitivity analysis. Because this study focused solely on the impacts of climate change, technological improvements and political measures to reduce impacts in the 2050 scenario are not taken into account. Options to mitigate the environmental impacts are discussed.
This chapter deals with the application of Life Cycle Assessment to evaluate the environmental sustainability of agriculture and food processing. The life cycle of a food product is split into six stages: production and transportation of inputs to the farm, cultivation, processing, distribution, consumption and waste management. A large number of LCA studies focus on the two first stages in cradle-to-farm gate studies, as they are the stages where most impacts typically occur, due to animal husbandry and manure handling, production and use of fertilisers and the consumption of fuel to operate farm machinery. In the processing step, the raw agricultural product leaving the farm gate is converted to a food item that can be consumed by the user. Distribution includes transportation of the food product before and after processing. In the consumption stage, environmental impacts arise due to storage, preparation and waste of the food. In the waste management stage, food waste can be handled using a number of technologies, such as landfilling, incineration, composting or digestion. A number of case studies are looked at here where the life cycles of typical food products (meat, cheese, bread, tomatoes, etc.), and an entire diet are discussed. Other case studies deal with what LCA can conclude on the differences between conventional and organic farming, and the perceived advantages of local food items. Finally, methodological issues in agricultural LCA are discussed: the choice of functional unit, setting the boundary between technosphere and ecosphere, modelling flows of nutrients and pesticides, and the generally limited number of impact categories included in LCA studies.
Application of PestLCI model to site-specific soil and climate conditions: the case of maize production in Northern Italy

The calculation of emissions from the use of pesticides is a critical issue in LCA studies of agrifood products and only occasionally discussed in details in literature studies. The objective of this study is to assess the results of the application of PestLCI 2.0 model to the production of maize in Northern Italy using site-specific soil and climate data, which were added for this purpose in PestLCI database. In this way, the application of the tool and its database were tailored to that area. Moreover, the results were compared with those obtained assuming maize cultivation on other soil typologies in the surrounding areas. Results show that soil variation scarcely affects the emissions to air and surface water whereas it affects significantly the emissions to groundwater. Finally, some features of PestLCI were highlighted and comments for a further improvement of the model were provided.

How to assess sustainability in automated manufacturing

The aim of this paper is to describe how sustainability in automation can be assessed. The assessment method is illustrated using a case study of a robot. Three aspects of sustainability assessment in automation are identified. Firstly, we consider automation as part of a larger system that fulfills the market demand for a given functionality. Secondly, three aspects of sustainability have to be assessed: environment, economy, and society. Thirdly, automation is part of a system with many levels, with different actors on each level, resulting in meeting the market demand. In this system, (sustainability) specifications move top-down, which helps avoiding sub-optimization and problem shifting. From these three aspects, sustainable automation is defined as automation that contributes to products that fulfill a market demand in a more sustainable way. The case study presents the carbon footprints of a robot, a production cell, a production line and the final product. The case study results illustrate that, depending on the actor and the level he/she acts at, sustainability and the actions that can be taken to contribute to a more sustainable product are perceived differently: even though the robot is a minor contributor to the carbon footprint at cell or line level, from the perspective of a robot producer reducing the electricity consumption during the robot's use stage can be a considerable improvement in the carbon footprint of a robot, and thus in the sustainability profile of the robot.
Managing the life cycle of production equipment: What does it matter?

Modélisation des émissions de pesticides au vignoble par le modèle Pest-LCI 2.0 pour le calcul du potentiel d’Ecotoxicité

Pesticide emission modelling and freshwater ecotoxicity assessment for Grapevine LCA: adaptation of PestLCI 2.0 to viticulture

Purpose Consumption of high quantities of pesticides in viticulture emphasizes the importance of including pesticide emissions and impacts hereof in viticulture LCAs. This paper addresses the lack of inventory models and characterization
factors suited for the quantification of emissions and ecotoxicological impacts of pesticides applied to viticulture. The paper presents (i) a tailored version of PestLCI 2.0, (ii) corresponding characterization factors for freshwater ecotoxicity characterization and (iii) result comparison with other inventory approaches. The purpose of this paper is hence to present a viticulture customized version of PestLCI 2.0 and illustrate the application of this customized version on a viticulture case study.

Methods The customization of the PestLCI 2.0 model for viticulture includes (i) addition of 29 pesticide active ingredients commonly used in vineyards, (ii) addition of 9 viticulture type specific spraying equipment and accounting the number of rows treated in one pass, and (iii) accounting for mixed canopy (vine/cover crop) pesticide interception. Applying USEtox™, the PestLCI 2.0 customization is further supported by the calculation of freshwater ecotoxicity characterization factors for active ingredients relevant for viticulture. Case studies on three different vineyard technical management routes illustrate the application of the inventory model. The inventory and freshwater ecotoxicity results are compared to two existing simplified emission modelling approaches.

Results and discussion The assessment results show considerably different emission fractions, quantities emitted and freshwater ecotoxicity impacts between the different active ingredient applications. Three out of 21 active ingredients dominate the overall freshwater ecotoxicity: Aclonifen, Fluopicolide and Cymoxanil. The comparison with two simplified emission modelling approaches, considering field soil and air as part of the ecosphere, shows that PestLCI 2.0 yields considerable lower emissions and, consequently, lower freshwater ecotoxicity. The sensitivity analyses reveal the importance of soil and climate characteristics, canopies (vine and cover crop) development and sprayer type on the emission results. These parameters should therefore be obtained with site-specific data, while literature or generic data that are acceptable inputs for parameters whose uncertainties have less influence on the result.

Conclusions Important specificities of viticulture have been added to the state-of-the-art inventory model PestLCI 2.0. They cover vertically trained vineyards, the most common vineyard training form; they are relevant for other perennial or bush crops provided equipment, shape of the canopy and pesticide active ingredients stay in the range of available options. A similar and compatible model is needed for inorganic pesticide active ingredients emission quantification, especially for organic viticulture impacts accounting.

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment, UPSP GRAPPE
Authors: Christel, R. (Ekstern), Dijkman, T. J. (Intern), Bjørn, A. (Intern), Birkved, M. (Intern)
Number of pages: 16
Pages: 1528-1543
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 20
Issue number: 11
ISSN (Print): 0948-3349
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
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
Sustainability in highly automated production systems: Methodology and algorithm for assessing production lines in the planning phase

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Rödger, J. (Intern), Dijkman, T. J. (Intern), Hauschild, M. Z. (Intern), Bey, N. (Intern)
Publication date: 2015
Event: Poster session presented at 7th International Conference on Life Cycle Management, Bordeaux, France.
Main Research Area: Technical/natural sciences
Electronic versions:
20150828_PosterLCM_januw.pdf
Source: PublicationPreSubmission
Source-ID: 127798323
Publication: Research - peer-review › Poster – Annual report year: 2016

The Glasgow consensus on the delineation between pesticide emission inventory and impact assessment for LCA
Pesticides are applied to agricultural fields to optimise crop yield and their global use is substantial. Their consideration in life cycle assessment (LCA) is affected by important inconsistencies between the emission inventory and impact assessment phases of LCA. A clear definition of the delineation between the product system model (life cycle
inventory—LCI, technosphere) and the natural environment (life cycle impact assessment—LCIA, ecosphere) is missing and could be established via consensus building. A workshop held in 2013 in Glasgow, UK, had the goal of establishing consensus and creating clear guidelines in the following topics: (1) boundary between emission inventory and impact characterisation model, (2) spatial dimensions and the time periods assumed for the application of substances to open agricultural fields or in greenhouses and (3) emissions to the natural environment and their potential impacts. More than 30 specialists in agrifood LCI, LCIA, risk assessment and ecotoxicology, representing industry, government and academia from 15 countries and four continents, met to discuss and reach consensus. The resulting guidelines target LCA practitioners, data (base) and characterisation method developers, and decision makers. The focus was on defining a clear interface between LCI and LCIA, capable of supporting any goal and scope requirements while avoiding double counting or exclusion of important emission flows/impacts. Consensus was reached accordingly on distinct sets of recommendations for LCI and LCIA, respectively, recommending, for example, that buffer zones should be considered as part of the crop production system and the change in yield be considered. While the spatial dimensions of the field were not fixed, the temporal boundary between dynamic LCI fate modelling and steady-state LCIA fate modelling needs to be defined. For pesticide application, the inventory should report pesticide identification, crop, mass applied per active ingredient, application method or formulation type, presence of buffer zones, location/country, application time before harvest and crop growth stage during application, adherence with Good Agricultural Practice, and whether the field is considered part of the technosphere or the ecosphere. Additionally, emission fractions to environmental media on-field and off-field should be reported. For LCIA, the directly concerned impact categories and a list of relevant fate and exposure processes were identified. Next steps were identified: (1) establishing default emission fractions to environmental media for integration into LCI databases and (2) interaction among impact model developers to extend current methods with new elements/processes mentioned in the recommendations.

General information
State: Published
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Number of pages: 12
Publication date: 2015
Main Research Area: Technical/natural sciences

Publication information
Journal: International Journal of Life Cycle Assessment
Volume: 20
Issue number: 6
ISSN (Print): 0948-3349
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
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
Scopus rating (2010): SJR 1.447 SNIP 1.861
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.201 SNIP 1.592
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.863 SNIP 1.33
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.8 SNIP 1.22
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.6 SNIP 1.387
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.633 SNIP 1.742
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.64 SNIP 1.439
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.509 SNIP 1.733
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.295 SNIP 0.977
Scopus rating (2001): SJR 0.478 SNIP 1.481
Scopus rating (2000): SJR 1.101 SNIP 1.864
Scopus rating (1999): SJR 0.421 SNIP 1.289
Original language: English
HASH(0x40fc658), Consensus, Ecosphere, Life cycle impact assessment (LCIA), Life cycle inventory (LCI), Pesticides, Spatial boundary, Technosphere, Temporal boundary
Electronic versions:
The_Glasgow_consensus_on_the_delineation_between_pesticide.pdf
DOIs:
10.1007/s11367-015-0871-1

Bibliographical note
The authors are grateful for the financial support provided by Syngenta and the TOX-TRAIN project (EU Grant Agreement no. 285286), which was used for the organisation of the workshop and the open-access publication of this manuscript.

Relations
Activities:
Towards consensus about the delimitation between life cycle inventory and impact assessment in LCAs with pesticide and fertilizer use
Source: FindIt
Source-ID: 274989613
Publication: Research - peer-review › Journal article – Annual report year: 2015

Modeling pesticides emissions for Grapevine LCA: adaptation of Pest-LCI model to viticulture
This paper presents a tailored version of PestLCI 2.0, the most advanced life cycle inventory model for quantification of organic pesticides emissions from arable land, customized to appropriately account for viticulture specificities affecting pesticides emissions from vineyards. PestLCI 2.0 customization is further supported by the calculation of USEtox™ freshwater ecotoxicity characterization factors for active ingredients relevant in viticulture. Case studies on two different vineyard management systems illustrate PestLCI 2.0 model application. The customization of the PestLCI 2.0 model includes addition of 29 active substances, 9 application techniques, interception by a dual canopy (vine/grass cover), new soil and climate databases and further account of multiple vinerow treatment. Four substances dominate the overall toxicity profiles. Comparing the results obtained with PestLCI 2.0 with existing static emission quantification approaches results reveals that PestLCI 2.0 yields considerable lower emission loads and consequently, lower toxicity impact burdens. The issue of accounting for inorganic substances is discussed.
Parameterisation of LCI/LCIA models of agricultural systems emissions under future pressures

Agricultural production currently faces two important challenges that need to be overcome in the next decades. Firstly, the expected increase of the global human population will put more pressure on productive ecosystems to accommodate the growing need for food. Secondly, climate change as a consequence of anthropogenic emissions is forecasted to increase the pressure on natural and semi-natural systems' productivity through various mechanisms resulting in e.g. an increased frequency of severe weather events or loss of nutrients in soil. An aspect that both the increasing food demand and environmental pressures have in common is the urge to enhance agricultural/food production efficiency, i.e. to produce more (while maintaining an acceptable quality) despite the difficulties raised by climate-driven pressures. Land-based food production is expected to compete with feed/non-food crops, forestry and protected areas for biodiversity, as well as land for bioenergy. Increasing agricultural yield may then be the best option. Accessible ways to rapidly ensure it consists of additional application of fertilisers and pesticides and an increase of their efficiency, while dealing with scarcity of phosphorus. Life Cycle Assessment (LCA) has been dealing with the environmental impacts from emissions and resources consumption from human activities including agriculture. Several approaches for inventory (LCI) and impact assessment (LCIA) modelling of agricultural activities have been published recently. To enhance the agriculture yield by adding nutrients and chemicals, humans will potentially increase the magnitude of the resulting emission flows to the ecosphere. The linearity of the emissions' fate and impact modelling suggests the assertion that the more nutrients or chemicals we apply in these systems, the greater the emissions and hence the impacts will be. This consequence will be illustrated by case studies describing how the impacts from fertilizer and pesticide use increase for such agricultural intensification and under future climatic circumstances. Models' sensitivity to the varying parameterisation from e.g. temperature raise or surface runoff (increased rainfall, drought), and the variation range of such inputs will also be addressed. LCA methodologies can provide useful information on the possible and predictable effects and damage to ecosystems and anticipate management and safety practices to minimise ecological, social, and economic impacts.
Modelling of pesticide emissions for Life Cycle Inventory analysis: Model development, applications and implications

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

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

Emissions of pesticides to surface water and groundwater calculated by PestLCI 2.0 were compared with models used for risk assessment. Compared to the MACRO module in SWASH 3.1 model, which calculates surface water emissions by runoff and drainage, pesticide emissions to surface water calculated by PestLCI 2.0 were generally higher, which was attributed to differences in the modelling approach between the two models. The model comparison for emissions to...
Calculating pesticide emissions for chemical footprinting of kiwifruit

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Dijkman, T. J. (Intern), Birkved, M. (Intern), Hauschild, M. Z. (Intern)
Number of pages: 95
Publication date: 2013

Publication information
Publisher: Department of Management Engineering, Technical University of Denmark
Original language: English
Main Research Area: Technical/natural sciences
Electronic versions:
Modelling_of_pesticide_emissions.pdf
Source: PublicationPreSubmission
Source-ID: 96649161
Publication: Research › Ph.D. thesis – Annual report year: 2014

In order to quantify the implications of using PestLCI 2.0, human toxicity and freshwater ecotoxicity impacts obtained with two inventory approaches were compared. The first approach was PestLCI 2.0, the second is the currently prevalent approach (the Ecoinvent approach), which assumes that 100% of the applied mass is emitted to agricultural soil. For both impact categories it was found that the PestLCI approach results in impacts that on average are three orders of magnitude lower. This conclusion was found to be valid for characterization of the impacts with both USEtox and US-ES-LCA 2.0 characterization factors.

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

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

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

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

Although PestLCI has been updated and expanded, further improvements are still possible. A number of improvements and suggestions to increase the model’s applicability are discussed. These suggestions focus on both the fate modelling (for example wind drift, degradation and volatilization from leaves) and the boundary setting of the model.
PestLCI 2.0: a second generation model for estimating emissions of pesticides from arable land in LCA

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

General information
State: Published
Organisations: Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Birkved, M. (Intern), Dijkman, T. J. (Intern)
Number of pages: 1
Publication date: 2012
Event: Poster session presented at 6th SETAC World Congress 2012, Berlin, Germany.
Main Research Area: Technical/natural sciences
An improved model for estimating pesticide emissions for agricultural LCA

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

Quantifying sustainability of genetically modified crops

Projects:

Automation and Robotics for EUnpean Sustainable Manufacturing

Department of Management Engineering
Quantitative Sustainability Assessment
Department of Mechanical Engineering
Manufacturing Engineering
Period: 01/09/2013 → 31/08/2016
Number of participants: 6
Acronym: AREUS
Project ID: 81375
Number of related Ph.D. students: 1
Project participant:
Bey, Niki (Intern)
Rödger, Jan-Markus (Intern)
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, Rosaile van (Ekstern)

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

Development of genetically modified cereals adapted to the increased CO2 levels of the future

Department of Management Engineering
Quantitative Sustainability Assessment
Period: 01/01/2010 → 31/12/2013
Number of participants: 3
Acronym: DANCER
Number of related Ph.D. students: 1
Project participant:
Birkved, Morten (Intern)
Dijkman, Teunis Johannes (Intern)
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Development of a method for long term spatially resolved management of the herring fishery in the North Sea and Illa taking the migration of the primary herring stocks, the fishery pattern and by-catch of mackerel into consideration (URSIN) (38731)

The overall objective is to develop a tool to create long-term management plans for the two main herring stocks in the North Sea and Illa, which may allow the industry an optimum use of the population under safe conditions relating to population maintenance and catch of mackerel.

The project will further develop, test and optimize a method for the quantification and prediction of herring stock spatial distribution in relation to life stages that is based on existing methods. This quantification of the migration patterns will provide more solid understanding of population development under various conditions. Moreover, the method will include a modeling of the herring fleet behavior, allowing for merging of herring spatial distribution in relation to life stage and hence potential economic value of fishing pattern. The historical and current behavior of the herring fleets will be quantified in collaboration with the industry. Similarly, mackerel skull occurrence will be mapped as it is of great importance for the herring fleet behavior, due to the economic incentives to minimize this by-catch.

The objective of the project is to generate a scientifically based tool for prediction of utilization of herring that can be used in future scientific advice to management, and information on optimal harvest strategies for the fishery in collaboration with the fishing industry. This is partly to increase the transparency and credibility of the scientific work and increase security in the input data and thus reduce uncertainty in the advice given in the end. Collaboration with industry includes Pelagic PO, Skagen PO and Esbjerg Fishermen and covers all types of fishing for herring (both industrial and human consumption).
The project is coordinated by DTU Aqua.

National Institute of Aquatic Resources
Section for Marine Living Resources
Danish Pelagic Producers Organisation
Danish Fishermen's Association
Period: 01/01/2009 → 31/12/2011
Number of participants: 6
Research area: Marine Living Resources

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