Life Cycle Assessment on Icelandic cod product based on two different fishing methods

Environmental impacts from fisheries

Aðalbjörg Birna Guttormsdóttir

Verkfræðideild

Háskóli Íslands

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60 eininga ritgerð sem er hluti af
Magister Scientiarum gráðu í Umhverfis og Auðlindafræði

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ABSTRACT

Human population is ever increasing. Population in 2009 is currently approaching 7 billion people and is expected to become 9.7 billion in 2050. Seafood is an important protein income for humans. According to FAO, more than 80% of all fish stock on Earth are either fully exploited or over exploited. Fisheries have considerable environmental impacts such as effects on seafloor caused by fishing gear, effects on biodiversity, use of fossil fuels and other chemicals that contribute to climate changes, acidification and ecosystem toxicity, and depletion of minerals.

By applying Life Cycle Assessment (LCA) a holistic overview over the whole life cycle of a final product can be gained. In this study 1 kg of frozen processed Icelandic cod product is assessed, caught by two different fishing gears, a long liner and a bottom trawler in order to evaluate their environmental impacts. The data was gathered from two seafood companies in Iceland, FISK Seafood that owned and operated the bottom trawler Hegranes Sk and Vísir Hf that owns and operates the long liner Kristín ÞH. Information came from two fish process plants owned by the seafood companies at Sauðárkrókur and Þingeyri. The product was followed from the processing plant through transportation to Sevilla in Spain where it is sold and consumed. The conclusions are that bottom trawled cod compared to long line caught cod, has higher environmental impacts within all categories assessed such as climate change, respiratory organics/inorganics, eco-toxicity, acidification and fossil fuel. The most dominating phase within both fishing methods is the fishery phase, which is due to fossil fuel consumption. For 1 kg of processed bottom trawled cod, 1.1 liter of fuel was combusted by the fishing vessel. For same amount of long liner caught cod, 0.36 liters were utilized. Substantial environmental impact is coming from processing phase, especially within the trawled cod product. This is mainly due to cooling agents that are utilized inside the processing plant and have great inputs from nature resources when produced together with emissions to soil, air and water. For long lined cod the second greatest environmental impact is the transportation with most of the environmental impact coming from trucks that transport the product in Iceland and in target country of the product. Carbon footprint was calculated both for trawled and for long lined cod. The trawled cod results in 5.14 kg CO_2 equivalence while the long lined cod calculates to be 1.58 kg CO_2 eq.

ÚTDRÁTTUR

Fólksfjöldi jarðar nálgast nú 7 milljarða. Ef tekið er tillit til spár Sameinuðu Þjóðanna þá mun fjöldi fólks árið 2050 verða kominn yfir 9 milljarða. Allur þessi fjöldi fólks þarf á fæðu að halda. Prótín frá sjávarafurðum er ein mikilvægasta prótín uppspretta sem við höfum aðgang að. Matvælastofnun Sameinuðu Þjóðanna hefur lýst því yfir að yfir 80% allra fiskistofna séu ýmist full- eða ofnýttir. Einnig hafa fiskveiðar eins og þær eru stundaðar í dag í för með sér töluverð umhverfisáhrif. Þar má nefna áhrif sem veiðarfæri hafa á sjávarbotninn, áhrif fiskveiða á líffræðilegan fjölbreytileika, áhrif jarðefnaeldsneytis á hlýnun jarðar, súrt regn og súrnun sjávar ásamt eituráhrifum innan vistkerfa og ofnýtingu á hráefnis birgðum jarðar.

Vistferilgreining (LCA) gerir okkur kleift að fá heilstæða mynd af lífsferli vöru eða þjónustu. Í þessu MS verkefni er tekið fyrir og borið saman 1 kg af léttsöltuðu lausfrystu þorskflaki með roði og beini veiddu með botnvörpu annars vegar og á línu hins vegar. Upplýsingum var safnað frá tveimur íslenskum sjávarútvegsfyrirtækjum FISK Seafood sem átti og rak ístogarann Hegranes SK og Vísi hf sem á og rekur línubátinn Kristínu ÞH. Gögnum var safnað frá vinnslustöðum beggja fyrirtækja, FISK Seafood á Sauðárkrók og Vísis hf á Þingeyri. Vörunni var svo fylgt frá vinnslu í gegnum flutninga til Sevilla á Spáni þar sem varan er seld. Helstu niðurstöður eru þær að þorskur veiddur í botnvörpu hefur umtalsvert meiri umhverfisáhrif innan allra þeirra umhverfisþátta sem tekið var tillit til. Mestu umhverfisáhrifin eru að finna innan fiskveiðanna sjálfra sem kemur til vegna olíunotkunar skipanna. Til að veiða 1 kg af því er samsvarar fullunninni afurð þá brennir fiskveiðiskipið með botnvörpuna 1,1 líter af olíu á meðan línuskip notar 0,36 lítra. Umtalsverð umhverfisáhrif er einnig að finna innan frystihúsanna þar sem að vinnslan fer fram sér í lagi vegna kælimiðla sem þar eru notaðir. Flutningur á afurðinni er einnig stór þáttur í umhverfisáhrifunum þar sem að afurðinni er keyrt kældri langar leiðir og flutt sjóleiðis í kældum gámum til Evrópu með tilheyrandi umhverfisáhrifum. Reiknuð voru út svokölluð sótspor sem segja til um útblástur gróðurhúsategunda umreiknuð yfir í koltvísýringsígildi. Sótspor 1 kg þorsks sem veiddur er með botnvörpu eru 5,14 kg koltvísýringsígildi á meðan sótspor sama magns af línuþorski er 1,58 kg koltvísýringsígildi.

To my baby girl Unnur Ösp and all the other children of this world.

It is for them that we should think and act in a sustainable way.

PREFACE

This project was submitted and written in 2009 at the University of Iceland, within Environment and Natural Resources M.Sc program at the department of Engineering and Natural Sciences. The project was funded by Matís ohf, the Icelandic Food Research and the work has been conducted within the department of the Value Chain and Processing at Skúlagata 4 where I have had my office desk for over a year now.

The guidance of this project was in the supervision of lic.techn. Páll Jensson, Dr. Brynhildur Davíðsdóttir from University of Iceland, Dr. Harpa Birgisdóttir from Efla Consulting Engineers and Dr. Sveinn Margeirsson from Matís ohf.

I would like to thank Matís ohf for funding this project, allowing me to use their facilities and providing me with the SimaPro software utilised in this project. I would also like to thank FISK Seafood and Vísir hf for providing me with information for this project and especially to Þórhallur and Viðar at Vísir hf at Þingeyri for welcoming me to their processing plant in autumn 2008. Special thanks go as well to the people at Iceland New Energy for their input, help and data.

Additionally I would like to thank my family and everyone that has helped in any way to undertake this study.

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LIST OF ABBREVIATIONS

CBD	Convention on Biological Diversity
CO_2	Carbon dioxide
CO_2 eq	Carbon dioxide equivalence
DALY	Disability Adjusted Human Life Years
DDT	Dichlorodiphenyltrichloroethane
EEA	European Economic Area
EU	European Union
FAO	Food and Agriculture Organization
Fe^2	Ferrous iron
GHA	Global hectares
GHG	Greenhouse gas
GIS	Geographic Information Systems
GWP	Gross World Productivity
H_2	Hydrogen
IPCC	Intergovernmental Panel on Climate Change
ISK	Icelandic currency
LCA	Life Cycle Assessment/ Life Cycle Analysis
MECO	MaterialsEnergyChemicalsOthers
PCB	Polychlorinated biphenyl
PDF	Potentially Disappeared Fraction
PEM	Polymer Electrolyte Membrane
PV	Photovoltaic
SETAC	Society of Environmental Toxicology and Chemistry
TBT	Tributyltin
UNCLOS	United Nations Convention on the Law of the Sea
UNCED	United Nations Conference on Environment and Development
UNEP	United Nation Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WCED	World Commission in Environment and Development
WSSD	World Summit on Sustainable Development
WWF	World Wildlife Fund

1 Introduction

Ever growing human population together with its maladaptive patterns of production and consumption is causing a great pressure on the planetary ecosystems. The world's oceans play an important role for life on our planet. Healthy seas and services that they offer is the key to our future (Nellemann et al., 2008).

The sea has been fished since prehistoric times and there are many testimonials of fisheries from Greece, Egypt and the Ancient Roman Empire. Fish has been a vital source of protein and when seafaring and navigation skills developed, great offshore fish resources were discovered (Kaiser et al., 2005). Fisheries began effecting fish stocks and the ecosystem on a global scale after the industrial revolution. The industry became more mechanised with large trawl nets, powered winches, sonar devices and freezer trawlers and finally fishing capacity became bigger than the capacity of the biological productivity of many fish species, for example of the cod stock (Kaiser et al., 2005; The World Bank, 2009). Ever increasing human population and economic growth pushes oceanic over-exploitation, pollution and habitat destruction. In shallow waters above the continental shelves, ninety percent of marine life is to be found. The proximity of the coastline makes marine resources and ecosystems very vulnerable for anthropological activities (Lakshman, 2003).

In 2006, the global marine production was 81.9 million tons of fish and according to FAO, the catch has reached the practical maximum that is expected to be taken from wild fish stocks (Food and Agricultural Organization, 2009). Fisheries are a key contributor to global food security and economy, but are unfortunately subsidised, wasteful and cause harmful environmental damage together with conflicts between nations (Kaiser et al., 2005)

Fisheries cause direct impacts on fish stocks and affect seafloor environment which again influences the entire marine ecosystem (Thrane, 2005). Besides reducing the biomass of both target and by- catch species, fisheries affect structure and function of the marine ecosystems through several mechanisms (Gislason, 2003). Discarding of by-catch and organic waste increases the scavenging species populations and can cause eutrophication where the discards fall to the seafloor (Gislason, 2003;Sinclair & Valdimarsson, 2003). Fishing gear that comes in contact to the seafloor modifies stones and boulders, influences and damages corals and other fauna and flora and causes changes in biodiversity of the seafloor (Løkkeborg, 2004).

The release of biocides such as TBT from anti fouling paint has an impact on the ecosystem together with the loss of the fishing gear that may continue to the catch, solid waste, fish waste and wastewater from tanks (Thrane , 2005). Combustion of fossil fuels and the release of greenhouse gases to the atmosphere cause environmental impact and contributes to climate changes and acidification. The global fishing fleet burns during fishery almost 50 billion L of fuel per year (average of 620 L of oil per ton of fish) pumping more than 130 million tons of CO_2 into the atmosphere which is an average of 1.7 tons of CO_2 per ton of landed product. (Tyedmers et al., 2005). Most of the pollution that is released into the environment is eventually deposited in the oceans, directly or indirectly. Combination of all of those processes is resulting in changes in the relative abundance and growth of species together with natural fluctuations in the physical environment and other anthropological activities (Gislason, 2003) .

1.1 Background and motivation

Anthropological activities are affecting natural fish populations and the fisheries as a whole. Environmental changes influence fish recruitment and alter the ecosystem habitats of the marine environment (Richardson, 2003).

Contaminants are substances that are toxic to living organisms. Contaminants deriving from both natural and anthropological sources can affect fisheries. They can enter ecosystems naturally like some metals or they may be produced and released by human activities such as oil, fertilisers, solid garbage, sewage and toxic chemical (Richardson, 2003; WWF, 2008)

The Intergovernmental Panel on Climate Change (IPCC) has stated that anthropogenic emissions of greenhouse gases are contributing significantly and causing negative impacts on the Earth’s climate. The Panel has warned that global mean temperatures are rising and patterns in precipitation and extreme weather events are becoming more extreme (The United Nations, 2008). Wide range of impacts and implications are expected for the world communities. Those impacts are i.e. increased water stress, food insecurity, population dynamics changes because of increased competition for land and resources, human settlements vulnerability and decline in health status of millions of individuals (The United Nations, 2008).

Each year, six billion tons of carbon dioxide (CO_2) and significant amounts of other greenhouse gases like methane, nitrous oxides and HFCs are discharged into the atmosphere by human activities (Lakshman, 2003). Greenhouse gases change the natural distribution of gases found in the atmosphere that surrounds the earth. When sunlight hits the surface of the earth some of it gets re-radiated back as infrared radiation. The greenhouse gases absorb the radiation and it gets trapped inside of the earth's atmosphere, causing global warming (EIA, 2008). The earth's stable climate requires a balance between incoming and outgoing heat (Lakshman, 2003).

It is expected that by 2010 CO_2 emissions will reach 7.9 billion tons per year and approximately 9.9 billion tons per year in 2020. According to the IPCC the atmospheric concentration of CO_2 has increased by 36% since the industrial revolution and the present CO_2 concentrations are the highest in at least 650.000 years (Environmental Protection Agency, 2008).

Today, more than 85% of the world energy supplies derive from fossil fuels resulting in great ecological and environmental impacts and is far from being sustainable (BACAS, 2006;Botkin and Keller, 2007). A part from the depletion of reserves and resources, air pollution and modification of the atmospheric composition together with their impacts on climate and on human health, have become a primary importance of investigation (BACAS, 2006).

181 nations of the world have signed and ratified the Kyoto Protocol that aims to combat global warming by reducing emissions of greenhouse gases. The Icelandic government has, according to the Kyoto agreement, committed not to increase the release of greenhouse gases more than 10% compared to 1990, i.e. to stay within 3800 ton CO_2 equivalents every year from 2008 to 2012. The Icelandic government has additionally set its ambitious goal to reduce the release of greenhouse gases of 50-75% compared to 1990, before the year 2050 (Icelandic Ministry for the Environment, 2007). To maintain the Icelandic government's goals it is certain that changes have to be done when it comes to fossil fuel combustion. In 2006 the emissions within the Icelandic fisheries was 15% of the total greenhouse gases emissions, with 12% coming from the fishing vessels directly. It has been pointed out that by substituting fossil fuels with renewable energy carrier such as hydrogen in the fishing vessels, the fisheries could reduce their emissions by 90% (Þórhallur Ásbjörnsson, 2005).

International groups of ecologists and economists have warned that worldwide fisheries could be in a danger of a total collapse by 2050 if no action is taken. In fact scientists have pointed out that the key factors for this collapse would be; over fishing, pollution, climate changes, increased acidity of the oceans and the destruction of marine habitats (Food and Agriculture Organization of the United Nations, 2005).

Many retailers within the seafood market have initiated campaigns where sustainability and environmental issues are promoted. Big supermarket chains in the UK, USA and

Germany such as Wal-Mart, Tesco, Whole Foods and Edeka have announced that they are taking action in environmental business. Wal-Mart states that environmental sustainability is one of the most important opportunities for the future of their business and for the future of the world. According to their website, their goal is to be supplied 100% by renewable energy, to create zero waste and to sell only products that are sustainable (WalMart, n.d). Tesco has as well committed to the principles of sustainability of their fish sources and promote ecolabled fish. Tesco is also preferring line fished cod and haddock over trawled ones (Tesco, 2005).

Early 2009, the biggest seafood retailer in Germany, Edeka, holding 25% of the German food retail market, announced that they would join WWF and support seafood coming from sustainable sources. According to new WWF survey, out of 1002 consumers, 85% wanted supermarkets and fish shops to offer only fish that can be proved to be from a sustainable source (IntraFish, 2009).

In 2008, three largest supermarkets in Switzerland announced they would no longer sell wild Icelandic cod since the fishery has no sustainability certification. Those supermarkets have 75% of the seafood market in Switzerland (Fiske, 2008).

In 2009 WWF published an article where cod, haddock and halibut from Iceland is recommended not to be bought. Icelandic fishery has now come up with its own label, stating that Icelandic fisheries are responsible fisheries in cooperation with the International Council for the Exploration of the Sea. This cooperation is said to ensure that the Marine Research Institute is working on demands that meet international criteria (Icelandic Fisheries, 2007) but no legal third part eco label certificatory is taking part in this certification and no international standardised environmental tool such as LCA is being applied to assess the sustainability or the environmental impacts caused by the Icelandic fisheries.

This thesis includes two Life Cycle Assessments made on 1 kg of light salted frozen cod fillet fished by two fishing vessels operating with two different fishing gears; Hegranes SK-2 a vessel owned by a company called Fisk Seafood and operates with a bottom trawl and Kristín ÞH 157 which is a long liner owned by the seafood company Vísir hf.

1.2 Objective

The objective of this thesis is to develop and set the basis for cleaner production methods within Icelandic seafood industry, to increase environmental consciousness and to gain more knowledge and support further research in the field of fisheries and Life Cycle Assessment.

The environmental gain of renewable energy carriers during fisheries combined with sustainable natural resource management will therefore be a step forward to meet the increasing demands of consumers towards environmental friendly products.

1.3 Research questions

The report will aim to answer the following research questions:

- Is there a substantial difference in the environmental performance between the two alternative fishing gears; cod fished by a bottom trawl and cod fished with a long line?

- Where are the hot spots within the life cycle of the product and what improvements can be made to reduce them?

1.4 Thesis structure

The thesis is organized as follows:

Chapter 1 includes the introduction, the background and motivation for this study, the objective and the research questions that are going to be answered. The end of the chapter describes the LCA background.

Chapter 2 discusses the LCA literature for codfish and impact of fisheries. Fishing gear is discussed and in particular bottom trawl and long line. Effects of fishing gear depending on the type of seafloor are discussed and the seafloor situation in Iceland is described. Environmental effects of long line are also discussed. In this chapter following issues are also discussed; climate changes, ecological and carbon footprints, biodiversity and natural capital, ocean pollution, world fish stock situation, international environmental law, fossil fuels, hydrogen and different ways of producing hydrogen. In the end there is a short overview about hydrogen fuel cells in boats and fishing vessels.

Chapter 3 describes the LCA methodology, such as the goal and the scope, functional unit, system boundaries, limitations and assumptions, impact categories and assessment methods. Characterization, normalization and weighing are described in theory. In this chapter the basic information of this study are introduced.

Chapter 4 covers the methodology and data collection. The chapter describes how and what data was collected and it was categorized into different phases, based on the life cycle of the product, 1kg of Icelandic cod.

Chapter 5 contains the results of the study made. Environmental impacts of cod fished by long liner and bottom trawl are assessed and described. A comparison is then made between the two products.

Chapter 6 is a short sensitivity analysis. The fishing vessels are pretended to run on hydrogen engine that does not have any air emission involved.

Chapter 7 discusses the results from chapter 5. Limitations and potential for improvements are described together with vision for further work.

2 Present work and data available

The European Union has promoted Life Cycle Assessment (LCA), an internationally standardised methodology, to help quantify the resources consumed and potential environmental impacts of products and services. LCA is a required methodology for different types of eco labels, such as the EU-flower, the Nordic Swan and Environmental Product Declarations (EDPs) (Fet et al., 2009). The entire life cycle of the good or service is taken into account with all its input and outputs, assisting decision makers in businesses and governments to realise how much resources are being consumed and the consequential impacts associated to the production. The method also provides a basis for product comparisons, identification of improvement options and monitoring of environmental performances (European Commission, 2008).

Life Cycle Assessment (LCA) was first introduced in the late sixties and early seventies in the United States and was mainly utilised in the energy sector as well as to identify the environmental impact of packaging. One of the first companies to consider life cycle aspects was the Coca Cola Company that in 1969 funded a study to compare resource consumption and environmental impact associated with containers of beverages (European Environment Agency, 1997). In Europe a similar inventory process was later known as “Eco-balance” and in fact in 1972 the total energy used in the production of various beverage containers was calculated in the United Kingdom. In those years, energy demand was considered as more important parameter than waste and outputs. This explains why there was a little distinction between the resources that went into the product and the interpretation of all associated impacts.

In the mid eighties and early nineties a real LCA interest began and more industries, design establishments and retailers started to use this decision support tool in their businesses. In 1992 at the UN Earth Summit, Life Cycle Assessment methodologies were announced to be the most promising tool for environmental management tasks (European Environment Agency, 1997) by stating “We must develop production and consumption policies to improve the products and services provided, while reducing environmental and health impacts, using, where appropriate, science-based approaches, such as Life Cycle Analysis" (UNEP, 2008). The United Nation Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) established an International Life Cycle Partnership that is known as the Life Cycle Initiative. This program enables users worldwide to put life cycle thinking into action and is a response to the call from governments for a life cycle economy in the 2000 Malmö declaration. The Life Cycle Initiative also contributes to the 10 year framework that promotes sustainability as required at the World Summit on Sustainable Development in Johannesburg in 2002 (UNEP, 2008).

The 1st of January 2005, the European Parliament and the Council of 28 January 2002 Regulation (EC) No 178/2002 establishes the European Food Safety Authority and relevant procedures in matters of food safety that environmental performances of entire life cycle from catch to dish will require a full life cycle analysis (European Parliament and Council of European Union, 2008;USDA, 2005). This legislation demands that all actors establish routines that ensure traceability (European Commission, 2001) of e.g. environmental information as provided in an environmental product declaration. This law applies to the European Economic Area (EEA), which includes the European Union, Norway and Iceland, and to all producers worldwide that import food products or ingredients into the EEA (Fet et al., 2009)

2.1 LCA literature

Not many papers are available for codfish LCA's. This chapter provides an overview of the work done within this field together with a broad discussion of many factors that affect and are affected by fisheries, both globally and in Iceland.

Papers and reports on Life Cycle Assessment are the following;

In 2009 the report "*A Framework for Environmental Analyses of Fish Food Production Systems based on Systems Engineering Principles*" was ready for publishing. The paper utilises system engineering methods with inputs from Life Cycle Assessment to create a framework for performing environmental analysis on fish from the North Sea. Life cycle environmental data from a medium sized Norwegian fishing vessel have been used and the framework demonstrates a systematic way to analyze and provide environmental information for fish food product systems that can become a framework for comparison of different food products. The report describes how LCA of food products is utilised for the development of environmental product declarations (Fet et al., 2009).

The report "*Environmental impacts of wild caught cod and farmed salmon-A comparison with chicken*" (Ellingsen and Aanondsen, 2006) concluded that the fishing phase of the cod dominates for all environmental impacts considered. The area of sea floor that was affected by bottom trawling was around 100 times larger than needed to produce chicken even though the effects on the sea floor are still not fully explored. Potential improvements were pointed out both for salmon farming and cod fishing when it comes to energy use. The report recommends that more effort should be put into adapting the LCA method to fisheries in order to gain more precise information about the environmental impacts of seafood products. More emphasis should be put into finding improved indicators for impacts of over-fishing, fuel emission from combustion at sea, use of antifouling and disturbances on seafloor ecosystems (Ellingsen and Aanondsen, 2006).

In 2006 "*Environmental Life Cycle Assessment of seafood products from capture fisheries*" (Ziegler, 2006) report was published. Two types of fisheries were studied in detail. First case scenario was Swedish cod fished in the Baltic sea using gillnets and trawls, second case scenario was Norway lobster caught on the Swedish west coast with conventional trawls, species selected trawls and creels. Both products were traced from the fishery through auction, to the wholesaler and retailer and out to the consumer. Both of the case studies conclude that the fishery is the dominant phase when it comes to environmental impact and that there is a relevant difference between fishing methods both regarding to resource depletion and environmental impact.

Cod fished in gillnet and lobster caught in creel had lower environmental impact compared to other methods i.e. trawls (Ziegler, 2006). It turns out that transport from retailer to consumer creates the most environmental impact inside the transport phase in both studies. Two methodological studies were made in order to evaluate emissions from fuel combustion while fishing cod and concerning the seafloor impact of the fishery. Emission per gram of fuel were higher in the gillnet fishing compared to the trawl fishing due to low engine load, but higher fuel consumption in trawling leads to higher emissions per kilogram of landed fish. A seafloor study was conducted in Kattegat with GIS analysis and overlaid by a map of marine habitat. The results showed that certain areas were highly affected by the fishing activities of trawls. Almost 50% of the muddy and some of the deep rocky habitats were greatly affected and left in permanently disturbed conditions, while the rest of the habitats were less disturbed (Ziegler, 2006).

The report "*Environmental Impacts from Danish Fish Products*" (Thrane, 2006) presents a detailed analysis of the environmental impacts of Danish seafood production. In this report again the most environmental burden is to be found during the fishing stage of the product as at this stage the characteristics is significant fuel consumption, release of toxic substances from anti-fouling paint, overexploitation of some fish stocks, by catch and seabed impact by bottom dragging fishing gear such as bottom trawls. The key processes that are particularly energy consuming from sea to table indicated in this report, are the fishing, transport and cooling. This report points out that if all flatfish in Denmark would be caught by Danish seine nets or gillnets it would theoretically be possible to save 30 million litres of fuel per year within the Danish fishery or 15% of their total fuel consumption in year. The conclusions in the report also mention that the two last stages, use and retail stages do as well represent a significant impact potential. This is in particular the use stage since the shopping, usually done by car, creates air and noise emissions (Thrane, 2006). It is interesting that the processing stage represents a relatively small impact, but that is related to modern wastewater treatment plants operating in Denmark (Thrane, 2006). The report also assesses impacts of seabed, exploitation of fish and by-catch and discards in a qualitative way to have large impact potential.

The "*Life cycle assessment of frozen cod fillets including fishery-specific environmental impacts*" (Ziegler et al., 2002) report had the goal to perform an environmental assessment of the entire life cycle of a seafood product where data for frozen block of cod fillets was collected from fisheries in the Baltic Sea where cod is mostly fished by benthic trawls and gillnets. The results are that all environmental impact categories assessed i.e. global warming potential, eutrophication potential, acidification potential, photochemical ozone creation potential and aquatic ecotoxicity are all dominated by the fishery. The report also states that 700 m^2 of seafloor are swept and affected by the fishing trawls per functional unit of 400 g of cod fillets. Transport and preparation in the household come as the second and third contributors to environmental impacts. It is pointed out as well that the process industry and sewage treatment do cause eutrophying emissions of considerable amount. The report concludes that there are considerable options for the seafood production chain to improve such as fishing from sustainable managed stocks, more frequent use of less energy intensive fishing gear, improved engine and fuel technology and the maintenance of high quality and less product losses during the life cycle of the product (Ziegler et al., 2002).

One report has been written on the subject in Iceland. The report "Environmental *Effects of Fish on the Consumers Dish – Life cycle assessment of Icelandic frozen cod products*" aimed to examine the viability and limitations of LCA. The main results of the report were that LCA can be used to indicate hot spots within production chain. The greatest environmental impact was during the fishery phase caused by oil consumption. 70% of the total oil consumption is used to operate the fishing gear. Consumption of oil was 0. 65 L per 1 kg of caught fish which in the end gives 400 g of fish fillets. The seafloor affected by the bottom trawls was calculated to be around 1000m^2 per kg of mixed fish for vessels larger than 2000kW (Helga Eyjólfsdóttir et al., 2003)

2.1.1 Common conclusions of cod LCA's

The common conclusions of all the LCA's that have been done for cod is that the fishery phase is the most dominant for all environmental impacts considered. None of the studies could include the impacts on seafloor but all of them recommend that more effort should be given to adapt them into the LCA methodology. It is also pointed out that more emphasis should be put into finding improved indicators for over fishing, seafloor ecosystem disturbances, discards and by-catch. Most of the reports have quantitatively described those impacts in order to gain an overview over the possible impacts caused by those factors. Some of the studies took into account swept seafloor by amount of functional unit, indicated by land use category within the LCA software.

2.2 Impacts of fisheries

Almost any human intervention in the marine environment whether it's positive like habitat restoration or negative such as dumping waste, results in some measure of ecological disturbance. Ecological disturbance has been defined as "*any discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substratum availability or the physical environment*" (Kaiser et al., 2005).

Besides reducing the biomass of both target and by- catch species, fisheries affect structure and function of the marine ecosystems through at least four known mechanisms (Gislason, 2003).

- ✓ Changes of the relative abundance of both the target and non target species. This can affect other species through alterations of predator-prey relationships as well as competition.
- ✓ Populations of species that are slow growing and mature late are more likely to be affected by fisheries than the small, rapidly growing and early maturing species. This can cause changes in the relative abundance of many species.
- ✓ Discarding of fish and other organic waste. It can increase the scavenging species populations and cause eutrophication where the discards fall to the seafloor (Gislason, 2003 ; Sinclair & Valdimarsson, 2003).
- ✓ Fishing gear that comes in contact to the seafloor and modifies stones and boulders, influences and damages corals and other fauna and flora.

It is likely that a combination of those four processes result in a changes in the relative abundance and growth of species together with natural fluctuations in the physical environment and other anthropological activities (Gislason, 2003).

Fisheries have therefore direct impacts on the fish stocks which again influences the entire marine ecosystem. Those impacts create a certain production condition for the remaining fish stocks (Thrane , 2005). Fisheries that cause direct damages to the seafloor are the one that utilise bottom tending fishing gear. In addition the release of biocides such as TBT from anti fouling paint has an impact on the ecosystem together with the loss of the fishing gear that may continue to the catch, solid waste, fish waste and wastewater from tanks (Thrane , 2005).

On of the big impacts related to fisheries is the combustion of fossil fuels such as diesel oil and the release of greenhouse gases to the atmosphere. Other factors that are worth mentioning are the disposal of waste that is brought from the fishing vessels to land and the environmental effects from the slipways where the vessels are being repaired and maintained (Thrane, 2005). Within the product chain there are involved fish processing industry, wholesale and transport. The impacts are mostly related to energy consumption, chemicals, water and other resources as well as the emission of wastewater and solid waste. The product is than sold and consumed and the major environmental impacts in that relation are the transport, storing, freezing, heating, preparation and final disposal (Thrane, 2005). All this involves consumption of energy and solid waste together with wastewater emission. There are environmental aspects to be considered within different life cycle stages. Greenhouse effects and seabed impacts may for example change the production conditions in the ecosystem which could than change the abundance and the composition of the species in a specific zone (Thrane, 2005).

The proximity of the coastline makes marine resources and ecosystems very vulnerable for anthropological activities. Ever increasing population and economic growth pushes oceanic over exploitation, pollution and habitat destruction. It is therefore very important to protect marine living ecosystems to ensure ecological balance and to secure this vital source of food (Lakshman, 2003).

Anthropological activities are affecting natural fish populations and the fisheries as a whole. Environmental changes can influence fish recruitment and alter the ecosystem habitats of the marine environment. Dams and re-routing of rivers can influence spawning grounds, erosions can lead to increased turbidity, eutrophication leads to alterations in habitats and food availability, introduction of new species in an ecosystem can seriously affect habitats and the whole ecosystem (Richardson, 2003).

2.3 Fishing gear

Humans use a broad variety of methods to catch fish that cause various impacts on the environment. Those methods range from simple hand line baited hooks to dynamite bombs that are thrown in the sea. Fishing gear is usually categorised into active and passive. Active gear is the one that is towed across the seafloor or used to catch fish by encircling it. This group contains normal bottom trawls and beam trawl nets that are towed by a fishing vessel on most of the continental shelves. Active gears also include dredges and gears such as spears, harpoons and explosives (Kaiser et al., 2005).

Figure 1: Hegranes operated by FISK Seafood

Passive gear on the other hand is a gear that catches fish which swims into the gear, like for example nets that are set on the seafloor or float on the sea surface (gillnets). Other passive gear that is widely utilised is a long line, baited pots and various types of fish traps (Kaiser, et al., 2005). The two objects of this report are bottom trawls that used to be operated by Hegranes from FISK Seafood and long line operated by Kristín owned by Vísir hf.

2.3.1 Bottom trawls

Bottom trawls are constructed like a cone-shaped nets that are towed on or right above the seafloor. It consists of a body unit that ends in a code where the catch is retained. The net has two lateral wings that extend forward from the opening. The trawl has a so-called mouth that is framed of by headline and ground rope (Helga Eyjólfsdóttir et al., 2003). The net is designed to catch species that live on or near the bottom. Bottom trawls can be operated in a wide range of depths, from only few meters down to 1500-2000 meters.

Bottom trawls are often operated and towed for several hours at a time, over long distances of seafloor. It has been estimated that the area swept by bottom trawling gear per one kg of mixed catch of fish is 1000 m^2/kg during the years 1991-1997[1] in Iceland. The swept area was estimated to be 0.94 nm^2 (nautical miles) per haul at mean depth of 468 meters (Helga Eyjólfsdóttir et al, 2003). Swedish research has showed that ca 700 m^2 of seafloor are swept

[1] Estimation for fishing vessel larger than 2000 kW

and affected by fishing trawls per functional unit of 400 g of cod fillets or ca 1711 m^2 per 1 kg (Ziegler et al., 2002).

Table 1 : Amount of annual global by-catch in tonnes and percentages (Davies et al., 2009)

Geographic area of estimates	By catch estimate (tonnes)	Estimated total catch (tonnes)	Percentage by catch of total catch
23 individual countries	27,453,242	63,291,770	43,4
North-east Atlantic	2,700,000	13,620,000	19,8
Mediterranean and Black Sea	306,000	1,453,000	21,1
Central America and Caribbean	242,000	375,500	64,4
Africa	6,992,000	224,000	70,2
Global shark fin	207,000	224,000	92,4
Tuna	605,000	6,300,000	9,6
Total	38,506,242	96,231,270	40,4

The impact of trawl towing depends on the habitat composition and the natural disturbance on the fishing ground (Kaiser et al 2005). Bottom trawls disturb animals and habitats when they are towed over seabed and have a great interaction with bottom sediments which results in removal and damage of sedimentary living organisms. (Helga Eyjólfsdóttir et al., 2003). On flat seafloors that consist of sand and mud, the sediments can be swept up into the water mass and be suspended. The short and the long term impact on the seafloor environment are poorly documented even though several scientific experiments have been carried out.

A major impact of bottom trawling is the capture and removal of small size organisms and non target species from the ecosystem, which are then frequently thrown back to sea (Food and Agricultural Organization, 2000-2008). A report published early 2009, states that unselective fishing in the north east Atlantic in FAO statistical area 27(see also Figure 9) has extremely high discard rates, mainly coming from the bottom trawling fleet (Davies et al, 2009). It is estimated that amount of 2.700,000 tonnes of discards are being dumped into the north east Atlantic per year. The by- catch is representing 19.8% of the total catch. If looked at global numbers discards are estimated to reach at least 38.5 million tonnes or 40.4% of estimated global marine catch. These numbers indicate only minimum by- catch since several important factors are missing from the research such as; data arrived mostly from trawler fisheries, meaning that data from for example gillnets and long liners are not included.

Juvenile catches in industrial fisheries have not been calculated for most countries. Existing data was utilised for by-catch of turtles, seabirds, cetaceans, and pinnipeds and are often estimated by individuals, not by weight. By-catch of invertebrates was not estimated even though it is highly important (Davies et al., 2009). Therefore it has been documented that an enormous amount of biomass is being shovelled from the oceans without effective management and it can be said with confidence that not many industries could tolerate 40% of wastage or lack of efficiency each year (Davies et al., 2009).

Towed bottom fishing gears, such as bottom trawls are designed to catch bottom dwelling species and therefore cause several physical impacts (Kaiser, 2003). Irregular flattening of the bottom topography is one of the major impacts, whereas the doors of the trawls normally made of steel, create paths or furrows on the seafloor. The landscape of the seafloor becomes more uniform after it has been swept by trawls which results in less hiding places for the remaining adult cod and the juveniles.

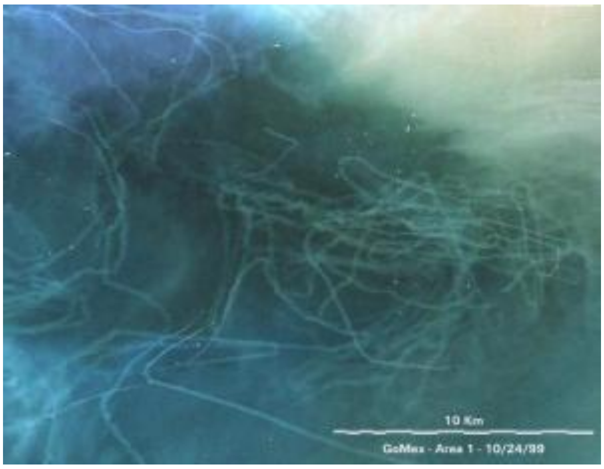

Figure 2: Effects of bottom trawling in Gulf of Mexico seen from space. Individual vessels are seen as bright spots at the end of each trail (Science, 2008).

Direct damage to benthic fauna in relation to depth and size of the area being swept is a potential stress factor together with direct and indirect community changes, which could cause less nutrition for remaining cod (Helga Eyjólfsdóttir et al., 2003).

Fisheries affect seafloors worldwide but those impacts are not uniform and differ with habitat type and environment in which they are found. Towed bottom fishing gears and hydraulic harvesting devices disturb the upper layers of the sediments and contaminants and fine particular matter is released into the water column. Seafloor sediments behave like a huge sink for many contaminants such as PAHs and many others low water solubility substances. The direct contact of the trawl to the seafloor also leads to re-suspension of sediments that have already settled on the seafloor. This has a variety of effects such as: releasing nutrients that often causes algal blooms, exposure of anoxic layers, release of pollutants, increased biological oxygen demand, and suffocation of feeding and respiratory organs (Kaiser, 2003).

The ecological impacts of the elimination of the natural bottom sediments are still poorly understood (Løkkeborg, 2004).

Complex habitats like sea grass meadows and biogenic reefs together with deep water mud substrata are more affected by fisheries than sediment habitats that are found in the shallowest coastal waters. Structurally complex and stable habitats are the ones that have longest recovery time of re colonisation of the habitat (Kaiser, 2003 ; Ziegler , 2006). Studies show that seafloor that has been exposed to different levels of fishing activities causes extinction of high biomass species that normally increase topographic complexity of the seafloor. On the contrary small organisms such as polychaete worms and scavengers, become the most dominant on heavily fished areas that may lead to changes in the resident fish fauna composition (Kaiser, 2003).

Recently it was discovered that the oceans surrounding Scandinavia is the home to the biggest coral reefs in the world, so called cold water coral reefs (Norden, 2008). Latest developments on new technologies have enabled research on the seafloor, and in many places due to these research restrictions have been made on fisheries in order to protect those areas. Different fishing gear causes different impacts. Bottom trawls and ploughs kill fish and other organisms besides the target species. It has also been proven that such fisheries methods do have destructive impacts on ecosystems, such as coral reefs, that decreases the biological diversity and destroys important spawning areas.

Many scientists have pointed out that more research on the seafloor is needed and the most important areas need to be mapped in order to protect them from destruction. Many scientists and environmentalists belief that it would be right to ban bottom trawl fisheries since it destroys and causes various impacts on the seafloor. Bottom trawl fisheries are also the most energy demanding fishing methods (Norden, 2008).

2.3.2 Trawling on soft seafloor habitats

One of the most extensive experiments on trawling effects is the three year study that was carried out on the Grand Banks of Newfoundland. A part of this fishing ground consists of rich, diverse and homogeneous benthic community that represents many areas outside the Canadian coast. This location had not been fished for a several years as a result of a sudden collapse of the ground fish stocks. Three experimental corridors were established and trawled 12 times in a five day period for 3 successive years. Epibenthic sledge was sampled and videos were taken by a large video equipped grab. The samples taken showed that the disturbances made by the trawling cause an average decrease of 24% in total biomass in the corridors that were trawled, occurring because of decline in biomass of several species such as sea urchins, soft corals, snow crabs, brittle stars and etc. Echinoderms such as sand dollar, brittle star and sea urchins were frequently subjects of physical damages. The study also showed decline in homogeneity and increased aggregation of mega-epibenthic organisms directly after the trawling operation (Løkkeborg, 2004). The samples taken over three years interval showed that total number of species together with total abundance decreased both for the trawled corridors and the undisturbed zones (Løkkeborg, 2004).

Experimental trawling impacts were studied in high seas fishing ground in the Barents Sea by Kutti et al. The seafloor consisted of silt/sand/gravel that was mixed with shell fragment. Five areas were established. One area was intensively trawled, one moderately and three zones were utilised as control sites. The results were that trawling had impacts on the benthic communities mainly because of re-suspension of sediments and displacement of infaunal bivalves. Again, significant decline in abundance and in biomass of most infaunal bivalves and burrowing gastropods were identified after the trawling. Crustaceans were found to decrease in abundance as well by moving out of the disturbed areas. (Løkkeborg, 2004).

In Kattegat a high resolution fishing effort data was analysed using Geographical Information System (GIS) during 2001-2003. Approximately 44% of the area was affected by trawling during the period, 56% was not affected. The area affected was trawled quite intensively and 10% of the area was towed more than twice per year. The biological effects of the fisheries were found by using a MarLIN database that contains marine habitat recoverability assessment. A considerable part of the mud habitats are left in a permanently altered condition that will take up to 25 years to recover from (Ziegler, 2006)

A study made by McConnaughey, Mier and Dew in 2000 conducted in Bering Sea, a previously unfished and heavily fished area were compared to investigate long term impacts for benthos communities. Samples were taken from a total of 42 pairs of unfished and heavily fished trawled areas. A great difference in biomass was discovered between the heavily and unfished areas. Biodiversity was significantly lower in the heavily fished area and so was niche breadth and diversity of the sedentary macrofauna compared to the unfished area (Løkkeborg, 2004).

Long term impacts on benthos communities were investigated in two areas off coast of England at different depths by Frid, Clark and Hall in 1999. One area was heavily fished; the other one was outside of the main fishing area. Changes of infaunal abundance and composition of species were compared in 27 years sampling period. Differences in macrofaunal abundance outside the fished area reflected the phytoplankton abundance in the area. This relationship was not found inside of the fished area. The individuals that were likely to show positive responds to fishing disturbances increased during intense fisheries and again declined with decreased fisheries (Løkkeborg, 2004).

2.3.3 Trawling on hard substrata seafloor habitats

Few studies have been carried out on hard rocky bottoms and one of them is the hard bottom habitat identified by Freese et al with video camera observation to estimate trawl impacts in the Gulf of Alaska. After each haul sampling was carried out and adjacent to each trawled path there was a control site. Considerable decline was in the number of large erect sessile invertebrates such as sponges and corals and large sessile fauna were severely affected after the trawl disturbances (Løkkeborg, 2004).

In Australia research has been made on the continental shelf by Moran and Stephenson in 2000. Attached benthos were identified and counted from video transects and compared within three sites. Two of them were trawled four times and one was held as control site. Density of macrobenthos such as sponges, soft corals and gorgonians declined by 15,5% after each haul leading to a reduction in density of ca 50% after four passes of trawl (Løkkeborg, 2004).

The MarLIN study on soft bottoms in Kattegat, also investigated hard substrata bottoms in that area. The study showed that most of the subtidal hard bottom habitats have rather fast recovery rates although habitats that are dominated by bivalve are considered to have very low recovery rate, or up to 25 years (Ziegler, 2006).

In the South Atlantic Bight in USA the effects on sponges and corals of one path of a research trawl over a hard bottom habitat was studied by Van Dolah, Wendt and Nicholson in 1987. Individuals of 10 cm and more of three species of sponges and four species of corals were assessed in the trawled path and in an adjacent control area by divers, before, immediately after and 12 months after the trawl disturbance. Significant decline was identified in the abundance of sponges and immediately after trawling, 32% of the remaining individuals were damaged. Some of the corals were found to be damaged but the study showed that it was not significant. It is of a great interest though, that 12 months later the sponges had reached their pre-trawled abundance size and even became greater in density. The authors concluded that commercial fisheries are likely to cause more severe damages to the large sessile fauna of the study area (Løkkeborg, 2004).

2.3.4 Icelandic seafloor situation

During the last 1.6 million years the land around the Nordic Seas has been severely denuded and all the material that was eroded, deposited in the ocean. Big coarse grained deposits are to be found along the continental margins but the finer sediments such as silt and clay are found in the deeper ocean.

The areas along the North Atlantic Ridges are dominated by volcanic sediments that are covered by thin layer of sediments (Garcia et al., 2006). In Nordic waters like in Iceland, habitat forming deep water corals is often dominating on hard substrate communities. According to a geologist working at the Marine Research Institute of Iceland, the seafloor around Iceland is dominated by hard substrata often covered with soft sediment. Some places on the seafloor represent “fjords” full with soft substrata between the hard bottom surfaces. Corals grow where the substratum is hard and in Iceland they seem to grow in lava- like environment (Guðrún Helgadóttir, 2009).

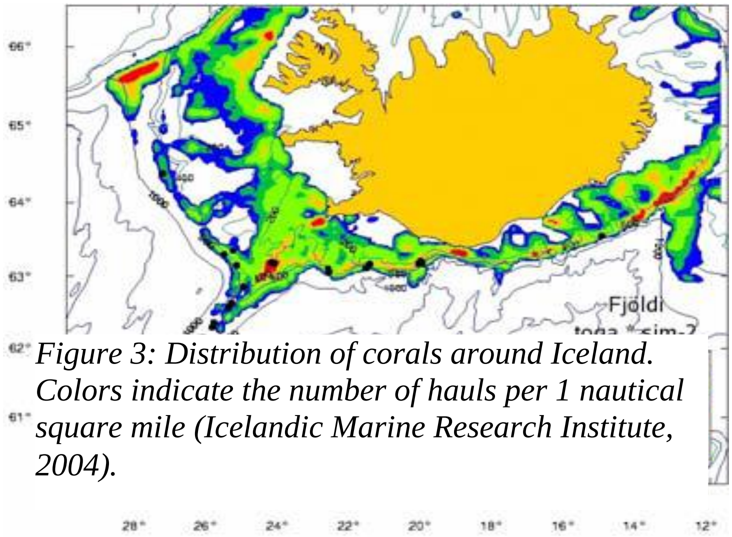

Figure 3: Distribution of corals around Iceland. Colors indicate the number of hauls per 1 nautical square mile (Icelandic Marine Research Institute, 2004).

The corals are distributed predominantly along the shelf margin on the slope and continental rise on submarine ridges such as the Reykjanes Ridge and are found in the south, west and north of Iceland (Garcia et al., 2006).

Several studies show that deep water corals provide important habitat for many invertebrate and ground fish species. They also provide shelter and enhance food availability for many organisms that live amongst the coral communities (Garcia et al., 2006). There have been identified more than 600 species associated with coral reefs off the coast of Norway and that number goes up to 1300 species if ground fish in the Northeast Atlantic is included. If coral reefs disappear it is very likely that other populations and species will have difficulty of sustaining themselves and may cause significant changes in distribution and biodiversity. Bottom trawling is a big threat to reefs and coral forests and severe damages have been documented on the fishing grounds off Norway and Iceland (Garcia et al., 2006).

The Marine Research Institute of Iceland in 2005 reported that the distribution of corals began to decline when bottom trawling initiated within the coral areas. Icelandic fishermen have reported that they have noted corals basically everywhere in deep waters until the 1990's but corals were often caught in bottom trawls (Icelandic Marine Research Institute, 2004). In that time fishing vessels started to fish inside of the main coral areas in the Southeast of Iceland and in the early 2000 the coral had almost disappeared in that zone, e.g. one on the Reykjanes Ridge ($36km^2$) and two near Öræfagrunn Bank, $68km^2$ and $30\ km^2$ respectively. Today it seems clear that the coral areas that existed in the early eighties have been destroyed or remain only a small fraction of what they used to be (Icelandic Marine Research Institute, 2004).

2.4 Long line

Long line is a fishing gear that has developed from hand lines and has over the years become much more effective. It is operated with fresh bait such as herring, mackerel, capelin or squid, on hooks (Icelandic Ministry of Fisheries, 2005). Long lines are utilised in many parts of the world to catch species like tuna, sharks, swordfishes and flatfish (Valdemarsen and Suuronen, 2003). Long line was the most commonly utilised fishing gear in Iceland until 1960's (Icelandic Ministry of Fisheries, 2005). Most long lines used in Iceland are for bottom catches with cod and haddock as primary target species. Like for most other gear, the long line has developed into becoming mechanised and today baiting and other long line processing are done automatically by machines. Long lines can reach a length of 20 km and have up to 16.000 hooks attached. The line is usually left at the bottom for one to four hours each time. Long line fisheries have a reputation of freshness since the fish is hauled alive into the boat (Icelandic Ministry of Fisheries, 2005).

The positive aspects of using long line for fishing are various. The fish is usually higher quality material, the distribution of landings is relatively even throughout the year, energy consumption is lower than for example the trawlers and the seafloor is treated with more gentleness (Andreassen, 2009).

English supermarket retailers advertise long line caught fish as environmental friendly and give it a prior to fish caught by trawlers. Tesco states that of 36 at risk species identified by Marine Conservation Society they do not sell 32 species. The four remaining species on the list are species caught by fishing gear that minimises environmental impact and increases sustainability. Therefore long line caught species such as cod and haddock are in preference to the trawled ones (Tesco, 2005).

Unfortunately long line can be dangerous to other marine animals such as seabirds that are attracted to the bait. The birds have learned to scavenge food from ships and when the line is set into the water the birds get hooked. Of 61 seabird species affected by long lines, 21 of them are counted as threatened by the World Conservation Union, or 38%. (Brothers et al., 1999). Other animals such as sea turtles, sharks and marine mammals are known to get entangled in the gear. In March 2006 the Hawaii long line swordfish fishing season was closed after excessive sea turtle by-catches (Pradan and Leung, 2008).

In some cases, long line fisheries can have high by-catches. The by-catch species are usually alive when hauled into the vessel and if released with care many can stay uninjured. Pressure and thermal differences can in any case, cause death of released fish. It is possible to make the catch more selective by modify the bait size and type and artificial baits that attract particular species are promising. The size and design of the hooks is also relevant (Valdemarsen and Suuronen, 2003).

2.5 Climate changes

Most of the pollution that is released into the environment is eventually deposited in the oceans, directly or indirectly. In shallow waters above the continental shelves, ninety percent of marine life is to be found. A big part of marine pollution comes from land based sources and is estimated to increase, mainly from countries in Southeast and East Asia due to rising populations and coastal developments (Nellemann et al., 2008). Climate changes are also considered to slow down the ocean thermohaline circulation and continental shelf "flushing and cleaning" sea current exchange systems that are very important to nutrition cycles and deep water production in more than 75% of the fishing grounds of the world. This reduction in intensity and frequency of the coastal flushing mechanisms will have impacts on both nutrient and larval transport and cause an increase in dead zones in many of those reproductive fishing areas. The number of dead zones has gone from being 149 in the year 2003 to over 200 in 2006 (Nellemann et al., 2008). This number is expected to multiply in few decades if nothing will be done to change the nowadays policies (Nellemann et al., 2008).

According to the IPCC the atmospheric concentration of CO_2 has increased by 36% since the industrial revolution and the present CO_2 concentrations are the highest in at least 650.000

years as seen in Figure 5 (Environmental Protection Agency, 2008). The same can be observed for other greenhouse gases such as methane and nitrous oxides (see appendix II).

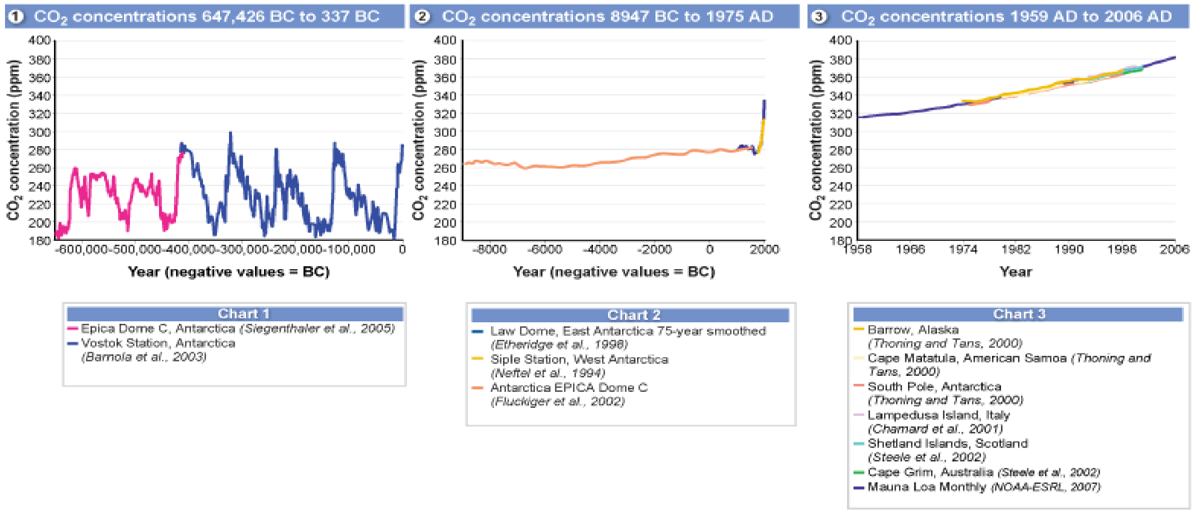

Figure 5: Atmospheric concentrations of carbon dioxide both in geological time and recent years (Environmental Protection Agency, 2008)

Even though the great complexity of atmospheric mechanisms cannot be fully assimilated by mathematical models, the majority of the scientific community agrees that global climate changes are and will impact the Earth's environment in a very negative way (Lakshman, 2003). That is why climate changes are one of the great challenges of the 21st century. Climate changes and actions taken to reduce them are a global task that is not going to be accomplished without the effort of every nation of the world.

UNEP (United Nations Environmental Program) has recently released a report named *In Dead Water* where it is stated that climate changes are emerging as the latest threat to the worlds reduced fish stocks (Nellemann et al., 2008). Kaiser et al also state that climate change threatens the sustainability of fisheries and is likely to affect biological processes and biodiversity at all regions of the planet at both small and large scales (Kaiser et al., 2005). Few of the changes that scientists have pointed out that are likely to occur as impacts of global warming, are; sea level rise, water column warming, changed wind speed and precipitation patterns, water column circulations and the intensity and frequency of storms (Kaiser et al., 2005). Physical and biological impact of global warming on marine and fresh water species is now causing distribution changes. Warmer water species are now moving towards the poles and therefore experiencing changes both in habitat size and in productivity. Higher temperatures will also have affect on physiological processes of fish in both positive and negative way.

Climate change has already started to put its mark on the seasonality of some of the biological processes i.e. altering marine and freshwater food webs. There are as well additional concerns related to risks of species invasions and a bust in vector borne diseases amongst fish and other marine organisms (Food and Agricultural Organization, 2009). It is known that alterations in temperature between land and oceans as well as between polar and tropical regions will trigger the intensity, frequency and seasonality of climate patterns and extreme weather conditions such as floods, droughts and storms. Rise in sea level, melting of glaciers, acidification of the oceans, precipitation changes, groundwater and river flows will have impacts on coral reefs, wetlands, rivers, lakes and estuaries (Food and Agricultural Organization, 2009). It is believed that climate changes are causing more than 80% of the Earth's coral reefs to be destroyed within decades whereas temperature increase of up to 3°C may result in bleaching impacts of coral reefs from 2030 – 2050 (IPCC, 2007 ; Nellemann et al., 2008).

Acidification due to CO_2 increase in the atmosphere also affects sea water and will severely damage cold water coral reefs and cause negative impacts on other organisms especially at higher latitudes. In addition, ocean acidification will cause bio calcification reduction of shell forming organisms like for example calcareous phytoplankton which may than have impact up the marine food chain (IPCC, 2007 ; Nellemann et al., 2008).

A recent study from Norway, reports that scientists have measured CO_2 concentrations in the sea that are so concentrated that it is causing acidic sea water. This is putting marine life along the Norwegian coast in danger. According to Norway Post this may have direct consequences for Norwegian shellfish and coral reefs which will affect the coral reef- reliant cod. It seems that this process of increasingly acidic sea water is occurring faster in the Arctic regions says Richard Bellerby a scientist at the climate centre Bjerknessenteret in Norway. Since cold water absorbs more CO_2 the water is turning acidic faster. This is a threat to fish stocks in Norway that already are facing effects of expanded oil and gas exploration. Some scientists state that this problem is leading to one of the most dramatic changes in marine chemistry for more than half a million years (Fishupdate.com, 2009).

2.6 Ecological and Carbon Footprints

There is a wide acceptance that Earth's ecosystems are not able to sustain our current level of economic growth and material consumption. Gross World Productivity (GWP) which is the measure of the world's economic activities is growing by 4%. One factor driving this growth is the expansion of the world's population. In 1950's, humans were 2.5 billion. In 2008 the population counted 6.7 billion and is projected to reach 9.7 billion by 2050, with most population boost in the developing countries (Population Reference Bureau, 2009 ; Wackernagel and Rees, 2007). Ecological Footprint is defined as "*the measure of the load imposed by a given population on nature, or the land necessary to sustain resource consumption and waste discharge* "(Wackernagel and Rees, 2007).

The Ecological Footprint therefore measures the humanity's demand on the biosphere related to biologically productive land and sea required to extract and provide the natural resources we need. In 2005 the globally available bio-capacity per person was 2.1 global hectares (gha). That year the United States of America and China had the biggest total footprints, each using 21% of the planet's total bio-capacity. An average person in the USA uses ca 10 gha per year. Humanity's footprint first exceeded the Earth's total bio-capacity in the 1980's and in 2005 the demand was 30% higher than the actual supply (World Wildlife Fund, 2008).

Figure 6: Cartoon of an Ecological Footprint (Wackernagel and Rees, 2007).

Carbon Footprint is a component of an Ecological Footprint defined as the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product. The Carbon Footprint is usually measured in equivalent tones of CO_2.

Fisheries contribute significantly to the emissions of greenhouse gases during production, transport, processing and storing of fish. The average estimated ratio of CO_2 emissions for capture fisheries is around 3 teragrams (10^{12}) per million tons of fuel combustion. Intercontinental airfreight emits up to 8. 5 kg of CO_2 per 1 kg of transported fish which is 3.5 times more than for sea freight and over 90 times more compared to local transportation where the fish is consumed within 400 km of catch (Food and Agricultural Organization, 2009)

2.7 Biodiversity and natural capital

Life on earth is sustained by plant-, animal- and micro organisms communities that interact with each other and their surrounding environment. Biodiversity consists of three concepts:

- ✓ genetic diversity within species,
- ✓ diversity of species,
- ✓ diversity of ecosystems within a region.

Biodiversity supports life on earth by maintaining atmospheric quality, absorbing contaminants, balancing local climates, producing and maintaining soils and protecting water resources. Greater diversity within an ecosystem increases its capacity to support life and adapt to changed conditions. Biological resources have a great economic value since it provides us with various services such as; food, medicines, chemicals, fibres, structural materials, fuels and many other valuable products (Lakshman, 2003). The environment or natural capital can be looked at as a stock which yields a flow of goods and services that are valuable.

There are two types of natural capital: renewable natural capital and the non renewable one. The ecological systems contribute both directly and indirectly to human welfare and therefore represent a share in the total economic value of the planet.

Dr. Robert Costanza and a group of ecological economics and other scientists have estimated the value of the earth's ecosystem services to be in the range of US$ 16-54 trillion (10^{12}) minimum per year with an average of 33 trillion (Costanza et al., 1997). To put this amount of money into perspective, the gross world's product (GWP) of all worlds' countries was ca 25 trillion US dollars.

There are many examples that describe the services that ecosystems provide us. One is for example coral reefs that provide habitats for fish. Coral reefs therefore have the value to increase and concentrate fish stocks. Changes within the coral reef quality or quantity can affect commercial fish markets. On the other hand other aspects of the value of the coral reef such as diving or biodiversity conservation are not visible in the markets value. Loss and degradation of natural capital is therefore likely to cause significant economic losses and finally prevent the economy to grow (Brynhildur Davíðsdóttir, n.d).

The economic health of the world's marine fisheries has been in decline for a long time and the global marine capture fisheries are an underperforming global asset. The fleet capacity and the deployment of ever increasing power within it, increasing pollution and habitat loss has depleted stocks all over the world. As seen in Figure 7 the global marine catch has been stagnant for over a decade while the catch per fisher/fishing vessel has declined (The World Bank, 2009). The global economic loss over the last three decades has been estimated to be two trillion dollars and in many countries the catching operations are held up with subsidies (The World Bank, 2009).

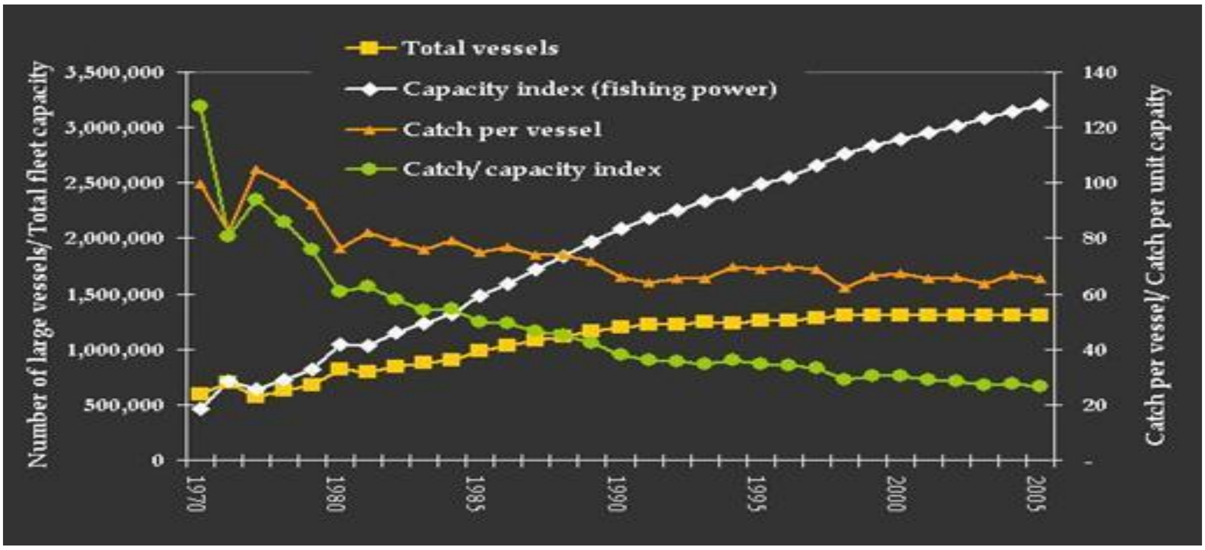

Figure 7: Declining productivity of fish stocks and the increasing fishing fleet and fishing power (The World Bank, 2009)

If the fish stocks were to be rebuilt it would be possible to catch the amount of fish that is being fished with only half of the current global fishing effort. This amongst other factors shows the great overcapacity in the global fleet and the excess of the vessels that are competing for the very limited fish resources in stagnant productivity and economic inefficiency (The World Bank, 2009). Rather than being a net drain on the global economy, fisheries operated in a sustainable manner can create an economic surplus and be a driver of economic growth, both within marine economy and other related sectors. It has to be reminded of, that sustainable fisheries are not only a problem that concerns biology and economy but is also very relevant within political and economic processes and decision makings (The World Bank, 2009). A reduction in the fishing effort increases productivity, profitability and economic benefits. Rebuilding fish stocks would increase sustainable yields and lower the fishing costs and at the same time provide fishers and fishing communities with incentives to fish responsibly and with efficiency. Greater allocation transparency of fish resources and increased public knowledge of healthy fish stocks will be a basis for certification of sustainable fisheries (The World Bank, 2009).

2.8 Ocean pollution

Contaminants are substances that are toxic to living organisms. Contaminants can enter ecosystems naturally or they may be produced and released by human activities such as oil combustion and spills, fertilisers, solid garbage, sewages and toxic chemicals from industries (Richardson, 2003 ; World Wildlife Fund, 2008). Persistent contaminants raise a considerable concern because of their long term and in many cases subtle, effects in the marine environment (Kaiser, 2003).

Figure 8: Algal bloom off shore Germany as a result of eutrophication (World Wildlife Fund, 2008.

Chemical contamination in water bodies influences the physiology and accumulates in body tissues of organisms. This is why both recruitment of fish species and marketing possibilities are affected by environmental contaminants. Contaminant concentrations monitoring in fish has become a standard protocol in many regions of the world. Knowledge of the impacts that contaminants cause on human health is slowly increasing and that is why some contamination concentrations that have been considered as safe for human consumption, are now in reconsideration and some of them have even been reduced (Richardson, 2003).

There are many different chemicals that are documented and considered as pollutants, from simple inorganic ions to complex organic molecules (Walker et al., 2006). Pollutants found in the oceans are subsequently detected in marine organisms as they live and thrive in the ocean environment.

It is known and documented from fresh water systems that land use changes can affect fish stocks and fisheries in a serious way and those impacts can be similar to the marine ecosystem. River dams can block migration routes and alter habitats for example by changed sedimentation, so that they become unsuitable for fish stocks. Farming activities cause runoff of pesticides and nutrients that leaks to the water bodies and to the marines. It has now been discovered that eutrophication is taking place in many coastal marine areas causing in its mildest form increased food availability for fish but in increased levels it leads to hypoxia and anoxia that makes the environment inhabitable for most species. Eutrophication also causes algal blooms which some contain ichthyotoxins that have direct impact on fish and human health (Richardson, 2003).

Atmospheric deposition is held responsible for more than 30% of marine pollution since polluting substances such as DDT and PCBs (Polychlorinated biphenyls) are released into the atmosphere by evaporation from the surface of the earth (Lakshman, 2003). In organisms some contaminants are required at low levels, such as copper, zinc and iron, and do only become toxic at high concentrations. Other metals such as cadmium, lead and mercury do not have any biological function and are therefore toxic even at low concentrations. Many contaminants are anthropologically produced and the most toxic ones are chlorinated or brominated compounds. Those compounds are for example pesticides such as DDT, lindane, brominated flame retardants, dioxins and PCBs. They are very resistant and persist in the environment for a long time which explains why they are frequently found in Arctic animals, far away from the source of release (Kaiser, 2003; Richardson, 2003).

There are increased reports of disease outbreaks amongst large number of fish and toxicity test that have been carried out under controlled laboratory conditions have identified physiological mechanisms where the immunological system of fish is affected by contaminants, creating a link between contaminant exposure and fish health (Richardson, 2003). Another known impact of toxic contaminants is the interference with endocrine system of organisms. Substances such as PCBs and TBT are known to cause endocrine disruption and the most publicised example is the imposex that is induced by TBT coming from antifouling painting on ship bodies, in marine gastropods, turning female individuals into males. Yet the overall ecological significance of the endocrine disruption in the natural environment has not been fully understood nor quantified (Kaiser , 2003 ; Richardson, 2003).

Ocean dumping[2] accounts for 10% of the marine pollution and the most important are dredged spoils and sediments removal from shipping channels. Ocean dumping causes impacts on marine habitats in two ways: settlement of the solid material suffocates the bottom dwelling organisms and the toxic contaminants in the dredged spoils or wastes are released into the water (Richardson, 2003).

2.9 World stock situation

The world's oceans are crucial for all life on the planet. Healthy seas, including all the services they offer are a key to the future development of human kind. The sea is a highly dynamic, structured and complex system. The seafloor is combined of vast shelves and plains

[2] Dumping is a term referring to marine pollution that is not included in landbased or vessel based pollution (Lakshman, 2003).

with huge mountains, canyons and ditches that are similar to landscapes seen on dry land (Nellemann et al., 2008). Half of all the world catch is caught in less than 10% of the ocean. Primary and the most important fishing areas of the world are found along the continental shelves, within less than 200 nautical miles from the shores. The fishing grounds are extremely localised and in 2004 more than 50% of all landings are caught within 100 km of the coast at less than 200 m depth, in an area that covers less than 7.5% of the world's oceans (Nellemann et al., 2008).

China is far the biggest fishery country in the world, accounting for 70% of the world catch while Iceland's catch counts for 1.8% of the total world catch (Ministry of Fisheries and Agriculture, 2008).

The status of the world's fishing stocks and their health is alarming. Some of the top international ecologists and economists in the world have published studies where global collapse by the mid 21st century of all species currently fished, is predicted (Food and Agricultural Organization of the United Nations, 2008). Myers and Worm have published a study saying that 90% of all large fish in the ocean is already gone (Myers and Worm, 2003).

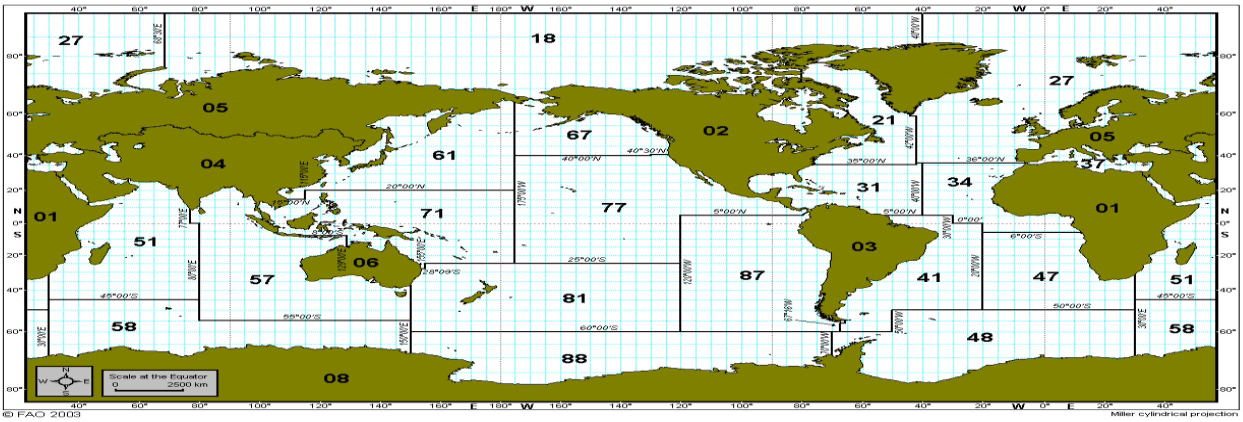

Figure 9: Statistical fishing areas of the world monitored by FAO (Food and Agricultural Organization of the United Nations, 2008).

The fishing areas of the world have been divided into specific zones with appropriate numbers as seen on Figure 9. Fish stocks monitored by FAO have been categorised and respectively information about the categories can be found related to the number of the fishing zone. There are four categories and they are;

D: Depleted

F-D: Ranging from fully exploited to deleted

O-D: Ranging from over exploited to depleted

U-D: Ranging from unexploited to depleted (Food and Agricultural Organization of the United Nations, 2008)

In the Atlantic closest to Iceland there are two areas, area 21(Northwest) and area 27 (Northeast). The northwest is primarily fished by Canada, USA and Greenland. Atlantic cod is there categorised as depleted. In the Northeast there is Norway, Iceland and Russia as the main fishery countries. The Atlantic cod is ranging from overexploited to depleted in that area according to FAO (Food and Agriculture Organization of the United Nations, 2005)

Overall in 2008 it was estimated that ca 80% of the world fish stocks are to be fully exploited or overexploited, compared to 75% in 2005. This is consistent with data from the Food and Agriculture Organization of the United Nation which report that in 2008; 52% of the fish stocks are fully exploited[3], 19% are overexploited[4], 8% are depleted[5] and 1% is recovering[6] from depletion. The organization monitors 600 marine fish stocks (Food and Agricultural Organization, 2009 ; Food and Agriculture Organization of the United Nations, 2005)

In 2008 the NGO, Greenpeace, published a list of seafood species that had entered on their red list by the logo “are you eating an endangered species”. This list has 20 species on it, including cod. Greenpeace enforces retailers and costumers not to buy fish that cannot be proved to come from a sustainable and healthy source and has not been fished by a destructive fishing gear (Greenpeace, 2008).

International groups of ecologists and economists have warned that worldwide fisheries could be in a danger of a total collapse by 2048 if no action is taken. The scientists have pointed out that the key factors for this collapse would be; over fishing, pollution, climate changes, increased acidity of the oceans and the destruction of marine habitats. Overall fish has provided 2.6 billion people with at least 20% of their average annual animal protein intake (Food and Agriculture Organization of the United Nations, 2005).

2.10 International environmental law (IEL)

It has taken 100 years for the global population to grow from 1.65 billion to over 6 billion people with almost 80% increase after 1950 (Lakshman, 2003). People are consuming more

[3] The fishery is operating at or close to an optimal yield level, with no expected room for further expansion
[4] The fishery is being exploited at above a level which is believed to be sustainable in the long term, with no potential room for further expansion and higher risk of stock depletion/collapse
[5] Catches are well below historical leves, irrespective of the amount of fishing effort exerted
[6] Catches are again increasing after having been depleted

and more of nature's resources and causing larger environmental impacts that lead to depletion or exhaustion of scarce natural resources.

International environmental law are set to control pollution and depletion of natural resources inside of sustainable development framework. It spans over 200 multilateral agreements and treaties, bilateral instruments, declarations, UN resolutions, soft laws and customary laws.

The starting point of IEL may have been in 1972 with the Stockholm Conference on the Human Environment held because of increasing concerns of environmental phenomena such as acid rain and poisoning of Japanese fisherman in Minimata bay. Even before the Stockholm Conference negotiations had been done concerning the law of the sea, United Nations Convention on the Law of the Sea (UNCLOS). UNCLOS was finally set into force in 1994 and is the strongest comprehensive environmental treaty that exists. A persistent problem appeared between two cultures, environmental protection and economical development. That is why in 1983 the World Commission on Environment and Development (WCED) was established by the General Assembly of the UN to come up with long term environmental strategies for sustainable development. After 4 years of worldwide consultation the Brundtland Report, *Our Common Future*, was published. In few words it rejects that environmental problems are not repairable and can only be arresting development and economical growth, but instead inspires that economic growth is both desirable and possible when it comes to sustainable development. That kind of development and growth expansion should have its roots within policies that sustain and expand the environmental resources in a manner that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

A global plan for sustainable development was drawn at the international conference in 1992 held by the UN General Assembly (Lakshman, 2003). This conference goes commonly by the name of the Rio de Janeiro Earth Summit or United Nations Conference on Environment and Development (UNCED), where for example Agenda 21 was put into action together with the Convention of Biodiversity and Climate Change. The Earth Summit was participated by 180 countries and 100 heads of states. Ten years after Earth Summit, the nations gathered together for a major international environmental conference in Johannesburg, the World Summit on Sustainable Development 2002 (WSSD). The WSSD gave birth to two documents: a political Declaration and an Implementation Plan. The Implementation Plan put forward several important goals that were supposed to be reached in next 20 years, such as production and use of non harmful chemicals, restoration of fish stocks and reduced rate of biodiversity loss (Lakshman, 2003).

The Convention on Biological Diversity (CBD) is a protocol signed by 150 government's leaders at the 1992 Rio Earth Summit and is dedicated to promote sustainable development. Since then more than 187 countries have ratified the agreement (UNEP, Convention on Biological Diversity, 2007). The agreement covers all ecosystems, species and genetic resources and it recognises for the first time that conservation of biological diversity is a concern for all humanity. The Convention is as well binding; countries that have joined are obligated to implement its provisions (UNEP, 2007).

United Nations Framework Convention on Climate Change (UNFCCC) is the international legal response to the threat of climate change, completed at the Earth Summit in 1992. This is a framework with built-in requirements. First it states that developed countries must aim to reduce their greenhouse gases emissions down to 1990 levels before year 2000. Secondly developed countries have commitments to the developing countries withholding financial and technological transfer. Third, both developed and developing countries have to document their greenhouse gases (Lakshman, 2003).

The Kyoto Protocol was signed in 1997 to the United Nations Framework on Climate Change and entered in force in 2005. The 14th of January 2009, 183 countries and the European Economic Community had ratified the protocol (UNFCCC, 2009). The protocol legally binds emission targets for a specific time period. The countries that have committed have to limit or reduce greenhouse gas emissions through national measures by; emission trading, clean development mechanism and joint implementation (UNFCCC, 2009).

The Code of Conduct for Responsible Fisheries set by FAO is compliance to the UNCLOS from 1982. It sets out principles and standards of behaviour for responsible practises to ensure effective conservation, management and development of living aquatic resources. States are encouraged to apply the code and give effect to it. The code is voluntary and not binding (Food and Agricultural Organization, 1995).

2.11 Fossil fuels

Non renewable energy resources are defined as energy source that will eventually run out. Fossil fuels are found within the rocks of the Earth's surface and are forms of stored solar energy in a way since plants collect solar energy and have the ability to convert solar energy to chemical energy via photosynthesis. The fossil fuels utilised in the world today were created from incomplete biological decomposition of organic matter, which are mainly plants and animal remains. This occurred over hundreds of millions of years ago when the organic matter was buried and converted by chemical reactions, to oil, coal and natural gas.

There are biological and geological processes that produce sedimentary rocks where fossil fuels are found (Botkin and Keller, 2007). Petroleum products have to undergo many processes containing many steps before it can be utilised. First, crude oil is pumped up from the sediments, perhaps in the Middle East where 2/3 of all known reserves are located, it is degassed, stabilised and stored before sent by tanker ships to the refineries. At the refinery it is stored and then refined and then stored again before it is carried with pipelines or boats to destinations where it is mixed with specific additives before being finally distributed by trucks to retailers that sell it to the consumers (BACAS, 2006)

2.12 Hydrogen

From the European Commission: *"Our current specific circumstances require the development and widespread deployment of energy technologies which do not depend on oil and gas and do not release significant quantities of CO_2 into the atmosphere. This implies significant changes in the energy industry which cannot be made quickly; with a turnover of roughly 3,000 billion euros world-wide, it inevitably has substantial inertia. Maximum effort to bring about the required changes must therefore be applied as soon as possible."* (BACAS, 2006)

When thinking of which energy or energy carrier could substitute fossil fuels, hydrogen is one of the many options. Hydrogen has been envisioned for a long time as a desired energy carrier for the sustainable future energy economy (Badin and Tagore, 1995). Hydrogen is an environmentally attractive fuel since it burns without producing CO_2 or causing other environmental impacts. Hydrogen is though not a primary source, i.e. not a substance that occurs freely in nature. It is an energy carrier that is usually bound to other elements and needs to be produced with the help from a primary energy source. It is the simplest and lightest of all elements and the most common in the universe (BACAS, 2006).

When produced, it can be used in two ways as a burnable substance in gas engines or gas turbines and can be applied almost everywhere where liquid and gaseous fuels are used. A new and innovative way to use hydrogen is by the help of fuel cells that are able to produce electricity (Mikkola, 2002).

2.12.1 Different methods of producing hydrogen

Hydrogen is an energy carrier that can be extracted or produced in many ways from all types of energy sources and the production can be categorised by the raw material that is used for0 the process. The extraction can be done through water electrolysis, gasification or chemical reforming of hydrocarbons (Fossdal et al., 2007). Hydrogen can be produced for example from fossil fuels with chemical reactions, with electrolysis from water with electricity as a resource, with biological methods and with thermal energy such as nuclear, sun and geothermal energy. Here, only couple of production methods that come from renewable energy resources are taken into consideration.

2.13 Sun power

The sun is a primary source and provides huge quantities of energy and is the basis for all life on Earth. Each square meter (m^2) on Earth's surface that faces the sun is a subject to 1368 W of sun radiation power. It is possible to extract large amounts of energy from the sun's radiation but it constantly sends 25.000 times more energy down to Earth than global energy demand per year. In 20 minutes the energy received from the sun could fulfil one year of global energy demand (Þorsteinn I Sigfússon, 2008). Even though sun energy is an obvious source of energy, it is only very recently that it became a research issue how to tame and store the sun radiation. When sun energy is caught and stored it is usually converted into electricity or heat. Solar panels technology is in constant development and it is assumed that the production of energy thrived from sun energy will increase from 0.5 GW in 2002, 11 GW in 2010 and 14-20 GW in 2020. That is the same amount of energy that is produced by 11 medium sized nuclear facilities.

Solar panels are mostly made of very thin silicon plates and currently the efficiency is only around 20%. The production of the silicon releases CO_2 but if looked holistically at the life cycle; the emissions are much lower compared to the current fossil fuel infrastructure (Þorsteinn I Sigfússon, 2008). Grid connected solar photovoltaic (PV) is the fastest growing power generation in the world and has increased by 50% between years 2006-2007 in cumulative installed capacity (Renewable Energy Policy Network, 2009).

2.14 Wind power

Wind power is simply a movement of mass of air. Scientists at the Stanford University have demonstrated how it would be possible to extract 72 TW from wind power that is comparable to the energy production of 72.000 nuclear facilities. By harvesting only 20% of 72 TW it would be possible fulfil the annual global energy demand (Þorsteinn I Sigfússon, 2008).

2.15 Hydropower

In many Nordic countries such as Norway, Sweden and Iceland but also in other countries such as USA and China a part of the electricity production takes place in big hydro power plants. Those hydro power plants could be a potential places to install electrolysis for hydrogen production (Þorsteinn I Sigfússon, 2008). There are though several environmental impacts related to hydropower production such as sinking land and reduce public areas due to damming. Damming areas that are in anyhow unique or have rich flora biodiversity also creates negative effects because of large amounts of carbon and methane that are released when water reservoirs are filled with water. Water flow changes can affect animal life and flora and changes to water level throughout the year can cause soil erosion in the regulation zone (Fossdal et al., 2007).

2.16 Biomass

Biomass is a renewable organic resource, including agriculture crop residues, forest residues, special crops grown specifically for energy use and organic waste. Biomass can be used to produce hydrogen. There are several methods to “extract” the hydrogen out of biomass. The most common and experimented at the time being are the gasification method and the so called dark fermentation method (Fossdal et al., 2007). The production of hydrogen out of biomass is tightly related to the production of several organic materials such as ethanol, methanol and methane. These can be used as carburant. The carburant or so called bio fuels can be converted through different processes into hydrogen (Fossdal et al., 2007 ; Þorsteinn I Sigfússon, 2008).

2.17 Biological methods

Biological hydrogen production consists of two methods; photo biological hydrogen production and fermentative hydrogen production.

The overall method process in photobiological/biophotolysis hydrogen production is based upon photosynthesis. Micro algae and cyanobacteria (blue green algae) along with higher plants can perform oxygenic photosynthesis by taking up CO_2 and H_2O from the atmosphere. Through the use of biochemical energy CO_2 is reduced into organic compounds like glucose and O_2 as rest products. Photochemical reaction creates energy where light energy is converted into biochemical energy, which is then used for CO_2 reduction of organic compounds by the Calvin-cycle enzymes. Under certain conditions (e.g. when depriving algae of sulphur) some groups of micro algae and cyanobacteria are capable of consuming the biochemical energy, instead of reducing CO_2, and producing molecular hydrogen. Such production is catalyzed by hydrogenase (found in micro algae) and nitrogenease (found in cyanobacteria) enzymes, which are responsible for hydrogen production (Miyamoto, 1997). This sort of hydrogen production is still on an experimental basis.

Bacteria like E. Coli, Enterobacter aerogenes and Clostridium are some of the bacteria that are able to ferment sugars (e.g. organic waste materials) and produce hydrogen by the use of multi enzyme systems. This kind of fermentation is referred to as "dark fermentation" as no light is needed for the reaction to happen and therefore the production of hydrogen can continue through day and night as long as there are organic compounds available (Princeton, 2006).

Dark fermentation is a relatively new and promising method for hydrogen production. Carbohydrates are utilized as an energy source and the hydrogenase enzyme is a catalyst of the producing process that together with producing hydrogen also produces CO_2. Maximum hydrogen yield through this process is achieved when using acetate as a fermentative product (Hawkes, 2006).

2.18 Geothermal power

Geothermal power is a major source of energy and it has been estimated that the amount of energy that is in the first 5 kilometres of the Earth's crust could sustain the global energy demand as it is today for the next 10.000 years (Þorsteinn I Sigfússon, 2008). A big part of hydrogen production in the world is produced by having natural gas reacting with steam at very high temperatures. As known, heat can be transformed to electricity, which makes a feasible choice to electrolysis. Also the steam can be used for SOE electrolysis. Iceland because of its volcanic situation makes a highly recommended place to alternative forms of hydrogen production. In Iceland only, it has been estimated that the geothermal energy in the Earth's crust is around 200 TW per year and from that it would be possible to cave 20-30 TW for electricity production (Bragi Árnason and Þorteinn I Sigfússon, 2004 ; Þorsteinn I Sigfússon, 2008). The possibilities are extensive and methods for further development are being carried out.

Hot water or steam can occur in a natural way up to Earth's surface. If not it is possible to drill down to it and pipe it up. Geothermal heat can and is being utilized by having the hot steam drive a turbine and create electricity. That energy can then be utilized to produce hydrogen. The production of hydrogen from thermal energy to electricity and electricity to hydrogen and oxygen by electrolysis is a conventional multi step technology. The geothermal processes are based on high heat water or steam cycles. The operating temperature is a key factor since the high temperatures enable faster chemical reactions and therefore higher efficiencies (Bragi Árnason and Þorsteinn I Sigfússon, 2004).

Steam from geothermal areas such as in Iceland and other parts of the world often include high concentrations of hydrogen that could be collected and utilized. This hydrogen is believed to be released when Fe^{2+} in melted magma go under a redox reaction and the hydrogen in the water and the iron ions oxidize to Fe^{3+} in a so called steam iron process. In Iceland steam from several bore holes has been analyzed and it has been found out that two bore holes in the Krafla geothermal station release up to 99.7 tons of hydrogen per year or 273 kg per day. That is twice the amount produced in the hydrogen station at Reykjavík (Bragi Árnason and Þorsteinn I Sigfússon, 2004).

In addition to this, H_2S is found in the steam from the bore holes. If the hydrogen would be extracted by breaking the bounds between the hydrogen and the sulphur, 40 more tons of hydrogen could be collected per year (Bragi Árnason and Þorsteinn I Sigfússon, 2004).

2.18.1 Hydrogen fuel cells in boats/fishing vessels

Converting the Icelandic fishing fleet from oil to hydrogen could be a unique step forward for Icelandic nation and could lead to sustainable production of energy made in Iceland (The Icelandic National Energy Authority, 2008).

Extensive studies have been carried out in last decades that lead to producing hydrogen to replace fossil fuels that are, for example, in Iceland an imported good (Bragi Árnason and Páll Valdimarsson, 1996). According to Hjalti Páll Ingólfsson former employee of the Icelandic hydrogen research company Icelandic New Energy, hydrogen is not only a considerable option for fishing vessels, but also very feasible for certain types of vessels, such as long liners. A long liner in Iceland consumes in average 165 ton/year of diesel oil. That is equivalent to 1.4 ton of H_2/trip or 19.6m^3 of liquid H_2/trip. A wet fish trawler consumes in average 964 ton/year of diesel oil that is equivalent to 9.6 ton H_2/trip or 135.7 m^3 of liquid H_2/trip (Hjalti Páll Ingólfson, 2006). One of the main problems for implementing hydrogen into fishing vessels is the storage. Storage capacity in an average long liner is ca 150 m^3 and therefore big enough to store the liquid hydrogen (Hjalti Páll Ingólfson, 2006).

2.19 What has been done

The first zero emission hydrogen fuelled public water taxi was demonstrated on San Francisco Bay October in 2003 powered by Millennium Cell's Hydrogen on Demand ™ fuel system. The Anuvu Power-X™ fuel cell battery electric hybrid engine was a result of almost 10 years of research and development (Business Wire, 2003). The boat was a demonstration of the hydrogen fuel utility in generating power for ships and according to Dr. Stephen Tang the CEO and President of Millennium Cell; environmental considerations have pushed the marine industry to seek for new solutions to relieve the pollution from diesel driven engines worldwide (Business Wire, 2003). A PEM[7] fuel cell engine from Anuvu and a hydrogen storage and delivery system from the Millennium Cell Hydrogen on Demand was implemented into a 30 feet long Duffy Herreshoff electric boat with the carrying capacity of 18 passengers. The system replaces a diesel generator that has been used to extend the range of the boat and provides the option to recharge the batteries from the Anuvu fuel cell engine without having to plug into electricity. The liquid hydrogen fuel is compatible with the conventional fossil fuel petroleum and produces the same amount of energy per gallon. The system produces hydrogen from sodium borate or more commonly referred to as borax (Business Wire, 2003). To produce hydrogen, borax is in fact dissolved in water and passed through a proprietary catalyst chamber where it releases a perfect stream of pure hydrogen which then powers the fuel cell or an internal combustion engine (Business Wire, 2003).

The American Navy is working on hybrid electric ships for the high seas. The Office of Naval Research (ONR) is developing innovative systems that are based on fuel-cell technology for future ships. To promote fast transition to this technology, ONR is putting money into the development of extracting hydrogen from diesel fuel (Walsh, 2004).

Proto Power Systems a producer of fuel cells and hybrid systems in 2007 unveiled a fuel cell driven passenger ship that ran on innovative hybrid fuel cell drive technology. It uses up to 50 kg of gaseous hydrogen that is stored in onboard tanks, enough for three days use (Proton, 2007)

[7] PEM is a Proton Exchange Membrane fuel cell that uses hydrogen fuel and oxygen from the air to produce electricity (Fueleconomy.gov, 2009)

SMART H2 was a demonstration project conducted in Iceland where a whale watching boat now has one of its two generators running on hydrogen. It provides the boat with electricity ob board for navigation, light and some other electricity run modules. The main engine still runs on diesel oil (Icelandic New Energy, n.d).

Further discussions on this subject are out of the boundaries of this project.

3 LCA on Icelandic cod

Life Cycle Assessment is an internationally standardized methodology (ISO 14000 series) that helps to quantify the resources that are consumed together with potential environmental impacts of goods and services (products). The methodology takes the entire life cycle of the product into account and it is often long and complicated since it covers all the areas from the extraction of natural resources, through their design, manufacture, assembly, marketing, distribution, sale and use to their final disposal as waste. Resource scarcity, environmental- and health impacts can be quantified in terms of indicators which are usually provided for climate change, cancer effects, land use and etc (European Commission, 2008).

The European platform on LCA was established by the European Commission in response to the Integrated Product Policy Communication (IPP)[8] in order to increase the availability of solid product life cycle data. To assure coherence, quality assurance and efficiency between instruments the platform supports the development of International Reference Life Cycle Data System, the European Life Cycle Database, an International resource directory and a discussion forum (European Commission, 2008).

LCA provides an existing and internationally agreed basis for the calculation of carbon footprints of goods and services in a robust way.

3.1 Goal and scope

Every LCA study should have a goal, a scope, a functional unit and a system boundary. The goal states the intended application that includes the reasons for doing the study and describes the group of people that the study should apply to (PRé, 2008). The scope describes the methodological choices that are most important i.e. assumptions and limitations. The functional flow is very important when it comes to comparing products and has to be chosen carefully. Making system boundaries tends to be quite complex as well. The researcher has to set some limits to his analysis since life cycles of products and services can be very extended and complicated (PRé, 2008).

[8] IPP started in 2004 within the European Commission. IPP seeks to minimise the environmental degradation from manufacturing, use and disposal of products, by creating an overview of all phases of a products life cycle and take action where it is most efective.

3.2 Goal of the study

The goal of this LCA study is to compare two widespread fishing methods to identify the hot spots within the life cycle of the product and to see which method has the least environmental impact. By doing a comparative LCA on a cod product fished with two different fishing methods, information will be provided to consumers that are increasingly choosing environmentally friendlier products, to governments and authorities that have to fulfil agreements and protocols related to traceability and to emissions of polluting substances together with the seafood companies as they will be able to investigate their hot spots and have a better overview over their production. In addition of having the possibility to gain better image as a company and that makes good choices regarding natural resources and cleaner production. This applies as well to Iceland as a nation as companies with good image should reflect in the country's image.

This study can also be accounted for spreading the calculation of carbon footprints into Icelandic companies since LCA is a tool that calculates the total amount of CO_2 released and how it attributes to global warming. The remaining questions to answer are: What does the product attribute to climate change, respiratory organics/inorganics, ecotoxicity, acidification and resource extraction?

It should be pointed out that since this is a comparative study, weighting and single score applications inside of the LCA software are not allowed for public debate (PRé, 2008).

3.3 Functional unit

The functional unit of the product chosen is 1 kg of frozen light salted cod fillets caught in Icelandic sea by a) a long liner, b) a trawler.

3.4 System boundaries

Since this is a thesis project and a complete LCA is very precise and time demanding it was decided to define the boundaries in a rather strict way due to time restrictions. This study can therefore be defined as an extended first order study (PRé, 2008) where only the production (in this case fisheries), use of chemicals and fishing gear, transportation and final disposal of the packages from the product, are included. This study also does not include the end use of the consumer i.e. the buying of the product together with the transportation from retailer to household and the cooking is all excluded from the research. This study is therefore not a complete "cradle to grave" assessment.

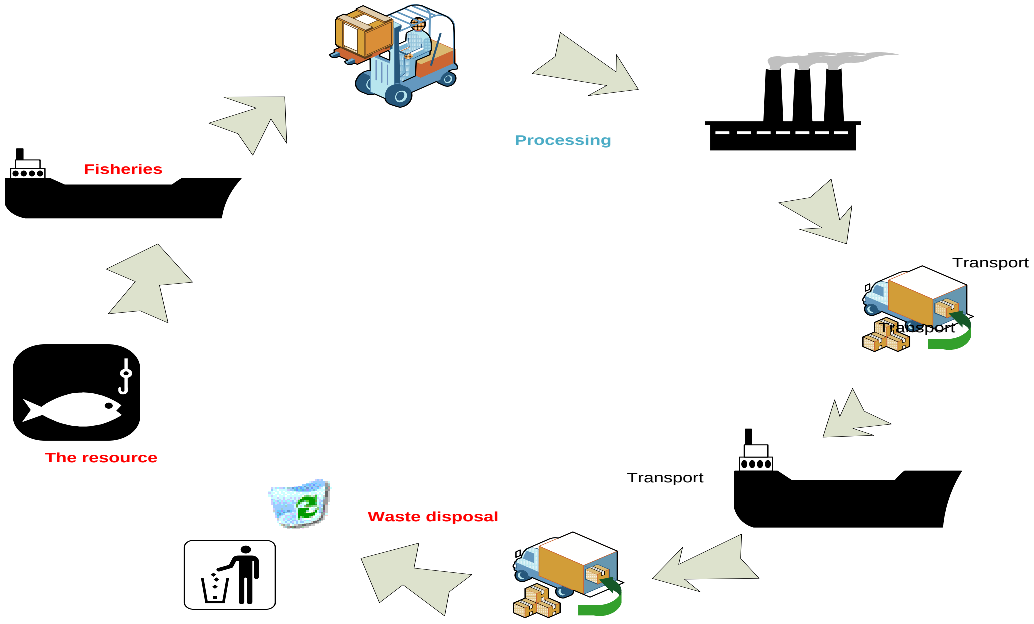

Figure 10: The main phases of the life cycle of the functional unit, 1 kg of Icelandic cod.

The life cycle of the functional product as showed in Figure 10 is divided into four main phases; fisheries phase, processing phase, transport phase and disposal phase. The boundaries of the studied system include the production of the fishing gear, anti fouling agents used on the vessels, the fossil fuel diesel oil utilised, packaging material, chemical utilisation inside of the fish factory and on the fishing vessels, together with domestic transportation of the product between places in Iceland, transportation from Reykjavík to Rotterdam in Holland and a truck that drives from Rotterdam to Sevilla in Spain where the final product is sold. Material and energy used for producing fishing vessels, transportation vehicles and container storages were not included in the study; neither was the transportation of chemicals or other related goods that are utilised in the production.

3.5 LCA and seafood limitations and assumptions– scope

An environmental impact from biotic resources is not as straight forward calculations such as fuel utilisation or carbon dioxide emissions. Resources such as land use and extraction of biological resources are quite new within the LCA and in development (Ziegler et al., 2002). Those impacts are very relevant when studying seafood's environmental impact and as for now there are several impacts such as by-catch/discards that cannot be calculated, both due to lack of information on quantity and also a lack of numerical parameters concerning their environmental effects. The same applies to the effects of fisheries on the seafloor but there are no numerical values or parameters that are applicable in order to quantify the impacts that fishing gear causes on the environment. Other impacts that are not included in the LCA methodology are the effects of ghost nets and the effects fisheries has on biodiversity. All these factors are therefore described qualitatively in this thesis.

3.6 Impact categories and impact assessment method

The impact categories considered in this thesis are climate change, respiratory organics/inorganics, ecotoxicity and acidification.

The impact assessment method that is applied to quantify these impact categories has been chosen to be the Eco-indicator 99. Within the method there are three damage categories;

Human Health: Damages to human health are expressed in Disability Adjusted Life Years [DALY], that means that different disabilities caused by diseases have been weighted such as fate analysis, exposure analysis, effect analysis, damage analysis (Life Cycle Strategies, 1998).

Ecosystem Quality: Measures the damage to ecosystem quality and is expressed as a percentage of species that disappear in a certain area because of environmental load (Potentially Disappeared Fraction, PDF). The PDF is than multiplied by the area size and time period. The unit is [PDF*m2yr] (Life Cycle Strategies, 1998)

Resources: Minerals and fossil fuels are indicated as surplus energy for the future mining of resources. Biotic resources such as fish are not modelled so far in the Eco-indicator 99 method. The unit is expressed in [MJ] (Life Cycle Strategies, 1998).

There are five steps of impact assessments within the methodology; Characterization, Damage Asesessment, Normalization, Weighting and Single score. The thesis only covers Characterization and Weighing but Normalisation is going to be described in theory as well (Life Cycle Strategies, 1998). The most frequently used database within SimaPro was BUWAL250.

Carbon footprints of the products have been calculated as well, using EDIP 2003 method within SimaPro that assesses kg of CO_2 equivalence.

Pt points are indicated within the Eco indicator 99 method. Those points are an indicator of ecological scarcity. The value of 1 Pt point represents one thousandth of the yearly environmental load of one average European inhabitant.

3.6.1 Characterization

Substances are aggregated within each class to produce an effect score. Some substances have more intense effects than other and therefore the problem is dealt with by applying weighting factors. This step is called the characterization step (PRé, 2009).

3.6.2 Normalization

The three damage categories Human Health, Ecosystem Quality and Resources all have different units. In order to gain perspective of a relative size of an effect, the Normalization is applied. Normalization is therefore a dimensionless weighting factor (PRé, 2009).

3.6.3 Weighing

Normalization improves our insight to the results but no final judgment can be made before all of the effects are set to have equal importance (PRé, 2009).

4 Life cycle inventory analysis

The fundamental basis for all LCA's is the creation of a model that contains all inputs and outputs of processes of the life cycle of a product and their amount. A compiled list for data collection, assumptions and description of individual phases of the life cycle is given in appendix 1.

4.1 Methodology and data collection

The product is 1 kg of light salted, frozen cod fillets fished by

a) long liner

b) bottom trawler.

The product coming from the long liner is fished by the long liner Kristín ÞH operated by the Icelandic seafood company Vísir hf. The comparative product is cod fished by a former bottom trawler Hegranes that used to be operated by the Icelandic company FISK Seafood.

The products life is divided into 4 main phases; fishery phase, processing phase, transportation phase and packages disposal phase. Each phase includes:

Fishing phase- oil consumption during steaming and fishing, waste from fishing vessel, antifouling paint, fishing gear.

Processing phase- all chemical usage inside of processing plants, cooling agents, heating oil, electricity and packaging material.

Transportation phase- domestic transportation in Iceland, sea transportation to Europe, land transportation in Europe, cooling agents during all transportations.

Packages disposal- Disposal of paper and plastic packages in Spain. Waste is sent to landfill or to recycling.

4.1.1 Fishing phase

Data from the years 2005- 2007 was gathered. Fishing tours of Kristín and Hegranes were investigated with priority to oil consumption and amount of cod catch. The oil consumption was found using data sheets coming from the fish industry companies. The amount of caught cod was subtracted from the total catch and the total oil consumption was utilised to find out the medium oil consumption per kg of cod. To find out the oil consumption for 1 kg of processed fish, yield of 50% was utilised throughout the study for both long liner and bottom trawl.

Information on waste coming from the vessels together with data on fishing gear and anti fouling paint was collected through the seafood companies. In this study it is estimated that 20% of the fishing gear (mainly PE, PP and steel) utilised per one year is damaged and ends up ghost netting in the oceans. Inside the SimaPro software it is modelled as emission to water.

4.1.2 Processing phase

Both processing houses are located in rural parts of Iceland. Þingeyri owned by Vísir hf is in the west fjords and FISK Seafood is located at Sauðárkrókur up north in Iceland. The processing company at Þingeyri was visited once during the study time but information gathering via email and telephone calls was the main communication method utilised. Information on packaging material, chemical usage, cooling agents, petrol and other related data was gathered from both processing houses, Þingeyri and Sauðárkrókur and through companies that sell and distribute chemicals, oil companies, packaging companies, maintenance companies and transportation companies. All data is calculated according to 50% yield during processing (mass allocation). All inputs that went into the SimaPro software have been calculated according to this. Calculations of chemicals were made by concentration data of substances within solutions. The input amount of chemicals was set as equal to the outputs since there is no sewage system in the two Icelandic processing houses that were taken into consideration. It can therefore be estimated that everything that goes into the system will lead to the exact same output emissions.

The processing plant at Sauðárkrókur has a large cooling system that utilises big amounts of ammonia and some amount of glycol cooling agents. The processing plant at Þingeyri on the other hand uses mainly glycol but small amount of ammonia.

Both processing plants pack their product into 11 kg packages that have been utilised during the calculations in this project.

4.1.3 Transportation phase

The product is transported from both processing plants to Reykjavík where it is lodged on a big container freighter that transports it to Rotterdam in Holland. From Rotterdam the product is loaded on trucks and driven to Sevilla in Spain where it is sold. The information gathered for domestic transport in Iceland and cargo transportation came mainly from the Icelandic transportation companies. The transportation data from abroad are mainly assumptions sustained with the information that were used for domestic transport in Iceland.

4.1.4 Disposal phase

In Spain the fish is consumed and the packages are sent either to recycling or to landfill according to the National Waste Management plan of Spain, where numbers for the percentage of household waste sent to recycling/landfilling are taken. According to the National Waste Management plan of Spain, 69% of paper and cardboard are sent to recycling, 31% goes to landfilling. Plastic waste on the other hand, 21% goes to recycling and 79% goes to landfilling. Those numbers for Spanish waste fraction have been used to estimate the waste flow of the packages of the codfish into either recycling or landfills.

In Figure 11 a flow chart of the inputs and outputs of the life cycle of cod is shown as worked with during the inventory analysis.

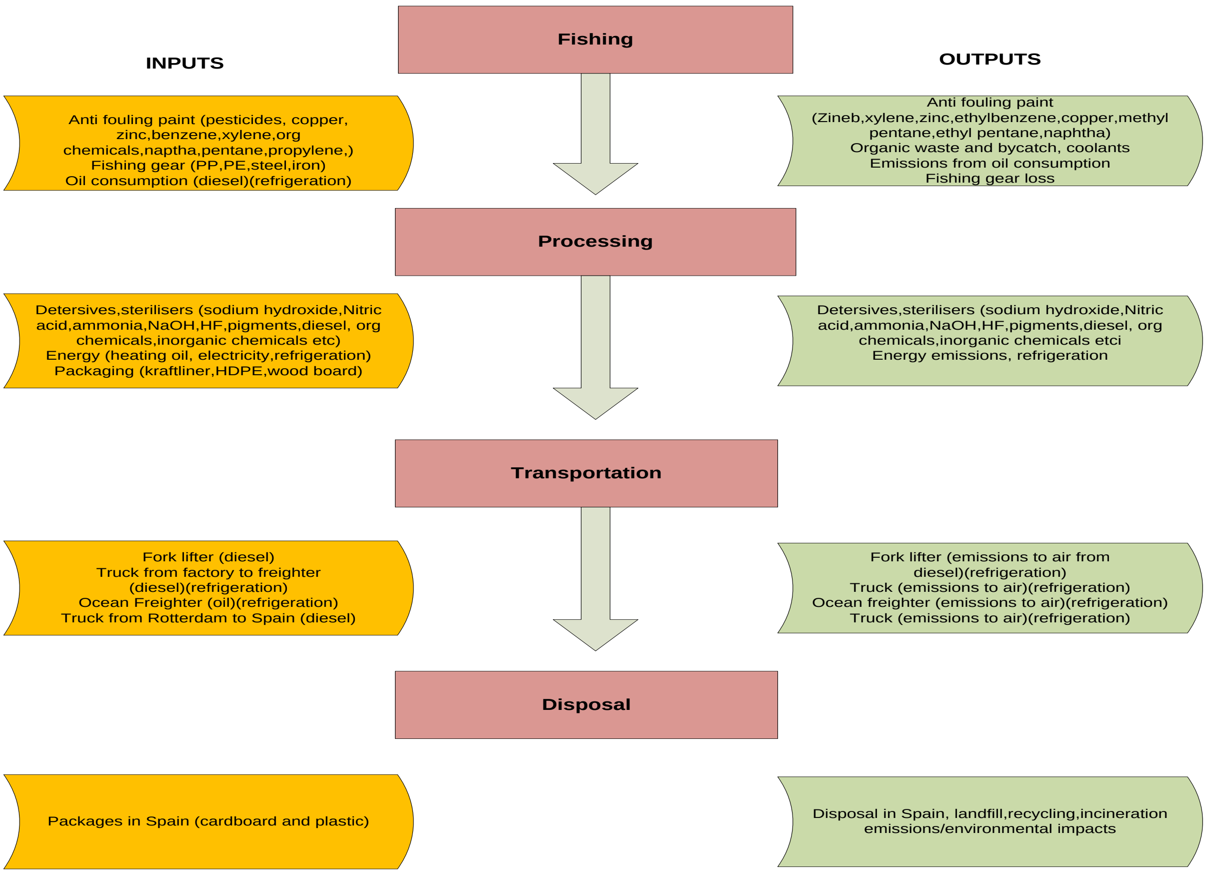

Figure 11: A flow chart of the inventory analysis made for the life cycle of cod.

4.2 Data

Data was organised using the MECO approach that is based on the concept that within each phase of the life cycle of the product, materials, energy, chemicals and other aspects, are inspected and documented. By using the MECO method it is easier to get a clear overview over the relevant inputs and outputs.

Hygiene is very important inside of fish processing plants. Therefore many chemical products such as soap and sterilizers are utilized. Amount of chemicals used during one year was collected. Security papers were used to get information about substances ingredients within each chemical together with their concentrations and risk statements. Then regulations from the European Union together with chemical databases were assessed in order to find out eco-toxicity information of each substance. The same was done for anti fouling paint used on fishing vessels. In Table 2 and Table 3 substances utilised inside of the processing plants and the anti fouling chemicals are listed with their effects on humans and the surrounding environment. The list is not complete since there were several substances that were impossible to trace.

Figure 12: Soap and sterilizers are utilized in processing plants. Picture taken at Vísir hf, Þingeyri.

Table 2: Substances utilized within the processing phase of cod production. The risk and concentration of substances comes from security papers of the products. The risk assessment is used by the European Union (EU, 2008)

Substances	Concentration	Risk	
Trisodium nitriloacetic acid	10%	H36/38	Irritating to eyes and skin
Potassium hydroxide	10-15%	H22-35	Harmful if swallowed, toxic to inhalation and contact to skin, causes burns, can liberate toxic gas.
Sodium hydroxide	2%-30%	H35	Causes severe burns
Sodium/natrium hypochlorite	5-15%	H31-34	Contact with acids can liberate very toxic gases, danger of accumulative effects, causes burns[9]
EDTA	0-1%	H36/38	Irritating to eyes and skin
Didecyldimethylammonium chloride	10-15%	H22-36/38	Dangerous for the environment. Poisons waters and kills organisms. Highly irritating.
Isopropanol	5-15%	R67	Vapors may cause drowsiness and dizziness
Alkyl alcohol etoxýlöt	5-15%	None	
Etanól	< 70%	H11	Contains substances such as chlorohexidingluconate that can be bio accumulative and is not biodegradable
Sulphuric acid	5%	R35	Causes severe burns
Quaternary ammonium	5%	H312	Toxicity to aquatic organisms, toxicity to humans
Coco amido propylbetaine	2,5%-30%	H36	Irritating to eyes
Tetrakalium pyrofosfat	5%	H36	Irritating to eyes
2,4,4-tríklóro-2-hýdroxydífenýl eter,	0-1%	H36/38-50/53	Irritating to eyes and skin. Very Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
2,4-díklóróbenzyl-o	0-1%	H41	Risk of serious damage to eyes
Citric acid	0-1%	H37/38-41	Irritating to the respiratory system, limited evidence of carcinogenic effects, danger of very serious irreversible effects.
1,2,4 trimethyl benzene	1-5%	R10/20/36/37/ 38/51/53	Flammable, harmful by inhalation, irritating to eyes, skin and respiratory system, Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
2-(2-butoxyethoxy)ethano	5-15%	R41	Risk of serious damage to eyes
Alkylamin fosfat,	<1%	R36/38,51-53	Irritating to eyes and skin. Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment
Benzoic acid	<2%	R-36/50/53	Irritating to eyes. Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment
1,2,5 trimethylbensene	0,1-1,0%	H10-37-51/53	Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment. Flammable.
1,2,4 trimethylbensene	1-5%	H10-20-36/37/38-51/53	Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment. Flammable. Irritating to eyes, respiratory system and skin
Ethyl benzene	0,1-1%	H11-20	Harmful by inhalation, flammable
Zineb			On the EU list of substances with documented endocrine-disrupting effects. Dangerous for human health
Xylene	1-5%	10-20/21-38	Flammable, Harmful by inhalation and in contact with skin, Irritating to the skin

As can be seen, there are many harmful ingredients used inside the processing plants. At least six substances are toxic to water bodies and cause severe damage in aquatic

[9] A special initiative for this substance has been given high priority - particularly because these substances are used in consumer products where there is a risk of formation of toxic substances when these substances are mixed with acid/NH_4. Sodium hypochlorite is undergoing risk evaluation in the EU (EU, 2008)

environment. It should be noted that those substances are though in very low concentrations within the solutions and are therefore not an important parameter within the LCA study as seen in Figure 15 and Figure 16 in chapter 5, that demonstrate the life cycles of both the products, 1 kg of cod fished by a long liner and a trawler.

Table 3: Substance ingredients in antifouling paint, concentration and risk categories.

Substances	Concentration	Risk	
Copper 1 oxide	40-50%	R22,R50-53	Very Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
Ethyl benzene	10%	R11,R20	Highly Flammable, Harmful by inhalation
Rosin	25%	R43	May cause sensitization by skin contact
Xylene	15-25%	R10,R20/21,R38	Flammable, Harmful by inhalation and in contact with skin, Irritating to the skin
Zinc oxide	25%	R50-53	Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
Zineb	10%	R37-R43	On the EU list of substances with documented endocrine-disrupting effects. Dangerous for human health
Methyl pentane	2,5%	R11,R20,R36/37,R66	Irritating to eyes and respiratory system, highly flammable, harmful by inhalation, skin dryness or cracking
Epoxy resin	1%	R36/38,R43,R51-53	Irritating to eyes and skin, Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
Naphtha petroleum	2,5%	R51-53,R65	Harmful: May cause lung damage if swallowed, toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment
Metylisobutylketon	2%	11,20,36/37,66	Irritating to eyes and respiratory system, harmful by inhalation, highly flammable, skin dryness or cracking
Ethanol	2%	11	Highly flammable
4,5 Dichloro-2-n-oktyl-4-Isothiasolin-3-on	1-5%	21/22/23,34,43,48,50	Harmful to skin and respiratory system, very toxic to aquatic organisms, danger of serious damage of health, causes burn.
Dicopperoxide	1-5%	22	Harmful if swallowed

Fishing vessels are painted with anti fouling paint every two year. Many of the substances in the painting are harmful both for human health and for aquatic organism and ecosystems and in this case the concentration of the harmful substances is rather high or 25-50% in the case of copper and zinc. Within the fishing phase as seen in Figure 13 it can be seen that the biggest environmental load is coming from the combustion of diesel oil of the fishing vessel. The second most environmental load is coming from the glycol cooling agent that is on board of the vessel.

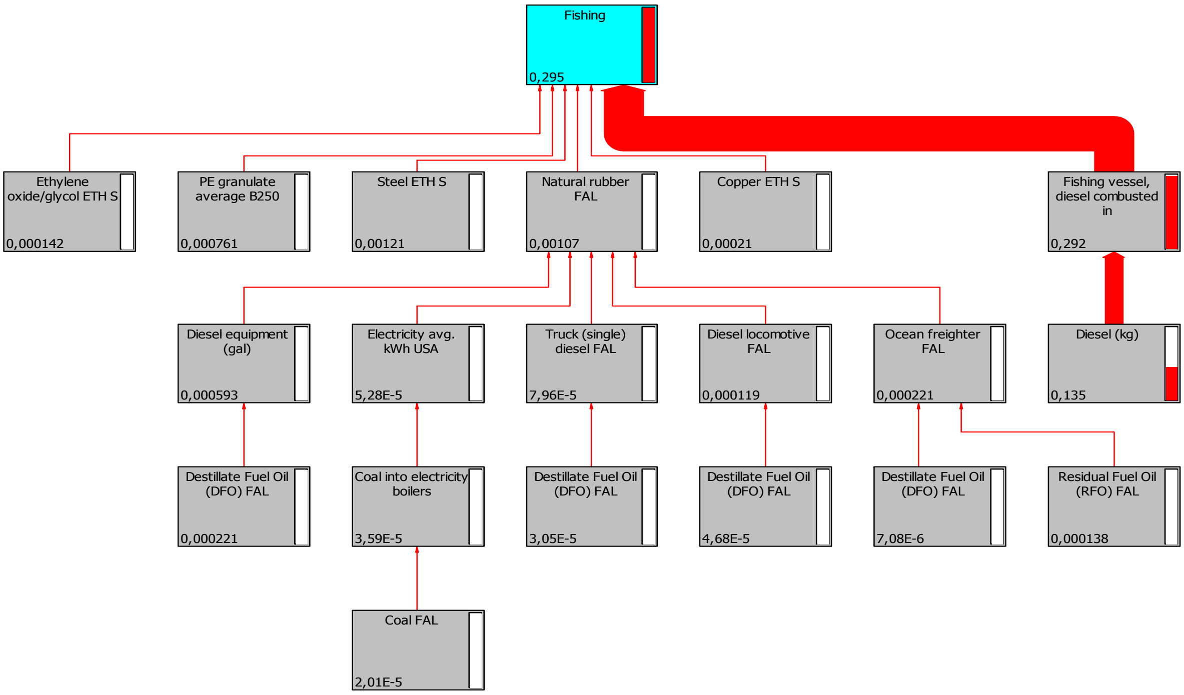

Figure 13: Network tree of the fishery phase for 1 kg of cod fished by trawler.

The most environmental load within the fishery phase of cod fished with trawler is as well coming from the combustion of diesel oil of the fishing vessel. Other parameters within the phase are contributing very equally to the total environmental load of the phase as seen in Figure 14.

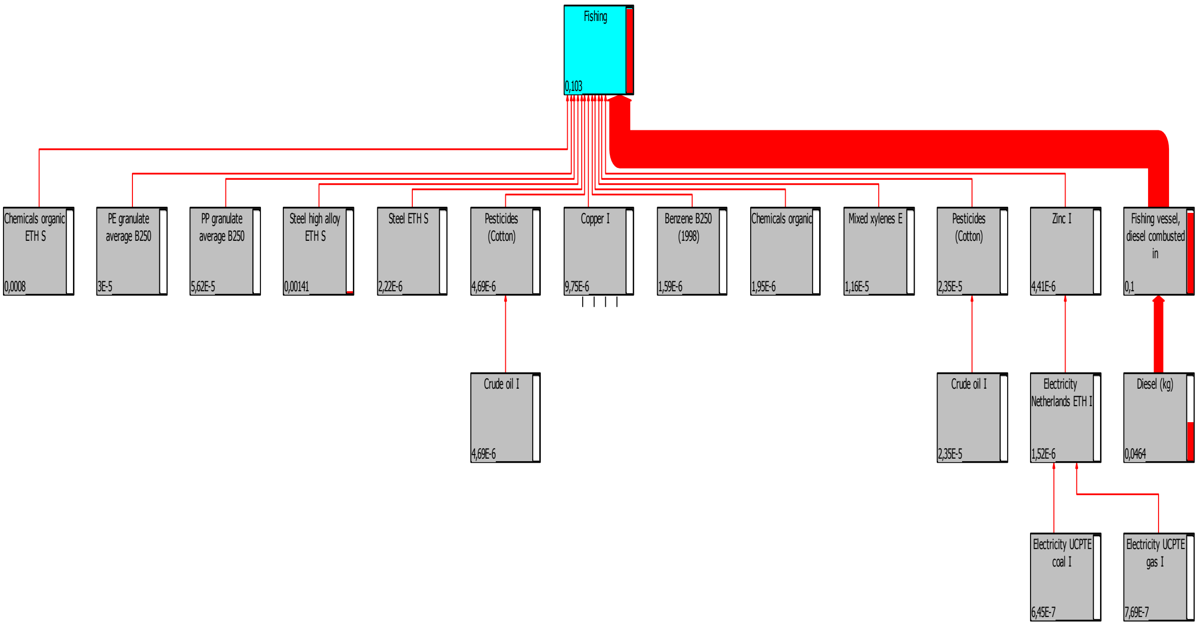

Figure 14: Network tree of the fishery phase for 1 kg of cod fished by a long liner.

5 Results

The results presented in this chapter are results coming from the gathering, analysis, assumptions and calculations of data coming from two fisheries companies in Iceland, FISK Seafood and Vísir hf. The numerical analysis of the life cycle assessment is based on LCA methodology modelled in the SimaPro software owned by the Belgian software and consultancy company, PRé.

The life cycle of frozen cod product fished by long liner and by a bottom trawl was modelled in SimaPro. The life cycles were divided into 4 main phases, in order to compare the results from different operations. Those four phases are: fishing phase, processing phase, transportation phase and package disposal. Which parameters are included in each phase depends on the fishing method and will be discussed later. An overview over the life cycles is show in Figure 15 and Figure 16. The red bars in the boxes show the relative environmental importance of each box, the bigger the bar is, the bigger is the environmental impact. The same goes with the red lines that come from each box, the thicker the line is the more environmental impact there is. Green lines indicate a positive impact, such as recycling of materials.

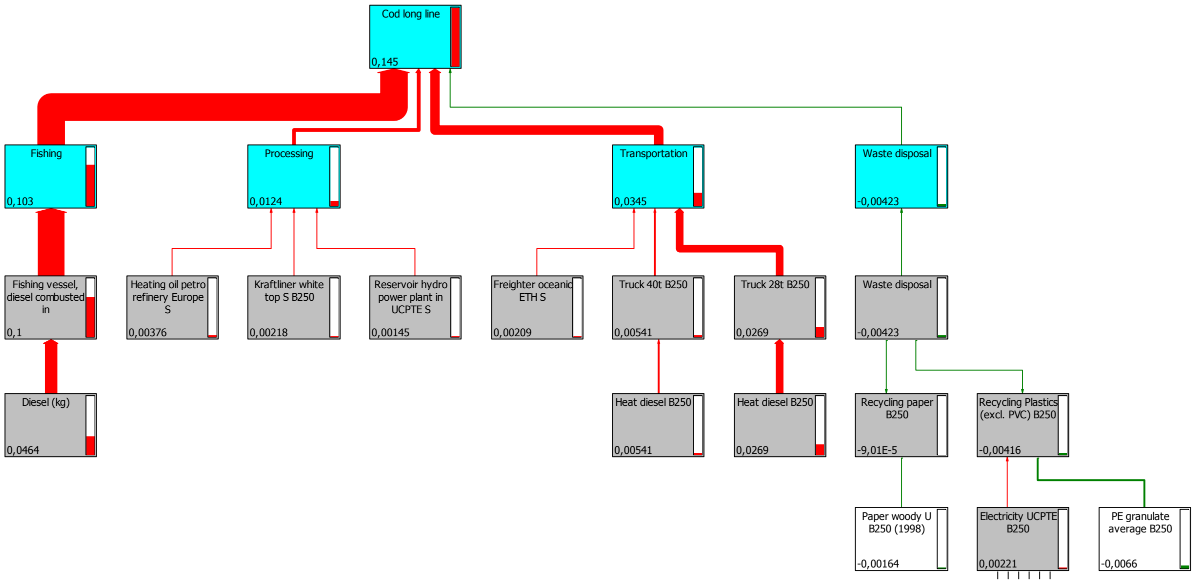

Figure 15: Main features of the life cycle of 1 kg of cod fished by a long liner.

It should be noted that only the main products of the trees are visible. In Figure 15 only 20 of 119 boxes are shown. The same goes for Figure 16.

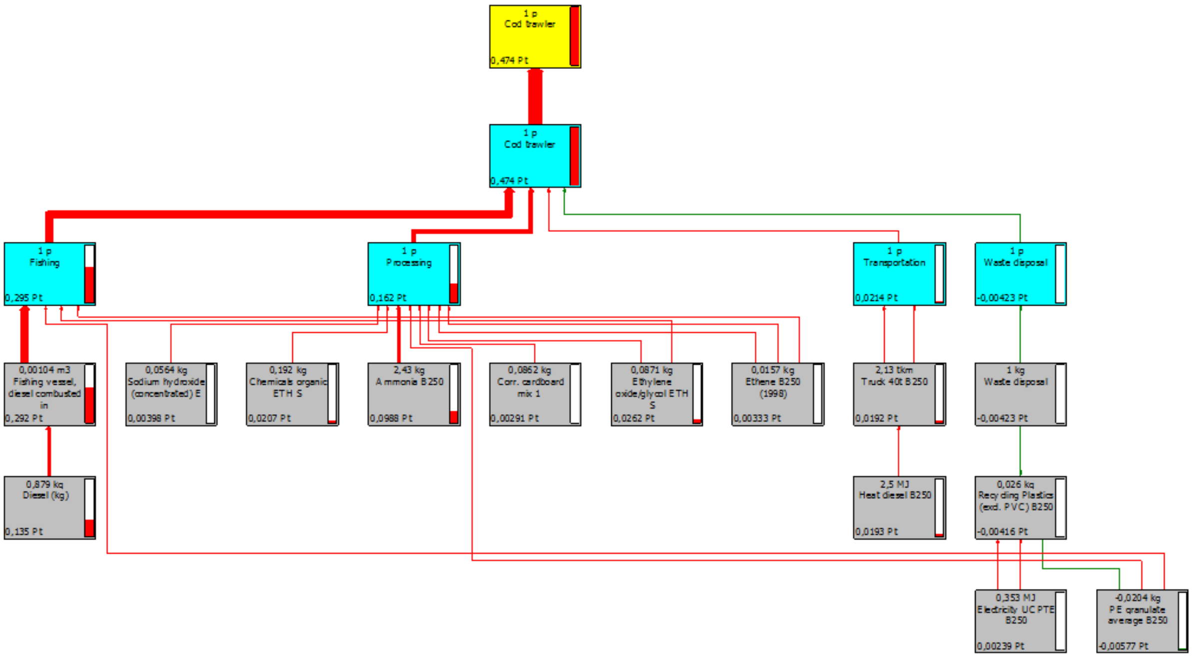

Figure 16: Main features of the life cycle of 1 kg of cod fished by a trawler.

According to preceding choice of impact categories in the goal and the scope; climate change, respiratory organics/inorganics, eco-toxicity and acidification were assessed.

5.1 Cod long line

Looking at the product, it can be seen from Figure 17 that the fishery phase (blue) is dominating when it comes to environmental impacts. Fishing phase contributes relatively most to almost all categories such as, carcinogens, respiratory organics and inorganics, climate change, radiation, ozone layer, eco-toxicity, acidification/eutrophication, minerals and fossil fuels. The dominating environmental impacts are related to the use of fossil fuel as seen in Figure 15. Processing dominates the land use category. It was decided not to put any specific land use for the fishery phase of a long liner, even though the hooks can break corals if they get in touch with them. Since no reliable numbers are to be found for this damage, it was decided not to include this impact. Transportation phase is the second biggest contributor to environmental impacts according to Figure 17 except for land use, radiation and carcinogens which are dominated by processing.

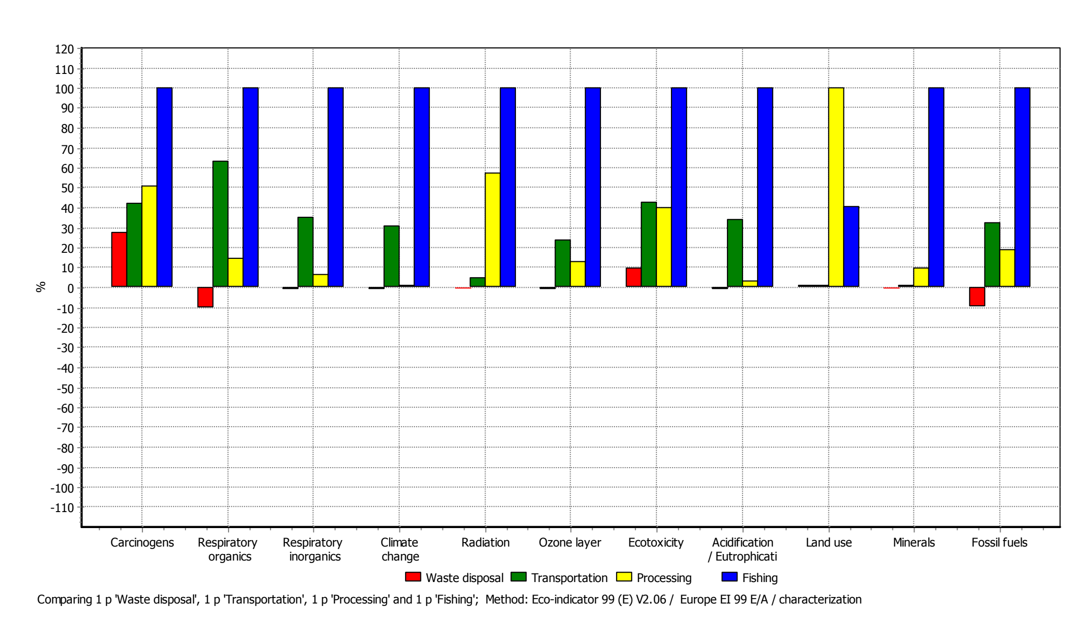

Figure 17: Characterization for 1 kg of cod caught by long liner.

If looked at Figure 18 weighting contribution of different categories for the 4 phases, is shown. Again it can be seen that the most dominant phases is the fishery phase and after that comes the transportation phase. It is interesting to see the results from weighting which is an assessment that sets all impacts equal. Figure 18 clearly shows that the fishery phase is contributing the most to respiratory inorganics, fossil fuels, acidification and climate change.

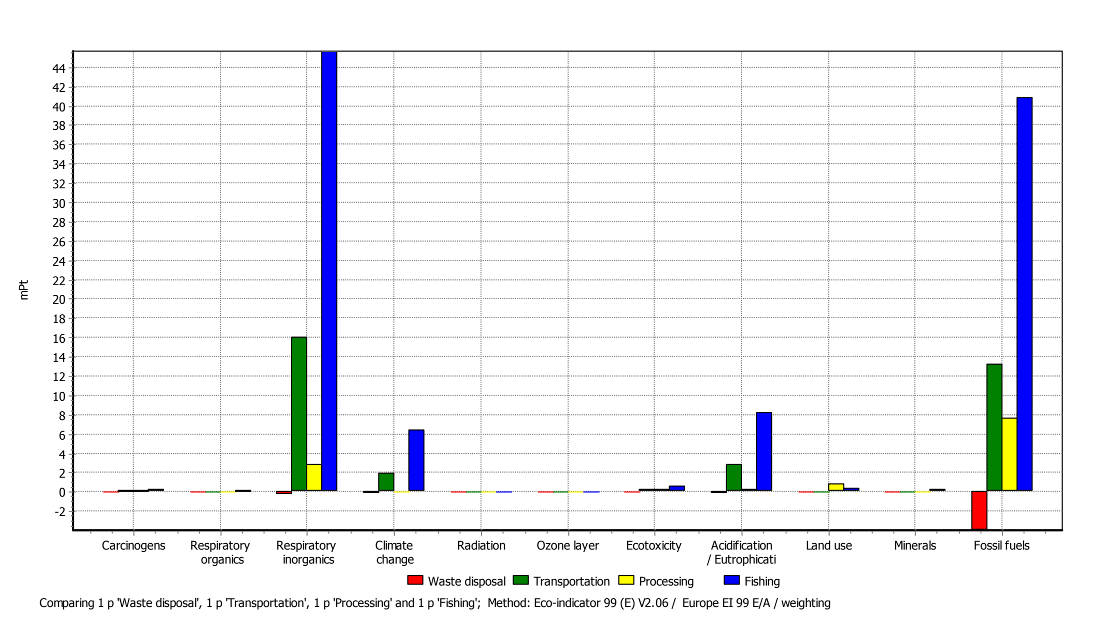

Figure 18: Weighting for 1 kg of cod caught by long liner.

If looked at Figure 19 it is clearly demonstrated that it is the diesel combustion (grey) that is making the most environmental impact compared to other material inputs. Both production of diesel and its combustion affect heavily the categories respiratory inorganics, fossil fuels, acidification/eutrophication and climate changes.

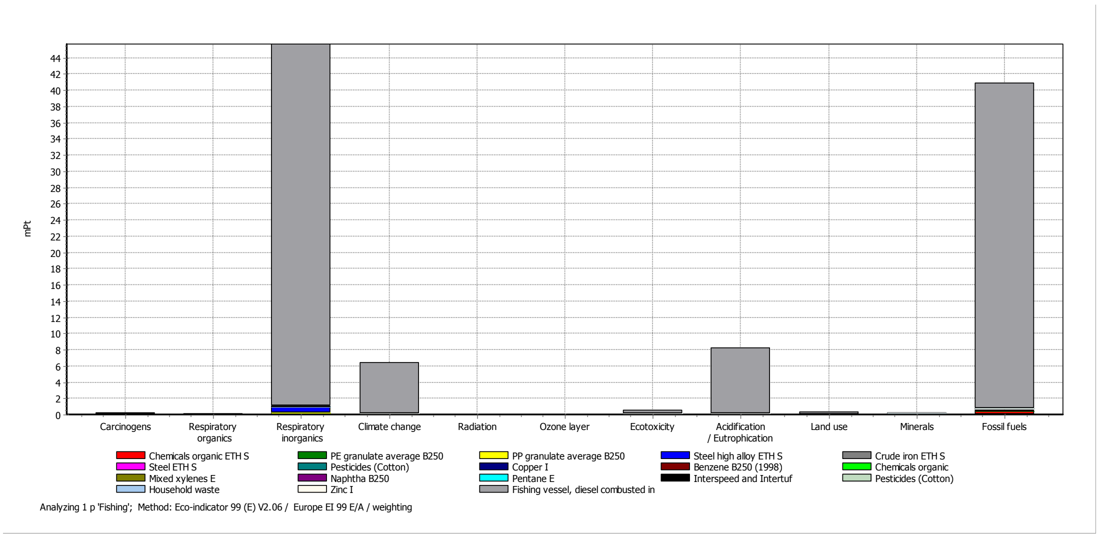

Figure 19: Weighting of the main attributors of environmental impact within the life cycle 1 kg of cod caught by long liner.

When single scores for the whole life cycle are analysed such as in Figure 20, it can be seen again that the overall most dominating phase is the fishery phase. It attributes the most to both respiratory inorganics (yellow) and fossil fuels (dark green).

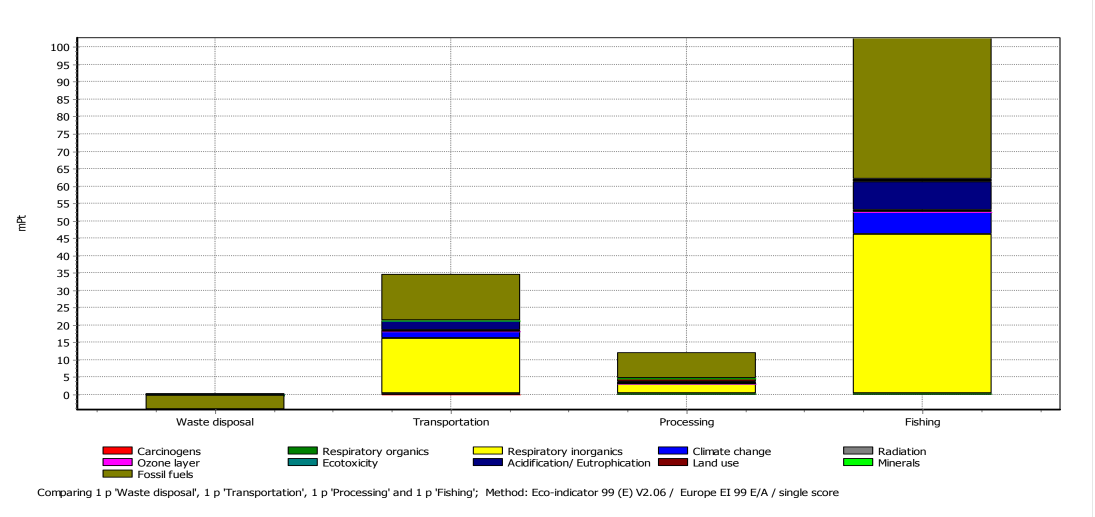

Figure 20: Single score for each phase for 1 kg of cod caught by a long liner.

5.2 Cod fished by trawler

Looking at the product caught by a bottom trawler, Figure 21 shows clearly that here as well for long liner, the fishery phase is the most dominating in most categories. Respiratory organics and inorganics, climate changes, ozone layer, eco-toxicity, acidification/eutrophication, minerals and fossil fuels are all categories that are dominated by the fishery phase. As seen in Figure 15 and Figure 16 it is the diesel oil consumption of the vessels that are contributing the most to environmental impacts within the fishery phases. For bottom trawled cod the consumption is 1.1 litre of diesel oil while the oil consumption of the long liner is 0.36 litres.

Processing on the other hand is dominating in carcinogens, radiation, land use and fossil fuels categories. It is very interesting to see that land use is not a dominating category for the fisheries. That is due to a lack of application inside of the software that does not account for seafloor as such but only traditional land as such. This is a great lack of impact assessment since it is a fact that 1000m^2 of seafloor is swept for one kg of caught fish (Helga Eyjólfsdóttir et al., 2003).

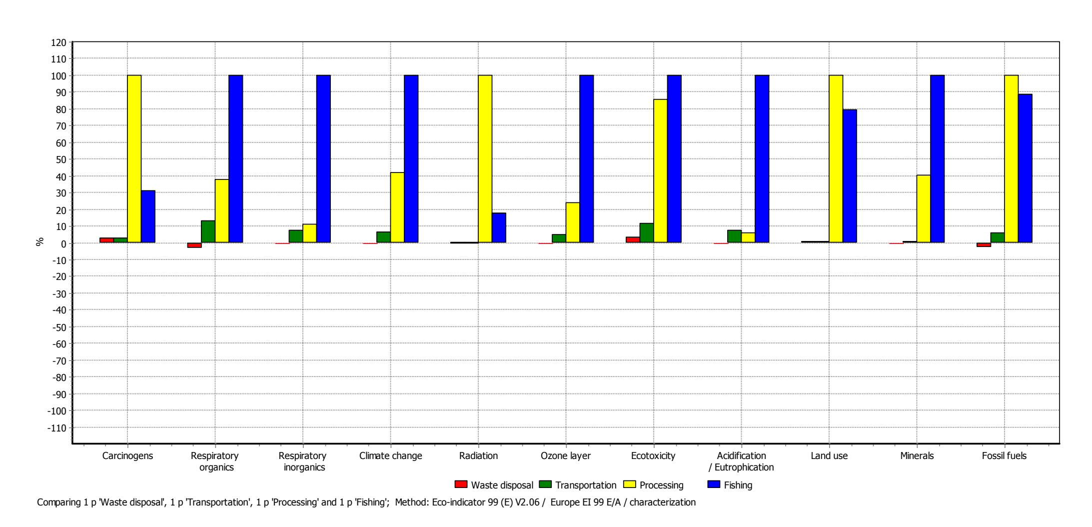

Figure 21: Characterization of 1 kg of cod fished by a bottom trawler.

Again, if looked at the weighting as seen in Figure 22, respiratory inorganics, fossil fuels, acidification/eutrophication and climate changes become the greatest categories and the others such as land use and carcinogens for example are almost wiped out.

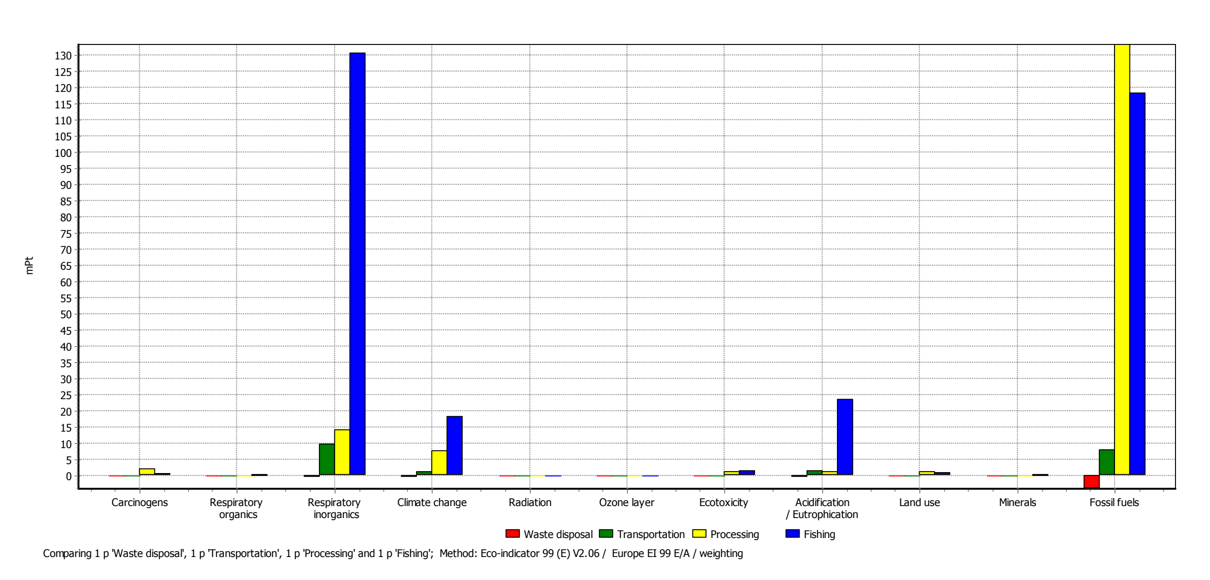

Figure 22: Weighting for 1 kg of cod caught by a bottom trawler.

If the results are looked at from a second point of view as done in Figure 23 it is clear that the diesel combustion (violet) is the process that is contributing the most over all other inputs.

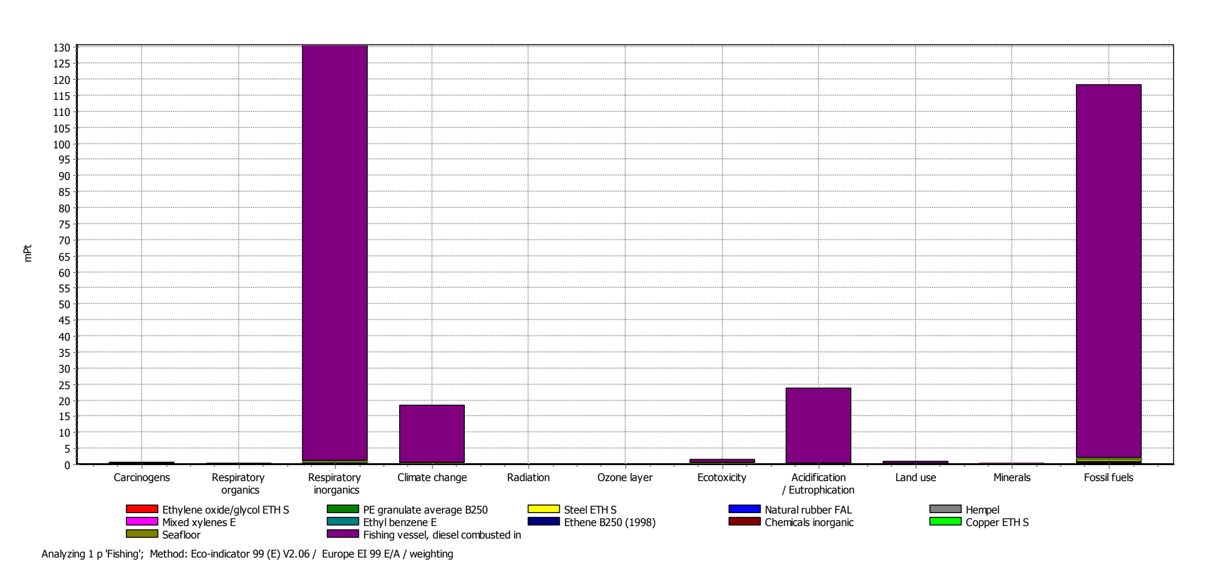

Figure 23: Weighting of the main attributors of environmental impact within the life cycle 1 kg of cod caught by bottom trawler.

Figure 24 shows the single score for each phase of the life cycle of 1 kg of cod caught by bottom trawl and again it is clear that the fishery phase is the most dominant of the 4 phases. It is interesting to see how much processing is contributing in this scenario but the reason for that is found to be because of great amount of ammonia utilized inside of the processing plant.

Processing therefore contributes second most after the fishery phase to environmental impacts of 1 kg of bottom trawled cod.

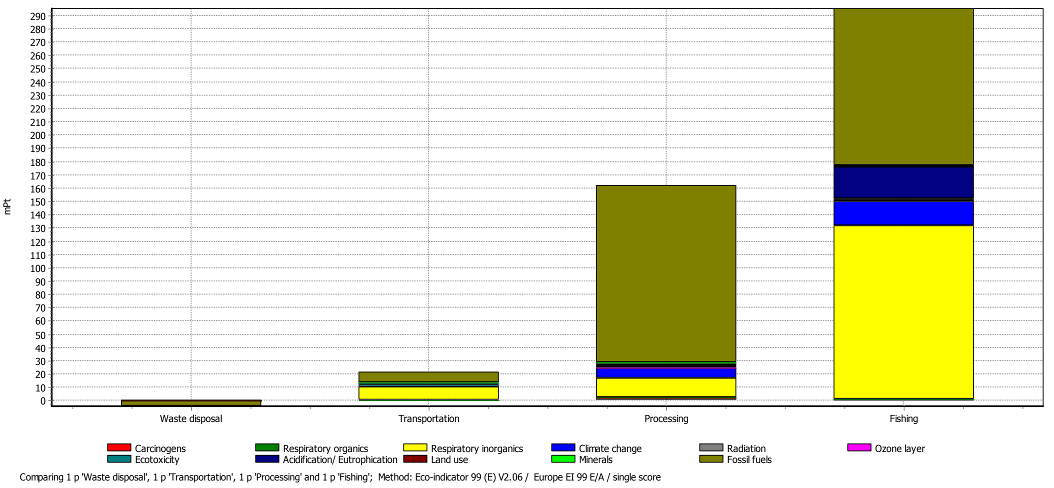

Figure 24: Single score for 1 kg of cod caught by bottom trawl.

5.3 Comparison between long liner caught cod and bottom trawled cod

When looking at both life cycles and comparing them within the software it can be seen which of the two is causing more environmental impacts.

Looking at Figure 25 the characterized comparison between the two products can be seen. Trawled cod is dominating in all categories. Again it shall be pointed out that it can be misleading to see the results for land use, again because the actual impact of fishing gear on seafloor and biodiversity is not included in the software application.

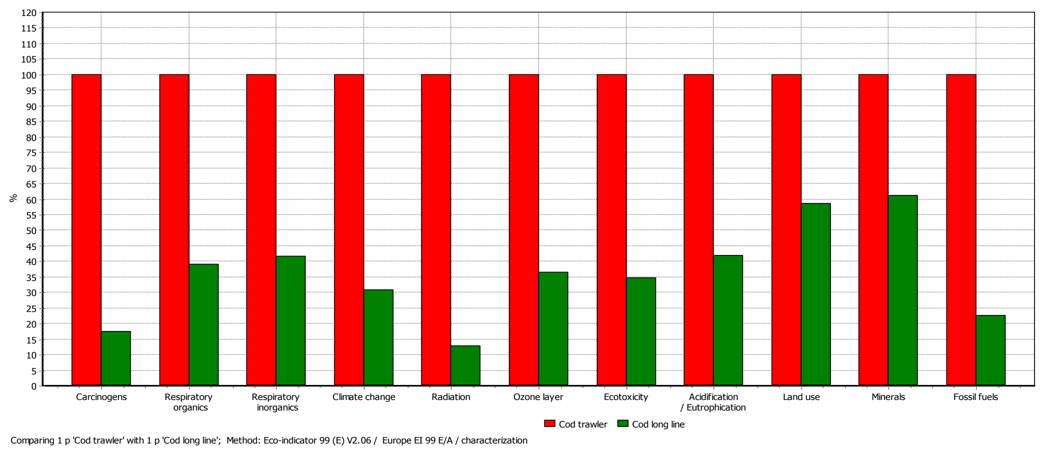

Figure 25: Characterization of cod fished by trawler (red) and cod fished by long liner (green).

When the weighting factor is assessed, it can clearly be seen that the biggest categories like before are the fossil fuels, respiratory inorganics, acidification/eutrophication and climate changes.

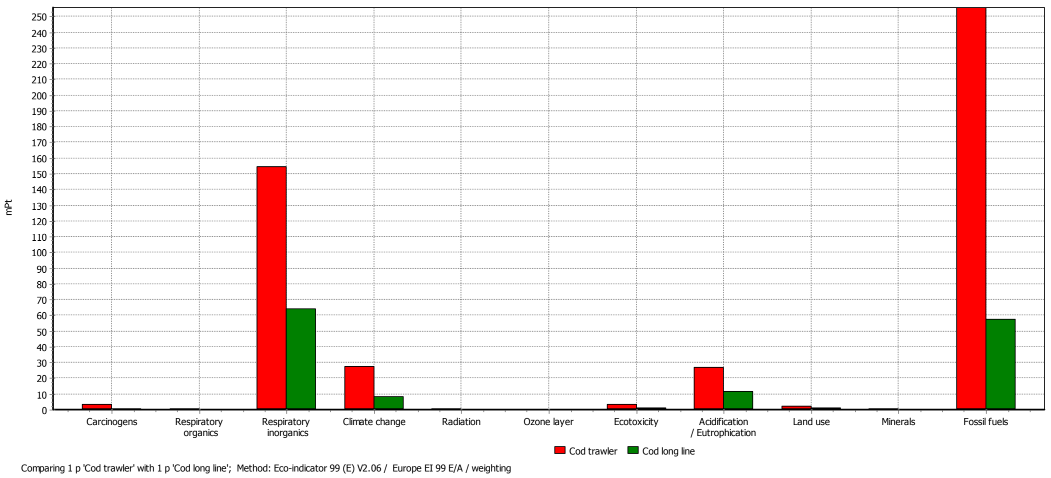

Figure 26: Weighting for 1 kg of cod caught by a bottom trawler (red) and long liner (green).

In Table 4 values for all impact categories can be compared between the two products according to the specified values for each impact category as calculated in SimaPro by utilizing the characterization impact assessment method. The units and their meaning were discussed in chapter 3 earlier in this report.

Table 4: Values of all impact categories for long liner and bottom trawl caught cod using characterization as an impact assessment method. The highlighted impact categories in bold are the one assessed in this project.

Impact category	Long liner	Bottom trawl	Unit
Carcinogens	2.048E-8 (17.5%)	1.17E-7 (100%)	DALY
Respiratory organic	**7.22E-9 (39.2%)**	**1.85E-8 (100%)**	**DALY**
Respiratory inorganic	**2.48E-6 (41.6%)**	**5.97E-6 (100%)**	**DALY**
Climate change	**3.25E-7 (30.8%)**	**1.06E-6 (100%)**	**DALY**
Radiation	1.59E-9 (12.8%)	1.25E-8 (100%)	DALY
Ozone layer	2.23E-9 (36.6%)	6.1E-9 (100%)	DALY
Acidification/Eutrophication	**0.144 (42%)**	**0.344 (100%)**	**PDF*m2yr**
Ecotoxicity	**0.405 (34.7%)**	**0.141 (100%)**	**PAF*m2yr**
Land use	0.0161 (58.5%)	0.0274 (100%)	PDF*m2yr
Minerals	0.00726 (61.3%)	0.0118 (100%)	MJ Surplus
Fossil fuels	1.71 (22.7%)	7.61 (100%)	MJ Surplus

As seen in table 4, trawled cod is dominating all impact categories compared to long lined cod. For the impact categories assessed in this project; climate change, respiratory organics/inorganics, eco-toxicity and acidification, trawled cod dominates within each category. Damages to human health are expressed in Disability Adjusted Life Years [DALY] and are found within climate change, respiratory organics and respiratory inorganics. Long lined cod scores 3.25E-7 or 30.8%, while trawled cod scores 1.06E-6 or 100%. Respiratory organics contribute 2.48E-6 or 41.6% but trawled cod 1.85E-8 or 100%. Within the category respiratory inorganics long lined cod results in 2.48E-6 (41.6%) while trawled cod dominates with 5.97E-6 or 100%. Within Ecosystem damage, eco-toxicity category for long lined cod measures 0.405 [PAF*m2yr] or 34.7% compared to the 0.141 [PAF*m2yr] or 100% for trawled cod. It is therefore clear that trawled cod is dominating within most categories causing over 50% more environmental impact

Table 5: Pt reference points for trawled cod versus long lined cod for each phase within the life cycle of the final product.

	Fishing phase (pt)	**Processing phase (pt)**	**Transportation phase (pt)**	**Disposal phase (pt)**
Trawled cod	0.295	0.162	0.0214	-0.004
Long lined cod	0.103	0.0124	0.0345	-0.00423

Table 5 shows the pt reference points of the SimaPro calculations inside the Eco-Indicator 99 (E) V2.06. Fishing phase for trawled cod is 0.295 pt while for long lined cod it is 0.103 pt. Processing phase is the second most dominating phase within the trawled cod with 0.162 pt while long lined cod it is 0.0124 pt. It can therefore be seen that transportation phase for long lined cod is the second biggest contributor to environmental impacts within its life cycle, with 0.0345 pt. Both disposal phases are a negative value, meaning that they are decreasing the environmental impacts of the life cycles.

Table 6: Hot spots within each phase of the two life cycles, cod caught with bottom trawl and cod caught with long liner.

	Fishing phase	Processing phase	Transportation phase	Disposal phase
Trawled cod	Fishing vessel diesel combustion Steel in fishing gear PE in fishing gear	Ammonia as cooling agent Glycol as cooling agent Organic chemicals	Diesel from truck in Europe	Positive hot spot is the recycling of PE plastics
Long lined cod	Fishing vessel diesel combustion Steel alloy in fishing gear PP plastics in fishing gear	Heating oil for processing plant Kraft liner in packages HDPE used in packages	Diesel from truck in Europe	Positive hot spot is the recycling of PE plastics

If looked at the actions that contribute the most within each phase of the two life cycles, it can be seen that the fishing vessels combustion of diesel oil within the fishery phases for both products is clearly a hot spot. Steel and plastic used in the fishing gear are also contributing in a substantial manner. Within processing the cooling agents are hot spots within the trawled cod but burning of heat oil and packages within the long lined cod. The hot spot within transportation is the truck that drives form Rotterdam to Sevilla. The positive hot spot within the disposal phases is the recycling of plastic PE. It should be stressed that SimaPro does not take in to account several factors that are important within the life cycle of seafood products, such as the environmental impact that fishing gear causes on seafloor, by-catch, discards. Biodiversity is not assessed either in the SimaPro software.

In appendix 1 the weighted environmental pt values for each phase are listed in the inventory analysis box.

Carbon footprints were calculated both for trawled and for long lined cod. The trawled cod results in 5.14 kg CO_2 equivalence while the long lined cod calculates to be 1.58 kg CO_2 eq.

If hypothetically both the fishing vessels used hydrogen as an energy carrier the carbon footprints calculated would be 1.72 kg CO_2 eq for bottom trawled cod and 0.4 kg CO_2 eq for long lined cod. That equals 73% reduction of carbon footprints for bottom trawled cod and 85% reduction of the carbon footprints for long lined cod. Here it has been assumed that all electricity is coming from hydro power plants and therefore the GHG emissions set to zero.

Further calculations are out of reach for this study since there are scientific uncertainties of the actual technology for hydrogen fishing vessels like for example energy efficiency and exactly how much energy the vessels in this project would actually utilize during fisheries. Until the technology has been implemented and tested in a fishing vessel, the uncertainties are too big for this project to predict.

6 Sensitivity analysis

To see exactly how much environmental gain it would be to have both the fishing vessels running on hydrogen, a sensitivity analysis was done by zeroing down the combustion of fossil fuels within the fisheries phase.

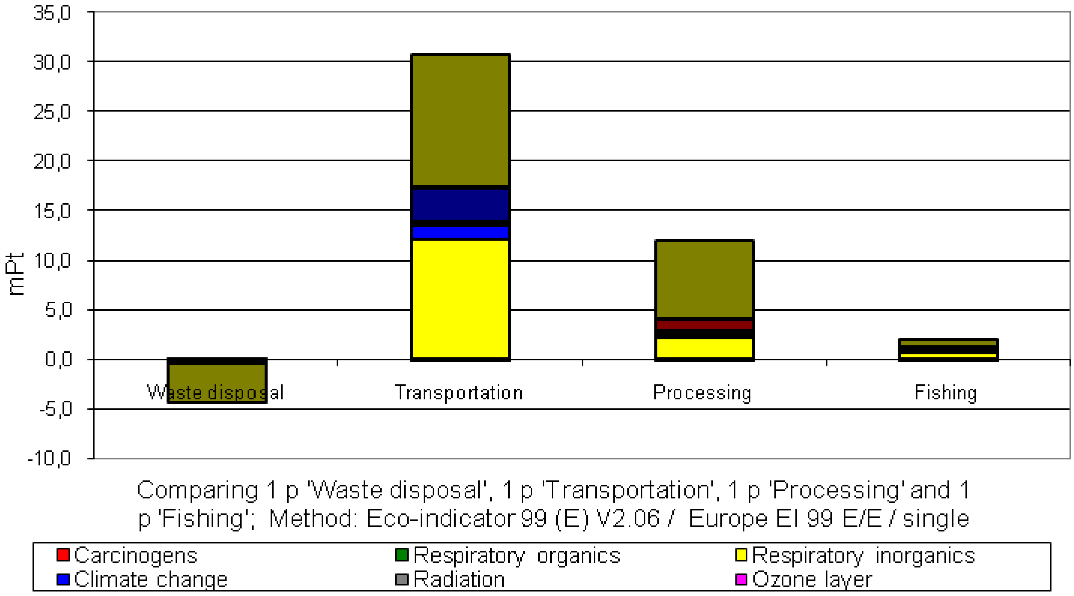

Figure 27: Single score for 1 kg of long lined cod running on hypothetical hydrogen engine.

Figure 27 shows the single score result for long lined cod when the fossil fuels have been eliminated from the fishery phase, resulting in no direct air emissions from the fishing vessel. The pt score (showed in mpt on the graph) goes from being 0.103 to 0.002 if the fossil fuels are entirely excluded. In this case transportation phase clearly has the most environmental load.

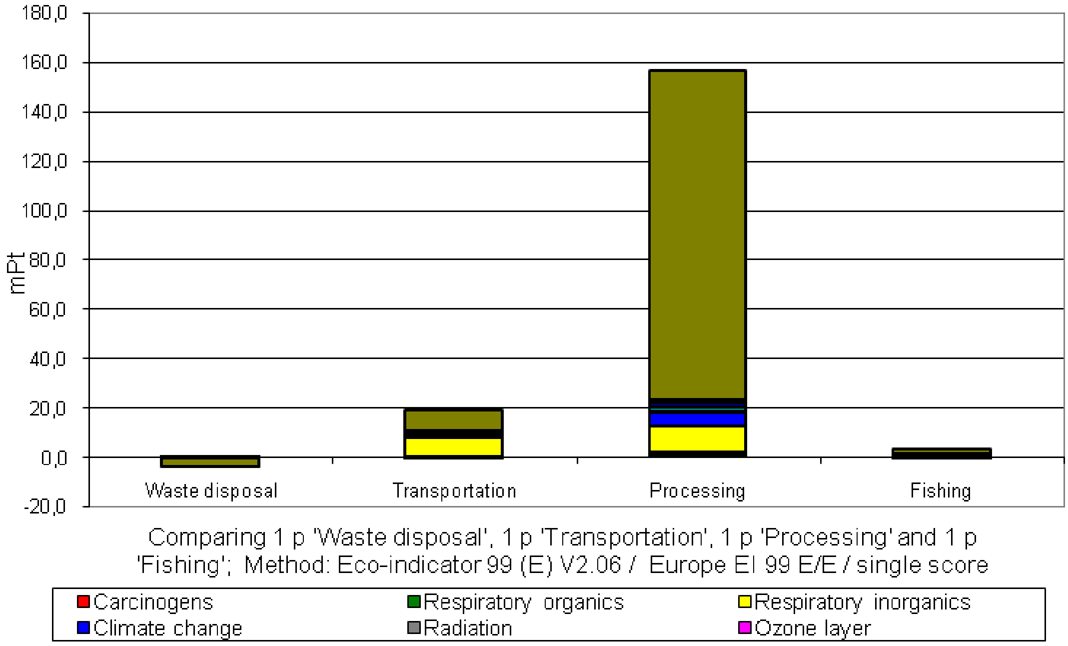

Figure 28: Single score for 1 kg of trawled cod running on hypothetical hydrogen engine.

When looked at the single score results for trawled cod in Figure 29 it can be seen that the fishery phase has become the smallest contributor to environmental load and processing the biggest one. Fishery phase drops from 0.295 pt down to 0.003 pt (showed in mpt on graph) by eliminating the fossil fuel combustion of the fishing vessel, pretending that it runs on hydrogen engine that does not emit any direct air pollution.

7 Discussions and potential improvements

Fisheries cause many environmental impacts. As thoroughly discussed in chapter 2 many research have been carried out but many remain as well to be done. The following impact categories are considered to be of great importance for cod fisheries:

Effects on seafloor caused by fishing gear

Effects on biodiversity and over exploitation

Use of fossil fuels that attribute to climate changes, acidification, human and ecosystem toxicity and depletion of fossil fuels and minerals

Use of chemicals and substances that are dangerous for the ecosystems and for human health.

By-catch, discards and waste disposal

Land use

In previous chapters the following environmental impacts have been discussed:

7.1 Seafloor impacts

Environmental impact caused by fishing gear on the seafloor is a hot topic that has been discussed for some time. Long distances of seafloor are towed, often for hours, and in Iceland it has been estimated that per 1 kg of mixed catch of fish this area is 1000m^2 (Helga Eyjólfsdóttir et al., 2003). Swedish research states that per 400 g of cod fillets the size of area swept is 700m^2 (Ziegler et al., 2002). The bottom dragging gear is designed to catch fish that stays near to the bottom and the doors of the trawl are usually made of steel that causes physical impacts such as flattening of the seabed, crushing of bottom dwelling species, destruction of hiding places, sediment resuspension and removal and catch of species that are not target species. The physical impacts of trawl towing are not uniform and depend amongst other things, on the substratum of the seabed. Soft seafloor habitats show tendency of decreased biomass, physical damage of bottom dwelling species and a difference in species composition. Considerable part of mud habitats seem to be, according to Ziegler 2006, left in permanently altered condition that will take a long time to recover from.

Hard substrata seafloors have been subjects to research as well and the results have not been quite uniform. Some research shows that the habitats trawled have quite fast recovery time others show otherwise. Corals are often located within rich fishing grounds and are often the basic element for the biodiversity found within that habitat. Fishing gear can be very destructive to corals and in Iceland big areas of coral destructions have been discovered (Icelandic Marine Research Institute, 2004). Seafloor impacts from fishing gear are not assessed within the LCA methodology.

7.2 Biodiversity

Biodiversity represents the variety of life forms sustained by plants, animals and microorganisms communities. The rate of species loss is faster today than it has ever been in human history with extinctions occurring at very high rates. Fisheries affect biodiversity both in direct way with removal of target and non target species and in an indirect way through climate changes and eco-toxicity. Biodiversity sustains and provides many of the economic services that human kind benefits but is not always clearly visible. This can apply for coral reefs that make the fishing grounds rich or a forest that purifies and regulates the atmosphere. According to FAO in 2008 over 80% of the worlds fish stocks were fully exploited or over exploited. Biodiversity is not assessed within the LCA methodology.

7.3 Climate changes

Climate changes are stated to be one of the greatest threats mankind has to react to. Atmospheric concentration of CO_2 has never been higher in at least 650.000 years and the same can be seen for other greenhouse gases (Environmental Protection Agency, 2008). Climate changes are destroying more than 80% of the corals in the world's oceans due to higher temperatures that result in bleaching impacts. Acidification due to increased CO_2 in the atmosphere affects seawater and has negative impacts on organisms, especially in higher latitudes. More impacts deriving from climate changes are for example higher sea level, species distribution changes and precipitation changes. Fisheries attribute to climate changes for example by pumping out to the atmosphere ca 130 million tons of CO_2 every year or an average of fuel consumption of 0.62 litres per every kg of landed fish (Tyedmers et al., 2005). The carbon footprints of Icelandic trawled cod are in this study calculated to be 5.12 kg CO_2 equivalence while the carbon footprint of cod fished by long liner is 1.58 kg CO_2 eq. Data found on carbon footprints of fish state that for every ton of live weight landed fish product, 1.7 tons of CO_2 equivalence are emitted (Seas at risk, 2007) (Tyedmers et al., 2005). That makes 1.7 kg CO_2 eq per every kg landed and then there has to be added yield, transportation, processing, cooling etc.

According to Guðmundsdóttir, 1 MJ of electricity coming from two different sources, 70% water power and 30% geothermal, releases 5,3 g of CO_2 equivalences (Rósa Guðmundsdóttir, 2008). 1 MJ of electricity produces 0.09 m^3 of hydrogen according to Sigfússon[10]. As said earlier in this report, a hydrogen long liner would hypothetically use ca 19.6 m^3 of hydrogen fuel per fishing tour. If the oil consumption on both the trawler and the long liner is set to zero, 73% reduction in carbon footprints for bottom trawled cod are detected, and 85% reduction of the carbon footprints for long lined cod. It can therefore be said that if the fishing vessels would be converted to hydrogen the greenhouse gases would decrease substantially.

It is though out of reach for this project to estimate the real gain of the converting of fuels for the fisheries fleet due to many uncertainties as said before like for example energy efficiency and real energy consumption during fisheries depending on various factors.

To finish up with the energy discussion it can be mentioned that the content of energy burned today by the global fisheries is 12.5 times greater than the protein energy content of the resulting catch (Seas at risk, 2007).

7.4 Marine pollution

There are many chemical substances in circulation in the world and a big part of those chemicals end up in the world's ecosystems, like in the oceans. Pollutants are therefore detected in marine organisms. Ocean pollution can also lead to eutrophication and so called algal blooms that make the environment inhabitable to many other species. Fisheries contribute to chemical pollution through several ways, such as ocean dumping of waste, chemical usage in processing plants and anti fouling paint on fishing vessels. Chemical pollution is assessed in LCA under eco toxicity and acidification/eutrophication categories.

7.5 LCA on Icelandic cod product

A Life Cycle Assessment study gives information on where to find the greatest environmental impacts within a production chain. The methodology though has several limitations that will be discussed later.

When following the life cycle of the chosen cod product through fishing, processing, transportation and final disposal of its packages, it can be seen that the fishery is the predominating factor, causing the greatest environmental impact of all phases. It can therefore be said that the "hot spots" within the production are clearly within the fishery phase and a proper attention should be given to this result despite the limitations of the software to

[10] Data from Þorsteinn Sigfússon received in an email, 22.05.2009.

calculate impacts such as seafloor effects, by catch, discards and impacts on biodiversity. All other LCA's on seafood give the same result. The oil consumption within the fishery phase for both bottom trawler and long liner is the predominating factor.

Oil consumption for bottom trawled product of Hegranes is 1.1 litre of diesel oil while the oil consumption of the long liner Kristín is 0.36 litres. This is comparable to the study made in Iceland by Eyjólfsdóttir et al in 2003 where oil consumption for a freezing trawler was 0.65 liters per 400 g of fillets. That calculates to be 1.6 liters per kg of processed codfish. The oil consumption of the trawler is comparable to oil consumption from other studies in Scandinavia where values range from 0.8 to 1.4 litres per kg. Danish data was found for oil consumption of Danish long liners and result to be from 0.12 to 0.34 litres for caught cod.

After unloading the fish from the fishing vessels it is processed inside of the processing plants. In this case the cod caught by the bottom trawl and processed at Sauðárkrókur, processing phase is the second biggest contributor to environmental impacts while for cod fished by long liner and processed at Þingeyri does not have as much impact. In fact transportation phase causes the second largest environmental impact for the long lined fished cod. The reason for the great environmental impact coming from the processing phase for the trawled cod is traced to big consumption of ammonia cooling agent inside the processing plant, but the cooling system in FISK Seafood's processing plant is extensive. Therefore the ammonia utilization can be marked as a "hot spot" within the processing phase for trawled cod. This does not configure to other LCA's made on codfish, where in all cases transportation phase comes as the second greatest impact process. Ziegler et al (2002) do though point out that the process industry and sewage do cause eutrophying emissions of considerable amount while Thrane (2005) concludes that the processing phase in most cases is irrelevant, due to good sewage treatments in Denmark.

Within the transportation phase it is interesting to see that the trucks that transport the product both in Iceland and abroad contribute more to environmental impacts then the oceanic freighter does. The "hot spots" with the transportation phase are therefore the trucks. It should be stressed that consumer transportation is not included but in many studies where included, this tend to be a "hot spot" of the transportation phase.

It can be stated with confidence that there is a substantial difference in the environmental performance between the two alternative fishing gears; cod fished by a bottom trawl and cod fished with a long line. Cod fished by bottom trawls is causing more environmental impacts than cod fished by a long line. Results from the characterization show that bottom trawled product is dominating within all impact categories and same can be said for the weighting factors. This does not come as a big surprise since the oil consumption within the fishery phase of trawled cod is over 3 times more compared to the long liner. The ammonia utilised inside the processing plant at Sauðárkrókur does also contribute significantly to the environmental performance of the product. It should though be emphasised that long liners use bait that is imported, in many cases from Asia, which is not taken into account in this study.

7.6 Limitations and potential for improvement

The high pressure that is put on fish stocks has a great ecological effect which reflects in changes in quality (species composition, size, commercial value, trophic level) of landed fish. The world‘s oceans are being completely exploited, from the poles to the tropics, from the littoral to the open sea, from surface and down to bottom, so there is no other place to go in order to employ existing excess fishing capacity (Sinclair and Valdimarsson, 2001). It is therefore in the best interest of the world community to secure a sustainable management of the world‘s fish stocks.

Even though LCA is an internationally accepted methodology to assess environmental impact from goods and services, it has its limitations.

It is a big disadvantage that it is not possible to estimate the effects the fishing gear, such as bottom trawls, have on the seafloor. Research have been conducted in order to estimate the fishing gear impact on the seafloor but there is an essential lack of methodology to carry out and make those researches uniform so that they can be applied to some extent. By catch, discards and effects on biodiversity are also problematic factors, since there are no such applications inside of the SimaPro software. Those limitations exist both because of lack of data and lack of accessibility since by-products and discards are in many cases “hidden” information.

In order to detect the response of the disturbances caused on habitats and ecosystems such as bottom fishing, correct measures have to be taken into account. Typically marine ecologists collect many but small samples of data from the bottom of the sea in order to detect responses to environmental changes. However in 2003, Kaiser pointed out that it was impossible to measure effects of fisheries on community diversity by small samples such as 0.1 m^2. He argued that it was only possible to detect those changes by collecting bigger samples which sampled more effectively the less common and more sensitive species (Kaiser, 2003).

As mentioned earlier, the LCA software often has uncertainties. When assessing chemicals, many of the chemicals needed, are not included in the software. Incorporating information for more chemicals together with their risk and hazard assessment is an essential thing in order to make the methodology more substantial and reduce uncertainties in general.

It is very important that once fish is caught and landed that it is efficiently utilised, product loss is minimised and high quality is maintained throughout the value chain. Some of the environmental burden could in that manner be lowered by decrease product losses.

In order to minimise the impacts from the fishery phase it is essential to minimise fossil fuel utilisation. This could be done either by switching to renewable energy or energy carriers such as hydrogen or to develop cleaner combustion technologies within the old fossil fuel system. In 2008, oil expenses for the Icelandic fishing fleet was 20% of the total income or 17.6 billion ISK so it is clear that oil expenses are high within Icelandic fisheries.

It is also important for fishing gear to become more environmentally friendly. Some have pointed out that bottom trawled should be banned and fish should be fished on line instead because of the great impact that they cause on the seabed and high fuel consumption. Bottom trawls are heavy and a lot of steel and fossil fuels are utilised for the production of the fishing gear. It should though be kept in mind that long liners also have environmental impacts even though they are less than for bottom trawls. For example in Iceland, the bait is usually imported which makes the carbon footprints for long lined fish bigger. This could be changed.

Cooling agents are contributing substantially to environmental impacts in this report, mainly ammonia that is utilised inside the processing plant at Sauðárkrókur. It would be a consideration to switch that cooling agent for another one more environmentally friendly but it is of course important that ozone depleting and greenhouse gas substances will not be chosen instead. It is therefore of great importance to investigate and evaluate each substance holistically to see the overall environmental burden that it causes, when choosing what to use.

The same applies for chemicals utilised inside of the processing plants. Many of those chemicals that are in use today have ingredients that can be toxic and dangerous both for humans and the ecosystem as a whole. Environmentally friendly products are more and more visible in the market today. It is possible to get products that are without dangerous chemical substances and to prove that they are specifically marked with eco labels. It is a recommendation to the seafood companies that they consider those products in regard to price and quality in order to safeguard healthier environment.

It should also be kept in mind that the truck that transports the product from Rotterdam to Sevilla is creating a substantial environmental impact. It would lower the environmental impacts if the ship would sail all the way to Spain instead of only to Rotterdam.

Finally it is to be stressed that it would be in the best interest of every company in business to have a holistic view over all its operation. In that manner all chains of the product life cycles would be supervised and it would be possible to detect the hot spots within the production. By having this overview it is possible to reduce i.e. energy consumption where it is too high, estimate if chemicals are being over utilised and perhaps if it would be possible to reduce the dosage or use more environmentally friendly substances, reduce packages and avoid too much transportation. This would both reduce waste and emissions and lower operation costs. During data gathering in this project it was noted that much information was difficult to reach, like for example within the transportation phase. This came as a surprise since it was thought that it would be important to see exactly where money is spent and on what within a company.

7.7 Further work

It is clear that there is a considerable amount of work left to do when it comes to assessing environmental impacts of fisheries. Important data is missing when it comes to assessing the effects of fishing gear on the seafloor and methods on how to implement such data into software such as SimaPro needs to be considered. The same applies to by-catch and discards which are factors that are currently not well incorporated into the methodology. Biodiversity is an impact category that would have been interesting to analyse in a study like this, but SimaPro does not cover it. Further development within the software is therefore needed together with more environmental and biological research so the LCA method will be better suited to assess environmental impacts from seafood products.

Oil consumption is the biggest contributor to the environmental impacts in this study. It would be interesting to have data from more fishing vessels in order to be able to calculate in more precise way the oil consumption, with standard deviation, normal distribution and confidence intervals to obtain more accurate data about the energy consumption within Icelandic fisheries and its environmental impacts.

It is clear as well that more research is needed within the energy sector when it comes to how to implement hydrogen into fishing vessels as an energy carrier. It would be interesting to implement and test a vessel that would run entirely on hydrogen since it is clear that the environmental impacts of fisheries would be reduced significantly if fossil fuels would be switched out for renewable energy options.

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Appendix I

Shows the inventory analysis for 1 kg of cod caught with a long liner

Fishing	Material input/output	Comments, boundary conditions and assumptions	Source of information	**Pt 0,103**
Steaming and fishing	Diesel engine	The average fuel consumption for Kristín ÞH was calculated 0.36 l per kg of cod in 2007. The yield to produce cod fillets is estimated 50%	Information from Vísir.	Pt is a reference point. For fishery phase this point is 0,103 pt
Waste from fishing vessel	Inert waste goes to landfill	Household waste from cooking etc, ca 200 kg each time	Vísir hf	
Antifouling paint Interspeed and Intertuf	Zineb pesticide	100 l of Interspeed every 2 years and 80 l of Intertuf every 2 years. End of life modelled as emission to water	Antifouling retailer	
	Copper I			
	Zinc I			
	Benzene			
	Organic chemicals			
	Mixed xylenes			
	Naphtha			
	Pentane			
	Zinc compounds			
Fishing gear	PE granulated	One long line weights ca 30 kg and there are 5 lines aboard each time containing 200.000 steel hooks	Information from Vísir hf and production fabric of long line	
	PP			
	Steel			
	Steel high alloy			
	Crude iron			
Fishing gear	Waste	Estimated that 20% of the fishing gear goes		

		ghost netting in the oceans		
Processing	Material input/output	Comments, boundary conditions and assumptions	Source of information	**Pt 0,124**
Cleansing materials, sterilisers and oil	Sodium hydroxide concentrated		All information come from Vísir hf and chemical retailers	
	Nitric acid			
	Ammonia			
	NaOH			
	Pigments			
	Diesel oil petro	3000 l pr year for fork lifters		
	Inorganic chemicals			
	Organic chemicals			
Coolants	R134a	Approximately 20 kg per year		
Energy	Heating oil petro	18000 litres pr year		
	Electricity hydro		Hydro power plant at Vestfirðir	
Packaging	Kraftliner	Each kg of processed fish is packed into 11 kg packaging. Inside each package is a plastic bag.	Information from Vísir hf and retailers for packages	
	HDPE	Plastic bag from inside the packages		
	Wood board	Each wood board contains 96 packages of 11 kg final product		
	Natural rubber	Tape ingredient		
	Organic chemicals	Tape ingredient		
	Ethene	Tape ingredient		
	Paper	Packages ticket		
	PE granulate average	Plastics to hold boxes together		
Transportation	Material input/output	Comments, boundary conditions and assumptions	Source of information	**Pt 0,0345**
	Fish is transported	Domestic transport in Iceland is 600 km	All information come from Vísir hf	

	from Þingeyri to Reykjavík Iceland	carrying 25 tons of fish, total weight of loaded truck is approximately 40 tons	and the transportation companies	
	Fish is transported with freighter from Reykjavík to Rotterdam	Transport from Reykjavík to Rotterdam is ca 2042 km		
	Fish is then transported from Rotterdam to Sevilla,Spain with truck	Transportation from Rotterdam to Sevilla each truck carries 18 tons.		
Coolants	R134a	Container contains 4,6 kg		
	R22 (R404a)	Truck contains 4,5 kg		
Waste disposal in Spain	Material input/output	Comments, boundary conditions and assumptions	Source of information	**Pt -0,00423**
	Recycling	Paper and cardboard 69% Plastics 21%	Information from Spain http://www.mma.es/secciones/calidad_contaminacion/residuos/planificacion_residuos/pdf/memoria_PNIR_26_11_2007.pdf	
	Landfill	Paper and cardboard 31% Plastics 79%		

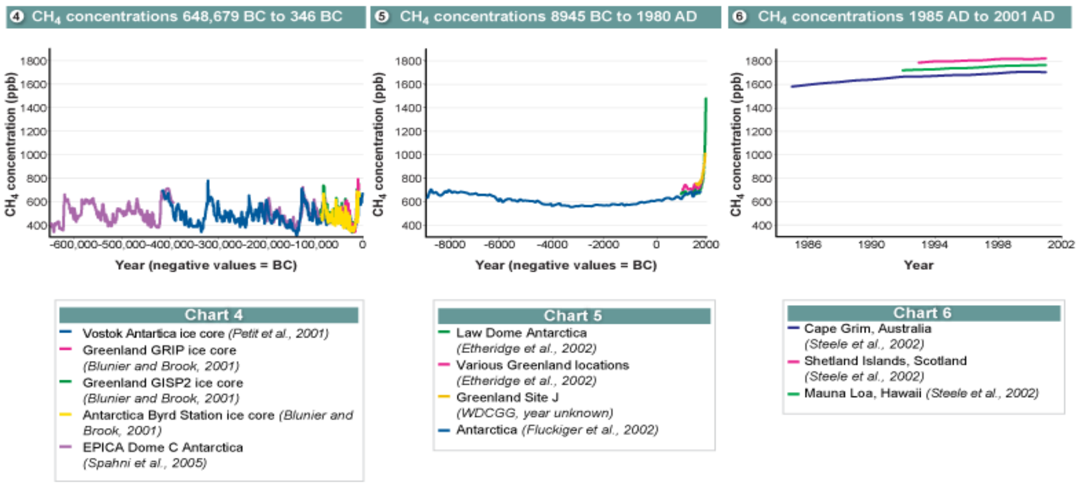
Shows the inventory analysis for 1 kg of trawled cod

Fishing	Material input/output	Comments, boundaries and assumptions	**Pt 0,295**
Steaming and fishing	Diesel engine 589 kW	1,1 l per kg of processed cod	
Waste from fishing vessel	Inorganic waste	Household waste from vessel goes to landfilling	
Antifouling paint Hempel	Ethyl benzene	Vessel is painted every 2 years with 220 l of Hempel anti fouling. Amount per functional unit is calculated with 50% yield	
	Xylene		
	Ethanol		
	Methyl ethyl ketone		
	Copper compounds		
	Inorganic chemical		
Fishing gear	PE granulated	One bottom trawl weights ca 11800 kg	
	Steel		
	Rubber		
Fishing gear	PE waste Steel waste Plastic waste	20% of the total weight	
Processing	Material input/output	Comments, boundaries and assumptions	**Pt 0,162**
Packaging		Each kg of processed fish is packed into 11 kg packaging.	
	HDPE		
	Cardboard		
	Natural rubber	Tape ingredient	
	Organic chemicals	Tape ingredient	
	Ethene	Tape ingredient	
	Paper	Ticket	
	PE granulate average	Plastics	
	Wood board		
Cleansing materials, sterilisers and oil	Sodium hydroxide concentrated		
	NaOH		
	Organic chemicals		

	Inorganic chemicals		
	Ammonia		
	R134a Cooling agent		
Transportation	Material input/output	Comments, boundary conditions and assumptions	**Pt** **0.0214**
	Fish is transported from Sauðárkrókur to Reykjavík in Iceland	Domestic transport in Iceland is 600 km carrying ca 24 tons of fish, total weight of loaded truck is approximately 40 tons	
	From Reykjavík it is transported to Rotterdam with freighter	Sea transport is 2042 km	
	From Rotterdam fish is transported with a truck to Sevilla Spain	Transportation with a truck loaded 18 tons travels 1814 km	
Cooling agents	R134a cooling agent in a car	Ca 4,5 kg utilised in each car	
	R144a in a container	Ca 4,6 kg utilised per container	
Waste disposal in Spain	Material input/output	Comments, boundaries and assumptions	**Pt** **-0,004**
	Recycling	Paper and cardboard 69% Plastics 21%	
	Landfill	Paper and cardboard 31% Plastics 79%	

APPENDIX II

Atmospheric concentrations of methane in geological and recent times (Environmental Protection Agency, 2008)



Atmospheric concentrations of nitrous oxide in geological and recent times *(Environmental Protection Agency, 2008)*