Martin Myrvang

LIFE CYCLE ASSESSMENT OF A MARINE FARM CO-LOCATED WITH A REFINERY

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LIFE CYCLE ASSESSMENT OF A MARINE FARM CO-LOCATED WITH A REFINERY

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Martin Myrvang
Programme: Industrial Ecology
Dept: Energy and Process Engineering
Faculty of Information Technology and Electrical Engineering
Norwegian University of Science and Technology

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Livssyklusanalyse av ett oppdrettsanlegg samlokalisert med ett Raffineri

Life Cycle Assessment of a marine farm co-located with a refinery

Bakgrunn
Oppgaven inngår prosjektet Mongstad Pilot. Det overordnede målet for dette prosjektet er å undersøke hvordan Mongstad som industriområde kan øke sin verdiskapning samtidig som det senker sin miljøbelastning.

Mongstad raffineri produserer pr i dag store mengder overskuddsvarme som ikke utnyttes. I ett industriøkologisk perspektiv på industriparker søker en å identifisere og analysere hvordan samlokalisering av aktiviteter og utveksling av biprodukter, som for eksempel varme, mellom disse kan gi mer miljøvennlig produksjon og økt verdiskapning.

Denne oppgaven skal med bakgrunn i en øko-industripark tilnærming analysere samlokalisering av ett oppdrettsanlegg ved Mongstad Raffineri.

Mål:
Det skal utføres en komparativ miljøevaluering av et oppdrettsanlegg samlokalisert med Mongstad Raffineri samt en alternativ produksjonsform med samme funksjonelle enhet ved bruk av livssyklusanalysemetodikk. Gjennom denne analysen skal dermed miljøfortrinn/ulemper knyttet til samlokalisering alternativ produksjon kvantifiseres og evalueres.

Elementer:

- Kandidaten skal gi en oversikt over modelleringstilnærminger av produksjonssystemer og deres miljøbelastninger i LCA og
- Med basis i modelloversikten skal valg av metode grunngis.
- Kandidaten skal i utføre valg av art(er) og teknologier som skal analyseres. Dette skal skje i samråd med veiledere.
- Utførelse av en LCA på de utvalgte produksjonssystemene.

Senest 14 dager etter utlevering av oppgaven skal kandidaten levere/sende instituttet en detaljert fremdrift- og evt. forsøksplan for oppgaven til evaluering og evt. diskusjon med faglig ansvarlig/ veiledere. Detaljer ved evt. utførelse av dataprogrammer skal avtales nærmere i samråd med faglig ansvarlig.

Besvarelsen redigeres mest mulig som en forskningsrapport med et sammendrag både på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse etc. Ved utarbeidelsen av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Med henblikk på lesning av besvarelsen er det viktig at de nødvendige henvisninger for korresponderende steder i tekst, tabeller og figurer anføres på begge steder. Ved bedømmelsen legges det stor vekt på at resultatene er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte, og at de er diskutert utførlig.

Alle benyttede kilder, også muntlige opplysninger, skal oppgis på fullstendig måte. (For tidsskrifter og bøker oppgis forfatter, tittel, årgang, sidetall og evt. figurnummer.)

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Til Instituttet innleveres to - 2 komplette, kopier av besvarelsen. Ytterligere kopier til evt. medveiledere/oppgavegivere skal avtales med, og evt. leveres direkte til, de respektive.
Til instituttet innleveres også en komplett kopi (inkl. konsentrerte sammendrag) på CD-ROM i Word-format eller tilsvarende.

Institutt for energi og prosessteknikk, 06.01.2006

Johan E. Hustad
Instituttleder

Professor Edgar G. Hertwich
Faglig ansvarlig/veileder

Kontaktperson(er)/medveileder(e):
Dr. Anders Hammer Strømman, NTNU-IVT/EPT/IndEcol
Dr. Jan Ove Evjemo, NTNU-NT/Biologi
Christian Solli, NTNU-IVT/IndEcol

“The terrain is to be assessed in terms of distance, difficulty or ease of travel, dimension, and safety.”

Sun Tzu

Preface

This thesis has been interesting and challenging to work with. Interesting since it has allowed me to develop my knowledge and understanding of LCA and hybrid LCA, challenging because I knew nothing about aquaculture activities before I began the data collection on a non-existent facility. At times it was a frustrating search for applicable data and many wasted phone calls and e-mails. Missing data on effluents from the operation of the fish farm has limited the study. After saying enough is enough on the data collection about 4 weeks overdue, we started analysing and I am very pleased with the modelling phase and the outcome.

I want to thank everyone that has provided data on and shared knowledge about land based marine farms. All the people at Industrial Ecology for inspiring discussions and letting me win the wine raffle three times in a row. Thanks to Glen Peters for helping me out with IOA technicalities and programming in Matlab.

Special thanks go to my supervisors Prof. Edgar G. Hertwich, Dr. Anders Strømman, Dr. Jan Ove Evjemo and MSc Christian Solli for finding time to guide me through difficulties on the way.

Trondheim, June 19, 2006-06-17

Martin Myrvang

Sammendrag

En hybrid livssyklusanalyse har blitt utført på et landbasert oppdrettsanlegg for piggvar. Oppdrettsanlegget har et stort oppvarmingsbehov for vann. Basis systemet i studien utnytter spillvarme av lav kvalitet fra raffineriet på Mongstad gjennom varmeveksling. Studien har vært komaprativ med hensyn på ulike energikilder brukt i oppvarmingen av vannmassene i systemet. Resultatene viser at de økonomiske kostnadene og miljøbelastningene øker betraktelig ved bruk av konvensjonelle energikilder kontra raffineriets spillvarme. Landbasert akvakultur er således en industri med gode insentiver for bi-produkt utveksling på Mongstad. Raffineriet vil dra nytte av senkede varmeutslipp, og regionen Nord-Hordaland vil få utvidet sin industri aktivitet ved oppstart av et slikt system på Mongstad.

Når det gjelder bærekraftighet ved oppdrettsanlegget er det vist i denne studien at oppstrøms-prosessene til fòrproduskjonen spiller en viktig rolle. Konvensjonelt fiske for anskaffelse av marine ingredienser, og produksjonen av diesel til fartøyene, er de viktigste prosessene i systemet med tanke på miljøbelastning. Produksjon av jordbruksvarer, og oversjøisk frakt av disse, utgjør også en betydelig del av den totale miljøbelastningen. Bygging av tankområdene og installasjonen av teknisk utstyr i fasilitetene har den største miljøbelastningen for resten av systemet, hovedsakelig gjennom økonomiske kjøp fra metall og bygg sektorene. Bruken av kjemikalier for å rense vannet og i konstruksjon av rørsystemet har merkbare miljøbelastninger.

I et scenario er norsk elektrisitet brukt til oppvarming i systemet. Dette fører til moderat økning i miljø-belastningene i forhold til basis systemet, og er et økonomisk foretrukket alternativ i forhold til de to tilfellene med fossile energikilder. Oppvarming av vannet ved fyringsolje fører til stor økt miljøbelastning fra systemet i forhold til basis tilfellet. Forbrenning av naturgass fører til mindre økt miljøbelastning enn fyringsolje i forhold til utnyttelse av spillvarme, men innebærer de største produksjonskostnadene av samtlige alternativer.

Summary

A hybrid life cycle assessment of a land based turbot farm was conducted. The aquaculture facility has large heat requirements regarding water. The base case in the study utilise low quality waste heat from the refinery at Mongstad through a heat exchanging process. It has been a comparative study investigating various energy sources heating the water volumes in the system. Comparing with using heat as a by-product at Mongstad, economic costs and environmental impacts increase significantly by using other energy sources, according to the results in this report. Land based aquaculture proves to be an industry with driving incentives for by-product exchange at Mongstad. The refinery benefits from lower waste heat emissions, and the industrial activity in the region expands when initialising such a system at Mongstad.

Concerning sustainability of the aquaculture facility this report states that the upstream processes of feed production are important. Conventional fishery to obtain the marine ingredients, and the production of diesel intended for the vessels, are the most important processes in the system in terms of environmental load. Agricultural products, and oceanic freight connected to them, constitute considerable part of the total environmental impact. In the rest of the system, the construction of fish tank area and installation of technical equipment stand for the largest environmental impact, mainly from purchases in the construction and metals sectors. The use of chemicals for disinfection purposes and in the construction of the pipe system has noticeable environmental impacts.

The energy scenarios were based on using electricity, heavy fuel oil and natural gas and they were compared to the base case, using waste heat. Heating the water with electricity purchased from the Norwegian grid lead to moderate increases in environmental impact, and is economically preferable compared to fossil fuels. Using heavy industrial oil to heat the water leads to large increases in impacts from the system. Combustion of natural gas lead to smaller increases in impact than oil, compared to using waste heat, but bears the largest production costs of the alternatives.

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1 Introduction

This report is part of the Mongstad Pilot research project. The objective of Mongstad Pilot is to investigate how Mongstad as an industrial site can increase its value added and resource efficiency. Today the refinery at Mongstad produces large amounts of unutilised surplus heat as a by-product. Co-location of industries at Mongstad and exchange of by-products between them can increase the on-site resource efficiency and environmental performance.

In the immediate surroundings of Mongstad refinery there is a 14000 m^2 prepared and levelled area. A concession for a marine fish farm in this area has been given to Mongstad Vekst AS by Norwegian authorities (Mongstad Vekst AS, 2006). Seawater used as cooling water in refinery processes is discharged to sea with temperature at approximately 25° C. Water at this temperature has potential as heating medium in fish farming through direct use or in heat exchangers.

The amount of excess cooling water available, for the purpose of fish farming is 6200 m^3/h (ibid), or approximately 180 MW heat. Cultivation of salmon in sea based cage systems and conventional harvest of marine fish is a well established industry in Norway. Land based fish farms exist in Norway, but are more common in parts of the world with warmer waters. The use of heated cooling water in Norway is a source to relatively high and stable water temperatures that are attractive to marine fish farms on land (Havbruks-rapport, 2003).

Seafood harvesting and the connected activities have exceeded the capacities of most of the world's oceans to sustain the seafood resources at the rate they are extracted by. Aquaculture of marine species can be a valuable and potentially resource saving activity for the seafood industry, but it is regarded with increasing concern. This type of aquaculture is an important part of the global food production, but is also problematic in terms of sustainability as well as product quality assurances. Marine animals are valuable sources of nutrition and marine food cultivation industries are developing based on protein rich dry feeds. These and other marine food industries have emerged without assessment of their sustainability (Willison et al, 2006). The aquaculture industry has been subjected to environmental criticism connected to its activities, especially connected to salmon and the spreading of salmon louse and genetic dilution among native stock caused by escaped farmed fish. Fish production in land based fish farms reduces the risk for similar environmental burdens.

Food consumption in general is a significant driving force behind environmental impact and resource consumption in Norwegian households, and in the rest of the world. Studies (Peters et al, 2005) have shown that the purchase of fish has the most polluting path in terms of food purchases in Norway. This reflects the large share of fish in the Norwegian diet and the high use of off-shore fishing vessels. Agriculture is the third most polluting industry in terms of food consumption in Norway. Both agriculture and the fishing industry is a part of the feed production connected to aquaculture.

Life cycle assessment (LCA) is a tool for an aggregated description of emissions, waste and resource use from a service or product. LCA can be an important tool when assessing the sustainability of the aquaculture and fishing industry and food production in general. This type of assessment can reveal bottlenecks with regards to pollution and resource consumption, thus a LCA of the planned system at Mongstad is useful. In addition LCA can be used to supplement economical analyses on a corporate and national level. Among the advantages

with this analytical approach is that it produces transparent conclusions for the total value chain of a product.
This study will describe the value of the heat exchange at Mongstad, qualitatively and quantitatively. Selection of species and technologies for the aquaculture facility and methodology to be used in the analysis is a part of this study, and will be discussed and decided on together with teaching supervisors.

2 Life Cycle Assessment methodology for this study

Life cycle assessment (LCA) is a tool developed to analyse environmental impact through the entire lifecycle of a product, process or service. The methodology constitutes a holistic view of the environmental performance associated with a product, process or service. If only one life stage or process of a larger system is analysed, then only a smaller part of the total environmental performance is taken into account. Therefore it is necessary to include as many life stages and processes connected to the system as possible, to more accurately describe the environmental performance.

When LCA is applied, problem shifting is less likely to occur. For instance if one solved environmental problem leads to another, by shifting problems from one part of the system to another or creating a different environmental problem. The computational structure of an LCA makes it a convenient tool for environmental performance comparisons between or within systems. LCA can in this manner influence the choice of one product instead of another. LCA may not be the appropriate tool whenever environmental management is needed since social and economic aspects of a product is usually not addressed, although environment issues chosen for inclusion may reflect such issues. This study will describe the economical costs of turbot farming as well as environmental impact.

The framework of LCA is formalised by the International Organization for Standardization (ISO) in the ISO 14040-14043, and this framework makes out the methodological basis for this report. An LCA consists of four phases (ISO, 1997) listed below. Conducting an LCA is an iterative process between these four phases:

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

The following chapters will give a description of these phases, emphasising on the content of this report.

2.1 Goal and scope definition

The framework for goal and scope is given in the ISO14040 standard (ISO, 1997). The goal of an LCA explains the reason for conducting the study. The scope defines and describes the functions and the boundaries of the study. A functional unit should be defined and the functional unit acts as a basis for the assessment. The functional unit is a quantitative measure and gives expression to the function the system fulfils. The purpose is to provide a reference flow which the inputs and outputs of the system are related to. *The functional unit in this analysis is one 2 kg wet weight turbot pre slaughter farmed in Nord-Hordaland, Norway.*

The system boundaries must be defined and thus involves choosing which processes to include and exclude in the LCA. These boundaries define to what level of detail the inventory analysis is conducted. This is further described in chapter 2.2. In comparative LCAs, the studies are based on the same functional unit. Therefore it is important that the system boundaries are the same for the system alternatives. If this is not the case, the comparisons may not be valid. Variations and differences between systems with respect to the system boundaries will be identified and reported. The system studied in this report is shown in the flow sheet in figure 1:

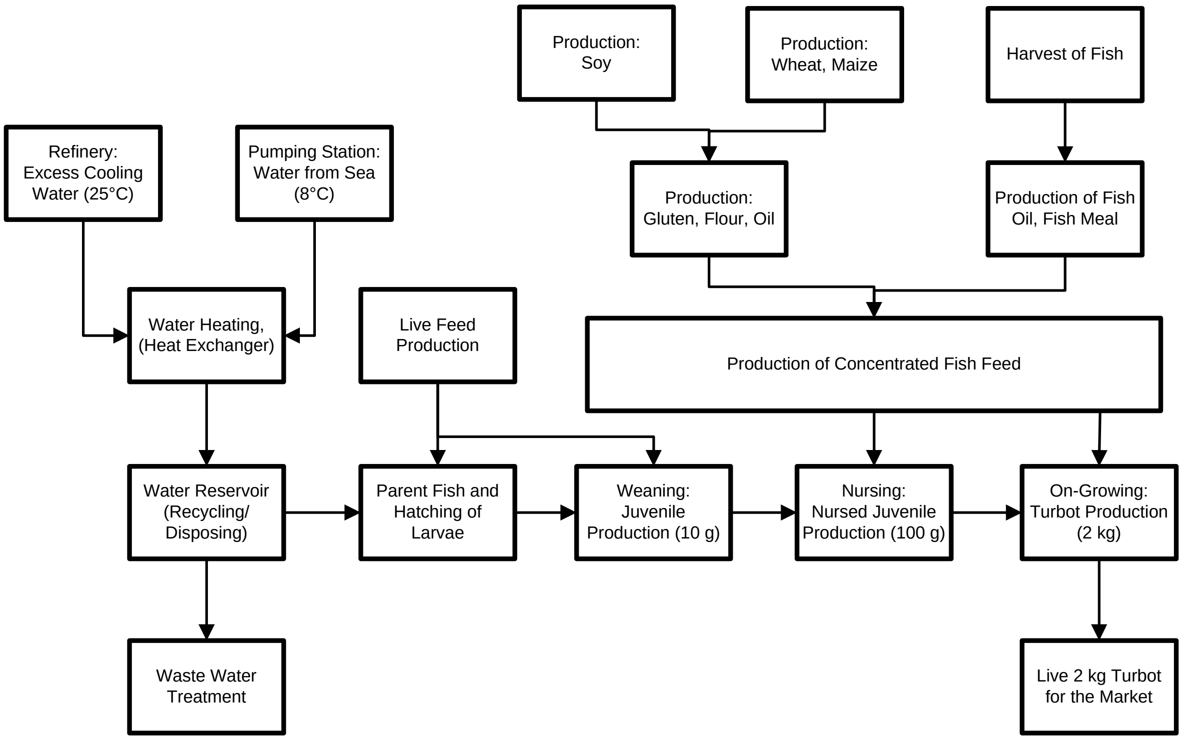

Figure 1: Flow sheet describing the aquaculture system.

Transport and energy use and waste handling is a part of the processes in the flow sheet, and they will be accounted for in the assessment. The top right-hand of figure 1 shows production of agricultural ingredients and harvest of fish, entering the fish feed production. The manufacturing of fishing vessels and agricultural machines as well as the infrastructure providing heat will not be a part of the system. Waste water from the aquaculture facility will be handled in a treatment plant. The effluents to be treated mainly consist of feed remnants, fish faeces and added chemicals used for disinfection purposes. An assumption that these effluents don't cause environmental impact is made in this study because of lack of data.

The left side of the flow sheet show the pumping of water from the sea and the flow of heated cooling water from the refinery. These water flows go through a heat exchanger, and the heated seawater then supplies the fish farming facilities with temperate water. The heat exchanging process is simplified in this study, assuming one large heat exchanger. The pumps in the system, and the energy required to operate them, will be a part of the assessment. Since the heated water coming from the refinery is an existing unutilised energy stream the purchase of this heat will not generate environmental impact in the base case. Thus it will not be a part of the environmental assessment, but the heat costs will be presented.

The cultivation of turbot will have three facilities. The parent fish or the brood stock supplies sperm and egg to produce turbot larvae which will be fed on-site produced live plankton feed. The fish will undergo weaning which make them ready for the nursery facility. Nursery is the stage where the juveniles grow to a 100 g size. From the nursery stage the fish will be routinely graded and moved to the on-growing facility where it will reach a size of 2 kg. The annual total production in the fish farm will be 576 tonnes of turbot, which is roughly 10 % of the annual turbot production in Europe. The construction and operation of the facilities is a part of the assessment. Slaughtering and filleting of the fish is not taken into account. Freezing facilities to store filleted fish is taken into account in the aquaculture facility investments, but are not a part of the operation. The system produces live 2 kg turbots, which allows for options of exporting live fish to for example China where live fish has a better price than filleted fish. Transporting and exporting of farmed fish is no a part of the assessment. Operating time for the system is 20 years. Deconstruction of the facilities is not a part of the assessment.

The goal of this study is a complete quantification and evaluation of environmental impacts, within the system boundaries, connected to producing 2 kg wet weight live turbot with the different production alternatives in the study. This report shall, from a product life cycle perspective and methodology, analyse the co-location of a fish farm next to a refinery with respect to environmental impact. The different production systems will focus on environmental impacts and expenditure, when comparing different means of heating the water in the recycling system. The source of energy in the base case is utilising heat from the refinery using a heat exchanger and the alternatives are using electricity, an industrial heavy oil furnace and an industrial natural gas furnace to heat the recycling water and input of raw water. Environmental impact from heating the water will be calculated in these scenarios. The presentation in chapter 3 and 4 will focus on the base case, while a description of the alternative systems will be given in the analysis chapter (5).

2.2 Life cycle inventory

Life cycle inventory analysis (LCI) involves the collection of data and calculations to quantify inputs and outputs of a product system. Guidelines for the LCI are found in ISO14041 (ISO, 1998). The system of the study is usually divided into several underlying unit processes. Between the unit processes there are flows of intermediate or final goods. The flow sheet in figure 1 gives a graphical overview of the system in this study.

The way of obtaining the data differs from study to study. Combinations of methods are usually used to obtain the necessary input and output data for the unit processes. The LCI data can be gathered by measurement of specific process data, data from literature, process modelling or existing databases may be used. Allocation procedures may be used to determine the inputs and outputs of a process, if the process has several product outputs. The LCI requires an iterative working procedure since new data may be required as the knowledge of the system increases (ISO, 1997, ISO 1998).

It can be time-consuming and difficult for the practitioner to build a life cycle inventory from scratch when considering large systems. Determining which processes to include within the system boundary is difficult because the negligibility of excluded processes can not be guaranteed. The traditional way of conducting LCI is based on process analysis where resource consumption and emissions from decided processes are assessed in detail (Suh et al, 2004). In this report a hybrid LCA approach is used. Economical data will be gathered to assess the environmental impact from the construction of the facilities and operating the aquaculture facilities. Every purchase in the economy can be assigned to an industry sector, which again has purchases from other sectors in the economy. This background system is described by vectors from input-output tables.

The ingredients entering the feed production and transport are strongly based on imports, while the construction and operation of the fish farm is assumed to affect the domestic economy. Therefore conventional LCA data is used to determine the environmental impacts from the processes connected to the feed production. This background system is described using inputs from the Danish LCA food database (Nielsen et al, 2003). The inventory data for feed is given in the fish feed chapter (3.4). Economical cost estimates on different items in the facilities are used to assess the environmental impact on other processes, assuming that these processes have the same emissions structure as the average of their respective economical sectors in the input-output system. An overview of the economical purchases in the foreground system is given in the investment and cost estimates chapter (4), and the detailed investment and operational cost estimates are given in Appendix 3.

Deciding on the system boundary is an important, but difficult aspect of LCA. The ISO standard allows for subjective decision making on which inputs and outputs to include from the analysis. Leaving out inputs and outputs from a system is known as a cutoff in LCA. It is necessary to include the most important inputs and outputs of a system, but it is impossible to gather and include all the data from all processes connected to a large system. The initial system boundary is chosen before the actual data collection in conventional process analysis LCA. At this stage it is difficult to determine if a cutoff could significantly affect the overall results. Process analysis covers resource uses and emissions from the main processes, while the remaining successive upstream inputs are considered negligible, by using the input-output tables more upstream processes enter the analysis (Suh et al, 2004).

2.3 Hybrid Life Cycle Assessment

The traditional way of conducting LCI is to construct the process flow chart, and physical data is used in a process chain analysis. Data concerning the emissions and resource use of each process is collected, and then aggregated. In hybrid LCI economic input-output tables (IOT) can be used in addition to conventional techniques. IOTs represent models of the economy by describing monetary flows between industrial sectors present in an economy. IOTs are constructed as part of the national accounts, and are collected by statistical offices. IOTs describe the structure of the economy in monetary units, i.e. how much is produced in which sectors and with which inputs. The IOTs contain gathered data on energy consumption, emissions and waste production in each sector. These data are used to calculate the total emissions and resource consumption per unit turn-over of each sector. Since input-output analysis (IOA) covers the whole economy, the system boundaries are larger than for traditional LCA (Hertwich, 2004).

2.3.1 Matrix notation approach and methodology

The hybrid LCA approach takes advantage of both process chain analysis and IOA. The foreground processes, which are directly connected to the life cycle of a product, are described by gathered data. Information about the background processes are harder to come by, thus the general IOT is used in an IOA to cover these processes. In the base case of this study there are no data on the emissions from- and resource use regarding the foreground system directly. The environmental impacts will be calculated based on the two background systems only, namely the IOT dataset and the data from the mentioned food database.

Input-output analysis combined with environmental data was introduced by Leontief (1970), and has since been developed further. The computations in IOA and LCA are performed within a matrix framework. The methodology for modelling in this report is adapted from Miller & Blair (1985) and United Nations (1999). The symbols used are explained in Table 1:

Table 1: Notations used in the calculations

Name	*Description*
n	Number of sectors.
m	Number of stressors.
p	Number of impacts.
I	Identity matrix. (Ones along the diagonal, zeroes elsewhere)
x_i	Output of sector i.
x	Vector of output from all sectors
y_i	Final demand/Reference flow on sector i.
y	Vector of Final demand/Reference flow on all sectors
z_{ij}	Flow of inputs from sector i to sector j.
Z	The Z matrix is the inter-industry flows between all sectors.
a_{ij}	Flow from sector i to sector j to produce one unit of output.
A	The A matrix is the normalised inter-industry flows between all sectors.
f_{ij}	The flows of stressors f from sector i to sector j.
F	Stressor intensity matrix for all sectors and stressors.
e	Vector of stressors.
E	Matrix of stressors for all processes.
C	Matrix of characterisation factors.
d	Vector of impacts.
D_p	Matrix of impacts from each process.
D_s	Matrix of impacts from each stressor.

The output of each sector in an economy is given by the vector x and represents the quantity and variety of goods produced by an economy. The final demand, given by the vector y, is the demand from all consumers on goods. The final demand on the system at hand is the functional unit, i.e. one farmed 2 kg turbot. The output x_i of a sector is given by the sector's inter-industrial deliveries and its deliveries to final demand as shown in equation 2.1:

$$\begin{aligned} x_1 &= z_{11} + z_{12} + \cdots + z_{1i} + \cdots + z_{1n} + y_1 \\ x_2 &= z_{21} + z_{22} + \cdots + z_{2i} + \cdots + z_{2n} + y_2 \\ &\vdots \\ x_i &= z_{i1} + z_{i2} + \cdots + z_{ii} + \cdots + z_{in} + y_i \\ &\vdots \\ x_n &= z_{n1} + z_{n2} + \cdots + z_{ni} + \cdots + z_{nn} + y_n \end{aligned} \tag{2.1}$$

The columns of z's in equation 2.1 represent the different sector's purchases, i.e. the quantity and variety of sectorial inputs between the industrial activities in an economy.

The flows described in the Z matrix is normalised in IOA to denote the inputs per unit output. This is done by forming a ratio of input from sector i to sector j to obtain the gross output of sector j. Each flow then has a technical coefficient a_{ij} shown in equation 2.2:

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{2.2}$$

Substituting equation 2.2 in equation 2.1 gives equation 2.3:

$$x = Ax + y \tag{2.3}$$

In matrix terms we define:

$$x = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}, \quad y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, \quad A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1i} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2i} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{ni} & \cdots & a_{nn} \end{pmatrix}, \quad I = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \cdots & 1 \end{pmatrix}$$

Rewriting equation 2.3 gives equation 2.4:

$$x = (I - A)^{-1} y, \tag{2.4}$$

Where $(I-A)^{-1}$ is known as the Leontief inverse. The total output can now be calculated after constructing the A matrix and knowing the reference flow vector y.

To find the flows of stressors, such as raw materials and emissions, a stressor intensity matrix denoted F is used. This matrix gives all related stressors connected to each sector given in the input output tables and the inputs from the LCA database. The amount of different stressors is found in the stressor matrix e, as shown in equation 2.5:

$$e = Fx = F(I - A)^{-1} y$$
$$\begin{pmatrix} e_1 \\ e_2 \\ \vdots \\ e_m \end{pmatrix} = \begin{pmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} \tag{2.5}$$

To find the flow of stressors from each of the processes, the E matrix is calculated as shown in equation 2.6:

$$E = F\hat{x}$$
$$\begin{pmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & \cdots & e_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ e_{m1} & e_{m2} & \cdots & e_{mn} \end{pmatrix} = \begin{pmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{pmatrix} \begin{pmatrix} x_1 & 0 & \cdots & 0 \\ 0 & x_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & x_n \end{pmatrix} \tag{2.6}$$

After collecting and structuring the data, the next step is to determine what kind of environmental impact the system causes in the impact assessment. The stressors are then distributed into interpretable environmental impacts by multiplication with characterisation factors. The impact assessment is explained in chapter 2.4.

2.3.2 Constructing the total A and F matrix

The A matrix describes the intermediate inputs to produce one unit of output. As mentioned above, the data used in this analysis come from different sources. In this study most processes are economical data where environmental emissions and impacts will be calculated based on input-output tables provided by statistics Norway (SSB, 2003). The input output requirements matrix is given by A_{nn} in equation 2.7. The production of fish feed and the connected processes are modelled using data from the LCA food database (Nielsen et al, 2003). The LCA database connects processes to each other and is given in the A_{mm} matrix of the A_{total} matrix. The LCA modelling software SimaPro 7.0, developed by Prè Consultants (2006), is used to assemble the necessary processes and then exported as matrices and connected to the foreground system. The total A matrix is then constructed with input-output and LCA data in Excel, before the matrices is imported and treated in Matlab 7.1.

The processes are divided into foreground processes, which are directly connected to the life cycle of the given product, and the background processes which provide upstream inputs to the foreground processes. The foreground processes in this analysis consist of the expenditure categories for the facilities along with feed production and have no direct emissions or resource use in the base case. The background processes is the A_{nn} and A_{mm} matrices. The A matrix needs to be constructed so that all the data are taken into account.

$$A_{total} = \begin{pmatrix} A_{ff} & 0 & 0 \\ A_{nf} & A_{nn} & 0 \\ A_{mf} & 0 & A_{mm} \end{pmatrix} \quad (2.7)$$

The total A matrix consists of several matrices constructed on the basis of different parts of the system. The A_{ff} matrix describes the unit flows between the foreground processes. The requirements the foreground processes have on the input-output sectors are assembled in the A_{nf} matrix. The A_{mm} matrix describes the LCA database processes, and the requirements from the foreground system on these processes is denoted A_{mf}. The matrices A_{fn}, A_{fm}, A_{nm} and A_{mn} are zero because it is assumed that the foreground system itself does not affect the background systems and because no flows between the two background systems are assumed.

Similarly the stressor intensity matrix F needs to correspond to the structure of the A matrix. The compartment structure of the stressors in the database used to analyse the feed production consists of four groups. These groups are raw material use, air emissions, water emissions and soil emissions. The foreground system has no direct emissions in the base case. The F matrix in the base case will have the following structure:

$$F_{total} = \begin{pmatrix} F_{f} \\ F_{n} \\ F_{m} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & F_{air} & 0 & 0 \\ F_{raw} & F_{air} & F_{water} & F_{soil} \end{pmatrix} \quad (2.8)$$

In this study the stressor matrix connected to the input output tables are limited to emissions released to air, while the assessment connected to the feed production data covers more compartments, such as water and soil, and also has emission data for more substances. This means that the environmental assessment of the feed system will be more detailed than the rest of the system which is based on input output tables. The systems could be made consistent in terms of the environmental assessment, but it is advantageous to report all sub-systems at the most detailed level possible, even if it means making parts of the system more detailed than others. It should be mentioned that this can make it more difficult to compare environmental performance of the processes in the feed system with the rest of the system

The work of assembling these matrices is time consuming and challenging, and is the basis for the analysis. The total F matrix has 8184 rows by 766 columns, but many of the stressors have no contribution to the impacts in this system.

2.4 Impact assessment

In the life cycle impact assessment (LCIA) the results from the inventory analysis are used to evaluate the significance of potential environmental impacts. Inventory data is associated with specific environmental impacts and seeks to understand the impacts at hand. The guideline for impact assessment in ISO14042 (ISO, 2000a) divides the LCIA in three steps.

- Selection of impact categories
- Classification
- Characterisation

The three steps are explained in the following chapters.

2.4.1 Selection of impact categories

The first step of LCIA is the selection of impact categories, which should be prepared with the goal and scope of the study in mind. All categories relevant to the study should be included, since this will help prevention of problem shifting. The choice of impact categories is especially important in a comparative LCA, i.e. including too few categories can fail in describing the total environmental performance of the compared systems. Hence the result of the LCA may favour the wrong alternative from an environmental perspective. The selected impact categories in this study are shown in table 2.

Table 2: Impact categories and the respective indicators.

Impact category	*Full name*	*Indicator*
ADP	Abiotic Depletion Potential	kg Sb-equivalents
GWP	Global Warming Potential	kg CO_2-equivalents
ODP	Ozone Layer Depletion Potential	kg CFC-11-equivalents
HTP	Human Toxicity Potential	kg 1,4-DB-equivalents[1]
TETP	Terrestrial Ecotoxicity Potential	kg 1,4-DB-equivalents[1]
PCOP	Photochemical Oxidation Potential	kg C_2H_2-equivalents
AP	Acidification Potential	kg SO_2-equivalents
EP	Eutrophication Potential	kg PO_4^{3-}-equivalents

[1] 1,4 Dichlorobenzene- equivalents

For the impact assessment the CML 2000 baseline method is used and all the CML baseline indicators are included, except fresh and marine water toxicity. The reason for omitting marine toxicity is the lack of data on the emissions from the treated waste water from the fish farm. Fresh water toxicity is omitted from the study because the impacts in this category are assumed to be negligible in the system. The CML baseline method is developed by Center for Environmental Studies at the University of Leiden (2006).

2.4.2 Classification

The next step is the classification or assignment of the LCI results. Pollutive outputs from the system can have environmental impact in one or multiple impact categories. The LCI results should be assigned to their respective categories, i.e. NO_x emissions may be assigned to ground-level ozone formation, eutrophication of soils and acidification. This study follows the classification properties of the CML method.

2.4.3 Characterisation

In the characterisation step of LCIA the emissions are multiplied with a characterisation factor specific for each category. For instance when considering global warming, the emissions are given in CO_2 equivalents, where CO_2 has a characterisation factor of 1, while methane has a characterisation factor of 23. This is a way of identifying the emissions that lead to a significant environmental burden. Although more substances and compartments are assessed for the feed system, both the process analysis emissions data and the input output emissions data are characterised in the same impact categories.

An LCA can be expressed mathematically in a single equation. Mathematically the stressors are distributed to their impact categories by multiplying the stressor flows by a matrix of characterisation factors, C, to obtain a vector of impacts d. This is done in equation 2.9:

$$d = Ce = CFx = CF(I - A)^{-1} y$$

$$\begin{pmatrix} d_1 \\ d_2 \\ \vdots \\ d_p \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ c_{p1} & c_{p2} & \cdots & c_{pm} \end{pmatrix} \begin{pmatrix} e_1 \\ e_2 \\ \vdots \\ e_m \end{pmatrix} \qquad (2.9)$$

To find impacts from each process the D_n matrix is calculated, shown in equation 2.8:

$$D_n = CE = CF\hat{x}$$

$$\begin{pmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{p1} & d_{p2} & \cdots & d_{pm} \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ c_{p1} & c_{p2} & \cdots & c_{pm} \end{pmatrix} \begin{pmatrix} e_1 & 0 & \cdots & 0 \\ 0 & e_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & e_m \end{pmatrix} \qquad (2.10)$$

Similarly we can find the impacts from each stressor by the D_m matrix, shown in equation 2.9:

$$D_m = C\hat{e}$$

$$\begin{pmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{p1} & d_{p2} & \cdots & d_{pn} \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ \vdots & \vdots & \ddots & \vdots \\ c_{p1} & c_{p2} & \cdots & c_{pm} \end{pmatrix} \begin{pmatrix} e_1 & \cdots & 0 \\ \vdots & \ddots & 0 \\ 0 & 0 & e_m \end{pmatrix} \qquad (2.11)$$

When using a matrix framework and general matrix theory when conducting LCA, the analysis results become more flexible and transparent. After all the data are in place and the results obtained, the next phase is interpretation.

2.4.4 Interpretation

The interpretation phase of LCA should provide an easy-to-follow presentation of the LCA, LCI and LCIA results to fulfil the requirements of the goal and scope. The guidelines for interpretation are available in ISO14043 (ISO, 2000b). The interpretation phase is a systematic procedure to identify, qualify, check and evaluate information from the generated results. Conclusions, limitations and recommendations based on the findings in the study are made and explained.

Identification and structuring of the information contained in the study is necessary to determine significant important and environmental issues. This is an iterative process, and is often done sufficiently in the LCI or LCIA phase. An evaluation of the material in hand is performed.

This report has the introduction of production alternatives and results in the analysis chapter (5). Assumptions and inventory data are given in chapters 3 and 4.

3 System Description

This report does not give a detailed projection of the fish farm, but attempts to use information from various sources to give a set of production parameters and describe how the farm could look like, as well as the related investment and operational costs. The data given in this chapter is used in the LCA calculations.

3.1 The turbot life cycle

The fish farm will be land based and annually produce 576 tons wet weight fish in 4 batches per year. The aquaculture facility will include a hatchery with cultivation of larvae and weaning, nursery of the juveniles and an on-growing section to produce edible fish. The study will treat the breeding of the marine flatfish turbot (*Scophthalmus Maximus*). Technology for breeding turbot is established, and the technology is transferable to other marine species (J. Stoss, 2000), such as halibut.

Turbot larvae are small compared to other marine species larvae. The hatching size is 2-3 mm in length and the weight is 0.5 mg. The feeding at the larvae stage needs precautions when it comes to the surroundings and nutrition. The initial feed is live feeds, mainly rotifer followed by Artemia. Survival of larvae to the juvenile stage varies, but can be assumed to be 20 % (FAO, 2006, FEAP, 2006). Weaned juveniles are sold in the market at the weight of 5-30 g, when they are 3-6 months old from hatching. The price is approximately 1 €/fish (L. Stoss, 2006). During the nursery stage, where the juveniles reach 100 g, a survival rate of 80 % is assumed as the stock grows to on-growing size. During the on-growing stage a survival rate of 90 % is assumed (Engell-Sørensen, 2006). This means an average survival rate of 72 % from the fully cultured larvae level to market size. After 24 months of breeding the turbot has reached a weight of 2 kg (Person-Le Ruyet, 2002). The turbot reaches pubescence at approximately 2 kg, which results in weight loss, and the fish is thus harvested at this point (J.Stoss, 2000). The fish are usually harvested manually and killed by placing them into containers filled with ice and seawater and transported to processing units (FAO, 2006). The lifecycle of the turbot is shown in figure 2:

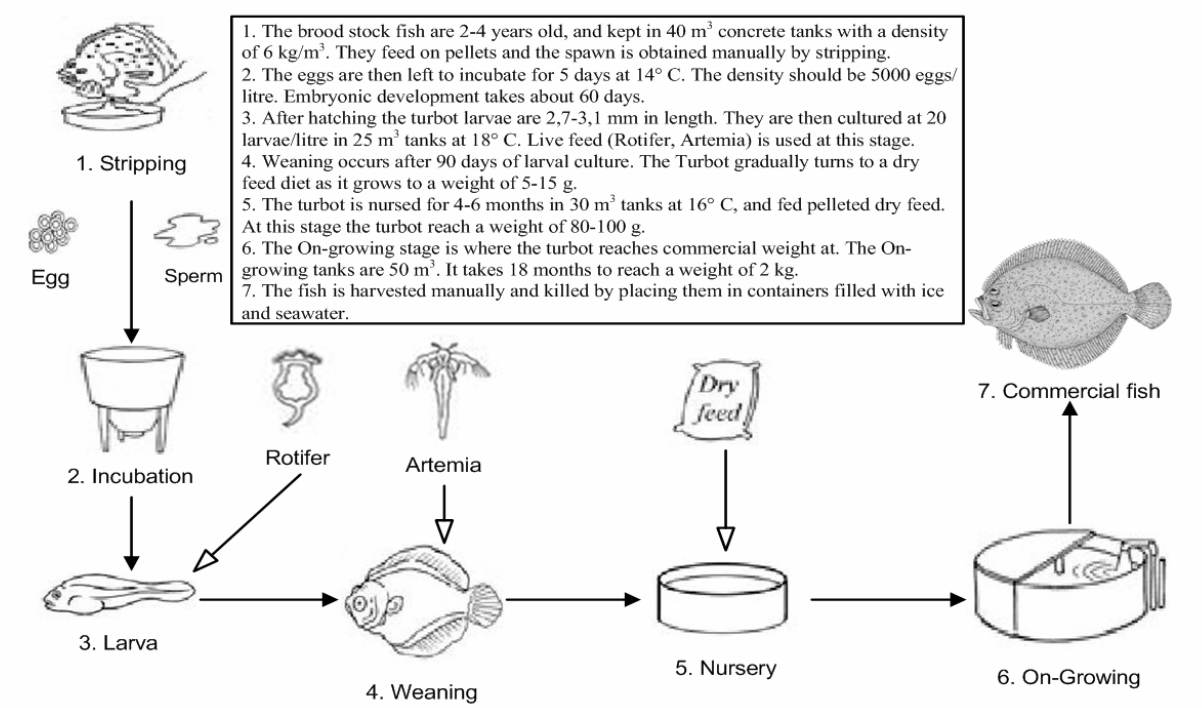

Figure 2: The turbot life cycle in the facility (FEAP, 2006, FAO, 2006)

The stages 1 to 4 in figure 2 is a part of the brood stock and larvae facility, while 5 and 6 represent the nursery and on-growing facilities.

3.2 Aquaculture facility

The facility consists of land based concrete tanks, and will have water recycling to maintain a stable microbial environment for the stock, and to cut down on energy consumption (Evjemo, 2006). The amount of recycled water and the water through-put in a cultivation system depends on the initial water quality, load in terms of feed amount, and the degree of the water treatment. The throughput of water needs to be large to provide the best growth conditions for the turbot. For nursery and on-growing of the fish, these data are given by Oppdretts-Teknologi (Skybakmoen, 2006) in this project.

For optimal growth the turbot needs a water temperature of 16° C (J. Stoss, 2000) while the juveniles need 20° C (Gislason, 2004), hence heating of the water is required. Excess cooling water from the refinery will go through a heat exchanger, which is necessary to reduce the risk for contamination of the water. The water needs a salinity of 25 ‰ (Gislason, 2004), and needs to maintain the correct oxygen level.

The farm consists of separate tanks for hatching, juveniles and on-growing fish, and also for different sizes within these groups. According to the economic data used for the on-growing phase, the turbot is cultivated in tanks with cultivation area 60 kg/m^2, and juveniles are nursed in an area of 1350 m^2. This means a fish density of 24 kg/m2 if the tanks were to contain 320000 juveniles with a weight of 100 g. The juveniles will not be of the same size in all tanks throughout the year so the actual density will be smaller. Person-Le Ruyet (2002) gives a detailed description of the density requirements: Juveniles at 10 g are stocked at a density of 10 kg/m^2, and a depth of 50 cm. The density increases to 30 kg/m^2 at the end of the nursery period. For the on-growing phase the depth is 0,7 m and the area used is 30-35 kg/m^2 for 300 g fish, 45 kg/m^2 of 750 g fish, and up to 60-80 kg m^2 for larger fish.

3.2.1 Brood stock and larvae production

The brood stock consists of fish from 2-4 years old. The density should be 3-6 kg/m^3, and the concrete tank size is 20-40 m^3 (FAO, 2006). The temperature should be 14° C for the brood stock, and the fish feeds on commercial dry pellets (Moksness et al, 2004). It is assumed that the system needs to produce 400000 reared larvae into juveniles at a weight of 10 g in 4 production cycles per year. The tanks for brood stock are assumed to be a part of the brood stock and larvae investment costs. The feeding costs concerning the parent fish is assumed to be negligible compared to the nursery and on-growing operations.

Turbot spawn during the summer months, but at a turbot hatchery this season can be manipulated by photoperiod and light to produce a year round supply of eggs. Females produce more than 1 million eggs/kg weight in each spawning season. A light regime of 16 hours light and 8 hours dark is used in the production of plankton, larvae and eggs (Minkoff et al, 1994). The light source will be limited to common light source tubes and switches (Evjemo, 2006), and is a part of the operational energy costs. The eggs are pelagic and spherical and the diameter varies between 0,9-1,2 mm. The fecundation of the eggs by sperm takes place in a laboratory through stripping. The eggs are stored for incubation for 5 days at a density of approximately 5000 eggs/l (FAO, 2006). The egg production is not restricting the production of turbot larvae and fry (Attramadal, 2006). It is thus assumed that the given amount of brood-stock is sufficient to supply the fish farm with eggs year round.

The embryonic development takes 60-70 days, and after hatching the larvae are 2,7-3,1 mm in length, and kept at a density of 15-20 larvae/l in a tank volume of 30 m^3 for each tank. The larvae are fed Rotifers from day 3 post hatch as they grow to a size of 4,5 mm. Then the larvae are fed Artemia for about 60 days. The temperature should be from 18-20° C (FAO, 2006). Both Rotifer and Artemia are live feeds which will be produced on-site.

The brood-stock and larval rearing require a total floor area of 1300 m^2, and a total tank volume of 200 m^3 (Minkoff et al, 1994). The brood stock will be kept in outside concrete tanks similar to the nursery and on-growing departments, but the tank volume is assumed negligible compared to the tank volumes of the nursery and on-growing facilities. The larvae will be kept in smaller plastic tanks, and will be disregarded in the assessment of environmental influence and resource consumption. After the larval culture is finished the juveniles need weaning to develop further and get used to the dry feed diet. Weaning occurs in round cornered square tanks. After this stage the juveniles have reached 10 g (FAO, 2006).

The water circulation varies from stagnant in the first 2-7 days of the turbot larvae stage, but it increases as it starts feeding on Artemia (IBSS, 1997). A capacity of 100 m^3/h water circulation is necessary (Minkoff et al, 1994). Assuming a 50 % renewal of the water in the total tank volume per day (IBSS, 1997) means that the input of water can reach 4,2 m^3/h, for the brood stock tanks and larvae rearing tanks combined. Table 3 shows the data connected to the brood stock and larval rearing facility.

Table 3: Data for the brood stock and larval rearing facility.

Broodstock and larval rearing	Unit	Value
Production output	[fish/yr]	400000
Production size	[kg]	0,01
Total Area	[m2]	1300
Production tank volume	[m3]	200
Water circulation (max.)	[m3/h]	135
Water input from sea	[m3/h]	4,2
Phytoplankton production (max.)	[cells/day]	2,4E+13
Rotifer consumption (max.)	[ind/day]	5,30E+08
Artemia consumption (max.)	[ind/day]	8,50E+08

These data, except production size and input from sea, are taken from Minkoff et al (1994) because of lack of updated data. An assumption is made to fit the data to this project, which is a linear relationship between production and cost when increasing the production from the original 300000 juveniles to 400000, which means that these data multiplied by a factor of 0,75 equals the original data.

3.2.2 Nursed juvenile production

The turbot reach the juvenile stage at about 20 mm, and is ready to begin a diet solely based on commercial dry feed. Usually farms get these juveniles from the hatcheries at about 8-12 g and 120 days old. At the end of the nursery period the turbot has reached approximately 100 g (FAO, 2006, FEAP, 2006). The amount of produced nursed juveniles entering the on-growing phase, need to be 320000 individuals in 4 batches. A death rate of 20 % is assumed during the nursery phase.

The nursery facility needs approximately 1350 m^2 tank area (Person-Le Ruyet, 2002). With a depth of 0,5 m, the required volume is 675 m^3. The throughput of water is based on water quality demand and needs to be dimensioned at 0,75 l/min*kg produced fish (Skybakmoen, 2006). When producing 320000 0,1 kg fish/yr the tanks need a throughput of water at 1440 m^3/h, which means that 53 % of the water volume passes through the tanks each hour. The recycle rate of the water is 75 % of the tank volume per day (Skybakmoen, 2006), so the input of heated water from the sea to the system reaches 21 m^3/h. An overview of the data for the nursery facility is given in table 4:

Table 4: Data for the nursery facility.

Nursery:	Unit	Value
Production output	[fish/yr]	320000
Production size	[kg]	0,1
Tank surface area	[m2]	1350
Water depth	[m]	0,5
Production tank volume	[m3]	675
Water circulation	[m3/h]	1440
Water input	[m3/h]	21
Feed consumption	[kg/fish]	0,125

The feed consumption is based on an average value at 1,25 kg feed per kg growth (Person-Le Ruyet, 2002).

3.2.3 On-Growing

The nursed juvenile turbot are routinely graded and stocked at a size of 80-100 g in the on-growing tanks. It takes about 2 years to grow a turbot into an average size of 2 kg (Strand, 1997). The tanks are covered by tarpaulin to prevent exposure to ultra violet light and heat loss (this applies to all outdoor tanks). The amount of fully cultivated turbots at 2 kg will be 288000 individuals.

For the on-growing phase a tank area of 9600 m^2 is required based on the mentioned area requirements (Engell-Sørensen, 2006). The depth in each tank will be 0,7 m so the volume of tanks are 6720 m^3. The circulation of water in the tanks is 0,45 l/min*kg (Skybakmoen, 2006). For producing 288000 fish per year weighing 2 kg, a total throughput of water in the tanks of 15552 m^3/h is needed. The recycle rate of the water is 50 % per day (ibid), so the input of heated water from the sea to the system reaches 154 m^3/h. Table 5 show the data for the on-growing facility.

Table 5: Data for the on-growing facility.

On-Growing	Unit	Value
Production output	[fish/yr]	288000
Production size	[kg]	2
Tank surface area	[m2]	9600
Water depth	[m]	0,7
Production tank volume	[m3]	6720
Water circulation	[m3/h]	15552
Water input	[m3/h]	154
Feed consumption	[kg/fish]	2,375

The drained water equals the water input and enters a treatment plant. The effluents from the system are assumed to have no environmental impact and are left out of the assessment.

3.3 Heat and electricity requirements

This chapter presents the heat and electricity requirements of the system. The detailed descriptions and calculations of heat and electricity requirements are given in Appendix 2.

3.3.1 Heat

The seawater used in the system will be pumped from the Fensfjord at a temperature of 8° C (Mongstad Vekst AS, 2006). It will be mixed with the recycled water in the facility and the water needs to be heated. The water temperatures in the fish tanks are assumed to be 16° C throughout the system. The normal average air temperature in Bergen, just south of Mongstad is 7,7° C (SSB, 2006b). This means that the system needs to compensate for heat loss from the outside tanks. The tanks are assumed to be covered with tarpaulins most of the time so the heat loss is due to radiation and convection from the surface to air. Heat loss due to aeration of the water to maintain the correct oxygen level is considered negligible and left out of the calculations. The heat loss calculations are given in appendix 2.2. The nursery and on-growing facilities will have fish tanks outside. The brood stock is kept in outside tanks, but the heat loss from these tanks is assumed negligible and will not enter the heat requirement calculations. This means that the larvae facility will not have any heat loss since the weaning operation is indoors. The heat requirements for the input of water from the sea and from heat losses are shown in table 6:

Table 6: Heat requirements in the system.

Input from sea:	**[kW]**	**[kWh/yr]**
Q_{sea}, Broodstock & Larvae	40	353641
Q_{sea}, Nursery	202	1768469
Q_{sea}, On-growing	1480	12968742
Total	*1723*	*15090852*
From heat loss:	**[kW]**	**[kWh/yr]**
Q_{loss}, Broodstock & Larvae	0	0
Q_{loss}, Nursery	239	2093640
Q_{loss}, On-growing	1570	13753200
Total	*1809*	*15846840*

This shows that the total heat requirements is 3553 kW, equivalent to 30,94 GWh per year or 107 kWh per fully grown turbot. This report considers the system at steady state, which means that the initial heating required to get the system temperatures is not taken into account. The price of heat from the refinery is not known, but will be decided on in confirmation with new businesses at Mongstad. After a discussion at a project meeting with Mongstad Vekst AS the price for heat is set to 10 % of the electricity price which is 0,266 NOK/kWh (IEA, 2003). The price of heat is thus 0,0266 NOK/kWh in this project. The amount of heat required from the refinery depends on the heat exchanger used in the system. The heat exchanger must compensate for the heat loss in the system and heat the pumped seawater.

3.3.1.1 Heat exchanger

The heat exchanger used in this projection is a shell and tube heat exchanger. A heat exchanger varies in price with the area of heat transfer. The recycling of water and the heat exchanger has been modelled in the process engineering tool HYSYS 3.2. (Read more about HYSYS and the heat exchanger calculations in Appendix 1). This model show that the water volume has a temperature of 15,8° C before entering the heat exchanger. The system needs to heat the water to 16° C. The cost of the heat exchanger and the heat from the refinery are listed in table 6:

Table 7: Heat exchanger properties and costs

Heat Exchanger	**Value**
Heat transfer coefficient [kJ/C*h]	2887000
Area [m2]	700
Investment cost [NOK]	2502170
Heat Costs	
Volumetric flow [m3/h]	395
Energy [kWh/yr] (25° C)	100816772
Price [NOK/kWh]	0,027
Total [NOK/yr]	2681726

The total cost of heat from the refinery is based on a 395 m^3/h flow of water, and a temperature of 25° C. This means that the refinery reduces heat waste by approximately 11,6 MW. The fish farm has an annual expenditure on heated water of 2,7 million NOK which means 9,31 NOK per fully grown turbot. The investment and heat costs are set to the on-growing facility because of their large share of the water consumption.

3.3.2 Electricity

The electricity needed in the system is related to general lighting, office requisites and for heating of the office buildings. In addition there is a need for illumination in connection with plankton and larvae production in the larval rearing facilities. Electricity driven pumps is used to lift the seawater to the on-shore aquaculture system and to circulate the water within the recycle system. The total water input from the sea to all facilities is 179,2 m^3/h. The electricity costs connected to the pump will be set to the on-growing facility since it consumes 86 % of the water input. Electricity costs connected to operation of other apparatus in the system is disregarded because of lack of data.

General building statistics supplied by Enova (Energistatistikk, 2004) is used to estimate the electricity demand in the different buildings. For office buildings, the electricity demand was 226,6 kWh/m^2 in 2004. The electricity price is 0,266 NOK/kWh (IEA, 2003). For the brood stock and larval rearing facility the general building area is 210 m^2 (Minkoff et al, 1994). Because of lack of data the same area is assumed for the general building area of the nursery. For the general buildings of the on-growing facility an area of 630 m^2 is assumed. The egg production is assumed to take place in a laboratory building with a electricity demand of 690,4 kWh/m^2yr, and the weaning is assumed to take place in a building with the same specifications as a storage hall with an electricity demand of 266,8 kWh/m^2yr. The requirements and costs of electricity in the system are given in table 7:

Table 8: Electricity requirements and costs at the facility

Electricity requirements	Area	Demand	Price	Costs
Brood stock & larval rearing:	[m2]	[kWh/m2*yr]	[NOK/kWh]	[NOK/yr]
Illumination (plankton & larvae production)	700,00	38,37	0,266	7144,49
Laboratory building (egg production)	160,00	690,40	0,266	29383,42
Weaning (heat)	230,00	266,80	0,266	16322,82
General building (heat, light and requisites)	210,00	226,60	0,266	12657,88
Total (B & L)	*1300,00*			*65508,62*
Nursery:	[m2]	[kWh/m2*yr]	[NOK/kWh]	[NOK/yr]
General building (heat and requisites)	*210,00*	*226,60*	*0,266*	*12657,88*
On-Growing	[m2]	[kWh/m2*yr]	[NOK/kWh]	[NOK/yr]
General building (heat and requisites)	*630,00*	*224,60*	*0,266*	*37638,47*
Pump (costs set to on-growing)	[kW]	[kWh/yr]	[NOK/kWh]	[NOK/yr]
Seawater input pump	9,50	*83220,00*	*0,266*	*22136,52*
Water circulation pump	426,90	3739644,00	*0,266*	*994745,30*
Total (on-growing)				*1054520,29*
SUM (all facilities)				1132686,79

The total electricity needed in all facilities is 4,26 GWh per year at a cost of 1,13 million NOK per year which is equal to 14,8 kWh and 3,9 NOK per fully grown turbot. 88 % of the electricity is consumed by the water circulation pump. Since the costs of running the pumps are set to the on-growing facility the on-growing facility has to bear the largest electricity costs with 93 % of the costs. The total use of electricity in the brood stock and larvae facility is 246,27 MWh per year at an annual cost of 65509 NOK. The nursery has the smallest expenditure at 12658 NOK per year.

3.4 Fish Feed

The feed has different composition in the turbot's life stages. At the nursery stage the turbot is not susceptible to large vegetable content. The marine content should therefore be maximised at this stage, but approximately 15 % wheat is necessary as binder (Galloway, 2006). This report will use one type of feed for the whole system, assuming that the differences in the feed composition are negligible. The food conversion rate averages at 1,2-1,3 according to (Person-Le Ruyet, 2002). It will be assumed that the farm has an average food ratio of 1,25 throughout the system. The system, producing 576 tonne turbot, needs 720 tonne fish feed annually.

The ingredients of the feed is adapted from Sæther et al (2001), and decided on in consultation with BioMar AS. It will be assumed that the feed is produced at BioMar's plant at Myre in Vesterålen, Norway. The feed will be transported by boat to Mongstad. The consumption of energy is based on an estimate given by BioMar AS (Galloway, 2006), the energy used in the production process is assumed to be electricity from the grid. In the analysis this electricity will be purchased from the Norwegian input-output tables. Table 7 show the energy use in production, costs, feed ratio, transport and ingredients of the feed used in this analysis.

Table 9: Turbot feed ingredients, production and transport.

Turbot feed	**Unit**	**Value**	**Area of production**
Energy use	[kWh/ton]	300	Norwegian energy mix
Transport cost	[kr/kg]	0,35	
Transport distance	[km]	1110	Vesterålen - Mongstad
Feed price	[kr/kg]	9,125	(incl. VAT)
Feed ratio	[kg/kg]	1,25	
Ingredients	**Unit**	**Value**	**Area of production**
Fish meal	[g/kg]	400	Scandinavia
Soya	[g/kg]	100	South America
Maizegluten	[g/kg]	173	North America
Fishoil	[g/kg]	210	Scandinavia
Wheat	[g/kg]	107	France
Vitamin and mineral premix	[g/kg]	10	N/A

Because of lacking data the maize gluten production is substituted by potato starch production. The maize gluten at the Biomar plant originates from the USA and this is taken into account when transporting it to Norway. There has not been data available for the vitamin and mineral premix. This ingredient will be disregarded in the analysis. Instead an additional 10 g of wheat is produced, and a transport from France will be accounted for. The transport distances are calculated based on a distance calculator (Indo, 2006). The transport of feed from the BioMar plant in Vesterålen to Mongstad equals 0,14 tkm, and the total 3,37 tkm (excluding transport of soy) per kg fish feed. The freight is assessed including manufacturing of the vessels and waste production.

3.4.1 Inventory from the LCA food database

The LCA food database (Nielsen et al, 2003) is used to simulate the feed production processes in SimaPro 7.0 (Pre, 2006).

3.4.1.1 Fishmeal and oil production

The data for producing fishmeal and oil refers to one factory in Esbjerg, Denmark. The factory produces about 220.000 ton of fishmeal and 60.000 ton of fish oil. Meal and oil are produced using industrial fish caught for reduction. The input of fish in the database is 100 % sand eel. The production process is described in the following steps:

1) The raw material of industrial fish is boiled by an indirect supply of steam.
2) The cooked fish is separated into a dry fraction and a liquid fraction by pressing.
3) The fish oil is separated from the liquid fraction by centrifugation.
4) The press cake is dried at temperatures ranging from 70 to 100°C by means of indirect steam until a moisture content of 5-10%.
5) The dried press cake is cooled and milled into fishmeal and antioxidant is added.
6) The oil is packed in metal drums and the meal is packed in bags before delivery.

All production processes as well as heating and lighting are included, but packaging is not a part of the database. Inputs associated with fishmeal and oil production are shown in the table 10 below. Data are provided per kg of fishmeal at the factory's gate.

Table 10: Inputs to the production of fishmeal and oil.

Materials, fuels	Unit	Value
Sand eel	kg	4,66
Formaline (37 % Formaldehyd)	g	10,80
Antioxidants	g	0,31
Sulphuric acid, H_2SO_4	g	2,10
Sodiumhydroxide, NaOH	g	4,80
Nitric acid, HNO_3	g	0,52
Hydrochloric acid, HCl	g	0,38
Electricity	kWh	0,19
Heat	MJ	6,20

Outputs associated with fishmeal and oil production are shown in the table 11. Data are provided per kg of fishmeal at the factory's gate.

Table 11: Outputs from the production of fishmeal and oil.

Products	Unit	Value
Fishmeal	kg	1,00
Fishoil	kg	0,21
Wastewater to treatment	**Unit**	**Value**
COD	g	4,50
Nitrogen total	g	1,10
Phosphorous total	mg	31,00
Emission to sea	**Unit**	**Value**
COD	g	0,56
Nitrogen total	g	0,54
Phosphorous total	mg	5,20

The database was initially constructed so that the fish oil substituted the production of rape seed oil. This has been changed in the analysis in this study. Since fish oil is a by-product of fish meal an economic allocation has been used to determine the environmental impact from these products, it is assumed that the added demand at the BioMar plant does not affect the market prices. This implies that the environmental impact from fish meal and oil is the same per value. The price of fish meal used is 7,5 NOK/kg and for fish oil 5,25 NOK/kg (Elvestad, 2006). This means that 87 % of the impact is allocated to the production of fish meal and 13 % to the fish oil production.

The average age of fishing vessels is more than 30 years, but the diesel engines applied are modern and well maintained. Steaming to and from the fishing site, the fishing operation and eventual cool storage of fish on board are the processes are included in industrial fishing for sand eel. Constructing and maintenance of the fishing vessels are not included (detailed information at www.lcafood.dk).

Transport of the fishmeal and oil to Mongstad from Esbjerg is 700 km, equivalent to 0,85 tkm per fully grown 2 kg turbot.

3.4.1.2 Ingredients from agriculture

Wheat

The production of wheat is based on average Danish data. The Inventory includes all processes on the farm necessary for the cultivation and preservation of crops such as soil preparation, sowing, fertilizing, plant protection, harvesting, making silage and transport of crops. For detailed information see the LCA food database website www.lcafood.dk.

Inputs and outputs associated with wheat flour production. Data are provided per kg flour at the factory's gate.

Table 12: Inputs and outputs in the production of wheat flour.

Inputs	Unit	Value
Grain	kg	1.0
Water	l	0.1
Natural gas	kWh	0.1
Electricity	kWh	0.08
Ascorbic acid	mg	40
Outputs	**Unit**	**Value**
Flour	kg	0.8
Bran etc.	kg	0.2
Solid waste	kg	0.01

Transport of wheat from France is 1300 km, equivalent to 0,30 tkm per fully grown 2 kg turbot.

Potato starch / flour

The maizegluten ingredient is substituted by potato starch/flour production, because of lack of data. The data used refer to potato flour production in a specific factory in Karup, Denmark. The production process is described in the following steps:

1) Potatoes from local farmers are transported to the factory by trucks.

2) The potatoes are washed and rasped into fine particles in a rotating grater.
3) Fruit juice and solid matter are separated into two streams in a rotating decanter.
4) Fresh water is added to the stream of solid matter and pulp is separated from the starch by centrifugation.
5) Starch is refined in hydro cyclones and vacuum filters.
6) The concentrated slurry is dried in a warm air stream until a final water content of 20 percent.
7) The starch is stored and packed for final distribution to the market and sold as potato flour or potato starch.

All production processes as well as administration and product storage are included. Packaging and a number of chemicals are ignored, and transportation processes to and from the factory have not been included. The inputs and outputs of the potato starch/flour production

Table 13: Inputs and outputs in the potato starch production.

Inputs	Unit	Quantity
Potatoes	ton	4.5
Water	m3	5.7
Electricity	kWh	164
Natural gas (heating)	m3	23.7
Sulphuric acid	kg	9.8
Outputs	**Unit**	**Quantity**
Potato flour	ton	1.00
Potato pulp	ton	0.73
Fruit juice	m3	6.6
Washing water	m3	1.2

Allocation of environmental impacts is 100 % to the potato flour/starch production. Transport from USA is 5600 km, equivalent to 1,94 tkm per fully grown 2 kg turbot.

Soy meal

Soy beans are crushed industrially to produce soy meal used in the feed production and soy oil. Soy beans are imported from Argentina and environmental impacts associated with soy beans have been derived from farms in Argentina. The data refer to soy crushing in Switzerland in early nineties where the production processes are:

1) Soybeans are received from farms
2) The soybeans are pulverized
3) The pulverized beans are pressed and soy oil and soy meal are separated
4) Oil remaining in soy meal is extracted with hexane
5) Soy meal is toasted, granulated, cooled and stored for distribution
6) Soy oil from hexane extraction is gained by vacuum distillation and mixed with oil from obtained from pressing
7) Soy oil is refined and stored for distribution.

Production processes related to soy crushing are included. Packaging is not included, but transport from South America is accounted for in the database. Inputs and outputs associated with soy crushing are shown in table 13. Data are presented per ton of soy oil at the factory's gate.

Table 14: Inputs and outputs in the production of soy meal and oil.

Inputs		
Materials/fuels	**Unit**	**Quantity**
Soy Bean	ton	5.6
Hexane	g	376
Outputs		
Products	**Unit**	**Quantity**
Soy meal	ton	4.6
Soy oil	ton	1.0
Energy	**Unit**	**Quantity**
Heat	MJ	2240
Electricity	kWh	64.7
Emission to air	**Unit**	**Quantity**
Hexane	g	376
CO2	kg	140
CO	g	22.7
NOx	g	169
VOC	g	66.1
SO2	g	12.1
Emission to water	**Unit**	**Quantity**
BOD	g	0.09
COD	g	0.32
Nitrate	g	0.02

The database was initially constructed so that the soy oil substituted the production of rape seed oil. This has been changed in this study to no substitutions. All the environmental impact is allocated to the soy meal production in this assessment, since soy oil does not enter the system boundaries.

4 Investment and operational cost estimates

The investment and operational costs are used to calculate environmental impact from economic activity in an input output analysis. The construction relates to constructing the tank area and buildings. The three facilities represent three different processes in the foreground system of the matrix system. The costs of producing one juvenile in the larvae facility are covered by the purchase of juveniles by the nursery facility. The on-growing facility then has to purchase nursed juveniles from the nursery facility, thus bearing the nursery costs. The economic purchases are connected to the delegated sectors in the Norwegian input output table. The emissions matrix containing emission data for each sector is used to find the environmental impacts caused by the economic activity. The input-output tables are provided by Statistics Norway (2003). The detailed economic data are given in Appendix 3.

4.1 Brood stock and larval rearing

The brood stock and larval rearing facility is divided into different compartments producing phyto- and zoo plankton, eggs, larvae and weaned juveniles. There is also a general area with office locations and such. The data are from Minkoff et al (1994), adjusted to fit the production of 400000 weaned juveniles. Figure 3 show the distribution of investment costs in the brood stock and larval rearing facility.

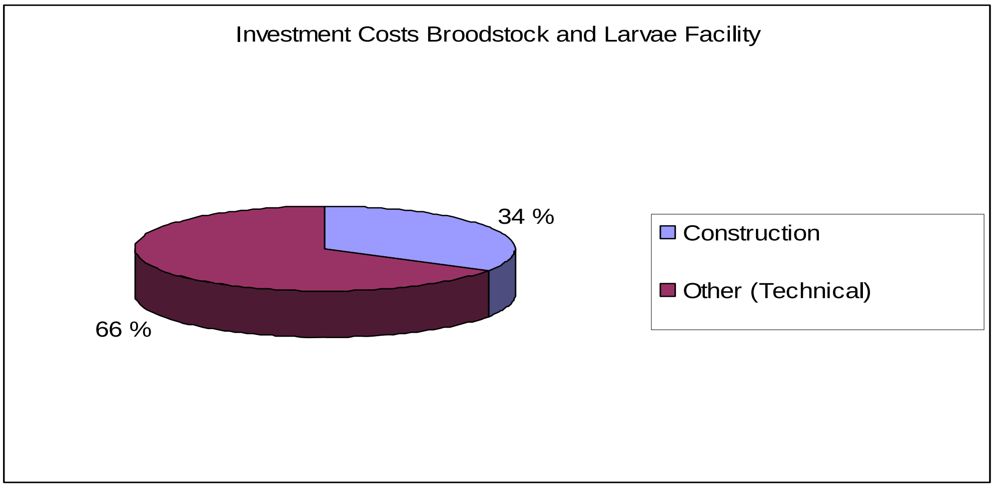

Figure 3: Investment costs for the brood stock and larvae facility.

Table 19 in appendix 3 show that the total investment costs are 6,65 million NOK. 34 % is associated with the construction of buildings and tanks, and 66 % is due to miscellaneous technical installations. Construction expenses are assigned to the construction sector in the input output tables, while technical installations have been designated to the most fitting sectors. The distribution of running costs connected to the brood stock and larvae facility are given in Figure 4:

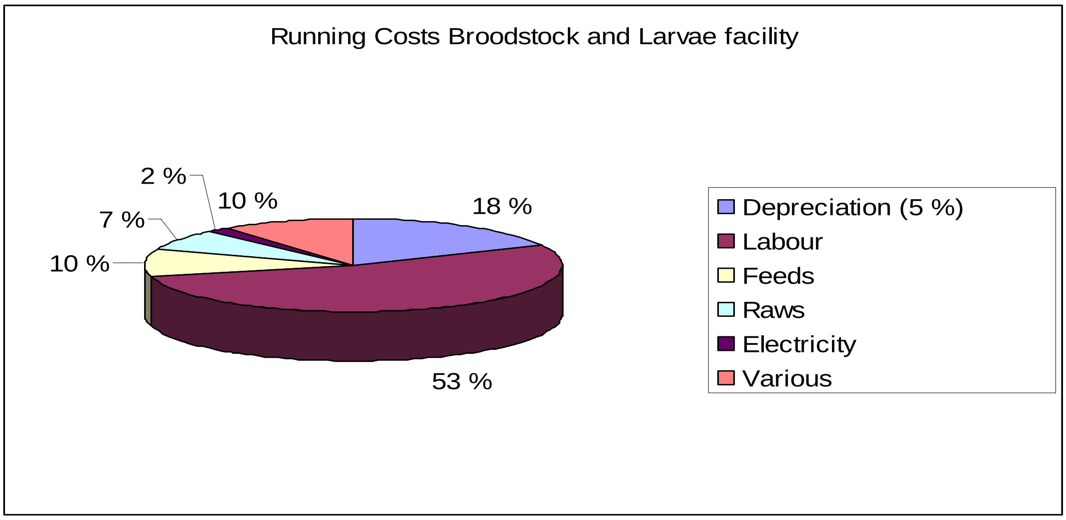

Figure 4: Running costs at the brood stock and larvae facility.

Table 19 in appendix 3.1 show that the running cost excluding depreciation is 2,5 million NOK. Including the down payment on investment, which stand for 18 % of the total running costs the annual costs are about 3 million NOK per year. When producing 400000 pre-nursed juveniles per year this results in a cost of approximately 7,50 NOK per juvenile. Labour costs are 53 % of the total costs, but costs connected to labour and depreciation will not enter the environmental assessment since it is assumed that the labour and down payments does not generate environmental impact. Expenditure on feeds and various costs connected to disinfection and water treatment each represent 10 % of the running costs, while raws, which is connected to raw materials required in the production of plankton feeds, and electricity stand for 7 % and 2 % respectively.

4.2 Nursery and on-growing

The cost estimates for the nursery and on-growing facilities are adapted from Engell Sørensen (2006). Table 20 in appendix 3.2 show that the total investment costs for the nursery facility is 10,5 million NOK. The distribution regarding investment costs in the nursery facility is given in figure 5.

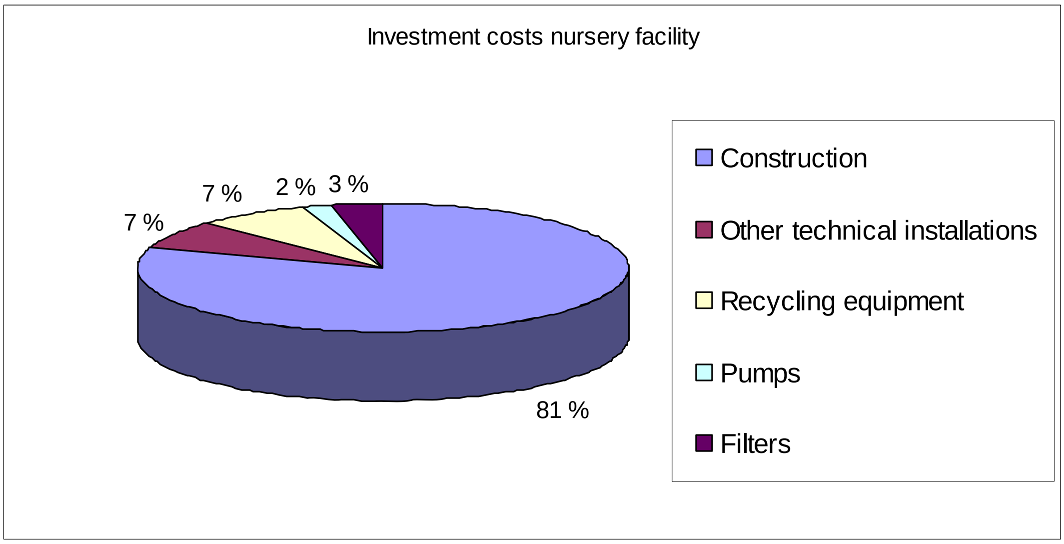

Figure 5: Investment costs in the nursery facility.

The construction of tanks and buildings stand for 81 % of the investment costs. The remaining 19 % is miscellaneous technical installations, where 7 % is various installations such as measuring, EDP and laboratory equipment. The recycling equipment stand for 7 %, the filters stand for 3 % and pumps in the system bears 2 % of the investment costs. Recycling equipment consists of pipes and other items needed to make the recycling of water possible.

Table 20 in appendix 3.2 show that the running costs for the nursery facility is 4.3 million NOK, excluding the expenditure on depreciation. Taking depreciation into account results in total running costs of 5,1 million NOK, equivalent to 16 NOK per nursed juvenile. The distribution of running costs is shown in figure 6.

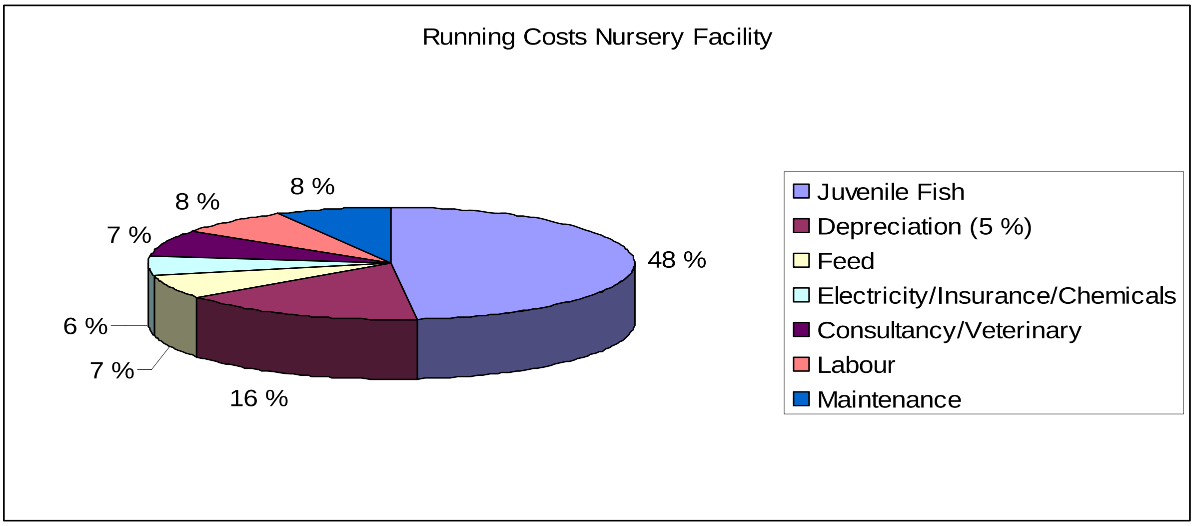

Figure 6: Running costs connected to the nursery facility.

The largest expenditures of the running costs are the input of Juvenile fish from the brood stock and larvae facility and depreciation with 48 % and 16 % of the total, respectively. Labour and maintenance each represents 8 % of the costs, and feed and consultancy and veterinary each represent 7 % of the costs. Electricity, insurance and chemicals stand for 6 % of the running costs. The electricity cost is based on electricity use in the building area only since running the pumps is set to the on-growing facility.

Table 21 in appendix 3.2 show that the total investment costs for the on-growing facility is 56 million NOK. The distribution regarding investment costs in the on-growing facility is given in figure 7.

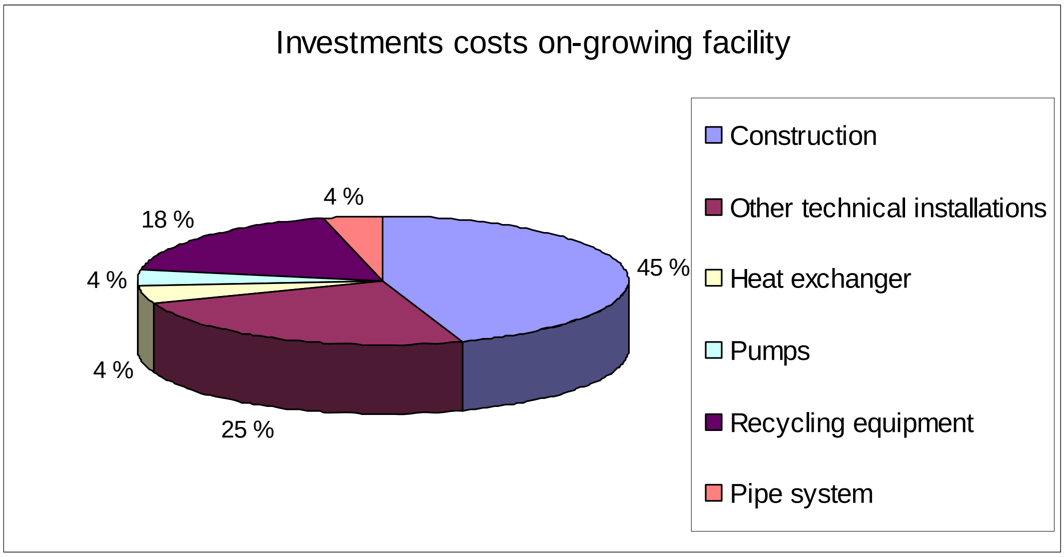

Figure 7: Investment costs in the on-growing facility.

The construction of tanks and buildings represent 45 % of the investment costs, while 55 % of the costs are connected to technical installations including pumps and heat exchanger.

Table 21 in appendix 3.2 show that the running costs for the on-growing facility is 16,9 million NOK, excluding the expenditure on depreciation. Taking depreciation into account results in total running costs of 21,1 million NOK, equivalent to 73,5 NOK perfully grown turbot. The distribution of running costs is shown in figure 8.

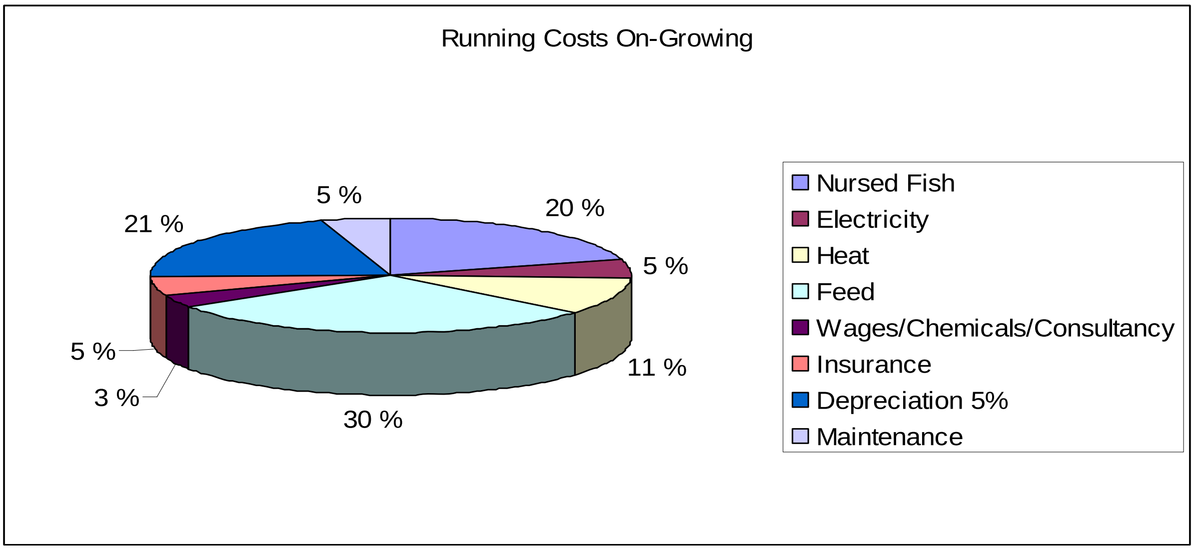

Figure 8: Running costs connected to the on-growing facility

The largest expenditure is on feed with 30 % of the running costs. Depreciation and costs connected to nursed juveniles comes next with 21 % and 20 % of the total costs respectively. The cost connected to the low grade heat from the refinery is 11 % of the total, and wages, chemicals and consultancy is 3 % of the total. Electricity, maintenance and insurance each represent 5 % of the running costs.

4.3 Assignment of purchases in the system to economic sectors

The Norwegian input output tables follow the classification of economic activities in the European community (NACE) (Eurostat, 2006). Every purchase in the system has been assigned to one of the economic sectors of NACE. Table 15 show which economic sector the purchases belong to:

Table 15: Assignment of processes based on economic data to economic sectors.

Process	Nr	Sector name
Recycling Equipment	29	Manufacture of machinery and equipment
Pipe system	25	Manufacture of rubber and plastic products
Water reservoir	45	Construction
Filters	29	Manufacture of machinery and equipment n.e.c.
Salt water intake	29	Manufacture of machinery and equipment n.e.c.
Freezing facilities	29	Manufacture of machinery and equipment n.e.c.
Aerial supply	29	Manufacture of machinery and equipment n.e.c.
UV-Water treatment	31	Manufacture of electrical machinery and apparatus n.e.c.
Pumps	29	Manufacture of machinery and equipment n.e.c.
Heat exchangers	29	Manufacture of machinery and equipment n.e.c.
Construction	45	Construction
Div. Technical Installations	29	Manufacture of machinery and equipment n.e.c.
Feed system and storage	45	Construction
Sewer, water, electricity connection	45	Construction
Sludge safekeeping	45	Construction
Emergency generator	31	Manufacture of electrical machinery and apparatus n.e.c.
Office equipment and such	30	Manufacture of office machinery and computers
Laboratory equipment	33	Manufacture of medical, precision and optical instruments, watches/clocks
EDP (hard/software, surveilance)	30	Manufacture of office machinery and computers
Chemicals, desinfection	24	Manufacture of chemicals and chemical products
Electricity	401	Electricity, gas, steam and hot water supply (40)
Plankton Production	5	Fishing, operation of fish hatcheries and farms; activities incidental to-
Insurance	65-	Financial intermediation
Heavy oil and Natural Gas	*232*	*Manufacture of coke, refined petroleum products and nuclear fuel (23)*

Heavy oil and Natural gas is acquired from sector 23, but purchases from this sector only occurs in the production alternatives where heavy oil or natural gas is used for heating the water in the facility.

5 Analysis

There has been some earlier work on LCA and fish farming. For example Papatryphon et al (2003) has conducted an assessment of trout farming in France with a farm level approach. The species and the production systems are different, but there are still some interesting findings with regards to this study on turbot. A significant variability was found in the impact categories for the same product species in the assessment of trout, mainly due to different production techniques and fish size. The feed processes are the major contributors to impact categories such as global warming and acidification, while the production phase contribute the most to eutrophication because of effluents from the system. This impact is mainly due to the emission of excess feed in the water. This report do not cover such emissions from the system, since the effluents is assumed treated in a way that cause no harm to the environment.

Papatryphon et al (2004) has conducted a more detailed analysis on environmental burden connected to the production of feeds. It indicated that a reduction in nutrient emissions at the farm and of biotic resource use is the most important environmental issues for feed development. The use of high quality plant ingredients and fish meal ingredients that are by-products of other processes, along with improvements in farm management to optimize feed efficiency and nutrient-waste removal, are potential means to reduce the environmental impacts of feed production. As mentioned there are no emissions of nutrients in our analysis. There has not been possible to assess the biotic resource use, with the method used in this study.

Mikkel Thrane (2004) has performed an LCA of many fish products, including 1 kg flatfish filet at consumer. Thrane has been involved in the creation of the Danish LCA food database (Nielsen et al, 2006) used in this assessment. His assessment on flatfish does not cover fish farming, but conventional fishing. The study shows that the most important stage for 1 kg flatfish filet, with respect to environmental impact, is the fishing stage and the fuel consumption. Fishing is a part of the feed production in fish farming through the manufacture of fish meal and oil, thus the results are interesting for our study for comparison.

5.1 Production system alternatives

The base case for the aquaculture facility has been described in the system description and in the cost estimates chapter. The heat flowing from the refinery is assumed to have no environmental impact, since it is an energy stream which is already in place and going to waste. To be able to quantify and evaluate the heat integration with the refinery, a set of production alternatives with other possible energy solutions for heating the water in the facility is calculated. This means that the facility is not dependant on a co-location with the refinery at Mongstad. The different scenarios will have the same parameters as the base case, such as average wind and temperature in the calculations of heat loss, and the transport of feed from Vesterålen. Therefore the location is limited to the same geographical area, meaning Nord-Hordaland or close to Bergen. There are some investments that will be redundant when analysing the production systems with the other heat sources. As opposed to the base case the heat exchanger will not be a part of the alternative production systems. Investments regarding installation of boilers to utilise the other heat sources will not be taken into account, thus only the obtaining and use phase or combustion of the energy sources is taken into account. The energy sources used for heating the water in the alternative production systems are electricity and combustion of natural gas and oil. The environmental impact of extracting and processing the energy sources will be calculated by using the input-output background system, while the emissions from combustion enter the emissions matrix directly.

5.1.1 Electricity

As shown in chapter 3.3 the total heat requirement from pumped seawater and heat loss from the tanks is close to 31 GWh/yr equivalent to 107,5 kWh per fully grown turbot. This is the amount of heat needed to maintain the necessary temperatures in the aquaculture system, thus it is the required amount of heat to be produced. This amount of electricity is purchased from the Norwegian grid where the electricity is produced by a renewable energy source through hydro power. The analysis disregards any imports to the Norwegian electricity market in the electricity scenario. Since the Norwegian electricity mix of today is incapable of supplying the demand of the near future, it could be argued that the marginal kWh in Norway is based on natural gas, and that a gas fired power plant should form the basis for environmental impact. The production system using natural gas combustion on-site will come close to assess a system where electricity is produced by natural gas.

The unit price of electricity is 0,266 NOK/kWh (IEA, 2003), which means an annual cost of 8,23 million NOK. The heat price per fully grown turbot will be 28,57 NOK/fish*yr, which means that the price for a fully grown turbot increases by 19,26 NOK compared to the base case, where the heat costs were 9,31 NOK/turbot. The increased electricity consumption will be added to the purchases from the energy sector for the on-growing facility and the increased environmental impact is calculated by the input output background system.

5.1.2 Heavy fuel oil

Total heat requirement for heating the pumped seawater and compensating for heat loss from the tanks is 31 GWh/yr, or 107,5 kWh per produced fish. The unit price for heavy fuel oil in Norway is 497,88 USD/tonne (IEA, 2003). This equals 0,281939 NOK/kWh using currency exchange from Oanda (2006), where 1 USD was 7,078 NOK in 2003, and an assumption that one ton oil equals 45 GJ or 12500 kWh. This means that the annual expenditure on heating the water in the facility is 8,73 million NOK. The heat price per 2 kg turbot is 30,28 NOK, an increase of 20,97 NOK per fish compared to the base case.

The purchase of heavy oil from the refined petroleum products sector is set to the on-growing facility, and the upstream environmental impacts of the extracting and refining the oil is calculated by the input output background system. The direct air emissions from the combustion of oil have to enter the emissions matrix F, and the emissions data is taken from the EcoInvent database developed by the Swiss centre for life cycle inventories (2006). An average European furnace of 1 MW is used as a unit process from the database and only the emissions to air from combustion are accounted for. The reference year for the non-modulating, non-condensing furnace is 2000.

5.1.3 Natural gas

Total heat requirement for heating the pumped seawater and compensating for heat loss from the tanks is 31 GWh/yr, or 107,5 kWh per produced fish. The unit price for natural gas is assumed to be the same as the european price level at €35/MWh, following the general directorate on energy and transport of the European commission (DG, 2006). This equals 0,2869 NOK/kWh using currency exchange from Oanda (2006), where 1 EUR was 8,198 NOK This means that the annual expenditure on heating the water in the facility is 8,88 million NOK. The heat price per 2 kg turbot is 30,82 NOK, an increase of 21,51 NOK per fish compared to the base case.

The purchase of natural gas from the refined petroleum products sector is set to the on-growing facility, and the upstream environmental impacts of the extracting and refining the gas is calculated by the input output background system. The emissions from the combustion of natural gas have to enter the emissions matrix F, and the emissions data is taken from the EcoInvent database developed by the Swiss centre for life cycle inventories (2006). A low NO_x furnace larger than 100 kW is used, and only the direct emissions to air from combustion are taken into account. It is an average European furnace extrapolated from Switzerland. The technology is from mid 1990's, and the emissions are from the early 1990's.

5.1.4 Production cost comparison between the production alternatives

Chapter 4 presented the costs related to the aquaculture facilities. Larvae production, nursing and on-growing in the base case had a production cost of 73,5 NOK per 2 kg turbot. This includes construction, installation of technical equipment, purchase of feed, depreciation at 5 % over 20 years, heat costs, wages and other operational costs. The different energy sources has varying energy price. Based on the calculations above, figure 9 show the production costs per fully grown turbot for the base case where heat from the refinery is used, as well as for using electricity, oil and gas to heat the recycling water in the facility.

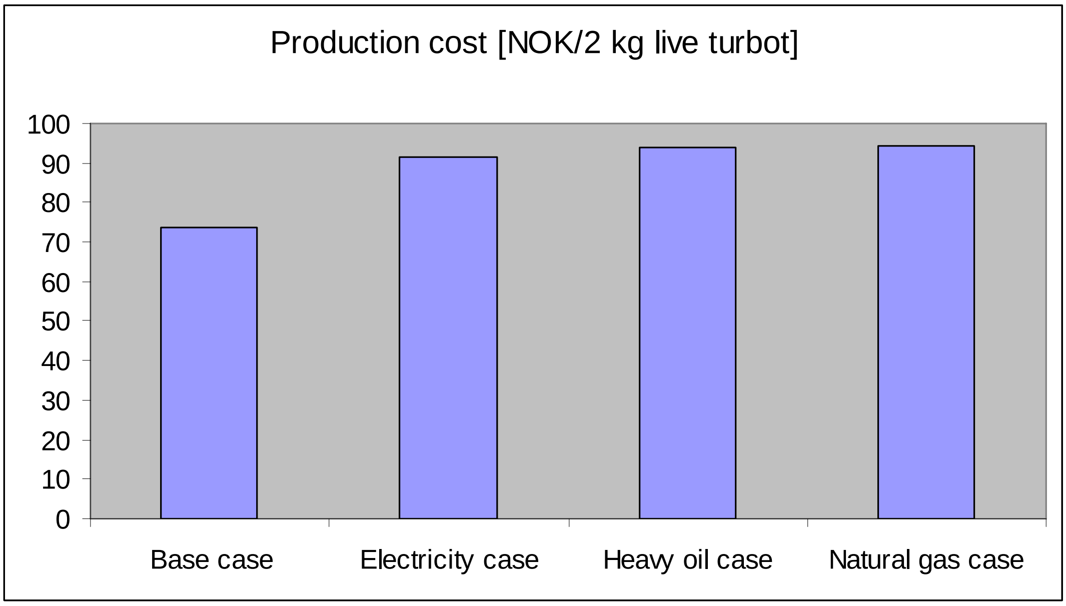

Figure 9: The production cost for the different production alternatives.

The difference between these systems is the source of energy to heat the water. The base case has the lowest cost at 73,5 NOK/2 kg live turbot, while the other alternatives raises the cost with approximately 20 NOK per 2 kg live turbot.

5.2 Results

After exporting the data from the LCA databases in Simapro (Pre, 2006), all the matrices and vectors were assembled in Matlab. Appendix B contains parts of the raw results, namely processes causing more than 1 % of the impact in each impact category, and the most important paths from structural path analysis in the base case are give.

5.2.1 Comparing the feed production with the other processes

The base case describes the impacts from the aquaculture activities, disregarding impacts from heating the water volume. Environmental impacts from the production of one 2 kg live turbot were calculated with the methodology described in chapter 2. The total results for each impact category selected in chapter 2.4.1, are given in table 16:

Table 16: Impact assessment results for producing one 2 kg live turbot with the base case.

Impact category	*Name*	*Value*	*Indicator*
ADP	Abiotic Depletion	0,014310325	kg Sb-equivalents
GWP	Global Warming	4,419102813	kg CO_2-equivalents
ODP	Ozone Layer Depletion	1,64613E-06	kg CFC-11-equivalents
HTP	Human Toxicity	0,960196918	kg 1,4-DB-equivalents
TETP	Terrestrial Ecotoxicity	0,005588915	kg 1,4-DB-equivalents
PCOP	Photochemical Oxidation	0,000820294	kg C_2H_2-equivalents
AP	Acidification	0,024240972	kg SO_2-equivalents
EP	Eutrophication	0,007913294	kg PO_4^{3-}-equivalents

In the base case, where heat is extracted from the existing energy stream from the refinery, there are no direct emissions in the foreground system. All of the impacts in table 16 are generated from the input output- and lca database background systems.

The feed system is represented by the B-LCA system, and the investment and other operations at the fish farm is represented by the B-IOA system. Figure 10 show the impacts distributed to the two background systems.

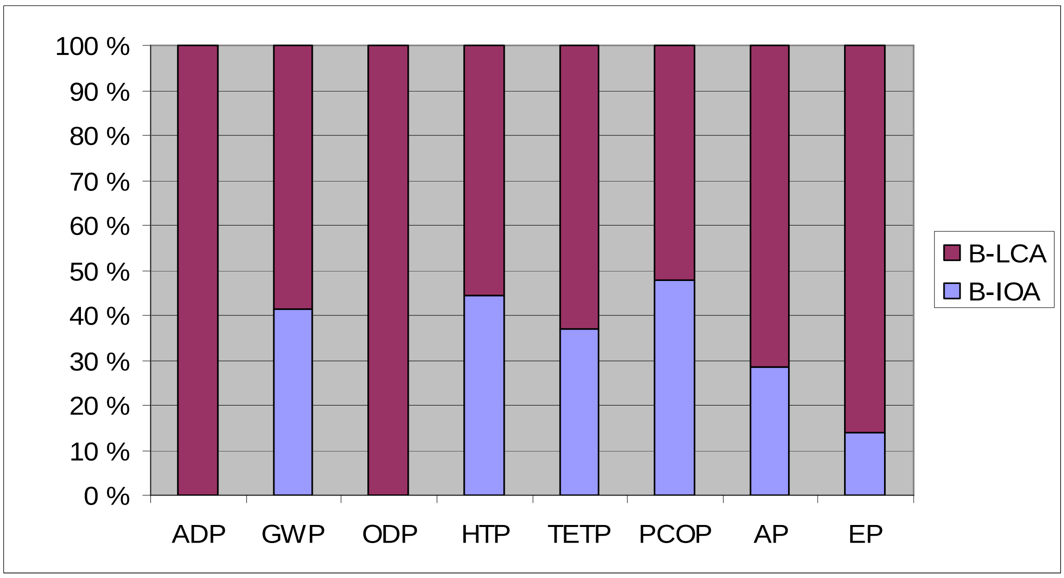

Figure 10: Distribution of impacts between the economic inputs (B-IOA) and the database inputs (B-LCA)

The feed production cause more impact in all impact categories than all the other activities in the aquaculture system. Since the substances causing abiotic and ozone depletion is not a part of the emissions data in the input output tables, the impacts in these categories are solely caused by the feed production. For global warming, human toxicity and photochemical oxidation the two systems have approximately equal impact load, while the upstream feed production processes dominates the terrestrial ecotoxicity, acidification and eutrophication categories by 62 %, 71 % and 83 % respectively.

5.2.2 Identifying processes and stressors leading to environmental impact in the base case

The D matrices described in chapter 2.5.3 generate the environmental impacts on each impact category from the different processes and stressors. In addition a structural path analysis (SPA) has been performed on the system, showing the paths of production processes which contributes to each impact category. The contribution to the total impact given in this chapter is based on the most contributing processes in the D_{pro} matrix, and the most important processes are presented graphically. This information does not say whether a production process contributes to the aquaculture or fishery value chains. For this the SPA is used. The 50 most contributing paths in each category have been considered when describing the impacts. The on-growing facility is by far the part of the system that generates the most impact in all categories; therefore it is not practical to compare the facilities. Most of the processes causing impact in the system can be allocated to the on-growing facility directly, but 4,5 % of the feed consumption occurs in the nursery facility. This chapter will present the most important processes in each impact category, mention the most important stressors and describe some of the important paths.

5.2.2.1 Abiotic depletion potential

The stressors regarding ADP are the extraction and depletion of fossil energy resources.
Figure 11 show the five most contributing processes to abiotic depletion in the system.

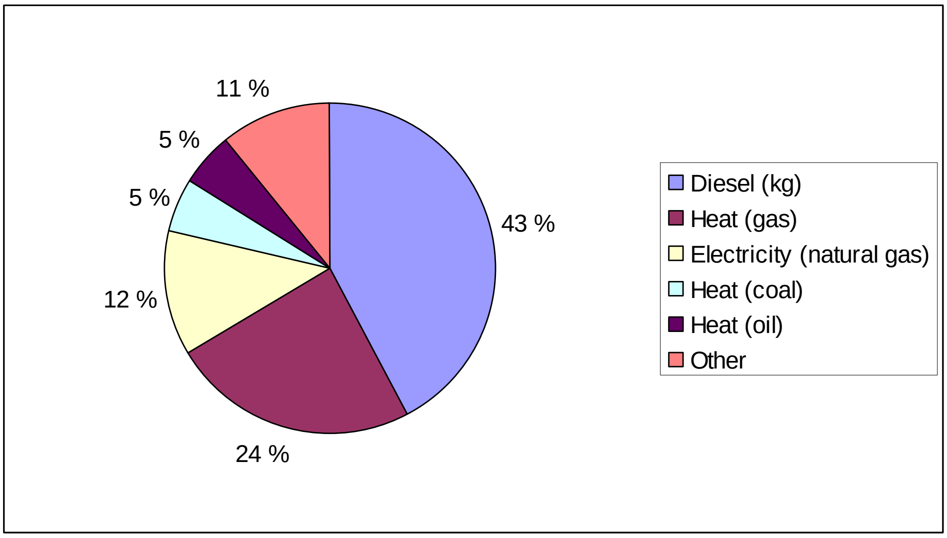

Figure 11: The processes contributing the most to ADP.

The process contributing the most to ADP is the upstream extraction of oil in the production of diesel, which stand for 42 % of the total contribution to this impact category. The SPA show that 87 % of the consumed diesel in the system is consumed by fishing vessels providing sand eel, the raw material in the fish meal and fish oil production. Traction in the production of potatoes, soy and wheat stand for 8 % of the diesel consumption.

The extraction of natural gas, used in heating processes is the second largest contributor to the ADP, covering 24 % of the total impact. The SPA shows that 90 % of extraction of natural gas for heat purposes is caused by the fish industry in the production of fish meal and fish oil. The processes of agricultural fish feed ingredient production is a part of the natural gas based heat consumption. Natural gas extracted to produce electricity stands for 12 % of the total ADP. Out of the 50 most important paths, the fish industry stands for 70 % of this natural gas consumption, while the production of potatoes and potato starch stand for 24 %. Depletion of coal and oil for heating purposes each stand for 5 % of the total impact and the paths are dominated by the fish industry.

The processes assembled from the LCA database contain system processes, which mean that when using diesel, heat and electricity the stressors from extracting the raw material is taken into account. That is why the diesel production appears as the most important process and not the upstream oil extraction.

5.2.2.2 Global warming potential

This is an impact category where the input output data has the same level of detail as the database system, because all the important contributors like CO_2, N_2O and methane emissions to air is a part of the input output dataset. The stressor contributing the most to the GWP is CO_2, covering 80 % of the impact. Emissions of N_2O and methane stand for 11 % and 8,5 % of the impact respectively. Figure 12 shows the five largest contributing processes to GWP, and the collective share of other contributing processes.

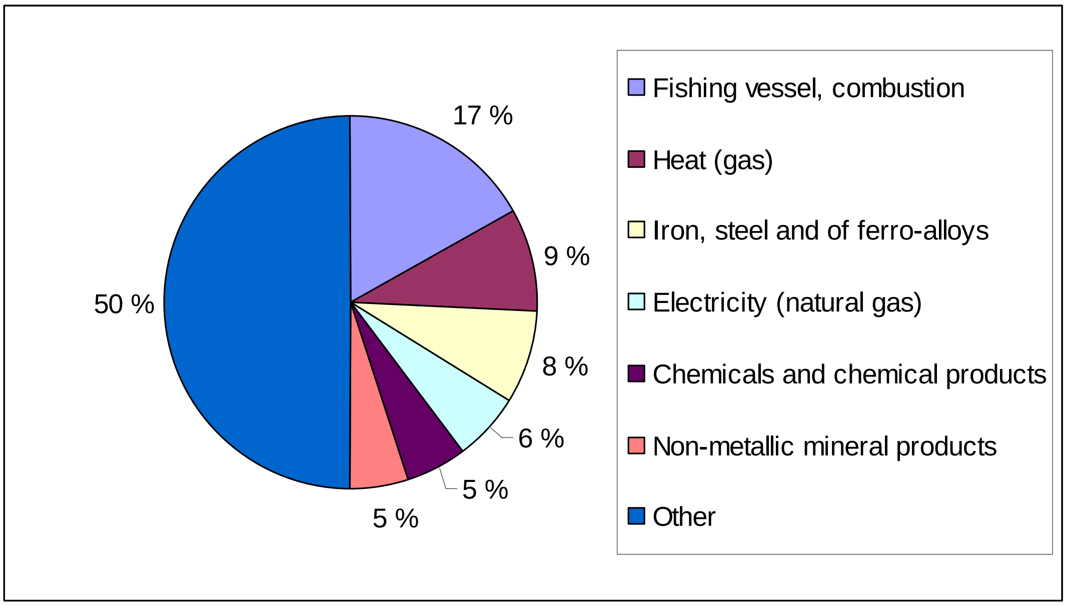

Figure 12: Five largest contributors to GWP.

Other processes have the largest share of figure 12, but none of them contribute more than 3 % alone to the total. The single most contributing process, with 17 % of the impact, is the combustion of diesel in the engines of fishing vessels providing raw materials for the fish meal and fish oil production, which is an important part of the feed produced in the system.

As mentioned under ADP, the fish industry stands for 90 % of the natural gas based heat consumption through the production of fish meal and fish oil. Combustion of natural gas for heat purposes is the second largest contributor, and stands for 9 % of the total impact in the GWP category.

Purchases from the economic sector manufacture of Iron, steel and Ferro alloys stand for 8 % of the impact to GWP. All of the purchases can be traced back to building the facilities in the SPA, and the single largest consuming group of items is the recycling equipment used in the on-growing facility, representing 17 % of these purchases.

The use of electricity generated by natural gas combustion stands for 6 % of the GWP. Out of the 50 most important paths in the system, the fish industry is responsible for 68 % of this process, while the production of potato starch and potatoes at farm contribute 10 %.

Various chemicals and chemical products are needed in the building of the facilities, and the production of these stand for 5 % of the impact. In the SPA the largest consumers of these products are the pipe system (11%), disinfection in the larvae facility (8 %) and construction of the on-growing facility (6 %).

The manufacturing of non-metallic mineral products contributes 5 % of the impact to GWP. Construction of the nursery and on-growing facilities dominates this sector with 57 % of the purchases.

5.2.2.3 Ozone depletion potential

The impact in the ODP category is caused by the flame retardant bromotrifluoromethane or Halon 1301. Other stressors stand for below 1 % of the impact. Figure 13 show the three most important processes contributing to ODP:

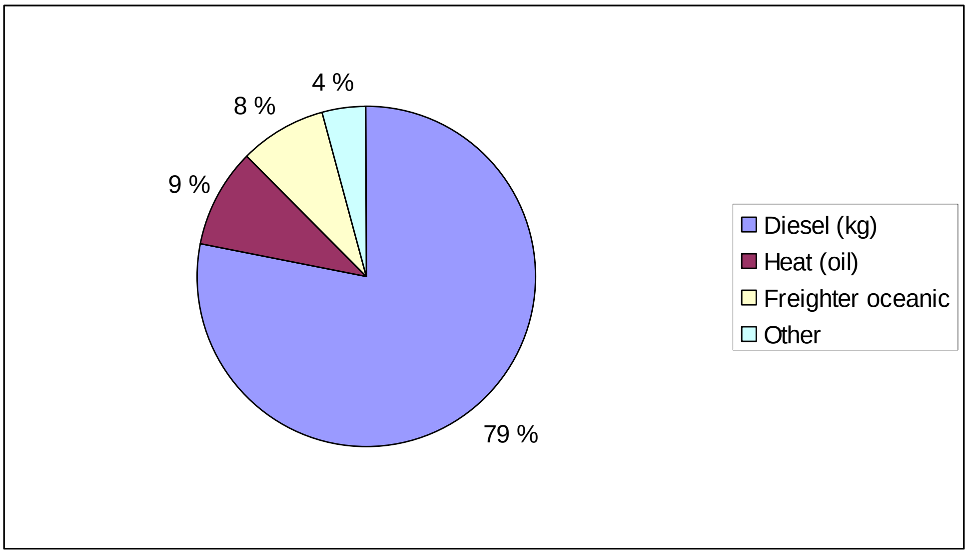

Figure 13: The three largest contributors to impact on ODP.

The systems demand on diesel stand for 79 % of the impact to ODP. Extraction, production and distribution of oil for heating purposes stand for 9 % of the ODP. The fish industry utilises 97 % of the heat based on oil resources. Transporting feed ingredients and feed by sea stand for 8 % of the impact.

5.2.2.4 Human toxicity potential

The stressors causing the most impact in the HTP category are polycyclic aromatic hydrocarbons (48 %), Barite (14 %), Arsenic (9 %) and Nickel (5 %). The most important processes regarding this impact category are given in figure 14:

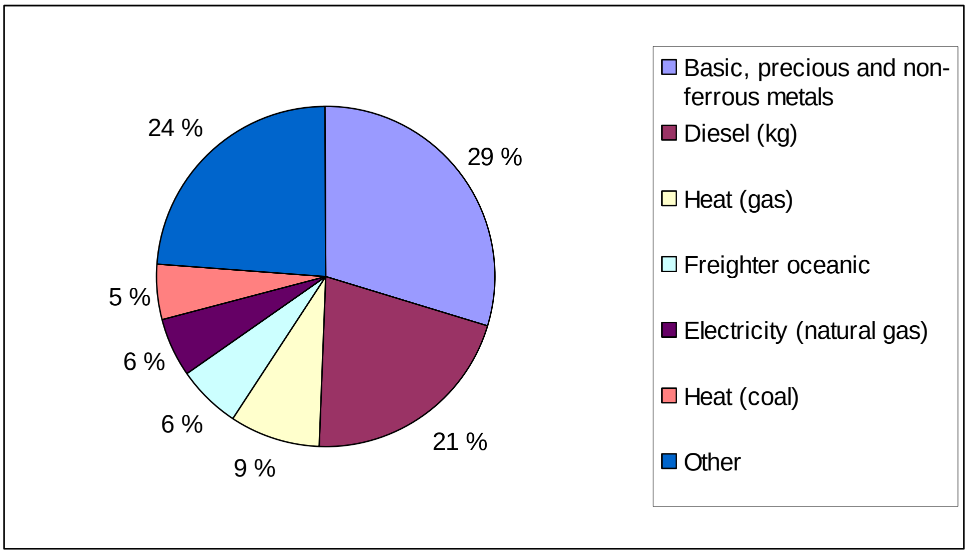

Figure 14: The processes contributing the most to human toxicity.

The largest source of impact in the system is the purchases of basic, precious and non-ferrous metals, causing 29 % of the impact. The purchase of technical equipment needed in the facilities and for constructing the fish tanks is the reason for this generated impact. Production of diesel and connected activities stand for 21 % and gas for heating purposes 9 % of the impact, and according to the SPA this is caused by the fish industry and agricultural sector providing raw materials for the turbot feed.

Oceanic freight and the use of electricity produced by natural gas cause 6 % of the impact each, and is both a part of the feed production processes with the most important paths connected to the fish industry in both processes. Heat produced by coal contribute 5 % to HTP, and is used in the Danish production of marine raw materials for the feed production. Other processes stand for 24 % of the impact.

5.2.2.5 Terrestrial ecotoxicity potential

The stressors leading to the most impact in the TETP category is Vanadium (51 %), Mercury (38 %) and Arsenic (8 %). The processes leading to the largest impact are shown in figure 15:

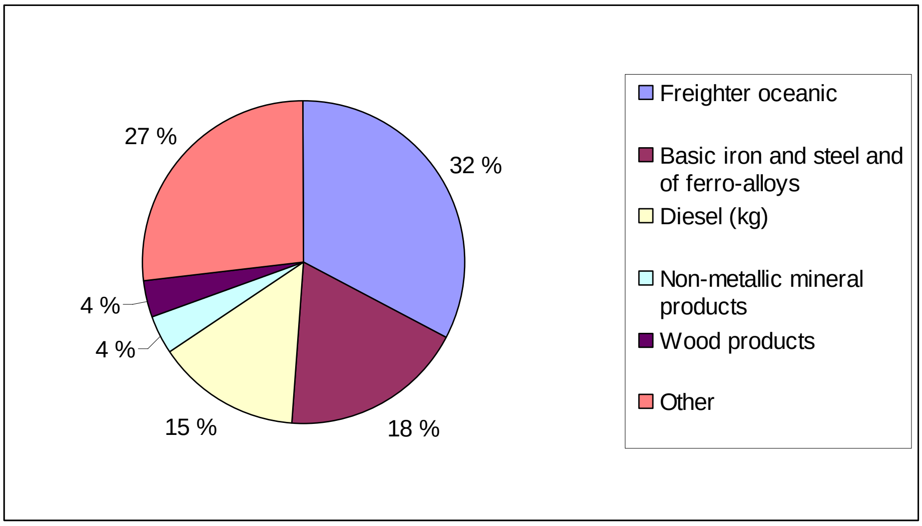

Figure 15: The processes leading to largest impact on TETP.

Oceanic freight, supplying ingredients to the feed production and the turbot feed to Mongstad, represent 32 % of the impact by releasing substances to air by fuel combustion. Manufacturing basic iron, steel and ferro-alloys for technical equipment in and construction of the facilities contribute 18 % of the impact. Production of diesel stands for 15 % of the consumption, and is caused by the upstream feed production processes. Purchases of non-metallic mineral products and wood products by the fish farming facilities each stand for 4 % of the impact.

5.2.2.6 Photochemical oxidation potential

PCOP is caused by different substances, and many of them are hydrocarbons. The most important stressors are Carbon monoxide (35 %), Sulfur oxides (23 %), Sulphur dioxide (18 %), Methane (12 %) and Nitrogen dioxide (3 %). Figure 16 shows the five largest contributors to impact in the PCOP category.

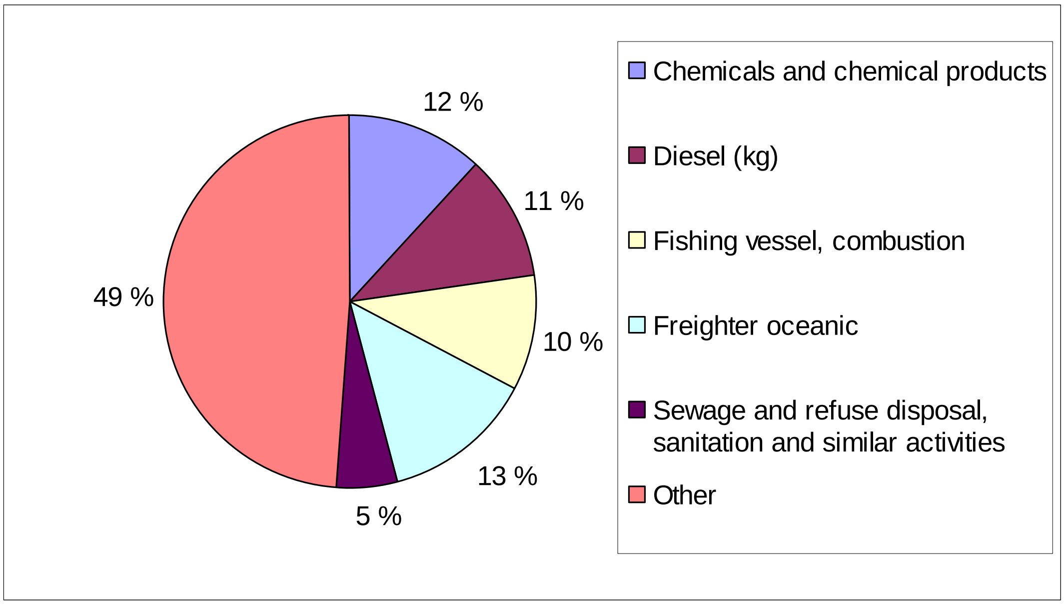

Figure 16: The five most important processes in the PCOP category, compared to other processes.

The single most contributing processes are freight connected to the feed production (13 %), and the purchase of chemicals and chemical products with 12 % of the total impact. The SPA shows that the largest purchases from the chemical sector are connected to the pipe system and the disinfection in the construction and operation of the facilities. The production of diesel and related upstream processes stand for 11 % of the impact, and combustion of diesel in fishing vessels contribute 10 % of the impact. Purchases from the sewage and refuse disposal sector contribute 5 % through the construction of the fish tanks and buildings. Many processes generate relatively small impacts in this category, and other processes that are not mentioned stand for 49 % of the impact.

5.2.2.7 Acidification potential

Nitrogen oxides (50 %), sulphur oxides (including SO_2) (34 %) and ammonia (15 %) are the most important stressors leading to environmental impact in the AP category. The processes contributing the most to environmental impact in the AP category are shown in figure 17:

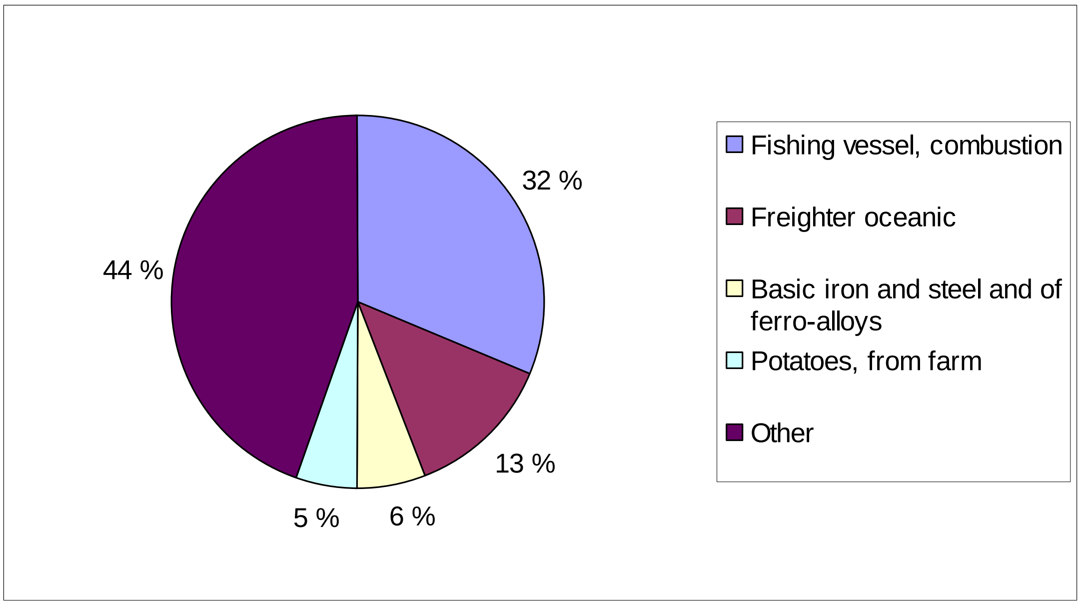

Figure 17: The four most important processes in the AP category.

Combustion of diesel in fishing vessels is the single most contributing process to AP in the system, contributing 32 % to the total impact. The fishing vessels are used in industrial fishing for sand eel used in the production of fish oil and meal. Oceanic transport of fish feed and feed ingredients cover 13 % of the total impact. Out of the four single most contributing processes purchases from the manufacturing of basic iron and steel sector stand for 6 % and the production of potatoes at farms represent 5 % of the environmental impact. Iron and steel goes into the production of technical equipment. Other processes collectively contribute 44 % of the total impact.

5.2.2.8 Eutrophication potential

The stressors contributing the most to the eutrophication potential is Nitrate (44 %), NO_x (40 %) and Ammonia (10 %). Figure 18 present the five single processes most important to the EP:

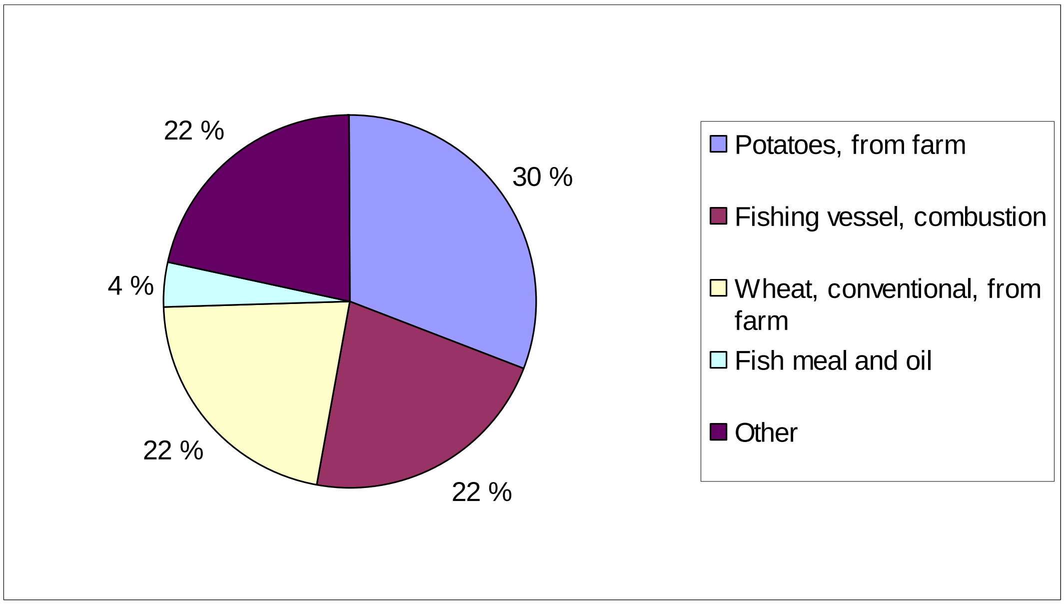

Figure 18: Five most important processes causing EP.

The largest contributor with 30 % of total impact to eutrophication potential is potatoes from farm delivered to the potato starch/flour production, which enters the feed production. The combustion process in fishing vessel cover 22 % of the impact and the production of wheat also stand for 22 %. Production of fishmeal and oil combined contribute 4 % to the total impact. Other processes collectively stand for 22 % of the impact.

5.2.3 Comparing production alternatives

Table 17 shows the overall comparison of the different production systems in terms of percent increased environmental impact in every impact category, compared to the base case.

Table 17: Percent increased environmental impact for the production alternatives compared to base case

Impact category	*Base case*	*Electricity case*	*Heavy oil case*	*Natural gas case*
ADP	0 %	0 %	0 %	0 %
GWP	0 %	6 %	83 %	68 %
ODP	0 %	0 %	0 %	0 %
HTP	0 %	4 %	169 %	28 %
TETP	0 %	4 %	997 %	7 %
PCOP	0 %	9 %	88 %	19 %
AP	0 %	4 %	85 %	19 %
EP	0 %	2 %	17 %	13 %

Heating the water with electricity purchased from the Norwegian grid increases the photochemical ozone depletion potential by 9 %, and global warming potential by 6 %. Acidification-, human toxicity-, terrestrial ecotoxicity- and eutrophication potential increases by 4 %, 3 %, 3 % and 2 % respectively. The reason for these moderate increases is the hydro power production dominating the Norwegian electricity production.

When switching to combustion of fossil fuel to heat the water, it results in large increases in most of the impact categories. Huge increases for human and terrestrial toxicity, 169 % and 997 % respectively, in the heavy oil case are caused by substances such as Vanadium, Nickel, Arsenic, Mercury and PAH (polycyclic aromatic hydrocarbons) released to air in the combustion process. GWP increases with 83 % in the heavy oil case and 68 % in the natural gas case. The largest increases in the TETP, PCOP, AP and EP categories are caused by the production of fuels, while the combustion causes the increased impact in GWP and HTP categories.

As opposed to the base and electricity cases, the heavy oil and the natural gas case has on-site emissions, occurring in the foreground system. The reason for no abiotic depletion and ozone depletion potential increase when using fossil energy sources in the system is that the combustion process does not account for resource consumption and emits no chlorine compounds. The ADP and ODP is not a part of the input output tables, therefore there are no impacts in these categories when purchasing fuels from the petroleum refining sector. These categories will be disregarded when comparing the production alternatives.

The impacts in the categories with contribution from both background systems in the base case are divided into process groups, and the result is presented in figure 19. This makes it possible to graphically describe the comparison between the production alternatives.

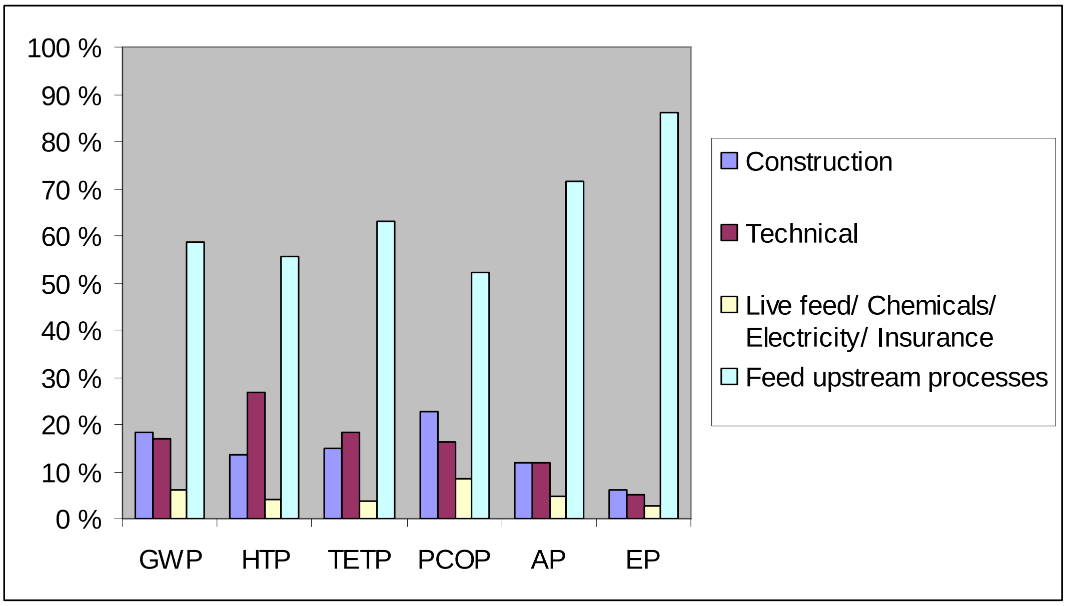

Figure 19: Percent contribution to impact in selected impact categories from four groups of processes in the base case.

After the upstream processes of feed production it is the construction of facilities and installation of technical equipment that contribute the most to the environmental impact in each category. Operational processes such as live feed production, use of chemicals and electricity cause little impact in all categories. The impact from the use of electricity includes the electricity used in the production of feed, pumps and buildings.

5.2.3.1 Heating water by electricity

The increases in environmental impact, when using electricity instead of heat integration with the refinery to heat the water, are caused by the increased expenditure on the electricity sector, which increases the economic activity in all sectors connected to it. The most important processes and stressors are the same as for the base case. The relative increase in impact caused by increased purchases in the electricity sector compared to the base case is shown in table 18:

Table 18: Relative increase in impact by the electricity sector caused by heating the water with electricity.

Impact category	*Name*	*Percent increase*	*Indicator*
GWP	Global Warming	448 %	kg CO_2-equivalents
HTP	Human Toxicity	459 %	kg 1,4-DB-equivalents
TETP	Terrestrial Ecotoxicity	462 %	kg 1,4-DB-equivalents
PCOP	Photochemical Oxidation	436 %	kg C_2H_2-equivalents
AP	Acidification	461 %	kg SO_2-equivalents
EP	Eutrophication	471 %	kg PO_4^{3-}-equivalents

Table 18 show that the relative impact from the electricity sector is approximately 4,5 times higher in all impact categories. The clean electricity production in Norway is the reason why this increase is relatively small in the overall comparison shown in table 17.

5.2.3.2 Heating water by heavy oil

The largest increases in impact, when using heavy oil to heat the water volume, come from the combustion of oil directly at the fish farm. There are also increases caused by the purchase of oil from the petroleum sector.

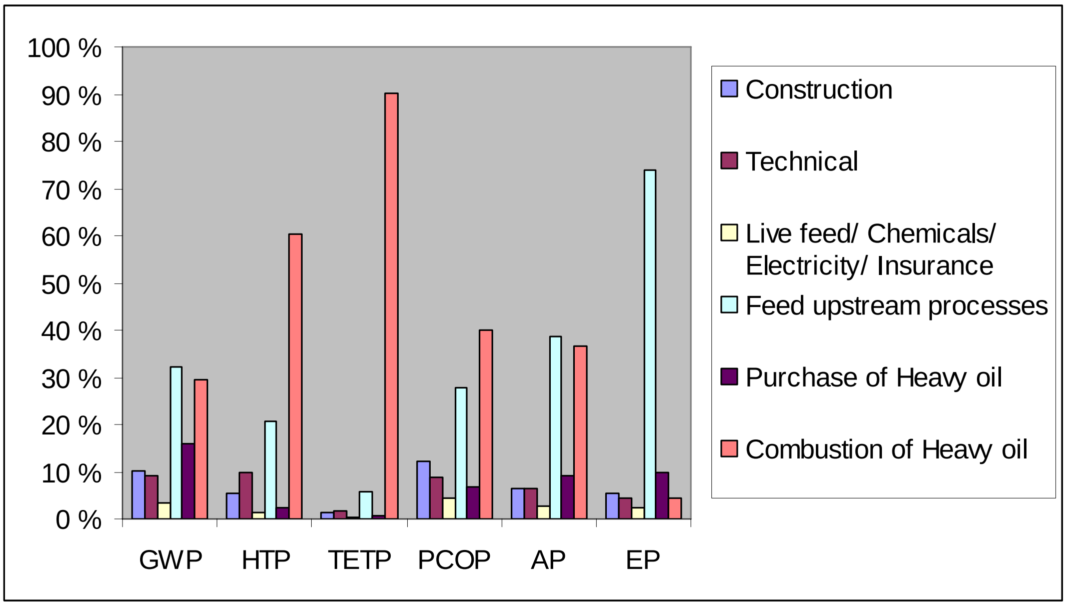

Figure 20: Percent contribution to impact in selected impact categories from six groups of processes in the heavy oil case.

The upstream processes of feed production contribute the most impact to the global warming potential with 33 % of the total in this production system. Combustion of heavy oil represent 30 % of the total impact in the GWP category and the purchase of heavy oil from the input output system stand for 17 %. The direct combustion of oil dominates the toxicity categories with 60 % for HTP and 90 % of TETP. The combustion and production of fossil fuels result in less upstream feed processes domination of the PCOP and AP categories. Eutrophication potential have 72 % impact coming from the processes of providing raw material to the feed production, which is caused by agriculture activities and combustion of diesel in fishing vessels.

5.2.3.3 Heating by natural gas

The upstream feed processes generate the largest share of impact in all categories when heating the water in the system with the combustion of natural gas. Figure 21 show the percent contribution from selected groups of processes in the natural gas case:

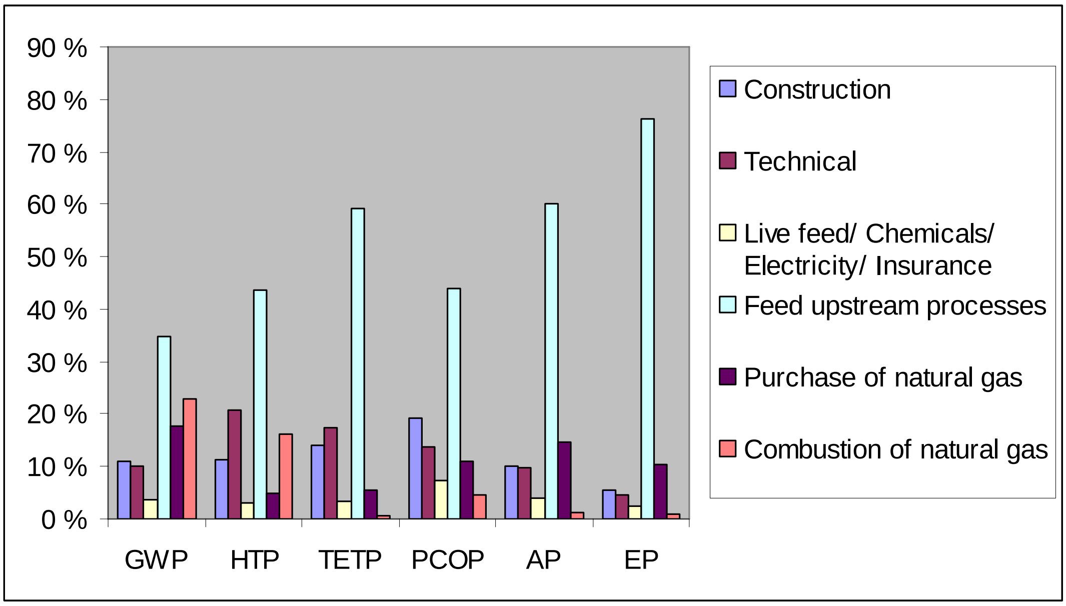

Figure 21: *Percent contribution to impact in selected impact categories from six groups of processes in the natural gas case.*

As shown in table 17, the introduction of natural gas as energy source leads to 68 % increase in total GWP in the system. 56 % of the increase is due to combustion, while 44 % is caused by the refining of gas. The production and combustion of natural gas combined stand for 40 % of GWP in this case, while the turbot feed ingredient processes contribute 35 %. Construction and technical installations each stand for approximately 10 % of the total impact.

The HTP category is dominated by the feed upstream processes (59 %), followed by technical installations (20 %). Combustion of natural gas stand for 18 % of the impact in HTP. The introduction of natural gas does not affect the TETP category much, but the production of gas has an impact of 6 % of the total. The production of gas also contributes more than combustion in the AP category, where it stands for 14 %. The EP is still dominated by the upstream feed processes (76 %), while the purchase of natural gas leads to 10 % of total impact in this category.

5.3 Discussion

The results coincide with the findings of Papatryphon (2004, 2003) and Thrane (2004), and show that fishery and other feed ingredient processes as one of the most important sources of impact regarding fish farming.

It can be argued that the upstream feed processes, obtained from databases, are causing more impact in the assessment because this part of the system is more detailed and contains more substances than the input output system. Calculations regarding the base case exclusively accounting for the emissions represented in the Norwegian input output dataset for both systems were conducted. These calculations indicated very small changes in the global warming potential, where impact from the upstream feed processes decreased by below 1 %. For the other categories the decreases in impact were larger, especially for the toxicity categories where the impact decreased by more than 80 %, which means that processes not involved in the value chain of feed production would cause most impact in these categories if only the emissions from the input output tables were accounted for. This underlines the problem of different system boundaries in different parts of the system regarding which stressors to include in this study. This assessment has focused on reporting the environmental impacts found in the system, and the consistency between sub compartments of the system yields to this comprehension.

There is system processes used in the assessment; this leads to that the manufacturing and maintenance of fishing vessels are not taken into account, while the manufacturing of tankers and end of life are a part of the assessment in the oceanic freight processes. The production of diesel is the most perceptible system process in the assessment; all upstream processes are taken into account in this process. Use of heat and electricity in the LCA database processes are also system processes.

There are no emissions in the foreground system in the base case, since all emissions are generated in the background matrices. An alternative would be to set the emissions from the input output dataset directly to the operations in the foreground system, but since several processes in the foreground system have purchases from the same economical sectors this was viewed as less practical.

The economic sectors in the input output tables are broadly defined. For instance is the expenditure on the construction sector in the whole system equal to 0,026 % of the total production in the construction sector of the input output tables. This means that the fish farm is accounted for 0,026 % of the emissions caused by the total construction sector, assuming that the relationship between expenditure and emissions are proportional. This could be regarded as an uncertainty when considering a small system like one fish farm. That said using the input output tables enables the calculations to take more upstream impacts into account because of the linkages between sectors. The assignment of costs to economic sectors is done subjectively, and is based on the names of the sectors and the understanding of the items in the cost estimates.

Agriculture is observed to be among the most contributing processes regarding eutrophication potential and acidification potential. Farming of potato for the starch production is the agricultural ingredient causing the most impact in the eutrophication category. Since potato starch production was used as a substitute for maize gluten production, these results bears an uncertainty. This assumption was based on the similarities between potato starch and maize gluten production, but growing maize could prove to be less environmentally harmful than potato production. Thus it is not possible to conclude that the maize gluten upstream processes dominate the mentioned impact categories from these results.

The large increases in environmental impact when heating with fossil fuels reflects the vast amounts of water in this aquaculture system, and hereby the large heat requirements, which are 107 kWh per produced fish. A heat exchanging process has been assumed in the base case, as opposed to using the excess cooling water directly in the system. Heat exchanging the water will lower the risk of exposing the fish stock to contaminants and it enables the option for a back up heater in case abruption of water flow occurs. There are uncertainties regarding the heat exchanger calculations in this study. The process of heat exchanging is very simplified, assuming one large heat exchanger. The amount of utilised cooling water from the refinery has been found through modelling in Hysys (A.1), and more accurate calculations could prove to alter the implicated results in this study. This part of the study has to be seen in connection with the goal and scope which was focused on the environmental assessment, and not the projection, of the aquaculture facility.

The electricity case assumed Norwegian electricity production and only small increases in impact were observed. This reflects the clean electricity production in Norway. However a marginal demand on electricity in the Norwegian grid would result in a marginal increase of coal based electricity which fulfils the marginal demand in Nordic countries. If imported electricity to Norway were taken into account the environmental impacts would be different, especially GWP.

The furnaces used in combustion of fossil fuels are based on a European average and the emissions data have been extracted and used without treatment in this study. The natural gas furnace is from mid 1990's, and the oil furnace is from 2000. Emissions from combusting heavy oil are newer than the data on natural gas. If a furnace for the natural gas case were built today, the emissions would be lower than what was the case in the mid 1990's.

6 Conclusion

This hybrid LCA has used LCA database data for the upstream feed production processes and economical data in an input output analysis for the building and operation of the fish farm. More substances and compartments are registered in the database than in the input output tables. The study would have better results if the input output data covered a larger part of the substances emitted and the compartments they affect. Except for global warming potential, this category has the same results when restricting to substances and compartments represented in the input output data. However, this analysis illustrates that the hybrid LCA is a constructive approach, with regard to environmental analysis and transparent conclusions.

The results for analysing the base case, which utilises waste heat from the refinery, showed that requiring the ingredients for feed production is the most important processes regarding overall environmental impact in the assessment. Marine ingredients obtained by fishing were the largest source of environmental impact in global warming and acidification categories, while agricultural activities dominated the eutrophication category. The acquisition of necessary fat, protein and carbohydrate sources in fish feed is an area of research that could make fish farming more sustainable.

The installation of technical equipment in and construction of the fish farm represent a noteable contribution to the global warming, acidification and human and terrestrial toxicity categories, mainly through the manufacturing of metals. Projection and planning of the fish farm is important when it comes to lowering the environmental impacts from such a system. The production of chemicals used in the operation of the farm and producing raw materials for the pipe system has noticeable contributions in global warming potential and is the single most contributing process in photo chemical oxidation potential.

Heating the water in the system with electricity gives small increases in environmental impact. The largest increase is observed in PCOP and GWP with 9 % and 6 % increase. For the natural gas case the emissions from natural gas combustion and production increased the global warming potential with 68 % compared to using waste heat from the refinery. The heavy oil case increases GWP with 83 % compared to the base case. Significant increases in all impact categories occur when heat based on fossil fuels is utilised in the system.

Utilisation of heat from the refinery in the base case equals 11,6 MW or 101,6 GWh per year, this equals 7 % of the total amount of water intended for aquaculture. Implementing heating of water with electricity, natural gas or heavy oil equals an increased heat cost of more than 200 %, and total cost with more than 22 % in each scenario. From an economical perspective this study shows that access to an inexpensive energy stream is vital for land based turbot production in Norway.

This study show that land based aquaculture of turbot is an industry with strong incentives for co-localisation with the refinery and by-product exchange at Mongstad, as opposed to locating the fish farm in other parts of Nord-Hordaland. The refinery would benefit from reduced waste heat emissions by the initialisation of a fish farm requiring heat. The region would benefit from increased industrial activity and employment opportunities. And Norway would benefit from the technology progress such a production would lead to.

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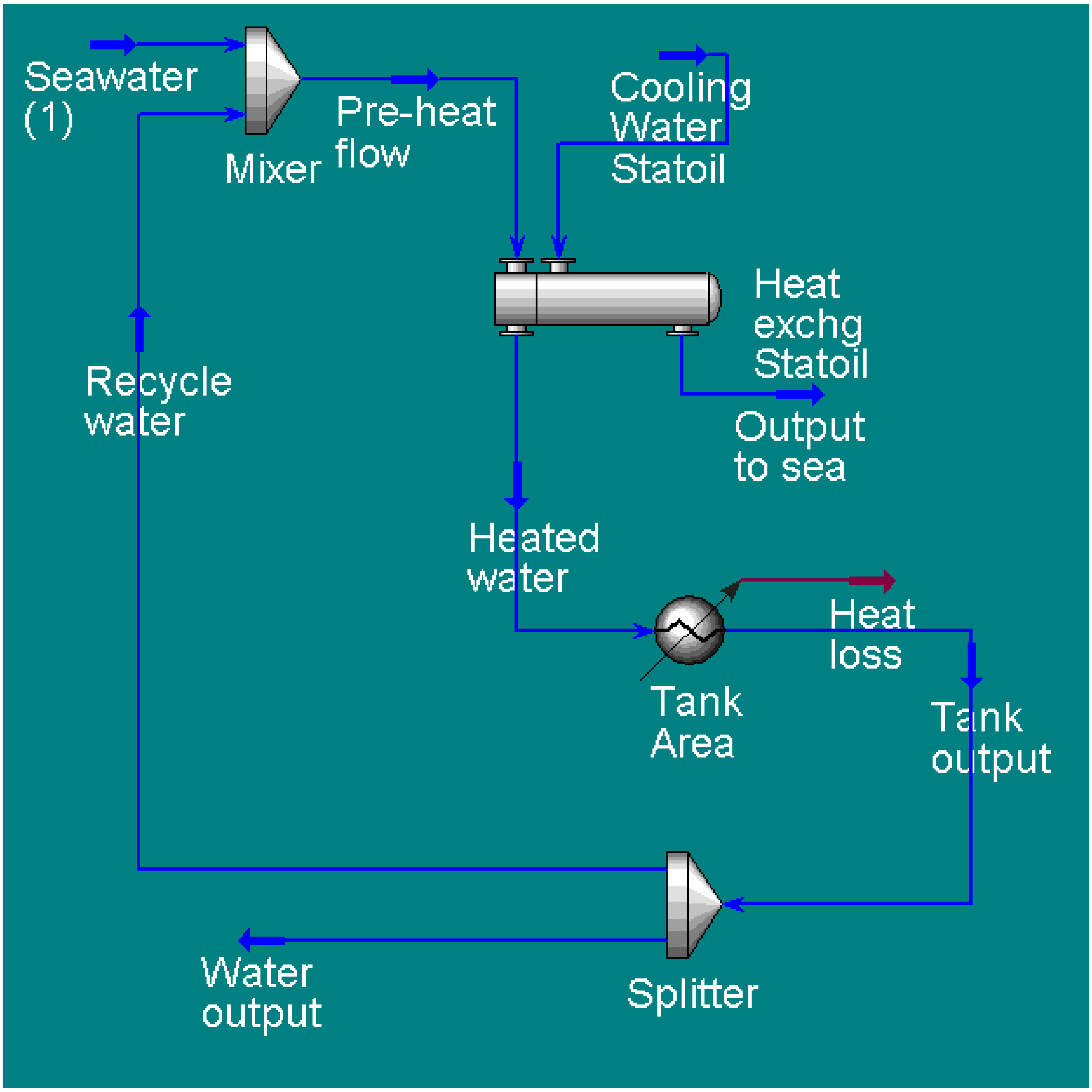
APPENDIX

Appendix A: Hysys modelling, Energy requirements and cost estimates.

A.1 Aquaculture facility simulation (HYSYS)

HYSYS is a process simulation tool, developed by AspenTech, designed to serve processing industries especially oil, gas and refining. The software was chosen for this project because it calculates the temperature changes in the water circulation as a result of varying heat loss. It also calculates heat exchanger properties. The heat exchanger in the aquaculture facility was modelled using the following case in HYSYS:



Figur 22: The water recycling system analysed in HYSYS.

In this case the volumetric flows cover the brood stock and larvae, nursery and on-growing facilities. The flow of seawater is 179,2 m^3/h and holds 8° C. This flow is mixed in the mixer with the recycled water stream. After the two volumes has mixed, the pre-heat flow has a volume of 17127 m^3/h and holds 15,8° C before entering the tube and shell heat exchanger. The heated water entering the tank area needs to hold 16° C.

The price for heat from the refinery will be 0,0266 NOK/kWh. This results in a yearly cost of over 40 million NOK/yr if 6000 m^3/h excess cooling water is utilised, or 3,4 million NOK/yr if 500 m^3/h is utilised. Sinnot (1999) has an overview of prices for heat exchangers with varying size. The heat exchanger with stainless steel to prevent corrosion in shell and tubes, and the largest area of 700 m^2 cost a little over 2,5 million NOK. It becomes evident that lowering the heat costs and maximising the investment made in the heat exchanger is preferable for the aquaculture facility unless the price on heat is lowered substantially. An overall heat transfer coefficient is U = 1150 W/m^2°C = 4140 kJ/m^2°Ch for water to water heat transfer (Sinnot, 1999) is used. The software generated an overall heat transfer coefficient of UA = 2,887 GJ/m^2°Ch using a basic shell and tube exchanger design. Dividing the two coefficients gives a heat transfer area of 700 m^2. With this area a volumetric flow of 395 m^3/h, and a temperature of 25° C is needed to acquire the right temperature.

The tank area has a heat loss of 1809 kW which lowers the temperature of the water to 15,9° C. The total tank output flow of 17127 m^3/h goes into a splitter, where 179,2 m^3/h of the water is output to treatment. A recycled water flow of 16947,8 m^3/h and a temperature of 15,9° C enters the mixer.

The investment cost of the heat exchanger is taken from Sinnot (1999), where a shell and tube heat exchanger with a heat transfer area of 700 m^2 has a cost of £200000. The base date for these data is mid 1998, and prices are thought to be accurate within ± 25 %. The price in NOK is 2502710 NOK, after using the average rate for 1998: 1 GBP = 12,51355 NOK (Oanda, 2006). The general inflation is assumed negligible because of the high uncertainties. The uncertainty of the heat exchanger price is high, and so is the area estimate since the overall heat transfer coefficient is used to determine the area of heat transfer. In a projection of an actual fish farm the possibility of several smaller heat exchangers is essential to elucidate.

The consumption of heat from the refinery is equal to the heat content in the water utilised which is calculated below:

$$E = \frac{395\ \text{m}^3/\text{h} \cdot 1000\ \text{kg/m}^3 \cdot 104{,}89\ \text{kJ/kg}}{3600\ \text{s/h}} \cdot 8760\ \text{h/yr} = 10{,}08\ \text{GWh/yr}$$

The price of the heat is set to 0,0266 NOK/kWh, which is 10 % of the electricity price used in this project. The costs are calculated below:

$$C_{heat} = 10{,}08\ \text{GWh/yr} \cdot 0{,}0266\ \text{NOK/kWh} = 2681726\ \text{NOK/yr}$$

The cost of heat exchanger investments and heat is set to the on-growing facility investments and running costs.

A.2 Energy calculations

The calculations and explanations regarding electricity and heat requirements are gathered in the following chapters.

A.2.1 Electricity

Electricity is used in the system for plankton and turbot larvae rearing in addition to lighting, heat and requisites in the working environment. According to Minkoff et al (1994) the light conditions for larval intensity need to be 2000-4000 lux. The growth of plankton and egg and larvae production require 3000 lux and a 16:8 (light : dark) hour regime (ibid). The area of the production segments is 700 m^2 (ibid). One lux is assumed to be equal to a power demand of 1,46 mW/m^2 which is valid for a wavelength in the middle of the visible spectrum at 555 nm (Wikipedia, 2006). The electric power required is then:

$$\dot{W}_{illum} = 3000 \text{ lux} \cdot 0{,}00146 \text{ W/lux} \cdot \text{m}^2 = 4{,}38 \text{ W/m}^2$$

$$E_{illum} = 4{,}38 \text{ W/m}^2 \cdot 700 \text{ m}^2 \cdot 8760 \text{ h/yr} = 26858 \text{ kWh/yr}$$

General building statistics supplied by Enova (Energistatistikk, 2004) are used to estimate the electricity demand in the office locations. The Enova report looks at energy in buildings. At the office locations electricity from the grid is used to fulfill the energy demand. For building of the size 0-1999 m^2, the electricity demand is 226,6 kWh/m^2 for office buildings in the year 2004. The average electricity price for Norwegian industry was 0,266 NOK/kWh the first quarter of 2005 (IEA, 2005). For the brood stock and larval rearing facility the general building area is 210 m^2 (Minkoff et al, 1994). An area of 160 m^2 is used for the production of eggs, and this process is assumed to take place in a laboratory building with an energy demand of 690,4 kWh/m^2. A 230 m^2 weaning hall is needed for the developing juveniles, and this is assumed to have the same properties as a storage house with an energy demand of 266,8 kWh/m^2. Because of lack of data, the same area is assumed for the office building area of the nursery, and an area of 630 m^2 is assumed for the general buildings in the on-growing facility. The fish tanks connected to the nursery and on-growing facilities are outside, but covered with a plastic tarpaulin.

There is also an electricity demand for the pumping of seawater input and the circulation of water in the system. The expenses regarding electricity to drive the pumps are charged to the on-growing facility, which stand for 86 % of the input from sea and 91 % of the circulated water. It is assumed that the pump for seawater input has to lift the water 17 meters, and that the circulation pump has to lift the water volume 2 meters. The efficiency of the pumps are set to 0,9. The electricity demands for these pumps are given by equation X:

$$\dot{W} = \frac{\rho \cdot g \cdot \Delta h \cdot \dot{V}}{\eta}$$

Where

$\dot{W}$ = Power [W]

ρ = Density = 1030 [kg/m^3]

g = Acceleration due to gravity = 9,8 [m/s^2]

Δh = Lifting height [m]

$\dot{V}$ = Volumetric flow [m^3/s]

η = Efficiency of the pump = 0,9

The total input of water from the sea is 179,2 m^3/h, equivalent to 0,04978 m^3/s, the electric power needed to drive the pump is:

$$\dot{W} = \frac{1030 \cdot 9,8 \cdot 17 \cdot 0,04977}{0,9} = 9,5 \text{ kW}$$

The total circulation of water in the system is 17127 m^3/h or 4,7575 m^3/s, the electric power needed to drive this pump is:

$$\dot{W} = \frac{1030 \cdot 9,8 \cdot 2 \cdot 4,7575}{0,9} = 426,9 \text{ kW}$$

A.2.2 Heat

A.2.2.1 Heating input from sea

The volumetric inputs of water from the sea, with an average temperature of 8° C (Mongstad Vekst AS, 2006), to the different parts of the system are known. Some assumptions regarding the thermodynamic properties of the water are made. The density is assumed uniform at the different temperatures at 1030 kg/m^3, the enthalpy, h, of the seawater is assumed to be equal to that of freshwater. The input of heat is dependent on the water volume and the temperature difference. The water need to be heated from 8° C to 16° C for the whole system, it is assumed that the average temperature in the brood stock and larval rearing facility is 16° C, although there are some variations since the brood stock need a temperature of 14° C and the larvae need 18° C. The properties of water are gathered from Moran et al (2000), and are listed below:

Enthalpy saturated liquid, h_f:
T = 8° C → h_f = 33,6 kJ/kg
T = 16° C → h_f = 67,2 kJ/kg
Δh_f = 33,6 kJ/kg
Density:
ρ = 1030 kg/m^3
For the brood stock and larval rearing facility an input of 4,2 m^3/h seawater is required. The required heat equals:

$$\dot{Q}_{\text{sea b\&l}} = \dot{V}_{\text{sea b\&l}} \cdot \rho \cdot \Delta h_f = \frac{4,2 \text{ m}^3/\text{h} \cdot 1030 \text{ kg/m}^3 \cdot 33,6 \text{ kJ/kg}}{3600 \text{ s/h}} = 40,37 \text{ kW}$$

For the nursery facility an input of 21 m^3/h seawater is required. The required heat equals:

$$\dot{Q}_{sea\ nurs} = \dot{V}_{sea\ nurs} \cdot \rho \cdot \Delta h_f = \frac{21\ m^3/h \ \cdot\ 1030\ kg/m^3 \cdot 33,6\ kJ/kg}{3600\ s/h} = 201,88\ kW$$

For the on-growing facility an input of 154 m^3/h seawater is required. The required heat equals:

$$\dot{Q}_{sea\ ongrow} = \dot{V}_{sea\ ongrow} \cdot \rho \cdot \Delta h_f = \frac{154\ m^3/h \ \cdot\ 1030\ kg/m^3 \cdot 33,6\ kJ/kg}{3600\ s/h} = 1480,45\ kW$$

The total heat required to heat the systems input of seawater is 1722,7 kW, equivalent to 15,1 Gwh per year.

A.2.2.2 Heat loss from outside tanks

There is heat loss from the outside tanks in the nursery end on-growing facilities. The tanks are assumed covered with tarpaulins, so the evaporative heat loss is assumed to be negligible. The heat loss is assumed to be equal to forced convection by merely turbulent flow over a flat plate as described in Mills (1995). Heat loss by radiation is calculated as described in Smith et al (1994). Conduction through the walls of the tanks is assumed to be negligible (Àlvarez et al, 2000). The average air temperature at Florida measuring station is 7,7° C (SSB, 2006b) and is the assumed air temperature at Mongstad. The temperature of the water and tarpaulins is assumed to be constant at 16° C. The average wind speed over the last 6 years is 3.7 m/s (Meterologisk institutt, 2006).

Convection (flow over flat plate)

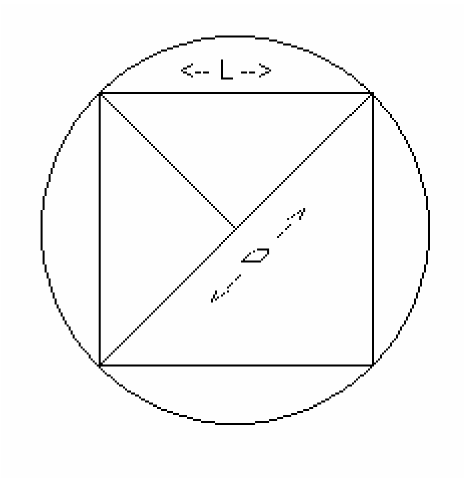
Properties of air at 280 K (Mills, 1995):

Thermal conductivity:	κ = 0,0255	W/m*K
Kinematic viscosity:	ν = 13,91*10^-6	m^2/s
Specific Heat:	c_p = 1008	J/kg*K
Dynamic viscosity:	μ = 17,6*10^-6	kg/m*s
Density:	ρ = 1,265	kg/m^3
Flow velocity:	V = 3,7	m/s

The tank area will actually consist of many smaller tanks, but is assumed to be the same as the area of the smaller tanks in one large circle. The characteristic length, L, of the tarpaulin covering the total area of the circular tanks is assumed to be the length of the maximum sized quadrant inside the circle. The characteristic length need to be calculated for the nursery and on-growing facility.

Calculating the characteristic lengths:

The area of the quadrant is given by two equally sized isosceles' triangles with base length equal to the circles diameter and height equals the radius of the circle. This is shown in the figure below:



For the on-growing facility the area, A_{circle}, is 9600 m^2. This is used to find the diameter, D_{circle}, area of the quadrant A_{quad} and the characteristic length $L_{on\text{-}grow}$:

$$D_{circle} = \sqrt{\frac{4 \cdot A_{circle}}{\pi}} = \sqrt{\frac{4 \cdot 9600\ m^2}{\pi}} = 110{,}56\ m$$

$$A_{quad} = \frac{D_{circle} \cdot \frac{D_{circle}}{2}}{2} \cdot 2 = 6111{,}55\ m^2$$

$$L_{on\text{-}grow} = \sqrt{A_{quad}} = \underline{78{,}18\ m}$$

For the nursery facility the area, A_{circle}, is 9600 m^2. This is used to find the diameter, D_{circle}, area of the quadrant A_{quad} and the characteristic length $L_{nursery}$:

$$D_{circle} = \sqrt{\frac{4 \cdot A_{circle}}{\pi}} = \sqrt{\frac{4 \cdot 1350\ m^2}{\pi}} = 41{,}46\ m$$

$$A_{quad} = \frac{D_{circle} \cdot \frac{D_{circle}}{2}}{2} \cdot 2 = 859{,}44\ m^2$$

$$L_{nursery} = \sqrt{A_{quad}} = \underline{29{,}32\ m}$$

To determine the heat loss, the average heat transfer coefficient ($W/m^2{*}K$), $\bar{h}_c$, is needed. The h_c is given by the average Nusselt number, denoted Nu, the characteristic length and the thermal conductivity. The Nusselt number is calculated by a formula based on the Reynolds number, Re, and the Prandtl number, Pr. There is no laminar flow over the plate so the equation for calculating the average Nussel number is given by:

$$\overline{Nu} = \frac{\overline{h}_c \cdot L}{\kappa} = 0{,}036 \cdot Re^{0{,}8} \cdot Pr^{0{,}43}$$

Which is valid for $0{,}7 \le Pr \le 400,\ 5 \times 10^5 \le Re \le 3 \times 10^7$. Starting with the on-growing facility the Prandtl and Reynolds numbers are calculated by these equations:

$$Pr = \frac{c_p \mu}{\kappa} \approx 0,7$$

$$Re_{ongrow} = \frac{\rho V L}{\mu} \approx 2,08 \times 10^7$$

This means the equation for Nu is valid. Calculating the average Nusselt number and average heat transfer coefficient for the on-growing facility:

$$\overline{Nu} = 0,036 \cdot (2,08 \times 10^7)^{0,8} \cdot 0,7^{0,43} = 22087,4$$

$$\Rightarrow \bar{h}_c = \frac{\overline{Nu} \cdot \kappa}{L} = \frac{22087,4 \cdot 0,0255 \text{ W/mK}}{78,18 \text{ m}} = 7,2 \text{ W/m}^2\text{K}$$

Following what is often called Newton's law of cooling:

$$\dot{q}_c = h_c (T_{high} - T_{low})$$

The heat loss can be found by using the heat transfer coefficient:

$$\dot{Q}_{c\ ongrow} = \dot{q}_{c\ ongrow} \cdot A_{tank} = \bar{h}_c \cdot \left(T_{tank} - T_{air}\right) \cdot A_{tank}$$

$$= 7,2 \text{ W/m}^2\text{K} \cdot \left(289,15 \text{ K} - 280,85 \text{ K}\right) \cdot 9600 \text{ m}^2$$

$$\underline{\dot{Q}_{c\ ongrow} = 574,04 \text{ kW}}$$

The heat loss in the on-growing tank system, caused by convection, is 574,04 kW, equivalent to 5,03 GWh per year. For the nursery facility the same calculations are made to find the heat loss. The Prandlt number for air is the same as for the on-growing facility, but since the characteristic length is different for the nursery, a new Reynolds number is needed:

$$Re_{nurs} = \frac{V \cdot L}{\nu} \approx 7,8 \times 10^6$$

This means that equation X is valid. Calculating the average Nusselt number and average heat transfer coefficient for the nursery facility:

$$\overline{Nu} = 0,036 \cdot (7,8 \times 10^6)^{0,8} \cdot 0,7^{0,43} = 10076,9$$

$$\Rightarrow \bar{h}_c = \frac{\overline{Nu} \cdot \kappa}{L} = \frac{10076,9 \cdot 0,0255 \text{ W/mK}}{29,32 \text{ m}} = 8,76 \text{ W/m}^2\text{K}$$

Applying Newton's law of cooling and calculating the heat loss for the nursery facility:

$$\dot{Q}_{c\ nurs} = \dot{q} \cdot A = \bar{h}_c \cdot \left(T_{tank} - T_{air}\right) \cdot A$$

$$= 8,76 \text{ W/m}^2\text{K} \cdot \left(289,15 \text{ K} - 280,85 \text{ K}\right) \cdot 1350 \text{ m}^2$$

$$\underline{\dot{Q}_{c\ nurs} = 98,15 \text{ kW}}$$

The heat loss in the nursery tank system, caused by convection, is 98,15 kW, equivalent to 0,86 GWh per year. The total heat loss by convection for both facilities is 679,19 kW.

Radiation

The heat loss due to radiation, Q_r, is calculated by following equation from Smith (1994):

$$\dot{Q}_{rad} = \dot{q}_{rad} \cdot A_{tank} = \varepsilon\sigma(T_{tank}^4 - T_{sky}^4)$$

Where Stefan Bolzmans constant is σ = 5,67*10^{-8} W/m^{2}K^4. The tarpaulin is assumed to be made of polypropylen with an emissivity of ε = 0,97 (ETI Ltd, 2006). The sky temperature, T_{sky}, is found by the following equation:

$$T_{sky} = T_{air}\left[0,8 + \frac{\left(T_{airdp} - 273\right)}{250}\right]^{\frac{1}{4}}$$

The average air dew point temperature, T_{airdp}, or the relative humidity has not been available for Mongstad. The air dew point temperature for Mongstad is assumed to equal a Danish reference year where average air temperature throughout the year is the same as for Mongstad 7,7° C, measured between 1959 and 1973. The yearly average air dew point in this area is approximately the same as the average monthly air temperature minus the average monthly difference between air temperature and air dew point temperature. Based on the dataset used (Sørensen et al, 2004) an average air dew point temperature of 5° C is assumed. Now the sky temperature can be found:

$$T_{sky} = 280,85 \cdot \left[0,8 + \frac{\left(278,15 - 273\right)}{250}\right]^{\frac{1}{4}} = 267,31 \text{ K}$$

Knowing that the temperature of the tank is 16° C, the heat loss caused by radiation at the on-growing facility can be found:

$$\dot{Q}_{\text{rad ongrow}} = 0,97 \cdot 5,67 \cdot 10^{-8} \text{ W/m}^2\text{K}^4 \cdot \left(289,15^4 \text{ K}^4 - 267,31^4 \text{ K}^4\right) \cdot 9600 \text{ m}^2$$

$$\underline{\dot{Q}_{\text{rad ongrow}} = 994,99 \text{ kW}}$$

The heat loss due to radiation at the on-growing facility is 994,99 kW, equivalent to 8,72 GWh per year. Likewise the heat loss due to radiation is found for the nursery facility:

$$\dot{Q}_{\text{rad nurs}} = 0,97 \cdot 5,67 \cdot 10^{-8} \text{ W/m}^2\text{K}^4 \cdot \left(289,15^4 \text{ K}^4 - 267,31^4 \text{ K}^4\right) \cdot 1350 \text{ m}^2$$

$$\underline{\dot{Q}_{\text{rad nurs}} = 139,92 \text{ kW}}$$

The heat loss due to radiation at the nursering facility is 139,92 kW, equivalent to 1,23 GWh per year.

The total heat loss from the on-growing tanks is 1570 kW, equivalent to 13,75 GWh per year. The total heat loss from the nursery tanks is 239 kW, equivalent to 2,1 GWh per year. The total heat loss from both facilities is 1809 kW, equivalent to over 15,8 GWh per year.

The heat required for heating the input water and compensate for the heat losses is 31 GWh per year.

A.3 Economic data for the facilities

The details of the cost estimates for the brood stock and larvae, nursery and on growing facilities are given in this chapter.

A.3.1 Brood stock and larvae facility cost estimate

The brood stock and larval rearing facility is divided into different compartments producing phyto- and zoo plankton, eggs, larvae and weaned juveniles. There is also a general area with office locations and such. The data are from Minkoff et al (1994), adjusted to fit the production of 400000 weaned juveniles. The investments described in this article were in spanish Pesetas. To fit the economic data to this report the value in Norwegian Kroner was calculated using exchange rates from 1994, 1 PTS = 0,05271 NOK (Oanda, 2006), and then multiply this value with the general consumer price index, a factor of 1,251 (SSB, 2006a). Table 19 show the cost estimate for the brood stock and larval rearing facility:

Table 19: Investment and operational cost for broodstock and larvae facility.

Broodstock & Larvae	Unit							
Lifetime	[yr]	20						
Produced juveniles	[ind]	400000						
Investments:		Phyto plankton	Zoo plankton	Eggs	Larvae	Weaning	General	**Total**
Construction	[NOK]	0,00	421000,00	316000,00	631000,00	447000,00	421000,00	2236000,00
Other (Technical)	[NOK]	465000,00	105000,00	640000,00	859000,00	1394000,00	947000,00	4410000,00
Total		*465000,00*	*526000,00*	*956000,00*	*1490000,00*	*1841000,00*	*1368000,00*	***6646000,00***
Depreciation (5 %)	[NOK/yr]							*533275,04*
Running costs:		Phyto plankton	Zoo plankton	Eggs	Larvae	Weaning	General	**Total**
Labour	[NOK/yr]	100000,00	100000,00	100000,00	200000,00	200000,00	900000,00	1600000,00
Feeds	[NOK/yr]	44000,00	123000,00	44000,00	0,00	88000,00	0,00	299000,00
Raws	[NOK/yr]	88000,00	26300,00	0,00	44000,00	0,00	44000,00	202300,00
Electricity	[NOK/yr]	2381,33	2381,33	27506,00	2381,33	15280,00	11849,00	61778,99
Various	[NOK/yr]	44000,00	44000,00	44000,00	132000,00	44000,00	0,00	308000,00
Total	[NOK/yr]	*278381,33*	*295681,33*	*215506,00*	*378381,33*	*347280,00*	*955849,00*	***2471078,99***
Area:		Phyto plankton	Zoo plankton	Eggs	Larvae	Weaning	General	**Total**
Floorspace	[m2]	160,00	215,00	160,00	320,00	230,00	215,00	1300,00

The total investment cost is 6646000 NOK and the annual running costs are 2471079 NOK excluding an annuity calculated on the basis of a 5 % interest. A 5 % interest is assumed since it was used in the initial cost estimate for the nursery and on-growing facility (Engell-Sørensen, 2006). Over a 20 year lifetime this results in an annuity factor of 0,08024, which gives an annual expenditure on depreciation at 533275 NOK. The annual costs with depreciation are a little over 3 million NOK, equivalent to 7,5 NOK per produced juvenile.

A.3.2 Nursery and on-growing facility cost estimates

The cost estimates for the nursery and on-growing facilities are adapted from Engell Sørensen (2006). The nursery facility covers the costs of producing juveniles in the brood stock and larvae facility, and the on-growing facility cover the costs connected to nursing the juveniles. The investments and running costs for the nursery are given in table 20:

Table 20: Investment and operational costs for the nursery facility.

Nursery		
Lifetime [years]	20	
Produced nursed juveniles [ind]	320000	
Investment:	Total [NOK]	Per nursed juvenile [NOK/ind]
Construction	8446000,00	1,31968750
Recycling equipment	789000,00	0,12328125
Pumps	225000,00	0,03515625
Filters	338000,00	0,05281250
IT (suveillance)	180000,00	0,02812500
Laboratory, Measuring	338000,00	0,05281250
Projection	225000,00	0,03515625
Total	10541000,00	1,64703125
Depreciation (5%) [NOK/yr]	845810,00	2,64315625
Running costs:	Total [NOK/yr]	Per nursed juvenile [NOK/ind]
Juveniles (400000 ind)	2471078,00	7,72211875
Electricity	12658,00	0,03955625
Feed	328750,00	1,02734375
Transport (feed)	13000,00	0,04062500
Div. (chemicals/desinfection)	57000,00	0,17812500
Insurance	225000,00	0,70312500
Labour	395000,00	1,23437500
Maintenance	395000,00	1,23437500
Consultancy and Veterinary	383000,00	1,19687500
Total	4280486,00	13,37651875

This table show that the total investment cost for the nursery facility is 10541000, with an annuity of 0,08024 this means an annual depreciation expenditure at 845810 NOK. The expenditure per year on running costs except depreciation is 4280486 NOK. The total running costs is 5126296 NOK.

The on-growing facility must pay a price of 16,02 NOK for each of the 320000 nursed juveniles. The investments and running costs at the on-growing facility are given in table 21:

Table 21: Investment and operational costs for the On-growing facility.

On-Growing		
Lifetime [years]	20	
Produced fish [ind]	288000	
Investment:	Total [NOK]	Per fish [NOK/ind]
Construction	25000000,00	4,340277778
Heat exchanger	2502170,00	0,434404514
Div. Technical Installations	4500000,00	0,781250000
Pumps	2250000,00	0,390625000
Recycling Equipment	10250000,00	1,779513889
Pipe system	2250000,00	0,390625000
UV-Water treatment	1470000,00	0,255208333
Feed system and storage	1410000,00	0,244791667
Aerial supply	877000,00	0,152256944
Freezing facilities	1700000,00	0,295138889
Sewer, water and electricity connection	565000,00	0,098090278
Water reservoir	455000,00	0,078993056
Sludge safekeeping	900000,00	0,156250000
Saltwater intake (pipe, pump, filter)	565000,00	0,098090278
Emergency generator	225000,00	0,039062500
Office equipment and such	225000,00	0,039062500
Laboratory equipment	225000,00	0,039062500
EDP (hardware, software and surveillance)	450000,00	0,078125000
Projection	225000,00	0,039062500
Total	56044170,00	9,729890625
Depreciation 5%	4296210,08	14,917396111
Running costs:	[NOK/yr]	[NOK/ind*yr]
Nursed Juveniles	4280486,00	14,862798611
Electricity	1054520,29	3,661528785
Heat	2213102,97	7,684385313
Feed	6242500,00	21,675347222
Transport (feed)	240000,00	0,833333333
Div. (water, chemicals)	113000,00	0,392361111
Insurance	1130000,00	3,923611111
Wages	541000,00	1,878472222
Maintenance	1014000,00	3,520833333
Consultancy and veterinary	68000,00	0,236111111
Total	16896609,26	58,6687822

The investment in the on-growing facility is a little more than 56 million NOK. With 5 % over 20 years and a down-payment based on annuity this means an annual depreciation expenditure of 4,3 million NOK. The annual costs of other running costs at the facility is 16,9 million NOK, which means a total expenditure on running costs at 21,2 million NOK per year. The total costs connected to a fully grown turbot is 73,5 NOK.

Appendix B: Raw results.

Processes contributing more than 1 % of total impact are shown. The most important paths in the SPA for the base case are shown.

B.1 D_{pro}, showing processes contributing to environmental impact.

Data for all production alternatives will be presented, ADP and ODP is presented for the base case only, since they do not vary in the different cases.

B.1.1 Base case

CML 2 baseline 2000 abiotic depletion	Absolute	Relative
Diesel (kg)	0,006043549	0,422320884
Heat (gas)	0,003443898	0,240658283
Electricity (natural gas)	0,001774818	0,124023621
Heat (coal)	0,000752781	0,05260405
Heat (oil)	0,000726466	0,050765133
[000f]Freighter oceanic	0,000494162	0,034531842
Natural gas	0,000364647	0,025481365
Freighter oceanic	0,000178576	0,012478854
Chemicals organic	0,00017808	0,012444127

CML 2 baseline 2000 global warming (GWP100)	Absolute	Relative
Fishing vessel, diesel combusted in	0,748382365	0,171931852
Heat (gas)	0,393054888	0,090299636
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,345558707	0,079387959
Electricity (natural gas)	0,254629998	0,058498181
Manufacture of chemicals and chemical products	0,230970417	0,053062677
Manufacture of other non-metallic mineral products	0,224209361	0,051509405
Fertiliser (N)	0,166802941	0,038320971
Sewage and refuse disposal, sanitation and similar activities	0,159028064	0,036534786
Soy bean, from farm	0,158580036	0,036431857
Diesel (kg)	0,155152815	0,035644494
Manufacture of basic precious and non-ferrous metals	0,130163016	0,029903388
Potatoes, from farm	0,127529043	0,029298265
Heat (oil)	0,11424578	0,026246595
Land transport; transport via pipelines (60)	0,11332627	0,026035348
Heat (coal)	0,09872561	0,022681022
Wheat, conventional, from farm	0,096520342	0,022174388
[000f]Freighter oceanic	0,074878964	0,017202542
Traction	0,066049843	0,015174157
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0,059820176	0,013742966
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,059342119	0,013633139
Air transport	0,053428504	0,012274557
Manufacture of coke, refined petroleum products and nuclear fuel (23)	0,053154225	0,012211544

Agriculture, hunting and related service activities	0,048182298	0,011069304
CML 2 baseline 2000 ozone layer depletion (ODP)	Absolute	Relative
Diesel (kg)	1,28615E-06	0,781316141
Heat (oil)	1,55628E-07	0,094541465
[000f]Freighter oceanic	1,00795E-07	0,061231628
Freighter oceanic	3,64247E-08	0,02212742
Heat (gas)	2,5954E-08	0,01576663
Chemicals organic	1,87376E-08	0,011382783

CML 2 baseline 2000 human toxicity	Absolute	Relative
Manufacture of basic precious and non-ferrous metals	0,278250098	0,294359879
Diesel (kg)	0,200721468	0,212342592
Heat (gas)	0,083255339	0,088075554
[000f]Freighter oceanic	0,057622703	0,060958871
Electricity (natural gas)	0,053738966	0,056850279
Heat (coal)	0,049442606	0,052305174
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,037693325	0,039875647
Manufacture of chemicals and chemical products	0,037029975	0,039173891
Heat (oil)	0,024829691	0,02626725
Freighter oceanic	0,020823254	0,022028853
Fishing vessel, diesel combusted in	0,015823859	0,01674001
Manufacture of other non-metallic mineral products	0,014179491	0,015000438
Chemicals organic	0,010895396	0,011526205
Land transport; transport via pipelines (60)	0,010483567	0,011090531

CML 2 baseline 2000 terrestrial ecotoxicity	Absolute	Relative
[000f]Freighter oceanic	0,001349323	0,243487092
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,000983724	0,177514257
Diesel (kg)	0,00081149	0,146434497
Freighter oceanic	0,000487608	0,087989512
Manufacture of other non-metallic mineral products	0,000226034	0,040788206
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0,000202965	0,036625244
Heat (coal)	0,000193704	0,034954155
Chemicals organic	0,000168228	0,030356908
Chemicals inorganic	0,000166116	0,029975781
Heat (oil)	0,000140414	0,025337916
Heat (gas)	0,00013977	0,025221694
Manufacture of pulp, paper and paper products	0,000137643	0,02483791
Manufacture of chemicals and chemical products	0,000128064	0,023109305
Steam and hot water supply	7,21405E-05	0,013017847

CML 2 baseline 2000 photochemical oxidation	Absolute	Relative
Manufacture of chemicals and chemical products	9,49138E-05	0,119022079
Diesel (kg)	8,65886E-05	0,108582248

Fishing vessel, diesel combusted in	7,97759E-05	0,10003907
[000f]Freighter oceanic	7,73631E-05	0,097013484
Sewage and refuse disposal, sanitation and similar activities	4,15488E-05	0,052102195
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	4,10682E-05	0,051499592
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	3,89533E-05	0,048847542
Heat (gas)	3,41026E-05	0,042764667
Heat (coal)	3,4011E-05	0,04264989
Freighter oceanic	2,79569E-05	0,035057994
Agriculture, hunting and related service activities	2,19999E-05	0,027587943
Post and telecommunications	2,09732E-05	0,026300404
Land transport; transport via pipelines (60)	2,0782E-05	0,026060652
Heat (oil)	1,67985E-05	0,0210653
Manufacture of other non-metallic mineral products	1,07176E-05	0,013439865
Electricity (natural gas)	1,02998E-05	0,01291592
[000a]Soy Meal (no avoid byprod)	9,91444E-06	0,012432721
Construction	8,97335E-06	0,011252595
Water transport (61)	8,90133E-06	0,011162273
Financial intermediation	8,51189E-06	0,010673919

CML 2 baseline 2000 acidification	Absolute	Relative
Fishing vessel, diesel combusted in	0,007386656	0,315032216
[000f]Freighter oceanic	0,00216932	0,092518958
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001371125	0,058476891
Potatoes, from farm	0,001252474	0,053416547
Diesel (kg)	0,001167188	0,04977919
Manufacture of chemicals and chemical products	0,000941295	0,040145119
Wheat, conventional, from farm	0,000894397	0,038144981
Freighter oceanic	0,000783932	0,033433797
Heat (coal)	0,000745294	0,031785918
Agriculture, hunting and related service activities	0,000729848	0,031127143
Water transport (61)	0,000615181	0,026236727
Manufacture of other non-metallic mineral products	0,000508059	0,021668121
Fertiliser (N)	0,000498504	0,021260595
Traction	0,000424634	0,018110142
Water transport	0,000422885	0,018035562
Land transport; transport via pipelines (60)	0,000413785	0,017647447
Heat (gas)	0,000410585	0,017510977
Heat (oil)	0,000265241	0,01131221

CML 2 baseline 2000 eutrophication	Absolute	Relative
Potatoes, from farm	0,00237964	0,307402244
Fishing vessel, diesel combusted in	0,001707138	0,220528381
Wheat, conventional, from farm	0,001673606	0,216196731
[000e]Fishmeal (martins)	0,00021395	0,027638032
Agriculture, hunting and related service activities	0,00016423	0,021215292

Manufacture of chemicals and chemical products	0,000113914	0,014715382
[000f]Freighter oceanic	0,000113096	0,014609737
Water transport (61)	0,000108634	0,014033335
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,000107571	0,013896006
Diesel (kg)	0,000105278	0,013599801
Traction	0,000104694	0,013524418
Land transport; transport via pipelines (60)	0,000103827	0,013412446
Water transport	9,86204E-05	0,012739796
Fertiliser (N)	8,6185E-05	0,011133393
[000d]Byproduct(Fish oil)	8,06922E-05	0,010423827

B.1.2 Electrisity case

CML 2 baseline 2000 global warming (GWP100)	Absolute	Relative
Fishing vessel, diesel combusted in	0,748382365	0,161547393
Heat (gas)	0,393054888	0,084845656
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,364442959	0,078669424
Manufacture of chemicals and chemical products	0,254691249	0,054978189
Electricity (natural gas)	0,254629998	0,054964967
Manufacture of other non-metallic mineral products	0,242430115	0,052331475
Sewage and refuse disposal, sanitation and similar activities	0,232568922	0,050202817
Fertiliser (N)	0,166802941	0,036006434
Soy bean, from farm	0,158580036	0,03423142
Diesel (kg)	0,155152815	0,033491613
Manufacture of basic precious and non-ferrous metals	0,140804922	0,030394447
Land transport; transport via pipelines (60)	0,133500437	0,028817685
Potatoes, from farm	0,127529043	0,027528688
Heat (oil)	0,11424578	0,024661335
Heat (coal)	0,09872561	0,021311118
Wheat, conventional, from farm	0,096520342	0,020835084
[000f]Freighter oceanic	0,074878964	0,016163531
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,068653625	0,014819716
Traction	0,066049843	0,014257658
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0,065370892	0,014111098
Air transport	0,06508247	0,014048839
Manufacture of coke, refined petroleum products and nuclear fuel (23)	0,064568892	0,013937977
Agriculture, hunting and related service activities	0,057501908	0,012412483
Construction	0,054658622	0,011798725
Water transport (61)	0,047244524	0,010198302
CML 2 baseline 2000 human toxicity	Absolute	Relative
Manufacture of basic precious and non-ferrous metals	0,30099935	0,305410257

Diesel (kg)	0,200721468	0,203662881
Heat (gas)	0,083255339	0,08447538
[000f]Freighter oceanic	0,057622703	0,058467118
Electricity (natural gas)	0,053738966	0,054526468
Heat (coal)	0,049442606	0,050167149
Manufacture of chemicals and chemical products	0,04083298	0,041431355
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,039753207	0,040335759
Heat (oil)	0,024829691	0,02519355
Freighter oceanic	0,020823254	0,021128402
Fishing vessel, diesel combusted in	0,015823859	0,016055745
Manufacture of other non-metallic mineral products	0,015331811	0,015556487
Land transport; transport via pipelines (60)	0,012349835	0,012530812
Chemicals organic	0,010895396	0,01105506
Manufacture of electrical machinery and apparatus n.e.c.	0,010810123	0,010968536

CML 2 baseline 2000 terrestrial ecotoxicity	Absolute	Relative
[000f]Freighter oceanic	0,001349323	0,234590945
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001037483	0,180374967
Diesel (kg)	0,00081149	0,141084305
Freighter oceanic	0,000487608	0,08477469
Manufacture of other non-metallic mineral products	0,000244403	0,042491566
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0,000221798	0,038561379
Heat (coal)	0,000193704	0,033677055
Manufacture of pulp, paper and paper products	0,000172482	0,02998736
Chemicals organic	0,000168228	0,029247775
Chemicals inorganic	0,000166116	0,028880573
Manufacture of chemicals and chemical products	0,000141216	0,024551603
Heat (oil)	0,000140414	0,024412159
Heat (gas)	0,00013977	0,024300183
Steam and hot water supply	7,93482E-05	0,013795338
Land transport; transport via pipelines (60)	5,8838E-05	0,010229479

CML 2 baseline 2000 photochemical oxidation	Absolute	Relative
Manufacture of chemicals and chemical products	0,000104662	0,120608253
Diesel (kg)	8,65886E-05	0,099781645
Fishing vessel, diesel combusted in	7,97759E-05	0,091930892
[000f]Freighter oceanic	7,73631E-05	0,08915053
Sewage and refuse disposal, sanitation and similar activities	6,07625E-05	0,070020589
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	4,48789E-05	0,051716884
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	4,10821E-05	0,047341528
Heat (gas)	3,41026E-05	0,039298587
Heat (coal)	3,4011E-05	0,039193112
Freighter oceanic	2,79569E-05	0,03221654
Post and telecommunications	2,77559E-05	0,031984854
Agriculture, hunting and related service activities	2,62552E-05	0,030255609

Land transport; transport via pipelines (60)	2,44816E-05	0,028211697
Heat (oil)	1,67985E-05	0,019357955
Construction	1,16284E-05	0,013400161
Manufacture of other non-metallic mineral products	1,15886E-05	0,013354252
Financial intermediation	1,14626E-05	0,013209039
Water transport (61)	1,07131E-05	0,012345352
Electricity (natural gas)	1,02998E-05	0,011869083
[000a]Soy Meal (no avoid byprod)	9,91444E-06	0,011425048
Manufacture of pulp, paper and paper products	9,25383E-06	0,010663779
Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods	8,86131E-06	0,010211464

CML 2 baseline 2000 acidification	Absolute	Relative
Fishing vessel, diesel combusted in	0,007386656	0,303175682
[000f]Freighter oceanic	0,00216932	0,08903692
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001446055	0,059351458
Potatoes, from farm	0,001252474	0,051406165
Diesel (kg)	0,001167188	0,047905704
Manufacture of chemicals and chemical products	0,001037966	0,042601982
Wheat, conventional, from farm	0,000894397	0,036709359
Agriculture, hunting and related service activities	0,000871018	0,035749782
Freighter oceanic	0,000783932	0,032175484
Heat (coal)	0,000745294	0,030589625
Water transport (61)	0,000740392	0,030388413
Manufacture of other non-metallic mineral products	0,000549347	0,022547245
Fertiliser (N)	0,000498504	0,020460433
Water transport	0,000496783	0,020389816
Land transport; transport via pipelines (60)	0,000487446	0,020006604
Traction	0,000424634	0,017428549
Heat (gas)	0,000410585	0,016851935
Heat (oil)	0,000265241	0,010886465
Construction	0,000261759	0,010743574

CML 2 baseline 2000 eutrophication	Absolute	Relative
Potatoes, from farm	0,00237964	0,300804998
Fishing vessel, diesel combusted in	0,001707138	0,215795559
Wheat, conventional, from farm	0,001673606	0,211556872
[000e]Fishmeal (martins)	0,00021395	0,027044884
Agriculture, hunting and related service activities	0,000195996	0,024775463
Water transport (61)	0,000130745	0,016527147
Manufacture of chemicals and chemical products	0,000125613	0,015878417
Land transport; transport via pipelines (60)	0,000122311	0,015461019
Water transport	0,000115854	0,014644843
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,000113449	0,014340878
[000f]Freighter oceanic	0,000113096	0,014296194
Diesel (kg)	0,000105278	0,013307932
Traction	0,000104694	0,013234167
Fertiliser (N)	8,6185E-05	0,010894456
[000d]Byproduct(Fish oil)	8,06922E-05	0,010200118

B.1.3 Heavy oil case

CML 2 baseline 2000 global warming (GWP100)	Absolute	Relative
Combustion of Heavy oil	2,342714936	0,293813228
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,981673148	0,123117223
Fishing vessel, diesel combusted in	0,748382365	0,093858896
Heat (gas)	0,393054888	0,049295253
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,387586246	0,048609399
Manufacture of chemicals and chemical products	0,265773574	0,033332178
Electricity (natural gas)	0,254629998	0,031934599
Manufacture of other non-metallic mineral products	0,238009403	0,029850115
Sewage and refuse disposal, sanitation and similar activities	0,193523814	0,024270924
Fertiliser (N)	0,166802941	0,020919707
Soy bean, from farm	0,158580036	0,019888426
Diesel (kg)	0,155152815	0,019458599
Manufacture of basic precious and non-ferrous metals	0,1470057	0,018436822
Land transport; transport via pipelines (60)	0,136149709	0,017075311
Manufacture of coke, refined petroleum products and nuclear fuel (23)	0,130369571	0,016350391
Potatoes, from farm	0,127529043	0,015994144
Heat (oil)	0,11424578	0,014328214
Heat (coal)	0,09872561	0,012381741
Wheat, conventional, from farm	0,096520342	0,012105166

CML 2 baseline 2000 human toxicity	Absolute	Relative
Combustion of Heavy oil	1,530272762	0,602309499

Manufacture of basic precious and non-ferrous metals	0,314254782	0,123689479
Diesel (kg)	0,200721468	0,079003201
Heat (gas)	0,083255339	0,032768983
[000f]Freighter oceanic	0,057622703	0,022680075
Electricity (natural gas)	0,053738966	0,021151451
Heat (coal)	0,049442606	0,019460421
Manufacture of chemicals and chemical products	0,042609737	0,016771029
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,042277663	0,016640326

CML 2 baseline 2000 terrestrial ecotoxicity	Absolute	Relative
Combustion of Heavy oil	0,054926512	0,903223966
[000f]Freighter oceanic	0,001349323	0,022188567
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001103366	0,018144002
Diesel (kg)	0,00081149	0,013344328

CML 2 baseline 2000 photochemical oxidation	Absolute	Relative
Combustion of Heavy oil	0,000597953	0,399016516
Manufacture of chemicals and chemical products	0,000109216	0,072880015
Diesel (kg)	8,65886E-05	0,057780901
Fishing vessel, diesel combusted in	7,97759E-05	0,053234739
[000f]Freighter oceanic	7,73631E-05	0,051624705
Sewage and refuse disposal, sanitation and similar activities	5,05614E-05	0,033739772
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	4,36909E-05	0,029155112
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	4,27058E-05	0,028497755
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	3,63488E-05	0,024255668
Heat (gas)	3,41026E-05	0,022756768
Heat (coal)	3,4011E-05	0,02269569
Freighter oceanic	2,79569E-05	0,018655743
Post and telecommunications	2,54472E-05	0,016981021
Agriculture, hunting and related service activities	2,53925E-05	0,016944492
Land transport; transport via pipelines (60)	2,49674E-05	0,01666084
Heat (oil)	1,67985E-05	0,011209678
Water transport (61)	1,50719E-05	0,010057529

CML 2 baseline 2000 acidification	Absolute	Relative
Combustion of Heavy oil	0,015826865	0,365204104
Fishing vessel, diesel combusted in	0,007386656	0,170446715
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,002705774	0,062435589
[000f]Freighter oceanic	0,00216932	0,050056952
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001537884	0,035486605
Potatoes, from farm	0,001252474	0,028900774
Diesel (kg)	0,001167188	0,026932799
Manufacture of chemicals and chemical products	0,001083131	0,024993199
Water transport (61)	0,001041635	0,024035683
Wheat, conventional, from farm	0,000894397	0,020638165
Agriculture, hunting and related service activities	0,000842395	0,019438228
Freighter oceanic	0,000783932	0,0180892
Heat (coal)	0,000745294	0,017197623
Water transport	0,00060875	0,014046879
Manufacture of other non-metallic mineral products	0,00053933	0,012445011
Fertiliser (N)	0,000498504	0,011502946
Land transport; transport via pipelines (60)	0,00049712	0,01147101

CML 2 baseline 2000 eutrophication	Absolute	Relative
Potatoes, from farm	0,00237964	0,263605158
Fishing vessel, diesel combusted in	0,001707138	0,189108635
Wheat, conventional, from farm	0,001673606	0,185394136
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,000683508	0,075715715
Combustion of Heavy oil	0,000388299	0,043013905
[000e]Fishmeal (martins)	0,00021395	0,023700307
Agriculture, hunting and related service activities	0,000189556	0,020998082
Water transport (61)	0,000183941	0,020376093
Water transport	0,000141966	0,015726274
Manufacture of chemicals and chemical products	0,000131078	0,014520241
Land transport; transport via pipelines (60)	0,000124738	0,013817867
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,000120654	0,013365444
[000f]Freighter oceanic	0,000113096	0,012528217
Diesel (kg)	0,000105278	0,011662172
Traction	0,000104694	0,011597529

B.1.4 Natural gas case

CML 2 baseline 2000 global warming (GWP100)	Absolute	Relative
Combustion of Natural gas	1,675167127	0,2285825
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,998038156	0,136185849
Fishing vessel, diesel combusted in	0,748382365	0,10211943
Heat (gas)	0,393054888	0,053633735
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,38812559	0,052961114
Manufacture of chemicals and chemical products	0,266397384	0,036350869
Electricity (natural gas)	0,254629998	0,034745167
Manufacture of other non-metallic mineral products	0,238365388	0,032525803
Sewage and refuse disposal, sanitation and similar activities	0,194142758	0,026491468
Fertiliser (N)	0,166802941	0,022760853
Soy bean, from farm	0,158580036	0,021638809
Diesel (kg)	0,155152815	0,021171152
Manufacture of basic precious and non-ferrous metals	0,147244582	0,020092046
Land transport; transport via pipelines (60)	0,13655476	0,018633382
Manufacture of coke, refined petroleum products and nuclear fuel (23)	0,131742449	0,017976725
Potatoes, from farm	0,127529043	0,017401791
Heat (oil)	0,11424578	0,015589242
Heat (coal)	0,09872561	0,01347146
Wheat, conventional, from farm	0,096520342	0,013170543
[000f]Freighter oceanic	0,074878964	0,0102175
Air transport	0,074087949	0,010109564

CML 2 baseline 2000 human toxicity	Absolute	Relative
Manufacture of basic precious and non-ferrous metals	0,314765441	0,261051836
Diesel (kg)	0,200721468	0,166469062
Combustion of Natural gas	0,19433973	0,161176345
Heat (gas)	0,083255339	0,069048111
[000f]Freighter oceanic	0,057622703	0,047789593
Electricity (natural gas)	0,053738966	0,044568603
Heat (coal)	0,049442606	0,041005401
Manufacture of chemicals and chemical products	0,042709748	0,035421481
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,042336494	0,035111921
Heat (oil)	0,024829691	0,020592592
Freighter oceanic	0,020823254	0,01726984
Fishing vessel, diesel combusted in	0,015823859	0,013123574
Manufacture of other non-metallic mineral products	0,015074749	0,012502297
Land transport; transport via pipelines (60)	0,012632384	0,010476712

CML 2 baseline 2000 terrestrial ecotoxicity	Absolute	Relative
[000f]Freighter oceanic	0,001349323	0,227953923
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001104902	0,186661524
Diesel (kg)	0,00081149	0,137092763
Freighter oceanic	0,000487608	0,082376254
Manufacture of other non-metallic mineral products	0,000240306	0,040597116
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0,000211316	0,035699636
Heat (coal)	0,000193704	0,032724267
Chemicals organic	0,000168228	0,0284203
Chemicals inorganic	0,000166116	0,028063487
Manufacture of pulp, paper and paper products	0,000162968	0,027531751
Manufacture of chemicals and chemical products	0,000147707	0,024953509
Heat (oil)	0,000140414	0,023721493
Heat (gas)	0,00013977	0,023612685
Steam and hot water supply	8,16578E-05	0,013795221
Water transport (61)	8,0168E-05	0,013543538
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	6,53944E-05	0,011047694
Land transport; transport via pipelines (60)	6,01842E-05	0,010167484

CML 2 baseline 2000 photochemical oxidation	Absolute	Relative
Manufacture of chemicals and chemical products	0,000109472	0,115727099
Diesel (kg)	8,65886E-05	0,091536176
Fishing vessel, diesel combusted in	7,97759E-05	0,084334171
[000f]Freighter oceanic	7,73631E-05	0,081783565
Sewage and refuse disposal, sanitation and similar activities	5,07231E-05	0,053621305
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	4,37517E-05	0,046251635
Combustion of Natural gas	4,34984E-05	0,045983823
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	4,27581E-05	0,045201189
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	3,69547E-05	0,039066268
Heat (gas)	3,41026E-05	0,036051143
Heat (coal)	3,4011E-05	0,035954384
Freighter oceanic	2,79569E-05	0,029554322
Post and telecommunications	2,55241E-05	0,02698251
Agriculture, hunting and related service activities	2,54545E-05	0,026908887
Land transport; transport via pipelines (60)	2,50417E-05	0,026472531
Heat (oil)	1,67985E-05	0,017758308
Water transport (61)	1,51804E-05	0,016047775
Financial intermediation	1,15626E-05	0,012223301
Manufacture of other non-metallic mineral products	1,13943E-05	0,012045318
Electricity (natural gas)	1,02998E-05	0,01088828
Construction	1,01648E-05	0,010745559
[000a]Soy Meal (no avoid byprod)	9,91444E-06	0,010480938

CML 2 baseline 2000 acidification	Absolute	Relative
Fishing vessel, diesel combusted in	0,007386656	0,264330256
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,00275088	0,098439792
[000f]Freighter oceanic	0,00216932	0,077628758
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,001540025	0,055109518
Potatoes, from farm	0,001252474	0,044819574
Diesel (kg)	0,001167188	0,041767621
Manufacture of chemicals and chemical products	0,001085674	0,038850646
Water transport (61)	0,001049134	0,03754307
Wheat, conventional, from farm	0,000894397	0,032005846
Agriculture, hunting and related service activities	0,000844451	0,030218552
Freighter oceanic	0,000783932	0,02805289
Heat (coal)	0,000745294	0,026670224
Water transport	0,00061202	0,021901023
Manufacture of other non-metallic mineral products	0,000540137	0,019328699
Land transport; transport via pipelines (60)	0,000498599	0,017842267
Fertiliser (N)	0,000498504	0,01783887
Traction	0,000424634	0,015195457
Heat (gas)	0,000410585	0,014692723
Combustion of Natural gas	0,000363111	0,012993871

CML 2 baseline 2000 eutrophication	Absolute	Relative
Potatoes, from farm	0,00237964	0,272139533
Fishing vessel, diesel combusted in	0,001707138	0,195231141
Wheat, conventional, from farm	0,001673606	0,191396383
Extraction of crude petroleum and natural gas; service activitiesincidental to oil and gas extraction, excluding surveying	0,000694902	0,079470142
[000e]Fishmeal (martins)	0,00021395	0,024467619
Agriculture, hunting and related service activities	0,000190018	0,02173082
Water transport (61)	0,000185265	0,021187208
Water transport	0,000142728	0,016322621
Manufacture of chemicals and chemical products	0,000131386	0,015025528
Land transport; transport via pipelines (60)	0,000125109	0,014307668
Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	0,000120822	0,013817359
[000f]Freighter oceanic	0,000113096	0,012933826
Diesel (kg)	0,000105278	0,012039742
Traction	0,000104694	0,011973006
Combustion of Natural gas	8,92847E-05	0,010210747

B.2 Structural paths for the base case

The paths are presented downwards in the tables. Path numberr 1 is the most important path in all impact categories

B.2.1 Abiotic depletion potential

Path Nr	1	2	3
Value (kg Sb equivalents)	0,003829432	0,002138732	0,00144429
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Fishmeal	Fish oil
Process 5	Sand eel	Heat (fish ind.)	Sand eel, ex harbour
Process 6	Fishing vessel, diesel combusted in	Heat (gas)	Fishing vessel, diesel combusted in
Process 7	Diesel (kg)		Diesel (kg)
Process 8			
Path Nr	4	5	6
Value (kg Sb equivalents)	0,000806634	0,00070818	0,000519289
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fish oil	Fishmeal	Fishmeal
Process 5	Heat (fish ind.)	Electricity (natural gas)	Heat (fish ind.)
Process 6	Heat (gas)		Heat (coal)
Process 7			
Process 8			
Path Nr	7	8	9
Value (kg Sb equivalents)	0,000484222	0,000469454	0,000307112
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Freighter oceanic	Potato starch / potato flour
Process 5	Heat (fish ind.)		Electricity (natural gas)
Process 6	Heat (oil)		
Process 7			
Process 8			
Path Nr	10	11	12
Value (kg Sb equivalents)	0,000280567	0,000267094	0,000225976
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Fish oil	Potato starch / potato flour
Process 5	Heat (gas)	Electricity (natural gas)	Potatoes, from farm
Process 6			Traction
Process 7			Diesel (kg)
Process 8			
Path Nr	13	14	15
Value (kg Sb equivalents)	0,000201549	0,00020007	0,000195853
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Nursery operation	Feed at Mongstad	Feed at Mongstad
Process 3	Feed at Mongstad	Fish feed	Fish feed

Process 4	Fish feed	Potato starch / potato flour	Fish oil
Process 5	Fishmeal	Potatoes, from farm	Heat (fish ind.)
Process 6	Sand eel, ex harbour	Fertiliser (N)	Heat (coal)
Process 7	Fishing vessel, diesel combusted in	Natural gas	
Process 8	Diesel (kg)		
Path Nr	16	17	18
Value (kg Sb equivalents)	0,000182627	0,000169648	0,000168517
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fish oil	Soy Meal (no avoid byprod)	Fishmeal
Process 5	Heat (fish ind.)	Freighter oceanic	Sand eel, ex harbour
Process 6	Heat (oil)		Ice
Process 7			Electricity (natural gas)
Process 8			
Path Nr	19	20	21
Value (kg Sb equivalents)	0,000146344	0,000133114	0,000119304
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Wheat, conventional, from farm	Wheat, conventional, from farm	Fishmeal
Process 5	Fertiliser (N)	Traction	Chemicals organic
Process 6	Natural gas	Diesel (kg)	
Process 7			
Process 8			
Path Nr	22	23	24
Value (kg Sb equivalents)	0,000112565	0,00010856	9,64255E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Nursery operation	Feed at Mongstad	Feed at Mongstad
Process 3	Feed at Mongstad	Fish feed	Fish feed
Process 4	Fish feed	Soy Meal (no avoid byprod)	Potato starch / potato flour
Process 5	Fishmeal	Soy bean, from farm	Potatoes, from farm
Process 6	Heat (fish ind.)	Traction	Electricity (natural gas)
Process 7	Heat (gas)	Diesel (kg)	
Process 8			
Path Nr	25	26	27
Value (kg Sb equivalents)	7,60153E-05	6,3557E-05	5,15538E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Nursery operation	Feed at Mongstad	Feed at Mongstad
Process 3	Feed at Mongstad	Fish feed	Fish feed
Process 4	Fish feed	Fish oil	Potato starch / potato flour
Process 5	Fish oil	Sand eel, ex harbour	Potatoes, from farm
Process 6	Sand eel, ex harbour	Ice	Fertiliser (K)
Process 7	Fishing vessel, diesel combusted in	Electricity (natural gas)	
Process 8	Diesel (kg)		
Path Nr	28	29	30
Value (kg Sb equivalents)	4,57709E-05	4,49959E-05	4,24544E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Soy Meal (no avoid byprod)	Fish oil	Fish feed

Process 5	Heat (gas)	Chemicals organic	Fish oil
Process 6			Heat (fish ind.)
Process 7			Heat (gas)
Process 8			
Path Nr	31	32	33
Value (kg Sb equivalents)	3,72726E-05	3,29394E-05	3,10604E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Nursery operation	Feed at Mongstad	Feed at Mongstad
Process 3	Feed at Mongstad	Fish feed	Fish feed
Process 4	Fish feed	Potato starch / potato flour	Potato starch / potato flour
Process 5	Fishmeal	Potatoes, from farm	Potatoes, from farm
Process 6	Electricity (natural gas)	Fertiliser (N)	Fertiliser (P)
Process 7		Heavy oil	
Process 8			
Path Nr	34	35	36
Value (kg Sb equivalents)	3,08968E-05	2,79629E-05	2,7331E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Potato starch / potato flour	Fishmeal	Fish feed
Process 5	Potatoes, from farm	Chemicals inorganic	Fishmeal
Process 6	Fertiliser (N)		Heat (fish ind.)
Process 7	Coal		Heat (coal)
Process 8			
Path Nr	37	38	39
Value (kg Sb equivalents)	2,54854E-05	2,47081E-05	2,40939E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Nursery operation	Nursery operation	Feed at Mongstad
Process 3	Feed at Mongstad	Feed at Mongstad	Fish feed
Process 4	Fish feed	Fish feed	Wheat, conventional, from farm
Process 5	Fishmeal	Freighter oceanic	Fertiliser (N)
Process 6	Heat (fish ind.)		Heavy oil
Process 7	Heat (oil)		
Process 8			
Path Nr	40	41	42
Value (kg Sb equivalents)	2,32939E-05	2,29214E-05	2,25999E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Soy Meal (no avoid byprod)	Soy Meal (no avoid byprod)	Wheat, conventional, from farm
Process 5	Heat (oil)	Soy bean, from farm	Fertiliser (N)
Process 6		Fertiliser (P205)	Coal
Process 7			
Process 8			
Path Nr	43	44	45
Value (kg Sb equivalents)	1,87705E-05	1,67251E-05	1,62572E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Fishmeal	Wheat, conventional, from farm
Process 5	Wastewater treatment, COD	Wastewater treatment N	Fertiliser (P)

Process 6	Electricity (natural gas)	Electricity (natural gas)	
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg Sb equivalents)	1,61638E-05	1,55989E-05	1,52249E-05
Process 1	On-Grow op.	On-Grow op.	On-Grow op.
Process 2	Nursery operation	Feed at Mongstad	Feed at Mongstad
Process 3	Feed at Mongstad	Fish feed	Fish feed
Process 4	Fish feed	Wheat, conventional, from farm	Soy Meal (no avoid byprod)
Process 5	Potato starch / potato flour	Fertiliser (K)	Electricity (natural gas)
Process 6	Electricity (natural gas)		
Process 7			
Process 8			
Path Nr	49	50	
Value (kg Sb equivalents)	1,47667E-05	1,40576E-05	
Process 1	On-Grow op.	On-Grow op.	
Process 2	Nursery operation	Nursery operation	
Process 3	Feed at Mongstad	Feed at Mongstad	
Process 4	Fish feed	Fish feed	
Process 5	Potato starch / potato flour	Fish oil	
Process 6	Heat (gas)	Electricity (natural gas)	
Process 7			
Process 8			

B.2.2 Global warming potential

Path Nr	1	2	3
Value (kg CO2 equivalents)	0,516255002	0,244095151	0,194708244
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Fishmeal	Fish oil
Process 5	Sand eel, ex harbour	Heat (fish ind.)	Sand eel, ex harbour
Process 6	Fishing vessel, diesel combusted in	Heat (gas)	Fishing vessel, diesel combusted in
Process 7			
Process 8			
Path Nr	4	5	6
Value (kg CO2 equivalents)	0,150651034	0,121152591	0,101601341
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Soy Meal (no avoid byprod)	Potato starch / potato flour	Fishmeal
Process 5	Soy bean, from farm	Potatoes, from farm	Electricity (natural gas)
Process 6			
Process 7			
Process 8			
Path Nr	7	8	9
Value (kg CO2 equivalents)	0,098310954	0,093040282	0,092061749

Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Feed at Mongstad
Process 3	Fish feed	Construction	Fish feed
Process 4	Fishmeal	Manufacture of other non-metallic mineral products	Fish oil
Process 5	Sand eel, ex harbour		Heat (fish ind.)
Process 6	Fishing vessel, diesel combusted in		Heat (gas)
Process 7	Diesel (kg)		
Process 8			
Path Nr	10	11	12
Value (kg CO2 equivalents)	0,091694325	0,091519643	0,076149906
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Wheat, conventional, from farm	Potato starch / potato flour	Fishmeal
Process 5		Potatoes, from farm	Heat (fish ind.)
Process 6		Fertiliser (N)	Heat (oil)
Process 7			
Process 8			
Path Nr	13	14	15
Value (kg CO2 equivalents)	0,071135016	0,068103676	0,066943151
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Freighter oceanic	Fishmeal	Wheat, conventional, from farm
Process 5		Heat (fish ind.)	Fertiliser (N)
Process 6		Heat (coal)	
Process 7			
Process 8			
Path Nr	16	17	18
Value (kg CO2 equivalents)	0,063061858	0,044060792	0,038319471
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	Feed at Mongstad
Process 3	Recycling Equipment	Fish feed	Fish feed
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Potato starch / potato flour	Fish oil
Process 5		Electricity (natural gas)	Electricity (natural gas)
Process 6			
Process 7			
Process 8			
Path Nr	19	20	21
Value (kg CO2 equivalents)	0,037078485	0,032021368	0,03032049
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fish oil	Potato starch / potato flour	Potato starch / potato flour
Process 5	Sand eel, ex harbour	Heat (gas)	Potatoes, from farm
Process 6	Fishing vessel, diesel		Traction

	combusted in		
Process 7	Diesel (kg)		
Process 8			
Path Nr	22	23	24
Value (kg CO2 equivalents)	0,028720331	0,027685694	0,027171316
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Div. Technical Installations	Feed at Mongstad
Process 4	Fish oil	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Fish feed
Process 5	Heat (fish ind.)		Fishmeal
Process 6	Heat (oil)		Sand eel, ex harbour
Process 7			Fishing vessel, diesel combusted in
Process 8			
Path Nr	25	26	27
Value (kg CO2 equivalents)	0,025706231	0,025685653	0,02490297
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	On-Growing facility
Process 3	Fish feed	Fish feed	Pipe system
Process 4	Soy Meal (no avoid byprod)	Fish oil	Manufacture of chemicals and chemical products
Process 5	Freighter oceanic	Heat (fish ind.)	
Process 6		Heat (coal)	
Process 7			
Process 8			
Path Nr	28	29	30
Value (kg CO2 equivalents)	0,024176796	0,023816941	0,018471738
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	On-Growing facility
Process 3	Fish feed	Construction	Construction
Process 4	Fishmeal	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Sewage and refuse disposal, sanitation and similar activities
Process 5	Sand eel, ex harbour		
Process 6	Ice		
Process 7	Electricity (natural gas)		
Process 8			
Path Nr	31	32	33
Value (kg CO2 equivalents)	0,017860697	0,017508319	0,016984416
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Broodstock operation	Fish feed
Process 4	Wheat, conventional, from farm	Chemicals, desinfection	Fishmeal
Process 5	Traction	Manufacture of chemicals and chemical products	Chemicals organic
Process 6			
Process 7			

Process 8			
Path Nr	34	35	36
Value (kg CO2 equivalents)	0,015413682	0,015394292	0,014729265
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	On-Growing facility
Process 3	Construction	Heat exchangers	Construction
Process 4	Construction	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Manufacture of chemicals and chemical products
Process 5	Manufacture of other non-metallic mineral products		
Process 6			
Process 7			
Process 8			
Path Nr	37	38	39
Value (kg CO2 equivalents)	0,014566164	0,014510104	0,013842847
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	On-Growing facility
Process 3	Fish feed	Construction	Pumps
Process 4	Soy Meal (no avoid byprod)	Land transport; transport via pipelines (60)	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Soy bean, from farm		
Process 6	Traction		
Process 7			
Process 8			
Path Nr	40	41	42
Value (kg CO2 equivalents)	0,01383399	0,01311575	0,012847113
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Construction	Feed at Mongstad
Process 4	Potato starch / potato flour	Construction	Fish feed
Process 5	Potatoes, from farm		Fishmeal
Process 6	Electricity (natural gas)		Heat (fish ind.)
Process 7			Heat (gas)
Process 8			
Path Nr	43	44	45
Value (kg CO2 equivalents)	0,012643588	0,012009309	0,011909125
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	On-Growing facility
Process 3	Construction	Recycling Equipment	Recycling Equipment
Process 4	Manufacture of fabricated metal products, except machinery and equipment	Manufacture of machinery and equipment n.e.c.	Manufacture of basic precious and non-ferrous metals
Process 5	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	
Process 6			
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg CO2 equivalents)	0,01045904	0,010247802	0,009118404
Process 1	On-Growing operation	On-Growing operation	On-Growing operation

Process 2	On-Growing facility	Nursery operation	Feed at Mongstad
Process 3	Freezing facilities	Feed at Mongstad	Fish feed
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Fish feed	Fish oil
Process 5		Fish oil	Sand eel, ex harbour
Process 6		Sand eel, ex harbour	Ice
Process 7		Fishing vessel, diesel combusted in	Electricity (natural gas)
Process 8			
Path Nr	49	50	
Value (kg CO2 equivalents)	0,008725789	0,007929002	
Process 1	On-Growing operation	On-Growing operation	
Process 2	On-Growing facility	Nursery operation	
Process 3	Construction	Feed at Mongstad	
Process 4	Manufacture of other non-metallic mineral products	Fish feed	
Process 5	Manufacture of other non-metallic mineral products	Soy Meal (no avoid byprod)	
Process 6		Soy bean, from farm	
Process 7			
Process 8			

B.2.3 Ozone depletion potential

Path Nr	1	2	3
Value (kg CFC-11 equivalents)	8,14956E-07	3,07365E-07	1,03733E-07
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Fish oil	Fishmeal
Process 5	Sand eel, ex harbour	Sand eel, ex harbour	Heat (fish ind.)
Process 6	Fishing vessel, diesel combusted in	Fishing vessel, diesel combusted in	Heat (oil)
Process 7	Diesel (kg)	Diesel (kg)	
Process 8			
Path Nr	4	5	6
Value (kg CFC-11 equivalents)	9,57556E-08	4,80908E-08	4,28924E-08
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Freighter oceanic	Potato starch / potato flour	Fish feed
Process 5		Potatoes, from farm	Fishmeal
Process 6		Traction	Sand eel, ex harbour
Process 7		Diesel (kg)	Fishing vessel, diesel combusted in
Process 8			Diesel (kg)
Path Nr	7	8	9
Value (kg CFC-11 equivalents)	3,91234E-08	3,46034E-08	2,83285E-08
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad

Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fish oil	Soy Meal (no avoid byprod)	Wheat, conventional, from farm
Process 5	Heat (fish ind.)	Freighter oceanic	Traction
Process 6	Heat (oil)		Diesel (kg)
Process 7			
Process 8			
Path Nr	10	11	12
Value (kg CFC-11 equivalents)	2,31031E-08	1,61771E-08	1,61179E-08
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Soy Meal (no avoid byprod)	Fish feed	Fishmeal
Process 5	Soy bean, from farm	Fish oil	Heat (fish ind.)
Process 6	Traction	Sand eel, ex harbour	Heat (gas)
Process 7	Diesel (kg)	Fishing vessel, diesel combusted in	
Process 8		Diesel (kg)	
Path Nr	13	14	15
Value (kg CFC-11 equivalents)	1,25532E-08	6,07897E-09	5,45963E-09
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Fishmeal	Fish oil	Fish feed
Process 5	Chemicals organic	Heat (fish ind.)	Fishmeal
Process 6		Heat (gas)	Heat (fish ind.)
Process 7			Heat (oil)
Process 8			
Path Nr	16	17	18
Value (kg CFC-11 equivalents)	5,17569E-09	5,03977E-09	4,99016E-09
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Fishmeal	Fish feed	Soy Meal (no avoid byprod)
Process 5	Chemicals inorganic	Freighter oceanic	Heat (oil)
Process 6			
Process 7			
Process 8			
Path Nr	19	20	21
Value (kg CFC-11 equivalents)	4,73449E-09	3,59165E-09	2,53109E-09
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Fish oil	Fishmeal	Fish feed
Process 5	Chemicals organic	Heat (fish ind.)	Potato starch / potato flour
Process 6		Heat (coal)	Potatoes, from farm
Process 7			Traction
Process 8			Diesel (kg)
Path Nr	22	23	24
Value (kg CFC-11 equivalents)	2,11442E-09	2,06283E-09	2,05913E-09
Process 1	On-Growing operation	On-Growing operation	On-Growing operation

Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Potato starch / potato flour	Fishmeal	Fish feed
Process 5	Heat (gas)	Electricity (natural gas)	Fish oil
Process 6			Heat (fish ind.)
Process 7			Heat (oil)
Process 8			
Path Nr	25	26	27
Value (kg CFC-11 equivalents)	1,95204E-09	1,82123E-09	1,6496E-09
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Fish oil	Fish feed	Fishmeal
Process 5	Chemicals inorganic	Soy Meal (no avoid byprod)	Sand eel, ex harbour
Process 6		Freighter oceanic	Lubricant oil (1)
Process 7			Chemicals inorganic
Process 8			
Path Nr	28	29	30
Value (kg CFC-11 equivalents)	1,49097E-09	1,35461E-09	1,21595E-09
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	Feed at Mongstad	Nursery operation
Process 3	Feed at Mongstad	Fish feed	Feed at Mongstad
Process 4	Fish feed	Fish oil	Fish feed
Process 5	Wheat, conventional, from farm	Heat (fish ind.)	Soy Meal (no avoid byprod)
Process 6	Traction	Heat (coal)	Soy bean, from farm
Process 7	Diesel (kg)		Traction
Process 8			Diesel (kg)
Path Nr	31	32	33
Value (kg CFC-11 equivalents)	8,94573E-10	8,48313E-10	7,78006E-10
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Potato starch / potato flour	Fish feed	Fish oil
Process 5	Electricity (natural gas)	Fishmeal	Electricity (natural gas)
Process 6		Heat (fish ind.)	
Process 7		Heat (gas)	
Process 8			
Path Nr	34	35	36
Value (kg CFC-11 equivalents)	7,57656E-10	6,60692E-10	6,22156E-10
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Potato starch / potato flour	Fish feed	Fish oil
Process 5	Potatoes, from farm	Fishmeal	Sand eel, ex harbour
Process 6	Lubricant oil (1)	Chemicals organic	Lubricant oil (1)
Process 7	Chemicals inorganic		Chemicals inorganic
Process 8			
Path Nr	37	38	39
Value (kg CFC-11 equivalents)	4,90865E-10	4,3544E-10	3,4494E-10

Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Wheat, conventional, from farm	Soy Meal (no avoid byprod)
Process 5	Sand eel, ex harbour	Lubricant oil (1)	Heat (gas)
Process 6	Ice	Chemicals inorganic	
Process 7	Electricity (natural gas)		
Process 8			
Path Nr	40	41	42
Value (kg CFC-11 equivalents)	3,37987E-10	3,34875E-10	3,19946E-10
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Fishmeal	Soy Meal (no avoid byprod)	Fish feed
Process 5	Sand eel, ex harbour	Soy bean, from farm	Fish oil
Process 6	Nylon	Lubricant oil (1)	Heat (fish ind.)
Process 7	Chemicals organic	Chemicals inorganic	Heat (gas)
Process 8			
Path Nr	43	44	45
Value (kg CFC-11 equivalents)	2,80874E-10	2,72405E-10	2,68745E-10
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Potato starch / potato flour	Fish feed	Potato starch / potato flour
Process 5	Potatoes, from farm	Fishmeal	H2SO4 ETH S
Process 6	Electricity (natural gas)	Chemicals inorganic	
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg CFC-11 equivalents)	2,6264E-10	2,49183E-10	1,94124E-10
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	Nursery operation	Feed at Mongstad
Process 3	Feed at Mongstad	Feed at Mongstad	Fish feed
Process 4	Fish feed	Fish feed	Fishmeal
Process 5	Soy Meal (no avoid byprod)	Fish oil	Heat (fish ind.)
Process 6	Heat (oil)	Chemicals organic	District heat
Process 7			Heat (spruce chips)
Process 8			
Path Nr	49	50	
Value (kg CFC-11 equivalents)	1,89034E-10	1,85132E-10	
Process 1	On-Growing operation	On-Growing operation	
Process 2	Nursery operation	Feed at Mongstad	
Process 3	Feed at Mongstad	Fish feed	
Process 4	Fish feed	Fish oil	
Process 5	Fishmeal	Sand eel, ex harbour	
Process 6	Heat (fish ind.)	Ice	
Process 7	Heat (coal)	Electricity (natural gas)	
Process 8			

B.2.4 Human toxicity potential

Path Nr	1	2	3
Value (kg 1,4-DB equivalents)	0,127185053	0,054741568	0,051703274
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Freighter oceanic	Fishmeal
Process 5	Sand eel, ex harbour		Heat (fish ind.)
Process 6	Fishing vessel, diesel combusted in		Heat (gas)
Process 7	Diesel (kg)		
Process 8			
Path Nr	4	5	6
Value (kg 1,4-DB equivalents)	0,047968501	0,034106887	0,025458193
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	On-Growing facility
Process 3	Fish feed	Fish feed	Recycling Equipment
Process 4	Fish oil	Fishmeal	Manufacture of basic precious and non-ferrous metals
Process 5	Sand eel, ex harbour	Heat (fish ind.)	
Process 6	Fishing vessel, diesel combusted in	Heat (coal)	
Process 7	Diesel (kg)		
Process 8			
Path Nr	7	8	9
Value (kg 1,4-DB equivalents)	0,021442686	0,019782091	0,019500157
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Soy Meal (no avoid byprod)	Fish oil
Process 5	Electricity (natural gas)	Freighter oceanic	Heat (fish ind.)
Process 6			Heat (gas)
Process 7			
Process 8			
Path Nr	10	11	12
Value (kg 1,4-DB equivalents)	0,016550096	0,012863589	0,011176768
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	On-Growing facility
Process 3	Fish feed	Fish feed	Div. Technical Installations
Process 4	Fishmeal	Fish oil	Manufacture of basic precious and non-ferrous metals
Process 5	Heat (fish ind.)	Heat (fish ind.)	
Process 6	Heat (oil)	Heat (coal)	
Process 7			
Process 8			
Path Nr	13	14	15

Value (kg 1,4-DB equivalents)	0,010915739	0,00978521	0,00929891
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Feed at Mongstad
Process 3	Fish feed	Recycling Equipment	Fish feed
Process 4	Fishmeal	Manufacture of basic precious and non-ferrous metals	Potato starch / potato flour
Process 5	Sand eel, ex harbour	Manufacture of basic precious and non-ferrous metals	Electricity (natural gas)
Process 6	Fishing vessel, diesel combusted in		
Process 7			
Process 8			
Path Nr	16	17	18
Value (kg 1,4-DB equivalents)	0,008385961	0,00808722	0,007505225
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	Feed at Mongstad
Process 3	UV-Water treatment	Fish feed	Fish feed
Process 4	Manufacture of basic precious and non-ferrous metals	Fish oil	Potato starch / potato flour
Process 5		Electricity (natural gas)	Potatoes, from farm
Process 6			Traction
Process 7			Diesel (kg)
Process 8			
Path Nr	19	20	21
Value (kg 1,4-DB equivalents)	0,00729932	0,006878748	0,00678264
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Feed at Mongstad
Process 3	Fish feed	Recycling Equipment	Fish feed
Process 4	Fishmeal	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Potato starch / potato flour
Process 5	Chemicals organic		Heat (gas)
Process 6			
Process 7			
Process 8			
Path Nr	22	23	24
Value (kg 1,4-DB equivalents)	0,00669395	0,006241954	0,006214705
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	Feed at Mongstad	On-Growing facility
Process 3	Feed at Mongstad	Fish feed	Heat exchangers
Process 4	Fish feed	Fish oil	Manufacture of basic precious and non-ferrous metals
Process 5	Fishmeal	Heat (fish ind.)	
Process 6	Sand eel, ex harbour	Heat (oil)	
Process 7	Fishing vessel, diesel combusted in		
Process 8	Diesel (kg)		
Path Nr	25	26	27
Value (kg 1,4-DB equivalents)	0,005884071	0,005588384	0,005253023

Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	On-Growing facility
Process 3	Construction	Pumps	Construction
Process 4	Manufacture of other non-metallic mineral products	Manufacture of basic precious and non-ferrous metals	Manufacture of fabricated metal products, except machinery and equipment
Process 5			Manufacture of basic precious and non-ferrous metals
Process 6			
Process 7			
Process 8			
Path Nr	28	29	30
Value (kg 1,4-DB equivalents)	0,005102447	0,004848181	0,004421055
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Feed at Mongstad
Process 3	Fish feed	Recycling Equipment	Fish feed
Process 4	Fishmeal	Manufacture of machinery and equipment n.e.c.	Wheat, conventional, from farm
Process 5	Sand eel, ex harbour	Manufacture of basic precious and non-ferrous metals	Traction
Process 6	Ice		Diesel (kg)
Process 7	Electricity (natural gas)		
Process 8			
Path Nr	31	32	33
Value (kg 1,4-DB equivalents)	0,004295946	0,004222335	0,004116927
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	Feed at Mongstad
Process 3	Div. Technical Installations	Freezing facilities	Fish feed
Process 4	Manufacture of basic precious and non-ferrous metals	Manufacture of basic precious and non-ferrous metals	Fish oil
Process 5	Manufacture of basic precious and non-ferrous metals		Sand eel, ex harbour
Process 6			Fishing vessel, diesel combusted in
Process 7			
Process 8			
Path Nr	34	35	36
Value (kg 1,4-DB equivalents)	0,00399253	0,003761081	0,00360556
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	Feed at Mongstad
Process 3	Pipe system	Recycling Equipment	Fish feed
Process 4	Manufacture of chemicals and chemical products	Manufacture of basic precious and non-ferrous metals	Soy Meal (no avoid byprod)
Process 5		Manufacture of basic precious and non-ferrous metals	Soy bean, from farm
Process 6		Manufacture of basic precious and non-ferrous metals	Traction
Process 7			Diesel (kg)

Process 8			
Path Nr	37	38	39
Value (kg 1,4-DB equivalents)	0,003564813	0,003243304	0,00322326
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	On-Growing facility
Process 3	Construction	Construction	UV-Water treatment
Process 4	Manufacture of electrical machinery and apparatus n.e.c.	Manufacture of basic precious and non-ferrous metals	Manufacture of basic precious and non-ferrous metals
Process 5	Manufacture of basic precious and non-ferrous metals		Manufacture of basic precious and non-ferrous metals
Process 6			
Process 7			
Process 8			
Path Nr	40	41	42
Value (kg 1,4-DB equivalents)	0,003019938	0,002957568	0,002919626
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	Feed at Mongstad
Process 3	Div. Technical Installations	Fish feed	Fish feed
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Fishmeal	Potato starch / potato flour
Process 5		Chemicals inorganic	Potatoes, from farm
Process 6			Electricity (natural gas)
Process 7			
Process 8			
Path Nr	43	44	45
Value (kg 1,4-DB equivalents)	0,002881135	0,002806994	0,002752976
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	Nursery operation	Feed at Mongstad
Process 3	Feed at Mongstad	Broodstock operation	Fish feed
Process 4	Fish feed	Chemicals, desinfection	Fish oil
Process 5	Freighter oceanic	Manufacture of chemicals and chemical products	Chemicals organic
Process 6			
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg 1,4-DB equivalents)	0,002721225	0,002583313	0,002524658
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	Nursery operation	Nursery operation
Process 3	Feed at Mongstad	Broodstock operation	Feed at Mongstad
Process 4	Fish feed	Broodstock facility	Fish feed
Process 5	Fishmeal	Div. Technical Installations	Fish oil
Process 6	Heat (fish ind.)	Manufacture of basic precious and non-ferrous metals	Sand eel, ex harbour
Process 7	Heat (gas)		Fishing vessel, diesel combusted in
Process 8			Diesel (kg)
Path Nr	49	50	
Value (kg 1,4-DB equivalents)	0,002388708	0,002361447	

Process 1	On-Growing operation	On-Growing operation	
Process 2	On-Growing facility	On-Growing facility	
Process 3	Heat exchangers	Construction	
Process 4	Manufacture of basic precious and non-ferrous metals	Manufacture of chemicals and chemical products	
Process 5	Manufacture of basic precious and non-ferrous metals		
Process 6			
Process 7			
Process 8			

B.2.5 Terrestrial ecotoxicity potential

Path Nr	1	2	3
Value (kg 1,4-DB equivalents)	0,001281857	0,000514192	0,000463228
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Freighter oceanic	Fishmeal	Soy Meal (no avoid byprod)
Process 5		Sand eel, ex harbour	Freighter oceanic
Process 6		Fishing vessel, diesel combusted in	
Process 7		Diesel (kg)	
Process 8			
Path Nr	4	5	6
Value (kg 1,4-DB equivalents)	0,00019393	0,000179522	0,000133622
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Feed at Mongstad
Process 3	Fish feed	Recycling Equipment	Fish feed
Process 4	Fish oil	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Fishmeal
Process 5	Sand eel, ex harbour		Heat (fish ind.)
Process 6	Fishing vessel, diesel combusted in		Heat (coal)
Process 7	Diesel (kg)		
Process 8			
Path Nr	7	8	9
Value (kg 1,4-DB equivalents)	0,000112703	9,37976E-05	9,35923E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Feed at Mongstad
Process 3	Fish feed	Construction	Fish feed
Process 4	Fishmeal	Manufacture of other non-metallic mineral products	Fishmeal

Process 5	Chemicals organic		Heat (fish ind.)
Process 6			Heat (oil)
Process 7			
Process 8			
Path Nr	10	11	12
Value (kg 1,4-DB equivalents)	8,68001E-05	8,08088E-05	7,88146E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	On-Growing facility
Process 3	Fish feed	Construction	Div. Technical Installations
Process 4	Fishmeal	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Heat (fish ind.)		
Process 6	Heat (gas)		
Process 7			
Process 8			
Path Nr	13	14	15
Value (kg 1,4-DB equivalents)	7,47452E-05	6,74661E-05	5,03964E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Fishmeal	Fish feed	Fish oil
Process 5	Chemicals inorganic	Freighter oceanic	Heat (fish ind.)
Process 6			Heat (coal)
Process 7			
Process 8			
Path Nr	16	17	18
Value (kg 1,4-DB equivalents)	4,38239E-05	4,25067E-05	3,94073E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	On-Growing facility
Process 3	Heat exchangers	Fish feed	Pumps
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Fish oil	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5		Chemicals organic	
Process 6			
Process 7			
Process 8			
Path Nr	19	20	21
Value (kg 1,4-DB equivalents)	3,59933E-05	3,52988E-05	3,41877E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	On-Growing facility
Process 3	Construction	Fish feed	Recycling Equipment
Process 4	Manufacture of fabricated metal products, except machinery and equipment	Fish oil	Manufacture of machinery and equipment n.e.c.
Process 5	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Heat (fish ind.)	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 6		Heat (oil)	

Process 7			
Process 8			
Path Nr	22	23	24
Value (kg 1,4-DB equivalents)	3,27371E-05	3,03426E-05	2,97744E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	On-Growing facility
Process 3	Fish feed	Fish feed	Freezing facilities
Process 4	Fish oil	Potato starch / potato flour	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Heat (fish ind.)	Potatoes, from farm	
Process 6	Heat (gas)	Traction	
Process 7		Diesel (kg)	
Process 8			
Path Nr	25	26	27
Value (kg 1,4-DB equivalents)	2,81905E-05	2,70628E-05	2,43804E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Nursery operation
Process 3	Fish feed	Feed at Mongstad	Feed at Mongstad
Process 4	Fish oil	Fish feed	Fish feed
Process 5	Chemicals inorganic	Fishmeal	Soy Meal (no avoid byprod)
Process 6		Sand eel, ex harbour	Freighter oceanic
Process 7		Fishing vessel, diesel combusted in	
Process 8		Diesel (kg)	
Path Nr	28	29	30
Value (kg 1,4-DB equivalents)	2,38229E-05	1,97444E-05	1,82166E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Recycling Equipment	Broodstock operation
Process 4	Fishmeal	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Broodstock facility
Process 5	Sand eel, ex harbour	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Div. Technical Installations
Process 6	Lubricant oil (1)		Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 7	Chemicals inorganic		
Process 8			
Path Nr	31	32	33
Value (kg 1,4-DB equivalents)	1,78737E-05	1,55391E-05	1,53601E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	On-Growing facility
Process 3	Fish feed	Construction	Aerial supply
Process 4	Wheat, conventional, from farm	Construction	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Traction	Manufacture of other non-metallic mineral products	
Process 6	Diesel (kg)		
Process 7			

Process 8			
Path Nr	34	35	36
Value (kg 1,4-DB equivalents)	1,52134E-05	1,50092E-05	1,46919E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	Feed at Mongstad
Process 3	Construction	Div. Technical Installations	Fish feed
Process 4	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacture of machinery and equipment n.e.c.	Fishmeal
Process 5	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Electricity (natural gas)
Process 6			
Process 7			
Process 8			
Path Nr	37	38	39
Value (kg 1,4-DB equivalents)	1,45768E-05	1,41577E-05	1,38077E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	On-Growing facility
Process 3	Fish feed	Recycling Equipment	Pipe system
Process 4	Soy Meal (no avoid byprod)	Manufacture of fabricated metal products, except machinery and equipment	Manufacture of chemicals and chemical products
Process 5	Soy bean, from farm	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	
Process 6	Traction		
Process 7	Diesel (kg)		
Process 8			
Path Nr	40	41	42
Value (kg 1,4-DB equivalents)	1,33873E-05	1,22732E-05	1,17567E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	On-Growing facility
Process 3	Construction	Construction	UV-Water treatment
Process 4	Construction	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials		
Process 6			
Process 7			
Process 8			
Path Nr	43	44	45
Value (kg 1,4-DB equivalents)	1,13868E-05	1,09418E-05	1,02069E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Feed at Mongstad

Process 4	Potato starch / potato flour	Potato starch / potato flour	Fish feed
Process 5	Heat (gas)	Potatoes, from farm	Fish oil
Process 6		Lubricant oil (1)	Sand eel, ex harbour
Process 7		Chemicals inorganic	Fishing vessel, diesel combusted in
Process 8			Diesel (kg)
Path Nr	46	47	48
Value (kg 1,4-DB equivalents)	9,89561E-06	9,70767E-06	8,98491E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Nursery operation	Feed at Mongstad
Process 3	Salt water intake	Broodstock operation	Fish feed
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Chemicals, desinfection	Fish oil
Process 5		Manufacture of chemicals and chemical products	Sand eel, ex harbour
Process 6			Lubricant oil (1)
Process 7			Chemicals inorganic
Process 8			
Path Nr	49	50	
Value (kg 1,4-DB equivalents)	8,79681E-06	8,66825E-06	
Process 1	On-Growing operation	On-Growing operation	
Process 2	On-Growing facility	On-Growing facility	
Process 3	Construction	Div. Technical Installations	
Process 4	Manufacture of other non-metallic mineral products	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	
Process 5	Manufacture of other non-metallic mineral products	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	
Process 6			
Process 7			
Process 8			

B.2.6 Photochemical oxidation potential

Path Nr	1	2	3
Value (kg 1,4-DB equivalents)	7,3495E-05	5,50316E-05	5,4866E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Freighter oceanic	Fishmeal	Fishmeal
Process 5		Sand eel, ex harbour	Sand eel, ex harbour
Process 6		Fishing vessel, diesel combusted in	Fishing vessel, diesel combusted in
Process 7			Diesel (kg)
Process 8			
Path Nr	4	5	6
Value (kg 1,4-DB equivalents)	2,65591E-05	2,34618E-05	2,11784E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed

Process 4	Soy Meal (no avoid byprod)	Fishmeal	Fishmeal
Process 5	Freighter oceanic	Heat (fish ind.)	Heat (fish ind.)
Process 6		Heat (coal)	Heat (gas)
Process 7			
Process 8			
Path Nr	7	8	9
Value (kg 1,4-DB equivalents)	2,07555E-05	2,0693E-05	1,6351E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Construction
Process 4	Fish oil	Fish oil	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Process 5	Sand eel, ex harbour	Sand eel, ex harbour	
Process 6	Fishing vessel, diesel combusted in	Fishing vessel, diesel combusted in	
Process 7		Diesel (kg)	
Process 8			
Path Nr	10	11	12
Value (kg 1,4-DB equivalents)	1,11969E-05	1,02335E-05	9,41872E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Pipe system	Fish feed
Process 4	Fishmeal	Manufacture of chemicals and chemical products	Soy Meal (no avoid byprod)
Process 5	Heat (fish ind.)		
Process 6	Heat (oil)		
Process 7			
Process 8			
Path Nr	13	14	15
Value (kg 1,4-DB equivalents)	8,84873E-06	7,98754E-06	7,19478E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Broodstock operation
Process 4	Fish oil	Fish oil	Chemicals, desinfection
Process 5	Heat (fish ind.)	Heat (fish ind.)	Manufacture of chemicals and chemical products
Process 6	Heat (coal)	Heat (gas)	
Process 7			
Process 8			
Path Nr	16	17	18
Value (kg 1,4-DB equivalents)	7,10869E-06	6,05277E-06	5,33674E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Recycling Equipment	Construction	Fish feed
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Manufacture of chemicals and chemical products	Fishmeal
Process 5			Chemicals organic
Process 6			
Process 7			

Process 8			
Path Nr	19	20	21
Value (kg 1,4-DB equivalents)	4,82605E-06	4,44748E-06	4,22298E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Construction	Construction	Fish feed
Process 4	Sewage and refuse disposal, sanitation and similar activities	Manufacture of other non-metallic mineral products	Fish oil
Process 5			Heat (fish ind.)
Process 6			Heat (oil)
Process 7			
Process 8			
Path Nr	22	23	24
Value (kg 1,4-DB equivalents)	4,10977E-06	3,90834E-06	3,86816E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Fishmeal	Potato starch / potato flour	Fish feed
Process 5	Electricity (natural gas)	Potatoes, from farm	Freighter oceanic
Process 6		Fertiliser (N)	
Process 7			
Process 8			
Path Nr	25	26	27
Value (kg 1,4-DB equivalents)	3,23766E-06	3,12089E-06	3,0783E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Div. Technical Installations	Construction
Process 4	Potato starch / potato flour	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Process 5	Potatoes, from farm		Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Process 6	Traction		
Process 7	Diesel (kg)		
Process 8			
Path Nr	28	29	30
Value (kg 1,4-DB equivalents)	2,95239E-06	2,8964E-06	2,88768E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Feed at Mongstad
Process 4	Potato starch / potato flour	Fish feed	Fish feed
Process 5	Potatoes, from farm	Fishmeal	Fishmeal
Process 6	Traction	Sand eel, ex harbour	Sand eel, ex harbour
Process 7		Fishing vessel, diesel combusted in	Fishing vessel, diesel combusted in
Process 8			Diesel (kg)
Path Nr	31	32	33

Value (kg 1,4-DB equivalents)	2,8588E-06	2,79032E-06	2,77827E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Construction	Fish feed
Process 4	Wheat, conventional, from farm	Construction	Potato starch / potato flour
Process 5	Fertiliser (N)		Heat (gas)
Process 6			
Process 7			
Process 8			
Path Nr	34	35	36
Value (kg 1,4-DB equivalents)	2,74005E-06	2,70882E-06	2,66089E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Construction	Construction
Process 4	Fishmeal	Construction	Land transport; transport via pipelines (60)
Process 5	Chemicals inorganic	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	
Process 6			
Process 7			
Process 8			
Path Nr	37	38	39
Value (kg 1,4-DB equivalents)	2,63964E-06	2,47179E-06	2,42899E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Manufacture of chemicals and chemical products	Broodstock operation	Pipe system
Process 4		Plankton Production	Manufacture of chemicals and chemical products
Process 5		Manufacture of food products and beverages	Manufacture of chemicals and chemical products
Process 6		Agriculture, hunting and related service activities	
Process 7			
Process 8			
Path Nr	40	41	42
Value (kg 1,4-DB equivalents)	2,38921E-06	2,36683E-06	2,06355E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Construction	Fish feed	Recycling Equipment
Process 4	Agriculture, hunting and related service activities	Potato starch / potato flour	Manufacture of chemicals and chemical products
Process 5		Potatoes, from farm	
Process 6		Fertiliser (P)	
Process 7			
Process 8			
Path Nr	43	44	45
Value (kg 1,4-DB equivalents)	2,01278E-06	1,90719E-06	1,79238E-06

Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Construction
Process 4	Fish oil	Wheat, conventional, from farm	Manufacture of rubber and plastic products
Process 5	Chemicals organic	Traction	Manufacture of chemicals and chemical products
Process 6		Diesel (kg)	
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg 1,4-DB equivalents)	1,78226E-06	1,74663E-06	1,73914E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Soy Meal (no avoid byprod)	Wheat, conventional, from farm
Process 5	Electricity (natural gas)	Soy bean, from farm	Traction
Process 6		Fertiliser (P205)	
Process 7			
Process 8			
Path Nr	49	50	
Value (kg 1,4-DB equivalents)	1,73533E-06	1,70773E-06	
Process 1	On-Growing operation	On-Growing operation	
Process 2	Feed at Mongstad	Feed at Mongstad	
Process 3	Heat exchangers	Broodstock operation	
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Chemicals, desinfection	
Process 5		Manufacture of chemicals and chemical products	
Process 6		Manufacture of chemicals and chemical products	
Process 7			
Process 8			

B.2.7 Acidification potential

Path Nr	1	2	3
Value (kg 1,4-DB equivalents)	0,005095521	0,002060854	0,001921802
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Freighter oceanic	Fish oil
Process 5	Sand eel, ex harbour		Sand eel, ex harbour
Process 6	Fishing vessel, diesel combusted in		Fishing vessel, diesel combusted in
Process 7			
Process 8			
Path Nr	4	5	6
Value (kg 1,4-DB equivalents)	0,00118985	0,000849677	0,000744736
Process 1	On-Growing operation	On-Growing operation	On-Growing operation

Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Wheat, conventional, from farm	[000a]Soy Meal (no avoid byprod)
Process 5	Potatoes, from farm		Freighter oceanic
Process 6			
Process 7			
Process 8			
Path Nr	7	8	9
Value (kg 1,4-DB equivalents)	0,000739576	0,000514125	0,000278935
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Fishmeal	Fishmeal	Fish oil
Process 5	Sand eel, ex harbour	Heat (fish ind.)	Sand eel, ex harbour
Process 6	Fishing vessel, diesel combusted in	Heat (coal)	Fishing vessel, diesel combusted in
Process 7	Diesel (kg)		Diesel (kg)
Process 8			
Path Nr	10	11	12
Value (kg 1,4-DB equivalents)	0,000273514	0,000268185	0,000254982
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Potato starch / potato flour	Fish feed	Fishmeal
Process 5	Potatoes, from farm	Fishmeal	Heat (fish ind.)
Process 6	Fertiliser (N)	Sand eel, ex harbour	Heat (gas)
Process 7		Fishing vessel, diesel combusted in	
Process 8			
Path Nr	13	14	15
Value (kg 1,4-DB equivalents)	0,00025022	0,00021083	0,000200065
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	Feed at Mongstad
Process 3	Recycling Equipment	Construction	Fish feed
Process 4	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Manufacture of other non-metallic mineral products	Wheat, conventional, from farm
Process 5			Fertiliser (N)
Process 6			
Process 7			
Process 8			
Path Nr	16	17	18
Value (kg 1,4-DB equivalents)	0,00019493	0,000193905	0,000176795
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Fish oil	Fishmeal
Process 5	Potatoes, from farm	Heat (fish ind.)	Heat (fish ind.)
Process 6	Traction	Heat (coal)	Heat (oil)
Process 7			
Process 8			

Path Nr	19	20	21
Value (kg 1,4-DB equivalents)	0,000131909	0,000114826	0,000109853
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	On-Growing facility
Process 3	Fish feed	Fish feed	Div. Technical Installations
Process 4	Fishmeal	Wheat, conventional, from farm	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Chemicals organic	Traction	
Process 6			
Process 7			
Process 8			
Path Nr	22	23	24
Value (kg 1,4-DB equivalents)	0,000108466	0,000101489	0,000101147
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	On-Growing facility	Nursery operation
Process 3	Feed at Mongstad	Pipe system	Feed at Mongstad
Process 4	Fish feed	Manufacture of chemicals and chemical products	Fish feed
Process 5	Freighter oceanic		Fish oil
Process 6			Sand eel, ex harbour
Process 7			Fishing vessel, diesel combusted in
Process 8			
Path Nr	25	26	27
Value (kg 1,4-DB equivalents)	9,61677E-05	9,36458E-05	8,20015E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation
Process 3	Fish feed	Fish feed	Broodstock operation
Process 4	Fish oil	Soy Meal (no avoid byprod)	Plankton Production
Process 5	Heat (fish ind.)	Soy bean, from farm	Manufacture of food products and beverages
Process 6	Heat (gas)	Traction	Agriculture, hunting and related service activities
Process 7			
Process 8			
Path Nr	28	29	30
Value (kg 1,4-DB equivalents)	7,9262E-05	7,322E-05	7,13532E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	Nursery operation
Process 3	Construction	Fish feed	Broodstock operation
Process 4	Agriculture, hunting and related service activities	Fishmeal	Chemicals, desinfection
Process 5		Electricity (natural gas)	Manufacture of chemicals and chemical products
Process 6			
Process 7			
Process 8			
Path Nr	31	32	33
Value (kg 1,4-DB equivalents)	6,86346E-05	6,67861E-05	6,66791E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad

Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Fishmeal	Fish oil
Process 5	Potatoes, from farm	Chemicals inorganic	Heat (fish ind.)
Process 6	Fertiliser (P)		Heat (oil)
Process 7			
Process 8			
Path Nr	34	35	36
Value (kg 1,4-DB equivalents)	6,28112E-05	6,26237E-05	6,10823E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Nursery operation	On-Growing facility
Process 3	Construction	Feed at Mongstad	Heat exchangers
Process 4	Construction	Fish feed	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5		Potato starch / potato flour	
Process 6		Potatoes, from farm	
Process 7			
Process 8			
Path Nr	37	38	39
Value (kg 1,4-DB equivalents)	6,00275E-05	5,87078E-05	5,49264E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Nursery operation	On-Growing facility
Process 3	Construction	Broodstock operation	Pumps
Process 4	Manufacture of chemicals and chemical products	Plankton Production	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5		Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing	
Process 6			
Process 7			
Process 8			
Path Nr	40	41	42
Value (kg 1,4-DB equivalents)	5,29803E-05	5,06498E-05	5,01679E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	On-Growing facility
Process 3	Construction	Fish feed	Construction
Process 4	Land transport; transport via pipelines (60)	Soy Meal (no avoid byprod)	Manufacture of fabricated metal products, except machinery and equipment
Process 5		Soy bean, from farm	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 6		Fertiliser (P205)	
Process 7			
Process 8			
Path Nr	43	44	45
Value (kg 1,4-DB equivalents)	4,975E-05	4,76511E-05	4,47198E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Recycling Equipment	Feed at Mongstad
Process 4	Fish oil	Manufacture of machinery	Fish feed

		and equipment n.e.c.	
Process 5	Chemicals organic	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Wheat, conventional, from farm
Process 6			
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg 1,4-DB equivalents)	4,36426E-05	4,14999E-05	3,91966E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Freezing facilities	Feed at Mongstad
Process 4	Potato starch / potato flour	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Fish feed
Process 5	Potatoes, from farm		Soy Meal (no avoid byprod)
Process 6	Traction		Freighter oceanic
Process 7	Diesel (kg)		
Process 8			
Path Nr	49	50	
Value (kg 1,4-DB equivalents)	3,89251E-05	3,86364E-05	
Process 1	On-Growing operation	On-Growing operation	
Process 2	Nursery operation	On-Growing facility	
Process 3	Feed at Mongstad	Construction	
Process 4	Fish feed	Water transport (61)	
Process 5	Fishmeal		
Process 6	Sand eel, ex harbour		
Process 7	Fishing vessel, diesel combusted in		
Process 8	Diesel (kg)		

B.2.8 Eutrophication potential

Path Nr	1	2	3
Value (kg 1,4-DB equivalents)	0,002260658	0,001589926	0,001177632
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Wheat, conventional, from farm	Fishmeal
Process 5	Potatoes, from farm		Sand eel, ex harbour
Process 6			Fishing vessel, diesel combusted in
Process 7			
Process 8			
Path Nr	4	5	6
Value (kg 1,4-DB equivalents)	0,00044415	0,000203252	0,000118982
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Nursery operation

Process 3	Fish feed	Fish feed	Feed at Mongstad
Process 4	Fish oil	Fishmeal	Fish feed
Process 5	Sand eel, ex harbour		Potato starch / potato flour
Process 6	Fishing vessel, diesel combusted in		Potatoes, from farm
Process 7			
Process 8			
Path Nr	7	8	9
Value (kg 1,4-DB equivalents)	0,000107441	8,36803E-05	7,66576E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Freighter oceanic	Fish feed	Fish oil
Process 5		Wheat, conventional, from farm	
Process 6			
Process 7			
Process 8			
Path Nr	10	11	12
Value (kg 1,4-DB equivalents)	6,67082E-05	6,19806E-05	4,80604E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Fishmeal	Fish feed	Potato starch / potato flour
Process 5	Sand eel, ex harbour	Fishmeal	Potatoes, from farm
Process 6	Fishing vessel, diesel combusted in	Sand eel, ex harbour	Traction
Process 7	Diesel (kg)	Fishing vessel, diesel combusted in	
Process 8			
Path Nr	13	14	15
Value (kg 1,4-DB equivalents)	4,72871E-05	3,88262E-05	3,45887E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Feed at Mongstad	Feed at Mongstad
Process 3	Fish feed	Fish feed	Fish feed
Process 4	Potato starch / potato flour	Soy Meal (no avoid byprod)	Wheat, conventional, from farm
Process 5	Potatoes, from farm	Freighter oceanic	Fertiliser (N)
Process 6	Fertiliser (N)		
Process 7			
Process 8			
Path Nr	16	17	18
Value (kg 1,4-DB equivalents)	2,99107E-05	2,83106E-05	2,51593E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	Feed at Mongstad
Process 3	Construction	Fish feed	Fish feed
Process 4	Manufacture of other non-metallic mineral products	Wheat, conventional, from farm	Fish oil
Process 5		Traction	Sand eel, ex harbour
Process 6			Fishing vessel, diesel combusted in
Process 7			Diesel (kg)
Process 8			

Path Nr	19	20	21
Value (kg 1,4-DB equivalents)	2,38E-05	2,33763E-05	2,31955E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Fishmeal	Fish feed	Fishmeal
Process 5	Heat (fish ind.)	Fish oil	Heat (fish ind.)
Process 6	Heat (coal)	Sand eel, ex harbour	Heat (gas)
Process 7		Fishing vessel, diesel combusted in	
Process 8			
Path Nr	22	23	24
Value (kg 1,4-DB equivalents)	2,30885E-05	1,96309E-05	1,8452E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Recycling Equipment	Broodstock operation
Process 4	Soy Meal (no avoid byprod)	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Plankton Production
Process 5	Soy bean, from farm		Manufacture of food products and beverages
Process 6	Traction		Agriculture, hunting and related service activities
Process 7			
Process 8			
Path Nr	25	26	27
Value (kg 1,4-DB equivalents)	1,78355E-05	1,78145E-05	1,51527E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	Feed at Mongstad	On-Growing facility
Process 3	Construction	Fish feed	Construction
Process 4	Agriculture, hunting and related service activities	Fishmeal	Construction
Process 5		Electricity (natural gas)	
Process 6			
Process 7			
Process 8			
Path Nr	28	29	30
Value (kg 1,4-DB equivalents)	1,43163E-05	1,32939E-05	1,2282E-05
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	On-Growing facility	On-Growing facility
Process 3	Broodstock operation	Construction	Pipe system
Process 4	Plankton Production	Land transport; transport via pipelines (60)	Manufacture of chemicals and chemical products
Process 5	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing		
Process 6			
Process 7			
Process 8			
Path Nr	31	32	33
Value (kg 1,4-DB equivalents)	1,13648E-05	1,06975E-05	8,97631E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation

Process 2	Feed at Mongstad	Nursery operation	Feed at Mongstad
Process 3	Fish feed	Feed at Mongstad	Fish feed
Process 4	Fishmeal	Fish feed	Fish oil
Process 5	Heat (fish ind.)	Fishmeal	Heat (fish ind.)
Process 6	Heat (oil)		Heat (coal)
Process 7			
Process 8			
Path Nr	34	35	36
Value (kg 1,4-DB equivalents)	8,74829E-06	8,63503E-06	8,61842E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	Nursery operation	On-Growing facility
Process 3	Fish feed	Broodstock operation	Div. Technical Installations
Process 4	Fish oil	Chemicals, desinfection	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1
Process 5	Heat (fish ind.)	Manufacture of chemicals and chemical products	
Process 6	Heat (gas)		
Process 7			
Process 8			
Path Nr	37	38	39
Value (kg 1,4-DB equivalents)	7,7255E-06	7,26441E-06	6,82274E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	On-Growing facility
Process 3	Fish feed	Construction	Construction
Process 4	Potato starch / potato flour	Manufacture of chemicals and chemical products	Water transport (61)
Process 5	Electricity (natural gas)		
Process 6			
Process 7			
Process 8			
Path Nr	40	41	42
Value (kg 1,4-DB equivalents)	6,71884E-06	5,868E-06	5,65479E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Feed at Mongstad	On-Growing facility	Nursery operation
Process 3	Fish feed	Recycling Equipment	Feed at Mongstad
Process 4	Fish oil	Water transport (61)	Fish feed
Process 5	Electricity (natural gas)		Freighter oceanic
Process 6			
Process 7			
Process 8			
Path Nr	43	44	45
Value (kg 1,4-DB equivalents)	5,21611E-06	4,95521E-06	4,89957E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	Nursery operation	On-Growing facility	On-Growing facility
Process 3	Broodstock operation	Construction	Construction
Process 4	Plankton Production	Construction	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Process 5	Manufacture of food products and beverages	Manufacture of other non-metallic mineral products	

Process 6	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing		
Process 7			
Process 8			
Path Nr	46	47	48
Value (kg 1,4-DB equivalents)	4,80797E-06	4,79217E-06	4,68925E-06
Process 1	On-Growing operation	On-Growing operation	On-Growing operation
Process 2	On-Growing facility	On-Growing facility	Nursery operation
Process 3	Construction	Heat exchangers	Broodstock operation
Process 4	Water transport	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	Plankton Production
Process 5			Manufacture of food products and beverages
Process 6			Manufacture of food products and beverages
Process 7			Agriculture, hunting and related service activities
Process 8			
Path Nr	49	50	
Value (kg 1,4-DB equivalents)	4,65015E-06	4,30921E-06	
Process 1	On-Growing operation	On-Growing operation	
Process 2	On-Growing facility	On-Growing facility	
Process 3	Recycling Equipment	Pumps	
Process 4	Land transport; transport via pipelines (60)	Manufacture of basic iron and steel and of ferro-alloys (ECSC)1	
Process 5			
Process 6			
Process 7			
Process 8			

Program for industriell økologi (IndEcol) er et tverrfaglig universitetsprogram etablert i 1998 for en periode på minst ti år ved Norges teknisk-naturvitenskapelige universitet (NTNU). Programmet omfatter et studieprogram opprettet i 1999 og et stort antall doktorgradsprosjekter og forskningsprosjekter rettet mot vareproduserende industri, energi- og byggesektoren. Tverrfaglig forskning og undervisning står sentralt ved IndEcol, og målet er å knytte sammen teknologiske, naturvitenskapelige og samfunnsvitenskapelige bidrag i letingen etter bærekraftige løsninger på produksjon og forbruk av energi og ressurser.

The Industrial Ecology Programme (IndEcol) is a multidisciplinary university programme established at the Norwegian University of Science and Technology (NTNU) in 1998 for a period of minimum ten years. It includes a comprehensive educational curriculum launched in 1999 and a significant number of doctoral students as well as research projects geared towards Norwegian manufacturing, energy and building industries. The activities at IndEcol have a strong attention to interdisciplinary research and teaching, bridging technology, natural and social sciences in the search for sustainable solutions for production and consumption of energy and resources.

NTNU-IndEcol
Industrial Ecology Programme
NO-7491 Trondheim

Tel.: + 47 73 59 89 40
Fax: + 47 73 59 89 43
E-mail: indecol@indecol.ntnu.no
Web: www.indecol.ntnu.no