Department of Planning
Rendsburggade 14
DK-9000 Aalborg
Karen-Emilie Trier Kreutzfeldt

# Environmentally Sustainable Protein Production in Danish Organic Agriculture

## A Comparative Life Cycle Assessment between Chinese Soybean Meal Import, Danish Fava Beans, and Danish Grass Protein Concentrate

Master Thesis

**Environmentally Sustainable Protein Production in Danish Organic Agriculture**

A Comparative Life Cycle Assessment between Chinese Soybean Meal Import, Danish Fava Beans, and Danish Grass Protein Concentrate

Master Thesis

June 3, 2022

By Karen-Emilie Trier Kreutzfeldt

10th Semester, Environmental Management & Sustainability Science

Aalborg University, Department of Planning, Rendsburggade 14, DK-9000 Aalborg Denmark

http://en.plan.aau.dk

**AALBORG UNIVERSITY**
STUDENT REPORT

**Title:**
Environmentally Sustainable Protein Production in Danish Organic Agriculture

**Theme:**
Master Thesis

**Project Period:**
Spring semester 2022


**Participants:**
Karen-Emilie Trier Kreutzfeldt

**Supervisor:**
Jannick Schmidt and Michele De Rosa


**Copies:** 1

**Page Numbers:** 118

**Date of Completion:**
June 3, 2022


**Abstract:**

**Background:** The organic sector aspires to a frontrunning position in sustainability by increasing self-sufficiency. In this case, it is desired to phase out the import of soybean meal as protein feed and instead increase national alternatives. Thus, this study aims to environmentally assess the differences in the impact of the soybean import compared to Danish fava beans and grass protein concentrate (GPC).
**Method:** The assessment is performed as a consequential life cycle assessment (LCA), based on the ISO14040, 2006 and ISO14044, 2006 with the use of Exiobase database.
**Results:** The LCA results show that soybean meals import have the lowest impact on nature occupation and global warming, fossil followed by fava beans and lastly GPC with the highest impacts. In respiratory inorganics, soybean meals have the highest impact, followed by GPC and fava beans with the lowest impact.
**Conclusion:** It can be concluded that the soybean meal import has the lowest environmental impacts compared to fava beans and grass protein concentrate. This indicates that the production site does not necessarily influence the environmental impact positively. Instead, it is a question of how to reduce the meat demand among consumers; thus, plant-based protein can increase market share. Danish production of protein crops for human consumption will positively affect the aspired position in sustainability.

# Preface

This report is a master thesis from *MSc Environmental Management and sustainability Science* at Aalborg University. It is conducted in the period from 01.02.2022 to 03.05.2022. The study aims to assess the organic protein feed in Denmark environmentally. This is done by utilizing a life cycle assessment to compare organic soybean meal import to the Danish alternatives, fava beans, and grass protein concentrate and their respective environmental performances. The report's audience is stakeholders within the organic sector: farmers, R&D organizations, advisors, consultants, and politicians. The last mentioned is included because the goal of the organic sector is to become global front-runners in sustainability, and the results from the study contribute to this goal.

I want to thank my supervisors, Jannick Schmidt and Michele De Rosa, for their valuable guidance, motivation, and input during the thesis. In addition, special thanks appear to the interview respondents, Organic sector chief, Kirsten Lund Jensen, chief consultant, Sven Hermansen, and Project leader, Erik Fog, both from Innovation Center for Organic Farming. Lastly, informal conversations with organic farmer, Henrik Kreutzfeldt and Lector in global value chains, Aske Skovmand Bosselmann, are highly appreciated.

**Reading instructions**

The Harvard referencing style is applied in the report. Tables and figures are referred to by the respective chapter and the sequential number within the chapter. Interview transcriptions, informal conversation descriptions, relevant LCI data and pictures can be found in Appendix B to D. The IO-table performed for the LCA is included in the external appendix. Further description is included in Appendix A.

*Karen-Emilie Trier Kreutzfeldt*

Karen-Emilie Trier Kreutzfeldt

kkreut17@student.aau.dk

# Abbreviations

| Acronyms | Countries and regions |
|---|---|
| **C** Carbon | **AR** Argentina |
| **CAP** Common Agricultural Policy | **BR** Brazil |
| **CP** Crude protein | **CN** China |
| **CPO** Crude palm oil | **DK** Denmark |
| **CPKO** Crude palm kernel oil | **ID** Indonesia |
| **CSBO** Crude soil bean oil | **GLO** Global |
| **dLUC** Direct land use changes | **MY** Malaysia |
| **DM** Dry matter | **RU** Russia |
| **EFB** Empty fruit bunches | **UA** Ukraine |
| **FFB** Fresh fruit bunches | **US** United States of America |
| **FB** Fava beans | **WA** Exiobase region: Rest of Asia (MY location) |
| **FM** Fresh matter | **WE** Exiobase region: Rest of Europe (UA location) |
| **GE** Gross energy | **WL** Exiobase region: Rest of Latin America (AR location) |
| **GPC** Green protein concentrate | |
| **HCV** High conservation value | |
| **iLUC** Indirect land use changes | |
| **IPPC** Intergovernmental Panel for Climate Changes | |
| **ISO** Intergovernmental Organization for Standardization | |
| **K** Potassium | |
| **KU** University of Copenhagen | |
| **LCA** Life Cycle Assessment | |
| **LCI** Life Cycle Inventory | |
| **LCIA** Life Cycle Impact Assessment | |
| **LUC** Land use changes | |
| **N** Nitrogen | |
| **NMVOC** Non-methane volatile organic compounds | |
| **PKO** Palm kernel oil | |
| **PO** Palm oil | |
| **POME** Palm Oil Mill Effluent | |
| **RBD** Refined, bleached and deodorized | |
| **SB** Soybeans | |
| **SBM** Soybean meal | |
| **TSP** Total Suspended Particulate | |

# Summary

The Danish agricultural sector aspires to a 70% reduction in $CO_2$ emissions in 2030 and to be climate neutral in 2050. One of the tools to reach said goals is to increase the organic arable land from 11% to 22% of the total arable land in Denmark. The organic sector is increasing, and the goal is to develop the most sustainable organic production globally. In this regard, the sector wants to phase out the import of soybean meal and substitute the protein source with national alternatives. In Denmark, the promising potentials are fava beans and grass protein concentrate (GPC). However, it is unknown whether national alternatives have lower environmental impacts than soybean meal import.

This thesis compares the environmental performance of the protein sources utilizing a life cycle assessment (LCA). The functional unit is 1 kg crude protein delivered at Aarhus Harbour. Three impact categories are assessed: 1) nature occupation, 2) global warming, fossil, and 3) respiratory inorganics. The results show that the soybean meal import has the lowest impact on nature occupation and global warning, followed by fava beans. That means the GPC has the highest impact in these two categories. In respiratory inorganics, soybean meal has the highest impact, followed by GPC, while fava beans have the lowest impact. In terms of nature occupation and global warming, contribution analyses show that the main cause is soybean oil (the by-product of soybean meal) substitutes palm oil, which significantly reduces the impact of soybean meal. In addition, indirect land use changes (iLUC) are the main contributor. GPC requires more land use to produce 1 kg crude protein resulting in the highest impacts compared to the productions of soybeans and fava beans. Regarding respiratory inorganics, the transportation of the soybean meal from China to Denmark is the main contributor to the soybean meal having the biggest impact.

These results conclude that soybean meal import is the most environmentally friendly production. However, this does not contribute to self-sufficiency, so different parameters and improvements are discussed to assess other results. The conclusion is still that the production site does not necessarily positively influence environmental sustainability. It is concluded that it is crucial to communicate the LCA results and describe iLUC. This leads to a discussion about whether organic consumers can decrease the meat demand; thus, plant-based proteins can increase the market share. By applying the *Multi-Level Perspective* theory, it describes how niche innovations in producing proteins for plant-based protein in Denmark can increase. Thus, they understand the necessity of improving plant-based protein instead of meat as it will contribute to the goal of being front-runners in sustainability. In addition, it might be possible to move the feed protein production to Denmark because the demand for livestock production has decreased. In this regard, it is relevant to improve both fava beans and GPC because they can enter the same crop rotation and be used for both feed and food.

## Table of Contents


**1 Introducing Danish Alternatives to Organic Soybean Meal Import** **2**

1.1 The goal of phasing out soybean meal import . . . 2
1.2 National alternatives to organic soybean meal import . . . 4
1.3 The size of arable land needed to replace soybean meal import . . . 7
1.4 The necessity of a comparative LCA . . . 8
1.5 Research Question . . . 9

**2 Research Methodology and Theory** **10**

2.1 Research design . . . 10
2.2 Qualitative methods . . . 12
2.3 Literature review . . . 14
2.4 Multi-Level Perspective theory . . . 15
2.5 Life cycle assessment: description . . . 17

**3 Goal and Scope** **18**

3.1 Function and functional unit . . . 18
3.2 System boundaries . . . 19
3.3 Life cycle inventory: background System . . . 21
3.4 Life cycle impact assessment: methodology . . . 23

**4 Life Cycle Inventory** **25**

4.1 LCI: Land use . . . 25
4.2 LCI: Transportation . . . 27
4.3 LCI: Capital goods during cultivation . . . 27
4.4 LCI: Seeds . . . 28
4.5 LCI: Fuel . . . 28
4.6 LCI: Markets for feed energy and feed protein . . . 29
4.7 LCI: Soybean meals . . . 31
4.8 LCI: Fava beans . . . 35
4.9 LCI: Grass protein concentrate . . . 37
4.10 Delimitations . . . 43

**5 Life Cycle Impact Assessment** **44**

5.1 Characterization . . . 44
5.2 Weighting . . . 45

5.3 Contribution analysis . . . 46
5.4 Summarized interpretation of the LCIA results . . . 49

**6 Reflection on other parameters not covered by the LCA results 50**
6.1 An increased organic market . . . 50
6.2 Improvements of the Danish alternatives . . . 52
6.3 Proteins for food - not feed . . . 54
6.4 Recommendation and further work . . . 56

**7 Conclusion 57**

**A IO-table 66**

**B LCI: Energy and Conventional Protein Crops 67**
B.1 Organic energy crops: spring oats and spring barley . . . 68
B.2 Conventional energy and protein crops . . . 69
B.3 Milling and refining conventional soybean meal and oil . . . 71

**C LCI: Palm oil 73**
C.1 Oil palm cultivation . . . 74
C.2 Palm oil milling process . . . 75
C.3 Palm kernel crushing . . . 76
C.4 Palm oil refinery . . . 77

**D Contribution Analyses - Tables 78**
D.1 Nature occupation . . . 78
D.2 Global warming . . . 79
D.3 Respiratory inorganics . . . 80

**E Interview Transcriptions 81**
E.1 Erik Fog - 10-03-2022 . . . 81
E.2 Kirsten Lund Jensen - 11-03-2022 . . . 91
E.3 Sven Hermansen - 11-03-2022 . . . 100

**F Phone Conversations 115**
F.1 Henrik Kreutzfeldt, organic farmer - multiple conversations . . . 115
F.2 Aske Skovmand Bosselmann, University of Copenhagen (KU) - 16-05-2022 . . . 115

**G Forum for Organic Advisement 116**

**H Communication of the LCA results** **117**

H.1 Shannon-Weaver communication model (SWCM) . . . . . . . . . . . . . . . . . . . . . . . . 117

## List of Figures


1.1 Fresh soybeans. Picture from [FAFC, 2022]. . . . . . . 2
1.2 Soybean meal ready for distribution. Picture from [Landbrugsavisen.dk, 2022]. . . . . . . 2
1.3 Distribution of four most common legumes i Danish, organic agriculture, divided into the land use of each legume in 2021 [MDAF, 2021]. . . . . . . 4
1.4 Fresh fava beans. Picture from [Landbrugsavisen.dk, 2022] . . . . . . . 5
1.5 Fresh clover grass. Picture from [DLF, 2022]. . . . . . . 5
1.6 Processes of producing GPC in biorefinery. Illustration inspired from [Santamaria-Fernandez et al., 2020] . . . . . . . 6

2.1 Research design. Visualized overview of the study and how the research question is answered. 11
2.2 An illustration of the systematic literature review and belonging selection process. . . . . 14
2.3 Multi-level perspectives on transition. Illustration from [Schot and Geels, 2008]. . . . . . . 15
2.4 Own illustration of the LCA framework prescribed by ISO14040, 2006. . . . . . . 17

3.1 System boundary of importing organic soybean meal (SBM) from China. Activities are shown as boxes and flows as arrows. . . . . . . 20
3.2 System boundary of national produced organic fava beans. Activities are shown as boxes and flows as arrows. . . . . . . 20
3.3 System boundary of nationally produced organic grass protein concentrate (GPC) before distributed at Aarhus Harbour. Activities are shown as boxes and flows as arrows. . . . . 21
3.4 An example of an IO-table (from the SBM system) where inputs to the foreground system are from the foreground system and the background system. The figure is inspired by [Schmidt and De Rosa, 2020]. . . . . . . 22

5.1 Weighted results for producing the 1 kg CP (FU) from SBM, FB and GPC. . . . . . . 45
5.2 Process contribution to nature occupation from producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively Own illustration. . . . . . . 47
5.3 Process contribution to global warming from producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. Own illustration. . . . . . . 48
5.4 Process contribution to respiratory inorganics from the production of the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. Own illustration. . . . . . . 49

6.1 The development of the top ten producing palm oil countries 2015 to 2020. The decrease from 2019 to 2020 is mainly due to COVID-19. Own illustration. Data provided by FAOSTAT, 2022. . . . . . . 50

6.2 Sensitivity analysis on nature occupation of increasing the yields with 10%, 20% and 30%. The default scenarios are SBM: 0.90 PDF*$m^2$/1 kg CP, FB: 1.04 PDF*$m^2$/ kg CP and GPC: 3.94 PDF*$m^2$/ kg CP. . . . 52
6.3 Sensitivity analysis on global warming of increasing the yields with 10%, 20%, and 30%. The default scenarios are SBM: -0.41 kg $CO_2$-eq/kg CP, FB: 0.51 kg $CO_2$-eq/ kg CP and GPC: 4.89 kg $CO_2$-eq/ kg CP. . . . 52
6.4 Sensitivity analysis on respiratory inorganics of increasing the yields with 10%, 20%, and 30%. The default scenarios are SBM: 1.95E-3 kg $PM_{2.5}$-eq/kg CP, FB: -1.04E-4 kg $PM_{2.5}$-eq/ kg CP and GPC: 1.29E-3 kg $PM_{2.5}$-eq/ kg CP. . . . 52

C.1 System boundary of the palm oil substitution when producing soybean meal. Own illustration. . . . 73

G.1 Inputs for future research. . . . 116
G.2 Participants subjectively voting for future research. . . . 116
G.3 Participants subjectively voting for future research . . . 116

H.1 Shannon-Weaver's model of communication. Visualization inspired by Communicationstheory.org, 2022. . . . 117

# List of Tables

1.1 Top five agricultural imports in Denmark in 2020. Data provided by FAOSTAT, 2022. The data is both conventional and organic. *Not else classified. . . . . . . . . . . . . . . . . 3

2.1 Overview of the conducted interviews and phone conversations, including a description of relevance, and how it helps answer the research question (Continued). . . . . . . . . . . . 12

2.1 Overview of the conducted interviews and phone conversations, including a description of relevance, and how it helps answer the research question. . . . . . . . . . . . . . . . . . . . . 13

3.1 Overview of the legumes, including the CP content, kg crop cultivated per kg feed, the DM percentage, and lastly the RFs. Data are acquired from Schmidt and De Rosa, 2020; SEGES Innovation, 2022a; Fog, 2022 and SEGES, 2020 . . . . . . . . . . . . . . . . . . . . . 19

3.2 Overview of Impact Categories in Stepwise2006.v.1.0.7. with the physical units and short descriptions. Impact category *Ionizing radiation* is excluded as it refers to radionuclide emissions from nuclear power in the electricity mix, which is non-relevant in Denmark [Fact-based sustainability, 2021]. The table is added from last year's semester project [Kreutzfeldt, 2021] (continued.). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 23

3.2 Overview of Impact Categories in Stepwise2006.v.1.0.7. with the respective units and short descriptions. Impact category *Ionizing radiation* is excluded as it refers to radionuclide emissions from nuclear power in the electricity mix, which is non-relevant in Denmark [Fact-based sustainability, 2021]. The table is added from last year semester project [Kreutzfeldt, 2021] . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 24

4.1 Yields of three assessed protein crop productions [Knudsen et al., 2010; SEGES Innovation, 2022a; Fog, 2022]. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 26

4.2 Land use for the three protein crop productions, including the $NPP_0$ factors from China (0.94 kg C/ha/yr) and Denmark (1.08 kg C/ha/yr). . . . . . . . . . . . . . . . . . . . . . 26

4.3 Overview of cultivation processes when producing Chinese soybeans, Danish fava beans, spring oats and spring barley. The data indicates how many times the respective process appears to cultivate 1 ha. *All data are provided by SEGES Innovation, 2022a. . . . . . . 28

4.4 LCI data for conventional and organic feed energy and protein. The crop cultivations for conventional GE crops and soybean meals can be seen in Table B.2. Organic GE crop cultivations are outlined in Table B.1 and soybeans cultivation in Table 4.5. . . . . . . . . 30

4.5 LCI data for cultivating 1 t organic SB in China. Data from [Knudsen et al., 2010] and Ecoinvent 3.8. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 32

4.6 Summary of LCI data for milling 0.77 t soybeans and treatment of 1 t CSBO. Additionally, with the inputs to the marginal market for vegetable oils, which in this case is CPO. See Table C.4. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 34
4.7 Summary of LCI data for producing 1 t FB [SEGES Innovation, 2022a]. . . . . . . . . . . 36
4.8 Summary of LCI data for cultivating 32.67 t fresh clover grass [Fog, 2022] (continued). . . 38
4.8 Summary of LCI data for cultivating 32.67 t fresh clover grass [Fog, 2022]. . . . . . . . . . 39
4.9 Summary of LCI data for refining 1 t GPC from the Ausumgaard.dk, 2022 plant (continued). 40
4.9 Summary of LCI data for refining 1 t GPC from the Ausumgaard.dk, 2022 plant. . . . . . 41
4.10 Summary of LCI data for treatment of green fibre and brown juice from Table 4.9, which is anaerobic digestion (biogas). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 42

5.1 Characterization results for producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 44
5.2 Summary of the characterized results on nature occupation, global warming, and respiratory inorganics when producing 1 kg CP from SBM, FB, and GPC, respectively. Stepwise.v.1.0.7 method is utilized. . . . . . . . . . . . . . . . . . . . . . . . . . . . . 46

7.1 Summary of the characterized results on nature occupation, global warming, and respiratory inorganics when producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. Stepwise.v.1.0.7 method is utilized. . . . . . . . . . . . . . . . . . . . . . . . 57

B.1 Summary of LCI data for the organic produced marginal mix of energy crops in Denmark (spring oats and spring barley). All data are from SEGES Innovation, 2022a, except for the transportation of slurry, which is assumed to be the same as for the grass production in Table 4.8. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 68
B.2 Summary of LCI data for cultivating conventional energy and protein crops. The links to Exiobase can be seen in Table B.3. (Continued). . . . . . . . . . . . . . . . . . . . . . . . 69
B.2 Summary of LCI data for cultivating conventional energy and protein crops. The links to Exiobase can be seen in Table B.3 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 70
B.3 Summary of LCI data for what background data from Exiobase that are used for the activities in Table B.2 (continued). The background activities are chosen for the respective countries. (Continued) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 70
B.3 Summary of LCI data for what background data from Exiobase that are used for the activities in Table B.2. The background activities are chosen for the respective countries. . 71
B.4 Summary of LCI data for conventional SB milling and treatment of CSBO together with the inputs to the marginal market for feed protein in Table 4.4 and vegetable oils, which in this case is CPO in Table C.4. (Continued). . . . . . . . . . . . . . . . . . . . . . . . 71

B.4 Summary of LCI data for conventional SB milling and treatment of CSBO together with the inputs to the marginal market for feed protein in Table 4.4 and vegetable oils, which in this case is CPO in Table C.4. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 72

C.1 LCI data for cultivating 17.00 t FFB. . . . . . . . . . . . . . . . . . . . . . . . . . . . . 74
C.2 Summary of LCI data for milling 1 t FFB. . . . . . . . . . . . . . . . . . . . . . . . . . . 75
C.3 Summary of LCI data for crushing 1 t PK. . . . . . . . . . . . . . . . . . . . . . . . . . . 76
C.4 Summary of LCI data for refining 1 t CPO and 1 t CPKO. . . . . . . . . . . . . . . . . . . 77

D.1 Process contribution to nature occupation from producing the functional unit: 1 kg CP from SBM, FB and GPC, respectively. . . . . . . . . . . . . . . . . . . . . . . . . . . . 78
D.2 Process contribution to global warming, fossil from the production of the functional unit: 1 kg CP from SBM, FB and GPC, respectively. . . . . . . . . . . . . . . . . . . . . . . . 79
D.3 Process contribution to respiratory inorganics from the production of the functional unit: 1 kg CP from SBM, FB and GPC, respectively. . . . . . . . . . . . . . . . . . . . . . . . 80

# Introduction

The awareness of sustainable development is growing at all levels of society. According to Al-Saidi, 2019 institutional changes are required to ensure a long-term implementation. These changes are about to happen in various sectors today, including agriculture. Among multiple examples, the changes in the agricultural sector can be seen in the newly described goal: 70% $CO_2$ reduction (from 1990 to 2030) [The Danish Government, 2021] and a climate-neutral sector by 2050 [DAFC, 2020a]. The reason for this is the sector's contribution to climate change, as it accounts for 22.4 percent of total $CO_2$-eq emissions [Nielsen et al., 2017].

The political discourse about sustainable agriculture is, among others, centred around organic practices and how an increase will contribute to the sustainable development. The current goal is to double the organic, arable land from 11% to 22% within 2030 [Finansministeriet, 2021]. Today, Denmark has an increasing organic sector because farmers, organizations, and authorities in unison improve the production and consumer trust [DAFC, 2021b]. For that reason, the 11.70% (300,000 ha.) results from a 1400% increase from 1992 (20,000 ha). Additionally, from an EU perspective, European Commission, 2022 finds organic food products being tantamount to high-quality products with low environmental impacts, which is why the main goal is to have 25% of the arable land in the EU organically cultivated within the 2050. This indicates a global interest, whereto DAFC, 2021b states the following goal:

*"We will be world champions in developing a sustainable, organic production."*

According to Jensen, 2022, sustainable, organic agriculture is about: *keeping the resources, thus we can deliver the soil to next generation in the same conditions"*. This is in concordance with the general description from the Brundtland Report stating that sustainability is about fulfilling the current need in the society without putting the future society's needs in danger [WCED, 1987]. Organic agriculture is also about self-sufficiency and a general system foundation. This means Denmark is independent of import [Jensen, 2022; DAFC, 2021b]. This is especially due to the soybean meals, as it is the primary protein source in feed for ruminants and monogastric animals [Santamaría-Fernández et al., 2017]. However, it remains proven that an organic, locally produced source of protein feed has lower environmental impacts than imported soybean meals. If Denmark prioritizes the national production, but the environmental impacts are higher than the import, it will negatively affect the goal of sustainable frontrunners. In addition, increasing the production of one crop will most likely lead to the decrease of another, which results in less dependency on soybean meal import but instead on import of the replaced crop. For that reason, this study will delve into Denmark being self-sufficient in protein feed and whether it is more environmental-friendly than importing soybean meals. Hence, the frontrunning position in sustainability can be achieved.

# Chapter 1

## Introducing Danish Alternatives to Organic Soybean Meal Import

*This chapter serves as a general description of the desire to phase out soybean meal import and provide current Danish organic alternatives. There is, furthermore, a focus on life cycle assessments (LCA) on organic productions and how LCA can be applied to improve sustainable development within the organic sector. Lastly, the research question of the study is outlined.*

## 1.1 The goal of phasing out soybean meal import

As stated in the Introduction, the organic sector in Denmark aspires to a position as the frontrunner in sustainability. In this regard, Denmark sets a goal to phase out the soybean meal (SBM) import (output of soybean milling). Firstly, 1/3 of the protein feed is European or national produced. Secondly, by 2025 the total import of soybeans and SBM will be replaced with European production or phased out by other European alternatives [DAFC, 2021b]. There are two principal reasons for achieving said goal. Firstly, the political goal of achieving self-sufficiency within the organic sector [Larsen et al., 2019; Santamaría-Fernández et al., 2017; Jensen, 2022]. This is based on the main discourse in the sector being self-sufficiency as the most sustainable solution. In addition, organic agriculture is based on a system foundation, which means that when Denmark decides to have livestock production, the main responsibility is to produce the appertaining feed coming along with this decision Fog, 2022.

**Figure 1.1:** Fresh soybeans. Picture from [FAFC, 2022].

**Figure 1.2:** Soybean meal ready for distribution. Picture from [Landbrugsavisen.dk, 2022].

The current lock-in in Danish agriculture is, however, centred around a specialization in producing cereal crops [Reckling et al., 2020], resulting in the current dependency on soybean meal import (due to amino acid content and taste [Cong and Termansen, 2016]), which challenges the aspired self-sufficiency.

Today, the soybean meal import equals 21% of the total agricultural import (conventional and organic summarized), indicating the biggest share within the Danish agriculture as illustrated in Table 1.1.

| Item | Unit | Value | % |
|---|---|---|---|
| Meal, soybeans | t | 1,667.959 | 21.32 |
| Meal, sunflower | t | 280,432 | 3.59 |
| Food wastes | t | 267,765 | 3.42 |
| Meal, rapeseed | t | 247,919 | 3.17 |
| Beet pulp | t | 209,023 | 2.67 |

**Table 1.1:** Top five agricultural imports in Denmark in 2020. Data provided by FAOSTAT, 2022. The data is both conventional and organic. *Not else classified.

According to Hermansen, 2022, the organic sector imported roughly 31,000 t soybean meals in 2019, equal to 24,000 ha. The main supplier is China because of the possible GMO-free production, which is a requirement in organic agriculture as well [Santamaría-Fernández et al., 2017]. China is currently challenged with the supply because of the COVID19 lockdown and the global consignments that follow [DAFC, 2021a; Santamaría-Fernández et al., 2017; Jensen, 2022]. Furthermore, PBE, 2022 reports that higher prices for organic protein feed imports occur due to a limited market, with prices for organic protein feed being higher than conventional. This further supports the out phasing of organic soybean meals.

Secondly, achieving the goal mentioned above is important due to environmental impacts from land use changes (LUC), with deforestation at its center. This mainly involves the rainforests of South America [Schmidt and De Rosa, 2020]. Even though the organic soybean meals are Chinese produced, the Danish import indirectly deforests the rainforest. According to Ren et al., 2021 and FAOSTAT, 2022 China is the biggest soybean importer, accounting for 60% of the global market. 90% of Chinese soy is imported primarily from Brazil, the US, and Argentina, increasing demand. Stressed by Arendt, 2022, China's import of conventional soybeans between 2021 and 2022 has increased by 241% (from 1.03m tons to 3.51m tons). However, China still produces soybeans meals because countries like Denmark import them. Lector in global, agricultural value chains at KU, Bosselmann, 2022 agrees on this and adds the critical impacts like biodiversity losses and negative impacts on socio-economics. This is, in other words, indirect land use changes (iLUC). Further description can be found in Section 4.1.

Stakeholders in the agricultural sector and consumers may be unaware of these consequences, implying the importance of effective communication. It is difficult, however, since global value chains are rarely transparent [Bosselmann, 2022]. As a result, there is some uncertainty behind the abovementioned conclusions, and more research is required. Nonetheless, it demonstrates the difficulties of global trade and how each country has its corporate model. This supports the argument that Denmark shall reduce its dependency on imports. As a result, it is necessary to consider the possible Danish options, which are outlined in the following section.

## 1.2 National alternatives to organic soybean meal import

Soybeans are not suitable for the Danish climate [Knudsen et al., 2010]. For that reason, DAFC, 2021b stresses that clover grass, peas, lupins, and fava beans are essential opportunities. The distribution of the four mentioned legumes in Denmark is illustrated in Figure 1.3. Clearly, clover grass is the biggest production (69,000 ha) followed by fava beans (12,000 ha), peas (3,000 and lastly lupins (2,000 ha) [MDAF, 2021]. This indicates especially clover grass and fava beans as promising potentials because of their well-known production processes in Denmark [DAFC, 2021b].

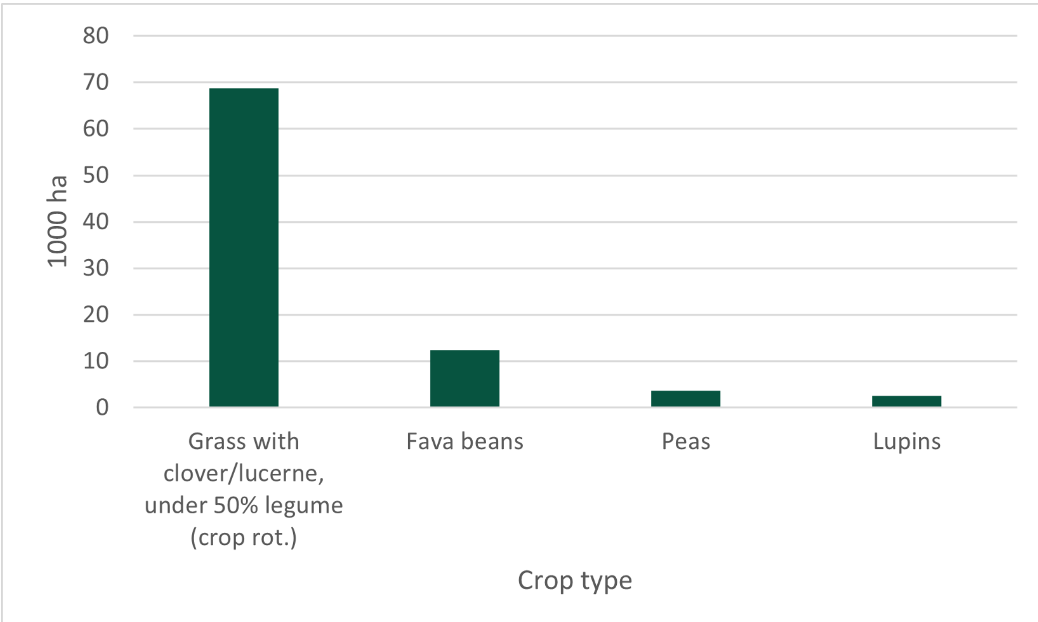


**Figure 1.3:** Distribution of four most common legumes i Danish, organic agriculture, divided into the land use of each legume in 2021 [MDAF, 2021].

Additionally, Fog, 2022 stresses the challenges of pea production based on the sensitivity to water application and a difficult harvesting process. When asking about lupins, Fog, 2022 argues that the yields are low, and they contain multiple poisonous substances, which require extra processing activities before they are eatable by livestock or humans [Santamaría-Fernández et al., 2017]. Looking at fava beans, the well-known production is caused by their ability to biologically nitrogen fixate, which means to catch nitrogen from the air and added to the soil [Reinsch et al., 2021; Jensen et al., 2020; Brozyna et al., 2013]. This is useful for organic farmers underlying strict fertilizer limitations [MFAFD, 2022]. This is the function for all legumes, but as fava beans are suitable for the Northern European climate, and they can be used for feed to both ruminants and monogastric animals, they are included in Danish agriculture [Santamaría-Fernández et al., 2017; Heusala et al., 2020]. Lastly, fava beans have no extra processes. After harvesting, the fava beans are dried and are ready for distribution. However, according to Hermansen, 2022 and Santamaría-Fernández et al., 2017, it is not possible to substitute soybean meals with fava beans 1:1 because of different nutrient contents. This means that feeding with fava beans requires a mix of different crops to achieve the same content as in soybean meals [Hermansen, 2022; Kreutzfeldt, 2022].

**Figure 1.4:** Fresh fava beans. Picture from [Landbrugsavisen.dk, 2022]

**Figure 1.5:** Fresh clover grass. Picture from [DLF, 2022].

The reason behind the big proportion of clover grass, is according to Hermansen, 2022, because 85% of the organic livestock are cattle (ruminants), which are fed with grass protein. To feed monogastric animals like pigs and poultry with substantial amounts of clover grass, it is necessary to extract grass protein concentrate (GPC) through a biorefinery, because of their digestion system [Santamaria-Fernandez et al., 2020; Larsen et al., 2019]. Karlsson et al., 2021 stresses that reducing soybean meal import is more an advantage for ruminant rather than monogastric animals, but both Fog, 2022 and Jensen, 2022 find GPC as a breakthrough to this problem. The GPC extraction is visualized in Figure 1.6.

Clover grass is furthermore an advantage in the crop rotation, because they are not affected by the same diseases as other legumes, and they have the BNF ability too [Fog, 2022]. Lastly, clover grass has a strong ability to carbon storage, which is an environmental benefit, along with an increased soil fertility [Fog, 2022; Reinsch et al., 2021]. According to Harbo et al., 2022 the yield gap between organic and conventional agriculture can be minimized by inclusion of clover grass.

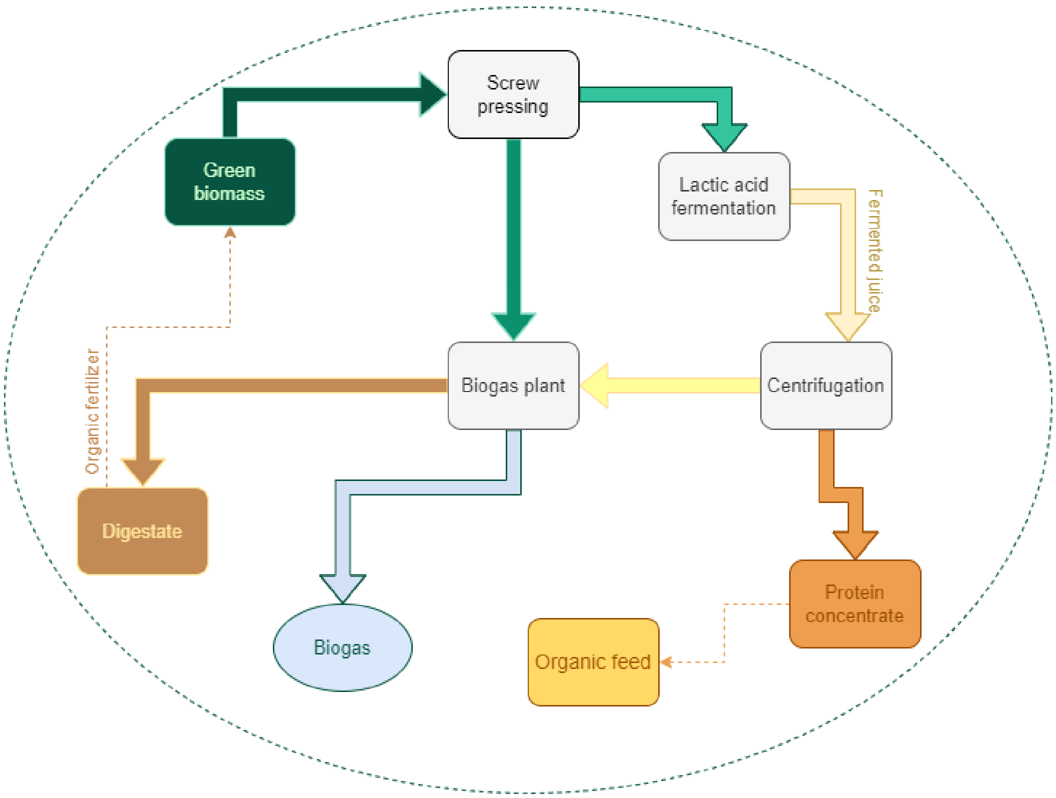


**Figure 1.6:** Processes of producing GPC in biorefinery. Illustration inspired from [Santamaria-Fernandez et al., 2020]

In Figure 1.6, the processes of producing GPC is illustrated. Firstly, the grass will be added to the screw presser after harvesting, where the outputs are green fibre and brown juice. The green fibre can either be an input to a biogas plant, where the output is biogas, and the digestate as green fertilizer, or as coarse fodder to ruminants [Santamaria-Fernandez et al., 2020; SEGES Innovation, 2022b]. The brown juice gets lactic acid fermented followed by a centrifugation process, where the output is the final GPC ready for distribution. As a result, according to numerous sources, clover grass as an input to biorefining contributes to feeding supply, energy supply, circularity, and self-sufficiency on a system level [Cong and Termansen, 2016].

Because of multiple benefits after the clover grass is treated, the Danish Climate Partnerships find GPC as one of the main solutions for $CO_2$ reductions in the Danish agriculture [Regerings Klimapartnerskaber, 2020]. Be that as it may, according to Fog, 2022, neither the production of GPC nor fava beans are environmentally assessed compared to organic soybean meal import. This can question the potential sustainability of many stakeholders assume Danish alternatives to be. Additionally, new information stated by Hermansen and Munk, 2022 concerns the land use needed to substitute the total soybean meals with national alternatives, which affect multiple aspects besides the environmental impacts. This is further described in the following section.

## 1.3 The size of arable land needed to replace soybean meal import

The most prominent subject in the literature review (see Section 2.3) is the aforementioned ability to biological nitrogen fixate (BNF). For that reason, the EU organic statutory instrument[1] requires a minimum of 20% legumes in the crop rotation in order to reduce external inputs [DAFC, 2021a]. Because of fertilizer limitations, Hermansen, 2022 stresses that Danish organic farmers already produce 33,000 ha of legumes in the crop rotation as of 2021.

Hermansen, 2022 has calculated the estimated land use needed in Denmark in order to fully replace the soybean meal import. Today, organic arable land can contain roughly 22,000 ha more with protein crops such as legumes, clover grass, and rapeseed. However, if the phase-out of soybean meals realizes it will require approximately 60,000 ha additional organic land use, with legumes, clover grass, and rapeseed included [Hermansen and Munk, 2022]. The reason behind this is twofold. Firstly, besides GPC, Danish alternatives have a lower protein content than soybean meals. Secondly, because of various soil-borne plant diseases related to the legume family, a time gap of +four years between the most common legume crops is necessary [Hermansen, 2022; DAFC, 2021b].

This means that the required organic land use suddenly depends on the market, incentivizing more conventional farmers to switch to organic farming in order to meet the goal of phasing out organic soybean meal imports [Hermansen, 2022]. However, as mentioned in the Introduction, the goal is to double the organic arable land before 2030, approximately 287,000 ha, making it possible to convert 60,000 ha. Additionally, during the yearly 'Forum for Organic Counselling' described in Section 2.2.2, multiple participants did further argue that conventional farmers are considering changing practices because of current prices [DAFC, 2022a].

Nevertheless, these land use requirements are not environmentally assessed, and, as stated in the Introduction, the replaced crops in favour of protein production are assumed to be in demand, resulting in production somewhere else than Denmark. This is another example of iLUC, which is further described in Section 4.1. Fog, 2022, among others, advocate for a life cycle assessment (LCA), in which the soybean meal import and the Danish alternatives, fava beans, and grass protein concentrate, are environmentally compared. As a result, the following sections delve deeper into the significance of conducting a comparative LCA.

[1] Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007

## 1.4 The necessity of a comparative LCA

The most common way to assess environmental impacts within the agricultural sector is LCAs Werf et al., 2020. However, only two LCAs in the literature review are based on conventionally produced protein crops, which foremost indicate the low amount of LCAs on protein crops, and secondly show the relevance of performing more LCAs on organic productions. This is crucial because there are few scientific arguments demonstrating the current impacts and possible environmental benefits of organic agriculture [Jensen, 2022].

The LCA comparison is further relevant because new research from 2.0 LCA Consultants, 2022 stresses that soybean meal production reduces the impacts on global warming because the soybean oil (RBD SBO) (the by-product after milling the soybeans into meal) substitutes palm oil (RBD PO) production. RBD PO has a higher environmental impact per kg than RBD SBO. By including iLUC in the modelling, this substitution will positively impact the environment because more emissions are avoided compared to the emissions from the RBD SBO production. The overall reason is the deforestation and intensification of land. These results challenge the arguments for increasing the national alternatives based on environmental reasons. Since these results may be unknown to multiple actors is due to the iLUC, which can be challenging for non-experts to understand. According to Schmidt et al., 2015, there is a general missing understanding of linking land use and deforestation together with a lack of consensus on how to improve said link. Especially in LCAs. Another example is the import of Chinese imports indirectly deforest the rainforest, described in Section 1.1. Since global value chains are untransparent and vague descriptions of iLUC, society is not aware of these consequences.

By performing a comparative LCA between soybean meal import and the two Danish alternatives, fava beans, and GPC, will foremost increase the knowledge about the environmental impacts of the different productions. Secondly, it will provide information on the decision process regarding sustainable organic protein production ISO14040, 2006. According to Fog, 2022, communicating an LCA understandably will increase the choice awareness among stakeholders. In addition, during the previously mentioned 'Forum for Organic Counselling,' the dilemma of a few organic LCAs and the importance of environmentally assessing the three protein sources were presented. By presenting these topics, the majority of the 50 participants agreed on the importance of both, and everyone was interested to learn more [DAFC, 2022a]. However, it is uncertain, *how* the LCA can be understandable and create momentum; thus, it contributes to the goal of being sustainable front-runners in organic agriculture. For that reason, the next section will outline the research question within this study, which is centered around an LCA that compares the three mentioned feed protein productions and how communication of it can contribute to transitional changes.

## 1.5 Research Question

As displayed in the Introduction, both the EU and Denmark aspire an increase organic production regarding sustainability. Within organic agriculture, to increase sustainable production, self-sufficiency is important. This means that the dependency on importing soybean meal from China as feed protein must be replaced with national alternatives. As stated in Section 1.2, Fava beans and grass protein concentrate (GPC) are the main protein alternatives. The organic sector does especially target GPC as the solution for sustainable improvements because of additional outputs like biogas and green manure, as described in Section 1.2. Be that as it may, it is clear that the different protein productions vary, and to increase sustainability in organic agriculture, more LCAs are necessary, as mentioned in Section 1.4. Therefore, this study aims to compare organic soybean meal import with the nationally produced fava beans and GPC in an LCA. In addition, other parameters are important to discuss having a holistic approach to improving protein production. Lastly, it is theoretically assessed how the LCA can contribute to transitioning Danish organic agriculture into a frontrunner in sustainability. The research question of this study is posed as follows:

*What protein production is the most preferable between imported soybean meal from China, Danish fava beans, and Danish grass protein concentrate from an environmental perspective?*

- What are the different environmental impacts of the three protein sources in a life cycle assessment (LCA)?
- What other parameters should be considered to make the most environmentally friendly decision regarding organic protein production?
- How can the LCA results be applied to organic agriculture's transitional changes towards a frontrunning position in sustainability?

# Chapter 2

## Research Methodology and Theory

*This chapter aims to outline the methodology behind answering the research question. Firstly, the research design will be described, followed by the different approaches in qualitative methods. Lastly, the methodology behind life cycle assessments (LCAs) is outlined. Understanding the methodological decisions through this study increases validity, representativity, and transparency.*

## 2.1 Research design

The three sub-questions associated with the research question in Section 1.5 are individually investigated. Thus, the answers collectively answer the main research question. This is inspired by Yin, 2009, who describes the design as 'getting from here to there, and at the end, the research question will be answered. This is visualized as a research design in Figure 2.1. According to Farthing, 2015 it is relevant to perform the design in advance of the study to ensure a consistent frame, including iteratively and circularity. This is done in this study as well.

Looking at Figure 2.1 the research design is divided into six categories; *Sub-questions, Approach, Methodology, Data sources, Theory, Analysis*, and *Research question*. The sub-questions are described at the top of the design, followed by a deductive approach. This means continuing from a certain point in an existing theory. From this theory, a hypothesis is outlined, where the purpose is to test whether this can be proven or disproven [Wilson, 2014]. The hypothetical perception in sub-question 1 is; that Danish protein alternatives are not necessarily more environmentally friendly than importing organic soybean meals from China. The hypothesis for sub-question 2 is the presumption that other parameters are necessary to consider besides the LCA results to make a valid decision regarding protein production. Sub-question 3 is answered by applying the Multi-Level Perspective theory (MLP). The hypothesis is next tested: useful conclusions and recommendations will emerge by utilizing the model from the standpoint of developing a sustainable organic industry.

The following section in the research design is the methodology behind answering each sub-question. As illustrated, the LCA is performed to answer sub-question 1, where a qualitative approach is used for sub-questions 2. In addition, the methodologies are supplemented by literature in all the sub-questions. For each methodology, different data collections appear. For the first sub-question, the data are provided by SEGES Innovation, 2022a, Fog, 2022, Knudsen et al., 2010 and Schmidt and De Rosa, 2020. To answer sub-question 2, data and information are provided from the interviews with Fog, 2022, Bosselmann, 2022, Hermansen, 2022 and participation in DAFC, 2022a. Next in line is the use of the theory MLP, which is utilized as a frame for analysing the transitional change in the organic sector Schot and Geels, 2008. The analyses, which are the next step in the research design, are informed by the methodology, data gathering, and application of theory. For sub-question 1, the analysis is interpreting the LCA results of the respective protein crops. The discussion of other relevant parameters to consider when determining which protein source to use is the focus of the analysis for the second sub-question 2. For the third sub-question, the analysis applies the MLP model in the organic sector and how the LCA may provide information on transitional sustainability changes. The three different analyses will give information to finally answer the main research question, indicating why it is at the bottom of the research design.

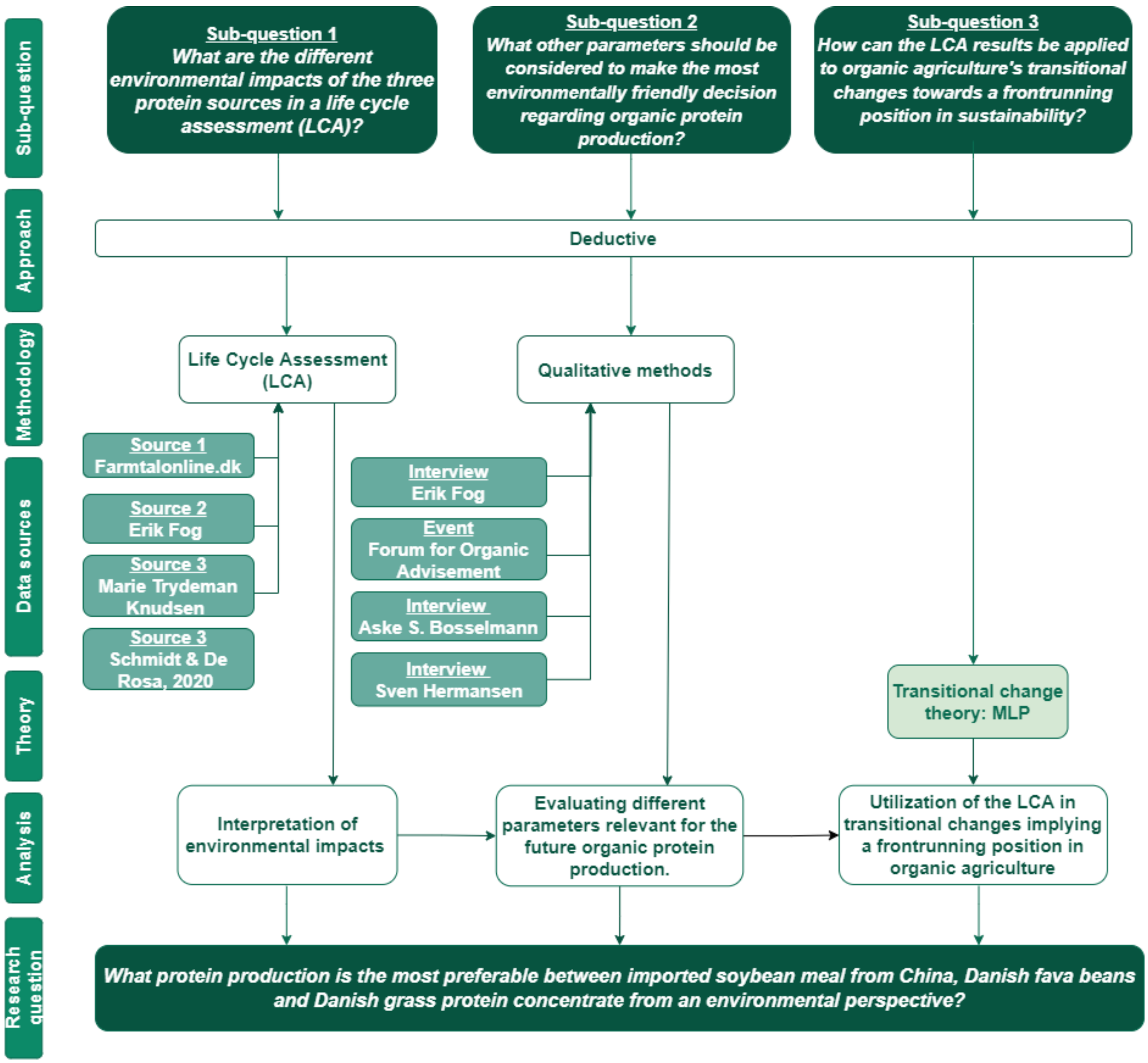


**Figure 2.1:** Research design. Visualized overview of the study and how the research question is answered.

## 2.2 Qualitative methods

To answer the research question, different qualitative methods are applied, and including the perspectives and knowledge of the respective respondents, it increases the authenticity of the study [Brinkmann and Tanggaard, 2015]. There are performed three interviews and two informal phone conversations, which all are described in Section 2.2.1. Furthermore, it has been possible to attend an event that is outlined in Section 2.2.2.

### 2.2.1 Interviews

To strengthen the validity and congruence of the study, the same thematization with keywords and terminologies from the research question, along with central problems from the literature, are used Brinkmann and Tanggaard, 2015. All interviews are semi-structured to ensure flexibility for both interviewer and respondent to diverge and to ask supplementary questions [Brinkmann and Tanggaard, 2015, p. 38-41]. However, interview guides are conducted beforehand to ensure a guideline, but as the interviews are semi-structured, the guides are open to avoid closed questionnaires. Additionally, the interviews are recorded and later transcribed, which all can be found in Appendix E. The interviews are performed in Danish to ensure confidence and more detailed answers. However, some arguments might get lost in translating citations into English. For that reason, all citations are sent to the respective respondents for approval. Verifying the citations increases the validity together with avoiding discrepancies between the citation and the respondent's answer [Aarhus University, 2022]. With regard to the two last mentioned in Table 2.1, Bosselmann, 2022 and Kreutzfeldt, 2022 provided information during informal phone conversations. Further description can be found in Appendix F.

| Respondent | Date | Description |
|---|---|---|
| **Erik Fog**<br>Consultant in bioenergy and biorefinery<br>ICOEL | Semi-structured interview | Fog, 2022 is an expert in bioenergy and biorefining of protein and is part of the Ausumgaard.dk, 2022 project, where efficiency on large-scale grass protein from GPR is researched. Data from Ausumgaard.dk, 2022 are used to answer sub-question 1. Additionally, Fog, 2022 has knowledge about LCA and how it is relevant in communication for answering sub-question 3. |
| **Kirsten Lund Jensen**<br>Head of the Organic Sector, Danish Agriculture and Food Counsil | Semi-structured interview | Jensen, 2022 is positioned between political authorities and practical stakeholders, making it possible to get descriptions of the current goals within the organic sector and how it generally works with sustainability. Furthermore, Jensen, 2022 is boardmember in innovation activities in ICROFS.dk, 2022 and describes the problem of missing LCAs on organic productions. |

**Table 2.1:** Overview of the conducted interviews and phone conversations, including a description of relevance, and how it helps answer the research question (Continued).

| Respondent | Date | Description |
|---|---|---|
| **Sven Hermansen**<br>Chief consultant<br>ICOEL | Semi-structured interview | Hermansen, 2022 is an expert in calculating indicators and estimates within different subjects, especially nutrient soil content. These calculations are helpful for the problem identification within this study, along with environmental considerations when increasing either fava beans or GPC in Denmark regarding the research question. |
| **Aske Skovmand Bosselmann**<br>Lector in agricultural value chains<br>KU | informal phone conversation | Bosselmann, 2022 provides information about global value chains and how the organic SBM import from China indirectly affects the rainforest in South America. Bosselmann, 2022 also has knowledge about LCA on food production and how consumer demand is a responsible contributor to environmental impacts as well. Both subjects help answer sub-question 3. |
| **Henrik Kreutzfeldt**<br>Organic farmer, Odder | informal phone conversation | Kreutzfeldt, 2022 provides information about organic cultivation to answer sub-question 1. Furthermore, Kreutzfeldt, 2022 has inputs to the increasing focus of legumes in the crop rotation and the possibilities and challenges Denmark faces if it becomes self-sufficient on protein feed. This is regarding sub-question 3. |

**Table 2.1:** Overview of the conducted interviews and phone conversations, including a description of relevance, and how it helps answer the research question.

### 2.2.2 Events

Because of my current student job at the Innovation Center for Organic Farming (ICOEL), it is possible to join different events to increase knowledge about organic agriculture and Danish protein crops compared to the soybean meal import. The most relevant event is the Forum for Organic Advisement, which is outlined in the following section.

#### Forum for Organic Advisement

The Forum for Organic Advisement is arranged yearly by DAFC, 2022a and ICOEL. The primary purpose is to narrow the gap between researchers and farmers by including both parts in a workshop and a presentation. Advisement companies and consultants are invited as well. 50 people participated, and each person has prepared one to five different inputs about what they would like the future research to center around. As presented in Appendix G, all inputs are collected on a board, where the participants vote on which they found most relevant and interesting. After the voting, the top six voted inputs were discussed in six different groups to create knowledge sharing and ideas. Thus the research idea becomes as useful as possible. All comments and ideas were collected by ICOEL and DAFC, 2022a for further work. Participating in this event increases the insight into agricultural stakeholders' knowledge about soybean meal import along with the possibilities and challenges of finding national alternatives. It further implies an understanding of the increasing familiarity with LCA performances and the relevance of improving the environmental sustainability within the organic sector. This has furthermore supplemented the choice of tool to answer sub-question 3.

## 2.3 Literature review

A literature review is conducted in Chapter 1 to state the art of the required LCA performance on organic soybean meal import in comparison to the Danish alternatives, fava beans and GPC. It is relevant when researching a specific topic; hence relevant literature within the same field is considered [Snyder, 2019]. In addition, to find respective gaps in the literature, create agendas, justify the research question, or just discuss the subject's matter. The approach is systematic. Hence, available evidence gets identified, and by minimizing possible biases, thus relevant conclusions and decisions can be made [Moher et al., 2009]. The review starts with developing a useful search string, where the final one can be seen at the bottom of Figure 2.2. Additionally, the results are narrowed down to be within the last ten years (2012-2022), only organic agriculture, written in English. Lastly, the subject areas are Agricultural and Biological Sciences and Environmental Science.

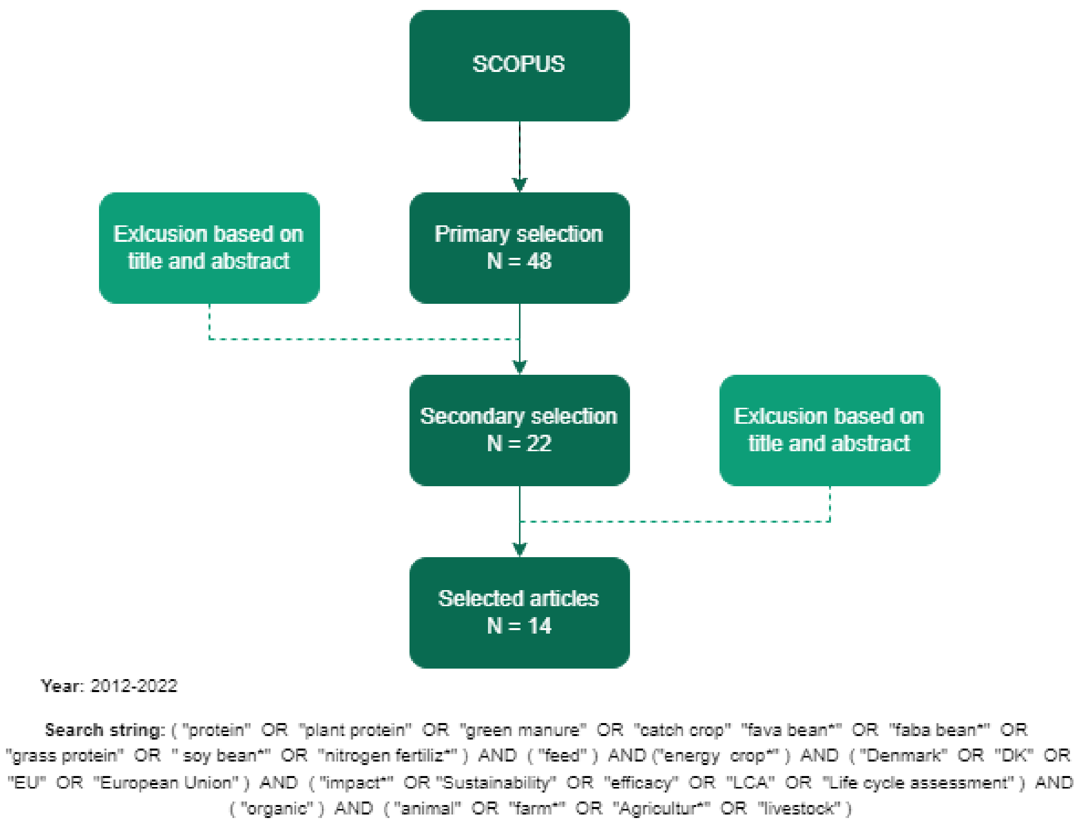


**Figure 2.2:** An illustration of the systematic literature review and belonging selection process.

The review and tied selection process is depicted in Figure 2.2. The first exclusion phase follows the initial search and is based on the title and abstract. The second exclusion procedure is based on a comprehensive evaluation of each of the articles selected in the first round. This results in 14 valuable articles that may be utilized to comprehend better difficult areas within the issue of national generated protein for feed against soybean meal imports, as well as current environmental assessments within this topic, which is explored in Chapter 1.

## 2.4 Multi-Level Perspective theory

To answer sub-question 3, regarding how the LCA results outlined in Chapter 5 contributing to a fron-trunning position in sustainability, it is relevant to apply the *Multi-Level Perspective (MLP)*. The reason is, the MLP helps to understand how society transitionally can change, and how the LCA increases stake-holders' and consumers' knowledge about the environmental impacts from feed protein. The MLP model divides transitional changes into three levels: *landscape, sociotechnical regime* and *niche innovations*.

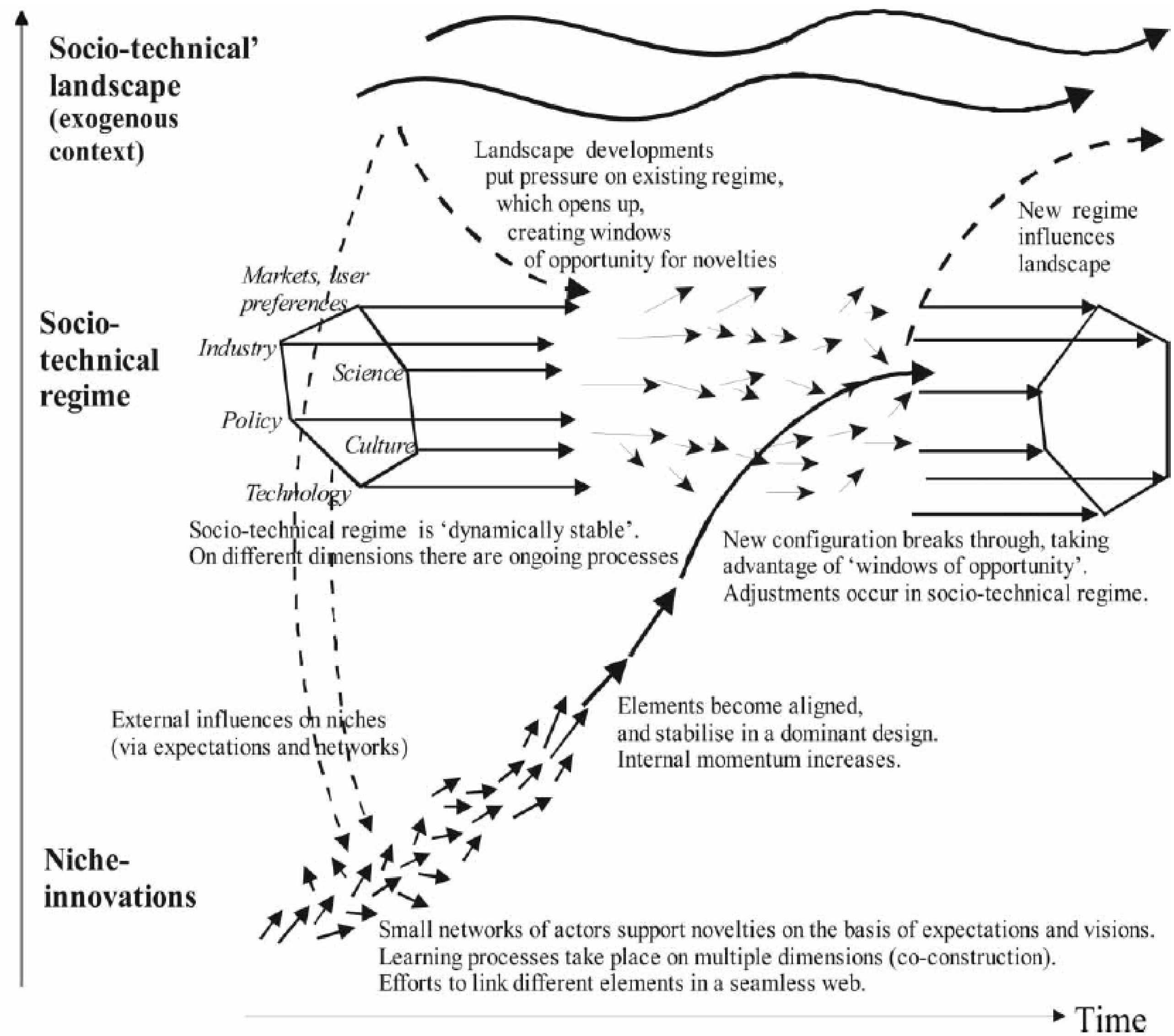


**Figure 2.3:** Multi-level perspectives on transition. Illustration from [Schot and Geels, 2008].

The first level is the *landscape*. It refers to the exogenous environment outside the regime and niche innovations and includes topics such as macropolitical developments, cultural patterns, and macroeconomics. Creating transitions in the landscape is based on slow and steady institutional changes. As the development in the landscape changes, it results in new regimes, which in turn alter the landscape, because it affects the exogenous environment [Schot and Geels, 2008; Harries, 2012].

The second level is the *sociotechnical regime*. That means the society's present and stable patterns, as well as shared cognitive routines [Schot and Geels, 2008]. This can be divided into different sectors in society. In the agricultural sector, current institutions in the regime are, for instance, the regulatory (the CAP and national regulation), political (national plans and goals of more organic land usage), and social (discourses, conventions, and market preferences).

The third and last level of the MLP model is *niche innovation* at the bottom of Figure 2.3. It is the micro-level where small networks of actors create novelties with the desire to infiltrate the sociotechnical regime. According to Smith, 2007, niches are not necessarily intended to replace the regime but rather to contribute to changes in behavior, habits, and routines. Plant-based protein is a niche innovation when looking in the agricultural sector. However, the niche emerging into the technological regime is increasing because the demand for meat alternatives increases.
The statements mentioned above entail that niches can only grow if they are linked to current processes at the regime and landscape levels [Schot and Geels, 2008]. However, regime shifts occur due to a bottom-up process based on niches indicating that all three levels influence each other. They are equally crucial regarding transitional changes in a sector and society.

The focus on plant-based protein and the application of the MLP model is discussed further in Section 6.3. Here, different aspects are considered concerning an increase in Danish protein production for food instead of feed.

## 2.5 Life cycle assessment: description

According to Thrane and Schmidt, 2007 a systematic and useful approach to environmentally assess different impacts between productions is to perform an LCA. By having a systematic frame, it will be possible to compare the productions, which will lead to useful information regarding environmental decision-making [ISO14040, 2006]. At an overall level, LCA follows the ISO14044, 2006 and ISO14044, 2006, where both ISO standards describe the framework of LCA as follows:

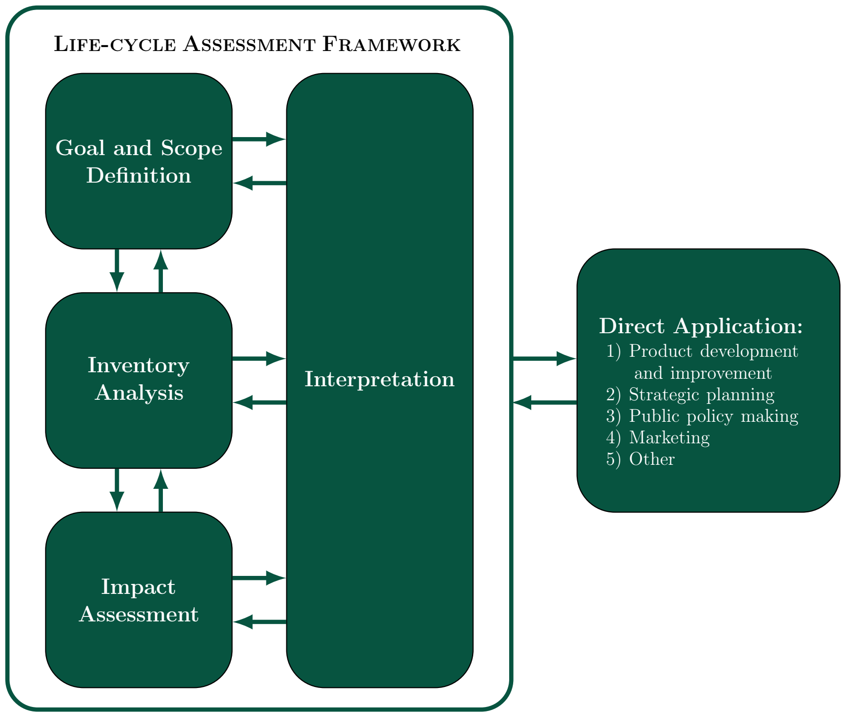


**Figure 2.4:** Own illustration of the LCA framework prescribed by ISO14040, 2006.

As illustrated, the framework is divided into four main steps: *Goal and scope, inventory analysis (LCI), impact assessment (LCIA)*, and *Interpretation*. The first three will be described in chapters 3, 4 and 5, including the interpretation of data and results in each step. After the LCA is completed, the results can be used in a variety of decision-making processes, including product development, strategic planning, and, in this case, determining if it is environmentally sustainable to replace soybean meal import with Danish alternatives like fava beans and grass protein concentrate [ISO14040, 2006].

# Chapter 3

## Goal and Scope

*This chapter describes the goal and scope of the LCA. This entails the main audience, the functional unit, and the system boundaries of the producing soybean meal, fava beans, and grass protein concentrate. Secondly, the chosen fore- and background data is described, followed by chosen methodology behind the life cycle impact assessment (LCIA) and weighting. This will improve transparency and create a better grasp of the LCA framework.*

The goal of performing this comparative LCA is two-sided. Firstly, the LCA will help decide whether fava beans or grass protein concentrate (GPC) is the most environmentally friendly than the soybean meal (SBM) import. As noted in Section 1.5, this implies relevant information about the intention of phasing out the SBM import. The main audience is stakeholders within the agricultural sector. Policymakers can utilize these findings to improve their understanding of self-sufficiency and the environmental consequences of achieving it. Other relevant audiences are R&D organizations like ICOEL, SEGES, Danish Agriculture and Food Council, and universities who all investigate Danish feed and food production to become as sustainable as possible. Feeding stuff companies like Vestjysk Andel and DLG are important to show the results. They are the intermediary between producers and buyers within feed for the livestock sector. Farmers can increase their knowledge about how they should prioritize protein production and generally increase their knowledge of the environmental impacts of producing protein crops.

## 3.1 Function and functional unit

Following the ISO14040, 2006 and ISO14044, 2006, both argue to centre the LCA performance around a quantitative and clear defined function unit (FU) to systemize the input and output data. The system function is to provide protein for feed from the respective protein sources researched in this study, which leads to the following FU:

FU: 1 kg crude protein (CP) distributed at Aarhus harbour

Additionally, it is necessary to describe the reference flow (RF) which is a reference all data will be normalized against (ISO 14044:2006). In this study, the RF is the required amount of the respective legume to fulfil the FU [Thrane and Schmidt, 2007]. On the right side of Table 3.1, an overview of the RFs is outlined, which is calculated by dividing 1 with the CP content of the feed included in the first column in table 3.1:

$$RF = \frac{1}{crudeprotein\ \%\ DM} \tag{3.1}$$

To describe the rest of Table 3.1, the column 'kg crop/kg feed' describes how much of the respective crops is necessary to cultivate, resulting in the final amount of feed to fulfil the FU. The data from Schmidt and De Rosa, 2020 describes that milling 1 kg soybeans will result in 0.77 kg soybean meal. By dividing these two, it results in 1.29 kg crop/kg feed, which is included in Table 3.1. The protein feed from fava beans is the beans themselves. Thus, the kg crop/kg feed is 1. About GPC, it is specified in the PEF data that 5.80 kg clover grass in dry matter (DM) is necessary to produce to get the output of 1 kg GPC. The fresh matter (FM) amounts are used to understand how this is calculated. The PEF data outlines, that 32.67 kg (DM percent: 16%) clover grass in FM treated in the GBR will result in 1 kg (DM percent: 90%) GPC FM. By multiplying with the DM percentages by the respective masses, it results in 5.23 kg grass DM, which will create an output of 0.9 kg GPC. Dividing these two in DM results in 5.80 kg crop/kg feed for GPC. The next column is the DM percentage, which is essential to consider in the cultivation processes because the output after harvesting always is in FM. It is assumed that SB has the same 88% DM as fava beans [Kreutzfeldt, 2022].

.

| Type | CP % of DM | kg crop/kg feed | DM percent | RF |
|---|---|---|---|---|
| Soybeans meal | 46.80 | 1.29 | 0.88 | 2.14 |
| Fava Beans | 26.60 | 1.00 | 0.88 | 3.76 |
| Grass protein concentrate | 47.00 | 5.81 | 0.90 | 2.13 |

**Table 3.1:** Overview of the legumes, including the CP content, kg crop cultivated per kg feed, the DM percentage, and lastly the RFs. Data are acquired from Schmidt and De Rosa, 2020; SEGES Innovation, 2022a; Fog, 2022 and SEGES, 2020

.

## 3.2 System boundaries

To understand what activities each LCA will contain, the system boundaries are simply defined and visualized in Figure 3.1, 3.2 and 3.3. The included activities reflect the study's goal, regarding comparing environmental assessments between importing organic SBM and nationally produced fava beans and GPC. It is modelled as a consequential LCA (CLCA), reflecting the consequences of the changes in demand for protein production. In addition, by-products are modelled with their substitutional effect, and inputs are assumed to be provided by the marginal suppliers of the respective market [Weidema et al., 2018; Weidema B P, 2009]. Each system boundary contains different activities and flows within the primary production of each protein crop. Furthermore, necessary processing activities are included before distributing to Aarhus Harbour, where the cut-off appears, as illustrated in all three figures. It is assumed that subsequent processes in all three lifecycles are similar.

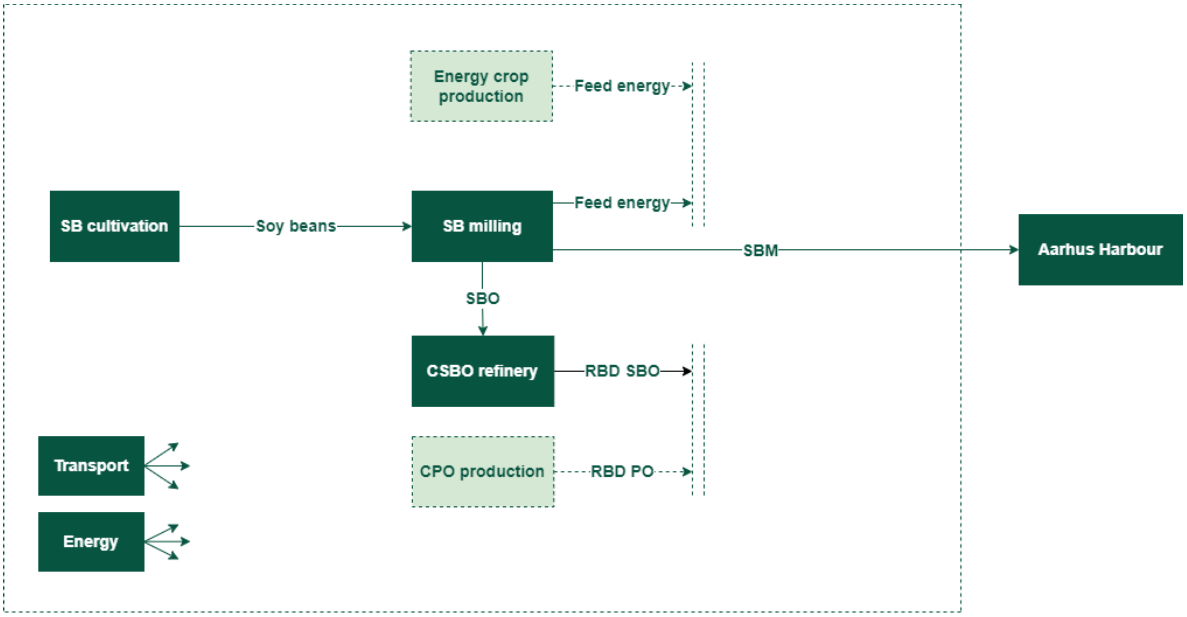


**Figure 3.1:** System boundary of importing organic soybean meal (SBM) from China. Activities are shown as boxes and flows as arrows.

Figure 3.1 contains the soybean meal (SBM) production and the connected substitutions. At an overall level, soybeans are cultivated in China. The soybeans are sent to a soy mill where the beans are crushed. The output is SBM with the by-product of soybean oil (CSBO). CSBO is further processed into Refined, Bleached, and deodorized SBO in a refinery plant (RBD SBO). RBD SBO substitutes palm oil (RBD PO). Further descriptions of the RBD CPO production are included in Appendix C. The SBM is distributed to Aarhus Harbour [Knudsen et al., 2010]. The SBM contains a certain amount of energy, which substitutes the production of energy crops. Lastly, energy and transportation are included in the activities.

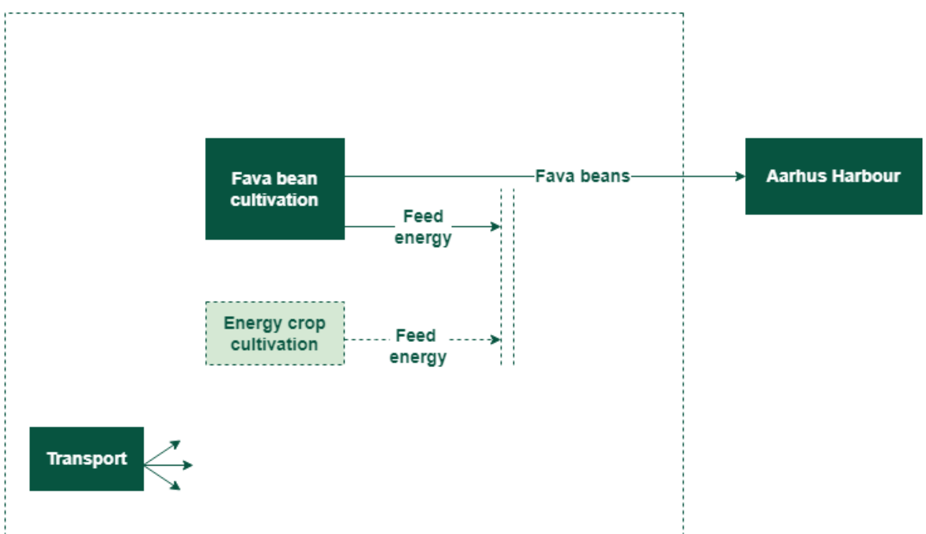


**Figure 3.2:** System boundary of national produced organic fava beans. Activities are shown as boxes and flows as arrows.

Figure 3.2 illustrates the cultivation of nationally produced fava beans (FB) before it is distributed to Aarhus Harbour in Denmark like SBM. FB substitutes feed energy crops as well.

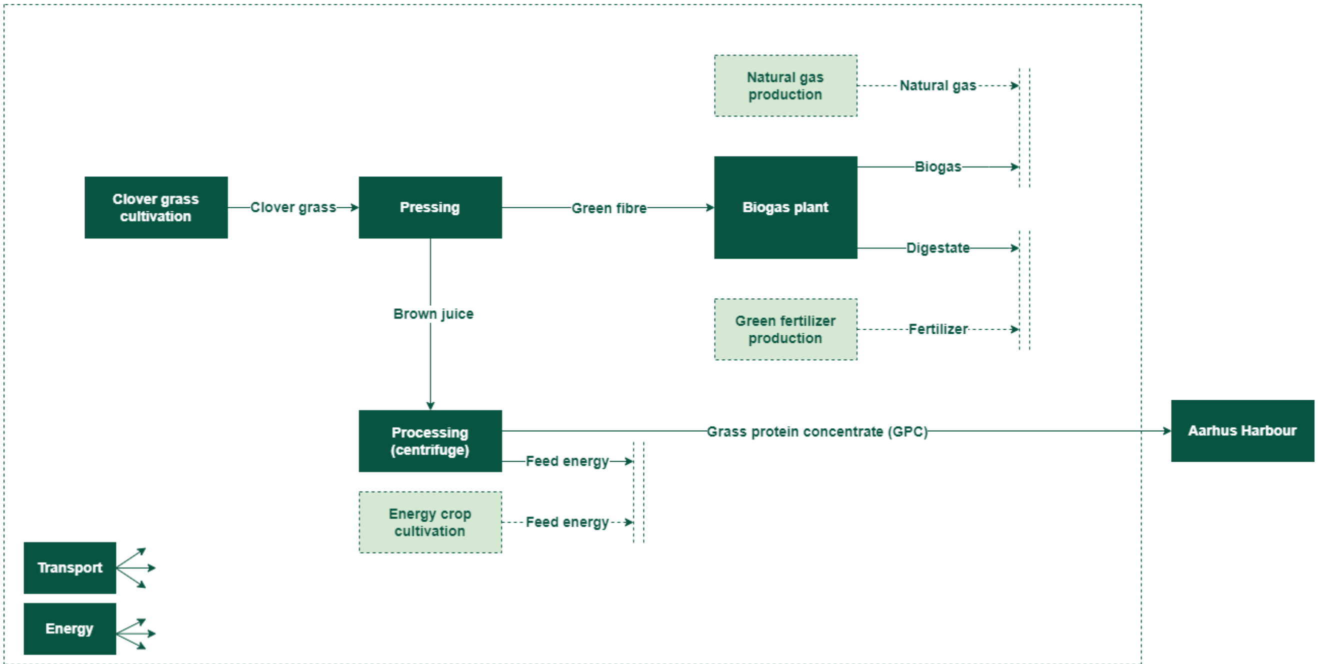


**Figure 3.3:** System boundary of nationally produced organic grass protein concentrate (GPC) before distributed at Aarhus Harbour. Activities are shown as boxes and flows as arrows.

Lastly, Figure 3.3 illustrates the production of GPC before being distributed to Aarhus Harbour. After harvesting, the grass is transported to the biorefinery plant, where the first step is pressing. Here the green fibre output continues to a biogas plant, which can substitute natural gas and fertilizer production. The brown juice will be processed in a centrifuge, where the output is the GPC ready for distribution. As GPC also contains energy, it will substitute feed energy crop productions. As for SBM, transportation and energy consumption also appear in the GPC production.

## 3.3 Life cycle inventory: background System

To model the three systems in Figure 3.1, 3.2 and 3.3 Exiobase v.3.1.13 database is used. Exiobase is a global, environmental extended hybrid input/output (IO) database. Hybrid means multiple units; monetary, mass, and energy. Exiobase can be used for both a detailed product LCA and a national level footprint [Exiobase.eu, 2022]. Furthermore, Exiobase has a cut-off criterion of 0% and is a more complete geographical database than any process database. The critical aspect is the level of aggregation, which limits the detail level compared to process databases like Ecoinvent 3.8. Nonetheless, Exiobase has a complete inventory, and it is possible to supplement with data from detailed process databases, which is also part of the hybrid LCA [De Rosa, 2017].

| | Foreground system | | |
|---|---|---|---|
| | Soybean {CN} Soybean cultivation, organic | SBM mill {CN} SBM milling | Crude SBM oil to treatment{CN} SBM refinery |
| ***Reference flow:*** | 1 | 1 | 1 |
| **Inputs from foreground:** | | | |
| Soybean {CN} Soybean cultivation, organic | | x | |
| SBM mill {CN} SBM milling | | | x |
| **Crude SBM oil to treatment{CN} SBM refinery** | | | |
| **Inputs from background:** | | | |
| Link to: Petroleum Refinery {CN-TW} | x | x | x |
| Link to: Electricity mix {CN-TW} | | | x |

**Figure 3.4:** An example of an IO-table (from the SBM system) where inputs to the foreground system are from the foreground system and the background system. The figure is inspired by [Schmidt and De Rosa, 2020].

Both foreground and background data are used to model the three systems above. This is illustrated further in the example in Figure 3.4, where the respective reference flows are at the top, followed by the foreground system and the background system at the bottom. For each foreground activity, different background inputs are used, which are described as, e.g., "Link to: Petroleum Refinery CN-TW". This indicates the exact activity in Exiobase.

The foreground data collection for the three systems is from different sources. For the soybean cultivation, the data is provided by Knudsen et al., 2010. The data are from 2010, indicating an uncertainty regarding its level of representativity. However, as it is difficult to access the exact cultivation data from China, it is assumed that the data from 2010 is acceptable. All the following processes, together with substitutions within the palm oil industry, are data from Schmidt and De Rosa, 2020. This can create some uncertainties as the two sources might have different approaches to collecting the data. The first-mentioned is based on organic cultivation of soybeans in China and the second-mentioned is conventional productions in the USA and Brazil. However, it is only the milling and refinery process, which are used from Schmidt and De Rosa, 2020, and it is assumed that these processes and flows will be identical if they occur in China.

The cultivations of the organic energy crops (spring oats and spring barley) and fava beans are top-down data from SEGES Innovation, 2022a. This is an average of all Danish farmers' agricultural productions who have reported their inputs in appertaining software. Additionally, to ensure representative data, they are 'verified' by the organic farmer, Kreutzfeldt, 2022, who produced the three crops in 2021. To model the grass protein concentrate (GPC) Fog, 2022 is a responsible part of the Ausumgaard.dk, 2022 project, where a Product Environmental Footprint (PEF) currently is performance. The PEF data is confidential because it is not published yet, but it has been possible to access the data through Fog, 2022. For that reason, all data to both the clover grass cultivation and the following processes extracting the GPC are drawn from this.

## 3.4 Life cycle impact assessment: methodology

As illustrated in Figure 2.4, the next step after outlining the LCI data is to perform the LCIA. According to ISO14044, 2006, LCIA consists of a classification where it is possible to divide the results into specific impact categories from the chosen method. In this study, Stepwise2006.v.1.0.7 is used, and the description of the categories is included in Table 3.2. All impacts can be multiplied with a categorization factor, where the LCI data gets converted into the physical units of the chosen impact categories in Table 3.2 and creates midpoint values for the three product systems [Schmidt and Watson, 2014; Hillege, 2019].

| Impact Category | Unit | Description |
|---|---|---|
| Global Warming | Kg $CO_2$-eq | This indicates potential global warming because of emissions of green house gasses. It is divided into fossil and non-fossil |
| Ozone depletion | kg CFC-11-eq | This is an indicator of emissions causing destruction of the ozone layer, where emissions of CFC-11-eq are important contributors. |
| Nature occupation | PDF*$m_2$ | Indicates the impacts of occupying 1 $mm^2$ of arable land in one year multiplied with the score of potential disappeared fraction (PDF) of the area during the respective time. |
| Acidification | $m^2$ UES | This indicates the ecosystem that receives the critical amount of acidification. The unit is $m^2$ of unprotected ecosystem (UES). |
| Respiratory Inorganics | Kg $PM_{2.5}$-eq | Indicates the impact on human health when inhaling 2.5 micrometer fractions or smaller particles. The unit is kg PM2.5 equivalents (eq) |
| Respiratory Organics | pers*ppm*h | Intake of fine particles expressed as the exposure of a person inhaling fine particles in one hour. This is an indicator of the impacts from photochemical ozone formation on human health. The unit is the amount of a person's intake of fine particles when inhaling in one hour. |
| Aquatic eutrophication | kg $NO_3$-eq | This is an indicator for nutrient emissions exposed into aquatic systems expressed as kg $NO_3$-eq. |

**Table 3.2:** Overview of Impact Categories in Stepwise2006.v.1.0.7. with the physical units and short descriptions. Impact category *Ionizing radiation* is excluded as it refers to radionuclide emissions from nuclear power in the electricity mix, which is non-relevant in Denmark [Fact-based sustainability, 2021]. The table is added from last year's semester project [Kreutzfeldt, 2021] (continued.).

| Impact Category | Unit | Description |
|---|---|---|
| Terrestrial eutrophication | $M^2$ UES | Nutrient emissions to terrestrial areas expressed as $m^2$ of unprotected ecosystem (UES). |
| Aquatic and terrestrial Ecotoxicity | Kg TEG-eq s | This indicates the emissions of toxic substances exposed into water and/or land. The unit is triethylene glycol (TEG) equivalents as no midpoint for ecotoxicity occur. |
| Human toxicity | kg $C_2H_3CI$-eq | This is an indicator of the impact on human health in relation to carcinogens (cancer-causing) and non-carcinogens. As no midpoint occur the reference substance $C_2H_3CI$-eq is chosen in stead. |
| Non-renewable energy | MJ primary | An indicator for the total use of non-renewable energy expressed in MJ. |
| Photochemical ozone, vegetation | $m^2$*ppm*hours | An indicator for the accumulated exposure of above 40 ppm, which is the treshold time the recieving area size. 40 ppm is chosen as lower than this make no og only small damages. The impact is expressed as $m^2$*ppm*hours. |
| Mineral Extraction | MJ extra | This indicates the energy extraction pr kg material extraction expressed in MJ. |

**Table 3.2:** Overview of Impact Categories in Stepwise2006.v.1.0.7. with the respective units and short descriptions. Impact category *Ionizing radiation* is excluded as it refers to radionuclide emissions from nuclear power in the electricity mix, which is non-relevant in Denmark [Fact-based sustainability, 2021]. The table is added from last year semester project [Kreutzfeldt, 2021]
.

### 3.4.1 Weighting

Weighting is applied to understand what impact categories are most relevant to further analyse [Pizzol et al., 2017]. According to ISO14040, 2006 and ISO14044, 2006, weighting is optional, where classification and characterization is mandatory. The weighting is converting the impact categories into the same single score unit. Thus they are possible to compare. As this study uses the Stepwise.v.1.0.7 method, the weighting factor will result in monetary endpoint values (EUR2003). By using this unit for weighting, it shows how much people are willing to sacrifice their budget in order to buy additional life years with maximum well-being in favor of either reducing impacts on humans or protecting the environment - or both [Weidema, 2008]. The results from the weighting are illustrated in Figure 5.1.

# Chapter 4

## Life Cycle Inventory

*This chapter aims to outline the LCI of the study, where necessary calculations and assumptions are described under each section to increase and ensure transparency and reproducibility.*

At first, general LCI data present for all three product systems are described, which are land use, transportation, capital goods, seeds and fuel (Sections 4.1 to 4.5). Afterward, Section 4.6 reports that the market mixes of energy and protein crops are reported because all three protein sources contain feed energy, which will substitute the marginal mix of energy crops as stated in Section 3.2. Lastly, Section 4.7 to 4.9 contain LCI data for soybean meals (SBM), fava beans (FB), and grass protein concentrate (GPC), respectively. All calculations are presented in Appendix A and connected to the IO-table performed for modelling this LCA.

### 4.1 LCI: Land use

It is crucial to involve land use changes when calculating environmental impacts, as these changes account for 11% of worldwide GHG emissions, according to IPCC, 2014. This study includes both direct (dLUC) and indirect land use changes (iLUC). dLUC means changing the reference situation into something else. The majority of reference lands are arable lands, which can be changed into other cultivations or human activities like buildings, infrastructure, etc. [Schmidt et al., 2015]. An example from this study is the change in the demand for nationally produced protein sources like fava beans or clover grass productions, which will change the current reference fields into protein feed cultivations. dLUC does often have minor impacts because the carbon stocks and biodiversity are similar to the reference land [Schmidt et al., 2015].

As stated in Section 1.1 iLUC means that the cultivation on the reference fields will be produced somewhere else, based on the assumption that the demand will not decrease [Schmidt et al., 2015]. To include iLUC in the modelling, the approach from Schmidt et al., 2015 is used because it breaks down the complexity of iLUC into more understandable and manageable pieces. The potential net primary production ($NPP_0$) is used as a productivity factor to determine how much land is required to produce compensated production. This factor is calculated by dividing the respective $NPP_0$ of the location by the global average $NPP_0$ for arable land. This is necessary because, e.g. one ha*year in warm and rainy climates might have higher yields than a ha*year in an opposite climate. As a result, it is more reasonable to measure potential productivity (ha*year-eq) rather than actual productivity (ha*year) [Schmidt et al., 2015]. Further description is that a well-managed and poorly-managed field at the same size will have the same iLUC impacts, but looking at the iLUC impacts pr. unit of the crop, the poorly-managed field will have higher impacts because of lower yields. This entails that the capacity of a country's crop output, represented in ad weighted ha*year (ha*year-eq), is more useful to measure. The $NPP_0$ factor for China is 5330 C/ha/year and 6150 kg C/ha/year in Denmark. Each is divided by the global average of 5680 C/ha/year:

$$\frac{NPP_{0\ China}}{NPP_{0\ global\ average}} = \frac{5330}{5680} = 0.94 \tag{4.1}$$

$$\frac{NPP_{0\ Denmark}}{NPP_{0\ global\ average}} = \frac{6150}{5680} = 1.08 \tag{4.2}$$

When comparing these productivity factors to the EU28 $NPP_0$ factor of 1 kg C/ha/yr, China's yields are lower because the potential productivity is 0.94 C/ha/yr. Producing 1 ha in Denmark, the potential productivity is 1.08 times higher than in EU28, which indicates a slightly higher yield than EU28 [Haberl et al., 2007]. For soybeans and fava beans, the $NPP_0$ factors are multiplied by 1 divided by the yields to get ha/t DM.

| | Unit | Soybeans | Fava beans | Clover grass | Reference |
|---|---|---|---|---|---|
| Yields (DM) | t/ha | 2.79 | 3.70 | 6.82 | [Knudsen et al., 2010; SEGES Innovation, 2022a; Fog, 2022] |

**Table 4.1:** Yields of three assessed protein crop productions [Knudsen et al., 2010; SEGES Innovation, 2022a; Fog, 2022].

Because the by-products of brown juice and green fibre in the GPC production are handled in a biogas plant, which replaces natural gas, it is required to find land usage for growing fresh clover grass for the GPC (see Section 4.9). The land use (0.77 ha/ 32.67 t fresh clover grass) is drawn from the previously mentioned PEF data and is further multiplied with the $NPP_0$ factor for Denmark. All land uses are included in Table 4.2.

| | Unit | Soybeans, DM | Fava beans, DM | Clover grass, FM |
|---|---|---|---|---|
| **Reference flow** | | | | |
| Land use | ha/t | 0.44 | 0.29 | 0.83 |

**Table 4.2:** Land use for the three protein crop productions, including the $NPP_0$ factors from China (0.94 kg C/ha/yr) and Denmark (1.08 kg C/ha/yr).

## 4.2 LCI: Transportation

Transport is modelled from three specific activities from Ecoinvent 3.8: *Transport, freight, lorry 16-32 metric ton, Transport, freight train* and *Transport, freight, sea, bulk carrier for dry goods*. Exiobase has transport activities in monetary values with fuel input in the mass unit. This information can further be calculated into kg diesel/EUR transport. Additionally, by looking in Ecoinvent 3.8, the corresponding proportion in units of kg diesel/tkm can be calculated. These two proportions can be combined and will result in converting the reference flow of the respective Exiobase transport activity into tkm. This is calculated for all transport inputs, which are given in km. The specific calculations can be seen in the Appendix A. After converting the unit into tkm, the background data used in Exiobase is *Other land transport, Transport via railways* and *Sea and coastal water transport*. All activities related to transport are set to zero, and the reference product is the respective amount of tkm.

It is assumed that all protein productions end at Aarhus Harbour as the import of SBM will, according to Knudsen et al., 2010. For that reason, a default distance of 150 km. is chosen for the distribution of fava beans and GPC.

## 4.3 LCI: Capital goods during cultivation

For the capital goods calculations, there are numerous assumptions and uncertainties. Foremost, the PEF data for the GPC includes agricultural machinery, biorefinery, and biogas plant machinery. SBM and fava beans' modelling solely includes agricultural machinery. It is uncertain that the machinery for milling and refining soybeans is not included to make it more comparable to GPC. Furthermore, no buildings are excluded from any product systems because of simplicity. The impacts of capital goods are, however, assumed to be negligible, making the exclusions acceptable.

To calculate the agricultural machinery for soybeans, fava beans, spring oats, and spring barley (energy crops), Exiobase requires converting the cultivation operations into the amount of machinery (kg). To do so, the following activities from Ecoinvent 3.8 is used:

- Tillage, harrowing, by spring tine harrow
- Tillage, ploughing
- Sowing
- Solid manure loading and spreading, by hydraulic loader and spreader
- Tillage, currying by weeder
- Combine harvesting

The reference flows in Ecoinvent are in hectare (ha), which is why Table 4.3 shows how many necessary occurrences of each cultivation activity appear on 1 ha. This means that even though some activities cultivate 2 or 3 ha, it indicates how many times it is applied on the same hectare.

| Cultivation Activities | Unit | Amount of times to applying the activity (ha) | Reference |
|---|---|---|---|
| Harrowing | ha | 3 | [SEGES Innovation, 2022a]* |
| Ploughing | ha | 1 | |
| Sowing | ha | 1 | |
| Manure spreading | ha | 1 (0 for SB and FB) | |
| Currying | ha | 3 | |
| Harvesting | ha | 1 | |

**Table 4.3:** Overview of cultivation processes when producing Chinese soybeans, Danish fava beans, spring oats and spring barley. The data indicates how many times the respective process appears to cultivate 1 ha. *All data are provided by SEGES Innovation, 2022a.

Furthermore, because the standard is to utilize a sewing machine with a rotator harrow, it is typical to harrow four times [SEGES Innovation, 2022a; Kreutzfeldt, 2022]. This equipment, however, does not appear in Ecoinvent; instead, a conventional sowing machine is provided, along with only three harrowing procedures. In addition, the three harrow activities included varying as well. The first round is done using a stubble harrow, and the others with a spring-tine harrow. Because there is no stubble harrow in Ecoinvent 3.8, it is presumed that all three processes are done with a spring-tine.
These Ecoinvent activities do not exist for Denmark, which is why Swizz {CH} data are used instead. It is assumed that the same cultivation activities occur within the cultivation of soybeans, where Chinese background data are chosen instead.

## 4.4 LCI: Seeds

Within all three cultivation activities, the production of seeds is included. It is assumed that seed production has equal cultivation activities as the three protein crops under study respectively. To avoid implications in the modelling, the specific amount of seeds needed is subtracted from the output of the different cultivation stages.

## 4.5 LCI: Fuel

The fuel activity chosen for all required activities is the background data: Petroleum Refinery. Concerning the modelling above of agricultural machinery in Section 4.3, the cultivation activities in Ecoinvent 3.8 do also contain the needed amount of diesel/ha (Ecoinvent database: Diesel). Hence, all diesel used for the field operations is summarized and added to the background data from Exiobase within the respective crop production except soybeans (see Section 4.7.1). The data on diesel consumption from Knudsen et al., 2010 matches the estimates for fava beans, spring oats, and barley, which validates the calculations.

## 4.6 LCI: Markets for feed energy and feed protein

Within the crop productions, by-products of either energy or protein occur. The soybean meals, fava beans, and grass protein concentrate contain energy, which will substitute the marginal sources of organic energy crops, and palm kernel meal (PKM) (see Section C.3). It will also contain ratios of vitamins, but the amounts are small; thus, it will be excluded from this study. PKM results in a substitution of the marginal mix of conventional soybean meals and energy crops [Schmidt and De Rosa, 2020]. The marginal suppliers are the ones that most likely will respond to a change in demand for protein or energy crops. It is assumed that the markets are global and independent [Schmidt and Weidema, 2007], where cereal grain is the marginal feed energy, and SBM is the marginal feed protein. Furthermore, energy crops contain protein, which will substitute for the SBM market, and vice-versa, the protein crops contain energy, which substitutes the energy crops. The LCI modeling creates a loop, which means that demanding more energy crops will displace protein crops, which again will displace minor parts of the energy crops on the market.

### 4.6.1 Organic market mix

As the markets for energy and protein crops are both organic and conventional, the marginal mixes differ. The organic marginal mix is only relevant to finding the marginal supply of energy crops in Denmark. This is because fava beans and GPC are Danish produced, and it is assumed that they will substitute national energy crops only. Based on data from DAFC, 2020b, the two most widely used grain crops are spring oats and spring barley, based on the biggest increases from 2011 to 2021 (see calculations in Appendix A). The size of the increases does further show an indicator for the competitiveness of the crops [Weidema B P, 2009; Weidema, 2003]. Ecoinvent is used for agricultural machinery and diesel, which is further described in Section 4.3. A summary of the LCI data are shown in Table B.1 in Appendix B.1.

### 4.6.2 Conventional market mix

As mentioned before, the PKM will substitute protein and energy crops, and because the palm oil industry is conventional only, it is necessary to find conventional market mixes. It is based on data from FAOSTAT, and the calculations are further described in Schmidt and De Rosa, 2020. The LCI data for both conventional and organic markets for protein and energy are included in Table 4.4. A summary of LCI data for cultivating these crops can be found in Appendix B.2. The amount of each crop is calculated based on the marginal share of energy and protein. Thus, it is possible to understand how much of each is necessary to produce to fulfil the reference product of 1 GJ and the respective protein content in each crop. The energy content (MJ) for all energy crops are calculated with following equation with data drawn from Møller et al., 2005:

$$GE\ [MJ] = Fat\,[kg]{*}36.6\,[MJ/kg]{+}Crude\,protein\,[kg]{*}24.1\,[MJ/kg]{*}Carbohydrates\,[kg]{*}18.5\,[MJ/kg] \tag{4.3}$$

| Flows | Unit | Conv. feed protein {GLO} Transform SBM to feed protein | Con. feed energy {GLO}Transform wheat and maize to feed energy | Org. feed protein {GLO} Transform SBM to feed protein | Org. feed protein {GLO} Transform FB to feed protein | Org. feed protein {GLO} Transform GPC to feed protein | Org. Feed energy {DK} Transform oat and barley to feed energy |
|---|---|---|---|---|---|---|---|
| **Output: reference flow** | | | | | | | |
| Feed protein, CP | kg | 0.47 | | 0.47 | 0.27 | 0.47 | |
| Feed energy, GE | MJ | | 1 | | | | 1 |
| **Output: by-products** | | | | | | | |
| Feed protein, CP | kg | | 5.20E-3 | | | | 4.75E-3 |
| Feed energy, GE | MJ | 19.90 | | 19.96 | 18.73 | 24.32 | |
| **Inputs** | | | | | | | |
| Maize {US} | kg | | 0.04 | | | | |
| Wheat {RU} | kg | | 0.01 | | | | |
| Maize {AR} | kg | | 0.01 | | | | |
| Wheat {UA} | kg | | 0.004 | | | | |
| Soybean meal {US} | kg | 0.52 | | | | | |
| Soybean meal {BR} | kg | 0.48 | | | | | |
| Spring oat {DK} | kg | | | | | | 0.03 |
| Spring barley {DK} | kg | | | | | | 0.02 |
| Soybean meal {CN} | kg | | | 1.00 | | | |
| Fava beans {DK} | kg | | | | 1.00 | | |
| Grass protein concentrate {DK} | kg | | | | | 1.00 | |

**Table 4.4:** LCI data for conventional and organic feed energy and protein. The crop cultivations for conventional GE crops and soybean meals can be seen in Table B.2. Organic GE crop cultivations are outlined in Table B.1 and soybeans cultivation in Table 4.5.

## 4.7 LCI: Soybean meals

As illustrated in Figure 3.1, there are three main activities to produce the SBM. Each activity requires different inputs, so it is necessary to divide the LCI section into the cultivation stage, milling stage, and refinery stage. The data from Knudsen et al., 2010 are reported with an interval, e.g., Organic N-fertilizer: 13 ± 4 kg N/ha, where the median is used and not the upper or lower fractile. A summary of the LCI data are shown in Table 4.5 and Table 4.6.

### 4.7.1 Soybean cultivation

The cultivation requires P-fertilizer inputs, agricultural machinery with connected diesel consumption, and transportation of soybeans to the refinery plant. These are further outlined in the following sections, including different uncertainties and assumptions.

#### Fertilizer

According to Knudsen et al., 2010, N and P fertilizer is added during the cultivation of soybeans in China. However, it is assumed that no N-fertilizer is externally added in this study because soybeans as legumes can nitrogen fixate, as mentioned in Section 1.3. The amount of P-fertilizer is shown in Table 4.5.

#### Capital Goods

It is assumed that the same kind of machinery used for the fava beans production is used for soybeans because the cultivation processes are similar. The machinery data from Table 4.3 is used for the Chinese soybean cultivation as well, but with the land use needed (0.44 ha/t DM) to fulfil the reference flow of soybeans (2.76 kg DM soybeans/kg CP).

#### Fuel

Because Knudsen et al., 2010 includes diesel consumption, this quantity is used as LCI data rather than the predicted consumption from Ecoinvent 3.8. See section 4.5.

#### Transportation

The data on transport from China to Denmark are drawn from Knudsen et al., 2010. It is assumed that the SBM is transported by truck and train from the Jilin Province (the biggest share of Chinese organic soybean production) to the processing activities, which are assumed to be the milling and refinery facilities.

#### Emissions

Dinitrogen monoxide and Ammonia emissions are drawn from Knudsen et al., 2010. The agricultural machinery from Ecoinvent 3.8 is used to calculate carbon dioxide emissions. For that reason, it is assumed that the machinery is the only contributor to $CO_2$-emissions, which is an uncertainty. However, it has not been possible to find others. Therefore, this is acceptable.

| Flows | Unit | SB cultivation | LCI data |
|---|---|---|---|
| **Output: reference flow** | | | |
| **Output: crop** | | | |
| SB {CN} | t | 1.00 | Reference flow |
| **Input: fertilizer** | | | |
| Organic P-fertilizer {CN} | kg | 3.48 | Link to: P- and other fertiliser {CN_TW} |
| **Input: seeds** | | | |
| Seeds {CN} | kg | 55.00 | See Table 4.5. Same cultivation activities as for SB. |
| **Input: fuel and energy** | | | |
| Diesel {CN} | kg | 13.06 | Link to: Petroleum Refinery {CN-TW} |
| **Input: land use** | | | |
| Land use | ha | 0.44 | Link to: Market for arable land {GLO} |
| **Input transport** | | | |
| Road transport {CN} | tkm | 80.00 | Link to: Other land transport {CN_TW} |
| Railway transport {CN} | tkm | 1,000.00 | Link to: Transport railways {CN_TW} |
| Sea transport {DK} | tkm | 20,280.00 | Link to: Sea and coastal water transport {DK} |
| **Input: agricultural machinery** | | | |
| Total machinery {CN} | kg | 7.74 | Link to: Manufacture of machinery and equipment n.e.c. (29) {CN_TW} |
| **Output: emissions to air** | | | |
| Dinitrogen monoxide | kg $N_2O$ | 0.44 | Elementary flow: emissions to air |
| Ammonia, {CN} | kg $NH_3$ | 1.22 | |
| Carbon dioxide | kg $CO_2$ | 109.90 | |

**Table 4.5:** LCI data for cultivating 1 t organic SB in China. Data from [Knudsen et al., 2010] and Ecoinvent 3.8.

### 4.7.2 The SBM milling stage

The purpose of the milling stage is to crush soybeans with the output of SBM and the by-product, soybean oil (CSBO). CSBO is further described in the following Section 4.7.3. The inputs are soybeans from the aforementioned cultivation stage, fuel, energy, water, and transportation. All background data used for the American processing in Schmidt and De Rosa, 2020 are replaced with Chinese inputs. E.g., *Link to: Electricity CN-TW market* instead of *Link to: Electricity US market*.

**Fuel and energy**

Natural gas, fuel oil, and electricity are required to run the milling plant.

**Transportation**

According to Knudsen et al., 2010, the SBM is transported by truck to the harbour of Dalian, China, where it is loaded onto a container ship, which sails directly to Aarhus harbour. Within the milling stage, a default distance of 200 km of road transportation appears as well [Schmidt and De Rosa, 2020]. Any inputs of fertilizer to the cultivation are assumed to be included in the road transportation, as nothing else is mentioned by Knudsen et al., 2010.

### 4.7.3 The soybean oil refinery stage

As mentioned above, SBM is co-produced with crude soybean oil during the milling stage (CSBO). This indicates that increased protein demand will have an impact on the oil market, which is dominated by palm oil [Schmidt and Weidema, 2007]. Further LCI calculations and descriptions of palm oil are outlined in Appendix C, but the LCI data for this substitution is presented in 4.6. The CSBO is transported to a refinery, which is a treatment activity because refining is required before it can be used as a by-product (RBD SBO) to replace alternative productions such as palm oil on the market. Besides the RBD SBO, landfills of bleaching earth and oil loss are also materials for treatments.

The refinery plant requires fuel oil, electricity, and water like the milling plant. Additionally, different chemicals are added, and a short transportation distance as well. A summary of the LCI data for milling soybeans and refining CSBO is included in Table 4.6.

### 4.7.4 LCI: Palm oil

Because the soybean oil substitutes palm oil, it is relevant to comprehend all the palm oil related operations. These are depicted in Figure 3.1 as palm oil production but revolve around oil palm cultivation, milling, refining, palm kernel oil (PKO), and palm kernel meal (PKM). In addition, associated substitutes in some processes. The LCI data and modelling are drawn from Schmidt and De Rosa, 2020, which may be found in Appendix C.

| Flows | Unit | SBM {CN} CSBO mill | CSBO {CN} Treatment refinery | LCI data |
|---|---|---|---|---|
| **Output: reference flow** | | | | |
| Output: SBM {CN} | t | 0.77 | | |
| Input: CSBO {CN} | t | | 1.00 | RBD SBO {CN} Treatment of CSBO in soybean oil refinery |
| **Input: feedstock** | | | | |
| SB {CN} SB cultivation | t | 1.00 | | See Table 4.5 |
| **Output: materials for treatment** | | | | |
| CSBO {CN} | t | 0.19 | | RBD SBO {CN} Soybean oil refinery |
| Landfill of bleaching earth {CN} | kg | | 5.79 | Link to: Landfill of waste: Inert/metal/hazardous {CN-TW} |
| Landfill of oil loss {CN} | kg | | 5.00 | Link to: Landfill of waste: Inert/metal/hazardous {CN-TW} |
| **Output: by-products that substitute alternative production** | | | | |
| Palm oil {ID} | t | | 0.98 | RBD palm oil {ID} Palm oil refinery |
| **Input: fuel and energy** | | | | |
| Natural gas {CN} | t | 1.36E-10 | | Link to: Extraction of natural gas and services {CN-TW} |
| Fuel oil {CN} | MJ | 3.40E-06 | 5.73E-06 | Link to: Petroleum Refinery {CN-TW} |
| Electricity {CN} | kWh | 12.20 | 14.50 | Link to: Electricity mix {CN-TW} |
| **Input: water** | | | | |
| Water{CN} | m3 | 0.10 | 0.01 | Link to: Collection, purification and distribution of water (41) {CN_TW} |
| **Input: transport** | | | | |
| Road transport {CN} | tkm | 200.00 | 1.38 | Link to: Other land transport {CN_TW} |
| **Input: material use** | | | | |
| Caustic Soda, as 100% conc. | kg | | 2.10 | Link to: Chemicals nec {CN_TW} |
| Phosphoric acid, as 100% conc. | kg | | 0.80 | Link to: Chemicals nec {CN_TW} |
| Bleaching earth | kg | | 9.00 | Link to: Chemicals nec {CN_TW} |
| Sulphuric acid, as 100% | kg | | 1.90 | Link to: Chemicals nec {CN_TW} |

**Table 4.6:** Summary of LCI data for milling 0.77 t soybeans and treatment of 1 t CSBO. Additionally, with the inputs to the marginal market for vegetable oils, which in this case is CPO. See Table C.4.

## 4.8 LCI: Fava beans

To produce fava beans (FB), the necessary inputs are agricultural machinery, appurtenant diesel consumption, and transportation. In addition, emissions are manually calculated. The LCI data for producing 1 t fava beans is outlined in Table 4.7.

**Capital goods**

The cultivation of fava beans requires the machinery described in Section 4.3. The quantity of ha is adjusted for the specific fava beans cultivation (0.29 ha/t DM) to calculate the exact amount (kg). With the data from Ecoinvent, described in Section 4.3, the final amount of machinery (kg) is added in the summary Table 4.7.

**Fuel**

The calculations for the amount of fuel to the cultivation stage are described in Section 4.5.

**Fertilizer**

No external N-fertilizer is added because fava beans nitrogen fixates itself [Kreutzfeldt, 2022; SEGES Innovation, 2022a].

**Transportation**

As stated in Section 4.7.1, 1 km distance from field to farm is included in the Ecoinvent 3.8 data. In addition, transportation of the final output of fava bean cultivation is described in Section 4.2.

**Emissions**

It is assumed that dinitrogen monoxide ($N_2O$) and carbon dioxide ($CO_2$) are the only emissions from fava beans production. $N_2O$ emissions are calculated through the standard equations from IPCC, 2006. These entail both direct and indirect $N_2O$ from managed soils. The calculations and further descriptions can be found in Appendix A. $CO_2$ emissions are from the agricultural machinery like described in Section 4.7.1.

| Flows | Unit | FB production DK | LCI data |
|---|---|---|---|
| **Output: reference flow** | | | |
| Output: fava beans | t | 1.00 | Reference flow |
| **Input: land use** | | | |
| Land use | ha | 0.27 | Link to: Market for arable land {GLO} |
| **Input: seeds** | | | |
| Organic FB seeds {DK} | kg | 230.00 | Same cultivation activities as for FB. |
| **Input: fuel** | | | |
| Diesel {DK} | kg | 27.71 | Link to: Petroleum Refinery {DK} |
| **Input: agricultural machinery** | | | |
| Total machinery {DK} | kg | 5.20 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| **Input: transport** | | | |
| Transportation, market {DK} | tkm | 150.00 | Link to: Other land transport {DK} |
| **Output: emissions to air** | | | |
| Dinitrogen monoxide<br>Carbon dioxide | kg $N_2O$<br>kg kg $CO_2$ | 0.37<br>73.86 | Elementary flows: emissions to air |

**Table 4.7:** Summary of LCI data for producing 1 t FB [SEGES Innovation, 2022a].

## 4.9 LCI: Grass protein concentrate

To produce the final output of GPC, there are three main activities: cultivation of clover grass, green biorefinery to extract GPC, and finally, an anaerobic activity where by-products from the biorefinery process are treated (see Figure 1.6 for details).

### 4.9.1 Clover grass cultivation

The inputs to produce clover grass are diesel, nutrients, different machinery, transportation of the nutrients to the farm, and lastly, transportation of the GPC to Aarhus harbour. This is all calculated in the data outlined in the summary Table 4.8. PEF requires a minimum of a three years average of the production [Fog, 2022]. Thus, this study builds upon the same average. Clover grass cultivation differs from other crops, especially due to the harvesting process. As fava beans and soybeans are harvested with a combine harvester once a year, clover grass fields are cut up to six times before new crops are sown on the field. The sum of the yields from the six cuts is the final yield from a field.

**Nutrients**

Manure is added to fields, but it is challenging to model, the PEF calculations do not account for adding the manure, but only the emissions. This is uncertain, as some emissions might be left out in the calculations. Lastly, lime and potassium vinasse is added during the cultivation stage too.

**Fuel and agricultural machinery**

Clover grass requires the following machinery: seeder, drum, wagon, manure spreader (for lime and vinasse application), slurry spreader, broadcaster, grass cutter, and tractors. The total amount of machinery is precalculated in the PEF data. The diesel used for the different agricultural machinery is precalculated in the PEF data.

**Transportation**

Manure, lime, and potassium vinasse are transported to the farm during the cultivation stage. Transportation from the field to the refinery is included in the refinery stage in Section 4.9.2.

**Emissions**

The emissions from the diesel combustion is modelled in the activity *Diesel DK Diesel and combustion, clover grass cultivation.* The input is background data from Exiobase Petroleum Refinery {DK} and the associated emissions seen in Table 4.8. $N_2O$ and $CH_3$ from the fertilizer additions are modelled as well.

| Flows | Unit | Clover grass cultivation {DK} | LCI data |
|---|---|---|---|
| **Output: reference flow** | | | |
| Output: clover grass | t | 32.67 | Reference flow |
| **Input: land use** | | | |
| Land use | ha | 0.83 | Link to: Market for arable land {GLO} |
| **Input: seeds** | | | |
| Organic clover grass seeds | kg | 7.16 | See Table 4.8 |
| **Input: energy** | | | |
| Diesel | kg | 58.67 | Link to: Petroleum Refinery {DK} |
| **Input: Nutrients** | | | |
| Manure slurry | kg | 16,358.31 | Not modelled {DK} |
| Lime | kg | 153.36 | Link to: Manufacture of cement, lime and plaster {DK} |
| Potassium vinasse | kg | 44.47 | Link to: P- and other fertiliser {DK} |
| **Input: agricultural machinery** | | | |
| Total machinery {DK} | kg | 1.57 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| **Input: transport** | | | |
| Transportation, slurry {DK} | tkm | 40.38 | Link to: Other land transport {DK} |
| Transportation, Lime {DK} | tkm | 109.50 | Link to: Other land transport {DK} |
| Transportation, Potassium vinasse {DK} | tkm | 708.24 | Link to: Other land transport {DK} |
| **Output: Emissions to air** | | | |
| $N_2O$, synthetic fertiliser and manure | kg | 1.62 | Elementary flow: emissions to air |
| $NH_3$, manure | kg | 17.70 | |
| $CO_2$, diesel combustion | kg | 211.08 | |
| $CH_4$, diesel combustion | kg | 0.01 | |
| Benzene ($C_6H_4$), diesel combustion | kg | 4.94E-04 | |
| Cadmium (Cd), diesel combustion | kg | 6.77E-07 | |
| Chromium (Cr), diesel combustion | kg | 3.38E-06 | |
| Copper (Cu), diesel combustion | kg | 1.15E-04 | |
| $N_2O$, diesel combustion | kg | 8.12E-03 | |
| Nickel (Ni), diesel combustion | kg | 4.74E-06 | |
| Zink (Zn), diesel combustion | kg | 6.77E-05 | |
| Benzo(a)pyrene (C20H12), diesel combustion | kg | 2.03E-06 | |
| Ammonia (NH3), diesel combustion | kg | 1.35E-03 | |
| Selenium (Se), diesel combustion | kg | 6.77E-07 | |
| HC, as NMVOC, diesel combustion | kg | 0.13 | |
| NOx, diesel combustion | kg | 2.26 | |

**Table 4.8:** Summary of LCI data for cultivating 32.67 t fresh clover grass [Fog, 2022] (continued).

| Flows | Unit | Clover grass cultivation {DK} | LCI data |
|---|---|---|---|
| CO, diesel combustion | kg | 0.51 | |
| PM, diesel combustion | kg | 0.06 | |
| $CO_2$ from lubricant, diesel combustion | kg | 0.17 | |
| **Output: Emissions to water** | | | |
| $NO_3$, synthetic fertiliser and manure | kg | 98.08 | Elementary flow: emissions to air |
| P, Water | kg | 0.62 | |

**Table 4.8:** Summary of LCI data for cultivating 32.67 t fresh clover grass [Fog, 2022].

### 4.9.2 Green biorefinery

To extract the GPC from the clover grass, it enters a biorefinery plant as described in Section 1.2. The other inputs are fuel and energy, chemicals, water, and transportation. The GPC is furthermore co-produced with green fibre and brown juice.

#### Fuel and energy

The biorefinery plant, Ausumgaard.dk, 2022, requires natural gas, diesel and electricity to run the extraction of GPC. The natural gas and diesel are modelled in the activities *Natural gas {DK} Natural gas and combustion* and *Diesel DK Diesel and combustion, GPC refinery* with *Extraction of Natural gas and services {DK}* and *petroleum Refinery {DK}* respectively. The reason behind is to model the associated direct emissions correctly.

#### Water and chemicals

Water and chemicals are added to extract the GPC. The chemicals are acidic cleaning agents, alkaline cleaning agents, and anti-foam oil, which all are modelled with the background data *Chemicals nes {DK}*.

#### Machinery

The machinery in the refinery plant is a buffer feed tank, a screw presser, and four heat exchangers. The amounts (kg) are summarized and modelled with *Manufacture of machinery and equipment, nes {DK}*.

#### Transportation

Transportation of the clover grass and chemicals is included in the model (background data *Other land transport {DK}*.

### By-products

The by-products are green fibre and brown juice, which are further treated in a biogas plant and are described in the next section. A summary of the LCI data for refining GPC is shown in Table 4.9.

### Emissions

Direct emissions are modelled from *Diesel DK Diesel and combustion, GPC refinery* and *Natural gas {DK} Natural gas and combustion.*

| Flows | Unit | GPC refining {DK} | LCI data |
|---|---|---|---|
| **Output: reference flow** | | | |
| Output: GPC | t | 1 | |
| **Input: feedstock** | | | |
| Clover grass | t | 32.67 | See Table 4.8 |
| **Input: energy** | | | |
| Electricity, processing | kWh | 108.77 | Link to: Electricity mix {DK} |
| Electricity, drying | kWh | 280.07 | Link to: Electricity mix {DK} |
| Natural gas | m3 | 85.02 | Link to: Extraction of natural gas and services {DK} |
| Diesel, loading | kg | 26.01 | Link to: Petroleum Refinery {DK} |
| Diesel, heating | kg | 45.54 | Link to: Petroleum Refinery {DK} |
| **Inputs: chemicals** | | | |
| Acidic cleaning agents | kg | 2.20 | Chemicals nec {DK} |
| Alkaline cleaning agents | kg | 10.80 | Chemicals nec {DK} |
| Anti foam oil | kg | 1.30 | Chemicals nec {DK} |
| **Inputs: natural resources** | | | |
| Water | t | 0.48 | Link to: Collection, purification and distribution of water (41) {DK} |
| **Inputs: machinery** | | | |
| Processing building | kg | 17.01 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Buffer feed tank | kg | 0.33 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Screw press | kg | 1.12 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Heat exchangers | kg | 0.99 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| **Input: transport** | | | |
| Transportation, packaging materials | tkm | 3.30 | Link to: Other land transport {DK} |
| Transportation, clover grass | tkm | 257.24 | Link to: Other land transport {DK} |
| Transportation, chemicals | tkm | 86.96 | Link to: Other land transport {DK} |
| Transportation, market | tkm | 150.00 | Link to: Other land transport {DK} |

**Table 4.9:** Summary of LCI data for refining 1 t GPC from the Ausumgaard.dk, 2022 plant (continued).

| Flows | Unit | GPC refining {DK} | LCI data |
|---|---|---|---|
| **Output: materials for treatment** | | | |
| Brown juice | t | 18.74 | See Table 4.10 |
| Press cake | t | 12.13 | See Table 4.10 |
| **Output: Emissions to air** | | | |
| $CO_2$, diesel combustion | kg | 237.15 | Elementary flow: emissions to air |
| $SO_2$, diesel combustion | kg | 0.08 | |
| $CH_4$, diesel combustion | kg | 0.01 | |
| Benzene ($C_6H_4$), diesel combustion | kg | 5.55E-04 | |
| Cadmium (Cd), diesel combustion | kg | 7.60E-07 | |
| Chromium (Cr), diesel combustion | kg | 3.80E-06 | |
| Copper (Cu), diesel combustion | kg | 1.29E-04 | |
| N2O, diesel combustion | kg | 9.12E-03 | |
| Nickel (Ni), diesel combustion | kg | 5.32E-06 | |
| Zink (Zn), diesel combustion | kg | 7.60E-05 | |
| Benzo(a)pyrene ($C_{20}H_{12}$), diesel combustion | kg | 2.28E-06 | |
| Ammonia ($NH_3$), diesel combustion | kg | 1.52E-03 | |
| Selenium (Se), diesel combustion | kg | 7.60E-07 | |
| HC, as NMVOC, diesel combustion | kg | 0.15 | |
| NOx, diesel combustion | kg | 2.54 | |
| CO, diesel combustion | kg | 0.58 | |
| PM, diesel combustion | kg | 0.07 | |
| $CO_2$ from lubricant, diesel combustion | kg | 0.19 | |
| $SO_2$, natural gas combustion | kg | 1.34E-03 | |
| NOX, natural gas combustion | kg | 0.10 | |
| NMVOC, natural gas combustion | kg | 0.01 | |
| $CH_4$, natural gas combustion | kg | 3.11E-03 | |
| CO, natural gas combustion | kg | 0.09 | |
| $CO_2$, natural gas combustion | kg | 177.55 | |
| $N_2O$, natural gas combustion | kg | 3.11E-03 | |
| TSP, natural gas combustion | kg | 3.11E-04 | |
| $PM_{10}$, natural gas combustion | kg | 3.11E-04 | |
| $PM_{2.5}$, natural gas combustion | kg | 3.11E-04 | |

**Table 4.9:** Summary of LCI data for refining 1 t GPC from the Ausumgaard.dk, 2022 plant.

### 4.9.3 Anaerobic digestion stage (biogas)

The advantage of producing GPC is the contribution to biogas. The by-products, green fibre and brown juice, are inputs to the biogas, where the output will substitute natural gas and fertilizer production. The biogas plant requires electricity and fuel to activate the anaerobic digestion processing. Biogas substitutes the natural 1:1 because it is assumed that they have the same calorific value. As the background data *N-fertilizer {DK}* and *P and other fertilizer {DK}* are aggregated in Exiobase, the substitution of N and K fertilizer is assumed to be 1:1 as well. A summary of the LCI data for the treatment of green fibre and brown juice is shown in Table 4.10.

| Flows | Unit | Anaerobic digestion {DK} | LCI data |
|---|---|---|---|
| **Output: reference flow** | | | |
| Output: biomethane {DK} | kg | 857.58 | |
| Output: Digestate - N {DK} | kg | 84.66 | |
| Output: Digestate - K {DK} | kg | 116.13 | |
| **Input: feedstock** | | | |
| Green fibre {DK} | t | 12.13 | See Table 4.9 |
| Brown juice {DK} | t | 18.74 | See Table 4.9 |
| **Input: energy** | | | |
| Electricity {DK} | kWh | 32.71 | Link to: Electricity mix {DK} |
| Diesel {DK} | kg | 26.01 | Link to: Petroleum Refinery {DK} |
| **Output: by-products that substitute alternative production** | | | |
| Natural gas {DK} | m3 | 857.58 | Link to: Extraction of natural gas and services {DK} |
| N-fertilizer {DK} (ammonium nitrate) | kg | 99.60 | Link to: N-fertiliser {DK} |
| K-fertilizer {DK} (potassium chloride) | kg | 134.00 | Link to: P- and other fertiliser {DK} |

**Table 4.10:** Summary of LCI data for treatment of green fibre and brown juice from Table 4.9, which is anaerobic digestion (biogas).

## 4.10 Delimitations

As described in Chapter 4, multiple assumptions and uncertainties appear in the inventory, which affects the validity and reproducibility of the study. Especially the lack of transparency of the GPC data, as the data is confidential PEF calculations, see Section 3.3. This makes it impossible for the reader to assess the data's validity, which, in turn, affects the study's validity. Furthermore, PEF uses a defined approach to perform the LCA, which may differ from the data gathered from a bottom-up approach. However, the data is from 2021, and mainly the cultivation data will differ because it is based on a three-year average, whereas soybeans and fava beans cultivations are based on one year. It may be claimed that the data collected for biorefinery and biogas will be equal to bottom-up collected data, as it is ordinary inputs like energy, fuel, amount of machinery, etc. In addition, the PEF calculations include direct emissions from all processes, indicating that more emissions are modelled, and thereby, GPC has a higher impact.

However, through the contribution analyses in Section 5.3, the main contributors are the arable land use and transportation. These emissions are from the Exiobase background data in all three product models. Thus, it can be argued that the conclusions of the LCA will still be similar, but with other results, if more direct emissions are added to the soybean meals and fava beans inventory. As stated in Section 1.2, fava beans can not substitute soybean meals 1:1 - especially for monogastric animal feed. This means that an expanded feed mix must be modelled before concluding about feeding with fava beans instead of soybean meals. In addition, it will increase the land use resulting in increased iLUC emissions from the fava beans production. However, as the FU is 1 kg CP, the LCA comparison is still valid.
Following the arguments that the LCI is legitimate, it is relevant to interpret the results in the LCIA in the following chapter.

# Chapter 5

## Life Cycle Impact Assessment

*The goal of this chapter is to provide results. First, the results are presented as characterized. Afterward, the results are weighted to choose which impact categories to investigate further. A contribution analysis is conducted to determine which activities in the three product systems have the biggest influence within the selected impact categories. Finally, a summary is written where attention is given to the most significant impacts.*

### 5.1 Characterization

As stated in Section 3.4, the characterized results are calculated with the method, Stepwise.v.1.07. Table 5.1 displays the results of each reference flow to fulfil the functional unit and feed energy substitution for the three productions, demonstrating how the impacts differ within the respective impact categories.

| Impact category | Unit | SBM CN | FB DK | GPC DK |
|---|---|---|---|---|
| Functional unit | kg CP | 1 | 1 | 1 |
| Reference flow | kg feed | 2.14 | 3.22 | 2.13 |
| Feed energy | MJ | -19.96 | -18.73 | -24.32 |
| Global warming, fossil | kg $CO_2$-eq | -0.41 | 0.51 | 4.89 |
| Nature occupation | PDF*$mm^2$ | 0.90 | 1.04 | 3.94 |
| Respiratory inorganics | kg $PM_{2.5}$-eq | 1.95-3 | -1.04E-4 | 1.29E-3 |
| Human toxicity, carcinogens | kg $C_2H_3Cl$-eq | 0.03 | 0.01 | 0.02 |
| Human toxicity, non-carc. | kg $C_2H_3Cl$-eq | 0.01 | 2.71E-03 | 0.01 |
| Ecotoxicity, aquatic | kg TEG-eq w | 2.90 | 0.74 | 4.88 |
| Ecotoxicity, terrestrial | kg TEG-eq | 5.49 | 1.79 | 7.03 |
| Acidification | m2 UES | 0.20 | 0.10 | 0.42 |
| Eutrophication, aquatic | kg $NO_3$-eq | -0.01 | 0.03 | 0.22 |
| Eutrophication, terrestrial | $m^2$ UES | 0.50 | 0.40 | 1.65 |
| Respiratory organics | pers*ppm*h | 4.41E-6 | 1.75E-4 | 2.19E-3 |
| Photochemical ozone, vegetat. | $m^2$*ppm*hours | 2.89 | 1.87 | 20.17 |
| Non-renewable energy | MJ primary | 9.53 | 2.61 | -76.21 |
| Mineral extraction | MJ extra | 2.26E-03 | 9.08E-03 | 2.41E-03 |

**Table 5.1:** Characterization results for producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively.

## 5.2 Weighting

Weighting is used to simplify the interpretation of the impact categories and to avoid insignificant ones. The weighting factor in Stepwise.v.1.07 is in EUR2003, which implies that after each impact has been monetized, the effects are all expressed in a monetary single score. See Section 3.4.1 for further description.

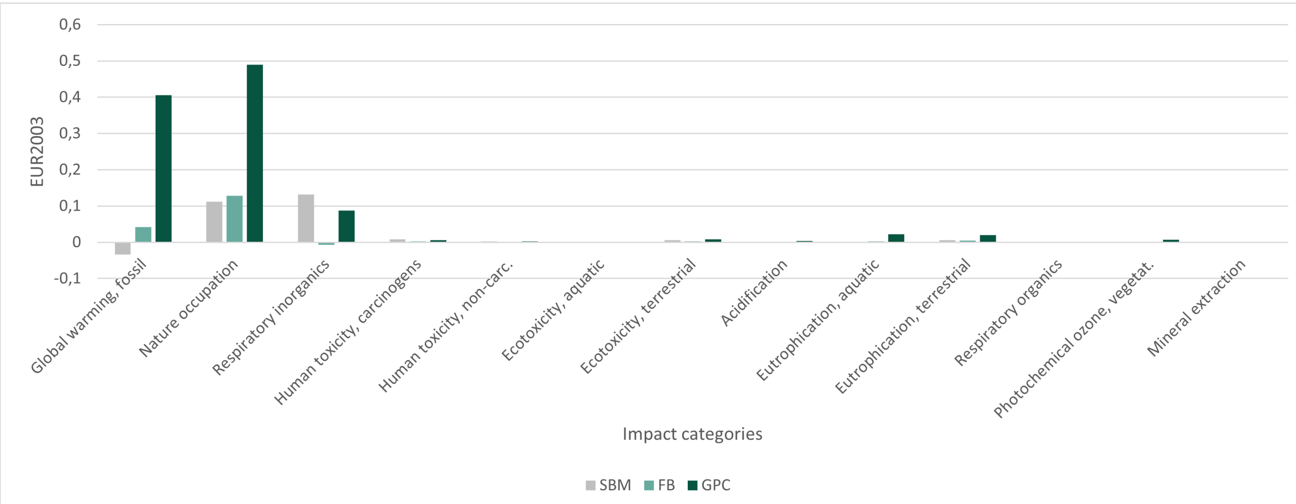


**Figure 5.1:** Weighted results for producing the 1 kg CP (FU) from SBM, FB and GPC.

The most relevant impact categories for all three product systems are nature occupation, global warming, fossil, and respiratory inorganics. In the following chapter, these three impact categories are explored further in a contribution analysis.

## 5.3 Contribution analysis

The contribution analysis is divided into the three impact categories, analysing 1 kg CP from soybean meal (SBM), fava beans (FB), and grass protein concentrate (GPC), respectively. The total impacts are displayed in Table 5.2, and the contributions within each impact category are visualized in the Figures 5.2, 5.3 and 5.4. Fuel & energy, feedstock, substitution, and others are evaluated within each section. By appraising the same parameters, a clear comparison is performed. The calculations behind the contribution analyses are found in Appendix D.

| Summary | Unit | Soybean meal | Fava beans | Grass protein concentrate |
|---|---|---|---|---|
| Functional unit | kg CP | 1 | 1 | 1 |
| Reference flow | kg feed | 2.14 | 3.22 | 2.13 |
| Feed energy | MJ | -19.96 | -18.73 | -24.32 |
| Nature occupation | PDF*$m^2$ | 0.90 | 1.03 | 3.94 |
| Global warming, fossil | kg $CO_2$-eq | -0.41 | 0.51 | 4.89 |
| Respiratory inorganics | kg $PM_{2.5}$-eq | 1.94E-3 | -1.00E-4 | 1.29E-3 |

**Table 5.2:** Summary of the characterized results on nature occupation, global warming, and respiratory inorganics when producing 1 kg CP from SBM, FB, and GPC, respectively. Stepwise.v.1.0.7 method is utilized.

### 5.3.1 Nature Occupation

The contribution analysis in nature occupation is displayed in Figure 5.2. The main contributor in all product systems is the iLUC (arable land ha*yr-eq) (SBM: 4.24 PDF*$m^2$, FB: 4.09 PDF*$m^2$ and GPC: 6.13 PDF*$m^2$). iLUC affecting nature occupation is due to transforming secondary forest into arable land. As stated in Section 4.1, the iLUC includes the consequences of the substituted production, which frequently result in deforestation. An example from Section 1.1 is the Chinese export of organic soybeans, which indirectly deforests the rainforest because China imports the South American soybeans.

Soybean meal production has the lowest impact because of the soybean oil (RBD SBO) substitution of palm oil (RBD PO). Producing 2.14 kg, soybean meal has a by-product of 0.53 kg CSBO, which substitutes 0.53 kg CPO (see Section 4.7). This substitution will avoid 1.53 PDF*$m^2$ because of the avoided land use for the oil palm cultivation. Concerning 'others', it is mainly due to transportation because the contributors are buildings and halls connected to the manufacturing of transport, which consists of wood. Furthermore, extraction and manufacturing of lime for the clover grass cultivation also affect nature occupation. Lastly, the substitution of energy crops reduces the PDF*$m^2$ impacts because the arable land use is avoided. This results in soybean meal and fava beans PDF*$m^2$ emissions being similar, and GPC has the highest impact.

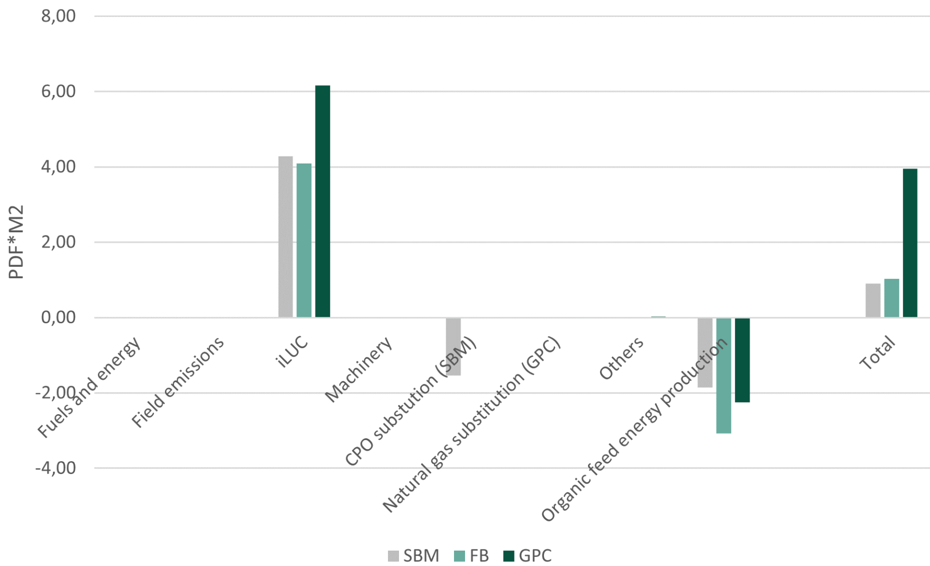


**Figure 5.2:** Process contribution to nature occupation from producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively Own illustration.

### 5.3.2 Global warming, fossil

As illustrated in Figure 5.3, the total impacts on global warming differ significantly. The soybean meals have the lowest impact because of the palm oil substitution, except for transport included in 'others'. Fuel emissions come from is used in all cultivations, the soybean milling, and refinery stages for soybean oil and GPC. Soybean milling and GPC biorefining also require natural gas and electricity as energy inputs. GPC biorefining has 6% direct emissions from diesel combustion and 6% direct emissions from natural gas combustion. Within the feedstock, field emissions are high from the clover grass production $CH_4$ emissions from manure. iLUC is the most significant contributor to all the protein productions. Besides iLUC causing secondary forest changed into arable land, it further constitutes intensification of the land, where $N_2O$ emissions highly contribute to global warming. Since GPC requires the biggest land use to produce 1 kg CP (0.83 ha/t), it has the highest impact. In the cultivation modelling only emissions from the agricultural machinery use are modelled for SBM and fava beans, whereas multiple emissions are included in the clover grass. This affects the global warming impacts. The content of 'others' in the GPC feedstock is, among others, the addition of chemicals and the manufacturing of lime.

When the by-products of the GPC production (brown juice and green fibre) enter a biogas plant, they reduce GHG emissions by 0.68 kg $CO_2$-eq. which avoids extraction of natural gas. The transportation included in 'others' contributes to GHG emissions. Transporting the SBM from China to Denmark (20,280 tkm) is the biggest contributor to this product system. For GPC, it is mainly during the cultivation stage, where transportation of manure, lime and potassium vinasse are transported 858 tkm. in total. Lastly, both fava beans and GPC are transported

150 km (default distance). Regarding the substitution of feed energy crops, it results in the final emissions from SBM being negative, the fava beans emissions are close to zero, and lastly, GPC is the one with the highest global warming impact.

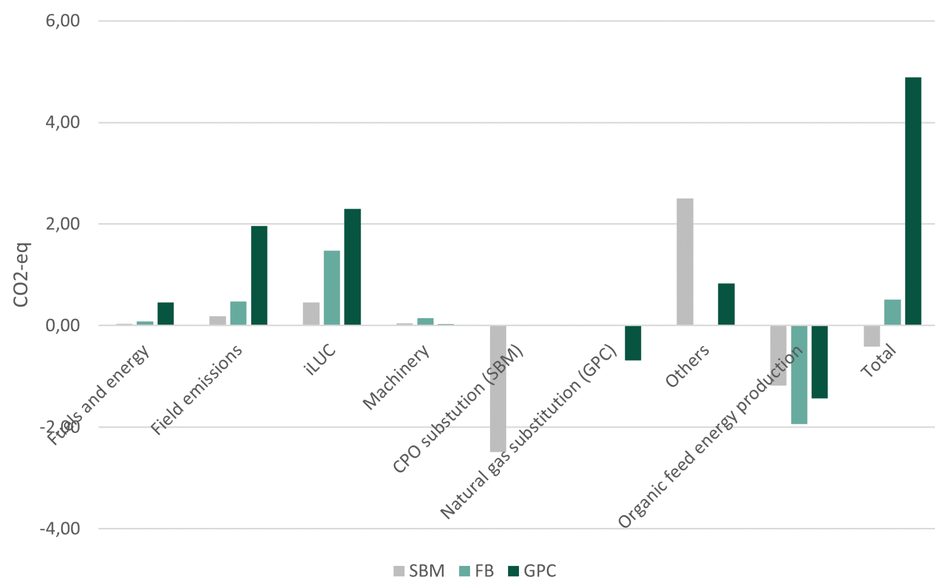


**Figure 5.3:** Process contribution to global warming from producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. Own illustration.

### 5.3.3 Respiratory inorganics

The contribution analysis in respiratory inorganics illustrated in Figure 5.4 is related to human health. This is the only impact category where the import of soybean meals has the highest impact. The biggest contributors are land use and transportation. During the cultivation, iLUC affects respiratory inorganics because of the intensification of land, where ammonia ($NH_3$) is the most contributing emission. Since GPC requires the biggest land use, the iLUC impacts are highest from this production.

Regarding the transportation, for soybean meals it is mainly due to the sea transport from China to Denmark and land transportation of fava beans and GPC. NOx and particles $< 2.5$ um and 10 um have the highest impact from transport. From GPC, manufacturing of lime and the use of N-fertilizer ($NH_3$, $S_2O$ and particulate emissions) included in 'others' for the clover grass cultivation contributes to respiratory inorganics. The substitution of natural gas reduces the $PM_{2.5}$-eq emissions. The feed energy substitution influences the results significantly because emissions from manure spreading and the $NH_3$ from the iLUC are avoided.

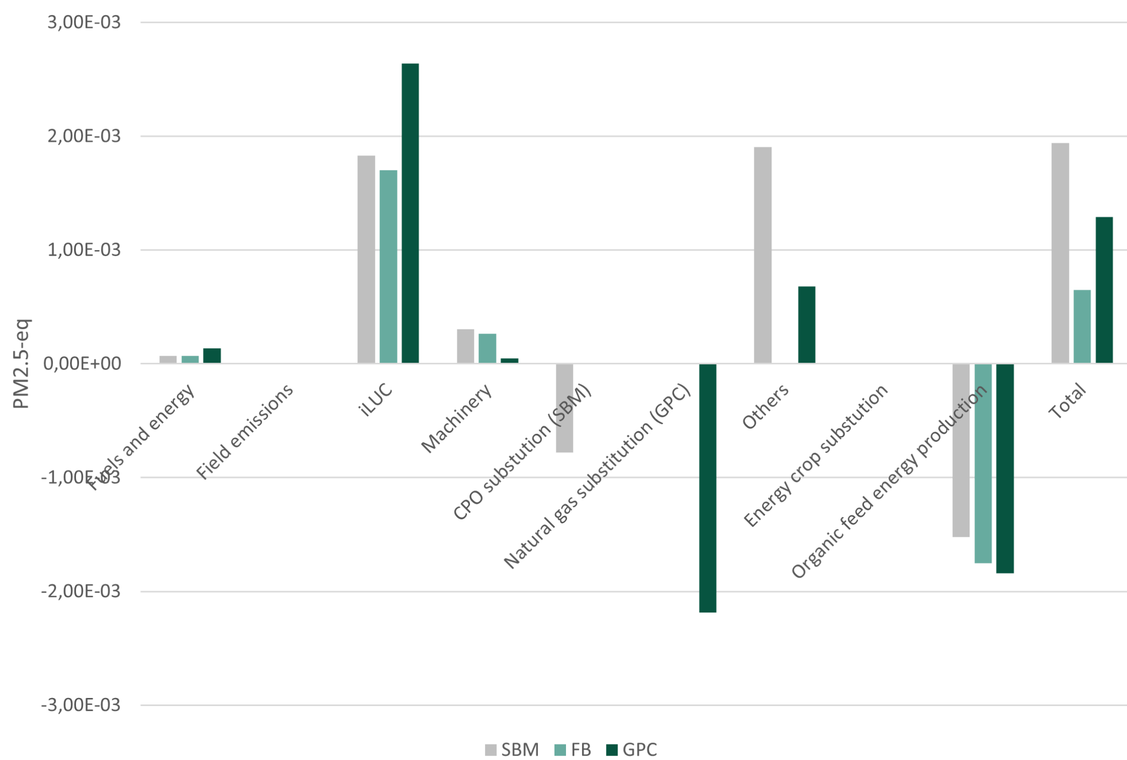


**Figure 5.4:** Process contribution to respiratory inorganics from the production of the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. Own illustration.

## 5.4 Summarized interpretation of the LCIA results

Based on the LCIA results, it can be concluded that the import of SBM has the smallest impact on nature occupation and global warming compared to fava beans and GPC. This is because soybean oil substitution of palm oil, which has a greater environmental impact, implying that avoiding palm oil will have a positive impact. In respiratory inorganics, the soybean meal has a slightly higher impact because of the transportation from China to Denmark. However, there might be some uncertainties in the calculations, since the transportation contributes more to respiratory inorganics than iLUC (see table D.3). The contribution analyses further show that iLUC is the biggest contributor in all the categories, indicating that yields and necessary kg crop produced per kg feed significantly impact the LCIA results. Lastly, since fava beans have the highest MJ content per kg CP, this production substitutes more energy crop production.

Concerning the hypothesis for sub-question 1: producing national alternatives to SBM import not necessarily, is more environmentally can be confirmed aside the respiratory inorganics impacts. However, as stated in Section 2.1, it is presumed that other parameters are important to consider in order to have a holistic approach to the solution of the organic protein production. This is further discussed in Chapter 6.

# Chapter 6

## Reflection on other parameters not covered by the LCA results

*The aim of this chapter is foremost to discuss different parameters influencing the LCA results. Secondly, rather than emphasizing protein production for livestock feed, it is explored whether it is conceivable to enhance protein production for human consumption instead. Discussing these aspects ensures a holistic approach to the LCA; thus, it is employed correctly in the decision process about Danish organic protein production.*

## 6.1 An increased organic market

As mentioned in Section 5.4, soybean oil substituting palm oil has a significant influence on the impacts from the soybean meal import. For that reason, it is relevant to discuss the impact of the palm oil substitution and how other parameters are important to take into account. One of the reasons for the significant consequences of palm oil is that peat areas, which emit large levels of $CO_2$, account for 20% of the land used for oil palm cultivation in Indonesia and Malaysia [Bosselmann et al., 2022; Schmidt and De Rosa, 2020]. Another important reason is that the wastewater treatment at palm oil mills emits large amounts of $CH_4$ emissions.

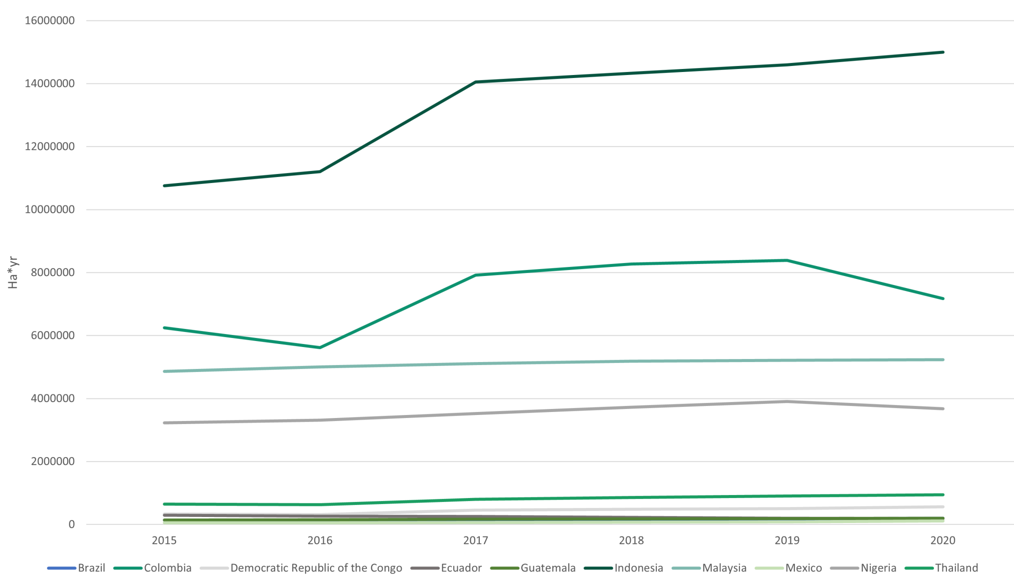


**Figure 6.1:** The development of the top ten producing palm oil countries 2015 to 2020. The decrease from 2019 to 2020 is mainly due to COVID-19. Own illustration. Data provided by FAOSTAT, 2022.

However, one of the main suppliers, Malaysia, are soon out of possible deforestation for palm production. Looking at the current market suppliers and their development that last five years in Figure 6.1, countries like Colombia and Nigeria are increasing [FAOSTAT, 2022]. These countries have possibility to produce oil palms on no peat lands, which is an environmental advantage. If the palm oil emissions are decreased, it will increase the impacts from soybean meal import, because the soybean oil will substitute fewer emissions. This will affect the results and maybe show the Danish alternatives as more favourable. Another relevant aspect is that the organic production enters an open market, where inputs can be conventional, and the organic products can enter the conventional sector as well.

An example of the firstly mentioned is the low amount of conventional manure addition in organic fields [MFAFD, 2022]. For the secondly mentioned, the example can be the soybean oil substituting conventional palm. However, as mentioned in the Introduction, the organic market is growing and will keep increasing in the future, which can argue for soybean oil substituting organic vegetable oils instead. According to Bosselmann et al., 2022, rapeseed oil, which is possible to produce in Denmark, has the fourth-biggest market share of vegetable oil. As an example, if soybean oil substitutes organic rapeseed oil instead, a simple scenario is modelled. According to Schmidt, 2015, 1 kg rapeseed oil (conventional) emits 3.09 kg $CO_2$-eq. In the modelling of 1 kg crude protein from soybean meals, a substitution of 0.19 kg rapeseed oil results in 0.73 kg $CO_2$-eq. instead of -0.37 kg $CO_2$-eq. from the palm substitution. This is a higher impact than Danish fava beans production (0.51 kg $CO_2$-eq), indicating a significant influence from the vegetable oil substitution. According to Bosselmann et al., 2022 the rapeseed production has lower yields than oil palms, but because of aforementioned peat lands, the impacts are higher from the palm production.

However, Kreutzfeldt, 2022 and Bosselmann et al., 2022 both stress, that 90% of the rapeseed oil produced in Denmark is for biofuel, which makes it difficult to expect the oil to be a part of the vegetable oil market rather than the fuel market. As mentioned in Section 4.7.2, the biggest vegetable oil on the market is the palm oil. Because other countries can increase production and Indonesia is still producing, it is assumed that soybean oil will continue to substitute for conventional palm, maintaining or slightly increasing the low impacts of imported SBM. If that is the case, it is important to investigate other environmental impacts and how this information can contribute to either phasing out or continuing soybean meal import.

## 6.2 Improvements of the Danish alternatives

To enhance the environmental implications of the two Danish options, fave beans (FB) and grass protein concentrate (GPC), it is necessary to discuss several criteria that can be adjusted to assess whether any solution is feasible. As stated in the contribution analyses in Section 5.3, land use is a substantial contributor to both national productions, implying that increased yields should be evaluated in order to lower the amount of land required. This is assessed through a sensitivity analysis illustrated in the Figure 6.2, 6.3, and 6.4. Within each impact category, the respective impacts are decreasing when the yields increase. The biggest change occurs on global warming, when the fava beans yield increases. The default scenario emits 0.51 kg CO2-eq per kg CP, but with a yield increase of 30%, the emissions reduces to 0.04 kg CO2-eq. However, it is still not enough to have a lower environmental impact than the soybean meal import.

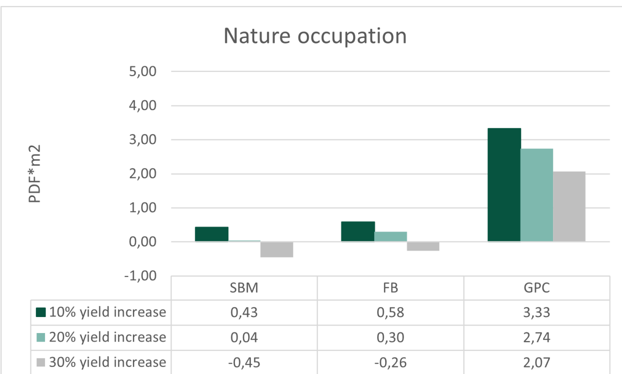


**Figure 6.2:** Sensitivity analysis on nature occupation of increasing the yields with 10%, 20% and 30%. The default scenarios are SBM: 0.90 PDF*$m^2$/1 kg CP, FB: 1.04 PDF*$m^2$/ kg CP and GPC: 3.94 PDF*$m^2$/ kg CP.

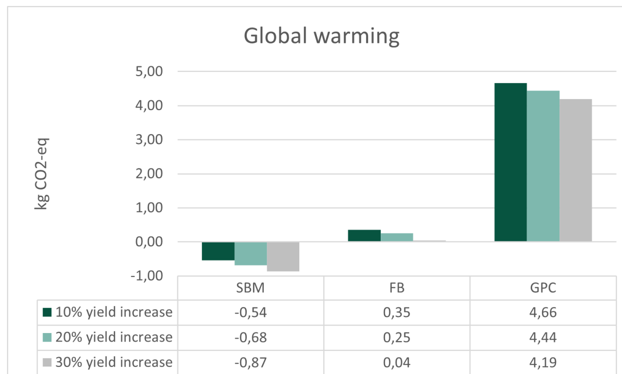


**Figure 6.3:** Sensitivity analysis on global warming of increasing the yields with 10%, 20%, and 30%. The default scenarios are SBM: -0.41 kg $CO_2$-eq/kg CP, FB: 0.51 kg $CO_2$-eq/ kg CP and GPC: 4.89 kg $CO_2$-eq/ kg CP.

The only impact category, which is relevant for the national alternatives, is respiratory inorganics. The impacts are significantly lower in the fava bean production, the more the yields increase. However, fava beans require a feed mix with other crops to contain the same nutrient content as soybean meal, as stated in Section 4.10. This indicates, that the impacts will increase, when this specific feed mix is environmentally assessed. In addition, substituting the total import of soybean meal with national protein crops requires up to 60-70,000 ha

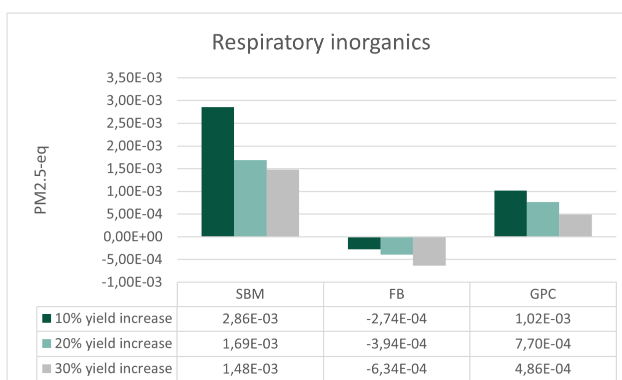


**Figure 6.4:** Sensitivity analysis on respiratory inorganics of increasing the yields with 10%, 20%, and 30%. The default scenarios are SBM: 1.95E-3 kg $PM_{2.5}$-eq/kg CP, FB: -1.04E-4 kg $PM_{2.5}$-eq/ kg CP and GPC: 1.29E-3 kg $PM_{2.5}$-eq/ kg CP.

converted from conventional to organic practices (see Section 1.3). Even though yields are improved, they still result in significant iLUC impacts. Regarding grass protein concentrate (GPC), Fog, 2022 describes that there are current researches of improving the protein extraction of GPC, hence less fresh grass is needed to produce 1 kg CP. However, an example of reducing the input to 10 kg clover grass (0.25 ha/t) instead of 32.76 kg (0.83 ha/t) results in 3.29 kg $CO_2$-eq, which is still the highest impact compared to the other protein sources in this study. However, this might be lower to the fava beans, when they are modelled with the necessary feed mix.

### 6.2.1 Pyrolysis of green fibre

Regarding the grass protein concentrate it might be possible to add green fibre from the biorefinery in a pyrolysis process or after entering the biogasification [DAFC, 2022b]. A pyrolysis process can create an output of biochar and a mix of oil and gas. Through this process, the carbon (C) is stored in the biochar. The biochar can be added to the fields and carbon storage for up to 500-1000 years, indicating a climatic advantage and better soil fertility for the farmer. The mix of oil and gas can be converted into fuel alternatives. According to DAFC, 2022b, pyrolysing of straw and fibre residues will reduce climate impacts from Danish agriculture by up to 50% and is an essential tool in the sustainable agenda. This means that adding the green fibre or the digestate from biogas through a pyrolysing process reduces the impacts even further because it is not only the substitution of natural gas. Further $CO_2$ emissions are bound as well, resulting in lower impacts from the GPC production. However, it is not assessed whether clover grass digestate is suitable for pyrolysis. In this section it can be concluded that land use remains the most significant factor, raising whether pyrolysis can mitigate the impacts. Hence, the grass protein concentrate has lower environmental impacts than soybean meal import.

Even though uncertainties appear in Section 6.2 and 6.2.1, the various changes will not be sufficient to relocate the complete protein feed production to Denmark. For that reason, it is relevant to question if protein production should be for human consumption rather than feed. The reason behind this is the increasing market preferences among consumers and the lower environmental impacts [Sepngang et al., 2020; DAFC, 2020a]. This is investigated further in the following Section.

## 6.3 Proteins for food - not feed

According to Watson et al., 2017 the production of plant-based protein is more environmentally friendly, because less land is required to be compared to animal protein. This is the reason why DAFC, 2020a finds it vital to boost plant-based protein consumption in Denmark in order to meet the target of a climate-neutral sector described in the Introduction. In addition, it is relevant to consider how self-sufficiency and sustainability can come together in organic agriculture in Denmark. Plant-based protein might be an answer to this. Nevertheless, there is a need to rethink the existing value chain before changing protein crops for human consumption from a niche to a mainstream production [Watson et al., 2017]. To understand the possibilities and challenges associated with the transitional changes in the organic sector, the theoretical model *Multi-Level Perspective* (MLP) from Section 2.4 is applied.

### 6.3.1 Application of the MLP

As stated in Section 2.4, the landscape is the exogenous environment, where overall macro-economics and cultural patterns in society are placed. As sustainability slowly is gaining momentum in the landscape, it destabilizes the regime, allowing niche innovations to emerge [Schot and Geels, 2008]. The landscape development creates new discourses about food products, continuously learning of more sustainable agriculture practices and environmental restrictions opens the opportunities for niches to break through the regime. For instance plant-based proteins [Voisin et al., 2014]. However, it can be discussed whether the regime can create the necessary changes, even though the landscape is moving in a sustainable direction. On the one hand, it is difficult because the current institutions result in the technological lock-in cause a specialization in cereal crops and livestock, with the necessary protein imported [Koutchadé et al., 2021; Meynard et al., 2018], as stated in Section 1.1. In addition, associated food supply chains are centred around market preferences, which is animal protein rather than plant-based protein. In terms of economic resources, this is why protein crops are not competitive enough for farmers compared to cereal crop production [Magrini et al., 2019].

On the other hand, as described in Section 2.4, niche innovations do not have the purpose of replacing the regime. It will contribute to changes in behaviour and routines. Today, the productions of both fava beans and clover grass are already in place in the regime, but the purposes differ. Fava beans are produced mainly to nitrogen fixate in the crop rotation, and the production of clover grass is ruminant feed (see Sections 1.2 and 1.3). This argues for the possibility of increasing plant-based protein production in Denmark, as organic farmers already know the cultivation practices. Some niche examples are Pure Dansk, 2022 and OPP, 2022, who use fava beans as Danish plant-based meat alternatives. In the case of grass protein concentrate (GPC), Fog, 2022 defines the intention of employing the concentrate for human consumption. GPC can, among other things, be used as protein powder, colouring agent, and fibre [SEGES Innovation, 2022b]. Based on the arguments mentioned above, it is possible to increase plant-based protein production in Denmark, but the realization requires more LCAs with iLUC and communication.

### 6.3.2 Fava beans and GPC as Danish plant-based protein

For plant-based protein to gain momentum in society knowledge sharing is crucial. It is vital to perform LCAs with iLUC to have a holistic understanding of the environmental impacts of organic agriculture. As stated in Section 1.1, it is unknown that importing soybean meal from China indirectly deforests the South American rainforest. By modelling consequential LCAs with iLUC included, it will help to understand these aspects. However, it is relevant to evaluate whether qualitative data can be communicated qualitatively to non-experts.
According to Heijungs, 2014, LCA information must be communicated in a simple and understandable manner, but it can be discussed how this can be achieved. In Appendix H an example of applying the *Shannon-Weaver communication model (SWCM)* is described. The communicative suggestion is to write about LCA results in articles or the like followed by a presentation/webinar, where participants can ask questions and get the LCA explained in detail.

According to Agger and Hoffmann, 2008 actor engagement and dialogue is namely the ultimate approach for information sharing, resulting in increased knowledge and motivation among the participants. Though, it can be questioned, whether LCAs will be understandable for the consumers, and if it will influence people's willingness to reduce the meat consumption in favour for the environment. Nevertheless, communicating LCAs will ensure the concept of *choice awareness* at a scientific basis [Jensen, 2022]. Choice awareness is concerned with the possibilities for societal transformation and refers to having a true choice and being aware of all choices and their consequences [Lund, 2014].

By communicating the LCA results of this study and the effects of iLUC, it will contribute to the organic sector's priority of substituting the organic protein import with nationally produced and instead improve the development of plant-based protein based on fava beans and GPC. Thus, the technological lock-in in the sochiotechnical regime changes, and more plant-based protein niches are included. Overall, this will contribute to the main goal of having the Danish organic sector being front-runner in sustainability.

## 6.4 Recommendation and further work

Based on this study, it is recommended that the Danish organic sector improve plant-based proteins. It is crucial to acknowledge that meat consumption must be reduced to minimize agricultural sector environmental impacts and ensure that the Danish organic sector is the most environmentally sustainable. Not that livestock production should be avoided, but the goal is to convince the industry and consumers that plant-based proteins are more environmentally friendly and should be prioritized above current meat production.

Both fava beans and grass protein concentrate (GPC) are useful in the sense that they can be produced in the Danish climate, they can enter the same crop rotation, and they can be used for food and feed. Even though GPC has higher environmental impacts, the current research of streamlining the biorefinery indicates sustainable potentials. Especially due to the amino acid content, which fava beans can not provide without entering a feed mix. In addition, it is important to increase LCAs to ensure quantitative arguments in the sustainable decision process within the organic sector. Furthermore, it is crucial to include iLUC when assessing agricultural products to ensure a holistic approach. To gain momentum, it is highly relevant to communicate the LCAs among non-experts through dialogues and simple explanations. Hence, it might be possible to increase plant-based protein and be self-sufficient in the necessary feed supply for organic livestock production, because of the reduction in meat production.

It is suggested that future studies in Denmark focus on a comparative LCA of other plant-based alternatives. This will raise choice awareness, influencing market preferences, policies, and other aspects of the sociotechnical regime. Finally, it will add to the organic sector's overall sustainability. According to Heijungs, 2014, It is crucial to note that LCA is not a sustainable assessment; rather, it is the environmental evaluation. Thus, when considering the future protein production in the organic sector future research must include assessments of economic and social sustainability.

# Chapter 7

## Conclusion

The aim of this study is to perform a comparative Life Cycle Assessment (LCA) between organic soybean meal import with the Danish alternatives: fava beans and grass protein concentrate (GPC). Based on the purpose to conclude, whether the goal of being self-sufficient on protein feed is more environmentally friendly than importing soybean meal. Furthermore, the LCA will contribute to the decision process in the Danish organic sector because the goal is to become a sustainable front-runner. The study's research question is posed as follows:

*What protein production is the most preferable between imported soybean meal from China, Danish fava beans, and Danish grass protein concentrate from an environmental perspective?*

Denmark is challenged by the current lock-in centered around livestock production and associated cereal crop production. This means that protein feed is imported, where the biggest organic market share is soybean meal from China. Despite the lock-in challenge, it is desired to phase out soybean meal and replace it with national alternatives. Therefore, this study tests the hypothesis; that national alternatives are not necessarily more environmentally friendly than the current import. Based on a consequential modelling the interpreted impact categories are 1) nature occupation, 2) global warming, fossil, and 3) respiratory inorganics. The functional unit is 1 kg of crude protein delivered at Aarhus Harbour, and the results are displayed in Table 7.1.

| Summary | Unit | Soybean meal | Fava beans | Grass protein concentrate |
|---|---|---|---|---|
| Functional unit | kg CP | 1 | 1 | 1 |
| Reference flow | kg feed | 2.14 | 3.22 | 2.13 |
| Feed energy | MJ | -19.96 | -18.73 | -24.32 |
| Nature occupation | PDF*$m^2$ | 0.90 | 1.03 | 3.942 |
| Global warming, fossil | kg $CO_2$-eq | -0.41 | 0.51 | 4.89 |
| Respiratory inorganics | kg $PM_{2.5}$-eq | 1.94E-3 | -1.00E-4 | 1.29E-3 |

**Table 7.1:** Summary of the characterized results on nature occupation, global warming, and respiratory inorganics when producing the functional unit: 1 kg CP from SBM, FB, and GPC, respectively. Stepwise.v.1.0.7 method is utilized.

Based on the LCA results, it can be concluded that the import of soybean meal is more environmentally friendly on nature occupation and global warming. This is because soybean oil (the by-product from milling soybeans into meals) substitutes palm oil. Palm oil has a greater environmental impact, implying that avoiding it will result in a positive impact. Fava beans have the

lowest impact on respiratory inorganics because this production requires the least transportation. Furthermore, iLUC is the biggest contributor in all the impact categories, indicating that yields and kg crop/ kg feed influence the impacts greatly. Moving to the GPC, the results show that it has the highest impact because of the required amount of fresh clover grass needed (0.83 ha/t DM GPC, 0.44 ha/t DM soybean meal, and 0.29 ha/t DM fava beans).
Initially, it is concluded that soybean meal is the preferred protein feed in the Danish organic sector regarding answering the research question. However, this will not live up to the goal of self-sufficiency. Thus, different parameters of the Danish alternatives are discussed, but regardless of improvements, the conclusion is still that soybean meal has the lowest impact. To prefer any Danish alternatives, the focus on protein production must change from feed to food.

Reducing meat consumption makes it possible to reduce land use significantly, which enables self-sufficiency. This will require transitional changes because of the current lock-in of cereal crop production to the meat demand. The model from Schot and Geels, 2008 *Multi-Level Perspective* (MLP) is applied, which divides transitional changes into three levels: *landscape, sociotechnical regime* and *niche innovations*. As sustainability is gaining momentum in society, it destabilizes the sociotechnical regime, which in this case is organic agriculture. Plant-based protein is a developing niche innovation, and it can emerge in the sociotechnical regime. Upcoming companies are using fava beans as a meat alternative, and the development of GPC is to create a product suitable for the same purpose. That means that the current production of fava beans and GPC in Denmark can continue in the sociotechnical regime, but with the purpose of human consumption instead. This will decrease the impacts significantly and contribute to the sustainable development of the organic sector. To improve plant-based proteins two recommendations are outlined. Firstly, more LCAs with iLUC included are highly important to gain scientifical data on environmental impacts. Secondly, communication of LCAs must be higher prioritized in the agricultural sector. This will increase choice awareness among stakeholders, meaning that everyone has a true choice and is aware of the respective consequences of each choice.

Finally, it can be concluded that the Danish organic sector can prefer both fava beans and grass protein, as they can enter the same crop rotation and be produced to food and feed. Based on the LCA results, it will not improve the sustainability if the protein feed production is moved to Denmark. It will be a reactive solution. To be proactive, the meat demand must decrease, and farmers should prioritize protein crops for human consumption. Through simple presentations and dialogues of consequential LCAs, it will increase stakeholders' knowledge about the direct and indirect environmental impacts of meat consumption. Thus, the organic sector can increase the self-sufficiency in plant-based proteins to improve its position as a sustainable front-runner.

# Bibliography

2.0 LCA Consultants (2022). *Better decision-making for sustainable development with life cycle assessment (LCA).* Last visited 02-06-2022 Link: https://lca-net.com/. 2022.

Aarhus University (2022). *Metodeguide*. Accessed 20-03-2022 https://metodeguiden.au.dk. 2022.

Agger, Annika and Birgitte Hoffmann (2008). *Borgerne På Banen: Håndbog til borgerdeltagelse i lokal byudvikling*. 1st ed. Velfærdsministeriet, 2008. ISBN: 978-87-754-6420-3.

Arendt, Peter (2022). *Markant stigning i kinesisk soja-import*. https://effektivtlandbrug.landbrugnet.dk/artikler/markedsfokus/76186/markant-stigning-i-kinesisk-soja-import.aspx. Effektivt Landbrug, 2022.

Ausumgaard.dk (2022). *Ny, banebrydende produktion af bæredygtigt planteprotein*. Accessed 08-03-2022 https://ausumgaard.dk/baeredygtig-energi/graesprotein/. 2022.

Bosselmann, Aske S., Jørgen E. Olesen, and Hiva Ahmadi (2022). *Derfor skal du ikke boykotte palmeolie*. Vid og Sans, 2022.

Bosselmann, Aske Skovmand (2020). *Dansk import af afskovningsfri soja fra Sydamerika: Notat vedrørende oplysninger til besvarelse af spørgsmål stillet til ministeren for fødevarer, fiskeri og ligestilling*. hhttps://static-curis.ku.dk/portal/files/235002522/IFRO_Udredning_2019_28.pdf. University of Copenhagen, 2020.

Bosselmann, Aske Skovmand (2022). *Phone correspondence with Aske S. Bosselmann - Lector at University of Copenhagen (KU).* Expert knowledge though phone conversations. Further description in Appendix F.2. 2022.

Brinkmann, Svend and Lene Tanggaard (2015). *Kvalitative metoder*. Hardback ISBN: 978-87-412-5904-8. Hans Reitzels Forlag, 2015.

Brozyna, Michal A, Søren O Petersen, Ngonidzashe Chirinda, and Jørgen E Olesen (2013). "Effects of grass-clover management and cover crops on nitrogen cycling and nitrous oxide emissions in a stockless organic crop rotation". In: *Agriculture, ecosystems and environment* 181 (2013), pp. 115–126.

Communicationstheory.org (2022). *Shannon and Weaver Model of Communication*. Last visited 15-05-2022 Link: https://www.communicationtheory.org/shannon-and-weaver-model-of-communication/. 2022.

Cong, Rong-Gang and Mette Termansen (2016). "A bio-economic analysis of a sustainable agricultural transition using green biorefinery". In: *The Science of the total environment* 571 (2016), pp. 153–163.

DAFC (2020a). *Plantebaserede fødevarer - Forsknings- og udviklingsstrategi for et nyt vækstområde i den danske fødevareproduktion*. PDF. DAFC, 2020. Danish Agriculture and Food Council.

DAFC (2020b). *Statistik over økologiske jordbrugsbedrifter 2020 Autorisation og produktion*. Accessed 06-03-2022 https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Oe kologi/Statistik/Statistik_over_oekologisk_jordbrugsbedrifter_2021.pdf. 2020. Danish Agriculture and Food Council.

DAFC (2021a). *Mere europæisk protein i foderet*. Last visited 08-03-2022 Link: https://lf.dk/for-medlemmer/oekologi/2020/december/mere-europaeisk-protein-i-foderet. Danish Agriculture and Food Council, 2021.

DAFC (2021b). *STRATEGI Landbrug & Fødevarer Økologi 2021-2023*. PDF. Danish Agriculture and Food Council F.m.b.A., 2021.

DAFC (2022a). *Forum for Organic Counselling*. Innovation Center for Organic Farming, Mar. 1, 2022.

DAFC (2022b). *Markant stigning i kinesisk soja-import*. Last visited 20-05-2022 Link: https://lf.dk/viden-om/klima/hvad-er-biokul. Danish Agriculture and Food Council, 2022.

De Rosa, M (2017). *Let us talk about Hybrid LCA*. Last visited 07-05-2021 Link: https://lca-net.com/blog/let-us-talk-hybrid-lca/. 2017.

DLF (2022). *DLF - Seeds and Science*. Last visited 01-06-2022 Link: https://www.dlf.dk/om-dlf/nyheder-og-presse/article/kloevergraes-i-foderrationen-giver-12-000-ekm.aspx?Action=1&PID=3445. 2022.

European Commission (2022). *Organic action plan*. Accessed 07-03-2022 https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/organic-action-plan_da. 2022.

Exiobase.eu (2022). *Exiobase*. Accessed 21-04-2022 https://www.exiobase.eu/index.php. 2022.

Fact-based sustainability (2021). *Obscure impacts demystified: Ionizing radiation*. Last visited 23-12-2021 Link: https://pre-sustainability.com/articles/obscure-impacts-demystified-ionizing-radiation/. 2021.

FAFC (2022). *Dansk landbrug forpligter sig til ansvarlig og afskovningsfri soja*. Last visited 01-06-2022 Link: https://lf.dk/aktuelt/nyheder/2020/august/dansk-landbrug-forpligter-sig-til-ansvarlig-og-afskovningsfri-soja. 2022. Danish Agriculture and Food Council.

FAOSTAT (2022). *Crops and livestock products*. Accessed 10-04-2022. 2022. URL: fao.org/faostat/en/#data/TCL.

Farthing, Stuart (2015). *Research design in urban planning: a student's guide*. Sage Publications, 2015. ISBN: 9781446294451.

Al-Fedaghi, Sabah (2020). "Underpinning Theories of Software Engineering: Dynamism in Physical Sources of the Shannon Weaver Communication Model". In: *International Journal of Computer Science and Network Security* 20.9 (2020), pp. 120–131.

Finansministeriet (2021). *Regeringen indgår bred aftale om grøn omstilling af dansk landbrug*. Accessed 06-03-2022 https://fm.dk/nyheder/nyhedsarkiv/2021/oktober/regeringen-indgaar-bred-aftale-om-groen-omstilling-af-dansk-landbrug/. 2021.

Fog, Erik (2022). *Interview with Erik Fog, consultant in bioenergy and biorefining*. Interview guide can be found in Appendix A.1. Innovation Center for Organic Farming, Mar. 10, 2022.

Haberl, Helmut, K Heinz Erb, Fridolin Krausmann, et al. (2007). “Quantifying and Mapping the Human Appropriation of Net Primary Production in Earth’s Terrestrial Ecosystems”. In: *Proceedings of the National Academy of Sciences - PNAS* 104.31 (2007), pp. 12942–12947. ISSN: 0027-8424.

Harbo, Laura Sofie, Chiara De Notaris, Jin Zhao, and Jørgen E Olesen (2022). “Productivity, light interception and radiation use efficiency of organic and conventional arable cropping systems”. In: *European journal of agronomy* 132 (2022), pp. 126407–.

Harries, Stephen (2012). “6 - Innovation and change: ideas, networks and communities”. In: *Records Management and Knowledge Mobilisation*. Ed. by Stephen Harries. Chandos Information Professional Series. Chandos Publishing, 2012, pp. 115–141. ISBN: 978-1-84334-653-1.

Heijungs, R (2014). “Ten easy lessons for good communication of LCA”. In: *The international journal of life cycle assessment* 19.3 (2014), pp. 473–476. ISSN: 0948-3349.

Hermansen, Sven (2022). *Interview with Sven Hermansen, Chief consultant*. Interview guide can be found in Appendix A.3. Innovation Center for Organic Farming, Mar. 11, 2022.

Hermansen, Sven and Arne Munk (2022). *Vurdering af forbrug af korn-, fedt- og proteinafgrøder hos fjerkræ, grise og malkekøer i den økologiske produktion*. Innovation Center for Organic Farming, 2022.

Heusala, Hannele, Taija Sinkko, Nesli Sözer, et al. (2020). “Carbon footprint and land use of oat and faba bean protein concentrates using a life cycle assessment approach”. In: *Journal of cleaner production* 242 (2020), pp. 118376–.

Hillege, Luc (2019). *Impact Categories (LCA) – Overview*. Last visited 01-05-2022 Link: `https://ecochain.com/knowledge/impact-categories-lca/`. 2019.

ICROFS.dk (2022). *ICROFS - International Centre for Research in Organic Food Systems*. Last visited 02-06-2022 Link: `https://icrofs.dk/`. 2022.

IPCC (2006). *Chapter 11 - $N_2O$ Emissions from Managed soils, and $CO_2$ emissions from Lime and Urea Application*. 2006. Intergovernmental Panel on Climate Change.

IPCC (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.) 2014.

ISO14040 (2006). *Environmental Assessment: Life Cycle Assessment - Principles and framework*. International Organization for Standardization, 2006.

ISO14044 (2006). *Environmental management: Life cycle assessment — Requirements and guidelines*. International Organization for Standardization, 2006.

Jensen, Erik Steen, Georg Carlsson, and Henrik Hauggaard-Nielsen (2020). “Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis”. In: *Agronomy for sustainable development* 40.1 (2020), pp. 5–.

Jensen, Kirsten Lund (2022). *Interview with Kirsten Lund Jensen, Head of the organic Sector*. Interview guide can be found in Appendix E. Danish Agriculture and Food Council, 2022.

Karlsson, Johan O, Alejano Parodi, Hannah H.E Zanten Van, Per-Anders Hansson, and Elin Röös (2021). "Halting European Union soybean feed imports favours ruminants over pigs and poultry". In: *Nature food* 2.1 (2021), pp. 38–46.

Knudsen, Marie Trydeman, Qiao Yu-Hui, Luo Yan, and Niels Halberg (2010). "Environmental assessment of organic soybean ( Glycine max.) imported from China to Denmark: a case study". In: *Journal of cleaner production* 18.14 (2010), pp. 1431–1439. ISSN: 0959-6526.

Koutchadé, Obafèmi P., Alain Carpentier, and Fabienne Femenia (2021). "Modeling Corners, Kinks, and Jumps in Crop Acreage Choices: Impacts of the EU Support to Protein Crops". In: *American journal of agricultural economics* 103.4 (2021), pp. 1502–1524. ISSN: 0002-9092.

Kreutzfeldt, Henrik (2022). *Phone correspondence with Henrik Kreutzfeldt - Organic farmer*. Expert knowledge though phone conversations. Further description in Appendix F.1. 2022.

Kreutzfeldt, Karen-Emilie Trier (2021). *Comparison Between Environmental Impacts of Danish Organic and Conventional Produced Fava Beans A Cradle-to-Farm Gate Life Cycle Assessment*. Semester project from the internship at Innovation Center for Organic Farming. Aalborg University, 2021.

Landbrugsavisen.dk (2022). *Lanbrugsavisen.dk*. Last visited 01-06-2022 Link: `https://landbrugsavisen.dk`. 2022.

Larsen, Søren Ugilt, Henning Jørgensen, Christian Bukh, and Jan K Schjoerring (2019). "Green biorefining: Effect of nitrogen fertilization on protein yield, protein extractability and amino acid composition of tall fescue biomass". In: *Industrial crops and products* 130 (2019), pp. 642–652.

Lund, Henrik (2014). "Chapter 2 - Theory: Choice Awareness Theses". In: *Renewable Energy Systems*. Second Edition. Elsevier Inc, 2014, pp. 15–34. ISBN: 012409595X.

Magrini, Marie-Benoit, Nicolas Befort, and Martino Nieddu (2019). "Technological Lock-In and Pathways for Crop Diversification in the Bio-Economy". In: *Agroecosystem Diversity: Reconciling Contemporary Agriculture and Environmental Quality*. Ed. by Gilles Lemaire, Paulo Carvalho, Scott Kronberg, and Sylvie Recou. 1st ed. Cambridge, Massachusetts: Academic Press, 2019. Chap. 24, pp. 375–388.

MDAF (2021). *Opgørelse af afgrødefordeling 2021 for økologiske arealer*. Accessed 09-03-2022 `https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Tilskud/Arealtilskud/Direkte_stoette_-_grundbetaling_mm/2021/Opgoerelse_af_oekologisk_afgroedefordeling_2021.pdf`. 2021. Ministry of Food, Agriculture and Fisheries of Denmark.

Meynard, Jean-Marc, François Charrier, M'hand Fares, et al. (2018). "Socio-technical lock-in hinders crop diversification in France". In: *Agronomy for sustainable development* 38.5 (2018), pp. 1–13.

MFAFD (2022). *Vejledning om økologisk jordbrugsproduktion*. Last visited 08-03-2022 Link: `https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Oekologi/OEkologivejledning_2022/OEkologivejledning_2022_-_vers._2.pdf`. 2022. Ministry of Food, Agriculture and Fisheries of Denmark.

Moher, D., A. Liberati, J. Tetzlaff, and D. G. Altman (2009). "Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement." In: *Annals of Internal Medicine* 152 (2009), pp. 264–269.

Møller, Jens, Rudolf Thøgersen, and Marianne Helleshøj (2005). *Fodermiddel tabel – Sammensætning og foderværdi af fodermidler til kvæg*. Dansk Kvæg, 2005.

Nielsen, Ole-Kenneth, Marlene S. Plejdrup, Morten Winther, et al. (2017). *DENMARK'S NATIONAL INVENTORY REPORT 2019 - Emission Inventories 1990-2017 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol*. Accessed 14-03-2022 https://dce2.au.dk/pub/SR318.pdf. Aarhus University, 2017.

OPP (2022). *Organic Plant Protein*. Last visited 22-05-2022 Link: https://organicplantprotein.dk/en/organic-plant-protein/. 2022. Organic Plant Protein.

PBE (2022). *Protein*. Last visited 21-05-2022 Link: https://fvm.dk/fileadmin/user_upload/MFVM/Miljoe/Cirkulaer_oekonomi/Anbefalinger_om_proteiner_fra_Det_Nationale_Biooekonomipanel.pdf. Ministry of Food, Agriculture and Fisheries of Denmark, 2022. The Panel for Bioeconomics.

Pizzol, Massimo, Alexis Laurent, Serenella Sala, et al. (2017). *Normalisation and weighting in life cycle assessment : Quo Vadis?* Technical University of Denmark, 2017.

Pure Dansk (2022). *Pure Dansk*. Last visited 22-05-2022 Link: https://puredansk.dk/. 2022.

Reckling, Moritz, Göran Bergkvist, Christine A Watson, Frederick L Stoddard, and Johann Bachinger (2020). "Re-designing organic grain legume cropping systems using systems agronomy". In: *European journal of agronomy* 112 (2020), pp. 125951–. ISSN: 1161-0301.

Regerings Klimapartnerskaber (2020). *Klimapartnerskabet for Fødevare- og Landbrugssektoren*. Accessed 08-03-2022 https://lf.dk/aktuelt/nyheder/2020/marts/rapport-fra-klimapartnerskabet. 2020.

Reinsch, Thorsten, Cecilia Loza, Carsten Stefan Malisch, et al. (2021). "Toward Specialized or Integrated Systems in Northwest Europe : On-Farm Eco-Efficiency of Dairy Farming in Germany". In: *Frontiers in sustainable food systems* 5 (2021).

Ren, Dandan, Hong Yang, Lingfeng Zhou, et al. (2021). "The Land-Water-Food-Environment nexus in the context of China's soybean import". In: *Advances in water resources* 151 (2021), pp. 103892–. ISSN: 0309-1708.

Al-Saidi, Mohammad (2019). "Institutional Change and Sustainable Development". In: *Encyclopedia of Sustainability in Higher Education*. Springer International Publishing, 2019, pp. 964–974. ISBN: 3030113515.

Santamaria-Fernandez, Maria, Nanna Karkov Ytting, Mette Lübeck, and Hinrich Uellendahl (2020). *Potential Nutrient Recovery in a Green Biorefinery for Production of Feed, Fuel and Fertilizer for Organic Farming*. 2020.

Santamaría-Fernández, M, B Molinuevo-Salces, P Kiel, et al. (2017). "Lactic acid fermentation for refining proteins from green crops and obtaining a high quality feed product for monogastric animals". In: *Journal of cleaner production* 162 (2017), pp. 875–881.

Schmidt, J and J Watson (2014). *Eco Island Ferry Comparative LCA of island ferry with carbon fibre composite based and steel based structures*. Last visited 01-05-2022 Link: https://vbn.aau.dk/ws/portalfiles/portal/196727000/Eco_E_Ferry_LCA_20130418_JS_.pdf. Aalborg University, 2014.

Schmidt, Jannick and Michele De Rosa (2020). "Certified palm oil reduces greenhouse gas emissions compared to non-certified". In: *Journal of cleaner production* 277 (2020), pp. 124045–. ISSN: 0959-6526.

Schmidt, Jannick H (2015). "Life cycle assessment of five vegetable oils". In: *Journal of cleaner production* 87 (2015), pp. 130–138. ISSN: 0959-6526.

Schmidt, Jannick H and Bo P Weidema (2007). "Shift in the marginal supply of vegetable oil". eng. In: *The international journal of life cycle assessment* 13.3 (2007), pp. 235–239. ISSN: 0948-3349.

Schmidt, Jannick H, Bo P Weidema, and Miguel Brandão (2015). "A framework for modelling indirect land use changes in Life Cycle Assessment". In: *Journal of cleaner production* 99 (2015), pp. 230–238.

Schot, Johan and Frank W. Geels (2008). "Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy". eng. In: *Technology analysis & strategic management* 20.5 (2008), pp. 537–554. ISSN: 0953-7325.

SEGES (2020). *Oversigt over landsforsøgene 2020*. eBook ISBN 978-87-93051-09-6. https://www.landbrugsinfo.dk/-/media/landbrugsinfo/public/4/b/1/planter_landsforsogene_oversigt_over_landsforsogene_2020.pdf. Aarhus N: SEGES, 2020.

SEGES Innovation (2022a). *Farmtal Online*. Accessed 30-04-2022 https://farmtalonline.dlbr.dk/. 2022.

SEGES Innovation (2022b). *Græsprotein er på vej til at blive en god forretning*. Last visited 06-05-2022 Link: https://www.seges.dk/da-dk/innovation-og-udvikling/graesprotein. 2022.

Sepngang, Bruno Kezeya, Frédéric Muel, Tiana Smadja, et al. (2020). *Report on legume markets in the EU*. Last visited 29-05-2022 Link: http://www.legvalue.eu/media/1511/d31-report-on-legume-markets-in-the-eu.pdf/. European commission, 2020.

Shannon, Claude E., Warren Weaver, and Norbert Wiener (1950). "The Mathematical Theory of Communication". In: *Physics today* 3.9 (1950), pp. 31–32. ISSN: 0031-9228.

Smith, Adrian (2007). "Translating Sustainabilities between Green Niches and Socio-Technical Regimes". In: *Technology analysis & strategic management* 19.4 (2007), pp. 427–450. ISSN: 0953-7325.

Snyder, Hannah (2019). "Literature review as a research methodology: An overview and guidelines". In: *Journal of business research* 104 (2019), pp. 333–339.

The Danish Government (2021). *Aftale om grøn omstilling af dansk landbrug*. PDF. An agreement together with following parties: Venstre, Dansk Folkeparti, Socialistisk Folkeparti, Radikale Venstre, Enhedslisten, Det Konservative Folkeparti, Nye Borgerlige, Liberal Alliance and Kristendemokraterne. Statsministeriet, 2021.

Thrane, Mikkel and Jannick Schmidt (2007). "Life Cycle Assessment". In: *Tools for Sustainable Development*. Ed. by Lone Kørnøv, Mikkel Thrane, Arne Remmen, and Henrik Lund. Aalborg Universitetsforlag, 2007. Chap. 12, pp. 204–239.

Voisin, Anne Sophie, Jacques Guéguen, Christian Huyghe, et al. (2014). "Legumes for feed, food, biomaterials and bioenergy in Europe: a review". In: *Agronomy for Sustainable Development* 34 (2 2014).

Watson, Christine A., Moritz Reckling, Sara Preissel, et al. (2017). "Grain Legume Production and Use in European Agricultural Systems". In: *Advances in Agronomy* 144 (2017), pp. 235–303.

WCED (1987). *Vores fælles fremtid: Brundtland kommissionens rapport om miljø og udvikling.* FN-forbundet, 1987. ISBN: 8770285152. World Commission on Environment and Development.

Weidema, Bo (2003). *Market information in life cycle assessment - Environmental Project No. 863 2003 Miljøprojekt.* Accessed 06-03-2022 https://lca-net.com/publications/show/market-information-life-cycle-assessment/. 2003.

Weidema, Bo, Massimo Pizzol, Jannick Schmidt, and Greg Thoma (2018). "Attributional or consequential Life Cycle Assessment: A matter of social responsibility". In: *Journal of cleaner production* 174 (2018), pp. 305–314.

Weidema, Bo P. (2008). "Using the budget constraint to monetarise impact assessment results". In: *Ecological Economics* 68 (2008), pp. 1591–1598.

Weidema B P Ekvall T, Heijungs R (2009). *Guidelines for applications of deepened and broadened LCA.* Deliverable D18 of work package 5 of the CALCAS project. Accessed 21-04-2022 http://lca-net.com/p/186. 2009.

Werf, Hayo M. G van der, Marie Trydeman Knudsen, and Christel Cederberg (2020). "Towards better representation of organic agriculture in life cycle assessment". eng. In: *Nature sustainability* 3.6 (2020), pp. 419–425. ISSN: 2398-9629.

Wilson, Jonathan (2014). *Essentials of Business Research: A Guide to Doing Your Research Project.* 2nd ed. eBook ISBN 978-1-4462-5732-6. SAGE, 2014.

Yin, Robert K. (2009). *Case Study Research : Design and Methods.* 2009.

# Appendix A

# IO-table

This Appendix refers to the performed IO-table. Data and calculations are included in the external Excel sheet *IO-table_ KarenEmilie_ TK_ Master_ Thesis*.

# Appendix B

# LCI: Energy and Conventional Protein Crops

This appendix contains LCI data for the organic and conventional energy crops along with the conventional soybean meal production.

- Section B.1, Organic energy crops: spring oats and spring barley
- Section B.2, Conventional energy and protein production
- Section B.3, Milling and refining conventional soybean meal and oil

## B.1 Organic energy crops: spring oats and spring barley

| Flows | Unit | Spring oat cultivation | Spring barley cultivation | LCI data |
|---|---|---|---|---|
| **Output: reference flow** | | | | |
| Output: crops | t | 1 | 1 | |
| **Input: land use** | | | | |
| Land use | ha | 0.20 | 0.25 | Link to: Market for arable land {GLO} |
| **Input: seeds** | | | | |
| Organic grass seeds | kg | 34.00 | 42.50 | See Table B.1 |
| **Input: energy** | | | | |
| Diesel | kg | 16.27 | 20.34 | Link to: Petroleum Refinery {DK} |
| **Input: nutrients** | | | | |
| Manure slurry | kg | 22.60 | 38.25 | Link to: N-fertiliser {DK} |
| **Input: agricultural machinery** | | | | |
| Harrowing | kg | 0.60 | 0.75 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| ploughing | kg | 0.43 | 0.25 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Sowing | kg | 0.19 | 0.25 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Manure spreading | kg | 3.78E-05 | 4.73E-05 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Currying by weeder | kg | 0.38 | 0.75 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Harvesting | kg | 1.26 | 0.25 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| Tractor | kg | 0.69 | 0.87 | Link to: Manufacture of machinery and equipment n.e.c. (29) {DK} |
| **Input: transport** | | | | |
| Transportation, slurry | tkm | 40.38 | 40.38 | Link to: Other land transport {DK} |
| **Output: emissions to air** | | | | |
| Dinitrogen monoxide | kg $N_2O$ | 0.31 | 0.26 | Link to emissions to air |
| Carbon dioxide | kg $CO_2$ | 54.81 | 68.51 | |

**Table B.1:** Summary of LCI data for the organic produced marginal mix of energy crops in Denmark (spring oats and spring barley). All data are from SEGES Innovation, 2022a, except for the transportation of slurry, which is assumed to be the same as for the grass production in Table 4.8.

## B.2 Conventional energy and protein crops

| Flows | Unit | Corn US Corn cultivation | Wheat RU Wheat cultivation | Corn AR Corn cultivation | Wheat UA Wheat cultivation | SB US SB cultivation | SB BR SB cultivation |
|---|---|---|---|---|---|---|---|
| **Reference flow** | | | | | | | |
| Output: Crop | t | 11.41 | 2.71 | 7.61 | 4.32 | 3.49 | 3.00 |
| **Input: Energy** | | | | | | | |
| Diesel | MJ | 2.90 | 3.31 | 2.90 | 3.31 | 1.71 | 1.71 |
| Lubricants and hydraulic oil | MJ | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 |
| **Inputs: Nutrients and chemicals** | | | | | | | |
| Urea | Kg N | 85.30 | 1.69 | 32.20 | 18.80 | 17.10 | 8.13 |
| Ammonium nitrate | Kg N | 107.00 | 32.20 | 0.00 | 39.00 | 21.30 | 2.02 |
| Calcium amm. nitrate | Kg N | 0.00 | 0.00 | 1.13 | 3.98 | 0.00 | 0.36 |
| Ammonium sulphate | Kg N | 8.95 | 3.35 | 1.62 | 0.67 | 1.79 | 1.73 |
| Phosphate rock | Kg P2O5 | 0.00 | 13.60 | 0.00 | 13.50 | 0.00 | 1.91 |
| Phosphate fertiliser | Kg P2O5 | 49.80 | 0.00 | 27.30 | 0.00 | 42.70 | 59.30 |
| Potassium chloride | Kg P2O5 | 51.20 | 6.21 | 0.24 | 13.80 | 54.00 | 68.00 |
| Potassium sulfate | Kg P2O5 | 2.35 | 1.37 | 0.00 | 0.00 | 2.48 | 0.14 |
| **Inputs: Irrigation** | | | | | | | |
| Irrigation (US) | m3 | 2792 | | | | | |
| Irrigation (RU) | m3 | | 935 | | | | |
| Irrigation (AR) | m3 | | | 1181 | | | |
| Irrigation (UA) | m3 | | | | 1490 | | |
| **Input: Transport** | | | | | | | |
| Road transport {US} | tkm | 0.74 | | | | 0.31 | |
| Road transport {RU} | tkm | | 0.12 | | | | |
| Road transport {AR} | tkm | | | 0.14 | | | |
| Road transport {UA} | tkm | | | | 0.20 | | |
| Road transport {BR} | tkm | | | | | | 0.30 |
| **Input: land, link to iLUC model** | | | | | | | |
| Market for arable land | ha-eq | 1.02 | 0.93 | 1.32 | 0.98 | 1.02 | 1.33 |
| **Input: Capital goods and services** | | | | | | | |
| Corn cultivation capital goods and services {US} | ha a | 1 | | | | | |
| Corn cultivation capital goods and services {RU} | ha a | | 1 | | | | |
| Corn cultivation capital goods and services {AR} | ha a | | | 1 | | | |
| Corn cultivation capital goods and services {UA} | ha a | | | | 1 | | |

**Table B.2:** Summary of LCI data for cultivating conventional energy and protein crops. The links to Exiobase can be seen in Table B.3. (Continued).

| Flows | Unit | Corn US Corn cultivation | Wheat RU Wheat cultivation | Corn AR Corn cultivation | Wheat UA Wheat cultivation | SB US SB cultivation | SB BR SB cultivation |
|---|---|---|---|---|---|---|---|
| Soybean cultivation capital goods and services {US} | ha a | | | | | 1 | |
| Soybean cultivation capital goods and services {BR} | ha a | | | | | | 1 |
| **Emissions** | | | | | | | |
| Ammonia | kg | 23.80 | 4.40 | 4.08 | 7.36 | 4.72 | 1.39 |
| Carbon dioxide | kg | 138.00 | 2.72 | 52.00 | 30.30 | 27.50 | 13.10 |
| Dinitrogen monoxide | kg | 5.76 | 1.41 | 1.81 | 2.25 | 1.62 | 0.96 |
| Nitrogen oxides | kg | 1.47 | 0.36 | 0.47 | 0.58 | 0.42 | 0.25 |
| Nitrate | kg | 376.00 | 93.00 | 121.00 | 149.00 | 108.00 | 65.20 |

**Table B.2:** Summary of LCI data for cultivating conventional energy and protein crops. The links to Exiobase can be seen in Table B.3

| Flows | LCI data |
|---|---|
| Diesel | Link to: Petroleum Refinery |
| Lubricants and hydraulic oil | Link to: Petroleum Refinery |
| Urea | Link to: N-fertiliser |
| Ammonium nitrate | Link to: N-fertiliser |
| Calcium amm. nitrate | Link to: N-fertiliser |
| Ammonium sulphate | Link to: N-fertiliser |
| Phosphate rock | Link to: P- and other fertiliser |
| Phosphate fertiliser | Link to: P- and other fertiliser |
| Potassium chloride | Link to: P- and other fertiliser |
| Potassium sulfate | Link to: P- and other fertiliser |
| Irrigation (US) | Link to: Collection, purification and distribution of water (41) {US} |
| Irrigation (RU) | Link to: Collection, purification and distribution of water (41) {RU} |
| Irrigation (AR) | Link to: Collection, purification and distribution of water (41) {WL} |
| Irrigation (UA) | Link to: Collection, purification and distribution of water (41) {WE} |
| Road transport {US} | Link to: Other land transport {US} |
| Road transport {RU} | Link to: Other land transport {RU} |
| Road transport {AR} | Link to: Other land transport {WL} |
| Road transport {UA} | Link to: Other land transport {WE} |
| Road transport {BR} | Link to: Other land transport {BR} |

**Table B.3:** Summary of LCI data for what background data from Exiobase that are used for the activities in Table B.2 (continued). The background activities are chosen for the respective countries. (Continued)

| Flows | LCI data |
|---|---|
| Corn cultivation capital goods and services {US} | Link to: Maize cultivation capital goods and services {US} |
| Corn cultivation capital goods and services {RU} | Link to: Wheat cultivation capital goods and services {RU} |
| Corn cultivation capital goods and services {AR} | Link to: Maize cultivation capital goods and services {AR} |
| Corn cultivation capital goods and services {UA} | Link to: Wheat cultivation capital goods and services {UA} |
| Soybean cultivation capital goods and services {US} | Link to: Soybean cultivation capital goods and services {US} |
| Soybean cultivation capital goods and services {BR} | Link to: Soybean cultivation capital goods and services {BR} |
| Ammonia<br>Carbon dioxide<br>Dinitrogen monoxide<br>Nitrogen oxides<br>Nitrate | Elementary flow: emissions to air |

**Table B.3:** Summary of LCI data for what background data from Exiobase that are used for the activities in Table B.2. The background activities are chosen for the respective countries.

## B.3 Milling and refining conventional soybean meal and oil

| Flows | Unit | SBM {US} CSBO mill | SBM {BR} CSBO mill | CSBO {US, BR} Treatment refinery | LCI data |
|---|---|---|---|---|---|
| **Output: reference flow** | | | | | |
| Output: soybean meal | t | 0.77 | 0.77 | | |
| Input: CSBO {US, BR} | t | | | 1.00 | CSBO {US,BR} Treatment of CSBO in soybean oil refinery |
| **Input: Feedstock** | | | | | |
| SB {US} SB cultivation | t | 1.00 | | | See Table B.2 |
| SB {BR} SB cultivation | t | | 1.00 | | See Table B.2 |
| **Output: Materials for treatment** | | | | | |
| CSBO {US} | t | 0.19 | | | CSBO {US,BR} Treatment of CSBO in soybean oil refinery |
| CSBO {BR} | t | | 0.19 | | CSBO {US,BR} Treatment of CSBO in soybean oil refinery |
| Landfill of bleaching earth {ID} | kg | | | 5.79 | Link to: Landfill of bleaching earth {ID} |
| Landfill of oil loss {ID} | kg | | | 5.00 | Link to: Landfill of oil loss {ID} |

**Table B.4:** Summary of LCI data for conventional SB milling and treatment of CSBO together with the inputs to the marginal market for feed protein in Table 4.4 and vegetable oils, which in this case is CPO in Table C.4. (Continued).

| Flows | Unit | SBM {US} CSBO mill | SBM {BR} CSBO mill | CSBO {US, BR} Treatment refinery | LCI data |
|---|---|---|---|---|---|
| **Output: By-products that substitute alternative production** | | | | | |
| CPO | t | | | 0.98 | RBD CPO {ID&MY} Palm oil refinery |
| **Input: Energy** | | | | | |
| Natural gas | t | 1.36E-10 | 1.36E-10 | | Link to: Extraction of natural gas and services US |
| Fuel oil | MJ | 3.40E-06 | 3.40E-06 | 5.73E-06 | Link to: Petroleum Refinery US |
| Electricity {US} | kWh | 12.20 | | 14.50 | Link to: Electricity mix US |
| Electricity {BR} | kWh | | 12.20 | 14.50 | Link to: Electricity mix BR |
| **Input: Water** | | | | | |
| Water{US} | m3 | 0.10 | | 0.014 | Link to: Collection, purification and distribution of water (41) US |
| Water{BR} | m3 | | 0.10 | 0.014 | Link to: Collection, purification and distribution of water (41) BR |
| **Input: Transport** | | | | | |
| Road transport {US} | tkm | 200.00 | | 1.38 | Link to: Other land transport US |
| Road transport {BR} | tkm | | 200.00 | 1.38 | Link to: Other land transport BR |
| **Input: Material use** | | | | | |
| Caustic Soda, as 100% conc. | kg | | | 2.10 | Link to: Caustic Soda, as 100% conc {ID&MY} |
| Phosphoric acid, as 100% conc. | kg | | | 0.80 | Link to: Phosphoric acid, as 100% conc {ID&MY} |
| Bleaching earth | kg | | | 9.00 | Link to: Bleaching earth {ID&MY} |
| Sulphuric acid, as 100% | kg | | | 1.90 | Link to: Sulphuric acid, as 100% conc {ID&MY} |

**Table B.4:** Summary of LCI data for conventional SB milling and treatment of CSBO together with the inputs to the marginal market for feed protein in Table 4.4 and vegetable oils, which in this case is CPO in Table C.4.

# Appendix C

# LCI: Palm oil

Schmidt and De Rosa, 2020 assess three palm oil productions; total industry, RSPO-certified and non-certified palm oil. In this study, the data from the total industry are used, as the focus is on the substitution of palm oil in general and not from a specific production. Furthermore, the biggest productions of palm oil occur in Indonesia and Malaysia, but for simplicity all background data are only chosen from Indonesia. Capital goods and Palm Fatty Acid Distillate/Palm Kernel Fatty Acid Distillate are excluded based on the timeframe of the project. The product system is displayed in Figure C.1 and a summary of all the activities can be seen under each, following sections.

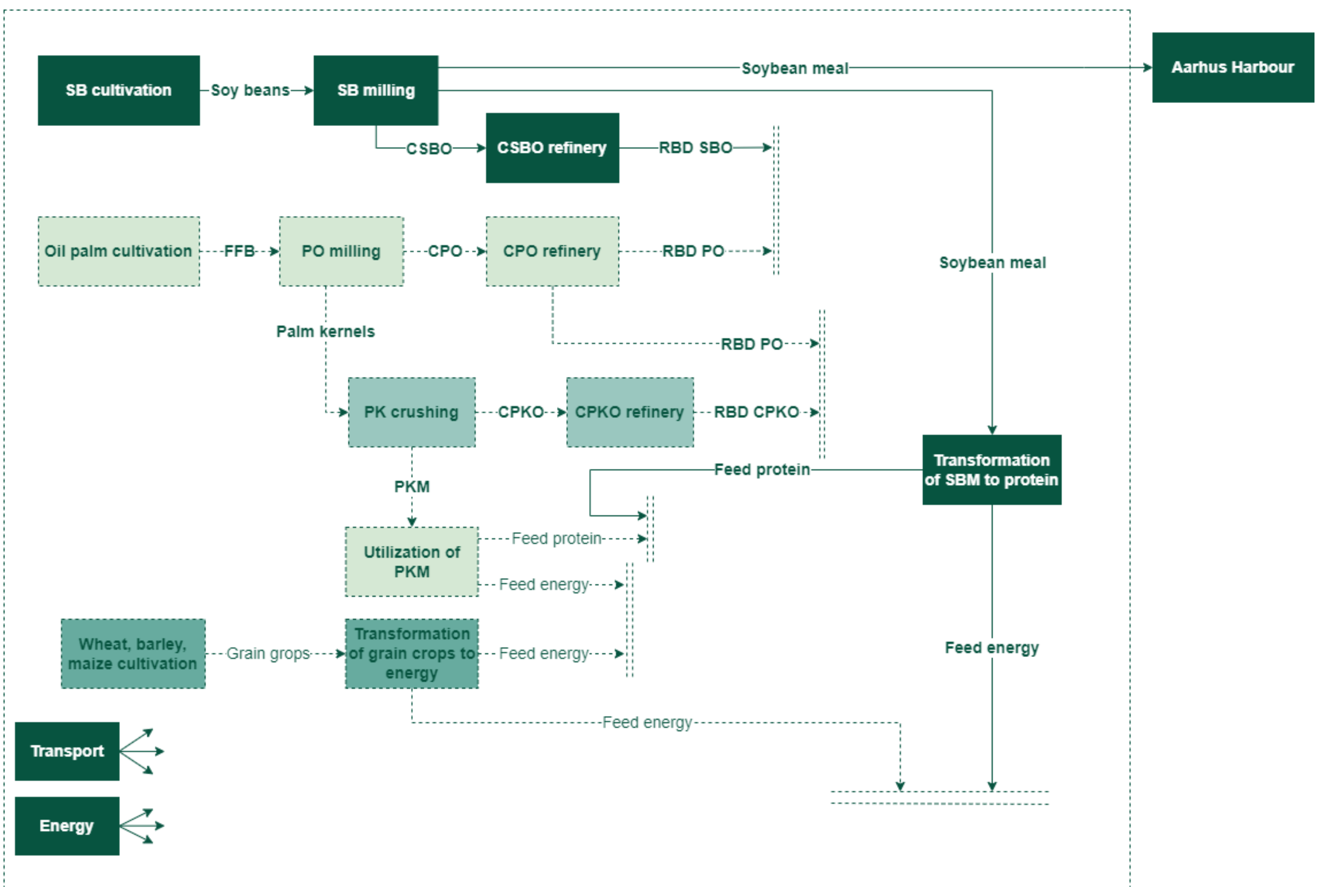


**Figure C.1:** System boundary of the palm oil substitution when producing soybean meal. Own illustration.

## C.1 Oil palm cultivation

| Flows | Unit | FFB cultivation | LCI data |
|---|---|---|---|
| **Output: Reference flow** | | | |
| FFB | t | 17.00 | Reference flow |
| **Elementary flow: Land** | | | |
| Harvested area | ha | 0.90 | Link to: Arable land, as ha*year-eq. |
| Immature/replanting area | ha | 0.10 | |
| Road/facilities | ha | 0.07 | |
| Input: Energy | | | |
| Diesel | MJ | 2.94 | Link to: Petroleum Refinery {ID} |
| **Input: Nutrients and chemicals** | | | |
| N-fertilizer, summarized, as N | kg | 27.67 | Link to: N-fertiliser {ID} |
| P-fertilizer, summarized, as P2O5 | kg | 40.68 | Link to: P- and other fertiliser {ID} |
| Pesticides, as total weight | kg | 7.20 | Link to: Chemicals nec {ID} |
| **Input: Packaging** | | | |
| Packaging plastics | kg | 0.28 | Link to:Plastics, basic {ID} |
| **Output: Waste to treatment** | | | |
| Plastic waste to landfill | kg | 0.18 | Link to: Landfill of waste: Plastic {ID} |
| Plastic waste to recycling | kg | 0.09 | Link to: Re-processing of secondary plastic into new plastic {ID} |
| **Input: Transport** | | | |
| Road transport {ID} 16-32 t truck | tkm | 103.00 | Link to: Other land transport {ID} |
| **Input: land link to iLUC model** | | | |
| Market for arable land {GLO} | ha-eq | 2.07 | Link to: Market for arable land {GLO} |
| **Output: Emissions to air** | | | |
| Carbon dioxide, peat | kg | 7.55 | Elementary flow: emissions to air |
| Dinitrogen monoxide | kg | 7.76 | |
| Dinitrogen monoxide, peat | kg | 0.03 | |
| Methane, fossil, peat | kg | -5.57 | |
| Nitrogen oxides | kg | 1.35 | |
| **Output: Emissions to water** | | | |
| Nitrate | kg | 451.00 | Elementary flow: emissions to water |
| Phosphorus | kg | 3.10 | |
| **Output: Emissions to soil** | | | |
| Pesticides, as active ingredient | kg | 1.80 | Elementary flow: emissions to soil |

**Table C.1:** LCI data for cultivating 17.00 t FFB.

## C.2 Palm oil milling process

.

| Flows | Unit | CPO ID CPO mill | LCI data |
|---|---|---|---|
| **Output: Reference flow** | | | |
| CPO {ID} | t | 0.20 | Reference flow |
| **Input: Feedstock** | | | |
| FFB {ID} | t | 1.00 | See Table OBS |
| **Output: Materials for treatment** | | | |
| Kernels {ID} | kg | 54.4 | See Table C.3 |
| EFB to land application, DM {ID} | kg | 72.60 | Link to: Landfill of waste: Food {ID} |
| POME to land application, DM {ID} | kg | 49 | Link to: Landfill of waste: Food {ID} |
| Shell exported as biofuel {ID} | kg | 1.76 | Link to: Electricity mix {ID} |
| Biogas, as $CH_4$ {ID} | kg | 0.40 | Link to: Biogasification of food waste, incl. land application {ID} |
| **Output: by-products that substitute alternative production** | | | |
| Electricity {ID} market | kWh | 8.40 | Link to: Electricity mix {ID} |
| Electricity {MY} market | kWh | 4.65 | Link to: Electricity mix {ID} |
| **Input: fuel use** | | | |
| Diesel | MJ | 24.80 | Link to: Petroleum Refinery {ID} |
| **Input: Transport** | | | |
| Road transport of fuels | tkm | 0.09 | Link to: Other land transport {ID} |
| Road transport of FFB | tkm | 31.00 | Link to: Other land transport {ID} |
| Road transport of shell and kernels | tkm | 8.45 | Link to: Other land transport {ID} |
| **Input: Nature conservation** | | | |
| **Output: Emissions to air** | | | |
| Ammonia | kg | 0.05 | Elementary flow: emissions to air |
| Dinitrogen monoxide | kg | 7.00E-4 | |
| Hydrogen sulphide | kg | 0.045 | |
| Methane, biogenic | kg | 10.00 | |
| Nitrogen dioxide | kg | 0.12 | |
| Particulates, >10 um | kg | 0.30 | |
| Sulphur dioxide | kg | 0.15 | |
| **Input: Resources** | | | |
| Water from river | t | 1.37 | Collection, purification and distribution of water (41) {ID} |

**Table C.2:** Summary of LCI data for milling 1 t FFB.

## C.3 Palm kernel crushing

| Flows | Unit | Total industry ID | LCI data |
|---|---|---|---|
| **Output: reference flow** | | | |
| PK | t | 1.00 | |
| **Output: Materials for treatment** | | | |
| CPKO | t | 0.45 | The CPKO is sent to processing in the PKO refinery |
| **Output: by-products that substitute alternative production** | | | |
| Palm kernel meal | t | 0.52 | See rows below |
| Market for feed protein, as protein | t | 0.08 | See table |
| Market for feed energy, as gross energy | GJ | 9.53 | |
| **Input: Energy use** | | | |
| Electricity {ID} market | kWh | 59.70 | Link to: Electricity mix {ID} |
| **Input: Material use** | | | |
| Water | t | 0.10 | Collection, purification and distribution of water (41) {ID} |

**Table C.3:** Summary of LCI data for crushing 1 t PK.

## C.4 Palm oil refinery

| Flows | Unit | CPO refining {ID} | CKPO refining {ID} | LCI data |
|---|---|---|---|---|
| **Reference flow** | | | | |
| Output: RDB PO | t | 0.95 | | |
| Input: CPKO | t | | 1.00 | |
| **Output: by-products that substitute alternative production** | | | | |
| RBD PKO | t | | 0.95 | RBD PKO substitutes RBD CPO. See column 'CPO refining {ID}' here. |
| **Input: Feedstock** | | | | |
| CPO | t | 1.00 | | See Table C.2 |
| **Input: Energy use** | | | | |
| Electricity {ID} market | kWh | 16.70 | 16.70 | Link to: Electricity mix {ID} |
| Electricity {MY} market | kWh | 9.30 | 9.30 | Link to: Electricity {MY} market |
| Diesel | MJ | 0.33 | 0.33 | Link to: Petroleum Refinery {ID} |
| Fuel oil | MJ | 0.30 | 0.30 | Link to: Petroleum Refinery {ID} |
| **Input: Transport** | | | | |
| Road transport {ID} | tkm | 0.99 | 0.99 | Link to: Other land transport {ID} |
| Road transport {MY} | tkm | 0.55 | 0.55 | Link to: Other land transport {ID} |
| **Input: Material use** | | | | |
| Caustic Soda, as 100% conc. | kg | 2.90 | 2.90 | Link to: Landfill of waste: Inert/metal/hazardous {ID} |
| Phosphoric acid, as 100% conc. | kg | 1.60 | 1.60 | Link to: Landfill of waste: Inert/metal/hazardous {ID} |
| Bleaching earth | kg | 0.64 | 0.64 | Link to: Landfill of waste: Inert/metal/hazardous {ID} |
| Water | t | 0.36 | 0.36 | Collection, purification and distribution of water (41) {ID} |
| **Output: Materials for treatment** | | | | |

**Table C.4:** Summary of LCI data for refining 1 t CPO and 1 t CPKO.

# Appendix D

# Contribution Analyses - Tables

The data behind the contribution analyses displayed in the Figures 5.2, 5.3 and 5.4 are outlined in Tables D.1, D.2 and D.3 respectively. The calculations behind is included in the external Excel sheet *Contribution analyses*.

## D.1 Nature occupation

| | SBM | FB | GPC |
|---|---|---|---|
| Unit | PDF*m$^2$ | kg PDF*m$^2$ | PDF*m$^2$ |
| Protein crop production | | | |
| **Fuels and energy** | 2.99E-04 | 1.18E-3 | 0.01 |
| **Feedstock** | 4.29 | 4.10 | 6.18 |
| Field emissions | 0.00 | 0.00 | 0.00 |
| iLUC | 4.28 | 4.09 | 6.16 |
| Machinery | 4.59E-03 | 4.09E-03 | 7.03E-4 |
| Others | 0.00 | 0.00 | 0.02 |
| **Substitutions** | | | |
| RBD PO substitution {CN} | -1.54 | | |
| Natural gas substitution {DK} | | | -0.01 |
| **Others** | 0.01 | 0.00 | 0.02 |
| **Sub-total (fuel & energy, feedstock, substitutions, others)** | 2.76 | 4.10 | 6.20 |
| Energy crop substution | | | |
| Unit | PDF*m$^2$ | PDF*m$^2$ | PDF*m$^2$ |
| Organic feed energy production | -1.86 | -3.07 | -2.25 |
| | | | |
| **Total** | **0.90** | **1.03** | **3.94** |

**Table D.1:** Process contribution to nature occupation from producing the functional unit: 1 kg CP from SBM, FB and GPC, respectively.

## D.2 Global warming

| | SBM | FB | GPC |
|---|---|---|---|
| Unit | kg $CO_2$-eq | kg $CO_2$-eq | kg $CO_2$-eq |
| Protein crop production | | | |
| **Fuels and energy** | 0.04 | 0.08 | 0.45 |
| **Feedstock** | 0.71 | 2.37 | 5.72 |
| Field emissions | 0.18 | 0.48 | 1.96 |
| iLUC | 0.46 | 1.48 | 2.30 |
| Machinery | 0.05 | 0.15 | 0.03 |
| Other | 0.02 | 0.00 | 1.43 |
| **Substitutions** | | | |
| RBD PO substution {CN} | -2.49 | | |
| Natural gas substitution {DK} | | | -0.68 |
| **Others** | 2.51 | 0.00 | 0.83 |
| **Sub-total (fuel & energy, feedstock, substitutions, others)** | 0.77 | 2.45 | 6.32 |
| Energy crop substution | | | |
| Unit | kg $CO_2$-eq | kg $CO_2$-eq | kg $CO_2$-eq |
| Organic feed energy production | -1.18 | -1.94 | -1.43 |
| | | | |
| **Total** | **-0.41** | **0.51** | **4.89** |

**Table D.2:** Process contribution to global warming, fossil from the production of the functional unit: 1 kg CP from SBM, FB and GPC, respectively.

## D.3 Respiratory inorganics

| | SBM | FB | GPC |
|---|---|---|---|
| Unit | $PM_{2.5}$-eq | $PM_{2.5}$-eq | $PM_{2.5}$-eq |
| Protein crop production | | | |
| **Fuels and energy** | 6.91E-5 | 7.16E-5 | 1.38E-4 |
| **Feedstock** | 2.26E-3 | 2.33E-3 | 4.50E-3 |
| Field emissions | 0.00 | 0.00 | 0.00 |
| iLUC | 1.83E-3 | 1.70E-3 | 2.64E-3 |
| Machinery | 3.06E-4 | 2.65E-4 | 4.68E-5 |
| Other | 2.26E-4 | 0.00 | 1.81E-3 |
| **Substitutions** | | | |
| RBD PO substution {CN} | -7.79E-4 | | |
| Natural gas substitution {DK} | | | -2.19E-3 |
| **Others** | 1.91E-3 | 0.00 | 6.82E-4 |
| **Sub-total (fuel & energy, feedstock, substitutions, others)** | 3.43E-3 | 2.40E-3 | 3.13E-3 |
| Energy crop substution | | | |
| Unit | $PM_{2.5}$-eq | $PM_{2.5}$-eq | $PM_{2.5}$-eq |
| Organic feed energy production | -1.52E-3 | -2.50E-3 | -1.84E-3 |
| | | | |
| **Total** | **1.94E-3** | **-1.00E-4** | **1.29E-3** |

**Table D.3:** Process contribution to respiratory inorganics from the production of the functional unit: 1 kg CP from SBM, FB and GPC, respectively.

# Appendix E

# Interview Transcriptions

## E.1 Erik Fog - 10-03-2022

Introduction

**Karen-Emilie:** "Nu fik jeg kort fortalt beskrevet, hvad jeg skulle skrive om, så nu vil jeg først og fremmest gøre høre din baggrund og nuværende stilling hos ICOEL?"

**Fog:** "Jeg er uddannet agronom på tidligere Landbohøjskolen, og så har jeg arbejdet som økologikonsulent de sidste 35 år her på stedet. Her de sidste ti år har vi arbejdet med biogas og efterfølgende bioraffinering til at lave økologisk protein. Så det er det, min baggrund er. Så er jeg sammen med resten flyttet over i ICOEL, men min dagligdag er stadig den samme."

**Karen-Emilie:** "Okay, og for at komme nærmere Græs-prof-projektet, som du kalder det, vil du så uddybe det projekt?"

**Fog:** "Jeg har været med til at generere det projekt og søge det hjem. Det består af, hvilket også yderligere kan læses på vores hjemmeside, så er det et projekt, som er en udløber af et projekt, vi afsluttede for at par år siden, som hed Super-grass-prof, som igen kom i forlængelse af projektet 'organic refinery', jeg også var med til at etablre, men hvor AAU var projektleder. Det var de første forsog på at se, om det kunne lade sig gøre som foder til høns. De lagde godt med æg, selvom de fik græsprotein."

**Karen-Emilie:** "Hvornår var de to projekter, sagde du?"

**Fog:** "Som jeg husker det, var det fra 14 til 17 og så fra 17 til 20 havde vi super-grass-prof. Her arbejde vi videre med det tekniske samt lavede forsøg på Foulum med grisefoder. Det viste sig også, at grisene ville spise det. Med Organic Refinery, som i dag er BioRefine anlægget, der kombineret vi det med Bio-Value projektet, hvor Foulum lavede fodringsforsøg med pulpen til kvæg. Der kom det overraskende resultat, at kørende gav mere mælk med dette foder i stedet for almindelig græs ensilage, men der var nogle usikkerheder med det ensilage, så måske det var forklaringen på, hvorfor græsproteinet viste bedre resultater. Dog er der lavet flere forsøg, og det tyder på, det er rigtigt."

**Karen-Emilie:** "Nå okay. Hvor imponerende."

**Fog:** "Så det betyder, der egentlig er mange ting, der er lykkedes, kan man sige af de indledende projekter. Det, som så var min tankegang med Græs-prof, det var så at sige, "hvor er de huller, der skal udfyldes, så det virkelig kan spille kommercielt". Det er derfor, vi kalder det Græs-Prof - altså professionalisering af produktionen. Her har vi så valgt fem indsatser ud, som er fordelt i fem arbejdspakker, som arbejder sideløbende med hinanden."

**Karen-Emilie:** "Ja okay."

**Fog:** "Arbejdspakke 1 handler om at screene en masser kløver og lucerne sorter til formålet. Det står DLF for. Her har vi koblet nogle tests af fibrene også i koncentratet samt biogas af fibreren og lidt andet. Hele græs-prof handler om at finjustere hele systemet. AP2 er om høstteknik, hvor firmaet MaxiGRass er med. de har en moderne høstmaskine, som kan høste helt græs uden at knuse det."

**Karen-Emilie:** "Er den ikke også kun på forsøgsniveau?"

**Fog:** "Nej, det er en irsk maskine, som er på kommercielt niveau."

**Karen-Emilie:** "Nå okay."

**Fog:** "Herudover er Kvernland på. MaxiGrass har kun tre meters skårlæggerbor, som kører mange gange op og ned, og man vil gerne minimere trykket på marken. Kvernland vil have en en ny maskine, som kan høste ni meter ad gangen og så samle det op i en vogn. Så er vi blevet enige om at sammenligne det med almindelig finsnitning, som Ausumgaard er gået i gang med, da de ikke kunne få systemet med få snittet helt græs, der var høstet - det kunne de ikke få til at virke. Her ser vi så på kapacitet, kvalitet, jorden osv. Så er der AP3, laver Foulum forsøg med udstyr, der kan neddele græsset, inden det kommer i skruepressen. Så fx i morgen skal jeg til Ausumgaard, hvor vi skal finde ud af, hvad de skal satse på her. AP4, så er vi tilbage på AAU igen. Mette Lübeck, som var projektleder for de første projekt, arbejder sammen med veterinærerne på KU om at trække aktive stoffer ud af sidestrømmene som pulpen for at se, om de kan udvinde stoffer, som kan bekæmpe indvoldsorme. Det kunne være med til at skabe et højværdiprodukt. De har faktisk fundet et stof, som kan bruges, og det har en enorm effekt på indvoldsorme. Nu har de så søgt penge til at bore ned i de stoffer der, og hvordan de kan ekstraheres. Femte arbejdspakke, det er så, hvor vi beregner PEF, som du kender. Der har vi så fået lavet den første beregning af græsprotein hos Ausumgaard. Så skal så laves en PEF på færdigfoder, som indeholder græsprotein. Det arbejde, du er i gang med, det kan lægges meget fint op af det arbejde i AP5."

**Karen-Emilie:** "Ja, fordi spørgsmålet er, om de beregninger, Benyamin har siddet med, om jeg må se det?"

**Fog:** "Ja, det tænker jeg, vi finder ud af. Alberto er også sulten efter at se regnearkene. Jeg tænker, at så længe vi kan holde det internt, så kan jeg jo godt få låning fra Ausumgaard, at du skal bruge det."

**Karen-Emilie:** "Ja, fordi de teknikker, de bruger på Ausumgaard, er ikke lige nogle, man kan finde i standard databaser. Om ikke kan jeg få inspiration fra det, han har gjort."

**Fog:** "Jeg tænker, det kan blive et kæmpe plus, hvis I kan i god dialog med Benyamin, bore jer ned i de PEF beregninger. Som jeg forstår Benyamin, så er PEF egentlig LCA baseret på en masse regler. Hvordan man må regne på det osv. Så et eller andet sted, så tænker jeg, at LCA er regneværktøjet, men PEF er rammen at regne i. Jeg så jo gerne, at vi kunne bakke om EU-initiativet om at få det gjort operationelt. Jeg skal have booket et møde med foderstofvirksomhederne om, hvad de egentlig gerne vil have, og det kunne jo fint bruges af dig også."

**Karen-Emilie:** "Ja, jeg kan også godt huske i starten af jeres forløb med PEF, at der var dialog om, hvad PEF'en overhovedet skulle bruges til, og hvad den skal sammenlignes med. Også fordi der er så mange regler til PEF."

**Fog:** "Ja, og jeg har et indtryk af, at Bo Wiedema, som er min gamle studiekammerat, så hvis du møder ham, må du hilse."

**Karen-Emilie:** "Ej hvor sjovt, ja det skal jeg gøre."

**Fog:** "Ja, og jeg kan huske, han mente, at det (red. LCA) vil være en verdensredning, hvor jeg så i stedet gik med økologien - så er det interessant at se, hvordan begge verdener har udviklet sig, og at begge dele nu mødes."

**Karen-Emilie:** "Ja, absolut. Det er enormt spændende."

**Fog:** "Hvis nu LCA kan være med til, at folk vælger "side"."

**Karen-Emilie:** "Ja, netop at oplyse mennesker i højere grad."

**Fog:** "Jo, men der er så meget oplysning, der er også masser af fake news, så jeg er mere optaget af at lave noget, der er operationelt, så det giver folk handle muligheder og valgmuligheder. Og det er det, LCA skal bruges til, synes jeg. Det skal vise, om det her er væsentligt bedre end det her på de og de parametre. Fordi så giver det god mening at kæmpe for at komme den vej."

**Karen-Emilie:** "Jo, det giver god mening".

**Fog:** "Så det kan vise, hvor meget man kan vinde ved at tage disse og disse beslutninger."

**Karen-Emilie:** "Jo, og LCA kan hjælpe til ren effektivisering ved at kunne udpege, hvor i produktionen, der er mest udledning osv."

**Fog:** "Ja, lige præcis. Det kunne jo være interessant at skifte varmefældning ud med fermentering."

**Karen-Emilie:** "Varmefældning i stedet for fermentering?"

**Fog:** "ja, vi høster frisk græs, og så presser vi det til saft. Den saft fermenterer man så for at få proteinet til at korkulere, og så kan det bundfælde."

**Karen-Emilie:** "Åh okay, på den måde. Ja, det giver mening."

**Fog:** "Så når vi sender det i gennem en centrifuge, så kan vi hevet protein gryn ud af saften."

**Karen-Emilie:** "Ja, okay. Så du tænkte på, man egentlig kunne miljøvurdere disse to processer for at se, hvilken en der var mest miljøvenlig?"

**Fog:** "Ja, lige præcis. Der er meget mindre energiforbrug i fermentering, da man der bruger den kemiske energi med mælkesyrebakterier, som æder sukkeret i saften."

**Karen-Emilie:** "Hvilken en bruger Benyamin i sine beregninger?"

**Fog:** "Der bruger vi varmefældning, fordi det er det, man bruger på Ausumgaard."

**Karen-Emilie:** "Okay."

**Fog:** "Men i BioRefinery brugte vi fermentering. Hos Foulum har de lavet forsøg med begge dele."

**Karen-Emilie:** "Okay, så processerne er lige effektive?"

**Fog:** "Nej, altså det ser ud til, at der give ret højere udbytte at bruge varmefældning. Det er nok fordi, en del af korkuleringen bliver optaget af mikoorganismer, så som jeg har forstået det, så er varmefældning mest effektiv. Men de er så her, man bruger mere energi, så det kan være, det belaster mere rent miljømæssigt. Så kunne det godt være, man skulle producere lidt mere pr. ton græs, men så til gengæld sparer du på energien."

**Karen-Emilie:** "Ja, og det er det, der er så brugbart med LCA. Man kan sammenligne på mange leder og kanter i en produktion."

**Fog:** "Ja, lige præcis."

**Karen-Emilie:** "Det var egentlig ret relevant, det du sagde før med, at LCA kan gøre det mere praktisk og operationelt for folk. Min ide er nemlig at kunne kommunikere mine resultater ud. Flere kan jo i dag prøve at lave en LCA, få nogle resultater og så klappe computeren i igen. Jeg vil jo gerne have en LCA, både jer og landmænd kan bruge til noget."

**Fog:** "Ja, man skal oversætte talle til, hvad det betyder i praksis."

**Karen-Emilie:** "Ja, det var bare ret relevant, at du sagde, hvor relevant LCA kan være i vores grønne omstilling. Den skal så bare netop operationaliseres og forstås."

**Fog:** "Når jeg ser ind i, hvor mange valg der skal træffes ift. PEF for eksempel, så har det jo stor betydning ift. 1:1 sammenligning. Der kan være taget nogle afgørende valg i den ene, som ikke er taget i den anden, og så er de ikke så voldsomt sammenlignelige, når det kommer til stykket. Og det viser også bare, at det ikke er straight forward endnu ift. at lave dem. Derudover er bæredygtighed jo en politisk kampplads, så der er jo også mange kræfter der, som trækker i hver sin retning. Det skal dog ikke forhindre os i at finde en løsning."

**Karen-Emilie:** "Nej, det er jo det. Nu kan det være, du selv kom lidt ind på det, men jeres nuværende status og resultater fra projektet?"

**Fog:** "Ja, nu har vi jo lige fået opdateret hjemmesiden, så du kan jo starte med at kigge på den. Der er både videoer og seneste artikler."

**Karen-Emilie:** "Okay, det gør jeg. Hvor længe varer projektet?"

**Fog:** "Det var til udgangen 2023."

**Karen-Emilie:** "Okay, det er kan være, det er et vidt begreb, da hver AP arbejder med hver sit, men hvad er næste step? Er I stadig i forskningsmode, eller hvor står I?"

**Fog:** "Hver AP knokler videre med hver deres, så fx med høstteknik, så skal vi have demonstreret det på en stor græsmarksdag til sommer samt til Øko-Markdag ugen efter. Men det er mere kommunikation."

**Karen-Emilie:** "Okay, det giver god mening. Så for at gå lidt fra selve projektet til græs protein generelt, set i din øjne, hvorfor satser Danmark på græsprotein som det bedste alternativ til sojaimport samt bæredygtighed generelt?"

**Fog:** "Man kan sige, at det hele starter et helt andet sted, nemlig med hestebønner, lupiner og ærter. Dem har vi brugt i mange år. Det, som jeg oplever, er centrale forhold til, at græsprotein er blevet så interessant, det er, at aminosyre sammensætningen i bælgsæd ikke er lige så optimalt som i græsprotein, som er meget tæt på sojas og på nogle punkter end da bedre end sojas. Det er også det, som afspejles i fodringsforsøgene - dyrene kan tåle temmelig meget græsprotein. Det er jo en af forklaringerne. Den anden er så, at når vi snakker økologi, så er bælgsæd meget følsomme overfor sædskiftesygdomme, som opformeres, hvis man dyrker det mere end hver femte år. Det lægger en klar begrænsning i, hvor meget man overhovedet kan producere. De sædskiftesygdomme påvirker overhovedet ikke kløvergræs, så udover at være en stærk proteinkilde, så kan vi gå fra før at have 20% bælgsæd i sædskiftet til have 20% bælgsæd + 20% græsprotein eller mere."

**Karen-Emilie:** "Så har du græsprotein på en mark, så kan du hurtigere placere hestebønner på samme mark, end hvis det havde været ærter, lupiner eller hestebønner?"

**Fog:** "Ja, det kan man. På den måde bliver kvælstoffikseringen i sædskiftet også meget højere, hvilket får de andre afgrøder til at performe endnu bedre."

**Karen-Emilie:** "Men kan det ikke også føre til udvaskning? Kan der ikke komme for meget kvælstof?"

**Fog:** "Jo, hvis man gør det dårligt fx ved at pløje kløvermarken ned, så vil man få et ordentligt boost, men det vil jo også være dumt, når man nu kan udvinde protein fra det for derefter at sende resterne gennem biogas, hvor kvælstoffet gemmes i en tank, for så at bringe det ud i de rigtige mængder på det rigtige tidspunkt."

**Karen-Emilie:** "Ja, det giver mening."

**Fog:** "Så er der også det med kulstofbinding. Ser man på klimadagsordenen vil man jo gerne binde noget mere kulstof, hvor kløvergræs er en superafgrøde lige efter træer. Flerårige kløvergræsmarker kan optage fantastisk meget kulstof og lagre det i jorden. Og her kan bælgsæd heller ikke levere så meget."

**Karen-Emilie:** "Ift. selve sammensætningen af græsprotein, er det så en blanding af kløvergræs og lucerne?"

**Fog:** "Ja, typisk blander man det sammen. Men det er jo bælgplanterne samler kvælstoffet i luften, hvor almindeligt græs skal have det tilført. Derfor blander man det. Dog kan man ikke komme op i de kæmpe udbytter, men til gengæld er inputtet mindre, hvilket gør at kvælstofbalancen er langt bedre. Derudover det kun mellem 20-40% af proteinet, vi får hentet ud, og det er måske kun 3% af de tons, vi kører ind, som bliver til protein. Det betyder, der er en enorm masse/volumen, der skal udnyttes, og der kan man sige, at basisudnyttelsen er biogas, så får vi også en masse vedvarende energi, som også er højaktuelt. Så det er endnu en grund til, man i Danmark vil bruge penge på græsprotein udviklingen."

**Karen-Emilie:** "ja, det bliver jo pludselig en systemtankegang."

**Fog:** "Ja, det er det, og det jo det, vi så godt kan lide i økologien."

**Karen-Emilie:** "Så det er pulpen, du putter i biogas?"

**Fog:** "Ja, og saften. Det udgør halvelen af vægten, og pulpen svarer næsten til en anden halvdel. Det er ikke meget, der er den egentlige protein koncentrat. Det med udfasning af soja, det startede nok, da man startede med at dyrke majs til ethanol i USA. Der opstod hele den der bevægelse, som fik øjnene op for, at soja æder sig ind på regnskoven. Og regnskoven har en helt speciel plads i vores hjerter, så det er også en forklaring på, at man fra offentlig side gør, man vil undgå det. Og det er også her, din opgave bliver rigtig interessant, også hvis du taler med Marie Trydeman, det er, at økologisk soja kommer fra Kina, hvor der ingen regnskov er. Så det synes jeg også er spændende at vide noget om. Altså hvad betyder det, når det ikke er en regnskovsproblematik, men en ren global forsyningsproblematik. Her bliver det virkelig også relevant med det dLUC og iLUC, som jeg stadig ikke helt forstår. Frank har nævnt, at når vi i Danmark importerer soja fra Kina, så skal de indkøbe soja til deres egen husdyrproduktion et andet sted, og det vil så typisk være fra Sydamerika."

**Karen-Emilie:** "Ja, lige præcis. og det er med andre ord iLUC."

**Fog:** "Og ift. det soja, så er der mange, der undrer sig over, hvorfor det er så kritisk. Altså flere steder i Sydamerika prøver de jo at producere det under bedre forhold, og hvor det ikke er regnskovsrydning. Så det bliver hurtigt sådan noget- Ukrainerne er gode, Russerne er dumme."

**Karen-Emilie:** "Ja, lige præcis. Apropos den konflikt, så kunne jeg læse mig frem til, at vi også importerer soja fra Ukraine. Ved du noget om det, eller kender du nogen, jeg skal spørge?"

**Fog:** "Du kan prøve at tale med Klaus Saabye Eriksen i DAKOFO. Han arbejder for brancheorganisationen indenfor foderstofindustrien, som hedder DAKOFO. Jeg sender dig lige kontaktoplysninger på mail nu."

**Karen-Emilie:** "Ja, det må du gerne. Tak."

**Fog:** "Han er i dialog med alle foderstofvirksomheder i Danmark samt samler statistik over, hvor foderet kommer fra osv."

**Karen-Emilie:** "Super, tak. Ift. at græsprotein skal erstatte soja, er det så realistisk?"

**Fog:** "Ift. et oplæg i en af de fokusgrupper, jeg er i, så har jeg talt med Sven om et oplæg, han har lavet for Thiese Mejeri på et tidspunkt. Det oplæg får du også lige. det handler om, at der er mere plads til bælgsæd og deres mængder af protein, men at der stadig er behov for ekstra plads i økologien for at opnå de 20% bælgsæd. Her kan græsprotein så spille en afgørende rolle."

**Karen-Emilie:** "Okay, super. Ja, det giver god mening. Tak, det vil jeg se nærmere på."

**Fog:** "Men ift. at få flere til at lægge om, så skal vi også forvente, der er et økologisk marked, der vil købe protienet. Her spørger vi foderstofvirksomhederne, og de spørger tilbage, hvad prisen bliver på proteinet. De forventer jo, det skal være en del dyrere end soja, og det gør, markedet ikke i sig selv trækker i den retning."

**Karen-Emilie:** "ift. dobbelt så meget økologisk areal, så vil disse krav til mere omlægning ift. bælgsæd sørge for, det sagtens kan nås, ikke?"

**Fog:** "Jo, bestemt. Og har vi kombi-løsningen, så når vi det længe inden 2030."

**Karen-Emilie:** "Ja, det giver god mening."

**Fog:** "Så det synes jeg ikke på nogen måde virker skræmmende, men det er jo teoretiske beregninger, og det skal være noget, folk har lyst til at dyrke, og der skal være adgang til levering af det hos bioraffineringsanlæg. Så det kalder jo på flere anlæg. Her er der kommet en ny tilskudsordning, som giver penge til flere bioraffineringsanlæg i Danmark, så den del af logistikken skulle gerne være på vej."

**Karen-Emilie:** "Ja, så lad os sige, at 20% af hver bliver en realitet, hvor mange anlæg er så nødvendige? Er der regnet på det?"

**Fog:** "Hvis vi nu siger, at et anlæg minimum skal bruge græs fra 3000 ha, så det er rentabelt. Der kan produceres ca. 1 ton protein i soja-ækvivalenter, hvor ca. 50% protein kan udvindes."

**Karen-Emilie:** "Også fra græsprotein?"

**Fog:** "Ja, teoretisk set. Vi har prøvet at komme helt op på 60% også."

**Karen-Emilie:** "Okay, hold da op."

**Fog:** "Ja, men det, som jeg har regnet med i min kalkule, så kan man udvinde 0,7 t rent protein pr. ha. Det vil sige, at 3000 ha gange 0,7 t/ha er 2100 t protein pr. anlæg. Og det kan man så dele op i 34.000 ha, hvilket er ca. 7 anlæg."

**Karen-Emilie:** "Ja, det giver god mening. Jeg kan se, at staten har smidt 14 mio. efter Ausumgaard."

**Fog:** "Ja, altså vi nærmer os nok mere 200 mio. kroner i alle udviklingsprojekterne, hvor af 14 mio. kr. til hvert anlæg indgår (red. Ausumgaard og BioRefine."

**Karen-Emilie:** "Okay. Det viser jo også bare, hvor meget man satser på, det skal blive til et stærkt alternativ til soja import. Tror du nogensinde, man kommer af med sojaimport? Altså bliver vi selvforsynende med protein, nu når vi bliver flere og flere mennesker, og folk ikke stopper med at spise kød?"

**Fog:** "Nå, der plejer økologerne at sige, at så må vi stoppe med at spise så meget kød."

**Karen-Emilie:** "Ej, spændende du siger det, fordi det kan gå hen og blive min konklusion eller en diskussion i mit projekt. Fordi du har jo ret. Min idé med min LCA er netop måske at kunne sige, miljøpåvirkningerne er de samme, eller det er minimalt reduceret herhjemme sammenlignet importen lig med, det hjælper ikke at flytte produktionen til Danmark. Vi kan ikke blive ved med at lade vores forbrug stige og så effektivisere rundt om det. Vi er nødt til snart at nøjes."

**Fog:** "Ja, der er nogle kemiske, biologiske grænser, som ikke lige kan flytte med."
**Karen-Emilie:** "Ja, så jeg håber, jeg kan komme frem til, at vi ikke kan blive ved med at forbruge."

**Fog:** "Ja, og problemet ligger jo i, vi har brugt økonomien som styringsredskab. Og her har man altid kunne finde et sted at trække ekstra på ressourcerne."

**Karen-Emilie:** "Ja, lige nøjagtigt."

**Fog:** "Og set i et økologisk perspektiv, så er det helt ulogisk. Altså vi har jo kun den her ene klode, så der er jo ikke mere at gøre med. Det er dog mere på dagsordenen end nogensinde før. Dog synes jeg ikke rigtigt, folk forholder sig til det."

**Karen-Emilie:** "Nej, folk drømmer om at have samme forbrug bare med god samvittighed."

**Fog:** "Ja, et teknologisk fiks, og så kører det igen. Men det skal lige siges, at det er meget værre med den konventionelle produktion. Foulum har lavet et notat til regeringen, som estimerer, at 500.000 ha. skal omlægges til protein produktion, hvor jeg mener, det nærmere er 1 mio. ha. og vi har 2 mio ha. i Danmark at gøre godt med. Så skal vi til at importere korn for at fodre husdyrene. Så den pointe skal nok materialiseres på et tidspunkt."

**Karen-Emilie:** "Ja, men man kan være ræd for, hvad folk går på kompromis på for at have samme forbrug."

**Fog:** "Soja er jo et glimrende produkt. Det er jo deres områders svar på vores hestebønner og ærter. Så der er jo ikke noget galt med soja som produkt, det er hele balancen, der er et problem, og det er svært for os mennesker at forstå at gøre noget ved. Os mennesker er indrettet til at dele ting op i godt eller skidt. Det der med, at det er måden, vi bruger tingene på, der er problemet, det er meget mere indviklet, og det så her LCA er et forsøg på at synliggøre problemet ved at kvantificere disse interaktioner, og det bliver bare så indviklet. Man kan sige, du skal bare lave et speciale, der lever op til de tilhørende rammer, men jeg kan godt høre, du har skyhøje ambitioner."

**Karen-Emilie:** "Uha ja, skyhøje ambitioner."

**Fog:** "Men bare, du lover mig at huske, du skal lave et godt speciale, som du får godkendt, og som du kan bruge som reference, når du søger jobs."

**Karen-Emilie:** "Ja, selvfølgelig. Det skal jeg nok. Mit sidste spørgsmål det er, hvis vi lige ser bort fra græsprotein, hvilke bælgplanter skal vi så satse på i Danmark?"

**Fog:** "For år tilbage var det meget ærter, man satsede på. Når man taler med plantebaserede proteinkoncentrat, så erærteprotein den største spiller. De senere år har det været hestebønner, man har satset på. Dog vil jeg sige, du skal tale med Inger. Det kan hun jo forfra og bagfra. Som jeg husker det, så er ærter knap så højt i udbytte sammenlignet med HB. De er følsomme overfor vand, og de sværere at høste, fordi de lægger sig ned. Så tror jeg også, man overgjorde man det dengang, hvor man ved mere om tingene i dag. Jeg tænker, aktualitetsmæssigt, er hestebønner mest interessante. Lupiner har et lavere udbytter samt en masse udfordringer med giftstoffer, der skal renses osv."

**Karen-Emilie:** "Okay super. Tak."

Ending the interview.

## E.2 Kirsten Lund Jensen - 11-03-2022

Introduction from Karen-Emilie about the subject of the thesis.

**Karen-Emilie:** "I øjeblikket jeg det, man kalder en problemanalyse, hvor man udpeger alle problemerne i det emne, man skriver om. Og i det her tilfælde er det også at finde alle de problemer, der er med sojaimport, og hvorfor har man sat målsætninger om at få det væk. Her kom jeg til at tænke på dig, fordi du jo sidder højere oppe i den økologiske sektor, og hvordan I arbejder med bæredygtighed. Så i første omgang har jeg et initierende spørgsmål om din baggrund og nuværende stilling?"

**Lund Jensen:** "Ja, men lige først, hvad er det, du læser?"

**Karen-Emilie:** "Min uddannelse hedder Environmental Management and Sustainability Science, som er en master på Aalborg Universitet, som er en ingeniør i grøn omstilling. Hele idéen bag vores uddannelse er at lære om grøn omstilling, og så skal vi selv finde den sektor, vi gerne vil bidrage til."

**Lund Jensen:** "Okay, ej jamen det er jo fantastisk."

**Karen-Emilie:** "Ja, så nu er jeg gået all in på fødevareproduktion og all in på økologien."

**Lund Jensen:** "Fantastisk. Du skal simpelthen være så velkommen. Godt, og så spurgte du om min baggrund og nuværende stilling?"

**Karen-Emilie:** "Ja, det gjorde jeg."

**Lund Jensen:** "Jeg er økologichef i Landbrug og Fødevarer, og jeg er sektorschef i økologi ift., hvilke innovationsaktiviteter vi har brug for i den økologiske sektor. Så vores økologi bestyrelse fungerer også som sektor bestyrelse i Landbrug og Fødevarer. Så udover de er erhvervs- og politiske opgaver, så varetager vi også de faglige interesser - altså hvilke faglige aktiviteter bliver sat i gang. Og der er jeg så deres forlængede arm, deres daglige person som sikrer, deres interesser bliver varetaget. Så derfor er det også mig, er står for samspillet over til Innovationscenter for økologisk landbrug. Derudover har jeg en fagekspertsrolle i bestyrelsen. Så jeg står for at varetage de økologiske interesser i L&F både ift. det politiske og ift. det faglige, både på landmændenes side og på virksomhedssiden, så vi står for hele pakken."

**Karen-Emilie:** "Super. Hvis vi så skal nærme os bæredygtighedsbegrebet en tak mere, da det er det, vi alle jo taler om og er afgørende. Så hvilke faktorer mener du, skal spille ind for at have et økologisk, bæredygtigt landbrug?"

**Lund Jensen:** "Det er et spørgsmål om at leve op til de principper, der ligger bag økologien: holde hus med ressourcerne, vi skal levere en jord videre til næste generation, som er i lige så god stand, som da man overtog den. Det vil sige, man ikke skal overudnytte det ressourcegrundlag, man har - man skal hele tiden sørge for at vedligeholde den såsom jordens frugtbarhed. Så handler det også om naturlighed - arbejde med de biologiske mekanismer i stedet for at forstyrre dem. På den måde skal man altid udvise størst mulig hensyn til miljø og natur og de naturlige processer. så er der også det med retfærdighed for arterne, så vi tager størst mulig hensyn til dyrevelfærd. Når vi nu tager dyr ind i et produktionssystem, så kan vi ikke påstå, vi giver dem de helt naturlige forhold, men vi skal prøve at give dem nogle muligheder, så de kan udøve deres naturlige adfærd bedst muligt. Der er jo de fire økologiprincipper: sundhed, retfærdighed, forsigtighed og økologiprincippet, hvilket er kredsløbstankegangen. Altså at ressourcerne skal køre i loop, så når vi sender næringsstoffer til byerne, så skal vi prøve at få dem tilbage igen. Det er den ideelle tankegang. Det er den ideelle bæredygtighedstankegang bag økologien. Dog kan man sige, at den økologiske produktion jo stadig har en impact - vi er jo ikke i mål. Det er også derfor, vores strategi har et fokusområde, der siger at vi skal tættere på de økologiske principper - hvordan kan vi hele tiden arbejde med at udvikle den praktiske produktion med det regelsæt, der er i økologien. Hvis vi gerne vil endnu tættere på at indfri den bæredygtige tankegang, hvad er det så, der skal til i vores udvikling."

**Karen-Emilie:** "Ja, og netop ift. det med cirkularitet og systemtankegang/selvforsyning er afgørende."

**Lund Jensen:** "Ja, specielt selvforsyning glemte jeg at sige, men det er altafgørende i økologien."

**Karen-Emilie:** "Ja, selvforsyning fornemmer jeg er en stærk spiller, hvilket ret naturligt fører os videre i samtalen om sojaimport, fordi vi vil gerne undgå import og finde danske alternativer. Her er vi egentlig rimelig langt, forskningsmæssigt, men det undrer mig stadig, altså *hvorfor* vil vi gerne være selvforsynende af protein - er det den miljømæssige baggrund/hele idéen om vores økologiske systemtankegang om at gøre tingene selv?"

**Lund Jensen:** "Ja, det er systemtankegangen, og det er der, økologien nok har været foran, det er der, hvor vi prøver at tanke alt ind i en sammenhæng. Det er jo ikke fordi, vi er imod samhandel med udlandet, men skal vi have en velfungerende, økologisk produktion i Danmark, så skal vi se på, hvordan planteavlen og husdyrproduktionen hænger sammen. Og det kan jo godt være, det ikke foregår på en enkelt bedrift det hele, men så ved at stille flere krav og mål om selvforsyning, så bliver de økologiske husdyrproduktioner aftagere fra produkter fra plantesektoren. Her kan græsproteinet spille den rolle at den bliver relevant i det sædskifte, som ikke selv har husdyr, men fordi de kan lave en afgrøde, husdyrproduktioner kan få gavn af, selvom det ikke ligger ved siden af hinanden. Græskløver er vigtigt, fordi det er afgørende i et økologisk sædskifte, og i dag er det fortrinsvis kvægbønder, der har kløvergræs i deres sædskifte, og når vi øger forventningerne om at hive kvælstof ned fra luften, som er det, kløvergræs kan, og får dem i spil i systemet. Det er jo en fornybar ressource, fordi kvælstof i luften altid er tilgængeligt og så skal vi ikke benytte os af ikke-fornybare ressourcer. Derudover bruger vi heller ikke fossile brændstoffer på det, da det jo er planter, er rent faktisk gør det."

**Karen-Emilie:** "Det giver god mening, at det normalt er kvægproducenterne, der har brugt det (red. kløvergræs), men at flere planteavlere kan producere det, så de får gavn af det.

**Lund Jensen:** "Det er en grundtanke i økologien at hente kvælstof fra luften, og af vores holdning, så skal vi videre med det, da vi ikke er kommet langt nok med det. Det skyldes, man har kunne hente næringsstoffer andre steder fra, og det er det, vi gerne vil stramme op på. Vi skal tættere på retningen af, man indretter sædskiftet efter, man faktisk henter de her næringsstoffer ind fra luften."

**Karen-Emilie:** "Okay, så det er også derfor, at kravet fra EU om minimum 20% bælgsæd er nødvendigt?"

**Lund Jensen:** "Ja, det er det."

**Karen-Emilie:** "Okay. Ift. soja, så er det generelt et forholdsvis negativt ladet ord, da man hurtigt tænker regnskovsrydning i de lande, man får det fra. Da jeg så så ind i økologisk import, så er det mest fra Asien, og hovedsageligt Kina, hvor det egentlig ikke er regnskov, man rydder for at producere soja. Så derfor slog det, mig, set ud fra miljøprofilen af økologi, altså kender man konkret miljøpåvirkningerne ved import af økologisk soja?"

**Lund Jensen:** "Jo, men det kommer jo an på, hvad man inkluderer i sin livscyklusanalyse, og nu ved jeg ikke, hvad du tager med af metoder, men der er jo både direct land use change og indirect land use change, og tager med iLUC med, så tæller sojaimport rigtig rigtig meget, selvom den ikke kommer fra Sydamerika. Altså det er jo rigtig komplekst at arbejde med, fordi forøger vi vores protein herhjemme, så fortrænger det jo noget andet produktion, som skal rykkes et andet sted hen. Så både hvis man inkluderer dLUC and iLUC, så tæller sojaproduktionen noget. Men det er jo hele idéen om, at vi skal stå for mål for vores egen produktion. Skal vi have det antal husdyr, vi har her i Danmark, så må vi også finde det foder, som kun belaster vores eget kredsløb, hvis du forstår, hvad jeg mener. Altså du kan sagtens sige, at vi importerer udefra, og det hænger fint sammen, men i økologien siger vi, at vi skal have det til at fungere i en sammenhæng, hvor det foder, vi giver til dyrene, passer ind i marksammenhængen og giver et fornuftigt sædskifte set i en økologisk, bæredygtig betragtning i Danmark. Det er ikke fordi, vi er imod import, men vi tager ansvar for det sædskifte, og den systembetragtning, der følger med i produktionen. Altså hvad kræver det i virkeligheden af det danske, økologiske fødevaresystem - at man i højere grad kommer derhen, at det positive ved at producere protein fra kløvergræs i Danmark er, at det giver en positiv effekt og en positiv miljøeffekt i de danske sædskifter."

**Karen-Emilie:** "Ja, fordi det er var en hel ny vinkel på det, jeg ikke har hørt fra andre. At vi må tage ansvar for den produktion, selv gerne vil have. Det er jo den nemme løsning at købe udefra, men vi er nødt til at tage ansvar for det, vi selv gerne vil producere. Det giver god mening."

**Lund Jensen:** "Ja, og det er jo ikke en enten-eller-tilgang, men hvis vi skal sætte en retning, så skal vi prøve at arbejde hen imod en balance, hvor vi kan stå på mål for den måde, vi har valgt at indrette vores fødevaresystem efter. Det betyder ikke, vi ikke kan købe eller sælge med andre lande, men at vi kommer endnu mere i retning af den helhedstænkning, vi har talt om her."

**Karen-Emilie:** "Jamen helt sikkert, det giver god mening. Og apropos, nu ved jeg ikke, hvor meget du kan sige om det, men hele Ukraine situationen, så læste jeg mig frem til, at vi også importerer en smule soja derfra, men er det korrekt?"

**Lund Jensen:** "Nej, eller det er vi også usikre på, men det er i hvert fald ikke meget. Det meste kommer fra Kina, og det har i forvejen været svært at få pga. COVID19, og det præger stadig markedet meget. Det, vi får fra Ukraine, er primært majs. Majs er den bedste proteinafgrøde indenfor kornafgrøder, så majs spiller godt ind, hvis man mangler proteinkilder, så kan majs være supplement. Der kommer meget majs og korn fra Ukraine og Kasakhstan, så derfor påvirker krigen rigtig meget, da det presser forsyningssikkerheden endnu mere med protein - specialt majs og solsikker fra Ukraine er i øjeblikket kritisk. Og så er transportsituationen bare stadig et mega dilemma."

**Karen-Emilie:** "Så Ukraine situationen blev pludselig et endnu mere spontant skub til at blive selvforsynende i Danmark?"

**Lund Jensen:** "Ja, hvor vi havde det som strategisk mål i forbindelse med de økologiske principper, så er det pludselig pga. forsyningssituationen blevet endnu mere aktuelt. Også ift. robustheden i vores system - det er blevet så synligt for os, hvor afhængige vi er af at handle med lande på tværs, og hvor skrøbeligt system pludselig er. Den økologiske tankegang ønsker en mere lokal produktion, hvor man ikke er så skrøbelig - hvor dyrene indgik i en lokal forsyningsbalance, så produkter ikke skal transporteres over lange afstande."

**Karen-Emilie:** "Ja, og ift. lange afstande, så tænker jeg også transparens. Jeg ved godt, EU har strikse regler med indkøb og import, men jeg talte bare med nogle kollegaer om økologisk soja fra Kina, og hvordan man sørger for, det er så økologisk, som vi har krav til, det er. I den forbindelse har jeg hørt, at kinesisk soja nogle gange ikke er 100% økologisk?!

**Lund Jensen:** "Der vil jeg så sige, at import fra Kasakhstan, Hviderusland, Ukraine og Kina, der har LBST faktisk siden 2019 lavet fuld kontrol. Dvs. at alle partier, der lander i Danmark, så bliver der taget stikprøver i dem alle. Så der er skærpet kontrol, da der var behov for øget sikkerhed for, der ikke var pesticider eller andet i partierne. Så der er streng kontrol, og foderstof virksomhederne har også streng kontrol, da det bliver et kæmpe problem for dem, hvis en kæmpe mængde bliver underkendt i kontrollen. Så mangler de pludselig foder til deres kunder. Så de er meget optaget af, importen er korrekt økologisk, så her fungerer EU systemet ret godt. Så det med, at importen ikke altid er god nok, det har der været historier om, men der er strenge krav og kontrol nu."

**Karen-Emilie:** "Okay, jamen det er jo bare rart at få afkræftet, at hvad man hører i krogene ikke er korrekt. Hvis vi nærmer en lille smule mere mit emne og LCA-beregninger, så til det her Forum for Økologisk Rådgivning, der udpegede du alle mine fire inputs, men specielt ift. flere økologiske LCA'er samt bedre forståelse af danske alternativer til soja import, det var der ret mange, som var deltagere, der synes var interessant. Nu har vi været lidt inde på det, så jeg skal lige se, om jeg kan dreje spørgsmålet lidt - ift. du sidder i bestyrelsen hos ICROFS og ift. kommende forskning og innovation, vi skal kigge på, er LCA så kommet mere på dagsordenen?"

**Lund Jensen:** "Ja, det synes jeg. vi prøver jo at prioritere projekter, hvor LCA indgår, da vi mener, der er for lidt viden om vugge-til-grav beregninger af økologiske produktioner. Så det er vi meget enige i. Der er nogle igangværende projekter med LCA af økologiske produkter, hvor Marie Trydeman er ansvarlig, men jeg ved ikke, om du har konktaktet hende?"

**Karen-Emilie:** "Jo, det har jeg ihærdigt forsøgt på, men hun er svær at komme i gennem til."

**Lund Jensen:** "Ja, hun har travlt, men hun er simpelthen mega dygtig, og hun kan sende dig de studier, du skal bruge. Jeg kan godt videresende det seneste, hun har sendt til mig, men hun er den, du skal snakke med."

**Karen-Emilie:** "Mange tak, du må du meget gerne."

**Lund Jensen:** "Hun har fingeren på pulsen, så hun vil være relevant at tale med, men også kontakt ICROFS og snak med dem om, hvad der er i gang, og få dem til at give dig links til relevante forskningsprojekter, der adresserer dette problem i et eller andet omfang."

**Karen-Emilie:** "Ja, det vil jeg gøre. Tak. Men altså i Danmark og EU har man stor konsensus om, at økologi er lig med bæredygtigt landbrug. Man peger hurtigt på økologi som en grønne løsning, så hvorfor er der behov for yderligere miljøvurderinger?"

**Lund Jensen:** "Altså på klimadelen har man ikke haft nogle specifikke krav i økologireglerne, så it. carbon footprint og LCA analyser, så har man brug for at få evalueret mange af de antagelser, der er. Fx at økologien fylder mere areal, så man et dårligere CF. Sådan tager folk det helt intuitivt, at sådan er det. Så derfor har vi behov for, der bliver lavet nogle analyser, der kan sige på den ene og den anden side. Altså det kan godt være, det fylder mere areal, men det indgår i en andet systemtankegang, hvor der er nogle afgrøder, der kulstofbinder bedre. Man bruger ikke fossile brændsler på at lave kunstgødning, der er ikke sprøjtemidler, og det trækker jo LCA beregningerne i en anden retning, og det er bare sådan noget, man kan gisne rigtig meget om, og derfor har vi brug for nogle tal på det, så det er videnskabeligt baseret."

**Karen-Emilie:** Jo, lige præcis. Sidste år lavede jeg en lille LCA mellem 1 ton konventionel og økologiske proucerede hestebønner for at undersøge den steorotype holdning, at økologi er værre rent klimamæssigt pga. arealet. Her var der jo gigantiske forskellige mellem de såkaldte impact kategories, man så på, som ikke var CO2 baserede. Der er jo mange miljøpåvirkninger, som ikke er CO2, og der viste økologi nogle helt anderledes resultater, som ikke er så belyst i samfundet."

**Lund Jensen:** "Ja, og det er præcis det, Marie Trydeman sidder med."

**Karen-Emilie:** "Ja, spændende. Hende vil jeg kæmpe lidt videre med at få fat på.

**Lund Jensen:** "Ja, gør endelig det."

**Karen-Emilie:** Så har jeg egentlig ikke så meget mere, men ift. målet om dobbelt så meget økologisk areal inden 2030, ved du så, hvor langt vi er? Når vi det inden 2030?"

**Lund Jensen:** "Altså i Danmark mener man, det er meget ambitiøst, men det er muligt, hvis man ser på EU målet om 25% mere økologi inden 2030. Men at vi skal opnå de ca. 20% af landbrugsarealet skal være økologisk, svarende til en fordobling, det tror jeg på, men ift. krigen i Europa osv., så kan jeg selvfølgelig være usikker på det. Men omvendt er der otte år til, og det kan lige passe, at krigen betyder, det bliver endnu mere relevant at blive økolog, fordi input stofferne ikke er tilgængelige. Man kan ikke vide, hvor det hele går hen - det kan gå begge veje."

**Karen-Emilie:** "Okay. Jeg fornemmede også til forummet, at nogle af økologer kender konventionelle, der overvejer at lægge om pga. priser, så der kan også være en tendens lige om lidt, der gør flere lægger om. Men det var egentlig også bare for at få din holdning, fordi jeg altid finder det spændende at høre folks holdninger til målsætninger."

**Lund Jensen:** "En ting, som du ikke har spurgt om, men som jeg gerne vil sparke ind, det er ift. det græsproteinet, og hvorfor det er relevant. Det er også fordi, man kan lave en aminosyre sammensætning, som passer rigtig godt til enmavede dyr. Den information skal også med, fordi en ting er det gode sædskifte-perspektiv, en anden ting er en god aminosyre sammensætning til enmavede dyr, da det har været et afgørende problem ift. selvforsyning af protein. Det betyder, man heller ikke behøver at overfodre med protein, hvilket man gør i dag for at få nok af de aminosyre, der mangler. Det betyder, der er for stor næringsstofudvaskning. Så det med at få optimeret næringstoffer til enmavede dyr er i sig selv en miljø og klimamæssig gevinst. og det med at få kløver i sædskiftet er også en klimagevinst. Og rent dyrevelfærdsmæssigt, er det jo også bedre at fodre dyrene optimalt end at overfodre dem."

**Karen-Emilie:** "Ja, helt bestemt."

**Lund Jensen:** "Og så det med, at det kan spille sammen med biogas. Der er bare mange gode perspektiver med det grønne protein, og det er også derfor, vi har en selvstændig målsætning om at forøge produktionen. Vi har et mål om, at græsprotein bliver en del af foderblandingen til grise og fjerkræ inden udgangen af 2023."

**Karen-Emilie:** "Jamen det giver god mening. Jeg har lavet et større litteraturstudie om forståelsen af proteiner, og det virker det til, at sojaudfasning hurtigt kun bliver en fordel for drøvtyggere pga. græs, hvor der var større problemer med at få proteinforholdet til enmavede dyr til at passe, hvor græsprotein til bioraffinering var den gyldne løsning pga. aminosammensætning".

**Lund Jensen:** "Ja, men selv med den nuværende sojaimport har de svært ved at sammensætte den perfekt fodermængde til enmavede dyr."

**Karen-Emilie:** "Ja okay. Det taler selvfølgelig endnu mere for græsprotein. Nu hørte jeg også Steen Bitsch fortælle om Ausumgaard i går, og det går fremad, så det er jo mega godt."

**Lund Jensen:** "Jeg vil også sige, at da jeg var æggeproducent fra 1992-2002 var proteinsammensætningen allerede et problem. I den konventionelle produktion kan de tilføje kunstig aminosyre for at opnå den perfekte sammensætning, hvilket vi jo ikke kan i økologien. Så vi har altid manglet aminosyre sammensætningen i økologien, hvor græsprotein gennem bioraffinering simpelthen er et gennembrud. Det er noget af det bedste, der er sket sammen med Nuro-robotten. De to ting er grunden til, at rent teknisk kan få økologien til at udvikle sig på en helt ny måde."

**Karen-Emilie:** "Også at det samtidig kan indgå i jeres systemtankegang. Der er jo så mange muligheder med græsprotein end bare selve hovedformålet."

**Lund Jensen:** "Ja, der er mange positive sideeffekter."

**Karen-Emilie:** "Den sidste, ting jeg vil komme ind på, er om jeg må invitere de samme mennesker, som var med til forum, til et oplæg, når jeg har lavet min LCA? Jeg vil gerne kommunikere mine resultater ud til flere."

**Lund Jensen:** "Altså vi kan jo aftale, du kommer og fremlægger til det næste Forum, vi afholder? Hvornår skal du holde oplægget?"

**Karen-Emilie:** "Altså jeg afleverer 3. juni, så det skal gerne være inden det."

**Lund Jensen:** "Okay, det kan vi ikke nå så."

**Karen-Emilie:** "Altså jeg kan jo selv invitere folk, det er bare, om jeg må det?"

**Lund Jensen:** "Ja, men jeg må ikke udlevere adresselisten til dig."

**Karen-Emilie:** "Nej okay."

**Lund Jensen:** "Altså jeg vil invitere til et online-møde. Så kan du få flere med, da de ikke transportmæssigt skal for langt, fordi så kommer folk ikke. Og så vil jeg nok invitere alle dine kollegaer til et oplæg, da de jo også kan få meget ud af det, du sidder med. Bare sig til, så vil jeg gerne hjælpe med at sprede budskabet om dit online-møde."

**Karen-Emilie:** "Ja, det var to gode idéer. Det vil jeg tænke over. Tak for hjælpen. Jeg vender tilbage med, hvad jeg ender med at gøre."

Ending the interview.

## E.3 Sven Hermansen - 11-03-2022

Introduction

**Karen-Emilie:** "Lige for at starte overordnet og mere initerende, hvad er så din baggrund og nuværende stilling hos ICOEL?"

**Hermansen:** "Jamen min uddannelse er faktisk lige atypisk. Jeg har en bachelor i ingeniør, og så har jeg yderligere en professionsbachelor i, hvad man kalder jordbrugsteknolog. Så jeg er strukket sammen med to halve uddannelser, hvis man kan sige det sådan."

**Karen-Emilie:** "Ja okay, på den måde."

**Hermansen:** "Det er lidt atypisk for sådan et hus her, hvor alle store, stærke akademikere."
**Karen-Emilie:** "Uha ja."

**Hermansen:** "Men det er fint - sådan er det. Jeg har faktisk lige lavet en anden præsentation, hvor jeg skulle introducere mig selv. Jeg kom frem til der, at jeg har arbejdet 35 år med økologi. I mange år har arbejdet med rådgivningsdelen og projektdelen. Hos SEGES har jeg arbejdet i syv år, hvor jeg så er i ICOEL nu. Jeg har haft en specieltkonsulent og siden chefkonsulent med næringsstoffer som hovedområde, og så har jeg med fagpolitisk sparing med de folkevalgte lag at gøre, som interesse varetagelse. Det vil sige, at hvis der er nogen på Axelborg, som skal bruge nogle skøn til en dagsorden, de skal fremme eller en strategi, så kan sådan en som mig blive brugt til at lave et notat eller diskutere nogle vinkler på udfasning af konventionel gødning eller sådan nogle ting der. Så laver vi nogle høringer, når der kommer nye love og bekendtgørelser, så samler vi høringssvar ind. Så det er både fagligt, men også politik. Der er jo meget politik i de nye regler og bekendtgørelser. Så det er det, jeg pt arbejder med her i huset."

**Karen-Emilie:** "Okay, spændende. Så det er også af den årsag, du er gået mere i dybden omkring soja og vores arealanvendelse og næringsstoffer, og om det overhovedet kan lade sig gøre."

**Hermansen:** "Ja, altså man kan sige som chefkonsulent i det her system, sammenlignet med specialtkonsulent, som er relativ smal faglighed, så er det en mere overordnet opgave om at samle tråde og bygge ting sammen. Så det er med den kasket, jeg gør det. Det er i virkeligheden ret udefineret arbejde, men også noget med, hvor økologien skal gå hen og alle de her ting."

**Karen-Emilie:** "Okay. Nu har jeg tilfældigvis lige talt med Kirsten Lund Jensen, har du så tit kontakt til hende?"

**Hermansen:** "Ja, det gør jeg. Har du også interviewet hende?"

**Karen-Emilie:** "Ja, lige her til formiddag omkring hende som sektorchef, og hvad hun sidder med, og hvordan hun ser bæredygtig økologi. Hvad tror hun på, bliver vejen frem for økologien, og hvorfor sidder hun med økologi osv."

**Hermansen:** "Ja, okay. Eftersom vi har siddet i mange år i økologien, så har vi meget fjern fortid sammen, hvor vi var nogle unge økologimennesker, hvor økologien var vildt mærkelig."

**Karen-Emilie:** "Ja, dengang det var en helt underlig niche. Hun fortalte godt, hun altid har arbejdet med økologi og har haft et landbrug engang osv. Altså lige nu er jeg i en proces i min rapport, hvor man plejer at skrive noget, der hedder en problemanalyse. Det betyder, at når jeg har valgt emnet om sojaimport og nationale alternativer, så skal jeg på en eller anden måde beskrive problemet, og hvorfor det overhovedet eksisterer. Og det kan være alle mulige ting - lige fra, hvorfor soja er så dårligt, og hvad folk tror om det, til de elementer, du kom med. Altså det er jo også en problematik, at det kræver flere omlægninger fra konventionel til økologi, hvis vi rykker proteinproduktionen til Danmark. Jeg vil gerne belyse så meget som muligt i den her problematik, så jeg kan blive stærk i mine argumenter omkring, om vi skal rykke det (red. proteinproduktionen), eller vi ikke skal rykke det. Derfor tænkte jeg på, om vi kunne gå gennem de tal, du fortalte om under min praktik? Jeg kan også se, at tallene er anderledes sammenlignet med 2020 og 2019 tal."

**Hermansen:** "Ja, jeg kan godt se, at Erik har givet dig nogle 2020 tal. Da jeg her til morgen sad og tænkte på det, vi skulle tale om, så overvejede jeg godt tallene også ift. et oplæg, jeg skal holde her om et par uger. Der skrev jeg lige til Arne Munk, fordi han har adgang til mange af de databaser. 2019 tallene er mest sikre, og ser man på kvægfodring, som er den største, økologiske animalske produktion, dem har vi meget data på. Det er noget, Arne har direkte adgang til i DMS (Danish Management System). 2019 er så efterføgleren på 2018, som var det ekstreme tørke år, hvor mælkeproducenterne producerede for lidt græs, som er den primære protein ration til køer. Det græs, som de producerede i 2018, det løb de så tør for i vinterfodringen 2019, og det viser, effekten slog ret hårdt i gennem året efter tørkeåret. De tal, jeg har, som er valideret og rigtige, de repræsenterer måske i virkeligheden et skævt år."

**Karen-Emilie:** "Åh okay, ja det kan jeg godt se."

**Hermansen:** "Ja, og så tænkte jeg, hvad er så et normalt år. I 2020 kan du måske også huske, der startede corona, og der lukkede Kina fuldstændig ned, og her var en masse sojatrafik, som ikke kom over i 2020. Så har vi 2021, som jo egentlig også har været et mærkeligt år, så hvad er egentlig et normalt år, hvilket jeg spurgte Arne om, som nærmest heller ikke vidste det. Så jeg tænker, at det skal vi selvfølgelig have i baghovedet, når vi ser på de her ting, men jeg holder fast i 2019 tallene, og der er ikke rigtigt forskel på 2020 tallene, kan jeg se, og hvad skal vi ellers gøre. Og det er jo en udfordring, man skal se på - altså hvad er det lige, vi dribler med her."

**Karen-Emilie:** "Ja, det er det."

**Hermansen:** "De her 2020 tal, dem har du ikke fået af mig, vel? De er fra Erik?"

**Karen-Emilie:** "Jo, det er det. Jeg kan lige dele excelarket."

**Hermansen:** "Ja, det kan jeg godt se, der står godt nok 2020. Men hvis jeg ser på mine 2019 tal, så i stedet for 34.000, så har jeg 31.000."

**Karen-Emilie:** "Ja, det er også dem, altså de 31.000 tons, jeg har set før."

**Hermansen:** "Er der en bemærkning på den røde markering?"

**Karen-Emilie:** "Ja, du kan se her."

**Hermansen:** "Ja okay, 68.000 tons sojabønner, det har jeg også i mine beregninger, men Erik har så 50% råprotein, det har jeg så ikke, jeg har 46%. Det er der, forskellen er."

**Karen-Emilie:** "Okay, og hvad tror du, er mest realistisk at gå med?"

**Hermansen:** "Det er mine tal, selvfølgelig. Ej, lad os lige prøve at se, fordi jeg har en tabel... I sojakage er der 49% protein i, men i sojabønner, har jeg mon den. Nu fandt jeg en gammel foderanalyse, hvor der er 41% protein i sojabønner. Så 50% er i hvert fald for meget."

**Karen-Emilie:** "Ja enig, fordi jeg har læst 40-45% et sted, men jeg vidste ikke, om det var mig, der så havde læst forkert."

**Hermansen:** "De 46% har jeg fået fra vores kvægfolk, men det ved jeg ikke, hvad vi skal gøre med. Det er jo en relativ stor forskel."

**Karen-Emilie:** "Ja, men hvis jeg bare ikke går med de 50%, fordi det fornemmer jeg er urealistisk, hvis jeg skal bruge det her."

**Hermansen:** "Ja, gør det."

**Karen-Emilie:** "Så står der her "Svens oplæg til Thise Mejeri" - alle de tal har du siddet med før?"

**Hermansen:** "Ja, det har jeg. Det Thise Mejeri oplæg vil jeg gerne gå i gennem med dig."

**Karen-Emilie:** "Ja, det lyder godt. Det er også det oplæg, jeg allerede har liggende, kan jeg fortælle dig."

**Hermansen:** "Ja, må jeg stadig godt vise det og dele det på skærmen?"

**Karen-Emilie:** "Ja, absolut. Meget gerne."

**Hermansen:** "På den her tabel, kan vi se den orange, som er al mark i omdrift. Så er der en kløvergræs-kurve, som er en andel af den orange, som nogenlunde følger mængden af køer. Så er der også en anden andel af den orange søjle, og det er bælgsæd, altså hestebønner, lupiner og ærter."

**Karen-Emilie:** "Ja okay. Ift. kløvergræs, så er det en del af den grønne, men kan andelen af kløver i græs ikke også være under 50%. Altså er det rent kløvergræs?"

**Hermansen:** "Ja, altså kløvergræs er en blanding af kløver og græs. Jeg kigger på de afgrøderkoder i indberetningerne, og der er en kode, der hedder kløvergræs 31-50% kløver, som er den største kode, og så tager jeg de andre med kløvergræs også. Så den grønne er den delmængde af den orange, og den røde er en delmængde af den orange."

**Karen-Emilie:** "Ja okay. Det giver god mening."

**Hermansen:** "Og her kan man sige, at bælgsæd det er de 23.000 ha, som du havde før (red. i excelarket), og i 2020 stod der 26.000 ha, og de er taget direkte fra indberetningsstatistikkerne."

**Karen-Emilie:** "Ja okay."

**Hermansen:** "Så vil jeg gerne vise dig, at der er nogle data, man er nødt til at anslå, fordi man ikke umiddelbart kender arealanvendelsen af bælgsæd, da man ikke kan nøjes med bare at kigge på det på et år. Kan du se mig, jeg sidder og vifter med hænderne?"

**Karen-Emilie:** "Ja, det kan jeg godt."

**Hermansen:** "Okay, det er godt. Så vi er nødt til at kigge på tidsdimensionen over år, så derfor kan jeg ikke bare sige, hvor meget der er plads til af bælgsæd. Men jeg kan så vise her, hvordan jeg har prøvet at gøre det. Jeg ved, der er ca. på økologiske arealer tre år med kløvergræs, så kan der være noget højværdiafgrøde, som kløvergræs har været forfrugt til, og så noget bælgsæd og noget vårbyg. Hvis nu vi anslår, at de 240.000 ha økologisk areal i omdrift, hvis de alle var baseret på kvægproduktion, så vil der være 100.000 ha kløvergræs og 34.000 ha bælgsæd. Bælgsæd vil der ikke være mere af, da der jo skal være et x antal frie år i mellem. Så i det her system, så kan der ikke puttes to bælgsædsafgrøder ind efter kløvergræs. Så en mælkeproducent her vil højest have 1/7 af set areal med bælgsæd, sådan ca. Det er i høj grad antagelser. Tager man så de 240.000 ha som kun planteavl, så kunne der var bælgsæd ca. hver femte år max. Det har vi snakket om mange gange, ikke. Bælgsæden kan så være enten hestebønner, ærter eller lupiner. Så kunne der så være 48.000 ha bælgsæd. Sådan ser verden så bare ikke ud. Jeg ved, at ca. 85% af vores økologiske areal er tilknyttet mælkeproduktion. 15% er tilknyttet planteavl eller husdyrproduktioner med enmavede dyr. Det er en antagelse, jeg laver her, men den er også kvalificeret ud fra erfaringsbasis. Tager vi så de forholdstal - hvis det er ren kvægproduktion, kunne det være så meget areal (peger på skærm), og hvis det er planteavl og enmavede dyr, kunne det være så meget areal (peger på skærm). Med almindelig købmandsregning, så mellem disse forhold, så kan der i 2021 være ca. 36.000 ha bælgsæd på det økologiske areal. Forstår du, hvad jeg gør her?"

**Karen-Emilie:** "Ja, det gør jeg."

**Hermansen:** "Og man kan sige, det er helt klart en antagelse, men jeg er ret sikker på, at er her en skydeskive, så er jeg helt sikker på, vi rammer skiven. Jeg er også sikker på, vi ikke rammer helt plet, fordi der kan være mange ting i mellem, men det er noget i den her retning. Herfra går jeg så videre og ser på, hvordan vi kan fodre sojaprotein, som svarer til 31.000 ha. med dansk bælgsæd. Det er for alle produktioner, så vil det kræve 24.000 ha. bælgsæd i Danmark.

Nu lavede jeg det her oplæg for producenter hos Thise Mejeri, hvor jeg beregnede sojaprotein kun til mælkeproduktionen, så kunne man gøre det, at man tager 15.000 ha nye arealer med bælgsæd, eller man kunne lave det samme ved at inkludere 15.000 ha vinterraps, 7000 ha kløvergræs, fordi køer kan godt æde mere kløvergræs, end de gør i dag, og så behøver man kun 8000 nye ha. med bælgsæd."

**Karen-Emilie:** "Åh okay, så de 15.000 ha, det vil kræve, kan nu pludselig skæres ned til kun 8.000 ha?"

**Hermansen:** "Ja, og jeg har arbejder med mange ubekendte faktorer, og dette er bare en kombination af faktorer. Det er jo alle faktorer, der kan producere råprotein."

**Karen-Emilie:** "Ja okay. Når du siger, man kan forøge vinterraps og kløver, er det så fordi, du vurderer, der er plads til disse afgrøder i sædskiftet?"

**Hermansen:** "Ja, fordi afgrøderne kræver noget forskelligt. Lige nu er det 5.000 ha vinterraps i 2021, så den forøgelse kan godt lade sig gøre. 2019 tallene, der var der ikke lige så meget."

**Karen-Emilie:** "Så det er derfor, du skriver, der pludselig er plads til 12.000 ha ydere bælgsæd?"

**Hermansen:** "Altså hvis vi tager 2019 tallene, så var der 23.000 ha (red. ha bælgsæd), og det kunne jo godt være væsentligt større for at komme op på max. Så fra der 23.000 til 36.000 ha, det er så 14.000 ha, men øko arealet var så heller ikke lige så stort som i 2021."

**Karen-Emilie:** "Ja okay."

**Hermansen:** "Men i forhold til at få det optimeret, så er noget økologisk areal fordelt på meget små ejendomme med 10-15 ha. Og det er slet ikke sikkert, de dyrker bælgsæd. Så skal de have flere forskellige afgrøder, de måske slet ikke har kapacitet til, økonomien til eller udstyret til."

**Karen-Emilie:** "Jamen hvordan får de så tilføjet næring?"

**Hermansen:** "De små ejendomme er jo meget udfordret i de nye gødningsregler, men de vil jo have en nabo, som vil okmme forbi deres gyllevogn, eller de samarbejder med en mælkeproducent. Men der er flere små ejendomme, som producerer med lavinputs, så det giver ikke dækningsbidrag som sådan, men det er mere på hobby plan. Det er over 1000 ejendomme, som ligger på de der 10-15 ha."

**Karen-Emilie:** "Okay. Det giver god mening, de pludselig bliver udfordret, når de nye gødningsregler kommer, og de skal have et sædskifte, de ikke er vant til."

**Hermansen:** "Ja, det bliver udfordret i de nye regler, og de kan blive rigtig mugne over, der ikke er et mindste krav, sådan så hvis man har under 15 ha, så behøver man ikke overholde de nye regler."

**Karen-Emilie:** "Ja, okay. Er du så enig - kan du godt se deres dilemma eller er du uenig?"

**Hermansen:** "Jamen mest så er jeg enig i, man skal lave en undtagelse for dem, fordi de tæller ikke så meget i ha, og det giver en masse besvær. De er grundlæggende måske heller ikke dygtige eller fagligt interesserede landmænd, det er som sagt mere et hobby niveau deres økologiske landbrug. Men taler jeg med andre om dette, så er det vigtigt for den økologiske profil og omdømme, at reglerne gælder for alle. Men jeg ved ikke, jeg synes stadig ikke, det giver hel mening for de små landrug med lavinputs, at de skal til at lave afgrødediversitet i stor stil. Det bliver så besværgeligt i forhold til, hvad de egentlig producerer."

**Karen-Emilie:** "Ja okay. Jeg kan godt se begge sider af samme sag."

**Hermansen:** "Jeg synes i hvert fald ikke, der er et enkelt svar til det her. Man kigger tit på, hvad der er muligt at kontrollere, og det styrer i virkeligheden rigtig meget af, hvordan vores regler bliver. Og de her ting er relative lette at kontrollere - en markplan eller et fællesskema, som viser nogle nøgletal osv."

**Karen-Emilie:** "Appropos indberetning, det skema, du har der, det er baseret på indberetningsdata sagde du. Er det famtalonline?"

**Hermansen:** "Nej, det er faktisk fra fællesskemaerne, altså arealindberetninger."

**Karen-Emilie:** "Areanindberetninger. Har jeg adgang til det?"

**Hermansen:** "Ja, det har du faktisk, skal jeg lige se, om jeg kan finde dem til dig på en eller anden måde?"

**Karen-Emilie:** "Ja, det må du gerne, fordi jeg kunne godt tænke mig at lave samme overblik, som du har lavet i din (red. i sine beregninger)."

**Hermansen:** "Ja, jeg har egentlig noget her, du bare kan stjæle fra - jeg får den lige i visningsmode."

**Karen-Emilie:** "Okay, super."

**Hermansen:** "fra 2009 frem til 2021 er alle afgrødekoder oplyst. Her ses det økologiske areal fra 2009 til 2021. Og så kan du finde bælgsæd og korn med over 50% bælgsæd osv."

**Karen-Emilie:** "Ja, okay. Så din mængde bælgsæd i præsentationen til Thise, er har du bare langt de her til sammen (peger på skærm)."

**Hermansen:** "ja, det er det. De der nr. 31, 32 og 33, det er hestebønner, ærter og lupiner."

**Karen-Emilie:** "Ja, okay. På den måde. Det data vil være en drøm at få, hvis det er muligt?"

**Hermansen:** "Ja, det ligger også i Innovationscentermapperne, men jeg dig det bare lige her."

**Karen-Emilie:** "Nå, ja okay. Super, tusind tak."

**Hermansen:** "Vi dribler jo rundt i emnerne - jeg håber, du kan holde styr på det?"

**Karen-Emilie:** "Ja, det kan jeg sagtens. Jeg kan være ræd for, jeg tager for meget af din tid, men har du til 15 min mere?"

**Hermansen:** "Ja, det har jeg."

**Karen-Emilie:** "Nu sagde du før, at der potentielt er plads til 12.000 ha mere bælgsæd, men er vi ikke stadig i et problem? Fordi de beregninger, det er kune, hvis det er til malkekvæg, er det ikke?"

**Hermansen:** "Det er fuldstændig rigtigt. Så skal jeg lige have fundet tallene her. Du vil gerne se på sojaimport for hele den økologiske sektor og ikke kun et bestemt husdyrhold?"

**Karen-Emilie:** "Ja, for hele sektoren."

**Hermansen:** "Går vi med mine 46%, og vi kun ser på kg. tørstof, ikke pr. kg. frø - det skal du huske, der er forskel på."

**Karen-Emilie:** "Ja, det ved jeg godt. Det skal jeg nok huske."

**Hermansen:** "Super. Det har jeg det her regneark, jeg har vist dig før. Og så i øvrigt, så sad jeg med disse beregninger, fordi jeg har et andet oplæg, jeg skal holde (peger på skærm). I disse beregninger prøver jeg at se på, hvor mange tons råprotein, vi producerer herhjemme i Danmark. Og som du kan begynde at se, så ser vi problemstillingen fra flere og flere vinkler, fordi for eksempel nu, så kan vi ikke slå et bestemt sted og se et konkret tal på det, vi søger. Vi nærmer os det kun ved at beregne på det ind fra forskellige sider. Her prøver jeg så at regne på det ud fra protein siden. Jeg ved ikke helt, hvad jeg skal bruge beregningerne til endnu, men det kommer nok. Hvis og når jeg kommer med en konklusion, så fortæller jeg den selvfølgelig gerne."

**Karen-Emilie:** "Det er bare super. Det vil jeg gerne høre mere om."

**Hermansen:** "Hvis man øger bælgplante arealet, så det fylder 1/5 af det økologiske areal, så vi skal have 8.000*5, fordi det kun må fylde en femte del jo. Dermed kræver det 40.000 ha, og det kan man gøre på forskellig vis. Noget kan være kløvergræs, noget kan bælgplanter, og kommer hele min oprindelige pointe: så kommer der et areal, som skal bruges til korn eller i hvert fald noget, som ikke er proteinafgrøder, hvis er 4/5 af de 40.000 ha. Det var jo tidligere et problem, fordi den tidligere, økologiske kornproduktion var tilstrækkelig. Det svært at få gode priser på, fordi der kom en masse fra Østeuropa, Rumænien, Ukraine, Kasakhstan osv. derover fra. Men skal vi opretholde den animalske produktion, vi har i dag, så har vi i høj grad brug for en øget produktion af økologisk korn herhjemme."

**Karen-Emilie:** "Ja, og vel specielt indenfor de sidste to uger vel (red. Ukraine situationen)?"

**Hermansen:** "Ja, præcis. Det er jo den dagsorden, der pludselig skifter helt vildt. Så mine udregninger arbejder jeg videre med, og du får dem, så snart de er gennemgået igen inden det oplæg, jeg skal holde om to uger. Men det er de her problemstillinger vi arbejder med: kan vi skaffe protein nok? og når vi sondrer mellem enmavede og flermavede dyr, så er det fordi, kvæg i højere grad kan spise den aminosyre sammensætning, der er i hestebønner og lupiner osv, end de enmavede kan. Hvis man skal fodre enmavede med dansk protein, skal det i højere grad være Eriks græsprotein, der skal i spil, og det kan det også komme. Den anden vinkel er jo, at vi selv kan producere det her græsprotein. Vores anden kollega, Lars Egelund, han var ude og holde et oplæg i går."

**Karen-Emilie:** "Ja, jeg var med."

**Hermansen:** "Nå okay, var du med? Så hørte du ham fra Vestjysk Andel, om at nu kan de faktisk producere 1 kg græsprotein til en sammenlignelig pris med soja, fordi han kan få værdi på de afledte produkter?"

**Karen-Emilie:** "Ja, det var noget i den stil. Folk var stadig meget skeptiske omkring, om det var en engangsforestilling, at de kunne få det til samme pris, fordi ellers havde man hørt 16-20 kr. Så folk var kritiske overfor, om han havde regnet rigtigt. Men pga. det med GreenLab, så kunne man få bedre priser ud af det. Så ja, priserne nærmer sig pludselig hinanden helt vildt."

**Hermansen:** "Ja, og de ekstremt høje gaspriser er jo også med til at hjælpe på det jo. Pludselig kommer der værdi på mange led i det produkt der. Så det viser jo, at tingene flytter sig hele tiden, og så kan pludselig producere protein af en kvalitet, så også de enmavede kan blive fodret med dansk protein. Og så er det noget med, de også kan oprense det så meget, at det ikke smager af græs mere, så det også kan bruges til human konsum?"

**Karen-Emilie:** "Ja, jeg tror nu stadig, det kun er i proces. Men drømmen er at få fjernet græssmagen helt. Jeg forstår da godt, de kun fokuserer på foder - der er jo ikke et marked for græsprotein til mennesker alligevel lige nu."

**Hermansen:** "Ja okay. Nu sidder du jo over for Klaus Lør, har du hilst på ham?"

**Karen-Emilie:** "Ja, det gør jeg, og jeg har kun kort hilst på ham."

**Hermansen:** "han er jo vegetar hele sit liv, og jeg diskuterer nogle gange med ham om den protein, man skal have i fødevarer. Der siger han, at de 10% protein, der er i mange vores kornprodukter, det er rigeligt til danskere - vi har slet ikke brug for højprotein."

**Karen-Emilie:** "Jamen det er også rigtigt. Protein er blevet kædet sammen med sundhed, og det er frygteligt, det er kort sådan op."

**Hermansen:** "Ja, og jeg er helt med på, vi skal erstatte vores kødprotein med planteprotein, men hvis der er for meget protein i kødet, så er det jo ikke samme mængde, vi skal erstatte med. Det er jo helt forkert, men sådan gør vi jo."

**Karen-Emilie:** "Ja, og det er også derfor, jeg synes, planteproteiner er spændende. Det er blandede informationer, folk har, og der er også rigtig meget, de slet ikke ved. Nå, men der fik du faktisk også svaret på nummer tre spørgsmål omkring, hvad din holdning er som de bedste alternativer til soja import. Her ser du det også altafgørende, vi forøger græsprotein og specielt gennem bioraffinering?"

**Hermansen:** "Ja, det er en ret afgørende faktor for, at vi bevarer en god balance i vores produktion. Men altså ift. det vores nuværende benspænd med forsyningssikkerhed, så bliver det et kæmpe issue. Folks kontrakter, der bliver ophævet pga. manglende produktioner i andre lande osv. Det går jo forhåbentligt over, så vi kan handle med hinanden igen, men så bare indenfor EU, kan jeg forstå, I hørte om i går, det også bliver et problem?"

**Karen-Emilie:** "Ja, bestemt. Der er mange lande, som er begyndt at tage imod flygtninge, og de trækker sig pt. fra sine kontrakter, fordi de ikke har mad nok til alle. Så de lukker kontrakterne for at sikre, de kan brødføde alle selv."

**Hermansen:** "Nej, lad håbe, det ikke er vedvarende."

**Karen-Emilie:** "Men omvendt sagde Kirsten Lund også, at det fordrer dansk samfund til at hurtigt at blive god til selvforsyning. Vi får bare rykket vores viden og forskning i turbo fart sammenlignet med den planlagte tid. Man kan håbe, at krigen presser Danmark til at blive dygtige til det, vi aller helst gerne vil, nemlig at være selvforsynende inden økologisk landbrug."

**Hermansen:** "Ja, men man kan så håbe, at de rigtige beslutninger bliver taget. Nogle gange kan det være de dårlige beslutninger, der bliver taget, når det er på kort tid, og det frygter man nok lidt nu. Men hvad det betyder for økologien, det er vanskeligt at forholde sig til, synes jeg."

**Karen-Emilie:** "Ja enig. Jeg tror faktisk ikke lige, jeg fik spurgt dig før, hvis vi skal rykke al økologisk sojaimport til Danmark, hvor meget ekstra areal kræver det?"

**Hermansen:** "Ja, det var så det, jeg prøvede at snige lidt udenom at svare konkret på. Mit eksempel før var udelukkende med hestebønner. Så kræver det jo tæt på en fordobling. Men kan vi lægge en del kløvergræs og raps ind som proteinkilder, så reducerer vi arealkravet, fordi de går ind i sædskiftet i stedet for at udvide det. Så det er helt afhængigt af, hvad vi kan. Raps er vi blevet relative dygtige til at producere herhjemme, og arealerne er vokset voldsomt. Er scenariet, at vi skal bruge ren bælgsæd, så skal vi bruge en fordobling, og så får vi en kæmpe produktion af korn, men blander vi kløver og raps med, bliver arealbehovet mindre. Så vi kommer nok til at lande midt i mellem disse scenarier. Rent forsyningssikkerhedsmæssigt, vil det være interessant at få et relativt stort kornareal med også. Så skal der til gengæld findes en masse næringsstoffer."

**Karen-Emilie:** "Ja okay, det giver god mening. Ift. at få udvidet arealet til økologisk produktion, så er det det der med, om det er realistisk at få flere konventionelle landmænd til at omlægge. Jeg ved godt, det er Jens Peter, der sidder mest med det, men oplever du, at flere omlægger lige for tiden?"

**Hermansen:** "Da jeg var omlægningskonsulent, der var det sådan, at folk næsten kun overvejer at omlægge, hvis der er en bedre økonomi i det, hvilket er fuldstændig fair. Det har jeg overhovedet ingen problemer med. Jeg plejer at se på, at der skal være ok stærk økonomi, fordi økologi indebærer væsentligt flere usikkerheder. Og det kan være svært at vise landmænd, fordi priserne på konventionelt korn er høje lige nu, men priserne på handelsgødning bliver enormt høje og adgang til pesticider bliver sværere og sværere. Nu er der endnu en historie ude med fund af pesticider i grundvandet. Alle de historier gør det bare sværere og mere og mere upopulært at køre med den marksprøjte ude på markerne. Om det bliver nemmere at omlægge til økologi - ja, det tror jeg faktisk, det gør, men vi er udfordret på, at de konventionelle også har høje priser. Mit gæt er, at konventionelt husdyrproduktion, specielt gris, bliver udfordret rigtig rigtig meget."

**Karen-Emilie:** "Okay, så i forhold til målsætningen om dobbelt så meget økologisk areal i 2030."

**Hermansen:** "Ja, der tror jeg, du har skrevet 50% i interviewguiden?"

**Karen-Emilie:** "Ja, jeg har skrevet forkert. Altså EU vil have 25% økologisk areal, og Danmark vil have fordoblet sit."

**Hermansen:** "Ja, altså Danmark vil gå fra 12% til ca. 25-30% økologisk areal. Eu siger 25%, og gennemsnittet i EU er under 8%, så EU ønsker faktisk en tredobling af økologisk areal."

**Karen-Emilie:** "Ja okay, så det er sådan, det hænger sammen. Jeg troede, man ønskede 25% mere, men EU vil have, at økologien udgør 25% af al landbrugsareal."

**Hermansen:** "Ja, præcis. Så de målsætninger er jo enormt stejle, og de kommer til at påvirke markedet, hvis folk får omlagt det. Polen er et måle-land her, fordi de har nogle kæmpe store arealer, som kan blive økologiske. Der kommer en indsats i Polen nu her, som vi måske skal ned og hjælpe med. De der planøkonomiske beslutninger, kommer jo til at påvirke markedet helt enormt meget. Sagen er, at hvis den danske regering eller EU kommissionen sætter sig sådan nogle mål her, så skal de også smide penge i, så de her mål også kan nås. Det er voldsomt, det der sker lige nu på alle planer."

**Karen-Emilie:** "Men tror du, vi kan nå det?"

**Hermansen:** "Nej, det tror jeg faktisk ikke, og det må du gerne citere mig for. Jeg tror, det bliver meget vanskeligt. Omvendt bliver alt kastet op i luften lige nu."

**Karen-Emilie:** "Ja, alt bliver vendt på hovedet, så jeg kan spørge dig igen om et halvt om, om du har samme holdning stadig."

**Hermansen:** "Ja, det kan du."

**Karen-Emilie:** "Så tanken om selvforsyning af økologiske protein til foder, tror du, det bliver en ting?"

**Hermansen:** "Ja, det tror jeg."

**Karen-Emilie:** "Okay, specielt pga. græsprotein?"

**Hermansen:** "Ja, de enmavede kommer kun med, når vi får græsprotein i gang. Og så er nogle mejerier allerede gået i front med at få udfaset soja til malkekøerne. Arla har ikke samme målsætning, da de arbejder på tværs af grænser, så de kan ikke lave nationale ordninger. Det er deres argument, men små mejerier gør det og bruger det som markedsføring, men det kan kun bruges en gang, kan man sige."

**Karen-Emilie:** "Ja, det er rigtigt."

**Hermansen:** "Jeg forstår godt, de små mejerier gør det med deres manøvreritet, de har."

**Karen-Emilie:** "Ja, og det lyder jo også godt i folks ører, fordi soja er så negativt ladet ord, det næsten ikke er til at bære."

**Hermansen:** "Ja, den er meget kommunikerbar".

**Karen-Emilie:** "Ja, men jeg synes bare, det er interessant at miljøvurdere. Der er jo ikk regnskov i Kina, så det er ikke det, vi ryder for at få soja."

**Hermansen:** "Er argumentet så ikke, at når vi køber fra Kina, så køber Kina bare Sydamerika?"

**Karen-Emilie:** "Ja, det er en ting. Noget andet er det, som hedder indirect land use changes. Hvis vi producerer protein herhjemme, så rykker vi nogle marker rundt, hvor måske produktionen af hvede vil falde. Den produktion vil så bare rykke til udlandet, og det optager bare en masse areal der i stedet for her. Det, som vi ikke selv producerer, det producerer nogle andre bare. Så kommer der overhovedet en effekt af at rykke det herhjem, fordi der ryger bare noget ud af landet igen, der skal produceres et andet sted. Det kan for eksempel være Kina, fordi de har dejlig lav pris eller sådan noget."

**Hermansen:** "ja, og det er vel det, vi reelt set kan kalde et nulsumsspil, hvis vi ikke regulerer på det. Hvis vi ikke regulerer på nogle faktorer, såsom reduktion i husdyr, så bliver det nulsum - det går lige op."

**Karen-Emilie:** "Ja, det er rigtigt. Men jeg håber, min LCA kan hjælpe med at skabe informationer omkring. Mit anden sidste spørgsmål er nok lidt for hypotetisk, men det er bare, om flere informationer om miljøpåvirkninger kan få flere til at omlægge."

**Hermansen:** "Ja, og det er faktisk relevant, fordi økologi bliver som regel lovet som den grønne værktøj i landbruget, fx da vi så fødevareminister, Rasmus Pren, til Økologikongressen i Horsens. Jeg for altid lidt ondt, når jeg hører sådan noget. På mange enkeltstående parametre, nitratudvaskning, ammoniakfordampning, der performer vi ikke, fordi vi kører med dyrevelfærd og store arealer i staldene, så der kan komme mere ammoniakfordampning på gulvene, og vi producerer meget kløvergræs, som kan udvaskes udenfor vækstsæsoner osv. og konventionelle kollegaer strammer hele tiden op på miljøkrav."

**Karen-Emilie:** "Ja, det er som om, økologien er blevet helliggjort som den grønne produktion, så regulering bliver hurtigt nedprioriteret."

**Hermansen:** "Ja, og jeg ved godt, at økologi har en mere holistisk tilgang, men regulering mangler. Men det kommer, er jeg sikker på."

**Karen-Emilie:** "Ja, specielt når landet forventer økologien som den grønne løsning, så skal der nok komme mere strikse rammer for at sikre denne udtagelse."

**Hermansen:** "Ja, mit gæt er også, at økologien bliver inddraget i det der regulerings regime.

Det slipper vi ikke for, og nu er vi 12%, og hvis det stiger yderligere de kommende år."

**Karen-Emilie:** "Ja, i øjeblikket bliver det jo industrialiseret helt vildt, så det er altafgørende, det bliver reguleret."

**Hermansen:** "Ja, da det økologiske areal var 1%, kunne man gøre, hvad det passede en, men nu vi nu har 12% og stadig stigende, så har man pludselig et stort ansvar."

**Karen-Emilie:** "Ja, og det hænger faktisk sammen med mit sidste spørgsmål, som jeg fik, efter jeg så dit sidste slide til Thise Mejeri præsentationen. Her skriver du, at vi skal have kollektive indsatser - det skal også virke, ellers er det nødvendigt med målrettet regulering, og det kan ramme økologerne. Hvad mener du præcist her?"

**Hermansen:** "Ja, det får jeg nogle gange skæld ud for at have med det slide her. Jeg tror stadig, det er rigtigt. Det kommer sig af de Landbrugets Klimapakke, der blev vedtaget i efteråret 2021, hvor landbruget skal levere på klima. Her er der nogle kollektive indsatser, som er minivådområder osv. Hvis der ikke bliver reduceret i 6 tons kvælstofudvaskning, så kommer der nye krav, der bliver lagt oven i hovedet på en. Det bliver lagt ud på markerne, færre kvælstofområder osv, og det er det, der hedder målrettet regulering. Og det jeg så skriver i slidet det er, at det også vil ramme økologerne. Vi kan ikke stå udenfor. Det er bare min vurdering."

**Karen-Emilie:** "Nej, men det er stadig en god overvejelse at huske. Det er jo et klassisk eksempel på, man ikke kan gøre tingene alene. Det er hele sektoren, der skal arbejde sammen, ellers bliver det træls for alle. Og her vil økologerne også blive ramt."

**Hermansen:** "Ja, medmindre man kan overtale indstandserne om, at økologi er et grønt virkemiddel i sig selv."

**Karen-Emilie:** "Ja, præcis. Det er jo det."

Ending the interview.

# Appendix F

# Phone Conversations

*This appendix includes the two phone conversations used in this study. The conversations are informal with no specific interview guide, as the purpose has been to clarify specific aspects.*

## F.1 Henrik Kreutzfeldt, organic farmer - multiple conversations

Kreutzfeldt, 2022 has 250 ha organic arable land. By having multiple conversations about cultivation procedures and legumes in the crop rotation. Additionally, it is relevant to insight into a farmers' opinion in the Danish organic sector, being self-sufficient with protein feed. Today, Kreutzfeldt, 2022 includes fava beans because of the ability to nitrogen fixate biologically, and because of the new EU regulation (see Section 1.3, where it has been become a requirement to include 20% legumes in the crop rotation. However, Kreutzfeldt, 2022 already includes more or less 20% because he is an organic farmer, where fertilizers, in general, are difficult to access. Lastly, Kreutzfeldt, 2022 has provided valuable contacts for this study; thus, the most relevant experts are interviewed.

## F.2 Aske Skovmand Bosselmann, University of Copenhagen (KU) - 16-05-2022

Bosselmann, 2022 is a lector at KU, Dept. of Food & Resource Economics, with a profession in socio-economics and agricultural value chains. The relevance of correspondence with Bosselmann, 2022 is the knowledge about the value chain within the global trade of SBM. In 2020 Bosselmann, 2022 wrote to the report "Dansk import of afskovningsfri soja fra Sydamerika" containing information on Denmark's import of soybeans and SBM affecting the rainforest in South America negatively [Bosselmann, 2020]. With regard to this study, the wonder came up if the same critical aspects appear when it is centered around organic SBM import. Here, Bosselmann, 2022 confirmed the hypothesis that China exports organic SBM and imports conventional imports from South America because of the strong business case for organic export. The reason why is that the majority of China's livestock production is conventional, and less strict rules appear regarding organic feed to organic livestock. Indicating that conventional SBM can be feet for organic livestock. This means that Bosselmann, 2022 agrees that Denmark contributes to the deforestation in South America, even when importing from Asia. Additionally, this contributes to biodiversity loss and critical social and work circumstances for the locals in South America.

# Appendix G

# Forum for Organic Advisement

Figure G.1 visualizes the overview of inputs from farmers, advisers and consultants regarding relevant, future research areas in the organic sector.

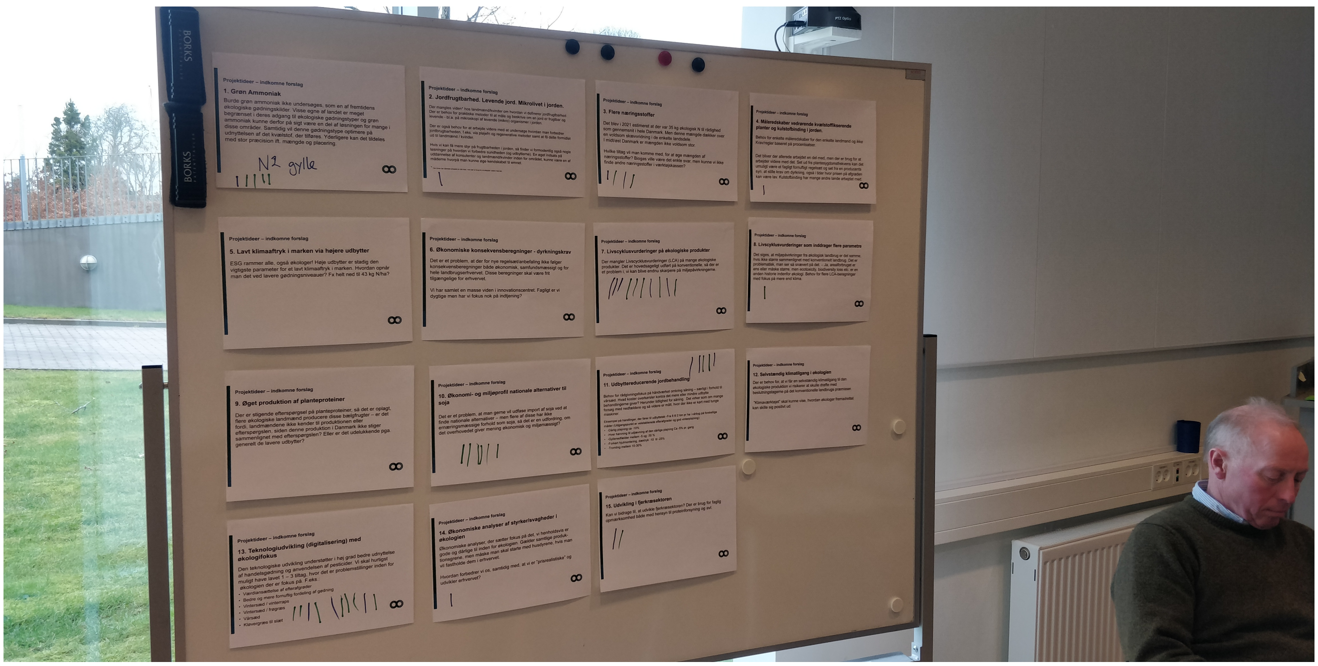


**Figure G.1:** Inputs for future research.

Figure and show the process, where participants individually voted on research subjects.

**Figure G.2:** Participants subjectively voting for future research.

**Figure G.3:** Participants subjectively voting for future research

# Appendix H

# Communication of the LCA results

*The aim of this chapter is to apply a communication product, hence the LCA results are used in decision-making accurately. Additionally, it is a requirement within this master thesis, that a communication product is developed.*

## H.1 Shannon-Weaver communication model (SWCM)

The Shannon-Weaver communication model (SWCM) from [Shannon et al., 1950] is the most common model of effective communication between *sender* and *receiver* today [Al-Fedaghi, 2020]. It has been modified to each respective communicated subject, but the foundation is often based on the model visualized in Figure H.1. The information source is the sender, who chooses an *encoder* that transmits the information. It can be translated to how the respective information is presented in the *channel*. The communication channel is the specific choice of tool to communicate the information. Suppose it should be written channels like Email, articles, SoMe content, etc., or an oral presentation like in-person meetings, phone-call, or a webinar. The *decoding* is the receiver's reception of the information, where it finally ends at the receiver understandably. Lastly, some feedback can be sent back to the sender to improve the information provided. As illustrated in Figure H.1, some *noise* can appear in the channel. Hence the information is not received clearly. Noise refers to unrelated distractions and uncomprehending encoding, like accidentally misreading an email or having a low connection during the webinar. Furthermore, if the encoding is weak, it can create noise in the communication channel because the information is not understandable resulting in misleading information to the receiver. This will lead to further confusion rather than clarification within the subject [Shannon et al., 1950].

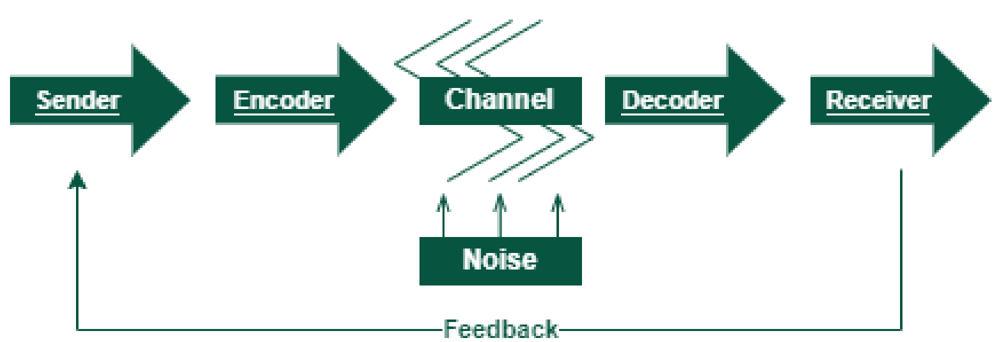


**Figure H.1:** Shannon-Weaver's model of communication. Visualization inspired by Communicationstheory.org, 2022.

With regard to communicating the LCA results from this study, it is relevant to understand the receivers to choose the right channel. As described in the goal and scope in Section 3, the main audience of the study is farmers, agricultural companies, R&D organizations, and politicians. Maybe R&D organizations have an insight into LCA performances. However, politicians and farmers might be more interested in the results and effects of their work rather than the methodology behind an LCA performance. However, as [Fog, 2022] points out, LCA results can increase the insight of environmental assessments more clearly than other methods if they are explained correctly. For that matter, both a written and an oral communication channel is chosen. For the written edition, a short overview of the current investigation regarding what protein source is the most environmentally friendly is outlined, followed by a short description of the LCA approach and, lastly, the conclusion. This is uploaded as a LinkedIn post and on the Innovation Center for Organic Farming (ICOEL) web page. In the newspaper from ICOEL, a link to the article on the webpage is attached. The information will reach multiple receivers, who will decode the information and increase their knowledge regarding protein production. However, even though it is a short written description, the noise can still appear. If the specifications of the study are hard to read or too marked by professional descriptions, it becomes obscure for the reader, and the decoding will be wrong. Thus, the ten communication recommendations from [Heijungs, 2014] are applied to ensure an understandable encoding. Among the ten advisers, one is especially used for the written channel: simple language with the correct technical terms. Then fewer misunderstandings appear, and the right terms ensure uniformity between this study and other researches [Heijungs, 2014].

In the LinkedIn post and article, an invitation to a webinar is also attached. If the written description is not enough for the receiver, or the person is more interested in the subject, an oral communication channel is also applied. This will eliminate misunderstandings and increase the possibility of feedback to the sender. It is assumed that it is easier for the receiver to orally ask questions or comment on the study than write an email or text. This is further recommended by Jensen, 2022. To avoid noise during the webinar, [Heijungs, 2014] stresses that besides the correct use of terms, graphs, figures, and tables must be simple and clear with descriptive captions. Lastly, it is relevant to have a dialogue with the participants, thus everybody understands the LCA, but also to have an insight into stakeholders' position on protein production both for food and feed.