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Life cycle assessment of fish feed produced from the black soldier fly (*Hermetia illucens*)

Ida Hexeberg Rustad

Master in Industrial Ecology
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Supervisor: Richard Wood, EPT
Co-supervisor: Kjartan Steen-Olsen, EPT

Norwegian University of Science and Technology
Department of Energy and Process Engineering

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MASTER THESIS

for

Student
Ida Hexeberg Rustad

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Life Cycle Assessment of fish feed produced from the black soldier fly (*Hermetia illucens*)

Livsløpsanalyse av fiskefôr produsert fra Hermetia illucens

Background and objective

The latest forecasts by the United Nations' statistics division puts the global population at almost ten billion by mid-century. This calls for significant growth in food production; at the same time, the current food production system is associated with grave environmental concerns in areas such as land use pressure, eutrophication, and climate change. Aquaculture is a growing sector with the potential to make significant contributions to the challenge of feeding a world of ten billion, but its current use of soy and wild fish as feed might not be sustainable. Insectivorous fish, like salmon, could be fed a diet of insects reared on organic waste. This system carries the potential of dramatically improving overall resource efficiency by partially closing the loop in the food supply system; however, to avoid problem shifting, a thorough assessment of the full supply-chain effects is needed.

The student is to evaluate the environmental sustainability of such a system compared to the most relevant alternatives. This will involve the creation of a comprehensive model of the full production chain for a system supplying aquaculture with black soldier fly-based feed. The model should include all production steps as well as all relevant auxiliary processes involved, such that the system is comparable to the main competing systems currently in use, to allow a fair comparison of environmental performances.

The following tasks are to be considered:

1. Perform a literature review on life cycle assessment (LCA) of various fish feed.
2. Perform a life cycle assessment (LCA) on the rearing and production of fish feed from the black soldier fly (*Hermetia illucens*). (Define goal and scope; system boundary; collect datasets in collaboration with industry on key process; perform impact assessment and re-interpret).
3. Compare the result from task 2 with the most common types of fish feed for salmon aquaculture to evaluate the overall sustainability of insect-based feed for aquaculture.

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 13. January 2016

Olav Boll

Olav Bolland
Department Head

Richard Wood
Academic Supervisor

Research Advisor: Kjartan Steen-Olsen

Abstract

The use of insects as feed is an emerging industry. Despite all the information on insects as a sustainable alternative, very few studies have been done on the environmental performance of insects compared to other feed ingredients. This study uses data from the insect rearing company HiProMine to perform a life cycle assessment of insect meal made of black soldier fly larvae (*Hermetia illucens*) which was fed pre-consumer food waste of plant origin. Fish meal is an important ingredient in salmon feed, and insect meal is a possible replacement for a growing aquaculture sector in the need of more feed. Therefore, the environmental impacts from those two feed ingredients have been compared. The global warming potential from insect meal is approximately 170 kg CO_2 eq per tonne, or 500 kg CO_2 eq per tonne when indirect impacts are included. Fish meal, on the other hand, has an impact of around 1400 kg CO_2 eq. Other impact categories show similar favourable results for insect meal. A reason why the insect results are so low, might be that not enough data is included, but it seems likely that insect meal is a better alternative than fish meal.

Sammendrag

Bruken av insekter som fôr tilhører en industri under utvikling. Til tross for all informasjon om at insekter er et bærekraftig alternative, så er det utført svært få studier om miljøkonsekvensene fra insekter sammenlignet med andre fôringredienser. Denne studien bruker data fra insektoppdrettsfirmaet HiProMine til å utføre en livsløpsvurdering av insektmel laget av larver av fluearten *Hermetia illucens* som var fôret med vegetabilsk matavfall som ikke hadde nådd forbrukerstadiet. Fiskemel er en viktig ingrediens i laksefôr, og insektmel er en mulig erstatning til en voksende akvakultur-sektor med behov for mer fôr. Miljøkonsekvensene fra disse to fôringrediensene har derfor blitt sammenlignet. Produksjonen av insektmel står for utslipp av 170 kg CO_2 eq per tonn, eller 500 kg CO_2 eq per tonnår indirekte konsekvenser er inkludert. Fiskemel, derimot, bidrar med utslipp av 1400 kg CO_2 eq per tonn. For andre miljøproblemer er det tilsvarende gode resultater for insektmel. En grunn til at insektmelresultatene er så lave, kan være at ikke nok data er inkludert, men det virker sannsynlig at insektmel er et bedre alternativ enn fiskemel.

Preface

This report is written as a final product in the course "TEP4930 Industrial Ecology, Master’s Thesis" in my last semester at the 2-year master program Industrial Ecology at The Norwegian University of Science and Technology (NTNU).

I would like to thank my supervisors, Richard Wood and Kjartan Steen-Olsen. It has been great to be provided with answers to my long lists of questions without getting the feeling that my questions were stupid or I was using too much of your valuable time. I have appreciated our discussions on choices in methods.

Damian Józefiak from the insect rearing company HiProMine in Poland has provided me with data for the analysis. Thanks for the insight to the process of farming black soldier fly larva.

I would also like to thank other researchers I have been in touch with, particularly Erik-Jan Lock, Sergiy Smetana, Dennis Oonincx and Nathan Pelletier.

I am grateful for the technical assistance and motivation I have been given by my husband, Anders Rustad. My mother-in-law, Turid Rustad, have been very kind to read and give me feedback on my thesis report. Anders’ father and brother, Helge and Bjørn Rustad, were very helpful with a math problem I had. Anders’ uncle, Kjell Maroni, has provided me with insight to the aquaculture industry. I am grateful to have such a supporting family here in Trondheim.

Knut Botngård, founder of Botngaard Bioprotix AS, was kind to include me in a one day seminar on their plans of rearing black soldier fly in Norway. It was helpful for my motivation and I gained new and useful knowledge.

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Abbreviations

AP – acidification potential

BRU – biotic resource use

BSF – black soldier fly (*Hermetia illucens*)

CED – cumulative energy demand

EP – eutrophication potential

eq - equivalents

EU – energy use

FCR – feed conversion ratio

GWP – global warming potential

HPB – high pressure biogas

LCA – life cycle assessment

LCI – life cycle inventory

LCIA – life cycle impact assessment

LPB – low pressure biogas

LU – land use

1 Introduction

The world’s population is assumed to be 9.7 billion by 2050 (UN, 2015). This calls for a substantial increase in food supply (Baulcombe *et al.*, 2009). One of the solutions is to avoid and utilize food waste.

According to Gustavsson *et al.* (2011) the loss and waste of edible parts of food produced for human consumption amounts to 1.3 billion ton per year, and it is not likely that we will have a zero food waste situation in the near future (Parfitt *et al.*, 2010). Instead of using the waste for production of compost or biogas, it can be upcycled as feed for farmed animals.

Food waste can be fed directly to animals we eat, like swine, or it can be given to animals like insects which could again be fed to e.g. salmon. At a first glance it seems like the most efficient solution is the one with the lowest numbers of trophic levels. However, both insects and salmon are cold-blooded animals with lower feed conversion ratios[1] (FCR) compared to warm-blooded farmed animals, like swine. In fact, the FCRs are so low that it is more resource efficient to feed food waste to larvae which is again fed to salmon, than giving the food waste directly to swine. You would get more salmon than pork from the same amount of food waste, even though there is an additional trophic level using larvae (Lock, 2016).

Another way to look at the issue of feeding the world, could be looking to the ocean for food supply. Most of the wild fish resources are either fully or overexploited (Frid and Paramor, 2012), so the growth in the fish industry must happen in aquaculture. Most farmed fish, at least in Europe, are fed a diet partly consisting of fish meal made from marine-captured fish (Boissy *et al.*, 2011).

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[1] Feed conversion ratio is the amount (mass) of feed needed per unit of edible animal mass produced.

Feeding fish with fish could be regarded as a waste of resources, limiting the availability of food for the poor. However, it is unrealistic to sell the feedfish to the poor, because the feedfish is typically landed in regions where the market is already satisfied, and processing and shipping the fish would make the product too expensive for the poor (Wijkström, 2009).

It is estimated that 17 million tonne of fresh fish was used for the production of fish meal and fish oil in 2010, of which 73% was used for fish farming (Béné *et al.*, 2015). Considering that the fish meal yield is 21.2% of the fresh fish weight (FAO, 1986), something like 2.6 million tonne of fish meal was used in aquaculture that year.

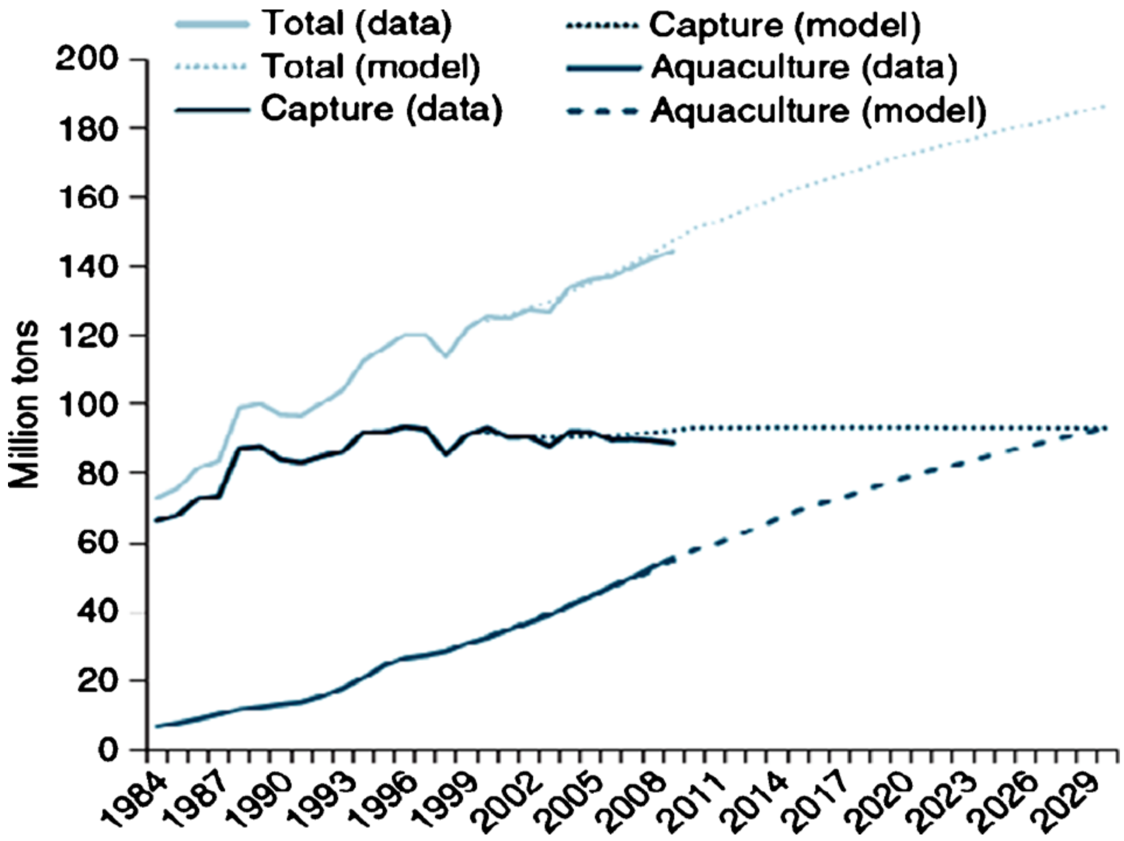

Figure 1.1. Annual yields from capture fisheries and aquaculture. From Béné *et al.* (2015).

Béné *et al.* (2015) states that most of the recent analyses agree that the era for exponential growth is over for the aquaculture industry. They assume that the growth will slow down due to freshwater scarcity, lower availability of locations for optimal production and high costs of fish meal, fish oil and other feeds. The yields from aquaculture is expected to increase by approximately 70% from 2010 to 2030 (Figure 1.1), a growth which should be achieved with only an 8% increase in global fish meal supply for the same period. This will be possible because the percentage of fish meal in feeds will decrease as a result of replacements like plant proteins and waste products from fish and terrestrial animals. Taking these numbers into consideration, the need for fish meal replacements should be about 2 million tonne more in 2030 than in 2010, although it might be a bit lower since the future breeds of aquaculture species will be more feed efficient. Béné *et al.* (2015) do not mention insects as a future feed ingredient, but there is a market for fish meal replacements, and insect meal has such properties.

For salmon farming, vegetable protein sources can replace a substantial part of the fish meal. However, these products have limitations due to unbalanced amino acid profiles, high fibre content, anti-nutritional factors and competition with use for human consumption (Sørensen et al. 2011). Insect meal, on the other hand, is an animal protein source with great nutritional qualities (Sørensen *et al.*, 2011). Insect meal from black soldier fly larvae in salmon feed does not change the odour, taste or texture of salmon filet, for up to 100% replacement of fish meal (Lock *et al.*, 2015).

It might seem like an unnecessary step to feed the insects to fish when we could have eaten them ourselves, but a lot of people think of insect eating with disgust, at least in the Western world. On the other hand, over 70% of consumers would eat fish, chicken or pork knowing that the animals where fed a diet containing insect protein (Smith and Barnes, 2015). A similar result was found in a study by

Verbeke *et al.* (2015), who also showed the clear difference in acceptance of the use of insects as animal feed (68%) as opposed to eating insects directly (27%).

The use of waste-fed insects is regarded as an environmentally friendly alternative to regular feed ingredients given to farmed animals (Huis *et al.*, 2013). However, even with low emissions at the production site, the insect alternative could be the worst option when looking at the entire production chain.

1.1 Insect LCAs

A good method for evaluating the overall environmental performance of a product is the technique called life cycle assessment (LCA), which is described in section 2.1 Life cycle assessment.

An LCA on mealworms (Oonincx and De Boer, 2012) shows that production of 1 kg protein from mealworms results in less greenhouse gas emissions and lower land use than protein from milk, chicken, pork and beef. A paper by van Zanten *et al.* (2015) describes an LCA on housefly larvae fed with manure and post-consumer food waste. They concluded that this insect meal production requires less land area than the production of fish meal and soybean meal, but requires more energy. However, the indirect effects of removing the waste from biogas production, are quite substantial.

It has been stated that there is a need for more LCAs on edible insects (EFSA Scientific Committee, 2015; Yen, 2014). The lack of insect LCAs is emphasized by van Zanten *et al.* (2015) who writes "*To our knowledge, however, no study has been published that quantified the reduction of the environmental impact of including waste-fed insects in livestock feed. Only one peer-reviewed study analyzed the environmental impact of insects, in this case mealworms*."

To the best of my knowledge, there has not been performed other than these two LCAs on insects as food or feed. Nevertheless, there has been performed an LCA on manure treatment with house fly larvae (Roffeis *et al.*, 2015). They used the functional unit *reduction of 1 kg manure dry matter*.

Manure fed insects will most likely not be used as feed in Europe in the near future (Botngård, 2016; EU-regulation 767/2009), whereas pre-consumer plant based material is regarded as a safe substrate to farm insects on (EFSA Scientific Committee, 2015). It would be valuable to know the environmental impacts from the sort of production system that would most likely be a reality in Europe when insects are allowed to be used as feed (See section 4.5 regarding regulations for insects as feed).

This study evaluates an insect farming system which is accepted by European regulations. The black soldier fly is used in the production, and it is regarded as one of the most promising insect species for industrial feed production (Huis *et al.*, 2013). The environmental performance of such a system has previously not been evaluated.

1.2 Research questions

This thesis looks at the following three tasks.

1. Perform a literature review on life cycle assessment (LCA) of various fish feed.
2. Perform a life cycle assessment (LCA) on the rearing and production of fish feed from the black soldier fly (*Hermetia illucens*). (Define goal and scope; system boundary; collect datasets in collaboration with industry on key process; perform impact assessment and re-interpret).

3. Compare the result from task 2 with the most common types of fish feed for salmon aquaculture to evaluate the overall sustainability of insect-based feed for aquaculture.

The literature review on fish feed is included in the end of Materials and methods as well as in the beginning of Results.

2 Materials and methods

2.1 Life cycle assessment

Life cycle assessment (LCA) is a method for evaluating the environmental impacts associated with a product, by gathering data for the inputs and outputs of a production system, from raw material extraction to final disposal, and then assessing the consequences of the total calculated emissions/stressors from the system (ISO, 1997). The following description of LCA as a method is based on the course TEP4223 Life Cycle Assessment at NTNU, if not otherwise specified.

The first part of an LCA is the goal and scope definition. As a part of this, a production system is defined. The system is built up by different processes, which are often named after the product coming out of the process. The system explains which processes that are inputs to each process (Figure 2.1).

The results need to be given in some meaningful unit, and this is why a so called functional unit must be chosen prior to an LCA study (ISO, 1997). My goal was to compare the insect meal results with the impacts from fish meal, as studied by Pelletier et al. (2009) and Boissy et al. (2011). They have both used the functional unit of 1 tonne fish meal. For this reason I have chosen the functional unit of 1 tonne insect meal, since this can replace a tonne of fish meal. My results are displayed as impact per tonne of insect meal.

For many production systems there are multiple products, in this case both insect meal and fertilizer. In such cases it must be decided how much of the impacts that should be allocated to the different products. The allocation method used in this analysis is called partitioning, which involves splitting the impacts based on a property like market value, mass or energy (Cherubini et al., 2011).

In addition to goal and scope definition and interpretation, there are two main parts of an LCA, namely life cycle inventory (LCI) and life cycle impact assessment (LCIA).

The LCI study analyses inputs and outputs, ending up with results that show the amounts of different stressors. These stressors can be emissions of a gas or liquid, but also things like the use of energy, land area or a fossil resource. For many of the emissions it is specified whether they are emitted to air, water or soil and whether it is high or low population density in the area. The number of stressors can be very high, close to 26000 stressors in my study.

In order to analyse the results, these stressors are grouped according to whether they have the potential to increase an environmental problem, like global warming or eutrophication. This part is the LCIA. Many of the units are "equivalents of some stressor", like kg of CO_2-equivalents (hereafter kg CO_2 eq), for which the impacts from other emissions are included, only they are given in units of how much CO_2 that is needed to induce the same impacts.

This analysis was performed using the software Arda Calculator (version 1.8.2), which is produced and used by the Programme of Industrial Ecology at the Norwegian University of Science and Technology. Arda was used with the background database ecoinvent (version 2.2) (Frischknecht *et al.*, 2005) and the impact assessment method ReCiPe (version 1.08) (Goedkoop *et al.*, 2013). A hierarchical view was chosen for the impact assessment, meaning that long-term impacts were taken into consideration.

2.2 Black soldier fly

This study evaluates the production of insect meal from larvae of the black soldier fly (BSF) (*Hermetia illucens*). BSF larvae are rich in proteins and fats, which make them ideal for animal feed. It is a tropical species, preferring a temperature around 26-28°C, having a life cycle of 18 to 24 days from egg and to the resulting fly lays new eggs (Józefiak, 2016).

2.3 Data

Data for the production system were provided by the Polish company HiProMine. At the time, they did not produce insect meal for the feed industry, so the data is based on their experiments on finding the most efficient production system. In addition, some assumptions have been made regarding building, transportation and processing.

No direct (foreground) stressors from the system have been considered. Methane emissions would be the most natural stressor to include since we are dealing with decaying organic matter, but van Zanten *et al.* (2015) found that they could look away from this due to the high feed turnover.

The production process is visualized in Figure 2.1 showing the inputs considered in the evaluated system. The different processes (in the boxes) are described more in detail in the following sections of this chapter.

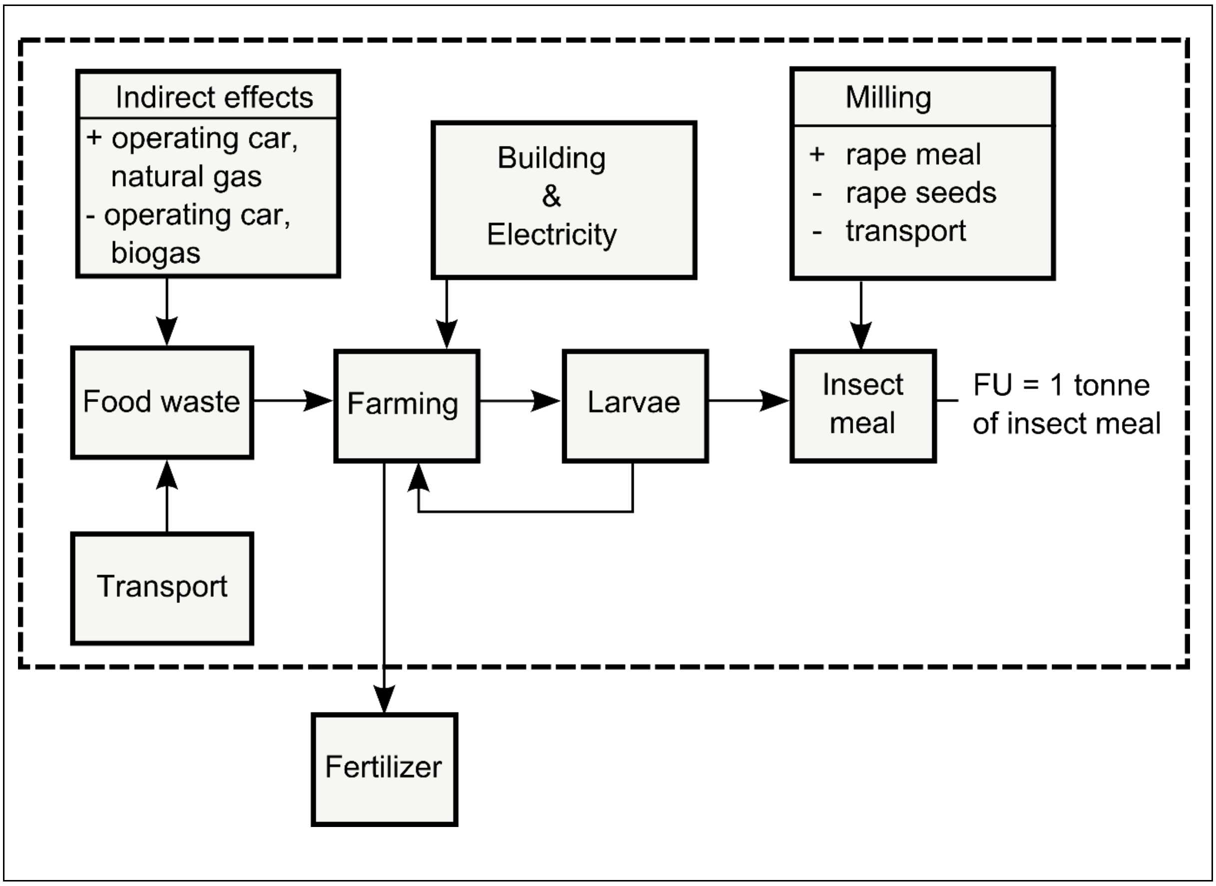

Figure 2.1. Production system. The dashed line is the system border.

2.4 Food waste as larvae feed

The BSF larvae are fed a diet of pre-consumer food waste of plant origin which HiProMine does not pay for. Inspired by van Zanten *et al.* (2015) I chose to consider indirect effects from using the food waste as larva feed. An alternative use of the food waste is using it for production of compost or biogas. Since ecoinvent contains in-depth information on biogas production, this alternative was chosen. Biogas can be used both for fuel and electricity production. They should both be easy choices, but I chose the fuel option since this seems like the most likely use of biogas in Norway, a nation of hydropower. Thus, although the insect meal data are not from Norway, the methodology would be useful if future research on Norwegian insect meal production is carried out.

In reality I am considering fish meal and biogas as comparable to insect meal and natural gas. Nevertheless, since I wanted a result for insect meal, I chose to subtract impacts from biogas, making it possible to compare with fish meal without additional products (Figure 2.2). However, I have in addition calculated the results for the sum of insect meal and natural gas and the sum of fish meal and biogas because it might be easier to interpret the results that way, since there were then no negative numbers.

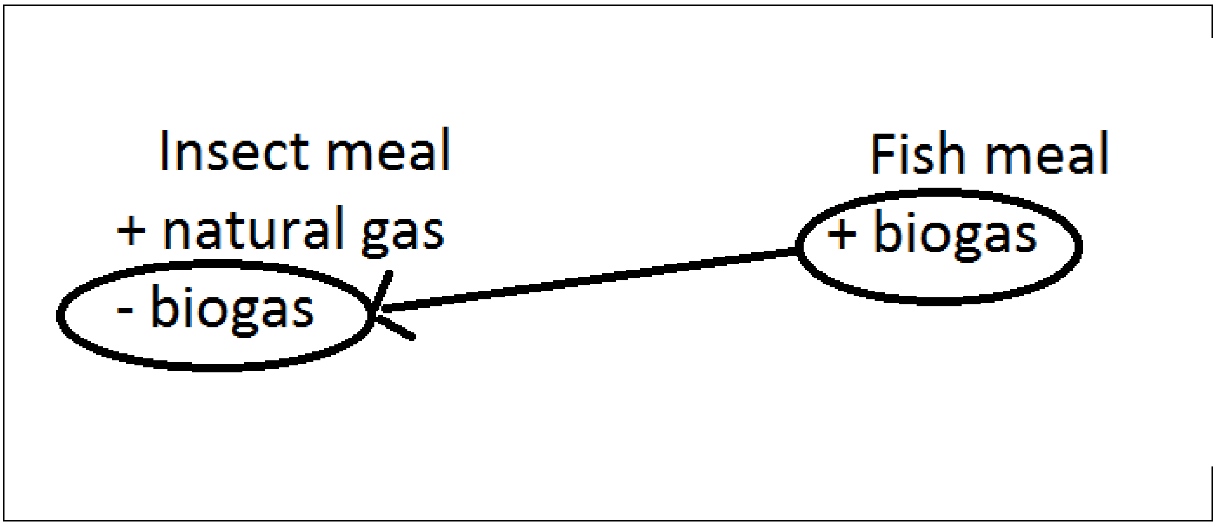

Figure 2.2. Visualization of methodology for indirect effects. Inclusion of fuels as indirect effects to using food waste as larvae feed.

Vehicles that run on natural gas can use methane from biogas as an alternative fuel. For this reason, I have chosen to use the two alternative processes operating a passenger car on methane from biogas (hereafter called “biogas”) and operating a passenger car on natural gas (hereafter called “natural gas”). This makes it a realistic and fair comparison as it is not necessary to buy a new car in order to switch fuel.

For inclusion of the indirect effects, I found the number of kilometres one can drive using biogas produced from one tonne of food waste (biowaste), a number I used as input to the food waste process in my model. To calculate this number, I inspected the ecoinvent database. I found the biogas-relevant input to the operation of a car on methane, and worked my way back to the input of crude biogas (Table 2.1).

Table 2.1. Food waste calculations. In order to calculate the food waste needed to drive one kilometre, I used data from ecoinvent. This table should be read with the inclusion of “needs input of” at the end of each row. For the processes marked with a *, the number is not taken directly from ecoinvent, but is adapted according to information following this table.

		operation, passenger car, methane, 96 vol-%, from biogas
0.07	kg/km	methane, 96 vol-%, from biogas, production mix, at service station
45.84	MJ/kg	methane, 96 vol-%, from biogas, high pressure, at consumer *
0.03	Nm^3/MJ	methane, 96 vol-%, from biogas, at purification
1.5	Nm^3/Nm^3	biogas, production mix, at storage
1	Nm^3/Nm^3	biogas, from biowaste, at storage *
0.01	tonne/Nm^3	biowaste*

Methane as *production mix* at service station has mainly input of *methane, 96 vol-%, from biogas, high pressure, at consumer* (HPB), but also input of some *methane, 96 vol-%, from biogas, low pressure, at consumer* (LPB), which is again produced from the HPB. The number 45.84 includes both direct input of HPB as well as the HPB needed to produce the LPB which is an input to the *production mix*. The formula behind the number is 44.916 + 0.91665 × 1.0072, where 44.916 is the direct input of HPB, and the two other numbers are the input of LPB to the *production mix* and the input (MJ) of HPB to produce a MJ of LPB, respectively.

Ecoinvent uses a biogas mix made from 0.48 Nm^3 biogas from biowaste and 0.52 Nm^3 from sewage sludge, I have chosen to set this number to 1, meaning the biogas in my calculation is made entirely from biowaste. There are some issues associated with this, as explained in the discussion.

No information is given in the ecoinvent database on the input of biowaste to *biogas, from biowaste, at storage,* but an ecoinvent report (Jungbluth *et al.*, 2007) states that the output is 0.1 Nm^3 biogas per kg biowaste. I have adapted this number to fit the unit I needed, giving me 0.01 tonne/Nm^3.

To calculate the number of kilometres, I multiplied the numbers in Table 2.1. The result was then inverted to fit the wanted unit. This gave 744 km per tonne of food waste.

In the requirements for food waste I have listed the following background processes as input.
+744 km of operation, passenger car, natural gas
-744 km of operation, passenger car, methane, 96 vol-%, from biogas

The reason for subtracting "biogas" has to do with food waste not being able to fuel a car without going through a production chain with several requirements along the way. By adding "natural gas" and subtracting "biogas", I am removing impacts from processing of the biowaste, leaving only impacts from the additional consequences from using crude oil as an input compared to using biowaste for the production of fuel.

To avoid results with negative numbers, I have additionally compared the scenarios of insect meal and natural gas with the case of using fish meal and biogas.

2.5 Transport of food waste

The food waste is collected at grocery stores and food manufacturers. Assuming the collection points are evenly distributed in a circular shaped area, and that the insect farm is placed in the centre of the circle, the average distance from the collection points to the insect farm is then 2/3 of the full radius, as shown in the following calculation (Rustad and Rustad, 2016).

Considering the radius r as a variable in the range of 0 to R. The sum of distances from the centre to all possible points in the circle, can then be described as

$$\int_{0}^{R} r \times 2\pi r = \frac{2\pi}{3} R^3$$

Dividing this by all the points in the circle (the area) gives the average distance,

$$\frac{\frac{2\pi}{3} R^3}{\pi R^2} = \frac{2}{3}\, R$$

Considering a city the size of Bergen, Norway, with a radius of approximately 10 km (NAF, 2004), the average direct distance is 6.67 km. Since the roads are not straight lines, we could probably assume the original 10 km as a driving distance.

I have assumed that the containers and packaging for the food waste is 5% of the weight of the useful food waste, meaning there is a need to transport 1.05 tonnes of food waste related mass for each tonne of prepared food waste used as larvae feed. 10.5 tkm (tonne-kilometres) is then a required input to the process prepared food waste. I am using input of the ecoinvent process *transport, lorry 3.5-16t, fleet average/ RER/ tkm*.

2.6 Farming

The feed conversion ratio for HiProMine’s larvae was given as seven tonnes of wet feed to produce one tonne of fresh larvae. I did not have access to data on the amount of larvae needed for production of flies who can lay eggs. For the lack of information on this, I have assumed that 0.5% of the larval mass is used for further breeding.

The larvae are assumed reared in a building hall (*building, hall/ CH/ m*^{2}) as defined by ecoinvent. This ecoinvent process includes construction, maintenance and deconstruction, which means that using one m^2 should be using it for the entire building life time of 50 years.

HiProMine informed me about a production capacity of 300 kg/m^2 for a 42 days cycle. This gives a production of 2.6 tonne/m^2/year. During the 50 year lifetime, the yield of larvae is 130 tonne/m^2. Inverting this number, I find that the area of ecoinvent's building hall needed to rear one tonne of larvae is 0.00767 m^2.

2.7 End product allocation

Regarding the allocation methods used in the studies I will be comparing my results with, Pelletier *et al.* (2009) use gross chemical energy and Boissy *et al.* (2011) use economic allocation. I have chosen economic allocation since this is the most common method in LCAs of livestock production (van Zanten *et al.*, 2015).

The production system has two products, insect meal and fertilizer. According to HiProMine (Józefiak, 2016), insect meal is valued at 1500€ per tonne and their production is 650 kg per tonne fresh larvae. Additionally they produce 2.5 tonnes of fertilizer per tonne of fresh larvae, with a market value of 300€ per tonne.

$$Insect\ meal: \quad 0.65\ tonne \times 1500\ €/tonne = 925\ €$$

$$Fertilizer: \quad 2.5\ tonne \times 300\ €/tonne = 725\ €$$

$$Partitioning\ coeeficient\ for\ insect\ meal, \alpha_{meal}: \ \frac{925\ €}{925\ € + 725\ €} = 0.565$$

For the sake of this partitioning, I am considering that the value of insect meal equals the value of the larvae used for producing that insect meal. I have defined a process called farming with the output given as “unit of farming output”. This is a combination of insect meal and fertilizer, and I am using this rather imaginary unit to make it easier to understand what I am doing in each step. Using the partitioning coefficient, the process fresh larvae then needs an input of

$$\frac{0.565 \times 1\, unit\ of\ farming\ output}{1\, tonne\ fresh\ larvae} = 0.565$$

2.8 Milling

Insect meal and oil can be separated using a press or a centrifuge (Lock, 2016). The process for insect meal and oil production would hence be similar to the milling of meal and oil from soybeans, rapeseeds and palm kernels (Jungbluth *et al.*, 2007). These are processes for which ecoinvent already have data. In order to choose the most ideal process to use as a substitute for insect milling, I looked at the different production processes. For the palm oil process in ecoinvent, the input is palm fruit bunches, which need to be threshed and the waste must be taken care of. Since I wanted to replace the raw material input with BSF larvae, it was simpler to use a process with input as equal as possible. For this reason I chose to use the process of rapeseed milling. Rape oil and soybean oil is in ecoinvent produced by solvent extraction instead of using a press (Jungbluth *et al.*, 2007).

It has to be said that ecoinvent does not have an individual process called rapeseed milling, but they have the products/processes rape meal and rape oil. Both processes have the exact same inputs, but in different amounts. The ratio is mostly the same for all inputs when I calculate the input to rape meal production divided by the sum of inputs to rape meal and oil production, with 18% of the inputs allocated to rape meal and 82% to rape oil. This, however, is a result of economic allocation since rape oil is valued higher than rape meal (Jungbluth *et al.*, 2007). It should be easy to understand that there is not a pure physical connection here, since there is only a 0.4 kg input of rape seeds for the production of 1 kg output of rape meal.

Since there is no process for the milling in itself, I have used input of rape meal, but subtracted input of rape seeds as well as transportation used for transporting the rape seeds to the mill. The size of the rape meal input is calculated in order to make the input of rape seeds match the input of larvae, because the ratios between raw material input and other inputs, like energy use, is still a physical relationship unlike those based on economic partitioning.

As far as I can understand the information given from HiProMine, the production of insect meal (not defatted) is 0.65 tonne per tonne of fresh larvae. Inverting this we have an input of 1.538 tonnes of fresh larvae needed to produce one tonne of insect meal.

Given that 1 kg larvae equals 1 kg rape seeds,

$$\frac{1538\ kg\ larvae\ /\ tonne\ insect\ meal}{0.4\ kg\ rape\ seeds\ /\ kg\ rape\ meal} = 3871\ kg\ rape\ meal\ /\ tonne\ insect\ meal$$

The input of rape meal indirectly includes an input of rape seeds in the same amounts as the larvae input. To remove this, I have subtracted 1538 kg of rape seeds. Transport inputs to rape meal is subtracted in the size of original input in ecoinvent multiplied by 3871 kg rape meal per tonne insect meal (Table 2.2).

Table 2.2. Calculation of milling numbers used in the analysis. The values in the column to the right was used as negative input to the process of insect meal.

Process name in ecoinvent	**Calculation**	**Unnecessary input to rape meal**
transport, lorry 3.5-16t, fleet average/ RER/ tkm	0.04 × 3781	154
transport, lorry >16t, fleet average/ RER/ tkm	0.00015 × 3781	0.59
transport, freight, rail/ RER/ tkm	0.0009 × 3781	3.5

2.9 Energy consumption

The Norwegian regulation for energy use in buildings (Byggteknisk forskrift, (TEK10) § 14-2) states that a building used for light industry should not consume more than 140 kWh/m^2 per year. This number is used for the assumed energy consumption of the insect farm facility. Since the larvae production is 2.6 tonne/m^2 for each year, the inverse is 0.38356 m^2/tonne. The energy consumption is then 53.7 kWh/tonne fresh larvae produced. This number includes all sorts of energy consumption, like heating, cooling, ventilation, processing the food waste into tiny particles as well as milling of the larvae to meal. German electricity mix was used as a proxy for the European average mix.

2.10 Common fish feed ingredients

Salmon feed, like feed for most other animals in industrial production, consists of a variety of ingredients, like meal and oil from fish like anchovy, herring and menhaden as well as plants like soybean and rape seed (Sørensen *et al.*, 2011). The insect meal in my LCA would replace fish meal and not the entire salmon feed. I was therefore in need of studies showing LCA-results for the different feed ingredients.

I have not found any studies which focus only on salmon feed or fish meal in specific. However, there are several studies of LCA on salmon farming (Boissy *et al.*, 2011; Pelletier *et al.*, 2009; Samuel-Fitwi *et al.*, 2013). The latter is a so called consequential LCA, while the two other ones are attributional LCAs, similar to my study. I have chosen to focus on the studies performed by Pelletier's and Boissy's teams.

My data material from Pelletier *et al.* (2009) are some tables in the supporting information, pages S13, S15, S16 and S17. I used the original spreadsheets (Pelletier, 2016). The data are originally collected from Norwegian fish farmers. I found the impacts for fish feed ingredients by adding the impacts from the production and processing phase. Transportation to the feed mill was not taken into consideration since it is not included in the insect meal analysis. In addition, I calculated the average fish meal impacts, weighted by the inclusion of the various fish meals in salmon feed in Norway. The fish meals are anchoveta meal to sprat meal as seen in Table 3.2.

Boissy *et al.* (2011) do not have impact numbers for different ingredients or different phases (production, processing, transportation). However, they do have results for the composite feed as a whole and contributions from different feed ingredients given in percent. Since I wanted to know the impact per tonne of fish meal, I used information on inclusion of fish meal in the salmon feed. This information was given as fraction of fish meal in standard salmon feed of the given pellet size (table 1, Boissy) and fraction of pellet size used in different stages of salmon life (section 2.1, Boissy). Multiplying and summing up, I found that 26 % of the composite feed was fish meal. For each impact category I then used the following equation to calculate impacts from one tonne of fish meal. It seems like Boissy et al. have not considered transportation to feed mill, which would make these results comparable to those of Pelletier's team.

$$\frac{amount\ of\ given\ impact\ category_i \times percentage\ contribution\ from\ fish\ meal_i}{mass\ percentage\ of\ fish\ meal\ in\ composite\ feed}$$

3 Results

3.1 Common fish feed ingredients

For the different feed ingredients, the global warming potential varies a lot and is in the range of 300 to 3800 kg CO_2 eq (Table 3.2 and Table 3.3).

The weighted average for fish meal from Pelletier *et al.* (2009) is 1388 kg CO_2 eq per tonne and the cumulative energy use is 21598 MJ per tonne. My calculations on data from (Boissy *et al.*, 2011) shows a global warming potential of 1431 kg CO_2 eq a cumulative energy demand of 19198 MJ and a land occupation of 6 m^2 per tonne of fish meal (Table 3.1).

Table 3.1. Impact per tonne of fish meal, a weighted average for several fish meals.

Impact category	**Unit**	**Pelletier *et al.***	**Boissy *et al.***
Global warming	kg CO_2-equivalents	1388	1431
Acidification	kg SO_2-equivalents	11	7
Eutrophication	kg PO_4-equivalents	5	2
Energy use (CED)	MJ	21598	19198
Land occupation	m^2	-	6
Water use	m^3	-	7
Terrestrial ecotoxicity	kg 1,4-DB-equivalents	-	3

Table 3.2. Inclusion rates and impacts from different sorts of feed ingredients. GWP is global warming potential in kg CO_2 eq, AP is acidification potential in kg SO_2 eq, EP is eutrophication potential in kg PO_4 eq, CED is cumulative energy demand in MJ and BRU is biotic resource use in tonnes of carbon. All impacts are per tonne of feed ingredient. The inclusion rates are for Norwegian salmon farmers in 2007. Calculated from (Pelletier *et al.*, 2009).

Feed Ingredient	**Country of Origin**	**Inclusion rate**	**GWP**	**AP**	**EP**	**CED**	**BRU**
Fava Beans	UK	1.60 %	343	5	4	3770	528
Maize Gluten Meal	USA	0.20 %	970	16	3	12900	544
Pea Protein Concentrate	France	4.93 %	511	5	4	7790	389
Rape Seed Oil	France	6.22 %	1780	29	12	16600	798
Soy Meal	Brazil	7.96 %	320	4	1	4550	389
Soy Oil	Brazil	0.92 %	703	9	3	10100	826
Soy Protein Concentrate	Brazil	5.40 %	330	4	1	4780	389
Sunflower Meal	France	6.05 %	717	14	5	6900	366
Sunflower Oil	France	0.92 %	1640	33	11	15800	796
Wheat	France	5.15 %	540	9	3	4080	409
Wheat Gluten Meal	France	2.98 %	1470	12	3	29500	545
Wheat Gluten Meal	UK	1.35 %	1880	12	2	28200	545
Anchoveta Meal	Peru	6.07 %	938	6	4	15500	18300
Blue Whiting Meal	Norway	9.49 %	2070	17	7	30900	490580
Capelin Meal	Iceland	0.25 %	722	3	3	11940	44930
Herring Meal	Denmark	3.14 %	1280	11	4	18800	46430
Herring Meal	Norway	2.05 %	1160	9	4	17300	46430
Herring Meal	Iceland	1.05 %	1250	10	4	18500	46430
Herring By-product Meal	Norway	1.10 %	1760	14	6	27400	68870
Jack Mackerel Meal	Chile	0.71 %	968	5	4	15100	103010
Menhaden Meal	US Gulf	3.14 %	379	2	2	11500	3440
Sand Eel Meal	Norway	0.50 %	1130	7	5	17700	81120
Sprat Meal	Denmark	3.14 %	1580	13	5	23200	33100
Sprat Meal	Norway	0.70 %	1330	10	5	20000	33100
Blue Whiting Oil	Norway	3.97 %	3790	31	13	57000	897630
Capelin Oil	Iceland	0.07 %	1370	5	7	22700	85380
Herring Oil	Denmark	2.76 %	2400	20	8	35300	81710
Herring Oil	Iceland	2.35 %	2340	20	8	34600	81710
Herring Oil	Norway	1.15 %	2170	18	8	32500	81710
Herring By-product Oil	Norway	0.57 %	3260	26	11	50800	127370
Sand Eel Oil	Norway	0.28 %	2110	13	9	33000	151810
Sprat Oil	Denmark	4.25 %	2960	24	10	43500	61880
Menhaden Oil	US Gulf	2.76 %	727	4	4	11500	6590
Anchoveta Oil	Peru	4.96 %	1850	11	8	29200	34530
Herring By-products	Norway	1.85 %	312	4	1	4530	18870

Table 3.3. Impacts from fish feed ingredients based on the study by Boissy et al. (2011).

	Acidification kg SO_2	**Eutrophication** kg PO_4	**Climate change** kg CO_2	**Terrestrial ecotoxicity** kg 1,4DB	**NPPU** kg C	**Water use** m^3	**Land occupation** m^2	**CED** MJ
Wheat	6	4	801	2	353	5	1455	7968
Wheat gluten	13	11	2541	15	939	30	3344	42711
Fish meal	7	2	1431	3	183146	7	6	19198
Soybean meal	7	6	844	4	370	9	1697	12156
Soya concentrate	7	7	1104	5	624	11	2211	11206
Fish oil	8	2	1866	4	311645	9	6	25883

3.2 Insect meal

The expectations I had to my own result, was that I would have something similar to the findings of van Zanten *et al.* (2015). They found that producing larvae meal from house fly larvae resulted in a global warming potential (GWP) of 770 kg CO_2 eq, energy use (EU) of 9329 MJ and land use (LU) of 32 m^2 per tonne dry matter larvae meal. These numbers increased substantially when including indirect effects from removing the insect feed from the original use in biogas production. In this case, 1 tonne larvae meal (dry matter) resulted in a GWP of 3132 kg CO_2 eq, an EU of 36 513 MJ and an LU of 66 m^2.

As for the results of my own analysis (Table 3.4), I found much lower impact from a tonne of insect meal (not dry matter). With no indirect effects included, the GWP is only 169 kg CO_2 eq, while with indirect effects it rises to 497 kg CO_2 eq which is still lower than van Zanten's results.

Including indirect effects does give higher impacts from categories like climate change and fossil depletion. However, in 19 of the 25 categories, the impacts are lower for insect meal with indirect effects. Some numbers are in fact negative due to the fact that biogas is subtracted. These negative numbers should be interpreted as positive for the environment. It might not be surprising that biogenic carbon dioxide turns up as a negative number. I was more surprised by the very negative result for water depletion, which turns out to be a consequence of the use of electricity from hydropower in the biogas/methane production chain. Since these impacts are subtracted, we end up with less than no impacts in the category of water depletion.

Table 3.4. Impacts from 1 tonne of insect meal. “No indirect” means that no indirect effects from feed (food waste) are considered. “With indirect” includes indirect effects (natural gas minus biogas). Note that the latter has some negative numbers which means that it is positive for the environment.

Full name of impact category	**No indirect**	**With indirect**	**Unit**
Agricultural land occupation	2	-3	m^{2}a
Climate change	169	497	kg CO_2 eq
Fossil depletion	57	356	kg oil eq
Freshwater ecotoxicity	1	-1.8	kg 1,4-DB eq
Freshwater eutrophication	0.08	0.01	kg P eq
Human toxicity	62	-28	kg 1,4-DB eq
Ionising radiation	46	-173	kg U235 eq
Marine ecotoxicity	1	-1	kg 1,4-DB eq
Marine eutrophication	0.03	-0.001	kg N eq
Metal depletion	5	-21	kg Fe eq
Natural land transformation	0.05	0.2	m^2
Ozone depletion	0.00	0.0002	kg CFC-11 eq
Particulate matter formation	0.1	0.009	kg PM10 eq
Photochemical oxidant formation	2	1.8	kg NMVOC
Terrestrial acidification	0.4	-0.2	kg SO_2 eq
Terrestrial ecotoxicity	0.01	0.01	kg 1,4-DB eq
Urban land occupation	1	-0.7	m^{2}a
Water depletion	421	-2132	m^3
Biogenic Carbon Dioxide	3	-1601	kg CO2
Fossil and LUC Carbon Dioxide	5805	4859	kg CO2
Nitrous Oxide	0.004	-0.09	kg N_2O
Nitrogen Oxides	0.3	0.3	kg NO_x
Particulate Matter	0.09	-0.01	kg PM
Sulphur Dioxide	0.2	0.1	kg SO_2
Carbon Monoxide	0.1	0.08	kg CO

Table 3.5. Global warming potential results from three different datasets.

Dataset	**kg CO_2 eq**
Direct effects with no burden to feed other than transportation to facility	169
Including natural gas as alternative fuel	497
Including natural gas, but no negative biogas	1126

The negative numbers do not appear when I only include natural gas, but do not subtract biogas. However, the results for global warming increases substantially (Table 3.5).

3.3 Comparing results

Comparing insect meal and natural gas with the case of using fish meal and biogas shows that insect meal and natural gas is the best alternative. Only 1126 kg CO_2 eq are emitted for the case of one tonne of insect meal and “natural gas” as described in Materials and methods. The comparable combination of fish meal and biogas leads to 2038 kg CO_2 eq, more than four times higher. Similar results are found in the categories eutrophication, acidification and terrestrial ecotoxicity, while for water depletion the results are more or less equal (Table 3.6).

Table 3.6. Insect meal and natural gas versus fish meal and biogas. Insect meal and natural gas outperformed fish meal and biogas in all the categories assessed.

		Insect meal & natural gas	**Fish meal & biogas**
Climate change	kg CO_2 eq	1.1×10^{3}	2.0×10^{3}
Eutrophication	kg PO4 eq	9.4×10^{-2}	3.5×10^{0}
Acidification	kg SO2 eq	1.5×10^{0}	1.1×10^{1}
Terrestrial ecotoxicity	kg 1,4-DB eq	9.8×10^{-2}	2.9×10^{0}
Water depletion	m^3	9.8×10^{2}	3.1×10^{3}

4 Discussion

In addition to data uncertainties, there are issues regarding the choices I made. The results have been affected by the assumptions done for the food waste calculations, the choice of functional unit and the choice of impact assessment method. Despite poor data quality and high uncertainties in the results, the methodological basis of the analysis should be useful to anyone building on this work in the future.

4.1 Food waste

In my calculation of how many kilometres a car can run on biogas produced from one tonne of biowaste, I assumed that all biogas was produced from biowaste, despite that ecoinvent uses a combination of sewage sludge and biowaste. This involves certain issues, like the fact that biogas from waste and sewage sludge could have different properties which affect the inputs needed down the production line. For instance, the bioenergy ecoinvent report (Jungbluth *et al.*, 2007) states that biowaste gas is 67% methane while sewage gas is 63% methane. I assume they probably differ in input to the purification process for producing the 96% methane needed for driving. Nevertheless, I chose to disregard this issue and assume equal properties for biowaste gas and sewage gas.

Even if the calculation of km per tonne of biowaste is correct, there is still the issue of sewage sludge input to the production line of *operation of biogas car*, which I use as an input in my model. When I calculated these indirect insect meal impacts, upstream impacts from sewage gas production was part of this calculation. I have compared impacts from the two processes *biogas, from biowaste, at storage* and *biogas, from sewage sludge, at storage*. They differ, but I'm not sure how much it affected the final insect meal results.

I checked the impact from natural gas (744 km) minus biogas (744 km), and as expected, it gives a positive (though negative for the environment) impact in categories like fossil depletion and global warming. In many other categories I have negative numbers. This means that when adding the impact from an alternative fuel, the impact from producing insect meal will be reduced in some categories. In my opinion, this makes it somewhat harder to interpret the results, and I would advocate not to include these processes in the calculation of indirect effects, but rather compare fish meal and biogas to insect meal and natural gas.

4.2 Functional unit

In the functional unit of 1 tonne of insect meal the content of moisture, proteins or fats was not specified. For a fair comparison between fish meal and insect meal, these parameters should be equal. The study by van Zanten *et al.* (2015) used the functional unit of 1 tonne larvae meal on dry matter basis. Hence, the water content was set to zero, but the nutritional value was not specified.

The sources for LCA-results on fish meal did not list the contents of each of the many fish meals they analysed. Even if they did, I have considered an average of the fish meals, meaning it would be time consuming to find the correct average nutrient content. If the details on the fish meal were available, the values for insect meal would most likely not be the same. It is easy to get equal value for one of the parameters since I could have had the functional unit of 1 tonne dry matter insect/fish meal, 1 tonne protein from insect/fish meal or 1 tonne fat from insect/fish meal. The inclusion of all these three properties, would be challenging, if not impossible. For future studies, it might be an idea to compare the compound feed needed to produce 1 kg salmon (Details in 4.4 Further research).

4.3 Impact assessment methods

This analysis is performed using ReCiPe, while the studies used for comparison with fish meal had CML as their impact assessment method. There are differences in these methods, for instance in impact categories and most likely also in the way the impacts are calculated. For future research it would be preferable to use CML if not fish meal results based on ReCiPe are found.

4.4 Further research

For future life cycle assessments of insects as salmon feed, a suggestion would be to use a functional unit like “compound feed needed to produce 1 kg salmon” (Details in 4.2 Functional unit). This should provide a fair comparison, given that the taste and nutrient level of the salmon is not affected by the presence of insects in the feed. However, this approach can end up as time consuming if there does not exist LCA-results on all the other compound feed ingredients.

The production of fish meal has impacts on life in the ocean, but life cycle impact assessment is not well developed for the marine ecosystem (Woods *et al.*, 2016). In addition, comparing land use results for insect meal and fish meal does not make that much sense because fish harvesting is occurring in the ocean. Therefore, it would be ideal to do a new analysis when a life cycle impact assessment method exists which fully include marine ecosystems. It would then be necessary to analyse both insect meal and fish meal using the new impact assessment method.

A Norwegian start-up called Botngaard Bioprotix AS plans on producing large amounts of BSF larvae to the salmon feed market (Botngård, 2016). They intend to feed the larvae with sea weed, pre-consumer food waste and other resources with a reasonable price. When the legislation opens up for it, they wish to sell the larvae unprocessed to the feed producers. This is different from the system analysed here, and it is a possibility for future research. To get in touch with other Nordic actors in the field of insects as feed, contact the recently developed Network on Insects in the Circular Economy (Forskningsrådet, 2016). The network is led by Erik-Jan Lock at the National Institute of Nutrition and Seafood Research (NIFES) (Lock, 2016).

4.5 The future of insect meal as a feed ingredient

The Norwegian research institute Nofima (Sørensen *et al.*, 2011) considers insect meal as a promising feed ingredient with favourable nutrient content. At the moment, however, insect meal production is expensive. The production of mealworms was in 2011 analysed to be 4.8 times more expensive than for normal chicken feed, particularly due to high costs for labour and housing (Huis *et al.*, 2013). With increasing farming efficiency in the future, the production costs can fall.

In the European Union, there is also the issue of the legislation not being adapted to insects as food or feed. Technically, processed animal proteins (PAPs) from insects can be given to aquaculture species, but only if processed in a registered slaughterhouse, which is not possible for insects (EU-regulation 56/2013; EU-regulation 999/2001). Under the current legislation, insects can only be used as feed in aquaculture after being hydrolysed (EU-regulation 999/2001).

5 Conclusion

The aquaculture sector is looking for fish meal replacements, and insect meal is one of the possible options. This study has compared the environmental impacts from fish meal production with impacts from production of insect meal.

The global warming potential from insect meal production is only 169 kg CO_2 eq per tonne or 497 kg CO_2 eq when indirect effects are included. This is far lower than for fish meal, which on average has a GWP of about 1400 kg CO_2 eq. My results are also lower than for a similar study with 770 kg CO_2 eq per tonne insect meal. There are similar low results for insect meal in all impact categories assessed.

It is not considered as an option to reduce the amount of fish meal used in the aquaculture industry today. However, the percentage of fish meal content in the feed could be reduced using insect meal as a replacement. This could result in a better environmental performance of a kg of salmon.

Although the data used for this analysis was of rather poor quality, it seems very likely that insect meal has lower environmental impacts than fish meal, but in reality probably not as low as the results of this analysis.

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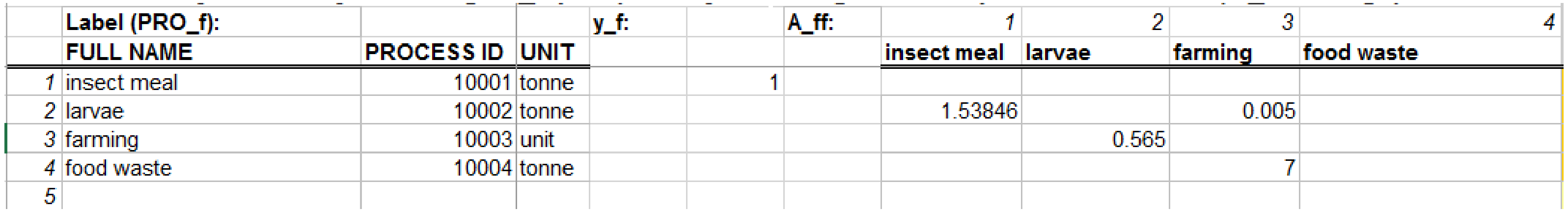
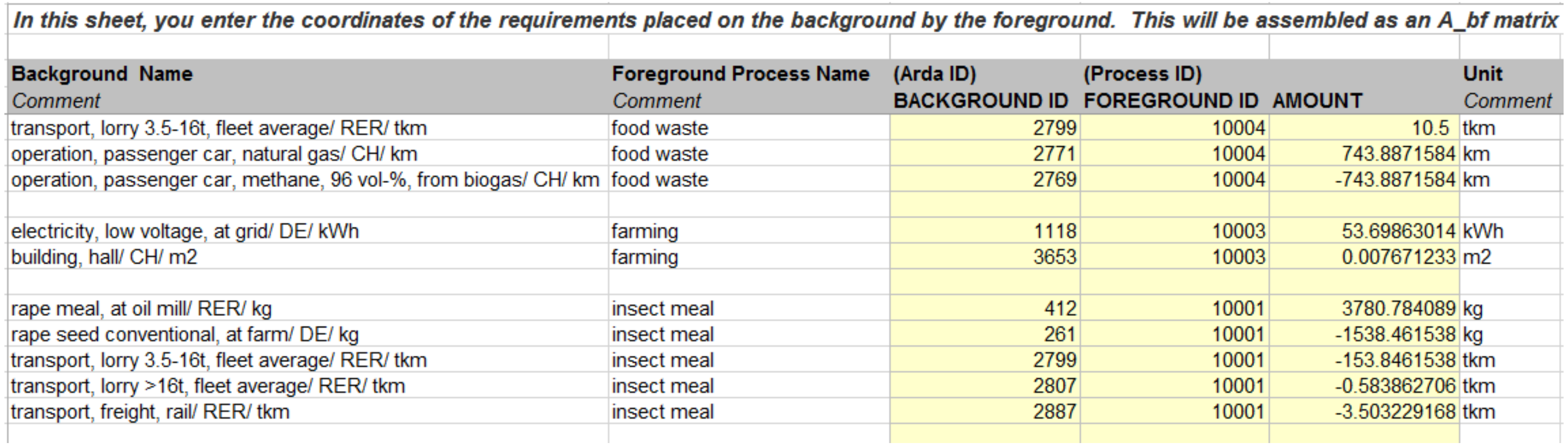
APPENDIX



	Label (PRO_f): FULL NAME	PROCESS ID	UNIT	y_f:		A_ff:	1 insect meal	2 larvae	3 farming	4 food waste
1	insect meal	10001	tonne		1					
2	larvae	10002	tonne				1.53846		0.005	
3	farming	10003	unit					0.565		
4	food waste	10004	tonne						7	
5										



In this sheet, you enter the coordinates of the requirements placed on the background by the foreground. This will be assembled as an A_bf matrix

Background Name *Comment*	**Foreground Process Name** *Comment*	**(Arda ID)** **BACKGROUND ID**	**(Process ID)** **FOREGROUND ID**	**AMOUNT**	**Unit** *Comment*
transport, lorry 3.5-16t, fleet average/ RER/ tkm	food waste	2799	10004	10.5	tkm
operation, passenger car, natural gas/ CH/ km	food waste	2771	10004	743.8871584	km
operation, passenger car, methane, 96 vol-%, from biogas/ CH/ km	food waste	2769	10004	-743.8871584	km
electricity, low voltage, at grid/ DE/ kWh	farming	1118	10003	53.69863014	kWh
building, hall/ CH/ m2	farming	3653	10003	0.007671233	m2
rape meal, at oil mill/ RER/ kg	insect meal	412	10001	3780.784089	kg
rape seed conventional, at farm/ DE/ kg	insect meal	261	10001	-1538.461538	kg
transport, lorry 3.5-16t, fleet average/ RER/ tkm	insect meal	2799	10001	-153.8461538	tkm
transport, lorry >16t, fleet average/ RER/ tkm	insect meal	2807	10001	-0.583862706	tkm
transport, freight, rail/ RER/ tkm	insect meal	2887	10001	-3.503229168	tkm

Table A.1 Inputs to production system. Foreground and background-to-foreground data used in Arda

NTNU HSE	Hazardous activity identification process	Prepared by	Number	Date
		HSE section	HMSRV2601E	09.01.2013
		Approved by		Replaces
		The Rector		01.12.2006

Unit: *(Department)* Enegi og prosessteknikk **Date:** 15 January 2016

Line manager:

Participants in the identification process (including their function)**:**

Short description of the main activity/main process: Master project for student xx. Project title.

Is the project work purely theoretical? (YES/NO): YES *Answer "YES" implies that supervisor is assured that no activities requiring risk assessment are involved in the work. If YES, briefly describe the activities below. The risk assessment form need not be filled out.*

Signatures: *Responsible supervisor:* *Student:* Ida Hex. Rustad

ID nr.	Activity/process	Responsible person	Existing documentation	Existing safety measures	Laws, regulations etc.	Comment
	Literature review					
	Perform a life cycle assessment					