

# BEYOND CARBON FOOTPRINTS

ADVANCING LCA FOR COMPREHENSIVE ENVIRONMENTAL ASSESSMENT IN AGRI-FOOD SYSTEMS

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DEPARTMENT OF AGROECOLOGY

AARHUS UNIVERSITY

AGROSCOPE CONFERENCE  
5. MAY 2026

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PROFESSOR, HEAD OF SECTION



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- Professor and Head of Section 'Agricultural Systems and Sustainability', Department of Agroecology, Aarhus University
- Member of the Danish Climate Council
- Agronomist and PhD in life cycle assessment (LCA) of agricultural products
- Scientific focus on climate and environmental impact and sustainability of food and agricultural systems – where I primarily use life cycle assessment as a tool.



# OUR WORK IN THE LCA TEAM



## PLANT PRODUCTION:

**VEGETABLES**  
([ClimateVeg](#),  
[CloseFerVeg](#))

**PROTEIN**  
([OatPro](#), [CropSys.](#))

**GRASS MIXTURES**  
([GrassTools](#), [MultiPlant.](#))

**SEAWEED**  
([SeaSoil](#))

**AGROFORESTRY:**  
(MIXED, OUTFIT)

**PEAT/PALUDI** ([PeatWise](#))  
**FEED** (DCA report)



## LIVESTOCK PRODUCTION:

**DAIRY**  
(SOLID, PATHWAYS)

**Alternative substrates**  
([BioSubstrate I and II](#),  
EUDP)

**PIG**  
([SuperGrassPork](#),  
MIXED, OUTFIT)

**Alternative protein**  
([GrassTools](#), [OatPro](#),  
ECOECO, )

**EGG/CHICKEN**  
([GreenEggs](#), [HOPeS](#))

**Alternative fertilizers**  
([ClimOptic](#), EUDP)

**Alternative packaging**  
([SinProPack](#))



## FOOD CONSUMPTION:

**Food composition**  
([SustainOrganic](#),  
[SustainFood](#), [ECOLABEL](#))



## PROCESSING AND BIOREFINING:

What is the climate and environmental impact at area and product level?

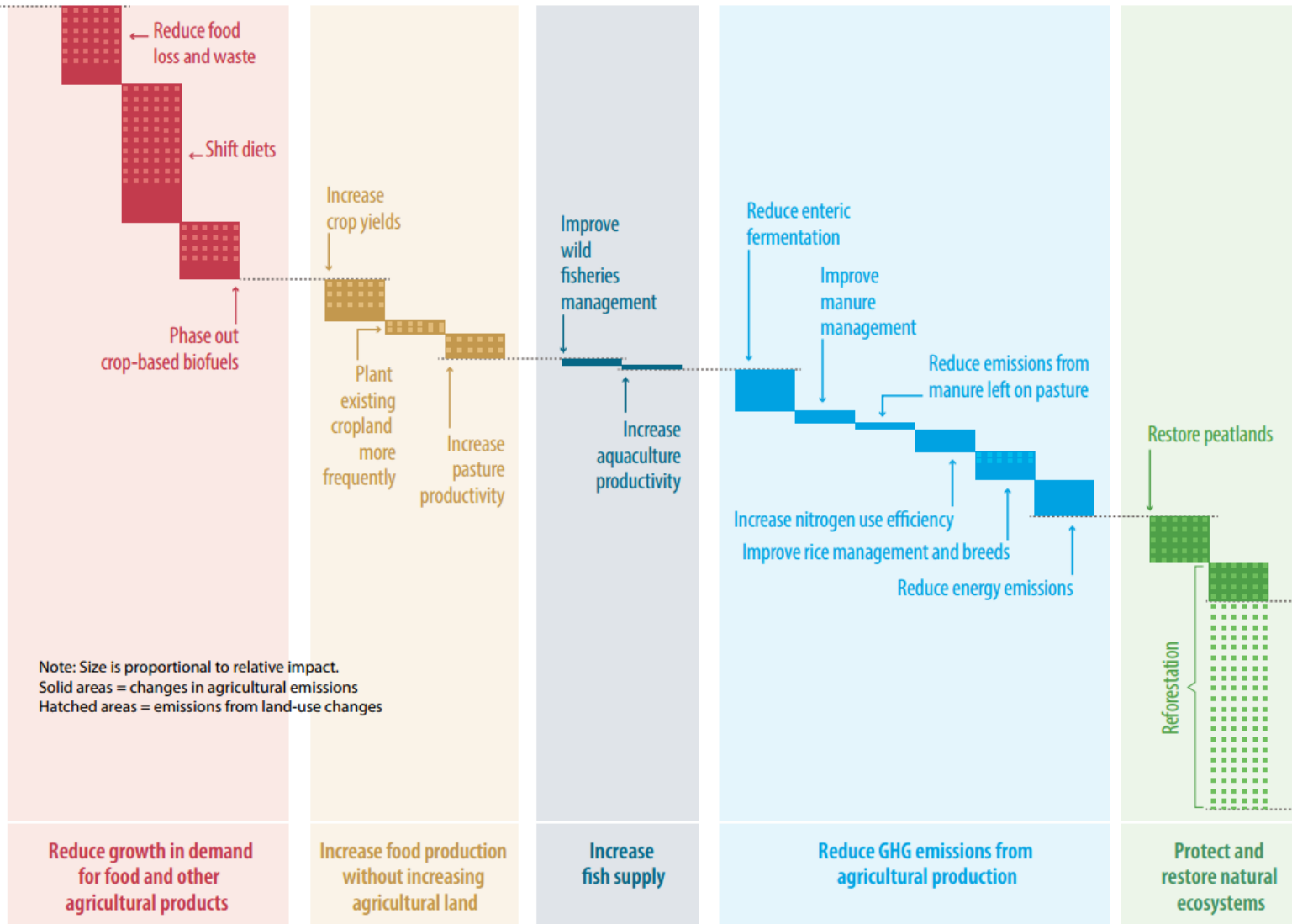
Hotspots and possible mitigation options

How is it estimated?

What is the methodological challenges?

How could they be solved?

# POSSIBILITIES TO REDUCE EMISSIONS FROM THE FOOD SYSTEM







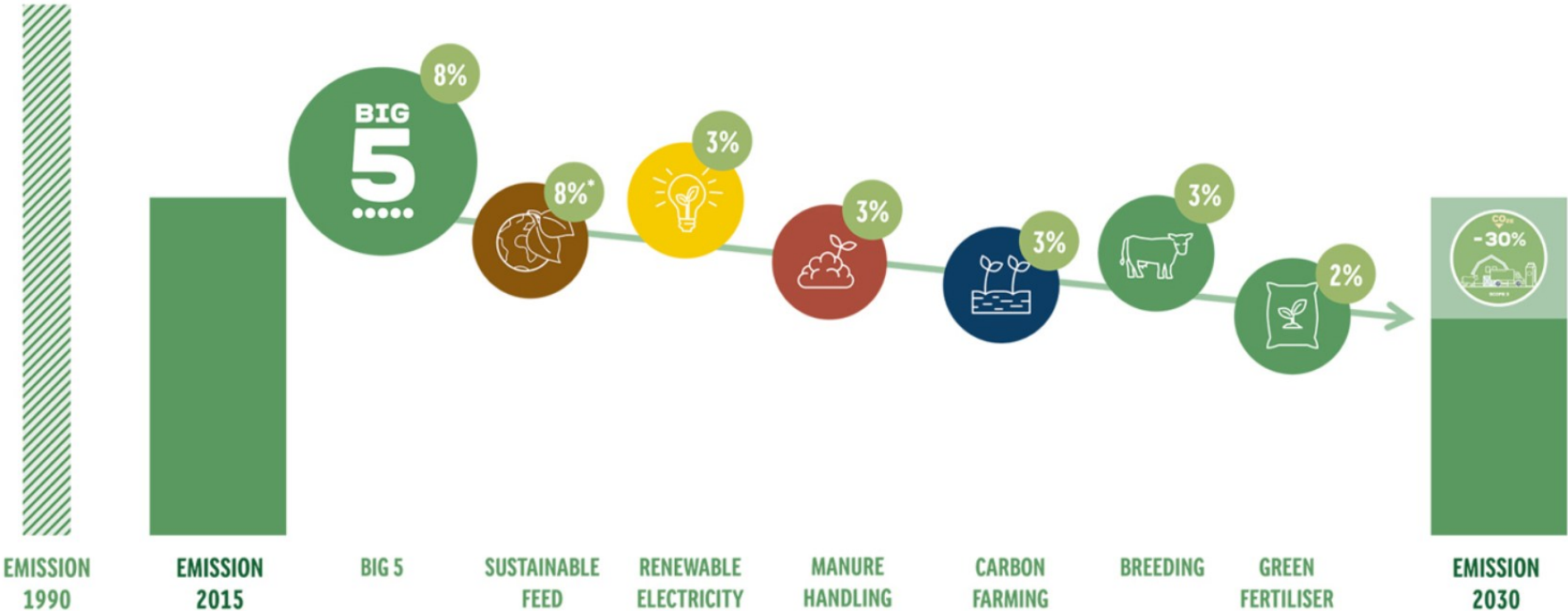
# PRODUCTION OF FOOD

Climate accounts at farm level



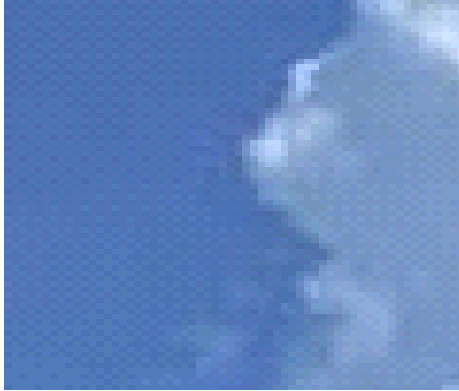
ARLA NOW ALL OUR BRANDS SUSTAINABILITY COMPANY

## Reducing CO<sub>2</sub>e emissions per kilo milk by 30%



# CLIMATE AND ENVIRONMENTAL IMPACT FROM FOOD

Climate



DEPARTMENT OF AGROECOLOGY

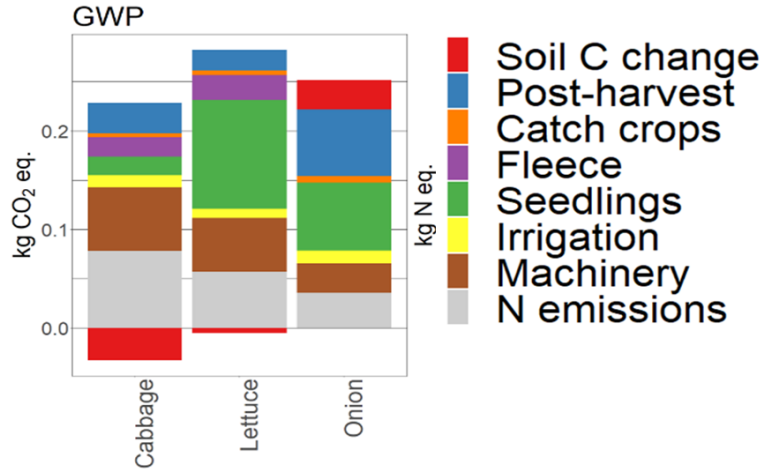
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AGROSCOPE CONFERENCE  
5. MAY 2026

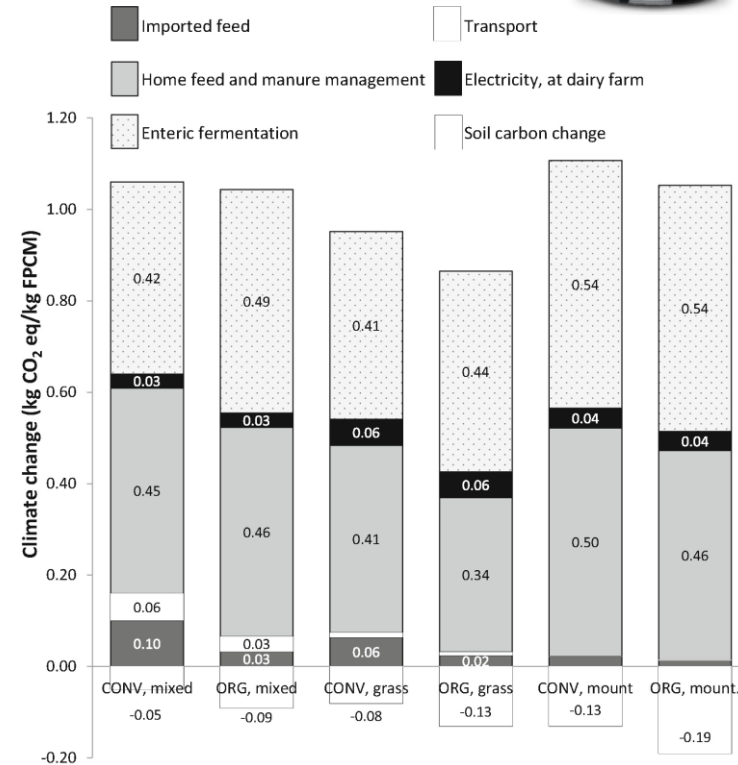
MARIE TRYDEMAN KNUDSEN  
PROFESSOR, HEAD OF SECTION



# CARBON FOOTPRINT OF FOOD



Jensen et al. (2024)



Knudsen et al. (2019)

# CARBON FOOTPRINT OF ORGANIC FOOD

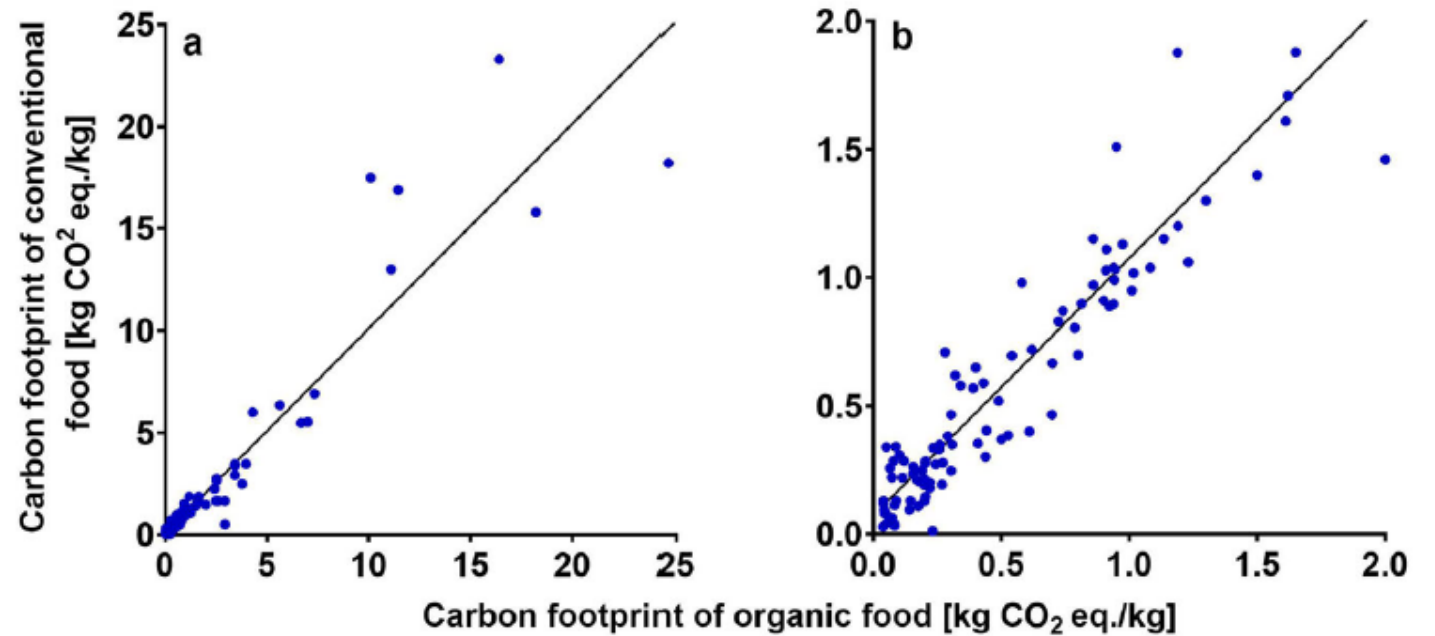
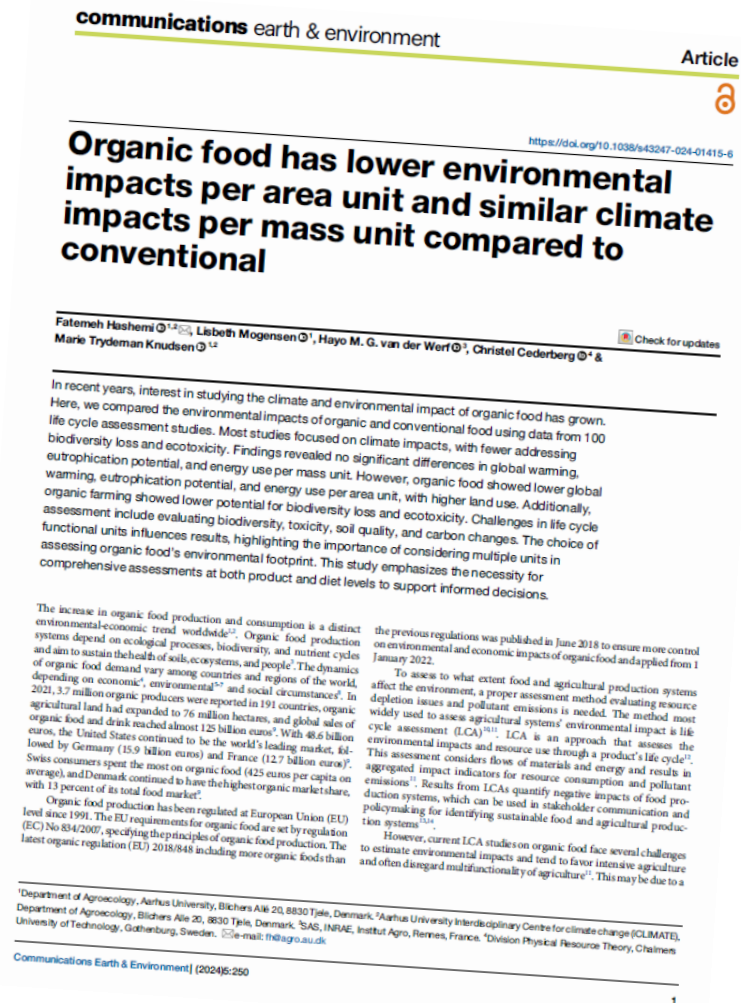


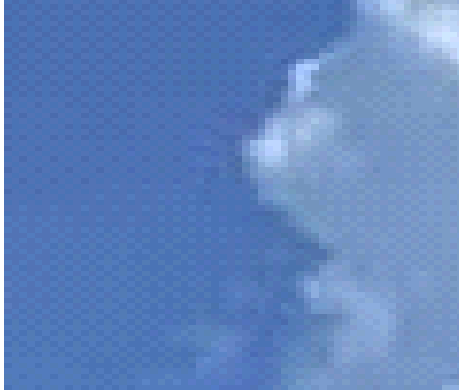
Fig. 5 | Carbon footprint comparison of organic and conventional foods. Carbon footprint for organic and conventional food (kg CO<sub>2</sub> equivalent per kg) based on comparative studies of the same product. (a) includes data for all food items, i.e., ranging from plant-based foods like fruits and vegetables at the low end of the scale to animal foods such as pork and beef at the high end. (b) zoomed in on the lower

end of the scale on plant-based food products and milk. The black line marks where the carbon footprint of organic and conventional foods is the same. Points below the line indicate a larger carbon footprint for organic food compared to conventional, while points above the line indicate a higher carbon footprint for conventional food compared to organic.



# CLIMATE AND ENVIRONMENTAL IMPACT FROM FOOD

Climate



Eutrophication



Soil quality and carbon seq.

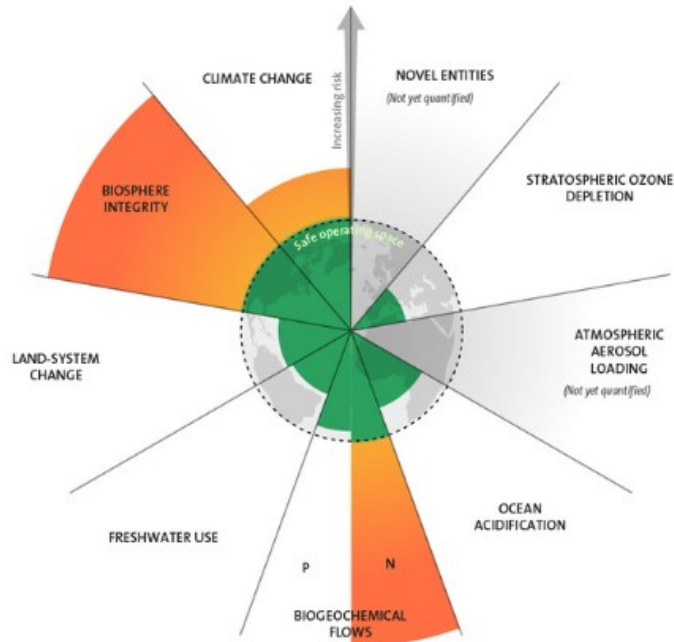


Ecotoxicity



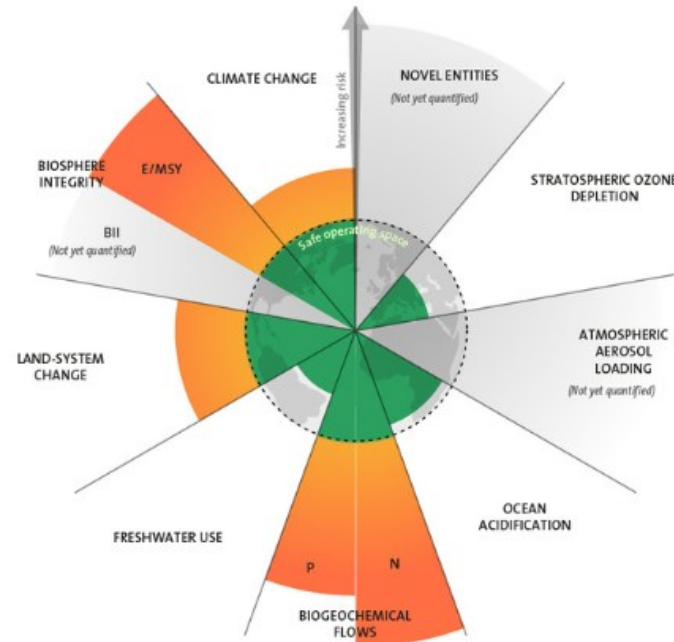
# PLANETARY BOUNDARIES

2009



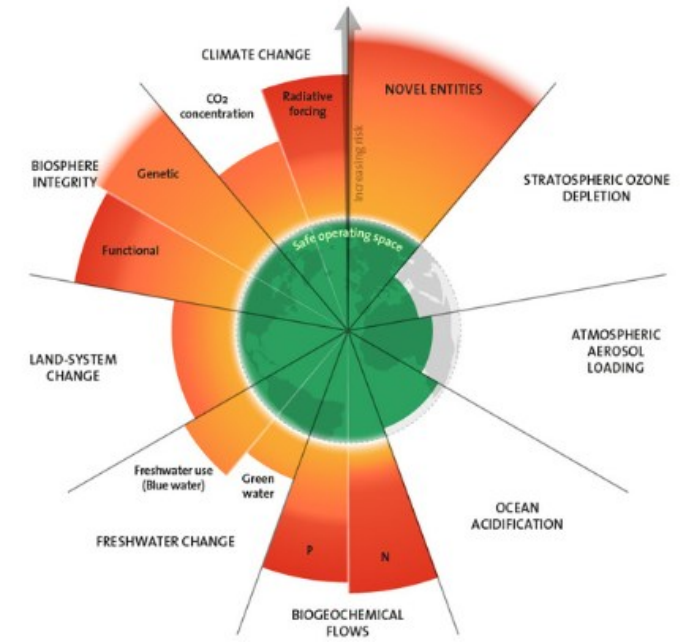
7 boundaries assessed,  
3 crossed

2015



7 boundaries assessed,  
4 crossed

2023



9 boundaries assessed,  
6 crossed

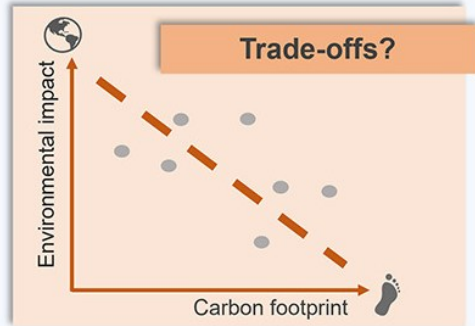


# TRADE-OFFS

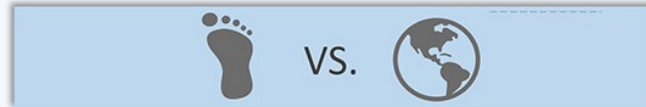
## Research question

## Method

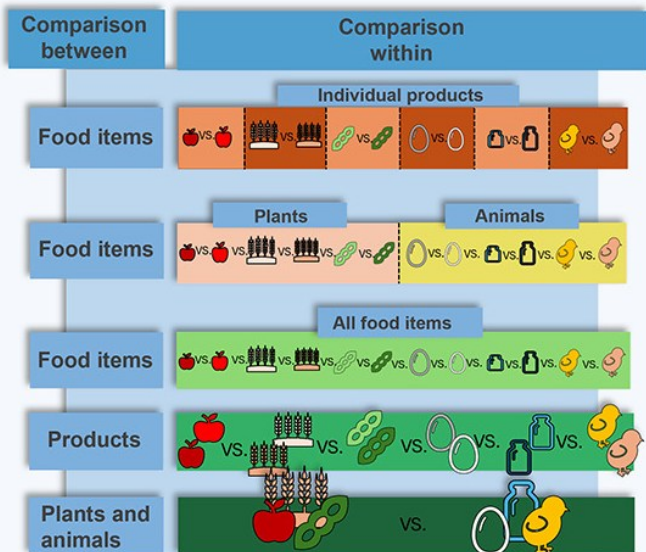
## Results



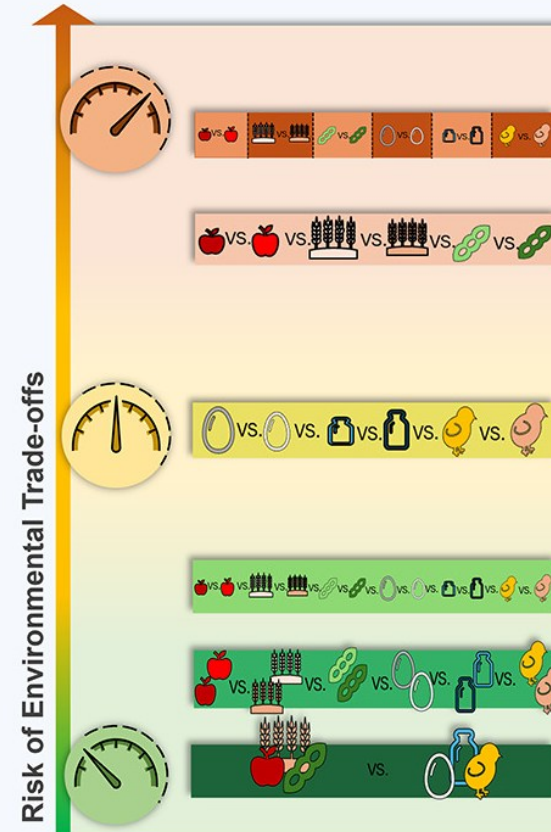
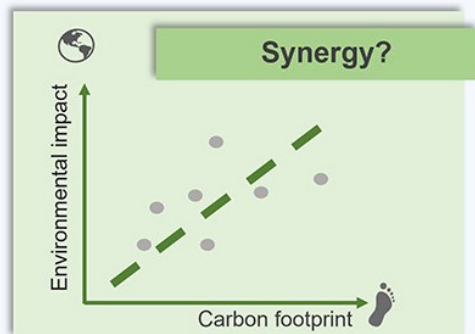
**Aim:** Comparing carbon footprint with 8 different environmental impacts



**Novelty:** Comparing 150 food items 5 times but grouped in a different way each time



**Research gap:** How is the carbon footprint of agricultural food products linked to other environmental impacts?



**Trade-off or synergy:** How is the carbon footprint of agricultural food products linked to other environmental impacts?

Bjorn Aamand Andersen<sup>a,\*</sup>, Lisbeth Mogensen<sup>a</sup>, Huayang Zhen<sup>a</sup>, Marie Trydeman Knudsen<sup>a</sup>

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### ARTICLE INFO

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LCA

### ABSTRACT

Current climate change emphasizes reducing greenhouse gas (GHG) emissions from our food systems. However, a sole focus to mitigate food-related GHGs risks causing environmental trade-offs, i.e., increasing other environmental impacts as GHG emissions are reduced. This paper assesses the relationship between the carbon footprint and 8 environmental impact categories, across 150 agricultural food products from the life cycle assessment database AGRIALIFE. The aim is to address whether there are synergies or trade-offs between the carbon footprint and other environmental impacts, including eutrophication, acidification, toxicity, land use and depletion of fossil and water resources. The novelty of this study is the decision to consider multiple comparisons using the same dataset but varying the level of resolution: comparing broad groups of foods, i.e. animal vs. plant-based food, comparing groups of food products, e.g., carrots vs. milk, and comparing food items within food products, e.g., within eggs.

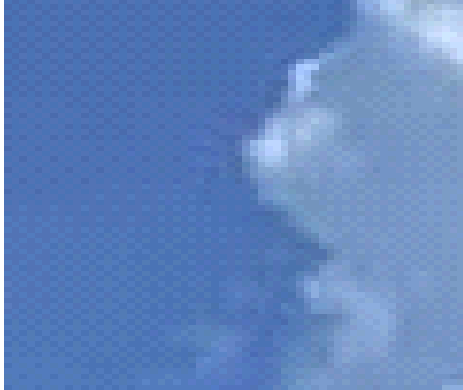
The main result of this article is that trade-offs are possible, commonly when comparisons are made between food items within a specific food product (e.g., comparing within eggs) and when comparisons are made between plant-based food items as a whole. This is especially true considering depletion of water and energy resources, freshwater eutrophication and land use, for which a correlation with the carbon footprint most often existed at finer resolution levels, explanatory powers commonly being below 0.5 for both squared Pearson's and Spearman's correlation coefficients ( $R^2 < 0.5$ ). Conversely, a synergy between the carbon footprint and all other assessed impacts was observed between foods grouped as animal and plant-based foods, the environmental impact being lowest for the plant-based foods considering all assessed impact categories according to Wilcoxon rank-sum test ( $P < 0.01$ ). We advocate that creation of environmental trade-offs should be taken when the effect of climate mitigation efforts is based on high-resolution comparisons. Conversely, shifting from animal-based to plant-based food components pose minor risk of provoking environmental trade-offs.

### 1. Introduction

Greenhouse gas (GHG) emissions represent a major negative environmental externality of the global food sector, contributing between 26 and 34% of all anthropogenic GHG emissions (Crippa et al., 2021; Poppo and Nemecek, 2018; Tubiello et al., 2022). It has been estimated that with dietary changes, emissions can be reduced (Fitzpatrick et al., 2018), e.g., a change towards the EAT-lancet reference diet which is based on the potential to reduce food-related GHG emissions, by 60% (Chen et al., 2022). As of that, stakeholders seek to incentivize climate-friendly consumption changes, e.g., through environmental labelling (Clark et al., 2020), dietary guidelines (Garnett et al., 2013) and taxes on agricultural GHG emissions as seen in Denmark (Rejnngren, 2024). Also in the agricultural production sector, climate mitigation has been suggested either in terms of new technology or system changes, e.g., use of 3-nitrooxypropanol (3-NOP) as an anti-methanogenic feed additive to reduce methane emissions in ruminant systems (Gibson et al., 2022) or soil amendment with biochar to create long-term carbon storage (Cross et al., 2013). It is the hope that such focused production and consumption changes can lower the carbon footprint of the food sector to meet global climate targets to keep the average global increase in temperatures well below 2 °C as set by the Paris Agreement (UN, 2015). Yet, the food sector also contributes to the transcendence of multiple other planetary boundaries than climate

# ENVIRONMENTAL IMPACT FROM AGRICULTURE/FOOD

Climate



Eutrophication



Soil quality and carbon seq.

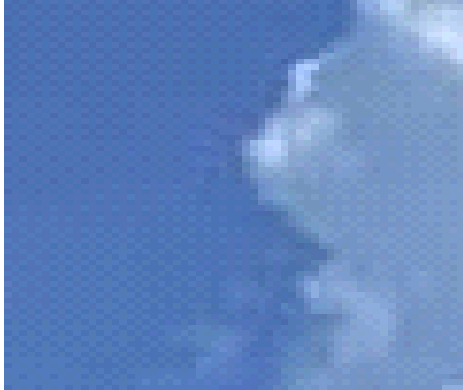


Ecotoxicity



# ENVIRONMENTAL IMPACT FROM AGRICULTURE/FOOD

Climate



Eutrophication



Soil quality and carbon seq.



Ecotoxicity

Biodiversity



A close-up photograph of a vibrant green field of clover. The plants are densely packed, with many pink clover flowers in various stages of bloom. Some flowers are fully open, showing their characteristic rounded, multi-petaled structure, while others are still in bud form. The leaves are bright green and appear to have small droplets of water on them, suggesting a recent rain or dew. In the lower-left quadrant, a butterfly with orange and black wings is partially visible, resting on a leaf. The overall scene is a rich, natural display of agricultural biodiversity.

**Some agricultural systems contribute more to biodiversity than others...**



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

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

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<sup>c</sup> Agroscope, Institute for Sustainability Sciences ISS, Zurich CH-8046, Switzerland

<sup>d</sup> Toulouse University, ENSEAT, UMR 1248 AGIR, Castanet-Tolosan F-31320, France

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<sup>f</sup> University of Natural Resources and Life Sciences Vienna, Vienna A-1180, Austria

<sup>g</sup> Institute of Environmental and Landscape Management, MJK, Szent Istvan University, Peter K. ut., Gödöllő H-2100, Hungary

<sup>h</sup> Norwegian Forest and Landscape Institute (NFI), N-1431 Ås, Norway

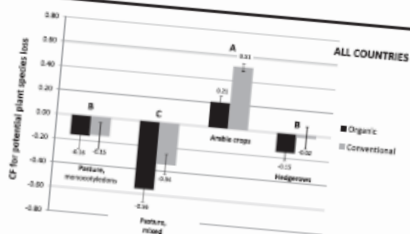
<sup>i</sup> Munich Technical University, Freising D-85350, Germany

<sup>j</sup> Institute of Biological, Environmental and Rural Sciences, Penglais Campus, Aberystwyth University, UK-SY23 3DD, UK

### HIGHLIGHTS

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

### GRAPHICAL ABSTRACT



### ABSTRACT

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

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E-mail address: [marie.triedeman@agro.au.dk](mailto:marie.triedeman@agro.au.dk) (M.T. Knudsen).

ENVIRONMENTAL  
Science & Technology

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## Toward Better Biodiversity Impact Assessment of Agricultural Land Management through Life Cycle Assessment: A Systematic Review

Huayang Zhen,<sup>\*</sup> Pietro Goglio, Fatemeh Hashemi, Christel Cederberg, Maxime Fossey, and Marie Trydeman Knudsen

Cite This: *Environ. Sci. Technol.* 2025, 59, 7440–7451

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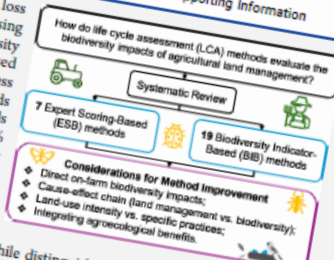
Article Recommendations

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Supporting Information

**ABSTRACT:** Agricultural intensification has driven global biodiversity loss through land management change. However, there is no consensus on assessing the biodiversity impacts of changes in land management practices and intensity levels using life cycle assessment (LCA). This study reviews 7 expert scoring-based (ESB) and 19 biodiversity indicator-based (BIB) LCA methods used to assess biodiversity impacts, aiming to evaluate their quality and identify research needs for incorporating land management change in LCA. Overall, BIB methods outperformed ESB methods across general criteria, especially in robustness (95% higher). BIB methods assess biodiversity impacts based on land management intensity levels, whereas ESB methods emphasize specific land management practices. Neither approach fully captures biodiversity impacts across supply chains. For future studies, it is advisable to (1) model the direct (on-farm) impacts of land management change at the midpoint level; (2) establish cause-effect relationships between key land management practices and biodiversity indicators, while distinguishing between direct (on-site) and indirect (off-site) biodiversity impacts resulting from land management change; (3) characterize land-use intensity levels with specific land management practices and include the positive impacts from agroecological practices. This Review examines LCA methods for biodiversity concerning land management and discusses improvements to better account for the biodiversity impacts of agricultural land management.

**KEYWORDS:** biodiversity, life cycle assessment, land management practices, agroecosystem, expert scoring



### 1. INTRODUCTION

Biodiversity underpins ecosystem functioning and human well-being.<sup>1</sup> However, extinction rates are now staggering—approximately 1000 times higher than natural background rates.<sup>2</sup> Approximately 25% of the remaining species are threatened by various direct drivers of biodiversity loss, including land and sea use changes, direct exploitation, climate change, and pollution.<sup>3</sup> Agroecosystems, including cropland and pastures, cover 46% of the Earth's land surface<sup>4</sup> and pose risks to 62% of globally threatened species,<sup>5</sup> thereby playing a role in global biodiversity conservation efforts.<sup>6</sup> Agricultural land is predicted to expand or intensify to meet the demands of a growing global population and rising per-capita consumption.<sup>7</sup> This will impose pressure on biodiversity through land use and land management changes.<sup>8</sup> At the same time, agriculture is also dependent on biodiversity, e.g., pollination, natural pest control, and the turnover of organic matter in the soil for C and N cycles.<sup>9</sup> Although the impacts of agricultural practices on local biodiversity can vary (e.g., grazed meadows versus intensive wheat production), the widespread nature of agroecosystems makes biodiversity losses due to agricultural management a major concern.<sup>10</sup> Besides, food consumption accounts for the largest share (40%) of global biodiversity loss

among all human consumption activities.<sup>11</sup> Understanding and mitigating these biodiversity losses will support sustainable agricultural management. Properly assessing the biodiversity impacts of agricultural products is fundamental for achieving the UN Sustainable Development Goals for Responsible Production and Consumption (SDG 12). Life cycle assessment (LCA) is a method used to evaluate the environmental impacts of products/services. LCA was initially developed to assess the impacts of extractions and emissions associated with material and energy flows in industrial products.<sup>12,13</sup> Following the issuance of the UNEP life cycle initiative's framework on global land use impact assessment,<sup>14,15</sup> many research studies have applied it to assess biodiversity impacts, e.g., Species-Area Relationship (SAR) method,<sup>16,17</sup> Countryside SAR (CSAR) method,<sup>18</sup> etc. Through ongoing methodological development, several opera-

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**Some agricultural systems contribute more to soil carbon sequestration than others...**



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journal homepage: [www.elsevier.com/locate/jclepro](http://www.elsevier.com/locate/jclepro)



## An approach to include soil carbon changes in life cycle assessments

Bjørn Molt Petersen<sup>a</sup>, Marie Trydeman Knudsen<sup>b,\*</sup>, John Erik Hermansen<sup>a</sup>,  
Niels Halberg<sup>c</sup>



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<sup>b</sup> Department of Agriculture and Ecology, Faculty of Life Sciences, University of Copenhagen, DK-2630 Taastrup, Denmark

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LCA

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Bioenergy

Organic

Conventional

Soybean

### ABSTRACT

Globally, soil carbon sequestration is expected to hold a major potential to mitigate agricultural greenhouse gas emissions. However, the majority of life cycle assessments (LCA) of agricultural products have not included possible changes in soil carbon sequestration. In the present study, a method to estimate carbon sequestration to be included in LCA is suggested and applied to two examples where the inclusion of carbon sequestration is especially relevant: 1) Bioenergy: removal of straw from a Danish soil for energy purposes and 2) Organic versus conventional farming: comparative study of soybean production in China. The suggested approach considers the time of the soil CO<sub>2</sub> emissions for the LCA by including the Bern Carbon Cycle Model. Time perspectives of 20, 100 and 200 years are used and a soil depth of 0–100 cm is considered. The application of the suggested method showed that the results were comparable to the IPCC 2006 tier 1 approach in a time perspective of 20 year, where after the suggested methodology showed a continued soil carbon change toward a new steady state. The suggested method estimated a carbon sequestration for the first example when storing straw in the soil instead of using it for bioenergy of 54, 97 and 213 kg C t<sup>-1</sup> straw C in a 200, 100 and 20 years perspective, respectively. For the conversion from conventional to organic soybean production, a difference of 32, 60 or 143 kg soil C ha<sup>-1</sup> yr<sup>-1</sup> in a 200, 100 or 20 years perspective, respectively was found. The study indicated that soil carbon changes included in an LCA can constitute a major contribution to the total greenhouse gas emissions per crop unit for plant products. The suggested approach takes into account the temporal aspects of soil carbon changes by combining the degradation and emissions of CO<sub>2</sub> from soil in the life cycle assessment of the product sphere. Further



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# Freshwater ecotoxicity assessment of pesticide use in crop production: Testing the influence of modeling choices

Nancy Peña <sup>a,b,\*</sup>, Marie T. Knudsen <sup>d</sup>, Peter Fantke <sup>c</sup>, Assumpció Antón <sup>a</sup>, John E. Hermansen <sup>d</sup>

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<sup>b</sup> Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona (UAB), E-08193, Bellaterra, Barcelona, Spain

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Inventory modeling  
Ecotoxicity characterization  
Life cycle impact assessment (LCIA)  
Feed crops  
Agriculture

## ABSTRACT

Pesticides help to control weeds, pests, and diseases contributing, therefore, to food availability. However, pesticide fractions not reaching the intended target may have adverse effects on the environment and the field ecosystems. Modeling pesticide emissions and the link with characterizing associated impacts is currently one of the main challenges in Life Cycle Assessment (LCA) of agricultural systems. To address this challenge, this study takes advantage of the latest recommendations for pesticide emission mass distribution of pesticide avoiding a temporal overlapping. Here, freshwater ecotoxicity impacts of the production of feed crops (maize, grass, winter wheat, spring barley, rapeseed, and peas) in Denmark were evaluated during a 3-year period, testing the effects of inventory modeling and the recent updates of the characterization method (USEtox). Potential freshwater ecotoxicity impacts were calculated in two functional units reflecting crop impact profiles per ha and extent of cultivation, respectively. Ecotoxicity impacts decreased over the period, mainly because of the reduction of insecticides use (e.g. cyperthrin). Three different emission modeling scenarios were tested; they differ on the underlining assumptions and data requirements. The main aspects influencing impact results are the interface between growth development and pesticide application method. Impact scores for AS2 were higher than RS and AS1, but the differences in the crops ranking was less apparent. On the other hand, the influence on the impact results modeled in scenarios RS and AS2. Thereby indicating the effect of inventory models on the ecotoxicity impact assessment.

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## 1. Introduction

With the increased global demand for agricultural products for food, fiber and bioenergy, and the interrelated concerns on the environmental impact thereof, there is a need to have efficient tools

to evaluate the environmental performance profiles of agricultural production, to facilitate a move towards more sustainable production systems. Life Cycle Assessment (LCA) is widely applied to quantify the potential impacts of products and systems along with their entire life cycles. One of the main challenges in assessing the environmental performance of agricultural systems in LCA is coupling with the impact characterization model (van Zelm et al., 2014). Over the past years, a significant number of LCA studies on agricultural systems were conducted (Gasol et al., 2012; Millà et al., 2006; Noya et al., 2017; Torrellas et al., 2012). However, ecotoxicity impacts as currently modeled may lead to inconsistent results and

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



# Towards a more comprehensive life cycle assessment framework for assessing toxicity-related impacts for livestock products: The case of Danish pork

Teodora Dorca-Preda <sup>a,\*</sup>, Peter Fantke <sup>b</sup>, Lisbeth Mogensen <sup>a</sup>, Marie Trydeman Knudsen <sup>a</sup>

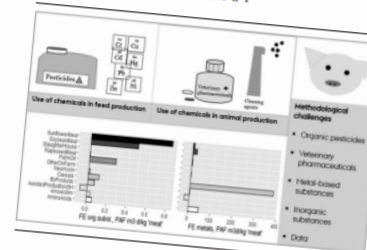
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<sup>b</sup> Quantitative Sustainability Assessment, Department of Technology, Management and Economics, Technical University of Denmark, Produktionstovstvej 424, 2800 Kgs Lyngby, Denmark

## HIGHLIGHTS

- A framework for assessing toxicity impacts of livestock production systems was defined.
- Pesticides, veterinary pharmaceuticals, and metals were assessed for Danish pork.
- Feed production is the main contributor to toxicity impacts of Danish pork.
- Emission fractions of pesticides to soil, air, and water highly influenced the results.
- Methodological gaps were discussed and ways forward were proposed.

## GRAPHICAL ABSTRACT



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## ABSTRACT

In life cycle assessments of livestock systems, toxicity-related impacts are not commonly considered or only specific aspects (such as pesticides, manufacturing of inputs) are assessed. In this context, the aim of this study was to define a framework for assessing toxicity-related impacts and to characterize human toxicity and freshwater ecotoxicity for a livestock product based on applying the state-of-the-art models Pest.LCI Consensus and USEtox. Furthermore, methodological gaps were discussed and ways forward were suggested. The case study focused on Danish pork production and the toxicity results were reported per kg 'meat' (the parts of pig used for human consumption) leaving the slaughterhouse. The assessment framework included the use of pesticides and heavy metals in feed production, the use of veterinary pharmaceuticals in pig production, and the manufacturing of inputs. The use of cleaning agents could not be assessed with the currently available methods. New characterization factors were calculated for 35 chemicals not available in USEtox. For Danish pork production, feed production was the main contributor to the analyzed toxicity impacts. The use of pesticides was the main driver for organic substances while heavy metal emissions related to the application of pig manure to fields were the hotspot for metal-based substances. The use of veterinary pharmaceuticals contributed only to freshwater ecotoxicity by 3%. Pest.LCI Consensus estimates were compared with different methodological gaps and research needs were identified regarding the assessment of pesticides, veterinary pharmaceuticals, metal-based substances, inorganic substances, and combined exposure to multiple chemicals. Better data related to the use and chemical properties of substances are needed to reduce uncertainty in toxicity modeling.



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## The importance of including soil carbon changes, ecotoxicity and biodiversity impacts in environmental life cycle assessments of organic and conventional milk in Western Europe

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Nancy Peña <sup>b</sup>, Susanne Padel <sup>c</sup>, Laurence G. Smith <sup>c</sup>, Werner Zollitsch <sup>d</sup>,  
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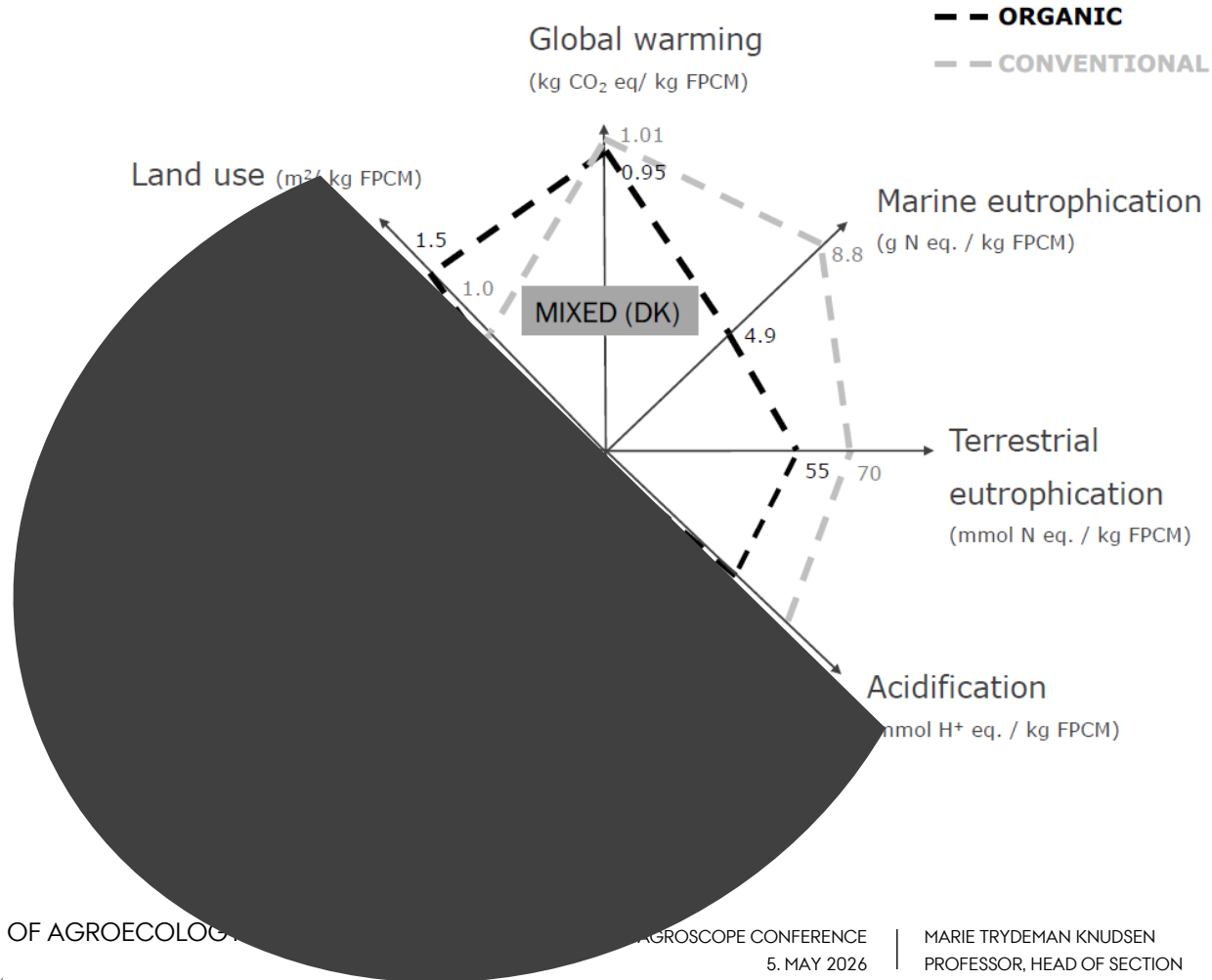
#### Keywords:

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Dairy  
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LCA  
Soil carbon

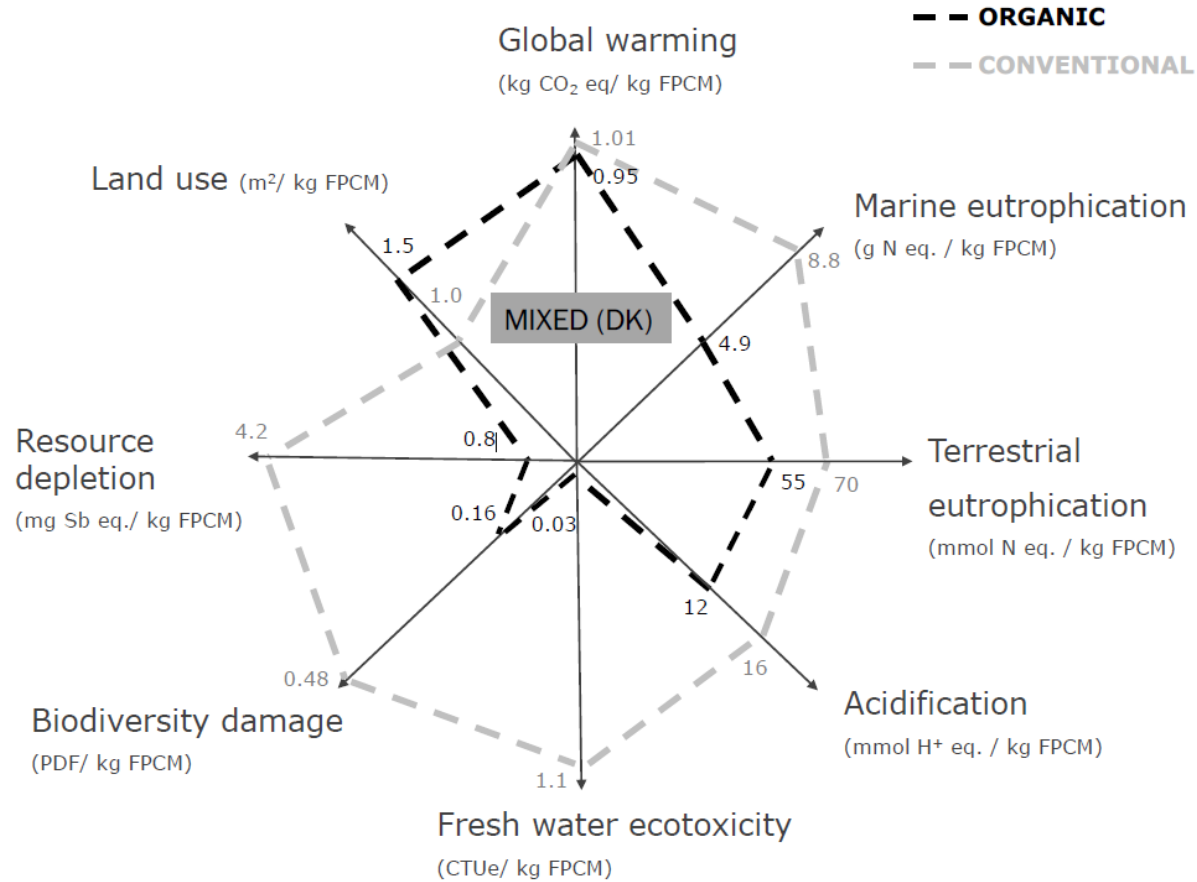
### ABSTRACT

Estimates of soil carbon changes, biodiversity and ecotoxicity have often been missing from life cycle assessment based studies of organic dairy products, despite evidence that the impacts of organic and conventional management may differ greatly within these areas. The aim of the present work was therefore to investigate the magnitude of including these impact categories within a comprehensive environmental impact assessment of organic and conventional dairy systems differing in basic production conditions. Three basic systems representative of a range of European approaches to dairy production were selected for the analysis, i.e. (i) low-land mixed crop-livestock systems, (ii) lowland grassland-based systems, (iii) and mountainous systems. As in previous publications, this study showed that when assessing climate change, eutrophication and acidification impact organic milk has similar or slightly lower impact than conventional, although land-use is higher under organic management. Including soil carbon changes reduced the global warming potential by 5–18%, mostly in organic systems with a high share of grass in the ration. The impacts of organic milk production on freshwater ecotoxicity, biodiversity and resource depletion were 2, 33 and 20% of the impacts of conventional management, respectively, across the basic systems considered. The study highlights the importance of including soil carbon changes, biodiversity and ecotoxicity in life cycle assessments of organic and conventional dairy products.

# LIFE CYCLE ASSESSMENT OF MILK



# LIFE CYCLE ASSESSMENT OF MILK



# PAPER IN “NATURE SUSTAINABILITY”

(Van der Werf, Knudsen & Cederberg)



## Towards better representation of organic agriculture in life cycle assessment

Hayo M. G. van der Werf<sup>1</sup>, Marie Trydeman Knudsen<sup>2</sup> and Christel Cederberg<sup>3</sup>

The environmental effects of agriculture and food are much discussed, with competing claims concerning the impacts of conventional and organic farming. Life cycle assessment (LCA) is the method most widely used to assess environmental impacts of agricultural products. Current LCA methodology and studies tend to favour high-input intensive agricultural systems and misrepresent less intensive agroecological systems such as organic agriculture. LCA assesses agroecological systems inadequately for three reasons: (1) a lack of operational indicators for three key environmental issues; (2) a narrow perspective on functions of agricultural systems; and (3) inconsistent modelling of indirect effects.

Societal interest in sustainable agriculture and food is great and growing<sup>1,2</sup>, leading to a demand for information about the environmental performance of agricultural systems, food products and overall food chains from almost all parts of society: policy makers, farmers, agribusinesses, public procurers, the media and consumers. From this diverse group of stakeholders, different questions arise, such as: 'is product A better or worse for the environment than product B? Does converting to this production system really decrease environmental impacts? Should this innovative management technology be encouraged from an environmental perspective?'

The method most widely used to answer such questions is life cycle assessment (LCA), whose use is now well established for assessing resource depletion issues and environmental and health impacts caused by production of agricultural products. LCA's basic principle<sup>3</sup> is to follow a product through its life cycle, defining a boundary between its 'product system' (the 'technosphere') and the surrounding environment. Energy and material flows crossing this boundary are related to the system's inputs (for example, resources) and outputs (for example, emissions to water and air). Resource consumption and pollutant emissions are then aggregated into impact indicators; LCA thus focuses on negative impacts rather than including positive impacts. The first LCAs were performed in the 1970s by Coca-Cola when it investigated consequences of switching from glass bottles to plastic bottles<sup>4</sup>. In the 1990s, application of LCA to agricultural systems began. From 1992 to 2018, the number of peer-reviewed English language articles using LCA to

approaches at multiple spatial and temporal scales<sup>5</sup>. Another example of a wider view of agriculture is the concept of agroecology (Fig. 2), recognized by United Nations (UN) institutions as a science and social movement in the transition to sustainable food systems and a pathway to achieving the UN's Sustainable Development Goals (SDGs)<sup>6</sup>. Organic agriculture includes many agroecological practices; its umbrella organization, International Federation of Organic Agriculture Movements (IFOAM) – Organics International, defines it as a "production system that sustains the health of soils, ecosystems and people" and "relies on ecological processes, biodiversity cycles adapted to local conditions", ultimately basing it on four principles: health, ecology, fairness and care<sup>10</sup>.

Willett et al.<sup>1</sup> highlight the urgency of transforming global food systems to meet the SDGs and the UN's Paris climate agreement; they propose planetary boundaries for six key Earth system processes (climate change, land-system change, freshwater use, nitrogen and phosphorus cycling, and biodiversity losses) on which food production and consumption have great impact. There is growing agreement on the need for changes in agri-food systems to make progress towards SDGs. Willett et al.<sup>1</sup> even call for a 'Great Food Transformation', which would require appropriate assessment tools and methods to examine the environmental performance of agriculture.

Here, we identify important deficiencies in LCA methodology when assessing agriculture based on agroecological principles, with examples of applying it to organic agriculture. We propose ways to strengthen the ability of LCA to capture environmental impacts of



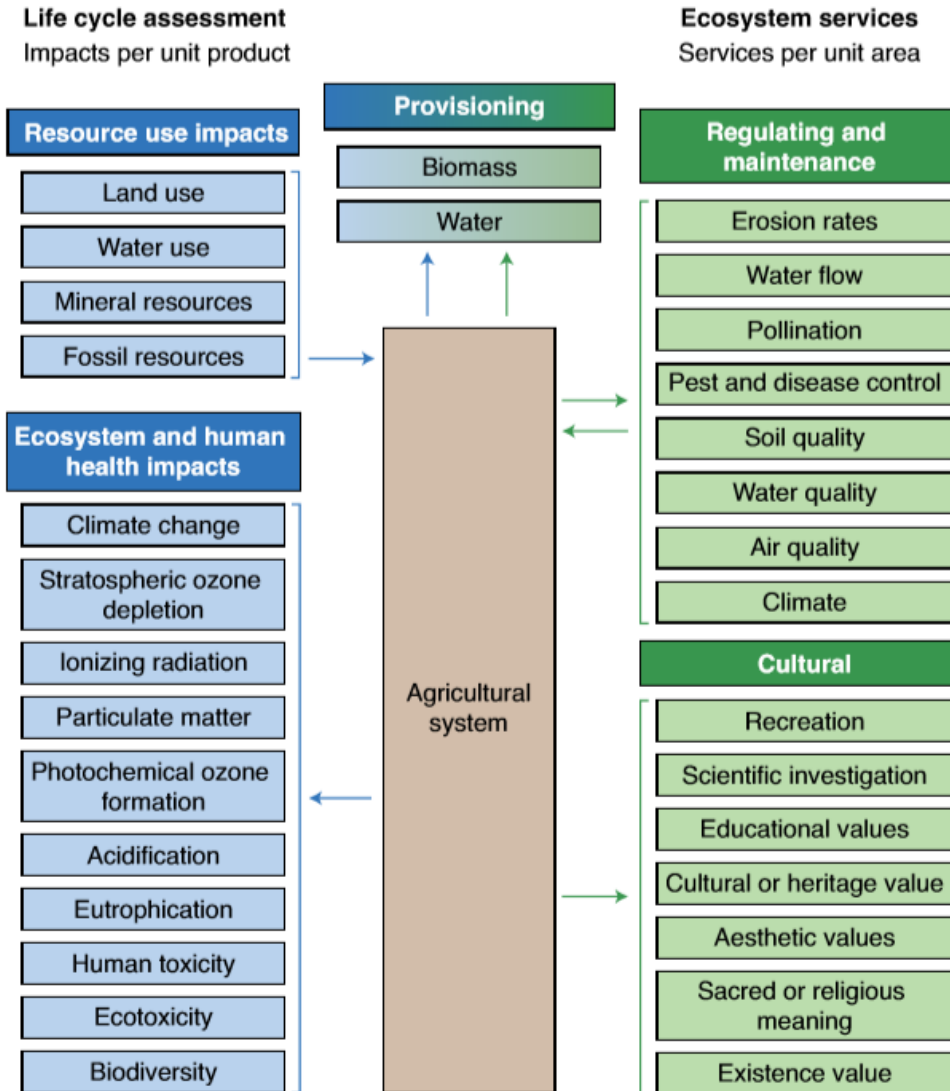
# PAPER IN “NATURE SUSTAINABILITY”

(Van der Werf, Knudsen & Cederberg, 2020)

- Additional indicators
  - Land degradation
  - Decline in biodiversity
  - Pesticide effects
- Broader perspective
  - Functional unit
  - Ecosystem services
- Indirect effect
  - Critical towards simplification in predicting indirect effects (iLUC and carbon opportunity cost)
  - Other indirect effects such as rebound effects, diet changes etc. should then also be included.

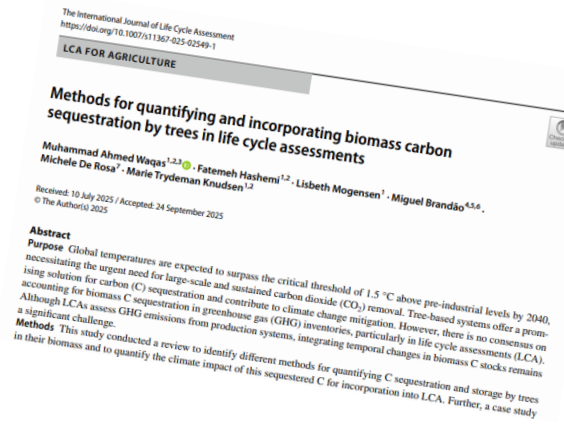
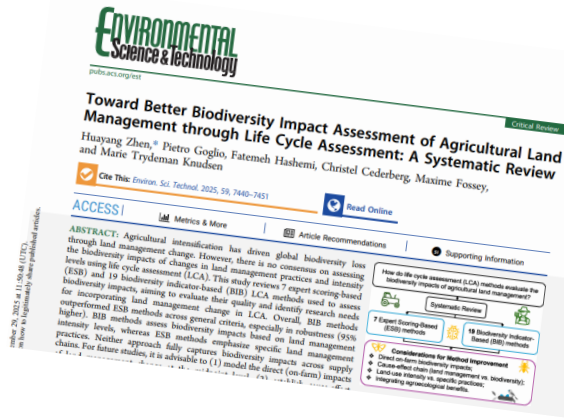
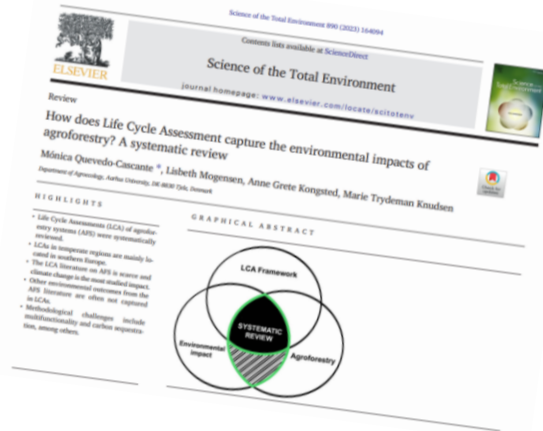


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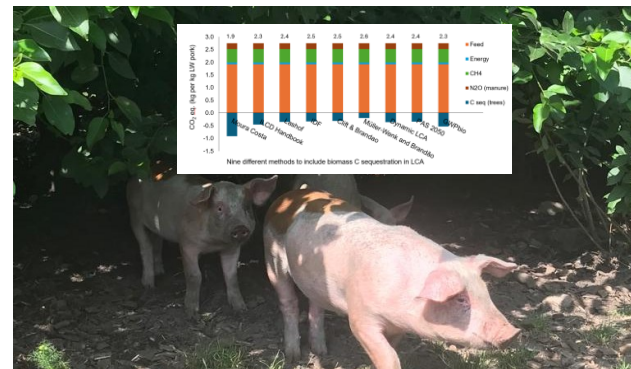


# EXAMPLE: MIXED PROJECT (H2020)

## REVIEWING AND ADAPTING THE LCA METHODOLOGY:



## ENVIRONMENTAL LCA OF AGROFORESTRY SYSTEMS – AND ACROSS SYSTEMS:



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Research article  
**Life cycle assessment and modeling approaches in silvopastoral systems: A case study of egg production integrated in an organic apple orchard**  
 Mónica Quevedo-Cascante<sup>a,\*</sup>, Teodora Dorca-Preda<sup>b</sup>, Lisbeth Mogensen<sup>b</sup>, Werner Zollitsch<sup>b</sup>,  
 Muhammad Ahmed Waqas<sup>b</sup>, Stefan Hörtenhuber<sup>b</sup>, Reinhard Geiß<sup>b</sup>, Anne Grete Kongsted<sup>a</sup>,  
 Marie Trydeman Knudsen<sup>a</sup>

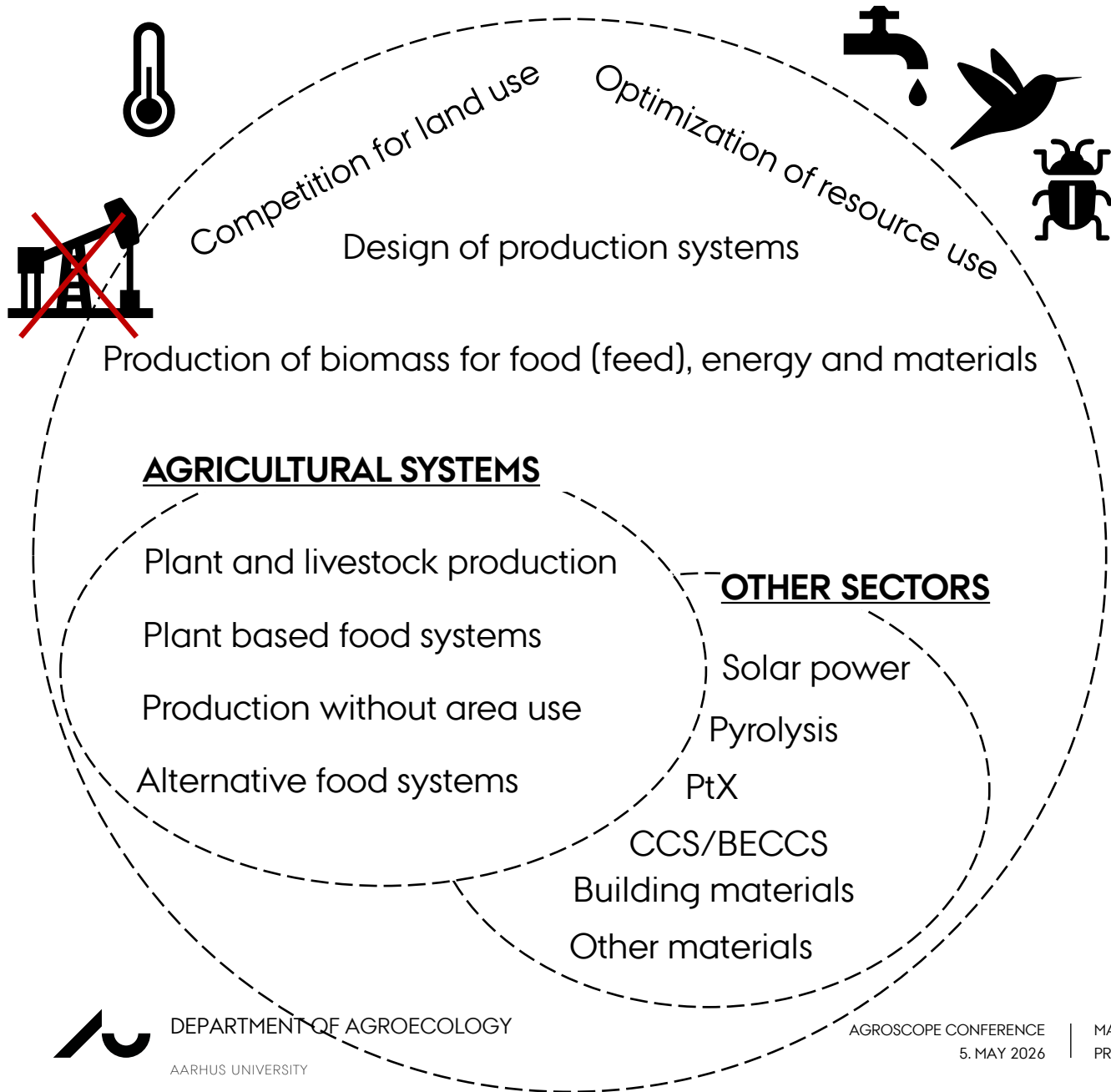
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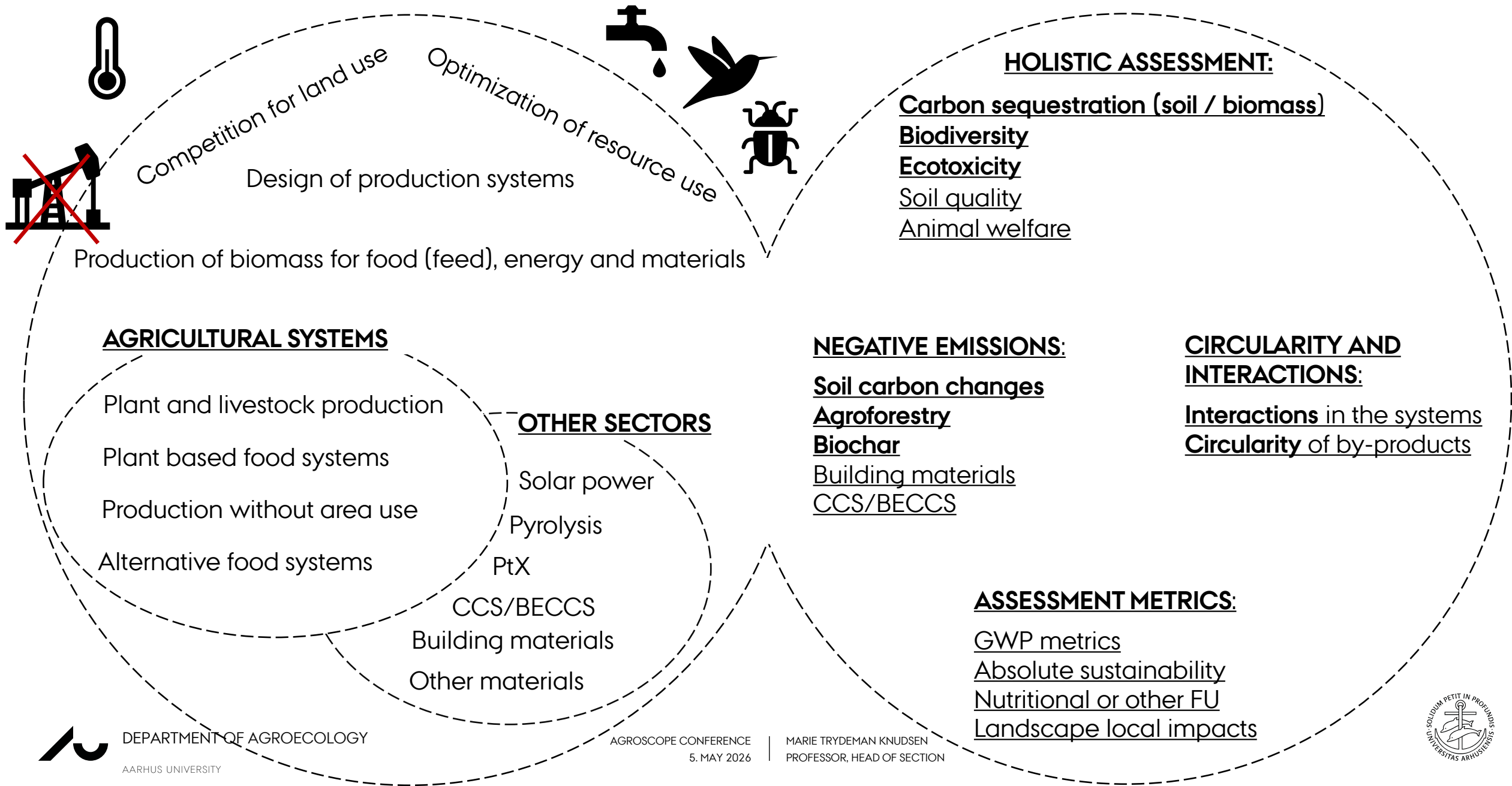
**ABSTRACT**  
 This paper aimed to assess the environmental impacts of two organic silvopastoral farms in Austria, using a Life Cycle Assessment approach. The two farms (F1, F2), with egg production integrated into an apple orchard, were compared to standard practices for each product. The functional unit was '1 kg fresh Class 1 apples' and '1 kg fresh Class 1 eggs'. The assessment covered two scopes: cradle-to-farm gate and cradle-to-retail for each product. Effects on climate (including carbon sequestration in the soil and woody biomass), eutrophication potential (EP), acidification potential (AP), and land occupation (LO) were assessed. Feed, manure, and land were three resource loops included in the system boundary. Two modeling approaches were used from cradle-to-farm gate for distributing the impacts of the entire system between apples and eggs: model 1 (M1) used economic allocation,

# DEVELOPMENT OF NEW FOOD AND AGRICULTURAL SYSTEMS



# DEVELOPMENT OF NEW FOOD AND AGRICULTURAL SYSTEMS

# METHODOLOGICAL DEVELOPMENT



# CONCLUSION

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Transformative re-design of our agri-food systems are urgently needed

It requires appropriate assessment methods and tools to examine the climate and environmental performance

- Improve both at production and consumption of food
- Assess impacts both per area unit and at product level
- Assess impacts not only on climate, but also on biodiversity, eutrophication, ecotoxicity and animal welfare
- Identify and assess trade-offs



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