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Environmental life cycle assessments of fish food products with emphasis on the fish catch process

Thesis for the degree of philosophiae doctor

Trondheim, February 2012

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- *If I have seen far, it is by standing on the shoulders of giants.*
Sir Isaac Newton

Preamble

This doctoral thesis is an integrated part of the strategic institute program *Sustainable Vessel Technology and Fleet Structure* at SINTEF Fisheries and Aquaculture running from 2003 to 2006.

Abstract

Sustainable development embraces economics, society and nature and is the global context for this PhD-thesis. Modern fishery is dependent on fossil fuels, which use is the antithesis of sustainable fishery.

Environmental degradation is closely related to health aspects, which are increasingly important to consumers and other stakeholders. For the fish food product (FFP), the main focus of prior research has been on threatened stock populations. Less attention has been focused on environmental problems related to the use of energy and material, not only by the fishing vessel, but for the whole life cycle of the FFP. This PhD-project is a contribution to closing this gap. The overall goal of the research behind this thesis is to demonstrate a methodology for systematic environmental life cycle assessments (LCA) of FFP with an emphasis on fishery. LCA has been developed for commodity products and this work contributes to expanding the application to food products. LCA is the basis for creating an environmental product declaration (EPD) by following the product category rules (PCR).

Systems engineering principles and processes provide the tools to systematize the analysis of the life cycle of the FFP, by modelling the fish food production systems. Systems engineering with input from LCA, stakeholder analysis and eco-labelling is used to develop a methodology presented as a framework for environmental analysis of the FFP. Three studies are combined into a single case study resulting in an LCA of fish products that has been used to develop an EPD for Atlantic herring (*Clupea harengus*) based on the PCR developed for wild caught fish. Environmental performance indicators relevant for FFP have been explored and a number of parameters are recommended for use in communicating the environmental impact of a FFP. Greatest attention has been on the fishing vessels because their energy consumption accounts for the largest environmental impacts of the FFP.

The research results contribute to better transparency about the environmental impact of the life cycle of FFP and thereby support more sustainable decision-making in the fishery sector.

In the future, the framework developed for environmental life cycle assessment of FFPs, could be expanded to other food products and so be used to compare different food products against each other.

Sammendrag (Norwegian summary)

En bærekraftig utvikling omfatter økonomi, samfunn og natur og er utgangspunktet for denne doktorgradsavhandlingen. Dagens fiskerier er avhenging av fossile energikilder, noe som skaper vansker for en bærekraftig utvikling.

Miljøproblemer er nært beslektet med helseproblemer, som blir viktigere og viktigere for forbrukere og andre interessenter. Hovedfokuset innenfor forskning på fisk har vært på hvordan overfiske kan unngås. Andre miljøproblemer, slik som klimaendringer, forurensning av vann og luft som et resultat av energi- og materialbruk har vært lavere prioritert. Dette gjelder ikke bare for fiskebåten, men hele livsløpet til fiskematproduktet, fra bunn til bord. Dette doktorgradsprosjektet er et bidrag til å rette opp denne skjevheten. Hovedmålet med forskningen bak denne doktorgradsavhandlingen er å demonstrere en metodikk for systematiske livsløpsanalyser (LCA) av fiskematprodukter, med hovedvekt på fisket.

Prinsipper og prosesser fra systemteknikk kan benyttes i analyser av miljøproblemer. Denne forskningen er den første til å benytte seg av systemteknikk for å analysere miljøproblemer i tilknytning til fiskematproduktet. Livsløpstenkning er en helhetlig tilnærming og gjør at forskyvning av miljøproblemer fra en fase til en annen i livsløpet blir synlig. LCA har blitt utviklet for vareproduserende industri. Denne forskningen er et bidrag til å anvende LCA også for matproduksjon, med større komplekse systemer som verdikjeder for fisk der fiskebåten og fangstmetodikk utgjør en vesentlig del av miljøprestasjonene. LCA danner grunnlaget for å utarbeide miljødeklarasjoner, kalt EPD, hvis retningslinjer er fastsatt i produktkategorireglene, såkalte PCR.

Systemteknikk i kombinasjon med LCA, interessentanalyse og EPD blir brukt til å utvikle et rammeverk for miljøanalyser av fiskeproduktets livsløp. Et sett av forskjellige studier, sammensatt til et case-studie, har resultert i en LCA av fiskeprodukter som har blitt brukt til å utvikle en EPD for sild (*Clupea harengus*) basert på PCRen utviklet for villfanget fisk. Miljøprestasjonsindikatorer relevante for fiskematprodukter er blitt undersøkt og et utvalg har blitt foreslått for bruk i kommunikasjon av miljøpåvirkning fra fiskematprodukter. Størst fokus har vært på fiskebåten, da særlig dennes energiforbruk bidrar til den største miljøpåvirkningen.

Forskningsresultatene bidrar til økt transparens hva gjelder miljøbelastningen fra fiskeprodukter og er dermed et bidrag til å drive utviklingen i fiskerisektoren i en bærekraftig retning. Videre utvikling kan være å utvide rammeverket for fiskematprodukter til også å omfatte flere matprodukter, slik at disse kan sammenlignes.

Zusammenfassung (German summary)

Nachhaltige Entwicklung beinhaltet Ökonomie, Gesellschaft und Natur und ist der Ausgangspunkt dieser Dissertation. Moderne Fischerei ist von fossilen Energiequellen abhängig, was Schwierigkeiten für eine nachhaltige Entwicklung bereitet.

Umweltprobleme sind stark mit gesundheitlichen Problemen verbunden, welche immer größere Bedeutung für Verbraucher und andere Betroffene annehmen. Schwerpunkt der Fischereiforschung war bislang die Überfischung der Fischressourcen. Anderen Umweltproblemen, wie Klimaänderung, Verunreinigung von Luft, Boden und Wasser, resultierend aus Energie- und Materialverbrauch wurde bisher weniger Beachtung geschenkt. Das gilt nicht nur für den Produktzyklus des Fischfangschiffs, sondern auch für den ganzen Lebenszyklus des Fischereierzeugnisses, vom Meeresboden auf den Tisch. Diese Dissertation leistet einen Beitrag zum Ausgleich dieses Ungleichgewichts. Das Hauptziel dieser Forschung ist die Demonstration einer Methodik zur systematischen Ökobilanzierung von Fischereierzeugnissen, wobei der Schwerpunkt auf dem Fischfangprozess liegt.

Prinzipien und Prozesse des Systems Engineering kommen in Analysen von Umweltproblemen zur Anwendung. Diese Forschung ist die erste, die das Systems Engineering verwendet, um Umweltprobleme in Verbindung mit Fischereierzeugnissen zu analysieren. Ökobilanzen sind ein ganzheitlicher Ansatz, um Problemverlagerung zwischen den Lebenszyklusphasen eines Produktes zu erkennen und zu vermeiden. Ökobilanzen wurden ursprünglich für Verbrauchsgüter entwickelt. Diese Forschung leistet einen Beitrag, diesen Ansatz auch auf Lebensmittel mit großen komplexen Systemen wie die Wertkette für Fisch, wo das Fischereischiff und verschiedene Fangtechniken einen wesentlichen Teil der Umweltleistung ausmachen, zu übertragen. Ökobilanzen bilden die Grundlage, um Umweltdeklarationen, deren Regeln und Anforderungen in den Produktkategorieregeln festgelegt sind, zu entwickeln.

Systems Engineering in Kombination mit der Ökobilanzmethode, Interessentenanalyse und Umweltdeklarationen wird verwendet, um einen Rahmen für Umweltanalysen der Lebenszyklen von Fischereierzeugnissen zu entwickeln.

Resultate einer Kombination unterschiedlicher Studien, zusammengesetzt zu einer Fallstudie, werden benutzt um;

- Umweltdeklarationen für Hering (*Clupea harengus*) basierend auf den für wild gefangenen Fisch entwickelten Produktkategorieregeln zu demonstrieren,
- Umweltleistungsindikatoren mit Relevanz für das Fischereierzeugnis zu untersuchen, und
- eine Auswahl davon zur Bekanntgabe von Umwelteinwirkung durch Fischereierzeugnisse zu empfehlen.

Der Schwerpunkt lag dabei auf dem Fischfangschiff, weil dessen Energieverbrauch die größte Umwelteinwirkung ausmacht.

Die Forschungsresultate tragen zur einen höheren Transparenz der Umweltbelastung durch Fischereierzeugnisse bei und führen so die Entwicklung innerhalb der Fischerei in eine nachhaltige Richtung.

Künftig könnte die in dieser Dissertation entwickelte Methode zur Untersuchung von Fischereierzeugnissen auf weitere Lebensmittel ausgedehnt werden, so dass ein Vergleich unterschiedlicher Lebensmittel möglich wird.

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The research described in this thesis has mainly been carried out at SINTEF Fisheries and aquaculture and the Department of Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU). The work is funded by the Research Council of Norway through the strategic institute program "Sustainable Vessel Technology and Fleet Structure" at SINTEF Fisheries and aquaculture.

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Family, especially Andrea, Selma and Alva who had to bear yet another day with an absent Erwin. Now there is more time to spend together, finally!

Contents

List of appendices

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List of publications

This thesis is based on the work contained in the following Papers I-V, referred to by Roman numerals in the text.

I	Fet, Annik Magerholm; Schau, Erwin A. Meissner and Haskins, Cecilia. “A framework for environmental analyses of fish food production systems based on Systems Engineering principles”. Systems Engineering 2010;13(2):109-118
II	Schau, Erwin Meissner and Fet, Annik Magerholm (2008). "LCA Studies of Food Products as Background for Environmental Product Declarations." International Journal of Life Cycle Assessment 13(3): 255 - 265.
III	Schau, Erwin M.; Fet, Annik Magerholm and Ellingsen, Harald "Environmental impact categories for fish food products based upon life cycle assessments in the food sector." Paper in progress.
IV	Schau, Erwin M.; Ellingsen, Harald; Endal, Anders and Aanondsen, Svein Aa. (2009). "Energy consumption in the Norwegian fisheries." Journal of Cleaner Production 17(3): 325-334.
V	Schau, Erwin M. (2008)."Environmental analysis of Norwegian fish food products." In: Thorvaldsen, Trine and Ellingsen, Harald (Eds.), Modernization of Fisheries Technology to Cope with Challenges and Profitability - Proceedings - Nor-Fishing Technology Conference 2006 - Trondheim, Norway 7-8 August. Trondheim, SINTEF Fisheries and aquaculture. (vol. 1) pp. 34-41.

There are three authors of Paper I, Fet and Schau jointly developed the framework described, and jointly wrote the initial paper. Schau performed the case study reported. Haskins provided editorial and other refinements to the paper.

There are two authors of Paper II, Schau performed the review reported. Schau and Fet jointly wrote the paper.

There are three authors of Paper III, Schau performed the study reported. Schau, Fet and Ellingsen jointly wrote the paper.

There are four authors of Paper IV. Schau performed the data collection from year 2000 and onward. Schau, Ellingsen, Endal and Aanondsen jointly performed the study reported. Schau, Ellingsen and Aanondsen jointly wrote the paper. Schau wrote the revised version.

Abbreviations

AP	acidification potential
CFP	carbon footprint of a product
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DALY	disability-adjusted life year
DCB	Dichlorobenzene
DDT	Dichlorodiphenyltrichloroethane
EP	eutrophication potential
EPD	environmental product declaration
EPI	environmental performance indicator
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FFP	fish food product
FFPS	fish food production system
FoS	Friend of the Sea
FU	functional unit
GDP	gross domestic product
GHG	greenhouse gas
GT	gross tonnage
GWP	global warming potential
ICES	International Council for the Exploration of the Seas
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
INCOSE	International Council on Systems Engineering
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IUU	illegal, unreported and unregulated (fishing)
LCA	life cycle assessment
LCI	life cycle inventory
LOHAS	lifestyle of health and sustainability
MAETP	marine aquatic eco-toxicity potential
MSC	Marine Stewardship Council
NGO	non-governmental organisation
NIMBUS	Nordic Project for Implementation of EPD Type III in the Business Sector
ODP	ozone layer depletion potential
OECD	Organisation for Economic Co-operation and Development
PCR	product category rules
POCP	photochemical ozone creation potential
QCFU	quality corrected functional unit
RAD	radioactive radiation
SE	Systems Engineering
TETP	terrestrial eco-toxicity potential
TBT	Tributyltin
UN	United Nations
VOC	volatile organic compounds
WBCSD	World Business Council for Sustainable Development
WWF	World Wide Fund For Nature

1 Introduction

Fish provides food and income for millions of people (FAO Fisheries Department, 2007); a resource fishers harvest without needing to sow. Fishing is a form of gathering from nature and can be compared to hunting, and as such is known since the earliest days of mankind (von Brandt, Borgstrom et al., 2009).

Fisheries are important for Norway with its 22 000 km coast line and one of the most productive marine areas in the world. Norway is the second largest export nation (after China) of fish and fishery product (FAO Fisheries Department, 2010), exporting to more than 150 countries worldwide (Fiskeri- og kystdepartementet, 2006). The fishing industry plays an important role in the Norwegian economy (Directorate of Fisheries, 2009) and in particular in rural districts along the coast (Almås, 1999; Rolstadås, 2006).

1.1 The global context

Sustainability is on the international agenda. Sustainability encompasses social, economic and environmental aspects and has its roots in the environmental and development communities (Levy, Hipel et al., 1998).

Environmental problems first reached the public consciousness in the 1960s through the book "Silent Spring" by Rachel Carson (1962). The title predicted that the continued use of pesticides, in particular dichlorodiphenyltrichloroethane (DDT), would lead to a silent nature without any birds. The main message is that humans are a part of nature, and also are threatened by pollution.

The Club of Rome and "Limits to Growth" (Meadows, Meadows et al., 1972) focused attention on the fact that resource consumption lead by industrial nations did not respect the constraints of the natural environment. In the same year, the first United Nations (UN) Conference on Human Environment in Stockholm (United Nations, 1972) marked the beginning of a global awareness of the pollution problem by world leaders and policy makers (Shah, 2008).

Sustainability as a concept was first introduced in the 1970s (Levy, Hipel et al., 1998) but did not reach the broader audience and the political agenda before the Brundtland commission published its report in 1987 (World Commission on Environment and Development, 1987) that stated that a sustainable growth needed development in three areas; the environment, the economic and the social aspects. One of the outcomes of the subsequent Rio Summit in 1992 was a recognition of the local aspects of sustainability; "Thinking global, acting local" (UNCED, 1992; Hens, 2005).

The Montreal Protocol (Ozone Secretariat UNEP, 2000) to reduce atmospheric ozone-depleting gases was a successful supra-national protocol to combat one of the largest threats to nature and humans (Andersen, Sarma et al., 2002).

The need for sustainable development is rooted in the foundation of the three pillars, where economical aspects have been in the forefront in a market driven economy, and social and environmental aspects have been less significant. One of the reason for this bias, was "the physical dimensions of (industrial) economic reality that are so completely hidden from conventional monetary analysis" (Rees, 1999:p. 25). Environmental aspects have to be taken into consideration as human activity, driven by technological advances, increasingly intervenes with nature (Wennersten, 2008).

Industry began to recognise their responsibility and an opportunity to fulfil their goals by embracing sustainability and by taking a role in the discussions between non-governmental organisations (NGO) and politicians. The original Business Council for Sustainable Development, later renamed the World Business Council for Sustainable Development (WBCSD), was founded in the beginning of the 1990s, and is a coalition of about 200 international companies that are involved in defining sustainable pathways for industry (Timberlake, 2006; WBCSD, 2011). WBCSD was one of the leading parties in introducing the term eco-efficiency, which in short means creating more value with less environmental impact (Jensen and Remmen, 2004).

One of the more difficult problems to handle is man-made climate change. Concrete global action was first proposed in the Kyoto-protocol (United Nations, 1998), where the world industrial nations agreed on concrete figures of how much to reduce emissions of greenhouse gases (GHG). The Intergovernmental Panel on Climate Change (IPCC) launched several reports (Houghton, Jenkins et al., 1990; Houghton, Callander et al., 1992; Houghton, Meira Filho et al., 1995; Houghton, Ding et al., 2001) that not only showed that global warming is already taking place, but also showed that the consequences of human activity will continue for centuries. With the 2007 report (Solomon, Qin et al., 2007), both scientists and policymakers set the global warming problem high on the agenda after the trend of increasing GHG was not abated by the Kyoto protocol, scheduled to end in 2012. In spite of this report, it was not possible to establish a binding follow-up to the Kyoto-protocol during the UN Climate Change Conference in Copenhagen in December 2009 (UNFCCC, 2009).

Health issues and crises in the poultry and meat industry in developed countries lead to increased demand for seafood products. In developing countries, population growth is the main driver for increased seafood demand (FAO Fisheries Department, 2004). At the same time, a market segment or demographic movement called the Lifestyle of Health and Sustainability (LOHAS) are demanding sustainable products such as organic food (Hentschel, 2007; Hilary, 2007; Maurie, 2007; Ernst & Young, 2008; Giger, 2008; Kreeb, Motzer et al., 2008). LOHAS followers are willing to pay more for organic and fair trade food products (Ernst & Young, 2008). A diary survey described by Jungbluth (2000), shows that Swiss environmental conscious consumers spend more money on fish than the average consumer. They also pay more per kg of fish than other consumers (Jungbluth, 2000). This attention to healthy and sustainable food products also encompasses seafood products (O'Sullivan, 2005; Verbeke, Vanhonacker et al., 2007; Vermeir and Verbeke, 2008). Their interest includes not only the health benefits of eating fish, but also how this food is produced and brought to the customer and how this can be documented and verified. Environmental documentation and certification of the fish food product (FFP) are seen as central challenges for the Norwegian fish industry, especially for the fish catching industry, in the years to come.

In this thesis fishery describes the organised commercial activity of harvesting fish and other aquatic species. Modern open seas fisheries are dependent on energy-demanding technologies, which in the present form contribute to climate change. Global warming impacts the modern seas fisheries, as fish stocks migrate to other waters (Warren, 2004; Loeng and Furevik, 2005; Lorentzen and Hannesson, 2005; Sullivan, 2006). These migrations also pose a special threat to fishers in other parts of the world, many of them poor and dependent on fisheries to survive (Allison, Adger et al., 2004).

In the issue of the environmental sustainability of fisheries, the problem of overfishing has dominated the debate until recently (Pauly, Christensen et al., 2002; Jacquet and Pauly, 2007; Parkes, Walmsley et al., 2009; Wikipedia, 2011). However, fishery activities have impacts on the environment beyond the stocks that are their immediate target (Degnbol, Carlberg et al., 2003).

1.2 Background

The impact on the environment from the fishing sector has been focused mainly on decreasing stock sizes. Overcapacity in the fishing fleet leading to non-sustainable exploitation of fish resources has been on the global agenda during the past two centuries and taken into consideration by policy makers, consumers and other interested parties (FAO Fisheries Department, 2007). This topic is well covered in the literature (e.g. (Myers and Worm, 2003; Pauly, Alder et al., 2003; Worm, Hilborn et al., 2009; Kurlansky, 1998)). Other environmental impacts have not been that much in focus (Pelletier and Tyedmers, 2008). Lillsunde (2001) shows in a case with the Finnish fishing industry, that the industry not only underestimates the impact of fishing on the marine environment but also on the overall environment.

This research casts the spotlight on vessels and technology. The program "Sustainable Vessel Technology and Fleet Structure" (Ellingsen, 2003) was launched by SINTEF Fisheries and aquaculture in 2003 with the main challenges to develop technologies and methodologies "... which ensure that the impact on the environment from the fishing sector is not only measurable and documentable, but which also makes a contribution towards fulfilling the objective of a sustainable fishing industry. This applies to national as well as international fishing activities." (sic, Ellingsen, 2003:p. 4).

The SINTEF program is comprised of 4 individual projects:

1) the fishing vessel environmental database,
2) life cycle assessment (LCA),
3) fleet analysis, and
4) sustainable vessel concept.

This thesis mainly contributes to project 2) life cycle assessment (LCA). The objective stated for this project is to "contribute to improved tools and a reference data platform that can be used in environmental lifetime assessments of fishing vessels" (Ellingsen, 2003:p. 16)

1.3 Research goal and questions

The SINTEF program (Ellingsen, 2003) and the challenges identified therein set the initial scope of this research, and the research results are contributions to this program. The overall goal of the research behind this thesis is to:

Develop and demonstrate a methodology for systematic assessment of the environmental impact for the entire lifecycle of fish food products (FFPs) based on a life cycle assessment approach with emphasis on the fishing phase.

This will be reached by the sub-goals:

1. Define a model for a system description of the fish food production system (FFPS) that supports environmental analysis.

2. Establish a set of impact categories and environmental performance indicators for FFPs based on LCA.
3. Develop a database with energy use data for Norwegian fishing vessels suitable for calculation of the carbon footprint of different FFPs.
4. Recommend a model for the communication of the environmental performance of FFPs to stakeholders.

For each of the four sub-goals there are research questions as presented in the following sub-clauses.

1.3.1 Model and analysis of FFPS

The fish industry is part of the global trade system, interchanging materials and products between actors, as well as interchanges with the economic system and nature. Industry tends to set the system boundaries close to its own production system where they have direct influence, to reduce the effort needed for the analysis. However, the system under study should not be so closed that important aspects are left out. This suggests the following questions:

a) How can a system for fish food production be modelled?

b) How can the environmental impacts of a FFPS be analysed in a systematic way?

1.3.2 Impact categories and indicators for FFPs

The supply of FFP to consumers is not without environmental impacts. Tools have been developed to analyse these impacts. The SINTEF Fisheries and Aquaculture research program has put an emphasis on LCA as one of the environmental management tools, and this research focuses on LCA, leading to the following questions:

a) Are the environmental impact categories normally used in LCA applicable for environmental impact assessment of FFPs?

b) What are the most appropriate environmental performance indicators for communicating environmental performance of the FFP?

1.3.3 Database of energy use data for Norwegian fishing vessels

Fuel consumption by the fishing vessel is to account for a significant environmental impact of the FFP. Up to now, statistical data of fuel used by Norwegian fishing vessels have been difficult to obtain. Norwegian fishing vessels target many different fish species and use different fishing gears. It is therefore not straightforward to calculate the fuel use per FFP. Two research questions are therefore:

a) How much fuel is used by Norwegian fishing vessels?

b) Does the fuel use vary between different fish species caught and different fishing gears applied?

1.3.4 Communication of the environmental performance of FFPs

Consumers and other buyers of seafood have increasingly demanded information about the environmental impact of sea food products so they can decide whether to purchase a product or not, and to choose between different products. Public procurement legislation in Norway requires that environmental aspects of the products are included in the decision process (FAD, 1999). The last research questions are therefore:

a) How can the environmental impact of FFPs be documented for the customers?

b) What are the communication needs for business-to-business or business-to-consumer communication?

1.4 Research methodology and outcome

The research goals and the questions are addressed by the research methodology illustrated in Figure 1.1. Systems Engineering (SE) constitutes the backbone of the methodology, which is expressed by steps 1-6 (Fet, 1997) in the centre of the figure.

The left column of the diagram illustrates the research questions and the appropriate methods and tools applied at each step of the process. On the right are the publications and outcomes produced in the subsequent papers and product category rules (PCR).

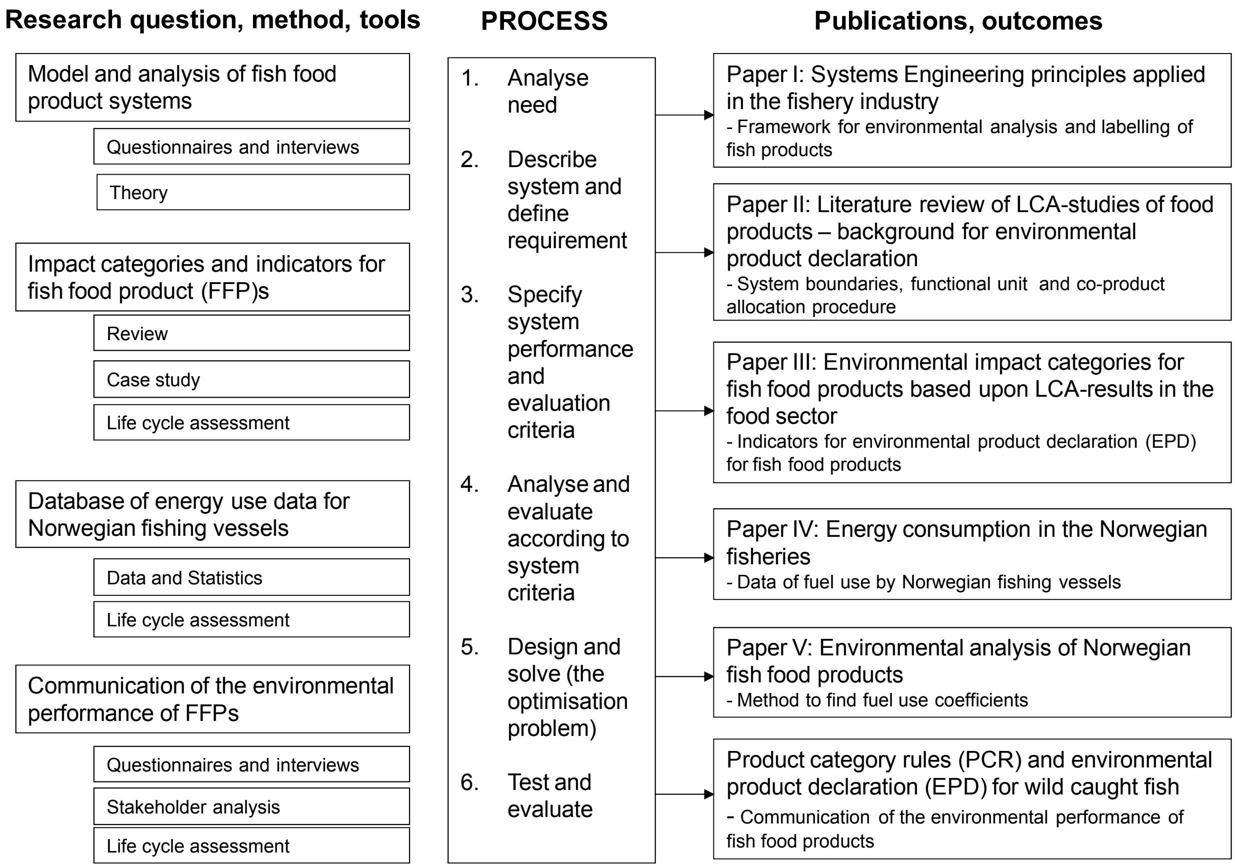


Figure 1.1: Research structure

The first two steps in this research method are used to model the system description and Figure 1.1 shows that Paper I provides the answer to sub-goal 1 and the related research questions. Further, Figure 1.1 shows that a literature review and an environmental impact assessment based upon LCA are used to achieve insight and knowledge about the performance of the system and thereby contribute to sub-goal 2. Steps 3 and 4 use LCA to analyze and evaluate the system according to international standards. Figure 1.1 illustrates further that the two last steps in the SE-methodology are used to answer sub-goal 3. Paper IV and Paper V present data and valuable information for answering the associated research questions.

1.5 Structure of the thesis

Following Section 1.1 and Section 1.2 where the background and the goals of the research are described, the theoretical and methodological context for this thesis is presented in Chapters 2 and 3, respectively. Section 2.1 briefly presents the concept of sustainable development followed by Section 2.2, which introduces the tragedy of the commons, while Section 2.3 presents the concept of life cycle thinking.

Chapter 3 presents the main methodologies applied in this research. Sections 3.1, 3.2 and 3.3 give a brief overview of the characteristics of literature review, case-study research and statistical analysis. SE is used as the methodological framework. A general overview of the SE methodology and its application in this research is given in Section 3.4.2. The LCA methodology, according to the International Organisation for Standardisation´s (ISO) 14040-series (ISO 14040, 2006; ISO 14044, 2006), is another essential tool in this research. LCA is presented in Section 3.5, organised according to the four phases of an LCA (ISO 14040, 2006); the goal and scope definition, the inventory phase, the impact assessment phase and the interpretation phase. Application of LCA is presented in Section 3.5.5. Stakeholder analysis and communication are presented in Section 3.6. How environmental information can be communicated by use of environmental labelling are presented in Section 3.7. Results from a small informal e-mail survey regarding target stakeholder groups of eco-labels for FFPs are found in Appendix H.

Chapter 4 gives an overview of the life cycle of the FFPs and associated environmental impacts of fishery (Section 4.1). The case study is briefly presented in Section 4.2. In Appendix G, an overview of the Norwegian fish management system is given.

Chapter 5 summarises the results of the research. The five research Papers I-V (presented in Appendices A-E) form the main work of this research. Sections 5.1 – 5.3 give a summary of the Papers I-III. Section 5.4 presents the results in the Papers IV and V. Section 5.5 describes the PCR and explains the environmental product declaration (EPD) found in Appendix F.

Chapter 6 discusses the results and major contributions from this research.

Conclusions are drawn and further research challenges are described in Chapter 7.

2 Theoretical foundations

2.1 The concept of sustainable development

There have been several attempts to define what sustainability is. Most are based on the definition of sustainable development offered by the Brundtland Commission; "*a development that meets the needs of the present without compromising the ability for future generations to meet their needs*" (World Commission on Environment and Development, 1987:p. 8). To reach or maintain sustainability, it is necessary to bring three aspects into harmony; environment, society and economy as depicted in Figure 2.1. None of these three components should dominate nor be below a minimum level (Costanza and Daly, 1992; Hediger, 2000). This indicates that the balance (if disturbed) has to be recovered within reasonable time such that the co-existence of the three factors is preserved.

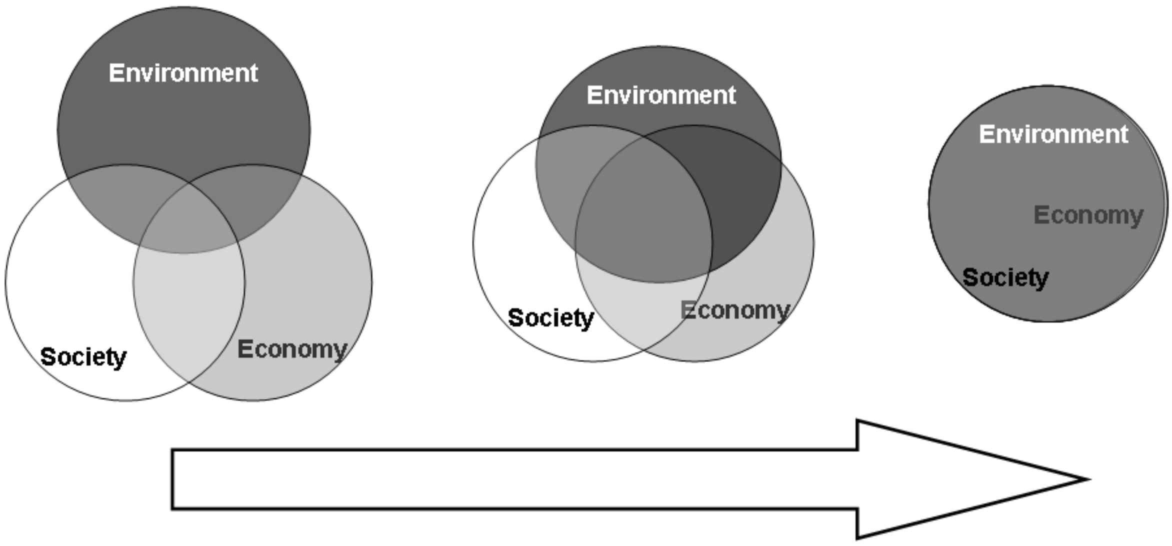


Figure 2.1: Sustainable development implies bringing the environment, society and economy into one sphere of interest [inspired by (Lozano, 2008)]

One aspect of sustainable development is the cumulative impact on the planet of the small individual contribution of each person. To separate between the different factors creating an impact on the environment, Ehrlich introduced in 1968 what later has been known as the Ehrlich equation:

$$I = P \times A \times T \qquad (1)$$

where I is the aggregated environmental impact, P is the population, A is the consumption per capita (affluence) and T is a technology factor (Ehrlich, 1968). This is sometimes called the ‘master equation’ (Graedel and Allenby, 1995; Ehrenfeld, 2000) when taking the gross domestic product (GDP) into account and setting *A* as GDP/person and *T* as environmental impact/unit of GDP (Graedel and Allenby, 1995).

2.2 The tragedy of the commons

The tragedy of the commons is a theory formalised by Hardin (1968), that can be used to explain why some non-sustainable use of resources and pollution occurs, even though we know that this is threatening our life-sustaining services (Batterham, 2003). Using fish resources, the argument goes like this: Open-access fisheries are a common resource. As nobody has property rights for the fish in the open ocean, there is little to gain for one fisher to try to conserve the stock by refraining from fishing, because the fish left in the water would be taken by someone else, who would have all the near-term benefit of that fish. The lack of property rights in connection to “freedom of the seas” and the misconception of unlimited marine resources leads to depletion of fish stocks (Hardin, 1968). The tragedy of the commons theory applies to a range of environmental problems, not only overfishing.

There is no technical solution to the tragedy of the commons, i.e. it is not enough to change only the techniques of natural science. Rather, the tragedy can only be overcome by a change or development in human values or morality (Hardin, 1968). The approach for avoiding the tragedy of the common requires a form of restriction on the use of the common resource combined with punishment when this restriction is exceeded. Where it is technically possible, the introduction of property rights is a much advocated (but not perfect) way to handle the tragedy of the commons (Helm, 2005). Another approach to avoid the tragedy of the commons is access control (Ellerbrock, Bayer et al., 2008), as Kaneko et al. illustrate with a pooling fishery system (Kaneko, Yamakawa et al., 2009).

Fisheries have been and still are subsidised (FAO Fisheries Department, 2009), which has implications not only on the economic aspects of sustainability, but also the ecological and social aspects. Subsidies stimulate overfishing (Pauly, Christensen et al., 2002; Schrank, 2003). The economic externalities have a temporal and spatial impact, i.e. future generations may experience the largest costs of shrinking fish resources. Externalities is an important concept in the economic literature where it refers to "situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided" (OECD, 2009).

2.3 Life cycle thinking and life cycle approach

As it becomes evident that the issues related to sustainable development are not bounded by individual actors, a more holistic approach is needed when studying these challenges. Life cycle thinking is one such approach, and is highly suitable for products, which are the focus of this thesis. Life cycle thinking means that organisations or individuals not only take into account their direct sphere of influence, but also expand their responsibility and considerations to the whole life cycle of their products. "*Thus, the life cycle approach implies a kind of 'social planner's view' on environmental issues, rather than the minimization of a company's direct environmental liabilities*" (Heiskanen, 2002:p. 428).

The Commission of the European Union has developed the EU Integrated Product Policy, which builds on life cycle thinking;

> *"… it considers a product's life-cycle and aims for a reduction of its cumulative environmental impacts - from the "cradle to the grave". In so doing it also aims to prevent individual parts of the life-cycle from being addressed in a way that just results in the environmental burden being shifted to another part. […] It encourages measures to reduce environmental impacts at the point in the life-cycle where they are likely to be most effective in reducing environmental impact and saving costs for business and society."* (European Commission, 2003:p. 5)

Life cycle thinking is a holistic approach and one of the main concepts supporting LCA. The positive effect of such thinking is that shifting of (environmental) burden becomes visible. This is important because the organisations or individuals that have the power to carry through changes may not be the one with the largest environmental impact in the life cycle of a product. For example,

> *"… the raw material acquisition, transportation, use and disposal of products do also cause several environmental impacts. The understanding of environmental problems, their cause and possible solutions is primarily linked to the activities in the product life cycle – from cradle to grave*." (Remmen and Thrane, 2004:p. 41)

For food products the retailers and consumers may have the largest power in the life cycle (Cotterill, 1997; Udo de Haes and de Snoo, 1997; Niva and Timonen, 2001; Belz and Pobisch, 2004), but the largest environmental impacts are initiated further back in the supply chain (Ziegler, Nilsson et al., 2003; Yakovleva, 2007b; Schau and Fet, 2008).

2.4 Systems thinking and systems engineering

Systems thinking is also a holistic approach to uncover the many perspectives of a problématique. Systems thinking uncovers the myriad interactions that lead to complexity. Boardman and Sauser (2008) describe two inherent tensions that underlie all complex systems. One is "the tension between short- and long-term goals and their accompanying actions" (Boardman and Sauser, 2008:p. 80) which they call temporal tension and is illustrated by the systems archetype of shifting the burden. The other is "between individual good and collective good" (Ibid) as captured by the tragedy of the commons and which they call contextual tension. Use of appropriate methodologies, such as systems engineering (SE), can help leverage these tensions, thereby contributing to a rational analysis of the situation.

SE is an appropriate approach when there is a need for a systematic and comprehensive analytical methodology, and especially for the analysis of complex systems. SE is, as defined by the International Council on Systems Engineering (INCOSE), "an interdisciplinary approach and means to enable the realization of successful systems" (Haskins, 2007b:p. 1.5). SE can be viewed both as a discipline and a process (Fet, 1997), and as applied system research (Olsson and Sjöstedt, 2004). In practice, SE is a comprehensive management tool for bringing large systems into being because it provides a systematic approach for understanding the complexity of a system, and a systemic, holistic and life cycle perspective. A simplified SE process has been tailored for use in this PhD-work.

SE has been used in previous studies of relevance for this PhD-work; e.g. for analysing environmental problems in the ship industry (Fet, 1997), to solve the conflicts between trade and environment (Hipel and Obeidi, 2005), to assist decision-makers in the waste management planning (Ljunggren Söderman, 2000; Eriksson, Olofsson et al., 2003; Ljunggren Söderman, 2003), in designing a plant environment for green productions (Gabbar, 2007) and to optimise the production systems for another important Norwegian export product, gas (Nørstebø, 2008). SE has been applied to the analysis of supply chains (Hassan, 2006; Haskins, 2007a) and to the fleet level of the Norwegian fish industry (Utne, 2006; 2007).

3 Research methods and tools

Figure 1.1 shows that SE was used as the backbone for the research. However, this research combines the use of multiple methods. The data and insight in the research problems were gained through literature review and case-studies, while the data and the systems under study were analysed by means of standardised methodologies. Several approaches and management tools were applicable for this research, but only a few were used. The selection of methods balanced appropriateness with international recognition and acceptance of the method by both the industry and consumers and the needs of the stakeholders throughout the life cycle. This chapter presents SE, LCA, and stakeholder analysis as the most significant methods. EPD is introduced as a tool for the communication of the environmental performance of a FFP. The combination of the methods and the application to the complex system represented by fishery, are part of the outcomes of this research.

3.1 Literature review

"Literature reviews are systematic syntheses of previous work around a particular topic" (Card, 2010:p. 725) and are an essential part of science because: "In practice we all start our own research from the work of our predecessors, that is, we hardly ever start from scratch" (Schumpeter, 1954:p. 38).

Hart (1998) provides details of the method and defines a literature review as:

> *"The selection of available documents (both published and unpublished) on the topic, which contain information, ideas, data and evidence written from a particular standpoint to fulfil certain aims or express certain views on the nature of the topic and how it is to be investigated, and the effective evaluation of these documents in relation to the research being proposed." (Hart, 1998:p. 13)*

Literature reviews can be placed in two main categories (Molka-Danielsen, 2008); the thorough literature review, which is as broad and as comprehensive as possible (Boote and Beile, 2005), and the narrower research literature review, which filters only literature with the possibility for answering a specific research question with the focus on relevance rather than on comprehensiveness (Maxwell, 2006). These two distinct but related categories also have different purposes. The former serves to inform the researcher and is valuable in a learning process; the latter is more suitable for publishing scientific papers, and can be viewed as a genre in the scientific literature. It is common in the scientific literature that a literature review is placed in the introduction of research papers (Card, 2010).

The process of conducting a literature review can be described in three steps (Levy and Ellis, 2006):

1. Input – search for quality literature to include in the literature review
2. Processing – knowing, comprehend, apply, analyse, synthesise and evaluate the literature
3. Outputs – write for the audience

Finding relevant studies is necessary for any literature review. Sources are dependent on the discipline. While scientific peer reviewed journals are a good starting point, grey literature, such as conference proceedings, reports, theses and unpublished studies (e.g. from colleagues) are also valuable sources. The iterative process of identifying relevant papers in a citation index is called snowballing (Glasziou, 2001). When deciding which studies to include in the review, a concept like the sampling of a population is useful (Card, 2010).

Literature reviews can use qualitative (narrative) or quantitative (meta-analyses) synthesis. There is a continuum between the pure qualitative and quantitative methods that includes intermediate approaches, such as vote counting methods (Card, 2010).

The literature review should be written with the target audience in mind. They can be divided into three categories; 1) the scholars themselves (e.g. in a thesis) (Boote and Beile, 2005; Boyne, 2009), 2) other researchers in the same discipline, and 3) educated lay persons and researchers from other disciplines (Green, Johnson et al., 2006; Card, 2010).

In this research, literature review has been used to collect background information to gain insight into Norwegian fisheries. The review targets all the audience categories mentioned above, i.e. own research, other LCA-experts and researchers from fisheries science, and is presented as part of Paper II.

3.2 Case studies

A case study is “a type of research that focuses on the intensive analysis of a particular place, group, or specific issue that is most often conducted using a mixed methods approach.” (Hardwick, 2009:p. 441). Such a study is particularly useful when the research question is of type how and why (Doorman, 1990; Yin, 2009) and offers a versatile approach to research (Putney, 2010). The object of a case study in its original form was the focus on one organisation or individual (Aaltio and Heilmann, 2009). Philanto (1994) stresses the subjectivist nature of the case study method where only a single entity is investigated within a limited time interval and therefore generalisation is difficult (Pihlanto, 1994).

Aaltio and Heilmann (2009) divide the process of conducting a case study into four phases:

1) Selecting the case study objects
2) Ensuring entrance to the case site
3) Outlining the theoretical frame as a foundation of the study
4) Data gathering, processing and analyses.

While the objects of the case study are decided from the research questions and problems, ensuring entrance to the case site requires support from the organisation where the case study is conducted. A good relationship and a written document between the researcher and the organization, especially the management and a contact person are recommended. The theoretical framework is as important for a case study as for any other research method. The framework helps the researcher to control the various data emerging from the case study. Case studies are conducted within a predefined time frame. However, the researcher needs to be prepared for changes and have an open-mind, as a case study often is characterised by surprises. The data gathering should be done in a systematic way that allows inclusion of ad-hoc data as these can bring in new ideas or throw new light on the researcher’s questions. The way the data are processed and analysed depends on the type of data gathered. A case study often results in both qualitative and quantitative data. The data gathering, processing and analyzing is an iterative process (Aaltio and Heilmann, 2009). Case studies apply different methods to gather data; these include, but are not limited to, surveys, interviews, direct observations and source documents. The latter can be websites, artefacts and archival records (Putney, 2010). Interviews may be structured, semi-structured or unstructured. A semi-structured interview gives both the interviewee and interviewer the opportunity to participate in the interview, and as such promote the information flow. The interviewee contributes to the understanding and interpretation of the information, rather than only passing on data to the interviewer (DiCicco-Bloom and Crabtree, 2006; Staller, 2010).

In this research, the case study was used to study Norwegian fisheries and their stakeholders. Representatives for NGOs were interviewed and the financial records of fishing vessel companies were reviewed. Published documents from fish food companies and NGOs also were studied.

3.3 Statistical analysis

Mean and weighted mean:

Mean or weighted mean is often used as synonym to "average" (Quirk, 2011) and is very useful in statistics "since it can be interpreted as a typically score" (Pollatsek, Lima et al., 1981:p. 191).

The notation for mean is $\tilde{x}$ and is calculated according to formula (2) (Gupta, 2011):

$$\tilde{x} = \frac{\sum x}{n} \quad (2)$$

where ∑ x is the sum of observations and n the number of observations.

Weighted mean is used to indicate the relative importance of the observations, and are calculated according to formula (3) (Gupta, 2011):

$$\tilde{x} = \frac{\sum wx}{w} \quad (3)$$

where w is the weight assigned to the observation x.

Standard deviation

The standard deviation is a measurement of the variability of the observations (Donohue, Wolfson et al., 2011), measures how close the observations are to the mean and is a parameter on how the observations are distributed (at great distance or close) to the mean (Quirk, 2011).

The standard deviation can be denoted S and is calculated according to formula (4) adopted from (Quirk, 2011):

$$S = \sqrt{\frac{\sum(X-\tilde{X})^2}{n-1}} \quad (4)$$

where the symbols are explained for formula (2).

The main uses of statistics in this research are to describe the fuel use coefficient for different fish species and different fishing gears shown in Paper IV and Paper V, and in Section 5.4, and also as a help to better understand the background data, e.g. the Food and Agriculture Organization of the United Nations (FAO) statistics on global catch.

3.4 Systems engineering (SE)

This PhD-project is the first to apply SE principles to structure the research around the environmental problems associated with the FFP.

3.4.1 Definition of a system

According to ISO and International Electrotechnical Commission (IEC) a system is a "combination of interacting elements organised to achieve one or more stated purposes" (ISO/IEC 15288, 2008:p. 6). The most important characteristics of a system are:

- A system constitutes a complex combination of resources, elements and subsystems that interact through interfaces
- A system is contained within some form of hierarchy
- A system may be broken down into subsystems
- A system has a purpose: it must be functional and able to respond to some identified stimuli, and meet the specified needs and requirements over a defined system life cycle.

Figure 3.1 illustrates the variety of interactions, which can be uni- or bi-directional. The system boundaries normally describe the boundary between the system under study and the environment, or the system under study and other interrelated systems. Most systems are part of a larger system. Systems can be defined top-down into sub-system and system elements, or bottom-up from elements to sub-system and system (Fet, 1997).

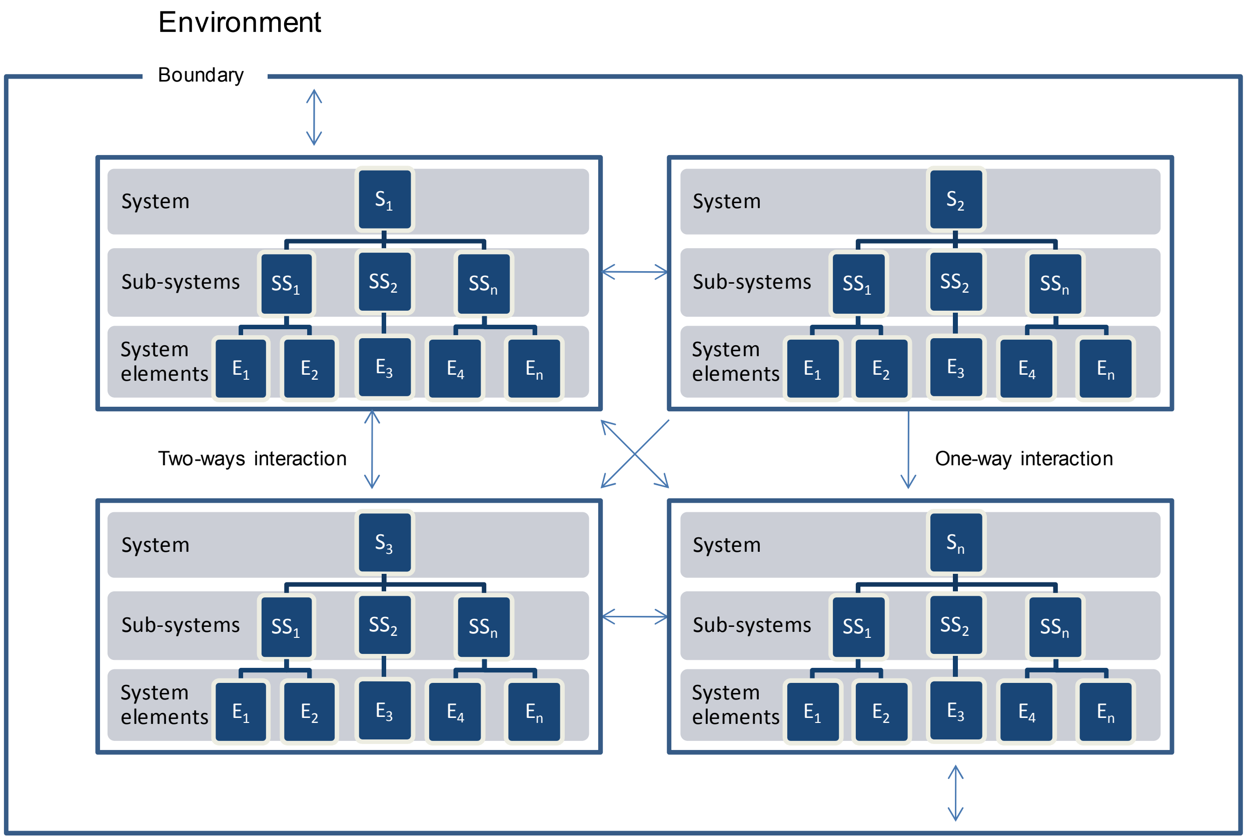


Figure 3.1: Systems, systems hierarchies and interactions [Inspired by (Michelsen, 2006)]

A system may be viewed as a combination of four different disciplines of roughly equal importance (Asbjørnsen, 1992):

- The disciplines of technology that include the physical equipment (Hardware),
- The disciplines of financial science that include the monetary aspects (Economics),
- The disciplines of information science that include instruction, rules and computer programs (Software),
- The disciplines of social science that include human factors, psychology and sociology (Personnel, Bioware).

Every man-made system operates within the context of a natural system, referred to in this thesis as the environment. Material and energy, economy, information and humans are interchanged between the system, its system elements and the environment. Such interchanges impact the environment, and the effects are explained by natural science. Changes in the environment caused by these impacts eventually affect the system later. A system in operation will always exert some affect on the environment, either significant or negligible. Therefore, when analyzing systems the environment must always be taken into consideration (Fet, 1997).

The system of interest in this research is the FFPS which consists of fishery and related systems needed to bring fish from the sea to the consumers' table as finished product ready for consumption. The FFPS is illustrated in Figure 3.2 with the physical system "the fishing vessel" with fish catching as an activity during the operation of the vessel. Fish processing can take place on board the fishing vessel depending on the type of fishery, or in a land based processing facility. Transport is another activity which requires physical systems as well. The main systems can be subdivided into smaller less complicated structures.

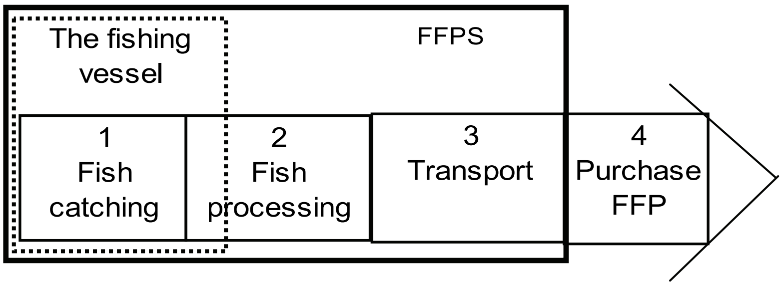


Figure 3.2: The Fish Food Production System (FFPS) and the supply chain of the fish food product (FFP) (Fet, Schau et al., 2010)

3.4.2 The SE-methodology

The tailored SE-process used for this research can be visualised using the six steps process (Fet, 2002) shown in Figure 3.3, and described here.

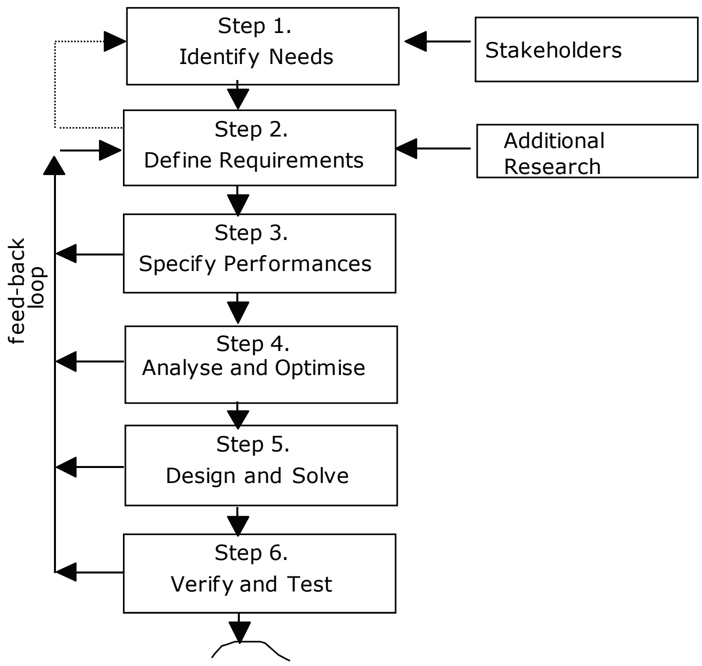


Figure 3.3: The Systems Engineering methodology (Fet, 2002)

Step 1: Identify Needs. In the first step the needs or desires for one or more results are identified as well as the most important stakeholders within the system's life cycle, who provide this information. Depending on the size of the system, there is always a variety of stakeholders, such as customers, banks and employees. To identify the needs, the following three questions can be asked (Fet, 1997):

- What is needed?
- Why is it needed?
- How may the needs be satisfied?

The answers to these questions provide the foundation for all further activity.

Step 2: Define Requirements. The next step is to define functional, operational and physical requirements. The functional requirements describe the systems ability to carry out work. This involves the description of the life cycle activities and the break down of the system into convenient parts. Functions are the answer to the "What?" in step 1. Operational requirements relate to the useful life of the system, and reflect the needs of the stakeholders, thereby answering the "Why?" in step 1. Physical requirements reflect the need for physical interactions between different sub-systems and system elements, and the system and the environment. Physical requirements answer the "How?" in step 1. Steps 1 and 2 occur in a tightly iterative process where the identification of needs and definition of requirements should be performed several times until the requirements are clearly defined. Requirements should address all stages of the system life cycle, and are the basis for the steps that follow.

For example, the requirements can be expressed as demands on a company to quantify environmental information about the company's activities, to provide eco-documentation of products or insight into the company's environmental impacts on the local neighbourhood.

Step 3: Specify Performance. The specification of the system performance is done by translating the requirements into definable and measurable criteria for the system and sub-system. This activity also recognises the full range of physical and regulatory constraints under which the system operates. For example, the environmental performance can be described for a selected product, for a process or an activity and may be expressed by means of environmental performance indicators (EPI) (ISO 14031, 1999; ISO 14005, 2010). Eventual verification of the system is dependent on satisfying these performance requirements.

Step 4: Analyse and Optimise. Based on the performance specification, the different options for a solution can be analysed, often by means of so called trade-off studies that help identify and balance conflicting interests. This also implies that the system requirements might have to be prioritised. An option when a win-win situation can not be identified is to establish an absolute performance requirement for one system element and then optimise the rest of the system with this constraint (Michelsen, 2006). Such absolute performance requirements could be limitations decreed by law or company policy. The analysis and optimisation step is an iterative process of improvement where the trade-off and specification of system performance are repeated until the potential for a satisfactory system design or solution is found.

Step 5: Design, Solve and Improve. The aim of Step 5 is to design a system that satisfies the needs of the stakeholders. This step very often requires a team of people with the skills and knowledge from several disciplines to secure the best solution. Knowledge and insight into the performance of the system during its entire life cycle is important, especially when it comes to solutions related to reduction of environmental impacts.

Step 6: Verify and Test. As the system is built, it should be verified according to the needs and requirements specified. A final test plan including a report with all the necessary data, test conditions and procedure should be written such that the process behind the development of the solution can be verified and used again for new types of problems.

The application of the SE process as the backbone of this research is described in Paper I, which presents the SE-based framework for environmental analysis of FFP, and is further summarised in Section 5.1.

3.5 Life cycle assessment (LCA)

This thesis contributes to the LCA project of the SINTEF program described in Section 1.2. LCA is a systems analysis tool (Wrisberg, Udo de Haes et al., 2002; Finnveden, Ekvall et al., 2004). The main stages of an LCA are goal and scope definition, inventory analyses, impact assessment, and interpretation of results (ISO 14040, 2006), which will further be described here. LCA is an iterative technique (ISO 14040, 2006), such that the goal and scope definition may be adjusted in the inventory analyses stage.

3.5.1 Goal and scope definition

Goal and scope definition for LCA includes the description of the system to be analysed and a clear definition of the system boundaries. Ideally, the system boundary should define the bounds of the technological system with respect to nature. Such a system boundary is always debatable – particularly with food production, where the inclusion of biological processes renders the distinction between technological systems and nature unclear (Berlin, 2002; Berlin and Uhlin, 2004).

LCA provides a systematic approach to impact analysis of a product and, ideally, should include all phases of the product's life cycle, from raw material extraction to consumption and waste disposal. The definition of system boundaries largely determines the outcome of an LCA. To usefully compare different products, the system boundaries must therefore be similar (Andersson and Ohlsson, 1999).

Functional unit (FU)

The functional unit (FU) is the reference unit that forms the basis for comparisons between different systems. The FU must be defined in the goal and scope definition stage of the LCA.

Co-product allocation procedures

When one process results in two or more valuable product outputs, allocation of resources and emissions in the production of the products must be performed. For example, in the production of milk and beef, Cederberg and Stadig (2003) state that "the two production schemes are closely interlinked; surplus calves and meat from culled dairy cows are an important base for beef production" (Cederberg and Stadig, 2003:p. 350).

The ISO 14044-standard for LCA suggests a three step procedure for handling allocation (ISO 14044, 2006):

1. Avoid allocation by a) separating multifunctional processes into sub-processes (sub-dividing) or b) expand the system to include the functions of co-products (system expansion).
2. If allocation cannot be avoided, an underlying physical relationship should be used as a basis for allocation.
3. If an underlying physical relationship cannot be established, impacts can be allocated according to another relationship (e.g. economic value) between environmental burdens and functions.

With the availability of the fuel consumption and catch data at the vessel-level in the Norwegian fisheries, it is possible to find fuel consumption per species and per fishing gear. Option 3 in ISO 14044, allocation through another relationship, has been performed in this PhD-project. The co-product allocation has been based on mass and economic value. A thorough description of the rationale and how this has been done is given in Paper IV.

3.5.2 Life cycle inventory (LCI)

The inventory analysis stage involves the collection and calculation of all relevant input and output data for each phase of the life cycle included in the study. The inventory analysis results in a list of resource uses and emissions to land, air and water. It is possible to make interpretations based on these results, but most input and output results must first be aggregated in the life cycle impact assessment phase.

Different software tools and/or databases can be used to facilitate inventory analysis and the subsequent impact assessment. Several databases containing materials and energy use data are publicly available (Carlsson-Kanyama and Faist, 2000; IKP and PE, 2002; Nielsen, Nielsen et al., 2003; Frischknecht, Jungbluth et al., 2004; European platform on LCA, 2007; Goedkoop, Oele et al., 2008)[1].

3.5.3 Life cycle impact assessment

The impact assessment stage of an LCA consists of classification and characterisation, and can also include the valuation steps of normalisation and weighting. Classification involves the assignment of inventory data (i.e. the inputs and outputs) to different impact categories. For example, CO_2-emissions would be assigned to the global warming impact category. Inputs and outputs can be assigned to more than one impact category. Within each impact category, every input/output is assigned a characterisation factor, and the total potential impact of each impact category is calculated. Further, to better understand the relative magnitude of the impact category results, they can be normalised against a reference value. Such a reference value could be the total resource use or emissions for a given area (e.g. Europe). Finally, weighting, an optional step in the ISO 14040-series, is the converting of indicator results of different impact categories to a common scale (ISO 14040, 2006; ISO 14044, 2006).

The LCA-methodology according to the ISO 14040-series, opens up for weighting of different environmental impact categories against each other (ISO 14040, 2006; ISO 14044, 2006). This is an opportunity as long as the underlying results also are accessible. However, a weighting scheme is often based on expert judgement or policy goals and, introduces subjectivity, such that weighting should be used with care and

[1] http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm of the joint research center of the European Commission provides a more comprehensive list of LCA databases for the interested reader.

adjusted to different stakeholders. Weighting schemes can invalidate comparisons between products.

3.5.4 Life cycle interpretation

Life cycle interpretation is the final phase of an LCA. In this iterative phase the goal and scope, LCI and life cycle impact assessment are reviewed, checked for consistency and valuated. Significant issues are identified. The results are presented, conclusions drawn and recommendations for the stakeholders are provided consistent with the goal and scope of the study (ISO 14040, 2006). In this phase, sensitivity and limitations of the results are evaluated (ISO 14044, 2006).

3.5.5 Applications of LCA

According to ISO 14040, LCA can be used in product development and improvement, strategic planning, public policy making, marketing and other applications (ISO 14040, 2006). LCA was originally developed for the commodities-producing industries, but has been expanded in the last two decades to address diverse product groups and production processes (Audsley, 2003; Nemecek and Gaillard, 2009). Among these is food production, for example apples (Stadig, 1998; Milà i Canals, Burnip et al., 2006; Mouron, Scholz et al., 2006), beef (Cederberg and Darelius, 2000), bread (Andersson and Ohlsson, 1999), cheese (Berlin, 2002), chicken (Ellingsen and Aanondsen, 2006), milk (Cederberg and Mattsson, 2000; Eide, 2002; De Boer, 2003; Hospido, Moreira et al., 2003), oranges (Sanjuán, Clemente et al., 2004), sugar (Brentrup, Küsters et al., 2001; Ramjeawon, 2004), tomato ketchup (Andersson, Ohlsson et al., 1998) and wheat (Brentrup, Küsters, Kuhlmann et al., 2004; Brentrup, Küsters, Lammel et al., 2004). Complete meals are only to a certain degree investigated, see for example (Davis and Sonesson, 2008)

A range of sea food products also have been investigated with LCA. Among these are Cod (Eyjólfsdóttir, Jónsdóttir et al., 2003; Ziegler, Nilsson et al., 2003; Ellingsen and Aanondsen, 2006; Vold and Svanes, 2009; Svanes, Vold et al., 2011), Shrimp(Mungkung, 2005; Mungkung, Udo de Haes et al., 2006; Ziegler, Eichelsheim et al., 2009), Tuna (Hospido and Tyedmers, 2005; Hospido, Vazquez et al., 2006), various Finnish FFPs (Silvenius and Grönroos, 2004), various Danish FFPs (Thrane, 2006), Salmon (Ellingsen and Aanondsen, 2006; Watanabe and Tahara, 2008; Pelletier, Tyedmers et al., 2009), Norway lobster (Ziegler and Valentinsson, 2008), Pacific saury (Ishida, Watanabe et al., 2008) and Horse Mackerel (Vázquez-Rowe, Moreira et al., 2010).

A series of LCA-Food conferences have been held in Brussels (Ceuterick, 1998), Gothenburg (SIK, 2001; 2007), Bygholm (Halberg, 2004), Zurich (Nemecek, 2008) and Bari (Notarnicola, Settanni et al., 2010). Food products are one of the major contributors to the environmental impacts from households. LCAs of food products are receiving a growing interest, not only in Europe, but also in non-OECD countries. LCA of food products contributes to the methodological development of LCA and data availability, especially in areas such as land use, biodiversity and resource (e.g. water) use. However, further improvement of the LCI data for and the impact assessment in these categories are needed.

3.6 Stakeholder analysis and communication

A stakeholder is an individual or a group that can influence or be influenced by a decision (Mitchell, Agle et al., 1997) and that has an interest - "stake" – in a product or company (Jensen and Remmen, 2004). Stakeholders provide the 'reason for being' for the system, and identifying them is a precondition for step 1 of the SE process.

Stakeholder analysis is the process of identifying key stakeholder, assessing the stakeholders' interests and the way those interests affects the project or the firms' risk and viability (Allen and Kilvington, 2003) .

A stakeholder analysis involves three main steps (Allen and Kilvington, 2003):

1. Identifying major stakeholder groups
2. Determining interests, importance and influence
3. Establishing strategies for involvement

Stakeholders to the FFPS include, but are not limited to, fishers and fishing vessel owners and their associations, regulatory authorities, NGOs, retail chains, and consumers (Schau, 2005). In addition to the authorities, NGOs as a stakeholder group are not directly involved in the value chain but are important when it comes to monitoring the environmental aspects of FFPs. Some argue that environmental NGOs are one of the most trusted information sources for environmental information, also about products (Pieniak, Verbeke et al., 2007). For example, environmental NGOs may launch a marketing campaign focusing on the existing concerns of consumers with the intention of influencing the value chain, and simultaneously expand and deepen consumer demand for more sustainable products (O'Rourke, 2005; Solheim, 2011).

NGOs are a collection of many interested parties, of which environmental groups are considered among the most important NGOs. Three environmental organisations and their requirements to the FFPS were researched. These are the Friends of the Earth Norway / Norwegian Society for the Conservation of Nature, which is member of Friends of the Earth International (Friends of the earth Norway, 2005), WWF, the global Conservation Organization with WWF-Norway as the Norwegian branch (Esmark, 2005), and Greenpeace International (Greenpeace, 1998).

The most important issues for these three environmental NGOs regarding fishing are as follows (Greenpeace, 1998; Esmark, 2005; Friends of the earth Norway, 2005):

- Respect the precautionary principles and scientific advice
- Good management of fish stock
- Close fishing grounds with juvenile fish to protect the stock
- Minimum catch size should be respected by the fishing industry
- Do not push for higher quotas
- Fishing gears should be highly selective such that by-catch of fish, sea mammals and birds is reduced
- A substantial part of the fishing should be pursued with passive fishing gears
- The energy use must be reduced in the fisheries and minimised throughout the production cycle
- The packaging should be minimised, reused and recycled in that order
- Control schemes where the FFP are traced throughout the value chain (documenting where the fishing vessels operate and how much each boat catches)
- Important marine areas, like coral reefs should be protected from fishing and other activities and be awarded the status of marine protected areas
- Clear labelling of products such that species on the red list (in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) appendix) do not show up on the market
- The use of fish resources for aquaculture

Greenpeace stresses the fact that "as consumers can only exercise their choice on the basis of adequate information regarding the impact of their consumption, the fish trading, processing and retailing industry must provide direct access to information. This can be done, for example, through detailed product labelling or point-of-purchase and other forms of information directly accessible by consumers." (Greenpeace, 1998:p. 7).

The stakeholder analysis is used to find the target audience of environmental information to determine what kind of environmental information the different targets groups need, and thereby specify the requirement for information desired.

3.7 Environmental labelling

As described in the previous section, the stakeholders require environmental information about the FFP. Environmental labelling is one way to provide such information. The purchaser can use environmental labelling for decision making such that demand for and supply of more environmentally sound products increases (ISO 14020, 2000).

3.7.1 Labelling standards

The ISO 14020-series distinguishes between three types of environmental declarations, which all require that life cycle aspects are taken into consideration. These are:

- Type I programmes - multiple criteria-based, third party programmes awarding labels claiming overall environmental preferability (ISO 14024, 1999; Mungkung, Udo de Haes et al., 2006);
- Type II programmes - self-declared environmental claims where life cycle considerations are taken into account (ISO 14021, 1999); and
- Type III programmes – quantified environmental declaration of the life cycle of a product for comparisons between products fulfilling the same function (ISO 14025, 2006).

To obtain a Type III EPD the requirements are to conduct an LCA of the product in accordance with the ISO 14040-standards series (ISO 14040, 2006; ISO 14044, 2006), and obtain a third party verification of the LCA and the EPD. An important requirement for the development of an EPD is that product categories rules (PCR) exist (ISO 14025, 2006).

A precautionary approach should be taken when introducing environmental product labelling, such that unwanted and unexpected outcomes are prevented. Given the growing demand for fisheries products (European Commission, 2005:p. 15), if at the same time the market accepts all sorts of fish, i.e. both sustainably and unsustainably harvested stock, then providing more environmental information may be contra-productive, as the consumers may begin to increase their demand for FFP. However, it could happen that the cheapest FFP, which are not necessarily the most sustainable, are preferred (DG Agri, 2009:p. 89). Therefore, environmental product labelling cannot be a substitute for the regulation of the fisheries. The actual decision made by the different stakeholders facing the environmental information of the FFP (e.g. through the EPD) should be investigated and evaluated for its effectiveness in promoting sustainable fishery after the EPD is tried out in the market. The aim of this investigation should be to determine if the end-result of the EPD is contributing to an increased demand for fish coming from overexploited fish stocks and, if so, propose corrective action.

Various names are used for Type III-programs and appurtenant product declarations, for example EcoLeaf (JEMAI, 2002), eco-profile (Tillman, 1998), environmental declaration of product (KOECO, 2007), environmental profile data sheet (Row and Wieler, 2003) and environmental product declaration (EPD) (SIRII, 2002). EPD is used throughout this thesis.

3.7.2 Alternative labelling schemes

The carbon footprint focuses on the single impact category global warming, and is receiving broad attention from retailers (Leahy, 2007) and governments (Kaji, Kishida et al., 2008; Teknologirådet, 2008). Work is ongoing to establish an ISO standard for the carbon footprint of products and is planned to be released as a standard in 2012 (ISO/CD 14067.3, 2011). The Swedish National Board of Trade reports about 200 different carbon labelling and climate declarations schemes worldwide (Kommerskollegium, 2011). Upham, Dendler et al. (2011) define carbon labelling as "the practice of publicly communicating, via a label associated with a product or service, the greenhouse gas (GHG) emissions associated with the life cycle of that product or service" (Upham, Dendler et al., 2011:p. 348). In the committee draft of ISO 14067.3 the terms used are carbon footprint of a product (CFP) defined as "sum of greenhouse gas emissions and greenhouse gas removals of a product system, expressed in CO_2-equivalents" (ISO/CD 14067.3, 2011:p. 4) and CFP declaration defined as "declaration of the CFP made according to CFP-PCR developed specifically for CFP communication, or relevant Type III environmental declaration PCR" (ISO/CD 14067.3, 2011:p. 5). Especially for food products, carbon footprint declaration has gained increased attention in recent years; see (Carbon Trust, 2007; Buser, Lieback et al., 2008; Teknologirådet, 2008; Baldo, Marino et al., 2009; Finkbeiner, 2009; Friedl, 2009; Schmidt, 2009; Winther, Ziegler et al., 2009; Iribarren, Hospido et al., 2010; Kaufman, 2010; KRAV, 2010). The main reason for this large interest in the carbon footprint of food product may be explained by the large share of a household's GHG account related to the life cycle of the food product consumed therein (Tukker, Huppes et al., 2006; Buser, Lieback et al., 2008).

Various levels of information are currently provided for carbon footprint. They range from the qualitative; a logo indicating that the carbon footprint of the product has been assessed (e.g. German Carbon Footprint project (Friedl, 2009)), to the quantitative reporting of the number of CO_2-equivalent grams, e.g Carbon Trust in the UK (Carbon Trust, 2008). The Casino-group have a logo with the amount of CO_2 per 100 g of products accompanied by additional detailed information on the backside of the packaging, explaining the method briefly, a comparison with other products and what the consumer can do to reduce the carbon footprint (Picard, 2008).

3.7.3 Environmental labelling for FFP

For Norwegian FFPs there are currently - as of May 2011 (Norsk Sjømat, 2011) – three environmental labels used based on the FAO Code of Conduct for responsible fisheries (FAO, 1995); namely, the KRAV-label, the Marine Stewardship Council (MSC) and Friend of the Sea (FoS). KRAV, MSC and FoS present respective logos that indicate that the FFP fulfils the requirement set down in the labelling program and hence are from sustainable fisheries (KRAV, 2009; Parkes, Walmsley et al., 2009; Friend of the Sea, 2010; Marine Stewardship Council, 2010). MSC uses the blue and white MSC logo and an appurtenant chain-of-custody code. This code can be used to find additional information on the internet page of MSC (internet address provided as part of the logo) about the producer of the FFP and a contact person to check the validity of certificates and scopes (Derichs, 2011). KRAV also informs the consumer about where (within 10 nautical miles) the fish has been caught and the FAO catch zone using a consumer understandable geographical name (e.g. Bjørnøya – Barents Sea) (Cejie, 2011).

Eco-labels for FFPs may have different target stakeholder groups, serving the information need of the stakeholders in different ways. How these stakeholders are prioritised is useful information when new eco-labels are designed. A small informal e-mail survey regarding the eco-labels existing for Norwegian sea food products today - as of December 2010 (Norsk Sjømat, 2010) – was conducted to gain insight into the target stakeholder groups of eco-labels for FFP. The survey was sent to the directors of the eco-labelling organisations for KRAV, MSC and FoS. Responses were received from Brand, the Baltic Commercial Officer at MSC; Bray, Director at FoS; and Hällbom, Director of Regulatory Affairs at KRAV. They were asked to rate the importance of different stakeholder groups for their own eco-label in addition to rate how important, in their opinion, these stakeholders are for other eco-labels. Environmental NGOs and environmentally conscious consumers, followed by retailers and the fish processing industry are the most important target stakeholder groups for eco-labels of FFP. As a general trend, MSC, KRAV and FoS regard, not very surprising, their own label to be more important than the other eco-labels. However, all agree that environmental NGOs are very important stakeholders for EPD and CFP. Other stakeholders who are considered to be important target groups for EPDs are environmentally conscious consumers and organic food consumers, retailers, fish food processors and authorities. The detailed responses can be found in Appendix H.

4 Fishery and the environment

Fishery involves a range of stakeholders, encompasses different management goals and policies, and includes a variety of fishing species and gears. A comprehensive overview of fishery and fishing gears is given in Appendix G. The focus in this research is on the environmental aspects of fishery and the impact it has on the environment in a life cycle perspective.

4.1 Environmental impacts of fishery

Fishing impacts the environment in different ways. During fish catching, the environmental impacts can be divided into two main categories; 1) direct impact on the marine ecosystems, and 2) indirect, ecological impact on marine and terrestrial ecosystems through the effects of substances emitted to the atmosphere and to the sea water. Feedback loops exist between these two main categories (Thrane, Ziegler et al., 2009).

Overfishing (unsustainable fishing – where fish stocks are eventually reduced to extinction) is regarded to be the most serious environmental impact to the marine ecosystem (Nordic Technical Working Group on Fisheries Ecolabelling Criteria, 2000; Jackson, Kirby et al., 2001; Myers and Worm, 2003), with impact on both the target species and supporting marine environment (Pauly, Christensen et al., 2002). Fishing also impacts other biological resources through by-catch of target species and non-target species, such as other fish, marine mammals and birds (Piatt and Nettleship, 1987; Alverson, Freeberg et al., 1994; Tasker, Camphuysen et al., 2000; Chuenpagdee, Morgan et al., 2003; Kvalsvik, Huse et al., 2006). The use of bottom fishing gear leads to disturbance of the sea floor and epifauna (Auster, 1998; Collie, Hall et al., 2000). Another problem with fishing gear is that if they get lost, some still continue to fish which is called ghost fishing (Humborstad, Løkkeborg et al., 2003; Matsuoka, Nakashima et al., 2005; Brown and Macfadyen, 2007). Ghost fishing is mainly a problem for static fishing gear like pots and nets (Breen, 1990).

Indirect impacts from the fishing process are mainly connected to the use of fossil energy and antifouling, which cause emissions to the atmosphere and sea water. In some situations the use of refrigerants to cool down/freeze and keep the fish cold/frozen causes emissions to the atmosphere (Winther, Ziegler et al., 2009). The use of fossil energy sources is a problem itself because this is a non-renewable shrinking resource (Campbell and Laherrere, 1998; de Almeida and Silva, 2009). Modern fisheries heavily depend on fossil energy sources, and the energy input (diesel) for many fisheries is larger than the energy output (edible fish) (Tyedmers, 2004; Tyedmers, Watson et al., 2005). Combustion of fossil fuel (e.g. in form of marine diesel) leads to emissions to the atmosphere of carbon dioxide (CO_2), sulphur oxides (SO_x), nitrogen oxides (NO_X), volatile organic compounds (VOC) and other gases and particles (Hellén, 2003; Ziegler and Hansson, 2003; Bergh, 2004) which in turn impact the environment by e.g. global warming, acidification and eutrophication (Häfele, Riemer et al., 1986; Daly, 1994).

Antifouling is the use of biocides and (more recently) other technologies to prevent fouling, i.e. organism growth (Magin, Cooper et al., 2010). Antifouling is used on the under-water hull of the ship with the purpose of minimising the water resistance of the ship or on the propeller to reduce its resistance. Antifouling leads to toxic pollution in the seawater and sea bed (Brekke and Nes, 2000; Strømmen, 2000; Anderson, Atlar et al., 2003), especially near maintenance shipyards (Prasad and Schafran, 2006) due to lack of routines for collection of flush down water from maintenance of bottom hulls (Fet and Stavseng, 1996). Antifouling may also be used on some fishing nets to prevent fouling, but this is mainly a problem for standing nets, i.e. in the fish farming industry (Braithwaite and McEvoy, 2004). Historically, copper and tributyltin (TBT) are chemicals most often used as antifouling materials (Anderson, Atlar et al., 2003). TBT was phased out as the toxic impact on the marine environment became evident (Yebra, Kiil et al., 2004). In fact, TBT was internationally banned when the International Convention on the Control of Harmful Anti-Fouling Systems on Ships came into force 18 September 2008 (IMO, 2011). However, the process of finding replacements for TBT is not straightforward, as TBT has proven to be the most effective material for antifouling (Champ, 2000). This creates a problem because increased fouling leads to increased fuel use (Brekke and Nes, 2000). New techniques apply copper, zinc, and a variety of organic compounds as the active, antifouling components (Magin, Cooper et al., 2010).

Considering all the life cycle phases of the fishing vessel, the construction, maintenance and scrapping of the vessel mainly impact the local environment at the actual construction-, maintenance- and scrapping-yard (Hayman, Dogliani et al., 2000; Ellingsen, Fet et al., 2002). The material used in the vessel causes other impacts as well, related to the extraction of raw materials.

4.2 Case study

As part of the research, a case study was conducted to define an LCA for fish products. Three fishing vessels were involved:

- Trønderkari – a small size steel fishing vessel of 382 gross tonnage (GT - the overall size) using combined purse seiner, Danish seine, demersal and pelagic trawl equipment for species such as Atlantic herring, Atlantic cod, saithe, haddock and capelin (Ulsund, 2006)
- Trønderbas – a medium-size steel fishing vessel of 2213 GT (Shipbase, 2006), using purse seiner, set net and pelagic and demersal trawl equipment for Atlantic herring, Atlantic cod, saithe and blue whiting (Steinseide and Ølmheim, 2006).
- A medium-size steel fishing vessel of 1904 GT, using combined purse seiner and pelagic trawler equipment for species such as Atlantic herring, mackerel, blue whiting, and capelin for fish catching in the North East Atlantic [source confidential].

As the contribution from the construction of the fishing vessel to the environmental life cycle performance of the FFP has not been available before, the construction phase was of special interest for researchers, LCA practitioners and the fishing vessel construction industry (Aanondsen, 1997). For this purpose, data have been gathered from another research project, Technology Energy Efficient Ships (TEES) (Thomsen, 2002). The LCA data of this fishing vessel stored in a GaBi-LCA database (IKP and PE, 2002) also contributed to the case study. The TEES ship was deemed to have sufficiently similar properties compared with the fishing vessels listed above.

The processing of the fish is performed in a processing plant in the Norwegian county Møre and Romsdal, and the finished and packed product is transported by ship from Ålesund to Ijmuiden in the Netherlands, and then by truck 530 km to the wholesaler.

The entire case study is based upon two different end points;
1) a wholesaler near Paris, France (used in Paper I)
2) an average German consumer (used in Paper III and the EPD in Appendix F).
The second endpoint requires the additional transport distance of 300 km by truck to the retailer, the transport to the consumer and the consumption phase based on an average German consumer.

An illustration of the systems and their underlying processes in the case study (end point Germany) is given in Figure 4.1. It shows the life cycle of the FFP on the horizontal line of the drawing. It also shows how the life cycle of the fishing vessel crosses the life cycle of the FFP in the fishing phase and further where the packaging enters the FFP's life cycle. Solid lines indicate that data have been gathered specifically for this case, whereas dotted lines indicate the use of data taken from literature (Fet, Michelsen et al., 2000; Karlsen and Angelfoss, 2000; Bøe, 2003) and databases (IKP and PE, 2002; Wiegmann, Eberle et al., 2005). The case is modelled and stored in the GaBi 4 software (IKP and PE, 2002). By necessity, the system boundary does not include human digestion, or the fate of the eventually discarded packaging.

Statistical data on environmental issues have been difficult to obtain especially from the fishing phase of the products life cycle. Such data are generally lacking in food supply chains. One reason may be that many food producers are privately owned and do not publish annual reports to the general population (Yakovleva, 2007b). The data used in the case study for the refinement and processing is an exception in this regard, as this data was published in an annual environmental report (Bøe, 2003).

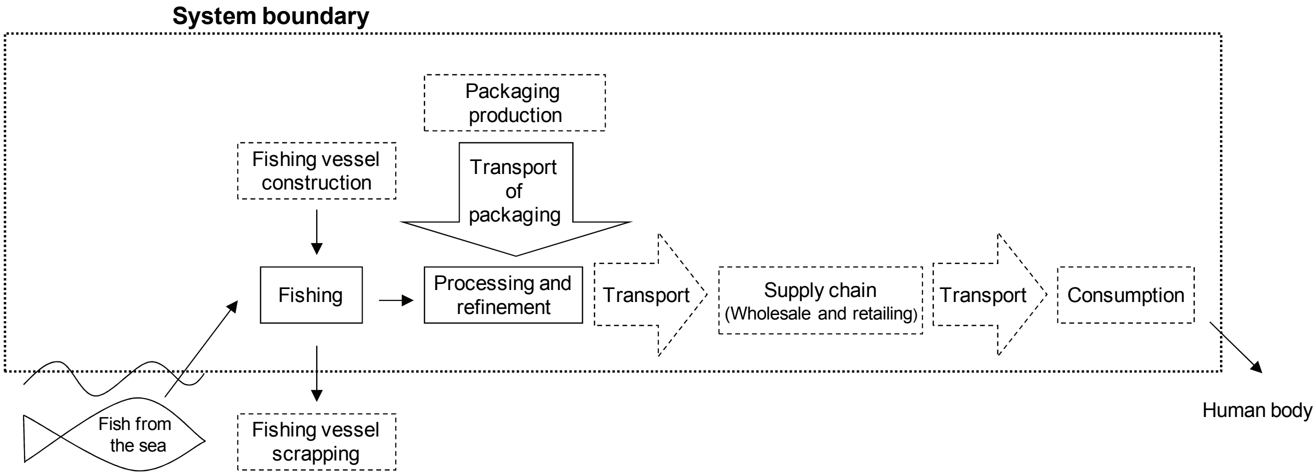


Figure 4.1: Illustration of the systems of the case study

The case study results have two main outcomes:

1) An LCA analysis of a FFP that is further used as the basis for an EPD; and,

2) A quantification of the environmental performance of the FFP life cycle, and especially how the construction of the fishing vessel contributes to the environmental performance of the fish product.

The results show that the fishing phase dominates the life cycle environmental impact of the FFP, but also that the fishing vessel construction contribution is significant in the marine aquatic eco-toxicity impact category. The results from the case study are presented in more detail in Paper III, the EPD in Appendix F and Chapter 5.

4.3 Stakeholder analysis and communication

The most important stakeholders of the FFP and their interests are described in (Schau, 2005). Fishers and fishing vessel owners and their associations, authorities, NGOs, retailers and consumers are regarded to be among the most important stakeholders to the FFP, with diverse interests regarding environmental information.

The fishers and their organisations have a key role in the FFPS. Because they catch fish from the ocean, they have a strong incentive to preserve this environment and ensure that the marine environment is perceived as clean by the consumers of FFP. The fishers organisations together with fish sales organisations and fish farmers organisations in Norway have published common environmental goals and a accompanying strategy (Lorentsen, Valland et al., 2003). This focus on fish stock condition, resource exploitation, pollution and other environmental aspects associated with the fishing itself and pollution of the marine environment from other sources and involve avoiding by-catch of fish and birds, alternatives to and increased efficiency of fossil fuels in both the fishery phase and transportation, promoting pollution requirement and environmental documentation as well as documentation and communication of environmental aspects and production processes (Lorentsen, Valland et al., 2003).

However, the environmental concerns of the fishers as a whole are not necessary the same as one single fisher (cf. the tragedy of the commons). In a brainstorming session with fishers along the coast of Norway (Kristiansen, 2004), there were two main concerns: 1) the high energy usage of the fishing vessels and 2) fish that could be used for direct human consumption often are used for fish meal and fish oil instead. Also the environmental impact of cooling medium was concerning (Kristiansen, 2004).

Another important stakeholder group is the authorities (Lorentsen, Valland et al., 2003), here represented by the Norwegian government, which publish their policy in a combined white paper and status report (Det kongelige miljøverndepartement, 2005). The needs and requirements applicable on the environmental performance are to stop the loss of biodiversity and environmental poisons, fulfil the Kyoto protocol (United Nations, 1998) and the Gothenburg protocol (UNECE, 1999) that bind the Norwegian GHG- and NO_x-emissions respectively, and to reduce the environmental impact of waste and increase the use of waste as a resource (Det kongelige miljøverndepartement, 2005).

Consumers are probably the most dispersed group of stakeholders. While some regard the price and quality (e.g. nutritional value) of the FFP to be most important, a significant number of consumers are interested in the environmental impact of the FFP they buy.

For this last group, typically middle class consumers, some name them LOHAS - Lifestyle Of Health And Sustainability (Maurie, 2007; Bilharz and Belz, 2008; Ernst & Young, 2008), environmental information is important: "Middle-class consumers in many developed and developing countries are becoming increasingly influential and concerned about what they eat and at what cost food is produced, especially in the case of internationally traded products"(FAO Fisheries Department, 2004:p. 61). The information to consumers should not be too complex, therefore environmental labelling is a good choice. However as the consumer groups are so dispersed (some interested in animal welfare, some about climate change) to have more specific environmental information at hand for those requesting these could mean a competitive advantage.

The stakeholder analysis is used to set the requirement to the environmental information that should be provided from the FFPS. These are:

- Consider the entire life cycle of the FFP
- Provide objective scientific and reliable information, possibly verified by a third party
- Provide detailed information throughout the process with straightforward information focusing on some key aspects
- Provide quantitative data that could be used for improvement monitoring, with qualitative information where quantitative data collection is too resource intensive

The stakeholder analysis has resulted in a statement of requirements for the environmental information from the FFPS. These requirements show that a life cycle approach that takes the whole life cycle of the FFP and not only some phases, is necessary. Further, the type of environmental information provided need to take the different needs of the stakeholders into account, where some stakeholders need thorough, detailed and when possible quantitative data, whereas other stakeholders need only information about key aspects

5 Results presented in the Papers I - V

As shown in Figure 1.1, the answers to the research questions have been documented by Papers I-V in the Appendixes A-E of this thesis. Appendix F presents an example of a PCR and an EPD for FFP, while Appendix G gives a brief overview of Norwegian fisheries. A summary of each paper is presented in this chapter; for details the entire papers should be read.

5.1 Paper I: A framework for environmental analyses of FFPS based on Systems Engineering principles

The food industry has for several years faced legislation requiring that producers provide traceability for food products from retailers back to the source (European Commission, 2001; European Parliament and Council of European Union, 2002). Grocery chains in different European countries have initiated carbon labelling programs that take the life cycle of food products into account (Leahy, 2007; Picard, 2008). The fish food supply chain is a complex system with several interacting sub-systems (Eyjólfsdóttir, Jónsdóttir et al., 2003; Utne, 2007), and therefore a systematic approach is helpful to analyse the environmental impacts of the FFP life cycles. For this reason, a SE methodology is applied to enhance the understanding of the interactions between these systems and their environments.

The goals of Paper I are therefore:

1) To describe the FFPS and sub-systems;
2) To apply SE methods to create a framework for environmental analysis of FFP;
3) To demonstrate briefly the use of the framework.

5.1.1 Description of the FFPS

SE is used to make simple models of the systems under investigation. The main system model is the FFPS. This consists of the three main elements; 1) the fish catching (where the fishing vessel is a substantial part), 2) fish processing (which may be performed on the vessel) and 3) transport as indicated in Figure 3.2.

5.1.1.1 The fishing vessel and the fish catching sub-systems

The fishing vessel is one of the sub-systems in the FFPS, and it interacts with the supply chain of the FFP in the fish catching operation. The fish catching can be described as a process with inputs and outputs. The fishing vessel requires fuel oil, lubrication oil and cooling agents. Some fish catching systems (see Appendix G) also require bait. The outputs are different fish catch, emissions to air, such as CO_2, NO_x and SO_x, and discharges to sea. The system also has an impact on the sea bottom that depends on the fishing gear that is used (Collie, Hall et al., 2000; Galbraith, Rice et al., 2004).

5.1.1.2 The fish processing sub-system

Fish processing varies with the type of fishery. Figure 5.1 shows three models of the fish processing phase of the FFPS. Each model compares four elements: "Fishing vessel", "Processing plant", "Refinement plant" and "Grocery store". Model 1, on the left, is typical for white fish excluding high value species. Model 2 is typical for cod fish products caught by factory trawlers in the open ocean, a long way from the coast and fish processing plants. Model 3 is also used for cod trawlers and other whitefish, but here the fish is cooled down, not frozen, on the vessel and brought to shore fresh. A fourth model, not shown in the figure, is to bring the fish catch to the shore and directly freeze it into round frozen fish, which is brought to the grocery store (Foster, unpublished).

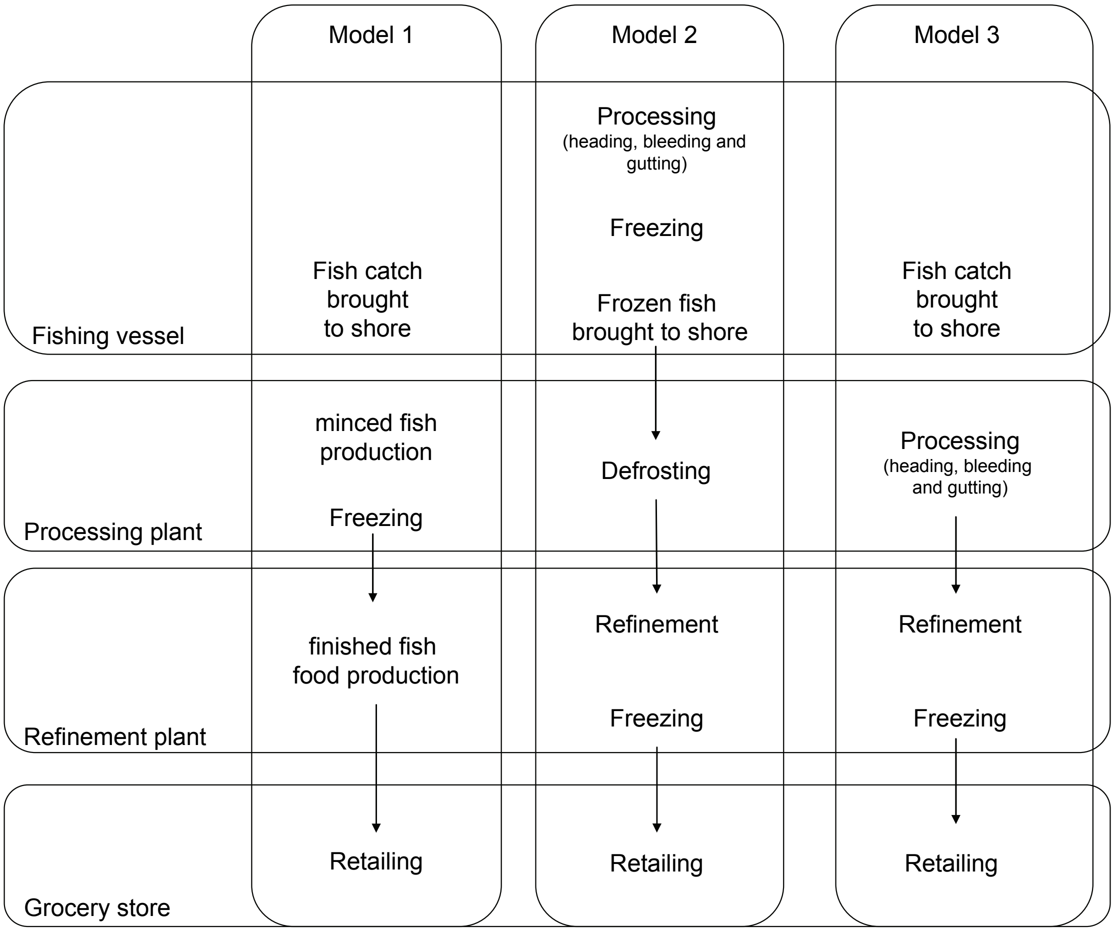


Figure 5.1: The fish processing sub-system (Fet, Schau et al., 2010)

5.1.1.3 Transport

The fishing vessel is a transport mean in itself. In addition there are different types of transport depending on the model 1-3. Transport operations are illustrated by the arrows in Figure 5.1. For a globally traded commodity such as fish, the transport distances can be large.

5.1.2 An application of the SE-methodology to create a framework for environmental analysis of FFP

Figure 5.2 presents the framework for environmental analysis of FFP. In Figure 5.2 the steps A-H present the activities that are necessary for an environmental analysis of a FFP. While steps A-H could be performed without using standardised methodologies or stakeholder requirements, the purpose of integrating steps A-H to the SE 6-step process (see Figure 3.3) is to create a more robust framework. Activities A and B will result in the description of the FFPS. In step 1 and 2 the stakeholders to the FFPS are analysed and their requirements documented. This will have an influence on the selection of impact categories (e.g. carbon footprint or all the categories typically addressed in an LCA or the categories addressed in MSC, KRAV or FoS) and further on the description of the FU. This is illustrated by the arrows to box C and E. Step 3 is achieved by activities C and D. Step 4 is achieved by steps E, F, and G. Figure 5.2 further shows how tracing systems and the standardised methodologies for LCA (ISO 14040-series) and environmental product information (ISO 14025, 2006) can be incorporated in the framework. A more detailed description about how the framework is developed is found in Paper I.

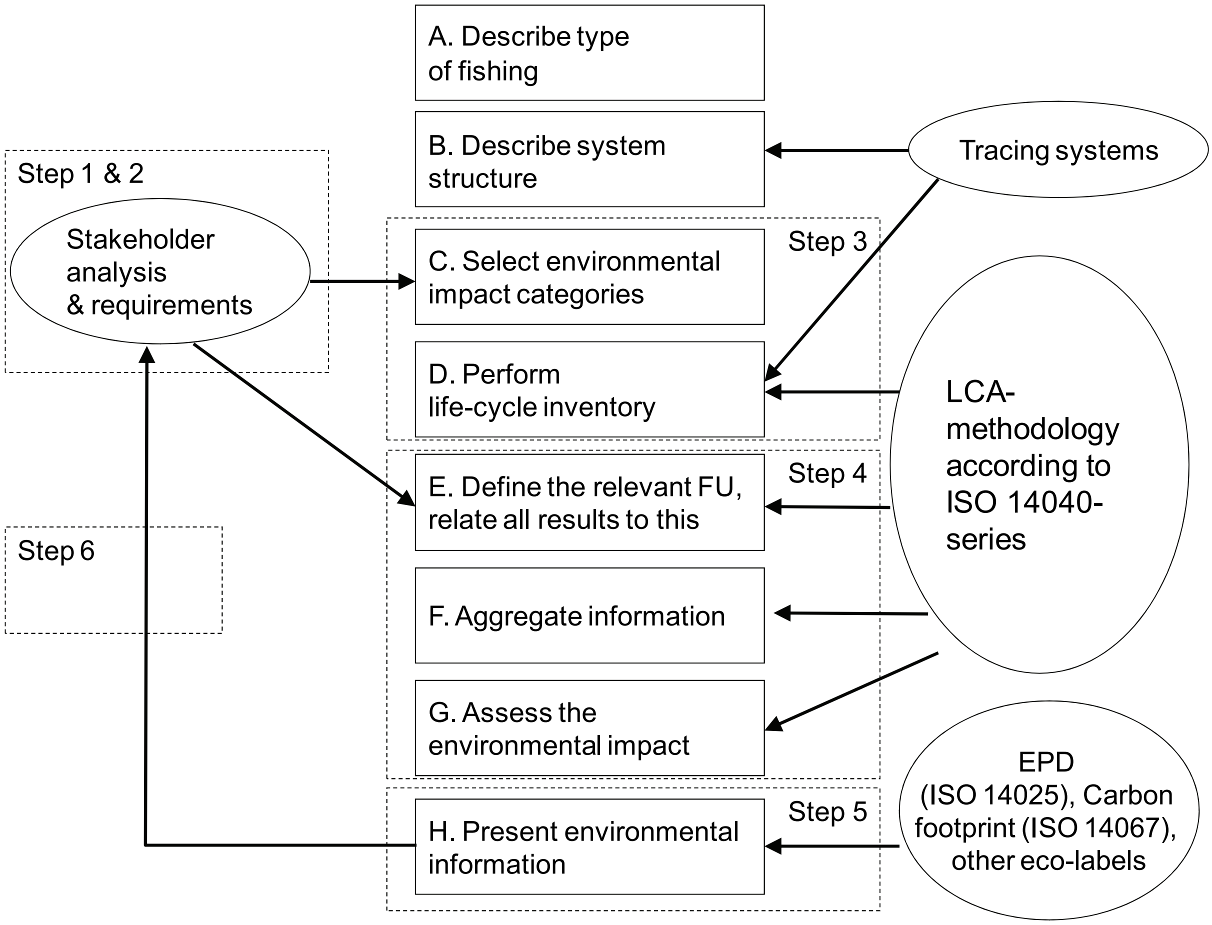


Figure 5.2: Framework for environmental analysis of the fish food production system [Based on (Fet, Schau et al., 2010)]

The framework can also be used in combination with the standards for carbon footprint of products (when this is ready) or with MSC, KRAV-declarations and other labels as appropriate. Tracing systems already in place for fish food systems (Pálsson, Storøy et al., 2000; CWA 14660, 2003; Denton, 2003; Roos, Dulsrud et al., 2005; Karlsen, 2011) can help when describing the system structure (B), performing the life cycle inventory (D) and to make sure that the FFP can be traced back to the origin. It is proposed that steps E, F and G in the framework will follow strictly the LCA-methodology, and the information will be presented (part H in the framework) in an EPD according to the requirements in ISO 14025 or as an eco-label on the fish food packaging, or in another way based on the requirements from the stakeholders. Step 6 in the SE-methodology in Figure 3.3 is about verifying and testing. In this context it is about applying the framework to an actual case, and demonstrating that the result or outcome can be verified according to the requirement set by the stakeholders.

5.1.3 Testing of the framework

Paper I fully describes how the framework in Figure 5.2 is tested for one environmental impact category namely, CO_2-emissions or the carbon-footprint (using a narrow definition including only CO_2-emissions). The data for this case study are taken from earlier publications and reports (Fet, Michelsen et al., 2000; Karlsen and Angelfoss, 2000; IKP and PE, 2002; Bøe, 2003; Hamre, 2004; 2006; Steinseide and Ølmheim, 2006; Schau, Ellingsen et al., 2009). The result shows that the carbon-footprint of the life cycle of 1 kg frozen fish fillet (the FU) delivered at the store in Paris is 1.04, that means 1.04 kg CO_2-emmisions per FU. The calculated result is not critically analysed and evaluated against other carbon footprints since the demonstration uses data collected from earlier case studies.

In summary, the main outcomes of Paper I are:

- Models for the description and the understanding of systems and sub-systems of the FFPS
- A demonstration of the SE-application for FFPS
- A robust framework for environmental analysis of the FFP
- A demonstration of this framework for the purpose of calculating carbon footprint of 1 kg of frozen fish fillet.

5.2 Paper II: LCA studies of food products as background for environmental product declarations

As Paper I is a description of the framework, Paper II goes into more detail for LCA. The goal of Paper II is to contribute to exploring the suitable FU, system boundaries and allocation procedures for LCA in food production in general, and the PCR and EPD for food products in specific.

Based on a review of published scientific articles and conference papers treating LCA of food products, Paper II is used to highlight and discuss different ways of defining the goal and scope of the LCA of food products, with an emphasis on defining the FU, setting the system boundaries and choosing a co-product allocation method.

5.2.1 System boundaries and FU

Food production systems closely interlink nature and the technical sphere. Setting the system boundaries means to choose which processes to take into account and is of course very important for the results. To be able to compare different products, the system boundaries need to be similar. Since the choice of system boundaries strongly influences the results, there is a need for a set of rules to determine the system boundaries such that comparison of the environmental impacts of products can be possible. Such rules can be made available through PCR for different product categories, which in turn must be linked to the choice of FU.

The basic function of food is to deliver energy and nutrients to the body, but in developed countries the function is much more complex. The most commonly used FU in food production systems are based on mass, e.g. 1 kg (Schau and Fet, 2008). There exist, however, some exceptions, that of milk where the FU reflects the energy content (measured in amount of fat), protein content and lactose content (Cederberg and Mattsson, 2000; Casey and Holden, 2005). As shown in Paper II, using only mass for food products has certain drawbacks. One of these is the many different functions of food, which are not simply fulfilled by the property mass of a product. In particular for food products, energy content and other aspects such as hydrocarbon-share, protein-share, vitamin-share (e.g., the qualitative difference between different types of food products like meat and vegetables) could be reflected in the FU. One of the main properties of food products is to deliver energy to the body (Carpenter, Kent-Jones et al., 2011), such that the energy content should be taken into consideration. One way to take the multifunctionality of food products into account in LCA is to relate the results to a FU that takes more than one function of food products into account (Charles, Jolliet et al., 1998; Marshall, 2001). A quality corrected FU (QCFU) that takes this multifunctionality of food products into account is presented in Paper II and can be written as in formula (5), where X, Y and Z are factors and k is a constant which should be agreed upon among experts on different food products (Schau and Fet, 2008):

$$QCFU = \text{yield [kg]} \times (X \times \text{fat [g/kg]} + Y \times \text{protein [g/kg]} + Z \times \text{carbohydrate [g/kg]} + k) \qquad (5)$$

5.2.2 Allocation procedure in LCA of food products

The co-product allocation issue is important because it strongly influences the result of a food-product LCA (Ceuterick, Cowell et al., 1998; Cederberg and Stadig, 2003; Ayer, Tyedmers et al., 2007).

Biological causality is not mentioned in the ISO 14044 standard step 2 for handling co-product allocation, where only physical causality is mentioned. However, when it comes to food production, biological causality could be put on par with physical causality, as long as the different products and functions "reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system" (ISO 14044, 2006:p. 14). For example, biological causality could be used to allocate the environmental burden, e.g. the important GHG methane emission in milk and beef production system. As the fodder (input) is important for both the methane emission and the quantity and quality of milk and beef (the co-products output) from the system, there is a biological causality between input and output that can be used for co-product allocation (Schau and Fet, 2008). As most food production includes biological processes, allocation according to biological causalities is an opportunity for food products LCA.

One of the main uses of LCA is to overcome the deficit of the economic system to provide the total cost (environmental cost inclusive) of a product. Besides the price of a product, LCA is aiming at giving additional information to the decision maker. The results can be presented in an EPD. Using economic allocation could introduce this deficit of the economic system into LCA (and thereby EPD) (Pelletier and Tyedmers, 2011). Paper II argues that the product category rules (PCR) (for the EPD) establishes the allocation procedure and that the allocation procedure therefore must be seen in relation to the choice of FU (which is connected to the product category). In some cases, a sophisticated choice of FU could eliminate the co-product allocation problem. Remaining co-product allocation problems should be solved according to the recommendations in ISO 14044, taking into account the following remarks (Schau and Fet, 2008): System expansion should only be used where there is a possibility to subtract the additional function. In food production, biological causality should be put on a par with physical causality. If there is still a co-product allocation problem to solve, mass or volume and different quality aspects, including nutrient contents of food should be regarded alone or in combination as a basis for allocation in food products LCA. The result of the QCFU as presented in formula (5) could be used as a basis for co-product allocation. Economic co-product allocation should be used with care in LCA of food products.

Paper II concludes that LCA methodology is a valuable tool in conducting environmental impact assessments of food products, but further methodological development to account for food-specific functions like nutrient content is needed. To facilitate valid comparison between different products, system boundary description and FU need further development and standardisation. A more sophisticated choice of FU taking nutrient content of the food into consideration in addition to mass could both reflect the function of the food better and provide a solution to the co-product allocation problem that exists for some food products.

To sum up, the main outcome of Paper II has been:

- A recommendation for system boundaries, FU and allocation procedure
- A proposal for a quality corrected functional unit (QCFU) for food products

5.3 Paper III: Environmental impact categories for fish food products based upon a review of life cycle assessments in the food sector

There is a general consensus that the whole life cycle needs to be taken into account when looking at the environmental impacts of food products (PAS 2050, 2008; Baldo, Marino et al., 2009; Sinden, 2009). However, there is still a lack of a holistic view of (environmental) sustainable food production, which has to include more than only the global warming potential (GWP) issue of production and consumption (Yakovleva, 2007a; 2007b), especially where there are tradeoffs between GWP and other environmental impacts of food products.

The objective of Paper III is to find the most appropriate environmental performance indicators (EPI) for LCA of FFP aiming at communicating environmental performance to decision makers and other stakeholders.

Based on a broad review of food-LCAs, impact categories commonly used in food-LCAs are found. These include, but are not limited to, GWP, acidification potential (AP), eutrophication potential (EP), energy use, photochemical ozone creation potentials (POCP), ozone layer depletion potential (ODP), different toxicity potentials (like eco-, human- and aquatic toxicity), land and sea floor use and raw materials use. In addition, impact categories specific for food products like pesticides use, biotic depletion, biodiversity and animal welfare are in use for food products LCA. Seafloor use, by-catch and discard are impacts categories of special relevance for FFP.

Among the identified impact categories commonly used in food-LCA, the following criteria, which are derived from (Tyteca, 2001), are used to find the most appropriate EPIs for FFP:

The impact category 1) is accepted by the scientific community, 2) is of interest for stakeholders, 3) results are significant, and 4) is practicable when performing the LCA.

The suggested EPIs are as listed in the left column in Table 5.1.

The table gives the range of results for non-seafood products in the review, the range of results for seafood products in the review, and the figures from the LCA of pelagic FFP per FU which is said to be 1 kg frozen fish fillet.

Table 5.1: Environmental impact categories of relevance for FFP and the contribution to these impact categories

Environmental impact categories	Equivalents unit	Range of results for non-seafood products in the review (per kg food product)	Range of results for seafood products in the review (per kg seafood product)	Figures from the LCA of pelagic FFP per functional unit (FU) (1 kg frozen fillet)
Marine Aquatic Eco-toxicity Potential (MAETP)	[kg 1,4-DCB-Equivalent]	N.A.	$5.6 \times 10^{+1}$ - $7.2 \times 10^{+1}$ (b)	$6.72 \times 10^{+1}$
Energy use	[MJ]	5.50×10^{-1} - $1,58 \times 10^{+2}$	$1.51 \times 10^{+1}$ – $1.31 \times 10^{+2}$	$3.70 \times 10^{+1}$
Acidification potential (AP)	[kg SO_2-Equivalent]	5.50×10^{-4} - 1.36×10^{-1}	2.40×10^{-2} – 1.56×10^{-1}	1.71×10^{-2}
Eutrophication potential (EP) (a)	[kg Phosphate-equivalent]	1.32×10^{-4} - 1.91×10^{-2}	3.40×10^{-3} - 4.5×10^{-3} (b)	4.36×10^{-3}
Global Warming potential (GWP 100 years)	[kg CO_2-equivalent]	6.75×10^{-2} - $2.23 \times 10^{+1}$	1.80 - $2.09 \times 10^{+1}$	2.14
Photochemical ozone creation potential (POCP)	[kg Ethene-Equivalent]	2.37×10^{-5} - 2.55×10^{-3}	1.20×10^{-4} – 2.40×10^{-2}	2.03×10^{-3}
Radioactive radiation (RAD)	[DALY]	N.A.	N.A.	3.56×10^{-9}

Abbreviations: DCB : 1,4-dichlorobenzene
DALY: disability-adjusted life year

(a) Only studies with Phosphate as the equivalent unit has been considered in this table.
(b) The range of results for seafood products in the review are from (Hospido and Tyedmers, 2005) only.

In addition, the following specific EPIs are suggested for FFP (based on a review of diverse FFP, see Papers II and III):

- Fish consumption (target species, round weight)
- By-catch
- Discard to sea and
- Sea floor use.

Paper III shows that the contribution to an impact category can be presented by an EPI. This means that a set of EPIs for FFP could be presented as the last column in Table 5.1 The PCR-document for FFP should reflect this set of performance indicators and the LCA-results that have led to these results. The PCR for FFP should also state that EPDs shall only be made for wild caught fish from healthy stocks as other environmental impacts compared to non-sustainable fishing would be relatively unimportant and therefore not worth an EPD. Fish from stock where the quota are set too high or fish from illegal, unreported and unregulated (IUU) fishing should not be permitted.

In summary, Paper III has suggested a set of suitable EPIs for FFP.

5.4 Paper IV and Paper V: Energy consumption in the Norwegian fisheries (Paper IV) and Environmental analysis of Norwegian fish food products (Paper V)

Running a fishing vessel outside and along the coast of Norway is challenging and energy demanding. Catching seafood is often a net energy loss in many modern industrial fisheries targeting high valuable species (Tyedmers, 2004; Ellingsen and Aanondsen, 2006). Therefore, strong increase in oil prices leads to economic difficulties for most fleet segments. In some segments more than 30% of the catch value is used to pay for the fuel, and this is hardly economically sustainable in the long run. At the same time, Norway has signed several international agreements aiming at reducing the total emission of damaging combustion gases. The Kyoto protocol for abating GHG (United Nations, 1998) and the Gothenburg-agreement from 1999 (UNECE, 1999) which regulates the yearly output of sulphur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3) and VOC are relevant for the energy use in the fishing industry. At the same time, the market profile of "sound and fresh food from the sea" may be threatened if the environmental effects imposed by the sea food production exceed acceptable limits.

The catch phase is only one part of the FFPS, but is the dominant contributor to pollution. This is shown in Paper I and Paper III and supported by a number of studies, even when different fishing methods and distances to the fishing banks are taken into consideration (Christensen, Madsen et al., 2001; Eyjólfsdóttir, Jónsdóttir et al., 2003; Ziegler and Hansson, 2003; Ziegler, Nilsson et al., 2003; Hospido and Tyedmers, 2005; Ellingsen and Aanondsen, 2006; Thrane, 2006; Ziegler, 2006).

The goals of Paper IV are to:

- Identify the level of energy consumption in Norwegian fisheries as fuel use coefficients for various fleet segments over time
- Identify trends and potential influences (e.g. catch volume and fuel price) and find the basis for the development of better strategies to reduce fuel consumption
- Analyse fuel inputs allocated to major species landed and to different fishing gears

The goal of Paper V is to:

- Describe a method to find the fuel use coefficients (named specific fuel usage in Paper V) of the different fish species caught by the Norwegian fishing fleet

Paper IV shows that Norwegian fuel consumption in the fisheries is characterised by pronounced variations, between different years, fleet groups, fishing gears used and species caught. Dependencies exist between specific fuel consumption and catch rates on a yearly basis and between fuel consumption and oil prices on a longer term basis. The long term trend for all fleet segments investigated in Paper IV shows an increase in fuel consumption in the period 1980-2005. Trawling (wet fish and factory trawling) is shown to be more energy-intensive than other types of fishing fleet segments. In order to find sources of variation of energy consumption, inverse correlation between catch rate and fuel use coefficient [kg fuel/kg fish] as well as a long term inverse correlation between fuel use coefficient and the fuel prices was identified. The large number of fishing vessels, from which the statistics in Papers IV and V are based, makes it possible to get reasonable results for fuel use coefficient for different fishing gears and species even when a simple allocation method based on mass or economic value is used. This is not possible with one or very few fishing vessels where simple allocation would results in the same fuel use coefficient for all fishing gears used or species caught. Therefore, the allocation method presented in Papers IV and V, should only be used in cases where the number of fishing vessels are large (more than 30). This is in accordance with general statistics knowledge (Ringdal, 2001). Even though ISO 14044 recommends not to use mass allocation (ISO 14044, 2006), Paper III shows that together statistical methods and a large enough number of observations can yield reasonable results for simple mass allocation.

Table 5.2 shows the fuel use coefficients for most of the different fishing gears used by the Norwegian fleet. Purse seine and pelagic trawl are clearly the most fuel efficient fishing gears. Hook (handline and trolling line) is also a fuel efficient fishing gear in the Norwegian fisheries.

Table 5.2 Fuel use coefficients and statistics for gear types for the years 2001-2004 aggregated (Schau, Ellingsen et al., 2009)

		Allocation of fuel according to mass		Allocation of fuel according to value	
Gear type	Number of vessels reporting catch with gear	Average [kg fuel/kg fish]	St. dev.	Average [kg fuel/kg fish]	St. dev.
Bottom trawl	449	0.28	0.46	0.26	0.61
Double trawl	26	1.01	0.59	1.01	1.43
Pelagic trawl	307	0.09	0.10	0.06	0.11
Net	1152	0.19	0.19	0.18	0.18
Hook	708	0.15	0.14	0.11	0.10
Longline	694	0.31	0.14	0.32	0.16
Shrimp trawl	356	1.04	0.73	1.08	0.77
Purse seine/ ring seine	726	0.09	0.08	0.13	0.09
Danish seine/round-fish trawl/ Flat fish trawl	343	0.11	0.11	0.19	0.13
Fish trap (with and without bait within)	282	0.13	0.47	0.24	1.31

The difference between mass and economic allocation is small for double trawl, shrimp trawl and longliners and largest for fish traps. The small difference between the allocation methods for double trawl and shrimp trawl can be explained by the fact that the catch is dominated by a single species (shrimp) which in broad terms makes the choice between mass and economic allocation superfluous.

When it comes to fuel use coefficient for individual species, Paper IV shows that turbot (*Psetta maxima*), Dover sole (*Solea solea*) and brill (*Scophthalmus rhombus*) are species that require more than 2 kg of fuel/kg of fish. Shoaling fish like mackerel, Atlantic herring and capelin have lower specific fuel use than the more dispersed fish species (e.g. cod), as expected.

Norway lobster requires 1.04 kg fuel/kg catch when mass allocation is used and 3.09 kg fuel/kg catch when economic allocation is used. As shown in Paper IV, the difference between economic and mass-based allocation can be very high for some species.

Table 5.3 shows some important species caught by Norwegian fisheries over the period 2000–2004, the number of vessels reporting the catch of these species, the weighted average fuel consumption per kilogram of fish after using both mass allocation and economic allocation and their standard deviations. The last column in Table 5.3 shows the average first hand price obtained.

Table 5.3 Fuel use coefficients and statistics for some important species landed in Norway for the years 2001–2004 aggregated (excerpt from Table 4 in Paper IV)

		Mass allocation		Economic allocation		
Species name	# vessels reporting catch	Average [kg fuel / kg fish]	St. dev.	Average [kg fuel / kg fish]	St. dev.	Average 1. hand value of species [NOK / kg]
Atlantic cod (*Gadus morhua*)	1229	0.35	0.22	0.50	0.31	12.21
Atlantic herring (*Clupea harengus*)	471	0.09	0.099	0.14	0.099	3.41
Atlantic wolffish (*Anarhichas lupus*)	1003	0.34	0.37	0.25	0.47	6.89
Blue whiting (*Micromesistius poutassou*)	254	0.09	0.059	0.05	0.031	0.83
Capelin (*Mallotus villosus*)	236	0.09	0.050	0.05	0.027	1.16
Golden redfish (*Sebastes marinus*)	1234	0.37	0.32	0.32	0.27	7.36
Greenland halibut (*Reinhardtius hippoglossoides*)	1129	0.43	0.39	0.87	1.10	20.22
Haddock (*Melanogrammus aeglefinus*)	1545	0.40	0.39	0.40	0.26	9.23
Ling (*Molva molva*)	1235	0.31	0.41	0.38	0.27	13.89
Mackerel (*Scomber scombrus*)	782	0.09	0.18	0.31	0.19	7.62
Northern prawn (*Pandalus borealis*)	229	1.04	0.73	1.08	0.79	11.61
Norway pout (*Trisopterus esmarkii*)	50	0.10	0.040	0.05	0.025	0.80
Saithe (*Pollachius virens*)	1658	0.37	0.37	0.24	0.15	4.46

Fuel use coefficients are found by connecting two databases, A and B, using the unique identifier Fishing ID and year. Database A is the Norwegian fish catch register, which contains all registered catches landed in Norway, with information about which fishing vessel that is landing the catch (the Fishing ID), fish species, fish weight, catching area and first price paid. Database B contains the results of the yearly profitability investigations, which have been performed since 1966 among a statistically representative draw (e.g. in 2003 only 607 out of the total 2056 fishing vessels operated for a whole year). Database B also holds information related to the fishing vessel such as the unique identifier Fishing ID, size of the fishing vessel (length, width, tonnage), age of the fishing vessel, number of operating days and days in the sea, yearly fuel costs and other financial parameters from the fishing vessels annual financial statement; and, since 2001, the yearly fuel used measured in litre.

Table 5.4 is an update of the data from Paper IV and Paper V, with additional information of edible yield (in the last column). The edible yield varies considerable among different species, and is therefore important when it comes to the environmental impact of FFP together with the figures for fuel consumption per kg round fish.

Table 5.4 Fuel use coefficients and statistics and yield for some important species landed in Norway in 2005 (based on Table 4 in Paper IV – updated with 2005-statistics (Steinseide and Ølmheim, 2006)and yield from (Fiskeridirektoratet, 2010))

Species name	Number of vessels reporting catch	Fuel consumption - mass based allocation Weighted Average [l/kg]	St.dev.	Fuel consumption - economic allocation Weighted Average [l/kg]	St.dev.	Price [NOK/ kg]	Edible yield [%] (Skinn off, boneless fillet)
Angler/monkfish	358	0.337	0.332	0.615	0.425	23.83	17.9
Argentines	13	0.135	0.131	0.108	0.072	2.69	50.0
Atlantic cod	555	0.341	0.331	0.492	0.288	13.56	30.8
Atlantic halibut	382	0.378	0.275	1.186	0.677	37.71	37.0
Atlantic Herring	246	0.111	0.130	0.135	0.103	3.87	50.0
Atlantic redfishes	11	0.891	0.414	0.306	0.173	7.55	21.0
Atlantic wolfish	317	0.421	0.289	0.405	0.302	7.07	24.5
Beaked redfish	39	0.500	0.190	0.503	0.176	9.66	21.0
Blue ling	97	0.335	0.381	0.190	0.101	5.97	35.7
Blue whiting	169	0.104	0.132	0.036	0.018	0.72	35.7
Brill	27	2.518	0.660	7.768	1.854	55.60	41.7
Dover sole	25	2.663	0.649	11.219	2.665	75.02	41.7
Forkbeard	27	0.311	0.567	0.147	0.557	5.71	35.7
Golden redfish	451	0.384	0.284	0.373	0.171	9.17	21.0
Greenland halibut	229	0.389	0.179	0.847	0.393	22.05	50.8
Haddock	563	0.364	0.325	0.368	0.175	8.90	31.7
Hake	180	0.410	0.370	0.561	0.290	21.56	35.7
Lemon sole	63	0.720	0.582	1.707	0.725	17.76	41.7
Ling	465	0.319	0.349	0.344	0.156	12.70	35.7
Mackerel	201	0.111	0.117	0.449	0.211	12.86	38.5
Pollack	297	0.252	0.311	0.243	0.207	8.72	38.5
Roughhead grenadier	30	0.385	0.208	0.191	0.080	5.40	22.3
Saithe	629	0.340	0.312	0.261	0.148	4.81	33.3
Spoted sea cat	190	0.370	0.183	0.257	0.127	8.95	24.5
Turbot	97	2.141	0.468	8.836	1.846	70.61	41.7
Tusk(= Cusk)	431	0.324	0.274	0.219	0.121	7.92	20.8
Whiting	63	0.921	0.711	0.509	0.231	5.74	35.7
Witch	54	1.187	0.739	0.985	0.507	15.46	41.7

Table 5.4 shows that Dover sole, brill and turbot are the fish species with the highest specific fuel consumption, both for allocation based on mass and economic allocation. The most fuel efficient species in Table 5.4 are blue whiting, capelin and Atlantic herring when mass allocation are used. This finding is also valid for economic allocation, except that argentines are slightly better than Atlantic herring. However, for argentines, the number of vessels reporting catch of argentines are not very high (only 13), which suggests that the statistical base is not very good.

The data for the edible yield of fish is not easily accessible. Conversion factors, which are developed to find the weight of whole fish (round fish weight) when landed in prepared format have been used. Other edible yield can be found from a study finding the best species for fish farming (Quéméner, Suquet et al., 2002). The Norwegian conversion factors operate with several different fish product categories like different gutted products, fillet products and backs. In Table 5.4, the fillet products without skin and bones are used. For this fish product category the conversion factor for most species exist. Therefore, the yield data in Table 5.4 indicates how much of the different species are edible fillet. How much of the product are co-products has not been discovered on a species level. Data from RUBIN, a foundation working for more use of by-product of Norwegian fish, show that only a fraction of the round fish is used (RUBIN, 2010). Of cod-fish (Atlantic cod, saithe, haddock, Greenland halibut, tusk, ling/blue ling, pollack, Atlantic wolffish and Atlantic redfishes) only 72 000 tonn (out of 244 000 tonns) or 29.5% was used in different products for human consumption (28500 tons), feed for fur animals (21 000 ton) and other products in year 2009 (RUBIN, 2010; Olafsen, 2011).

The allocation method applied in Paper IV and Paper V may also be of interest for other food products, where there is a complex allocation problem, as for example for the production of milk and beef from cattle.

Papers IV and V together with added information in this section have shown:

- A method for finding the fuel use coefficient of different fishing gear and species
- Fuel use data from Norwegian fisheries allocated to fishing gear and species, and
- Yield of different species

Fuel data coefficient of different fishing gear and species are of great importance when it comes to the standard for PCR for FFP which are under development in Norway coordinated by Standards Norway. Thanks to the preparation for this PhD, the fuel data is now made accessible, quality assured and maintained by the Directorate of Fisheries (Steinseide and Ølmheim, 2006).

5.5 PCR for wild caught fish and an EPD for Atlantic herring

5.5.1 PCR for wild caught fish

A product category is a group of products that fulfil the same function[2]. The objective of the PCR is to set out the requirement that must be met when preparing an EPD. The PCR found in Appendix F defines the criteria for the specific product category wild caught fish. The PCR aims to identify and define rules for the process of creating an EPD, in order to enable a comparison between products. The PCR for wild caught fish:

- Identifies the functional and performance characteristics of the product
- Defines the criteria to be used in the LCA study of products belonging to the category wild caught fish
- Specifies the information that must be reported in the EPD.

The PCR complies with the requirements of ISO 14025 and the ISO 14040 standards on LCA. The development of the PCR-document has been done parallel to and as an integrated part of this PhD-project. This is the first known PCR that has been developed for seafood, and it received an international hearing before it was approved by the verification committee of The Norwegian EPD Foundation (EPD-Norge). In addition, the PCR has been posted on the homepage for EPD-Norge since 2006 (The Norwegian EPD Foundation, 2011). Since the validation date now is passed, a project, involving scientific experts, as well as people from industry, has been launched by Standards Norway. The aim of the project is to develop a Norwegian PCR for carbon footprint for seafood according to ISO 14067 to be ready for use in 2012 (Standard Norge, 2011).

5.5.2 EPD for Atlantic herring

The objective of the EPD presented in Appendix F is to communicate the results from the case study of Atlantic herring consumed in Germany. The EPD follows, with minor adjustment, the proposed format from the Nordic Project for Implementation of EPD Type III in the Business Sector (NIMBUS) (Hanssen, Stranddorf et al., 2001) and is based on the PCR for wild caught fish. The EPD contains information about the compiler of the EPD and a picture of the product. The key information is given on page 1 in a red frame to highlight key environmental information. Also some fishery specific environmental information such as by-catch and discard are given on the first page. On the following pages, results from the LCI and LCA are given in the form of tables and figures. Also a description of the system investigated, methodological choices and a figure of the system boundary are found in the EPD. The EPD presents all the information from the LCA that

[2] For a thorough description and discussion of the function of food products, see Schau, EM and Fet, AM (2008).

the stakeholder may be interested in, and at the same time presents the key information that could be used in product labelling in a simple way.

Calculations show that 3.03 kg Atlantic herring from the sea is the required amount to produce 1 kg frozen fish fillet (the FU) for consumption. The by-catch is 32.9 kg (mainly Saithe and Blue whiting), and the total discard to sea is 0 g due to legal requirement in Norway where discard is not allowed (Oust, Luther et al., 2004). The total energy consumption is 37.0 MJ/FU. How this is distributed between the different life cycle phases and energy sources is shown in Figure 5.3. Results from the other impact categories investigated are shown in Figure 5.4.

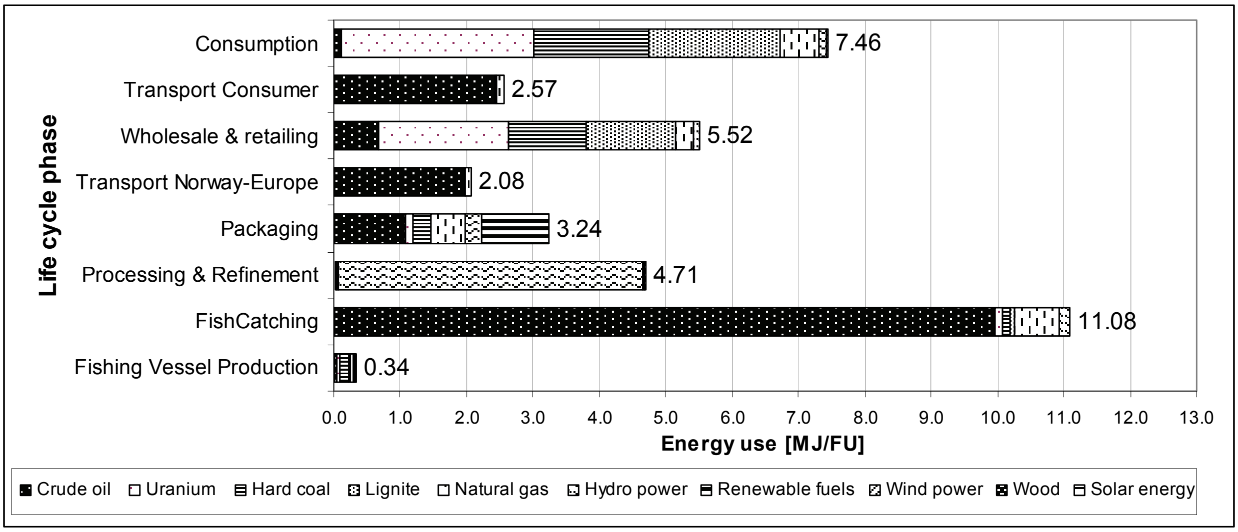
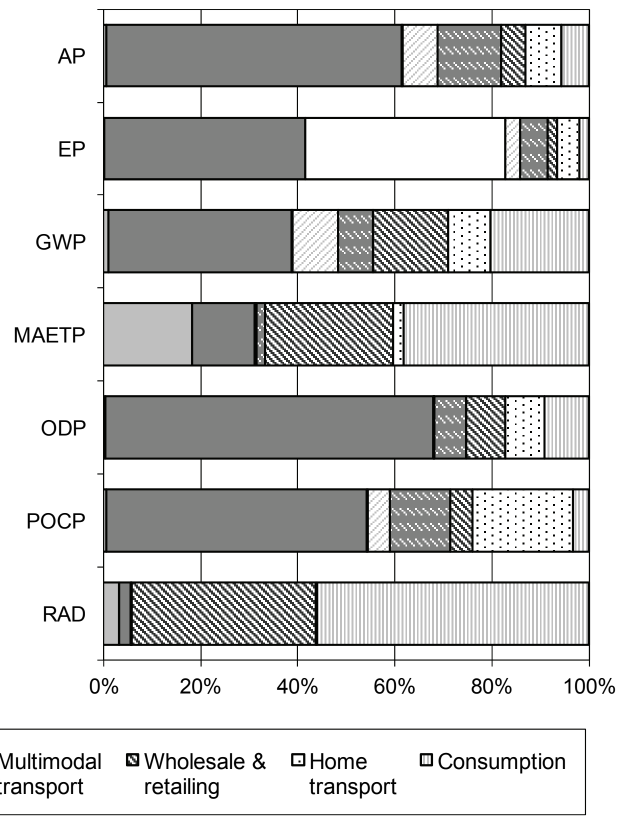


Figure 5.3: Energy use and sources for the life cycle phases of the FFP

The results show that fish catching process dominates the AP, ODP and POCP impact categories. Fish catching is the largest contributor to the impact categories EP and global warming potential. The consumption phase dominates the RAD impact category and is the largest in the MAETP impact category (sic.). But for these last impact categories, also the wholesale and retailing phase are important.

Impact category	Total
Acidification Potential (AP) [g SO_2-equivalent]	17.1
Eutrophication Potential (EP) [g PO_4-equivalent]	4.4
Global Warming Potential (GWP) [kg CO_2-equivalent]	2.14
Marine Aquatic Eco-toxicity Potential (MAETP) [kg DCB-equivalent]	67.2
Ozone Layer Depletion Potential (ODP) [mg R11-equivalent]	0.836
Photochem. Ozone Creation Pot. (POCP) [g Ethene-equivalent]	2.03
Radioactive Radiation (RAD) [DALY]	3.56×10^{-9}



Abbreviations: DCB : 1,4-dichlorobenzene
DALY: disability-adjusted life year

Figure 5.4: Impact categories - Results from the case study, total absolute values and share of the different life cycle phases.

One shortcoming with the presented EPD is that it does not reflect where the fish is caught, i.e. if it is from sustainable fishing according to the requirements of MSC or KRAV. But, as stated under the presentation of Paper III, an EPD should never be produced for FFP from unsustainable fishery. This requirement should also be stated clearly in the PCR. Another shortcoming is that the EPD does not reflect the damage on the sea floor; but the sample EPD is for Atlantic herring (a pelagic fish), and sea bottom trawling is not an actual impact in this case.

A summary for Appendix F is:

- An early model of a PCR was developed as a pioneer work, it is now time to update this.
- The EPD developed for Atlantic herring is another example of work in the forefront. No EPDs according to ISO 14025 were developed for FFP as early as 2009 and here too it is time to develop the template and the content further, and to see how the EPD can be harmonised with other eco-label schemes, like MSC and KRAV.

6 Discussion

This chapter reflects on the outcome of the research, and the discussion is structured according to
- Research methods
- The achievement of the main goal and sub-goals
- The contribution to environmental sustainability in fisheries

6.1 Research methods

Chapter 3 gives an overview of the research methods and this discussion mainly concentrates on the use of SE and LCA. Table 6.1 offers a visual summary of the outcomes of using these research methods to understand the problem domains of fishery, FFPS and FFP.

Table 6.1: Research methods outcomes

SE as an overall methodology to structure the papers and the thesis	Figure 1.1
SE applied to describe and analyse the FFPS	Figure 4.1
SE integrated in a framework for environmental analysis of the FFP	Figure 5.2
LCA integrated in a framework for environmental analysis of the FFP	Figure 5.2
LCA used to evaluate the carbon footprint of the FFP	Papers I, III
LCA used to calculate data on energy use in the Norwegian fishing fleet	Paper IV
LCA used to provide data for the EPD	Appendix F
LCA used to find significant EPI	Paper III

6.1.1 SE as applied in this thesis

6.1.1.1 SE as an overall methodology to structure the papers and the thesis

SE is used to structure and map the research questions with the appropriate methods onto the eventual publications and outcomes, as illustrated in Figure 1.1. NTNU has a strong tradition of applying SE as an umbrella methodology for structuring PhD research (Fet, 1997; Haskins, 2008; Nørstebø, 2008). SE provides a disciplined process that supports the researcher in a systematic conduct of the research over the many years of the PhD journey.

6.1.1.2 SE to describe and analyse the FFPS

SE has proven to be a valuable tool for describing and analysing the FFPS. The life cycle of the FFPS intersects several other systems, such as packaging. Keeping track of all these systems and their interactions was a challenge. Focusing on who are the stakeholders to the different systems, their needs and the derived requirements for the system, helped to define the important attributes of the different systems.

Development of a simple model demands skilful use of SE; it has been important to get both the fishing vessel and the different life cycle phases of the FFP into the same system model, to ensure that a holistic perspective is achieved in the analyses. It has been possible to view the intersections between the life cycle of the fishing vessel, the FFPS processes, and the life cycle of the FFP from extraction from the ocean to the tabletop of the consumer such as shown in Figure 4.1.

One challenge in the thesis has been to reduce the work to a manageable size and still fulfil the stated objectives. A by-product of using SE is that the problem domain could be expanded to be as inclusive as possible. Since SE is frequently applied to the development of large complex (often technical) systems, the process helped the researcher reach the right balance between detailed system descriptions and an easy-to-understand system description that includes enough details to be accurate.

6.1.1.3 The SE process applied to develop the framework for analyses of FFP

SE is integrated into the framework for environmental analysis of the FFP shown in figure 5.2. Again, the structure and discipline imposed by the SE process helped to organise the contributions from myriad ISO standards. The researcher followed a methodology developed from this framework to structure, organise and perform the activities indicated.

6.1.2 The use of LCA

LCA has been studied and applied in different ways in this study, and appears as an integral part of the framework for environmental analysis of the FFP. In addition, LCA has been:

- Used to evaluate the carbon footprint of the FFP
- Used to calculate data on energy use in the Norwegian fishing fleet
- Used to provide data for the EPD
- Used to find significant EPI

Discussions of EPI are found in Section 6.2.2; remaining topics are discussed below.

6.1.2.1 LCA as part of the framework

LCA also is integrated into the framework for environmental analysis of the FFP shown in figure 5.2. LCA is defined over multiple series of ISO standards, so the researcher must have some familiarity with the relevant standards to apply them appropriately. For example, the selection of appropriate impact categories appears in Part C of the framework. LCA is well suited to evaluate a range of different environmental impacts. However, for some impact categories that are of great importance for food products, there is need for further research, such as toxicity and the impact on biodiversity. Users of LCA results should keep in mind that there are uncertainties in the potential impacts identified. The fishery specific impact categories, fish consumption (target species), by-catch, discard to sea and sea floor use (cf. Section 5.3), are not (yet) recognised as general impact categories in the LCA. This may cause problem when comparing different fish species and especially when comparing fish products with other food products. However, these concerns do not in themselves invalidate the framework or the results achieved in the case study.

6.1.2.2 LCA used to evaluate the carbon footprint of the FFP

The carbon footprint of the FFP can be derived directly from the climate change impact category. In the example in Paper I, only CO_2–emissions are counted to illustrate the method; ideally, other GHGs should be included, as in Paper III. However, if the goal is to find the carbon footprint, a full LCA may be too resource intensive. Using LCA software, performing carbon footprint analysis and LCA is quite similar if the LCA includes only the standard impact categories. For an LCA of FFP there is some additional work to specify the fishery specific impact categories. However, if the FFP is from declining fish stock, the carbon stored in the fish resource also decreases, and this decrease of carbon has to be accounted for in some way. Further research is necessary if one wants to perform an LCA or a carbon footprint analysis on non-sustainable fisheries. However as noted in Paper I and exemplified in Paper III, I do not believe the efforts invested for performing a full LCA of non-sustainable fisheries pays off. The impact category *impact on target species* would completely dominate the results and the only life cycle phase worth investigating would be the fishing phase, instead of performing LCA of the FFP.

6.1.2.3 LCA used to find data on energy use in the fishing fleet

With the help of co-product allocation procedures from the LCA methodology, the fuel usage coefficients for distinct fish species and distinct fishing gears in the Norwegian fishing fleet were calculated. The results are the first of this kind.

An open point of discussion is the importance of including all kinds of fishing gears in the results for distinct species (Table 5.3 and 5.4) and likewise, all kind of species in the results for fishing gears (Table 5.2). For example, the low figures for the bottom trawl (0.28 kg fuel/ kg round fish using mass allocation), were surprising for the authors of Paper IV, until a further investigation of the single vessel specific data resolved that a large amount of blue whiting is caught with bottom trawl. Blue whiting is the fish species with the largest annual catches in the database. Even though blue whiting is mainly caught with seiner and pelagic trawl, the part of blue whiting caught with bottom trawl also has a relatively low energy coefficient. So low that the blue whiting fish caught with bottom trawl can draw the average mean figures for bottom trawling down to 0.28 kg fuel/ kg round fish using mass allocation. However, the overall results show significant variation in the fuel use coefficient for distinct fish species and distinct fishing gears, and therefore the results contribute to better understanding of which species and which fishing gear that use most fuel.

6.1.2.4 LCA used to provide data for the EPD

The main data source for the EPD is the underlying LCA studies. In addition, according to the PCR, the EPD can present further information. However, the EPD is a way to present the LCA result in a standardised manner according to (ISO 14025, 2006). As such the EPD is a contribution to make the LCA studies of FFP more comparable.

PCR and the framework is a help in this regards. Both require a harmonised FU, system boundaries and allocation procedure. On the other hand, in the development of LCA, more sophisticated FU for food product, such as the QCFU proposed in Paper II would be promising. LCA presently has the limitation, that environmental impacts that are not linearly related to the FU are hardly realised as impact categories. Examples of such environmental impacts from the FFPS are sustainability of the fish stock and ghost fishing. A way to overcome this problem is to combine LCA with other environmental labelling schemes based on or referring to the FAO Code of Conduct for responsible fisheries, like MSC and KRAV that have a focus on fishery specific impacts. These challenges are not unique for FFPS. Therefore, more sophisticated FU and focus of the need may be a way out of other allocation problems facing LCA practitioners. Finally, PCR, with its focus on specific product categories, gives more guidance to the LCA practitioners than the ISO-standards and general LCA literature. The development of additional PCRs for other product groups can draw on the work presented in this PhD thesis.

6.2 Discussion of the main goal and sub-goals

The main goal of this PhD-project is to *develop and demonstrate a methodology for systematic assessment of the environmental impact for the entire lifecycle of FFP based on a life cycle assessment approach with emphasis on the fishing phase*, as indicated by the title of this thesis.

Figure 4.1 illustrate how fish from the sea is introduced in the technosphere (system boundaries) in the fishing phase where the life cycle of the FFP starts, physically on the fishing vessel.

The fishing phase, which includes the catch of the fish, is the major contributor to impact categories like energy use, climate change, eutrophication, acidification and photochemical ozone creation potentials. This is one of the results of the case study as presented in Paper III and also supported by other LCA studies of fish (Ziegler, Nilsson et al., 2003; Hospido and Tyedmers, 2005; Vázquez-Rowe, Moreira et al., 2010)).

Even though the energy use of the fishing vessel has been of great concerns among the fishing industry and researchers (Hassel, Farstad et al., 2001; Tyedmers, Watson et al., 2005; e-fishing, 2010), the fishing vessels life cycle, with its design, choice of propulsion method and energy carrier in addition to fishing gears applied has often been omitted in LCAs of FFPs. Reasons for this exclusion is lack of data (Svanes, Vold et al., 2011), that the construction of the fishing vessel was considered to be negligible (Ziegler, Nilsson et al., 2003; Ellingsen and Aanondsen, 2006) in line with earlier studies (Ellingsen and Pedersen, 2004) or that the construction of fishing vessel is considered to be outside the system under study (in line with other capital equipment that is often left out of LCA-studies (Klöpffer and Grahl, 2009)). Therefore, the fishing vessel has been of special interest in this PhD-project. With the availability of LCI data from a construction of a fishing vessel, it has been possible to investigate the contribution of construction and maintenance of the fishing vessel to the overall life cycle of the FFP. The results from the case study (c.f. Paper III and the EPD) show, as expected, that energy use in the fishing phase is dominating most impact categories, but also that the construction of the fishing vessel significantly contributes to MAETP. The few other studies of FFP known that include the construction of the fishing vessel, support the conclusion that the material use in the construction phase of the fishing vessel is of minor importance in the impact categories investigated, except from the toxicity potential (Vázquez-Rowe, Moreira et al., 2010).

Weighting different environmental problems against each other involves normative references. Therefore, to compare traditional LCA impact categories against fishery specific environmental impacts is difficult. However, use of fossil energy sources is a problem in itself, as this is a finite non-renewable resource and the combustion of fuel contributes to other environmental impact categories like climate change, acidification and eutrophication. The extraction of oil, fuel production and transport of fuel also cause environmental impacts. The review in Paper II and the case study in Paper III show that the energy use and related emissions in the fishing phase dominate several impact categories.

This thesis recognises that fishery specific environmental impacts are important for the FFP, but argue that energy use and environmental impacts resulting thereof in the fishing phase are as well important when it comes to environmental sustainability of FFPs.

6.2.1 A model for system description and for environmental analysis of FFP

The first research questions were formulated to address this sub goal and are concerned with system modelling and environmental analysis.

The model of the FFPS as shown in Figure 5.1 includes the fishing vessel, with its own life cycle, and where the fish catch process is an important part, the fish processing, which also can be (but not always is) performed on the fishing vessel and transport. It has been a great challenge to find the best way to integrate the fishing vessel with its own life cycle into the FFPS. Figure 4.1 illustrates how this challenge has been resolved. The fishing vessel's life cycle crosses the life cycle of the FFP in the use phase which is the fish catching phase. The design and construction phase is an important life cycle phase of the fishing vessel, especially when it comes to environmental performance of the FFP. In the design and construction phase, parameters such as the energy use of the fishing vessel are largely determined. Examples of decisions taken in the design and construction phase are vessel shape, energy source, and gear used, which later in the use phase to a large degree determinate the environmental impacts.

The framework for environmental analysis of the FFPS presented in Figure 5.2, integrates the six-step SE method, international standards for environmental LCA and communication in addition to tracing systems for the FFP. The way Figure 5.2 is structured and how it can be used is described in detail in Section 5.1.2. This demonstrates that existing environmental analysis tools developed for the commodities industry can be used to assess the FFPS.

6.2.2 Impact categories and EPI

The research questions for this sub goal address the impact categories and EPI for FFP based on LCA.

Papers II and III review and apply impact categories used in the LCA of food products in general and FFP in specific. The topic of impact categories has been discussed in section 6.1.2.1.

EPI is a concept borrowed from environmental management of organisations (ISO 14031, 1999), but is in this thesis used on the environmental performance of products (the FFP) in line with Huijbregts, Rombouts et al (2005). The EPIs are found among the significant impact categories. The criteria for significant impact category are based on the case study and the review of LCA of food products and presented in Paper III. There is no guarantee that all FFP would give the same result. It may be that impact categories that are found insignificant in Paper III are found significant for other FFP.

Indicators are used for information to decision makers and other stakeholders of the FFP. Therefore, selection of EPI that are most appropriate to the market and embraced by the stakeholders should be evaluated after the EPD for FFP has been established and used for some time. This is left for further research.

6.2.3 Database with fuel use for fishing vessels and a method to calculate the fuel use coefficients based on this.

The set of research questions address the energy use of Norwegian fishing vessels and how this varies between the different species caught and different fishing gears applied.

Papers IV and V use official data collected and stored by the Norwegian Directorate of Fisheries. Thanks to the application of the data in this PhD-thesis, the database, with a representative draw of fuel use from about 500 Norwegian fishing vessels (engaged in year-round fishery), is also quality assured by the Norwegian Directorate of Fisheries. Further work remains to survey the fuel use of fishing vessels that only operate part of the year and small fishing vessels that do not participate in the survey conducted by the Norwegian Directorate of Fisheries.

The first use of this fuel data was in this PhD-project to find the level and long term trends of fuel consumption in addition to calculate the fuel use coefficient [kg fuel/ kg fish] for the Norwegian fish species and for fishing gear used in the Norwegian fishery. As a SINTEF-report (Winther, Ziegler et al., 2009) indicates, the data is not uniformly distributed based on the species caught and on the fishing gear used. For some species, where typically smaller vessels that only operate part of the year catch large quantities (e.g. the Lofoten cod fishery), the data presented in Papers IV and V are less representative than for large vessels operating the whole year, typically catching blue whiting with pelagic trawl. However, the overall representativeness is good (92.9 % of the total Norwegian landings was caught with fishing vessels larger than 8 meters with landings throughout the year 2004 (Fiskeridirektoratet, 2006)).

The data can further be used for carbon footprint of different FFPs as demonstrated by Paper I. However, for a complete carbon footprint, additional data about for example refrigerants use are needed.

The fuel use database employed in Paper IV gives some answer how the fuel use varies with different species and different fishing gear and over time. However, the variations in fuel use with seasons, distance to the fishing field from the home port and fishing vessel parameters such as length, GT and age remain unanswered questions the database can cast light on. Likewise, the fuel use variations with profitability of the fishing vessel company or the fishing vessel are only partially answered. From both a policy view and on behalf of fishers and fishing vessel companies, these are questions that may help to determine how to minimise the fuel use. The fuel use database could be helpful in such further research.

6.2.4 A model for the communication of the environmental performance of FFP

The final research questions address the documentation and communication of the environmental performance of FFP to the stakeholders and are grounded in the need for more information by decision makers. Without environmental information, other aspects of the product (e.g. price) are the sole basis for the decision.

Documentation of the environmental impacts should be according to well recognised standards and if possible verified procedures and tools, such that an overall regime for all food products could be made out of a common basis. This thesis proposes EPD as a tool for providing the consumer with information to make an informed decision based on environmental aspects of the FFP. As the EPD shows results from the whole life cycle, this improves the transparency of the FFPS for the user of the EPD.

Step H of the framework (Figure 5.2) is concerned with dissemination of environmental information about the FFP that is presented to the stakeholders. The EPD according to (ISO 14025, 2006) is chosen to present the environmental information of the FFP. Appendix F includes an example of an EPD and a PCR for wild caught fish. To meet the demand for stakeholders requiring extensive information, the EPD presents the comprehensive environmental information resulting from the life cycle impact assessment, and excerpts from the LCI and methodological choices in the LCA. To meet the demand of stakeholders that want only the most important information, the EPD summarises the product and some key information on the front page. The EPD can be used as a valuable source of information by a range of stakeholders such as public and private purchasers; especially those of grocery chains and the final consumers.

6.3 Contribution to environmental sustainability issues in the fisheries

A contribution to sustainable development in the fisheries is one of the overall goals of this thesis. As stated in the introduction, this PhD-work has been part of the SINTEF-project "Sustainable Vessel Technology and Fleet Structure" with the goals of developing technologies and methodologies that can be used to measure and document the environmental impact of fisheries and contribute to a more sustainable fishing industry. The results of this research have demonstrated that LCA in combination with SE is a comprehensive methodology that addresses the stakeholders view through the framework as presented and demonstrated for the case study.

Since fishery is based upon utilization or harvesting of natural resources, the global industry needs to adapt to the natural carrying capacity of this resource to contribute to a sustainable future. This is not always the case as it is practiced today. Furthermore, sustainability encompasses not only the environmental, but also the economic and social dimensions. This research has focused on the environment. However, it is left for future work to expand the framework as presented in Figure 5.2 to cover the other sustainability dimensions. This expansion will require that the framework is supplemented with other analytical tools to address the economic and social dimensions, e.g. social LCA (Dreyer, Hauschild et al., 2006; Basset-Mens, Small et al., 2008; Jørgensen, Le Bocq et al., 2008) and fair trade (Renard, 2003; Raynolds, 2009).

Focusing on the environmental aspects of sustainability for the fisheries, it is clear that eco-labelling is regarded by some stakeholders mainly "as a marketing tool, aimed at increasing market share, extracting a price premium, and in the case of retailers including sustainability in their fish and seafood procurement policies, a tool for attracting and maintaining customer loyalty" (Schmid and Connelly, 2009:p. 10). However, eco-labelling schemes are also used by the fish industry to assess the gap between today's practice and the requirements set in the eco-labelling scheme, even in cases where actual certification will not be possible. In addition, the fish industry may lobby their government for better fisheries management practice such that the fishery are eco-labelled (Schmid and Connelly, 2009). Where this occurs, the industry is on the right path to a more sustainable development.

The master equation as presented in Section 2.1 shows how the sustainability problem of fisheries can be divided into three factors. The first concerns the number of people depending upon the resources (too many people), the second concerns consumption (too much consumption) and the third is connected to the economic output for each unit of output. Regarding the number of people, this is unlikely to decrease from a fisheries point of view. From this it follows that fish as a food source will also be difficult to curb. However, the utilization of the FFP should be maximised and as little as possible wasted throughout the life cycle. The most obvious parameter to change therefore is the technology factor or eco-efficiency. This can be done through a higher price per unit of product, which can be attained by adding value to the product, for example through environmental labelling and gives the customer the satisfaction of doing the right thing – as an additional attribute of the product. Increased utilization of fish and fish residues that today go into fish oil and fish meal production can be directed toward human beings with the potential of earning a higher price since fish for (direct) human consumption is sold for a higher price than fish for the feed industry. A second option for addressing consumption is to reduce the environmental impact of the FFP (while keeping the price the same) by e.g. applying more fuel efficient fishing vessels and fishing gears. A third option, and frequently considered as the last resort for critically endangered fish stock, is to reduce – or stop - the fishing effort. In the short term, this may lead to reduced catch and (theoretically, as the supply decreases) higher prices, and in the longer term, hope for increasing the fish stock that may lead to more fish output with less effort.

The master equation also indicates a need to balance the environmental impacts of fishing, related to the fish resources on the one side and fossil fuel and emissions on the other side. The fish resources are at the same time both the outcome of the FFPS and an environmental impact (use of renewable resources), while the use of fossil fuel (non-renewable resource) and emissions are environmental impacts - unwanted side-effects that should be minimised. From the fishers' point of view, a large catch of fish can generate a high income, while use of fossil fuel (and connected emissions) should be minimised to reduce the financial and environmental costs.

Sustainability is a difficult notion where different stakeholders have their own view of what is sustainable. Eventually, the buyers use the information they have to decide what they want to buy. A buyer for one of the largest German supermarket chains has stated that "for us, sustainability deals with far more than catch and management. It also deals with, for instance, waste disposal, packaging and energy consumption" (Solheim, 2011). With that in mind, information for the whole life cycle of the FFP, including the energy for catching the fish, needs to be communicated to the stakeholders.

Transparency is a requirement for involving stakeholders in the decision making process (Mikalsen and Jentoft, 2008). Products have several attributes, such as the visual appearance, label, origin, producer etc. The price of a product is often the dominant attribute when it comes to the purchase decision. However, prices do not necessarily reflect the whole environmental costs of products, which is the case when externalities are externalised. Therefore, environmental information of a product is necessary, such that the environmental aspect of sustainability also is recognised besides the economic and social aspect in the decision-making process (Williams, 2004). By providing life cycle environmental information, the value chain transparency increases. This is important, as the main environmental problems arise early in the value chain, in the fish catching phase. With such environmental information, the decision makers, like consumers and retailers at the end of the value chain, have the opportunity to make more sustainable decisions.

7 Conclusion

The main objective of this research was to develop and demonstrate a methodology presented as a framework for systematic assessment of the environmental impact for the entire lifecycle of FFP with emphasis on the fishing phase. This chapter gives some concluding reflections on how well the goal of the research is achieved. It further gives a few thoughts around the contribution of this research to the SINTEF strategic institute program.

7.1 Conclusion on own research

A methodology for systematic environmental assessment of FFPS is developed and presented as a framework in Figure 5.2. The application of this framework is demonstrated on a case as presented in Paper I. The robustness of the framework has not been evaluated yet, especially when it comes to the combination with assessment tools other than LCA. The framework is further not tested on a larger set of cases, which is recommended for the development of a more generic framework for analyses of complex systems. A formal documentation of the methodology and the related activities offers an opportunity for further research.

Further, the case study has mainly focused on the fishing phase. The documentation that is developed (the EPDs) has information derived from LCA that does not reflect the environmental impact of overfishing nor other fishery specific effects e.g. fishing gears. This means that the current version of EPD-schemes does not provide complete information on the environmental impacts of FFP. Information covered by MSC and other eco-label schemes covers other aspects than (traditional) LCA-results. This is thus an area of further research. The system for EPDs gives information that is reliable and traceable, but does not cover all aspects of the FFP and can thereby result in misinformation.

Other outcomes of the research are, as presented in Figure 1.1:

- System boundaries, FU and co-product allocation procedure
- Indicators for EPD for FFPs
- Data of fuel use by Norwegian fishing vessels and a method to find the fuel use coefficient
- Communication of the environmental performance of FFPs

7.2 Final remarks

This PhD-project has thrown light on some important issues facing the fishing sector, both regarding data collection, knowledge of environmental impacts of the life cycle of FFP, and understanding of the impacts from different systems and sub-systems in the FFP's life cycle. The PhD-project has moved from data survey and literature research to the development of a comprehensive methodology presented as a framework that can be used to map the environmental impacts for FFPs. Ways in which the framework can be used to find the carbon footprint and produce results that can be documented by product declarations has been demonstrated. The framework can be further developed to address sustainability issues in a broader perspective.

During the years the results have emerged from the research and the situation today suggests that the results are highly relevant given articulated concerns over climate change and depleted fishery populations. The future should see continuing research on similar topics, hopefully some inspired by these research results.

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Appendices

A Paper I: A framework for environmental analyses of fish food production systems based on Systems Engineering principles

B Paper II: LCA Studies of Food Products as Background for Environmental Product Declarations

C Paper III: Environmental impact categories for fish food products based upon LCAs in the food sector

D Paper IV: Energy consumption in the Norwegian fisheries

E Paper V: Environmental analysis of Norwegian fish food products

F Environmental product declaration (EPD) and product category rules (PCR) for fish food products

G Overview Norwegian fisheries and management

H Eco-labels and stakeholders – Results from a small e-mail survey

Appendix A

Paper I:

Fet, AM; Schau, EM and Haskins, C (2010). "A framework for environmental analyses of fish food production systems based on systems engineering principles." Systems Engineering **13**(2): 109-118.

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Appendix B

Paper II:

Schau, EM and Fet, AM (2008). "LCA Studies of Food Products as Background for Environmental Product Declarations." International Journal of Life Cycle Assessment **13**(3): 255 - 265.

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Appendix C

Paper III:

Schau, EM.; Fet, AM and Ellingsen, H "Environmental impact categories for fish food products based upon life cycle assessments in the food sector."

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Appendix D

Paper IV:

Schau, EM; Ellingsen, H; Endal, A and Aanondsen, SA (2009). "Energy consumption in the Norwegian fisheries." Journal of Cleaner Production **17**(3): 325-334.

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Energy consumption in the Norwegian fisheries

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ABSTRACT

Energy use is of great concern within fisheries, due to both associated environmental effects and the cost of fuel to fishermen. This article explores the scale of energy consumed by most segments of the Norwegian fishing fleet for gadoid fish and for parts of the pelagic fleet for the period 1980–2005. Fuel use is assigned to the different species caught and different fishing gears using economic and mass-based allocation, where data permit. Correlations between variations in energy use and changing catch rates, quotas and oil prices are found. Inverse correlations are found between fuel consumption per kilogram of fish and catch rates on a yearly basis and between fuel consumption and oil prices on a longer term basis. A long term trend towards increased fuel consumption and reduced real prices is observed from the mid 1980s until 2000. This may indicate that low fuel prices do not motivate the development of energy efficient technology in the long run. Increased fuel use may further be used as an indication of over fishing as the correlation between low catch rates and increased fuel consumption is rather strong. Possible means of reducing energy use and emissions are discussed including changing operational strategies, hull forms and the use of alternative energy carriers. A comparison with measures taken in connection with the previous oil crisis around 1980 is done.

1. Introduction

Running a fishing vessel outside the Norwegian coastal waters is challenging and by its nature energy demanding. Many issues affect the energy consumed including: distance to the fishing ground, bad weather and rough waves, low temperatures and icing, operation of the fishing gear and preservation of the catch. Catching seafood is often a net energy loss in many modern industrial fisheries targeting high value species, as the energy in the fuel used by the fishing vessels may be an order of magnitude greater than the nutritional energy embodied in the fish caught [1,2].

1.1. Fuel costs

High rates of energy consumption are, however, a serious problem for fishing fleets for many reasons. The strong increase in oil prices in the recent years has led to financial difficulties for most fleet segments, e.g. for shrimp trawling, more than 30% of the catch value is used to pay for the fuel. This is hardly sustainable in the long run (Table 1).

1.2. Environmental aspects of fuel use

Norway has signed several international agreements aimed at reducing the total output of damaging gases to the atmosphere. Under the Kyoto-protocol, Norway committed to limit its greenhouse gas emissions to a maximum of 1% above the 1990 level in the period 2008–2012. In 2003, these emissions were 8% higher than in 1990 [3] which means that measures have to be taken by the authorities in order to reach the goal. In addition, the Gothenburg-agreement from 1999 regulates the yearly output of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds (VOC) [3] and is part of the Convention on Long-range Transboundary Air Pollution [4]. The main challenge that Norway faces in this regard is to reduce annual emissions of NO_x below 156 000 tonnes by 2010. To reach this goal, these emissions must be reduced by 45 000 tonnes, or about 30% relative to the situation in 2003.

Norwegian authorities are strongly focussing on national sea transport and fishing, which together account for 40% of the national NO_x output [5] and a NO_x-tax has been introduced amounting to 15 NOK (ca 2 EUR) per kilogram of NO_x emitted from

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Table 1
Average cost for fuel and lubrication oil and operating revenues per vessel for different fleet segments in 2005 (source: Ref. [25])

Fleet group	Average cost for fuel and lubrication oil [1000 NOK][a]	Average of operating revenues [1000 NOK][a]	Share fuel and lubrication cost
Coastal vessels 10–14.9 m	69	1262	5.5%
Coastal vessels 15–20.9 m	146	2709	5.4%
Autolining	2246	24 218	9.3%
Wet fish trawling	6042	36 341	16.6%
Factory trawling	8186	50 989	16.1%
Purse seining	4513	41 782	10.8%
Shrimp trawling	10 959	31 364	34.9%

[a] 1 Norwegian krone (NOK) ≈ 0.12 EUR ≈ 0.16 USD.

1 January 2007 [6]. This tax applies to many sectors including coastal sea transport and fisheries. According to the Norwegian fishing vessels owners association, this tax will add an extra 480 million NOK expense to the entire fishing industry and seriously challenge the profitability of large parts of the industry [7]. NO_x emissions can be reduced by various measures like cleaning packages or alternative energy carriers, but reducing energy consumption will be a fundamental premise in this connection. It is expected that similar measures will be introduced by the Norwegian government in the near future in order to reduce CO_2 emissions.

1.3. Market reliability

Reliability in the market is of vital importance for the fishing industry. The profile of Norwegian fish as sound and fresh food from the sea may however be threatened if the environmental impacts imposed by seafood production are outside acceptable limits. Consumers are more demanding with respect to not only fish as food but also the environmental impacts of food production [8]. The consumer of the future may prefer "green" food [9] which is another reason for keeping the energy consumption down. This is a global trend, which is reinforced by the growing power of the retail sector, the media and non-governmental organizations (NGO), all of which interpret and reinforce consumer perceptions [10,11]. As far as the major retail chains in Europe are concerned, it is, or at least is perceived as, a competitive advantage to promote the cause of consumers.

1.4. Catch phase important in the product life cycle

Within fisheries, the catch phase is only one part of the total value chain of the fish food product. However, a number of studies suggest that this is the dominant contributor to pollution even when different fishing methods and distances to the fishing banks are taken into consideration [12]. Comprehensive environmental life cycle analyses of cod (*Gadus morhua*) and Norway lobster (*Nephrops norvegicus*) fisheries have been performed [13] and conclude that the fishing stage itself is clearly the main contributor to environmental impacts. This is more specifically attributed to high fuel consumption and the consequent emissions [14,15]. This conclusion is supported by several other studies [2,16–19]. As fuel consumption in the fishing phase is so important to the profile of the fish food product, an analysis of fuel inputs allocated to major species landed and to different fishing gears is justified.

1.5. Norwegian fisheries

In 2003, Norway was the tenth largest producer of captured fish in the world [20], but the country was the second largest export nation of seafood, exporting to more than 150 countries worldwide [21]. The fishing industry plays an important role in the Norwegian economy and in particular in rural districts along the coast [22,23]. In 2004, the total Norwegian catch of wild fish amounted to 2 700 000 tonnes live weight. Of this, cod accounted for 231 000 tonnes while all groundfish species (e.g. haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), Greenland halibut (*Reinhardtius hippoglossoides*) etc.) together including Atlantic cod, amounted to around 606 000 tonnes. Even though the pelagic species (e.g. blue whiting (*Micromesistius poutassou*), capelin (*Mallotus villosus*), mackerel (*Scomber scombrus*) and herring (*Clupea harengus*)) dominate total landings, accounting for 1 850 000 tonnes, Atlantic cod was the most important species economically with a total value of 2.8 billion NOK [24].

1.6. Objective and structure of the paper

The objective of the paper is to:

- identify the level of energy consumption in Norwegian fisheries in the form of time series of fuel use coefficients for various fleet segments over time,
- from this, identify trends, and potential influences (e.g. catch volume and fuel price) and find the basis for the development of better strategies to reduce fuel consumption,
- where data permit, analyse fuel inputs allocated to major species landed and to different fishing gears.

The first part of the article describes the methods and the data used to calculate fuel coefficients for the fleet segments in the catch phase. The second part presents the results. The discussion includes some possibilities for the reduction of fuel use in the fishing fleet.

1.7. System boundaries

The data used in this article are fuel burned on fishing vessels. Therefore, the analyses include the processes on board the fishing vessels only. Energy inputs to the production of vessels, gears, baits, processing, ice production on land etc. are excluded.

2. Methods and data

2.1. Data sources

Since 1966, the Norwegian Budget Committee for the Fishing Industry [25] has been issuing statistics on the profitability of Norwegian fisheries. These statistics include, for example, financial data regarding revenues and costs such as catch income and fuel costs incurred by individual fleet segments. The data collection methods employed, and the ways in which they have been processed and organized have varied significantly since they were first issued in 1966. For the sake of statistical continuity we have chosen to look at the period from 1980 to 2005 and have selected the following fleet segments:

A: coastal gillnetting, jigging and Danish seining,
B: coastal longliners,
C: autoliners,
D: wet fish trawlers,
E: factory trawlers,
F: purse seiners.

The groups A–E catch mostly a mix of gadoid fish, the most important of which include: cod, ling (*Molva molva*), haddock, saithe, Greenland halibut and redfish (*Sebastes marinus*). Cod is the dominating species, especially in respect to catch value. Group F catches pelagic species such as blue whiting, capelin, mackerel and herring. Blue whiting dominates the landings of this segment while herring and mackerel are more economically important. While the vessels in group F use mostly purse seine gear to target the schooling species, pelagic or mid-water trawling is used in the blue whiting fisheries.

Although the statistics collected for these fleet segments have been fairly consistent from 1980 to 2005, there have been a number of changes and modifications within individual fleet segments with regard to denominations, vessel size classifications, etc. We have made certain simplifications and combinations in order to arrive at representative values throughout the time period. These include:

- From 1991 onward, catches are registered as round (live) weight instead of gutted weight. Prior to 1991, catches were reported as gutted weight. These values have been converted to an approximate round weight equivalent by multiplying by 1.41 (based on [25]).
- After 2001, data regarding direct fuel consumption by the fishing vessels were collected [26]. Prior to this no fuel use data were collected. Consequently, other techniques were used to quantify fuel inputs as described below.
- From 2003 onward, the grouping of vessels based on length and fishing gear changed to better reflect the Norwegian fishery regulations. This had a major effect on fleet segments A and B, which were combined into two new large vessel groups with other length limits. Consequently, the time series for fleet segments A and B are discontinued from 2003.

2.2. Fuel price data

Before 2001, only the cost of the fuel and not the actual amount of fuel used was surveyed [25]. Therefore, fuel prices are used to find the amount of fuel used for the different fleet segments.

The price paid by fishing vessels for fuel depends on the market spot price, the vessel owner's fuel consumption and to a certain extent, their negotiating ability. The Rotterdam price of crude oil has been of decisive influence for the marine market. Major rebates can, however, be obtained, and it is a general rule that major consumers, such as factory trawlers and purse seiners, pay the lowest prices. Furthermore, the basic fuel price varies during the course of the year.

Fuel prices are determined in two different ways. Before 1999, fuel prices for factory trawlers were found based on statistics from the Rotterdam oil exchange adjusted with information derived from various sources such as oil companies, fuel dealers and shipping companies [5]. This introduces a possible source of error in the available material, as it is difficult to survey the exact prices that individual vessel owners have actually paid for their fuel. Summed up at the fleet level, however, we can assume that the error is small, and not sufficient to have an influence on trends. Price differences between fuels bought in Norway and overseas have not been taken into consideration, as the price difference is considered small for the ocean going vessels that occasionally buy fuel abroad.

For the years 2000–2005 fuel prices are taken from the Norwegian Guarantee Fund for Fishermen (GFF)'s database, which among its other duties administers a refund scheme for the CO_2-tax on oil products. These data are considered to be very accurate. Fig. 1 shows the fuel prices for the various fleet segments used in the calculations.

2.3. Estimation of fuel consumption prior to 2001

In order to be able to estimate the fuel coefficient in litres or kilograms per catch unit it is essential to know both the fuel consumption and the corresponding catch data. Vessel profitability

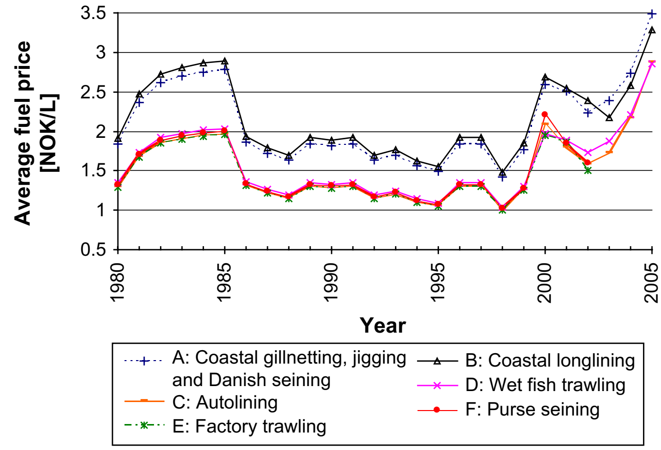

Fig. 1. Average fuel prices used in the calculations for the different fleet segments.

studies carried out by the Norwegian Directorate of Fisheries in the period 1980–2000 include only statistics of the fuel costs and the catch on an aggregated fleet level. Fuel consumption in litres or kilograms for this period is therefore not based on direct data, but estimated based on the financial figures for fuel expenditures combined with data on fuel prices for the year concerned. The typical fuel used for fishing vessels and in the calculations is marine gas oil (diesel) which has an energy content (lower heating value) of 42.8 MJ/kg and a density of 0.86 kg/L [27].

Yearly variations in energy use are further compared versus the changing availability of fish to find correlations. Factory trawling for gadoid fish is used as an example case. Catch rates for the various fleet segments for the years in question are illustrated in Fig. 2. Since the purse seiners with blue whiting licences (segment F) have considerably higher catch rates than the other groups these values are measured on the right axis in Fig. 2.

2.4. Analysis to species and gear level

For the years 1980–2000, only fuel costs at the fleet group level for mixed fisheries are available, as explained above. Fuel use is thus calculated for mixed fisheries. For the period 2001–2004, however, both catch and fuel consumption data are available on the vessel level. Actual prices obtained for the various species by

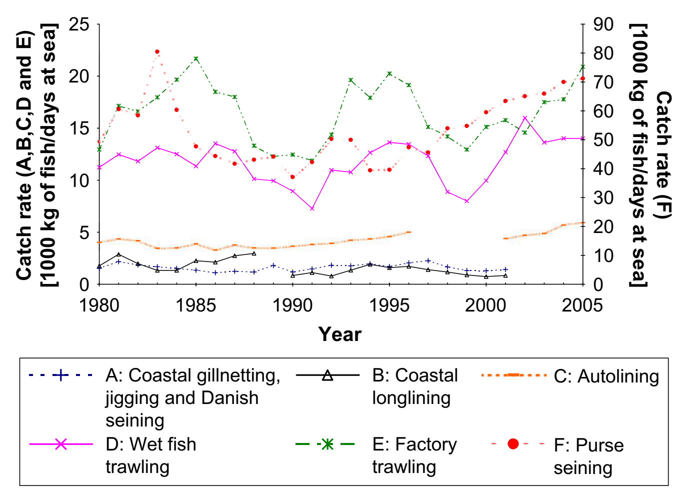

Fig. 2. Catch rate of different fleet segments. Purse seining on the right axis with a different scale. Source: Ref. [25].

individual fishing vessels are also available. In order to achieve continuity for trend analyses for specific fuel consumption at the group level, these data are also aggregated for mixed fisheries in line with the data for the previous years.

With the availability of the fuel consumption and catch data on the individual vessel level for the years 2001–2004, as collected by the Norwegian Directorate of Fisheries, fuel use coefficients on a species-specific and fishing gear basis for the Norwegian fishing fleet are evaluated. The method used is co-products allocation determined from life cycle assessment (LCA) according to ISO 14044 [28].

In LCA, sub-dividing is an option only where a process can be split up into at least two more detailed processes. The sub-dividing of the multifunctional process of fish catching was not possible with the data resolution available, and is for some species (like Atlantic cod and haddock) generally very difficult or not possible as these species are often caught in the same haul. Sub-dividing to avoid allocation is not common in seafood LCA [29] and in more general, it is questioned that sub-dividing can provide a solution for the allocation problem [30].

Likewise, system expansion was not possible given the data available. Given the nature of the capture fisheries, it is also very difficult to vary the underlying process (fishing) to alter the physical outputs substantially.

The third option found in ISO 14044 [28], allocation on other relationships, has been performed, namely co-product allocation based on mass and based on economic value. A description of the rationale and how this has been done are given. Equivalent procedures were used for allocating the fuel among different fishing gears and different species. The particular case for species is described in Sections 2.4.1 and 2.4.2 and results derived from both will be presented in Section 3.

2.4.1. Co-product allocation based on mass of the catch

Most industrial fisheries are restricted by quotas that are fully exploited. Given that one vessel has a fixed quota, and the quota limit is based on mass, an allocation based on the mass of each fish species caught will be a natural choice. Basing the allocation on the relative mass of landings is also easier and more stable longitudinally in contrast to economic allocation, where the relative price fluctuations of the fish vary over time.

Previously, mass-based allocation of fuel used by fishing boats (and associated emissions) has been used in analyses of Icelandic and Norwegian fisheries [2,18].

Here, the fish catch data were presented as a matrix **A** with the mass a_{ij} [kg] of fish species j caught by the different fishing vessels i and a matrix **Y** with fuel use y_i [L] of the fishing vessel i. An example case with three fishing boats catching two different species could be presented as:

$$A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \end{pmatrix} \quad \text{and} \quad Y = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix}$$

The first column in matrix **A** represents the catch of species 1 and the second column the catch of species 2. The first row in matrix **A** represents the catches of fishing vessel 1; the second row the catches of fishing vessel 2 and so on.

The equations in the following description are found in Table 2. The fuel use y_{ij} for species j caught by fishing vessel i can be found by allocating the fuel y_i of fishing vessel i on the fish species j as described by Eq. (1), where $i = 1 \ldots m$, where m is the number of fishing vessels, and $j = 1 \ldots n$, where n is the number of different species caught by the fishing fleet. The fuel use coefficient for species j caught by vessel i, x_{ij} [L/kg], is given by Eq. (2). The mass allocated weighted average fuel use coefficient for fish species j, $\bar{x}_j$, is then given by Eq. (3).

2.4.2. Co-product allocation based on value of the catch

Basing the co-product allocation on the value of the catch is motivated by viewing fishers as economic actors that can invest more (here, use more fuel) to land more valuable catch. Economic actors, everything else being equal and in line with the LCA methodology, would go for the most valuable catch; such valuable catch should be allocated a greater environmental burden (here fuel) than less valuable catch. This rationale was followed in the study of cod [15] and Norway lobster [13] fisheries in Sweden.

The value allocated weighted average fuel use coefficient for fish species j, $\bar{\bar{x}}_j$, is found similar to the co-product allocation based on mass, by using Eqs. (4–6) in Table 2. The actual first hand price catch value [NOK] obtained for species j caught by vessel i is described by b_{ij}.

3. Results

3.1. Energy consumption in Norwegian fisheries over time

Fig. 3 shows fuel consumption expressed as the fuel use coefficient [kilogram of fuel per kilogram of fish landed] for various

Table 2
Equations for allocating fuel use among different species and different fishing gears

Mass-based allocation		Economic allocation	
$y_{ij} = \frac{a_{ij}}{\sum_k a_{ik}} \cdot y_i$	(1)	$\hat{y}_{ij} = \frac{b_{ij}}{\sum_k b_{ik}} \cdot y_i$	(4)
$x_{ij} = \frac{y_{ij}}{a_{ij}} = \frac{\frac{a_{ij}}{\sum_k a_{ik}} \cdot y_i}{a_{ij}} = \frac{y_i}{\sum_k a_{ik}}$	(2)	$\hat{x}_{ij} = \frac{\hat{y}_{ij}}{a_{ij}} = \frac{\frac{b_{ij}}{\sum_k b_{ik}} \cdot y_i}{a_{ij}}$	(5)
$\bar{x}_j = \frac{\sum_i x_{ij} \cdot (a_{ij})}{\sum_i (a_{ij})} = \frac{\sum_i x_{ij} \cdot a_{ij}}{\sum_i a_{ij}} = \frac{\sum_i \frac{y_i}{\sum_k a_{ik}} \cdot a_{ij}}{\sum_i a_{ij}}$	(3)	$\bar{\bar{x}}_j = \frac{\sum_i \hat{x}_{ij} \cdot a_{ij}}{\sum_i a_{ij}} = \frac{\sum_i \frac{\frac{b_{ij}}{\sum_k b_{ik}} \cdot y_i}{a_{ij}} \cdot a_{ij}}{\sum_i a_{ij}} = \frac{\sum_i \frac{y_i}{\sum_k b_{ik}} \cdot b_{ij}}{\sum_i a_{ij}}$	(6)

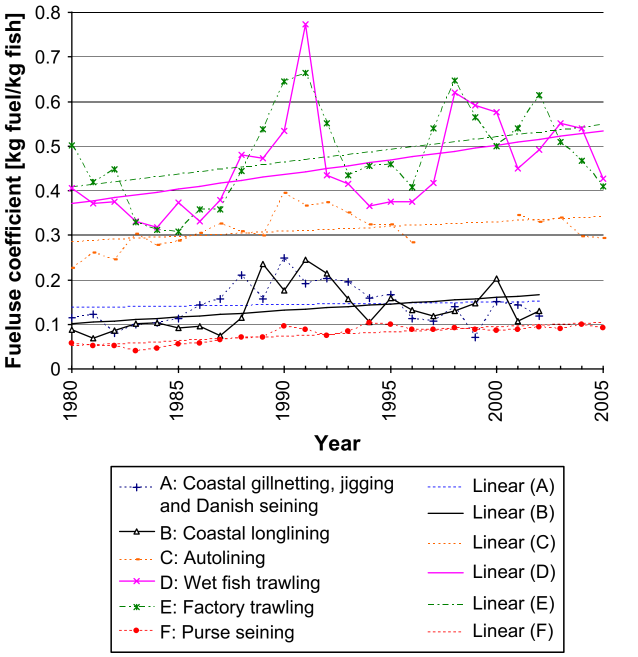

Fig. 3. Fuel use coefficient and linear trend lines for different fleet segments.

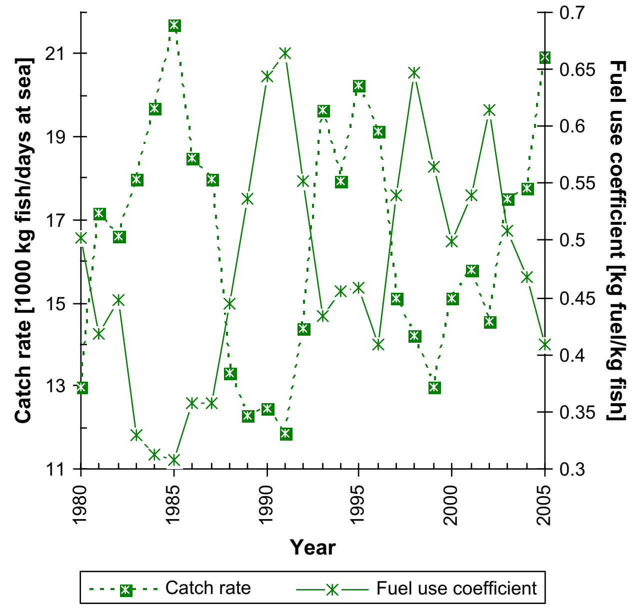

Fig. 4. Catch rate and fuel use coefficient for fleet segment E: factory trawling.

segments of the Norwegian fishing fleet for the years 1980–2005. Trend lines are also plotted in the figure. A clear trend of trawling being more energy-intensive than other types of fishing is shown. The energy coefficient of wet fish trawling, for example, varies between 0.32 and 0.78, with a mean value of 0.45. The energy consumption of passive gears is lower overall, and does not vary so greatly in absolute terms from 1 year to another, even though coastal longlining varies between 0.07 and 0.24 in the energy coefficient, with a mean value of 0.13. However, purse seiners with blue whiting licences appear to be by far the most energy efficient type of fishing. The long term trend for all fleet segments shows an increase in fuel consumption, but a period of relatively high energy inputs centred around 1990 is also evident.

3.1.1. *Trend and potential influences*

In order to find sources of variation of energy consumption, we analysed the relationship between catch volume and fuel use and the relationship between the fluctuation of fuel price and fuel use. This was done for all fleet segments, but only the result for fleet segment E is presented here. Fig. 4 shows the annually registered catch rate and fuel use coefficient.

The results demonstrate an inverse correlation between fuel use coefficients and catch rate amongst trawlers. Large catches and good availability of fish result naturally in higher efficiency and low fuel use coefficient, and vice versa. When catch rates are low, the trawl is kept longer in the sea, with high energy consumption as the result. As far as passive types of gear, particularly in the coastal fisheries, are concerned, this relationship is much less well-defined, which may be an indication of greater flexibility in adapting catch effort to the availability of fish.

By comparing the fuel use coefficient with the fuel prices in index-regulated (base year 1998) NOK a long term inverse correlation was identified. This was done for factory trawling and the result is shown in Fig. 5 where linear trend lines also are plotted. Falling oil prices during the period 1981–1998 correlate with increased fuel use coefficients in the same period. Taking a closer look at the figure we can see that high oil prices around 1980 were followed by reduced fuel use per kilogram of fish landed in this period while the following reduction in oil prices corresponded with a general increase in fuel inputs per kilogram of fish.

A similar development can be seen for the latest years where increased oil prices from 1998 to 2000 and from 2002 to 2005 are reflected in falling fuel use coefficients. Fig. 5 indicates that factory trawlers are sensitive to the fuel price and able to adjust the fuel consumption per kilogram of fish to the various prices of fuel. The exception was around 1990, when the fuel price was falling slightly,

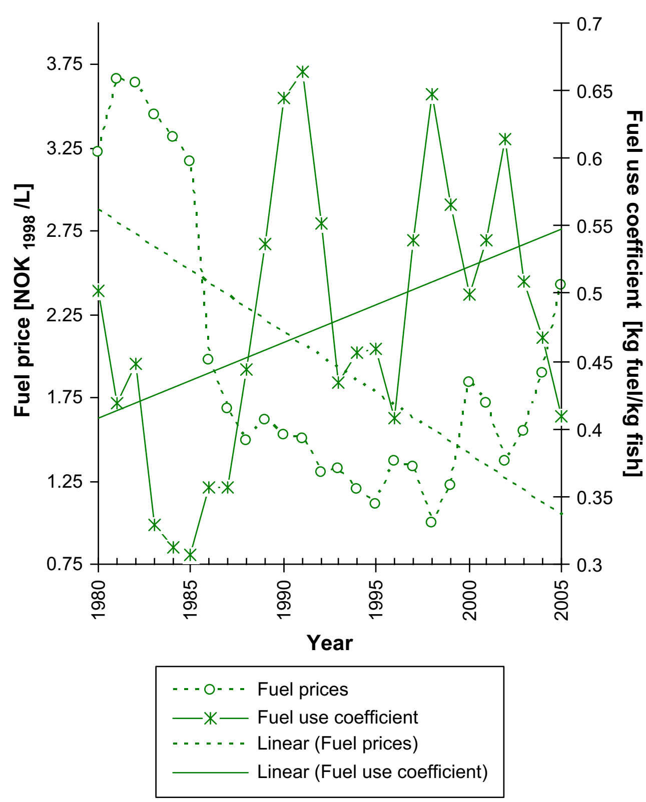

Fig. 5. Average fuel prices (1998 regulated) paid by and fuel use coefficient for fleet segment E: factory trawling.

but the fuel consumption made a jump. This exception could however be explained by the low catch rate (Fig. 4) at that time.

3.2. Fuel use coefficient for specific fishing gears

The Norwegian fishing fleet catches a large variety of species using diverse fishing gears. This had made it difficult previously to calculate the fuel use coefficient for individual species and specific fishing tools. However, in this paper, using vessel-specific fuel and catch data together with allocation methods used in life cycle assessments it was possible to present fuel coefficient data for individual species and for individual gears for the years 2001–2004 aggregated. As shown in Table 3, allocating fuel inputs based on mass resulted in values over 50% higher than when allocating fuel inputs based on the economic value of catch for fish traps and Danish seine/round-fish trawl/flat fish trawl. Vessels applying such fishing gears also use various other gears, but obtain a higher price for the catch caught with fish traps and Danish seine/round-fish trawl/flat fish trawl than with the other gears used. Pelagic trawl also shows a difference when mass and economic value are used to allocate fuel inputs; however, in this case, the fish caught with pelagic trawl are typically lower priced than the other catch these vessels obtain with other gears.

Table 3 shows the fuel use coefficients for most of the different fishing gears used by the Norwegian fleet. Purse seine and pelagic trawl are clearly the most fuel efficient fishing gears. Hook (hand-line and trolling line) is also a fuel efficient fishing gear in the Norwegian fisheries.

The large difference between the resulting fuel consumption for bottom trawl and double trawl (one boat pulling two nets) can partly be explained by the species these trawls are catching. Double trawl is used almost only for deep sea shrimp, requiring trawls with a small mesh size that lead to higher resistance and higher fuel consumption. Bottom trawl is used to catch different demersal fish species for which in many cases the government sets minimum legal size limits and consequently a minimum mesh size of the trawl. The catch quantum per haul is normally also higher for demersal fish than for shrimps, which again has an influence on the energy efficiency.

The last column in Table 3 shows the difference between the mass allocated and economic allocated weighted average in percentage relative to the mass allocated result. The difference between mass and economic allocation is small for double trawl, shrimp trawl and longliners and the largest for fish traps. The small difference between the allocation methods for double trawl and shrimp trawl can be explained by the fact that the catch is dominated by a single species (shrimp) which in broad terms makes the choice between mass and economic allocation superfluous. Longliners catch a wide range of groundfish (e.g. cod, blue ling, saithe and haddock); however, as these are of fairly similar value the difference between mass and economic allocation is again small. On the other hand the catch from trapping is a mixture of fish and crustaceans with large differences in the value, mainly high priced species, e.g. king crab (*Paralithodes camtschatica* 68.95 NOK/kg) and European lobster (*Homarus gammarus* 180.22 NOK/kg), resulting in large differences between the allocation methods. Also note that most fishing vessels applying trapping also use other fishing methods for other less valuable fish, e.g. Atlantic cod (12.21 NOK/kg). This suggests that if economic allocation is used, trapping would be the second less efficient gear.

3.3. Fuel use coefficient for individual species

Table 4 shows some species caught by Norwegian fisheries over the period 2000–2004, the number of vessels reporting the catch of these species, the weighted average fuel consumption per kilogram of fish after using both mass allocation and economic allocation and their standard deviations. The second to the last column in Table 4 shows the difference between the mass allocated and economic allocated weighted average in percentage relative to the mass allocated result. Also, the average first hand price obtained is given.

Turbot (*Psetta maxima*), Dover sole (*Solea solea*) and brill (*Scophthalmus rhombus*) are species that require more than 2 kg of fuel/kg of fish. Shoaling fish like mackerel, Atlantic herring (*C. harengus*) and capelin have lower specific fuel use than do the more dispersed fish species like cod, as expected.

Norway lobster requires 1.04 kg fuel/kg catch when mass allocation is used and 3.09 kg fuel/kg catch when economic allocation is used. As shown in Table 4, the difference between economic and mass-based allocation can be very high for some species, European lobster being the most pronounced example, where economic allocation gives a much higher result than mass allocation. Also, for king crab, turbot and Dover sole, the difference between the two allocation bases is more than 200%, mass allocation giving the lowest results. European lobster and king crab are mainly caught in fish traps by vessels that also target other species with various fishing gears during the year. Turbot and Dover sole are high priced species that often are caught as by-catch.

For mackerel, the results of mass allocation are more than 200% lower than the results of value allocation. The price of mackerel is not very high compared to other Norwegian fish species (Table 4). However, for purse seiners, which account for a large quantity of mackerel, this species is of a relatively high value compared to the other major species taken (e.g. capelin and Atlantic herring).

For species like pollack (*Pollachius pollachius*), haddock and deepwater prawns, the difference between mass-based allocation

Table 3
Calculated fuel use coefficients for select fishing gears used in Norway for the years 2001–2004 aggregated

Gear type	Number of vessels	Allocation by mass of species caught		Allocation by value of species caught		% Difference in mass and economic allocation
		Average [kg fuel/kg fish]	St. dev.	Average [kg fuel/kg fish]	St. dev.	
Bottom trawl	449	0.28	0.46	0.26	0.61	6.8%
Double trawl[a]	26	1.01	0.59	1.01	1.43	−0.2%
Pelagic trawl	307	0.09	0.10	0.06	0.11	39.7%
Gillnet	1152	0.19	0.19	0.18	0.18	4.9%
Hook (hand-line and trolling line)	708	0.15	0.14	0.11	0.10	26.4%
Longline (floating longline and autoline)	694	0.31	0.14	0.32	0.16	−3.3%
Shrimp trawl	356	1.04	0.73	1.08	0.77	−4.6%
Purse seine/ring seine	726	0.09	0.08	0.13	0.09	−35.5%
Danish seine/round-fish trawl/flat fish trawl	343	0.11	0.11	0.19	0.13	−71.8%
Trap (for various fish and crustaceans)	282	0.13	0.47	0.24	1.31	−83.9%

[a] Double trawl is one boat pulling two nets targeting deepwater prawns (*Pandalus borealis*) in the years 2003 and 2004 only.

Table 4
Calculated fuel use coefficients for species landed in Norway for the years 2001–2004 aggregated

Species name	Number of vessels	Mass allocation		Economic allocation		% Difference in mass and economic allocation	Average landed value of species [NOK/kg]
		Average [kg fuel/kg fish]	St. dev.	Average [kg fuel/kg fish]	St. dev.		
Atlantic cod (*Gadus morhua*)	1229	0.35	0.22	0.50	0.31	−43.5%	12.21
Atlantic herring (*Clupea harengus*)	471	0.09	0.099	0.14	0.099	−39.4%	3.41
Atlantic wolffish (*Anarhichas lupus*)	1003	0.34	0.37	0.25	0.47	25.8%	6.89
Beaked redfish (*Sebastes mentella*)	93	0.48	0.30	0.36	0.18	24.9%	6.08
Blue ling (*Molva dypterygia*)	354	0.32	0.40	0.28	0.20	9.8%	12.10
Blue whiting (*Micromesistius poutassou*)	254	0.09	0.059	0.05	0.031	50.4%	0.83
Brill (*Scophthalmus rhombus*)	86	2.15	0.65	5.28	1.41	−145.5%	47.20
Capelin (*Mallotus villosus*)	236	0.09	0.050	0.05	0.027	48.9%	1.16
Crustacean/mussel/mollusc	65	0.09	0.073	0.07	0.15	25.9%	6.73
Northern prawn (*Pandalus borealis*)	229	1.04	0.73	1.08	0.79	−4.4%	11.61
Dover sole (*Solea solea*)	70	2.45	0.86	7.65	2.47	−212.1%	59.24
Edible crab (*Cancer pagurus*)	46	0.13	0.11	0.12	0.11	6.7%	8.43
European lobster (*Homarus gammarus*)	58	0.26	0.36	3.80	2.18	−1383.3%	180.22
European sprat (*Sprattus sprattus*)	41	0.08	0.064	0.05	0.078	35.5%	2.19
Forkbeard (*Phycis blennoides*)	1288	0.33	0.35	0.25	0.20	22.7%	8.64
Golden redfish (*Sebastes marinus*)	1234	0.37	0.32	0.32	0.27	14.2%	7.36
Greenland halibut (*Reinhardtius hippoglossoides*)	1129	0.43	0.39	0.87	1.10	−101.6%	20.22
Haddock (*Melanogrammus aeglefinus*)	1545	0.40	0.39	0.40	0.26	−2.7%	9.23
Hake (*Merluccius merluccius*)	532	0.29	0.54	0.57	0.54	−91.9%	18.80
King crab (*Paralithodes camtschatica*)	93	0.14	0.088	0.68	0.54	−406.8%	68.95
Lemon sole (*Microstomus kitt*)	182	0.93	0.70	1.36	0.68	−46.9%	20.89
Ling (*Molva molva*)	1235	0.31	0.41	0.38	0.27	−21.7%	13.89
Lumpfish (*Cyclopterus lumpus*)	139	0.10	0.071	0.06	0.042	46.4%	5.09
Mackerel (*Scomber scombrus*)	782	0.09	0.18	0.31	0.19	−213.9%	7.62
Northern wolffish (*Anarhichas denticulatus*)	64	0.33	0.14	0.08	0.034	74.3%	2.89
Norway lobster (*Nephrops norvegicus*)	174	1.04	0.79	3.09	1.58	−196.4%	62.83
Norway pout (*Trisopterus esmarkii*)	50	0.10	0.040	0.05	0.025	46.9%	0.80
Piked (spiny) dogfish (*Squalus acanthias*)	448	0.22	0.466	0.16	0.257	26.1%	8.07
Plaice (*Pleuronectes platessa*)	589	1.84	0.58	1.33	0.41	27.7%	12.79
Pollack (*Pollachius pollachius*)	918	0.26	0.379	0.25	0.307	2.9%	7.63
Porbeagle (mackerel shark) (*Lamna nasus*)	110	0.21	0.29	0.44	0.69	−114.8%	20.32
Roughhead grenadier (*Macrourus berglax*)	69	0.38	0.22	0.15	0.14	60.1%	4.49
Roundnose grenadier (*Coryphaenoides rupestris*)	47	0.42	0.286	0.14	0.120	67.0%	2.84
Saithe (*Pollachius virens*)	1658	0.37	0.37	0.24	0.15	35.5%	4.46
Spotted wolffish (*Anarhichas minor*)	433	0.31	0.27	0.27	0.21	14.0%	9.43
Turbot (*Psetta maxima*)	305	2.08	0.55	7.04	2.66	−238.1%	62.35
Whiting (*Merlangius merlangus*)	228	0.40	0.712	0.34	0.216	15.3%	5.41
Witch (*Glyptocephalus cynoglossus*)	154	0.95	0.78	0.77	0.74	18.6%	15.62

and economic allocation is small. Norwegian vessels that are specialised on deepwater prawns and the only source of reported catch of this species are one explanation for the equal figures for deepwater prawns. In other cases, the relatively small differences between the results of the two allocation bases applied can only be explained by similar prices obtained for the species of interest and the rest of the catch of the vessel.

4. Discussion

4.1. International studies

A number of international studies of energy consumption in the fishing industry have been carried out. In this section, some of these findings are compared to our results.

As our results on fuel use coefficients for different fleet segments show (Fig. 3), the general trend is an increased fuel use coefficient over time, with a large inter-annual variability. This is also found in other North Atlantic fisheries [31]. For example, the bottom trawl Atlantic Canadian fishery had a fuel coefficient ranging with about a factor of 4 between 1996 (about 300 L/tonne) and a top in 1994 (about 1200 L/tonne) (see Figure 7 in [31]). The inter-annual variations in the Icelandic fleet are not as pronounced, but vary also considerably (i.e. for trawlers; about 300 L/tonne in 1981 and about 500 L/tonne in 1994) (see Figure 12 in [31]).

When it comes to variations between fleet segments or fishing gears, most studies have concluded that trawling, in general, is energy-intensive, although mid-water trawling emerges much better than bottom trawling. In Table 5, the figures from this study are compared with figures from Refs. [18,31], and some other Nordic studies. The fuel use coefficients that appear in the table vary widely, from 0.02 for the seine-net capelin fishery off Iceland to as much as 1.50 for bottom trawling in the Baltic Sea.

The figures from Iceland and Norwegian fisheries differ to some extent from the others, but by no more than might be expected given the degree of uncertainty that exists in the data. The tendency that bottom trawling is more energy-intensive than, for example, longlining or coastal fisheries is not as clear as observed in the long term Norwegian data (see Fig. 3); so care should be taken when drawing conclusions in this matter. The figures for Swedish and Danish fisheries indicate clearly higher levels of fuel coefficients, which may be due to the different fishing gears used and less dense stocks in the Baltic and the North Sea.

4.2. Influence of fishery management

Our results are based on experience data, which do not reflect differences in the management control system among the vessel groups. Norwegian fisheries are strictly managed, and the fisheries management systems influence fuel consumption. In Norway, the sea going trawler fleet is generally expected to take its catches throughout the year. Vessels that use conventional tools such as gillnets and Danish seine, run a more season-based fishery with a large number of smaller vessels. The Lofot fishery is an example

Table 5
Comparison of fuel use coefficients in various international fisheries

Fishery (home base or location)	Fuel use coefficients [kg fuel/kg fish][a]	Analysis includes energy inputs to	Source
Purse seining for capelin (Iceland)	0.02	Fuel	[32]
Purse seining for small pelagics (North Atlantic)	0.04	Fuel	[31]
Purse seining (Norway)	0.09	Fuel (mass alloc.)	This study
Trawling for small pelagics (North Atlantic)	0.08	Fuel	[31]
Trawling for pelagics (Norway)	0.09	Fuel (mass alloc.)	This study
Trawling for groundfish (North Atlantic)	0.44	Fuel	[31]
Trawling for groundfish (Baltic Sea)	1.50	Fuel	[15]
Trawling for groundfish (Denmark)	1.40	Fuel	[33]
Trawling for codfish (Denmark)	0.40	Fuel (system exp.)	[34]
Bottom trawling for flatfish (Denmark)	0.84	Fuel (system exp.)	[34]
Trawling for groundfish (Iceland)	0.65	Fuel	[18]
Trawling for groundfish[b] (Norway)	0.28	Fuel (mass alloc.)	This study
Trawling for shrimp (North Atlantic)	0.76	Fuel	[31]
Trawling for shrimp (Norway)	1.04	Fuel (mass alloc.)	This study
Trawling for Norway lobster (North Atlantic)	0.85	Fuel	[31]
Longlining for groundfish (North Atlantic)	0.41	Fuel	[31]
Longlining for groundfish (Norway)	0.31	Fuel (mass alloc.)	This study
Gillnetting for codfish (Denmark)	0.21	Fuel (system exp.)	[34]
Gillnetting for groundfish (North Atlantic)	0.53	Fuel	[31]
Gillnetting for groundfish (Norway)	0.19	Fuel (mass alloc.)	This study
Trapping crabs (North Atlantic)	0.28	Fuel	[31]
Trapping (mixed fish and crustaceans) (Norway)	0.13	Fuel (mass alloc.)	This study

[a] The numbers refer to round-fish or crustaceans and are converted to [kg/kg].
[b] Includes bottom trawling for blue whiting.

thereof. Typically these vessels catch Atlantic cod during February, March and April when cod is more easily available in concentrations close to the coast. Similarly, the larger trawlers take their catches outside the 12 mile zone throughout the year when cod is not that easily accessible [35].

4.3. Importance of non-fuel inputs to fishing

Some vessels, like factory trawlers, have a production plant on board and deliver processed products from the vessel while other vessels deliver a raw material that needs processing on land. Thus, the fuel use in our statistics for factory trawlers includes energy used both for fishing and for processing. On the other hand, fish from wet fish trawlers are processed on land, requiring energy outside our system boundaries. The Norwegian fish processing factory Domstein Måløy has, in its yearly Environmental Data Report, published that they used 283 kwh electricity/tonne of raw material during the years 1999–2004 [36,37]. This is comparable to 0.024 kg fuel/kg fish or less than 5% (4.48%) of the direct fuel use for factory trawlers in the same period. According to Ref. [18] processing of the catch consumes about 7% of the energy used on board an Icelandic factory trawler. This indicates that the fuel usage for factory trawlers should be corrected with 5–7% when comparing with other vessel groups without on board processing. When the environmental impact is of interest, a comparison of wet fish trawlers to factory trawlers might be reasonable, as the energy needed for the on-shore production is taken mainly from the electricity grid, which at least in Norway, consists of a dominant share of renewable hydro power. Compared to marine gas oil, energy from hydro power is environmentally preferable.

Cooling of the fish on board the vessels can also be performed in various ways requiring different amounts and types of energy. For larger vessels, power for refrigerated sea or fresh water, cold storage or ice production on board is produced by diesel engines such that the cooling energy is included in our fuel data. For smaller vessels, however, ice is often produced on land using energy from the electricity grid. The energy needed to produce 1 kg of ice with a commercial ice machine is 0.012 kWh [38], but this figure may vary from equipment to equipment. Typically, 1 kg ice/kg of fish is recommended to adequately chill fish, which means that 0.043 MJ of energy/kg of fish is required for ice, or the equivalent of 0.001 kg of fuel for each kilogram of fish. This is less than 1% (0.7%) of the average fuel consumption for small vessels. Our calculation of the importance of the energy needed for ice making is consistent with Ref. [39].

As with ice production, some fisheries use bait produced or processed on land and take this out to the fish place. The energy required for bait is not included in our fuel analysis. A comparison of longliners and vessels that do not use bait may therefore lead to wrong conclusions in favour of the longliners. The bait is however mostly produced from pelagic fish (mackerel and herring) and squid [40]. Pelagic species need little energy to catch compared, for example, to bottom trawling.

We do not have information on how much bait is used, but we can set up a worst case scenario where all the expenditure for bait, ice, salt and packaging derived from the statistics [25] is used for bait which we assume is pelagic fish caught by the purse seiners. By combining these figures with the average fish price and the average specific fuel expenditure for the pelagic species we have found that bait constitutes on average 25% of the catch weight for the coastal longliner fleet and 66% for the autoliners in the years 1980–1997. It can further be derived from these figures that the energy consumption for bait relative to the direct fuel consumption is 12% on average for the coastal longliner fleet and 13% in average for the autoliners in the same years. To sum up, the non-included energy for bait is small but probably significant.

4.4. Operational circumstances

Our data for the years 2001–2005 show a large variance between different vessels in the same fleet group in the same year. This is most pronounced for wet fish trawlers. Data from 1985 to 1994 [41] also show a large variance for specific fuel consumption between vessels in the same year, ranging from 0.24 to 1.06 kg fuel/kg fish for one wet fish trawler [41]. This may indicate that the energy consumption also depends on the operational circumstances not explained by vessel-specific data or variation from year to year in the fish stock. A large potential for fuel saving therefore probably exists in better operational routines.

The number of fishing vessels in Norway has been nearly halved from 1980 to 2004 [24]. Meanwhile, the total engine power has increased in the same period [42] and the total vessel tonnage has remained steady [43]. This means that the Norwegian fishing fleet consists of fewer but larger and more powerful fishing vessels. The motivation for more powerful fishing vessels is increased speed and towing power, but higher speed and larger engines are probably not ideal when considering fuel efficiency.

The results for the different fleet segments show that coastal vessels have a better fuel efficiency than larger trawlers. Measures to reduce specific fuel consumption for the Norwegian fishing fleet, therefore, may include changes in the fleet structure where more catch is taken by the coastal fleet. However, the cod fisheries of the coastal fleet have a problem with the declining stock of Norwegian coastal cod that interacts with the north east Arctic cod and may cause by-catch problems [44]. In addition there are many reasons to have a differentiated fleet structure with both small coastal vessels and large ocean going trawlers; one of these reasons is the fish processing industry on land and the market, which demands continuity in fish supply during the whole year.

4.5. Measures taken in the 1980s to reduce fuel consumption

In the late 1970s and early 1980s, there was an increase in fuel prices that initiated several measures to reduce the fuel consumption within Norwegian fisheries. One of these was the introduction of the New Deal 33 fishing vessel from the company Mørebas in 1982; a 10 m long coastal vessel, that introduced sail assisted propulsion combined with a low resistance hull design and large, slowly rotating propeller – all measures aimed at saving fuel. The advantageous hull design and slowly rotating propeller alone could reduce the fuel consumption by more than 50% compared to other typical Norwegian coastal vessels at that time. The sail could further reduce the fuel consumption in the range of 8–15% depending on the wind speed and angle. An analysis [45] concluded that the new hull design and propeller made the test vessel so fuel efficient that the current fuel price of 2.50 NOK/L did not justify an extra investment in the relatively high priced sail rig. However, non-economic aspects, such as improved safety and better comfort with the sail, could influence that decision [45].

4.6. Possible means to reduce energy consumption

A study [5] to assess the potential for energy saving in the Norwegian fisheries describes 16 different actions to reduce energy consumption and environmental damage. The technological actions that are assumed to have the largest effects are associated with changes in hull shapes, propulsion systems and propellers. These could provide improvements of 10–20% compared to today's energy consumption. The largest effect with respect to fuel-related discharges can be attained by changing the energy carrier. The use of liquefied natural gas is the best short term solution while hydrogen in combination with fuel cells is expected to be the long term solution for the fishing fleet [5]. The transition to natural gas could give a reduction of the discharge of NO_x of 85% and CO_2 of about 20% [5].

In addition to the above, it is assumed that there are possible gains through non-technological actions, such as changing behavior and the fishing strategy. These are actions that can be achieved through awareness campaigns and information about what energy is used for. This can be promoted through simple PC-based expert systems that can monitor consumption and the consequences of actions.

5. Conclusion

Norwegian fuel consumption in the fisheries is characterized by pronounced variations, between different years, fleet groups, fishing gears and species. Dependencies exist between specific fuel consumption and catch rates on a yearly basis and between fuel consumption and oil prices on a longer term basis. This may further indicate that low fuel prices do not motivate the development of energy efficient technology in the long run. Increased energy use may further be used as an indication of over fishing as the correlation between low catch rates and increased fuel consumption is rather strong.

The long term trend for energy consumption per kilogram of fish shows an increase during the period 1980–2005. However, during periods with increased fuel price, the fuel consumption per kilogram of fish has declined. Trawlers are the fleet group in Norway that have the highest fuel consumption and therefore are more sensitive to the fuel price. There is also a correlation between the catch rates and fuel consumption, most pronounced in the factory trawling and coastal longlining fleet groups.

Compared to fuel use figures in other Nordic fisheries, Iceland is comparable to Norway. Sweden and Denmark have a higher level of fuel consumption per kilogram of fish, which may be due to less effective fishing methods and less dense fish stocks in the Baltic and the North Sea.

Wet fish trawlers and factory trawlers are the fleet group with the highest fuel consumption per kilogram of fish. A partial explanation for the high energy use of these trawlers is the long distance to the fishing ground that many travel and that these trawlers deliver fish all year round. This is in contrast to the coastal fisheries, which are considerably less fuel-intensive. Purse seining that targets shoaling fish and blue whiting are the most fuel efficient fleet segment in the Norwegian fishery.

Changing the fleet composition to allow higher quotas to the coastal fisheries and purse seiners could, under certain conditions, reduce the overall fuel consumption, but could have other undesirable effects.

Vessel-specific fuel and catch data together with the allocation methods used in life cycle assessments made it possible to present fuel coefficient data for individual species and for individual gears for the years 2001–2004 aggregated. When considering all the different fishing vessels and species caught, the fishing gear in Norway with the highest fuel consumption per kilogram of catch is shrimp trawl (1.04). Pelagic trawl and purse seine/ring seine (both 0.09 kg fuel/kg fish) are the most fuel efficient fishing gears in this study. This has a clear influence on the fuel used to catch individual species: overall, European sprat (0.08) required the least fuel per kilogram and Dover sole (2.45) the most. The popular Norwegian export product, Atlantic cod, required 0.35 kg of fuel on average during the years 2001–2004.

For a number of reasons, the results regarding fuel inputs allocated to the major species landed and to different fishing gears are probably most interesting for consumers and purchasers. As species-specific data reflect many different fishing gears, fishing zones, etc. they may be of limited value to fishers, vessel owners and other stakeholders in the fishing industry who probably need more detailed data. For consumers and other stakeholders that do not need much specific information about the species caught, the fishing gear used, and local spatial differences, the data presented are the best available Norwegian data on fuel consumption. The high standard deviation indicates that the specific fuel consumption is highly variable, especially among the many small fishing vessels. Consumers and others interested in the environmental load of fisheries and energy-related environmental impacts in particular, should therefore ask for more specific fuel data for the fish purchased. Data on fuel consumption could be integrated in the TraceFish system, which handles data of the catch throughout the value chain from fishing to the store [46]. Improved data collection routines will make it possible to present individual species and gear fuel use data on a yearly basis after 2005 [26].

The most promising technical fuel reduction measure is to optimize the rotational speed of the propeller and the design thereof. Shifting the energy carrier from diesel to natural gas can reduce the NO_x output considerably and also reduce the CO_2 emission. Of the non-technical measurements, changed behavior and strategy in the fisheries, like reduced speed and more energy efficient operational pattern could give effects of up to 20% for some fleet groups. Reconsidering tapping into renewable energy sources such as wind could be an option if the cost of fuel continues to rise.

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Appendix E

Paper V:

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ENVIRONMENTAL ANALYSIS OF NORWEGIAN FISH FOOD PRODUCTS

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Abstract

Sustainable consumption is on the international agenda. Environmental product information is needed to help consumer and public and private purchasers to make an informed choice and to buy environmentally sound products. Life cycle assessment (LCA) follows the product from cradle to grave, from raw material extraction to consumption and waste handling, and provides information about all environmental aspects of the product. LCA can analyze the industrial aspects of modern fishery and accompanying energy and material flows, where especially fuel usage in the fishing phase is important. Environmental product declaration (EPD) is a standardised tool to communicate and make LCA information comparable. Fishing vessels are energy demanding, so to improve the environmental performance of the fish product, the vessel's energy usage is an area of special focus. Fuel data for 46 different species for each of the years 2001-2004 fished by Norwegian vessels are presented. The variations between the different species are considerable; i.e. in 2004 the fuel use for Atlantic herring (*Clupea harengus*), Blue whiting (*Micromesistius poutassou*) and Horse mackerel (*Trachurus trachurus*) was 0.12 litre kg^{-1}, and for Dover sole (*Solea solea*) 2.71 l kg^{-1}. Fuel use for Atlantic cod (*Cadus morhua*) was 0.39 l kg^{-1}. In total for all species, the fuel use increased 16.4 % from 0.170 l kg^{-1} in 2001 to 0.198 l kg^{-1} in 2004. The communication of the results to purchasers of fish may induce an increased demand for low fuel fish species.

1. Introduction

Sustainable consumption is on the international agenda. But in order for consumers and public and private purchasers to make informed choices about environmental impacts, product information is needed. Earlier life cycle assessments (LCA) of fish products have shown that the fishing phase is an important contributor to the environmental impact of the fish product (Eyjólfsdóttir et al. 2003; Ziegler et al. 2003; Hospido and Tyedmers 2005; Thrane 2006). Today's fishing vessels are energy demanding (Ellingsen and Aanondsen 2002), so to improve the environmental performance of the fish product, the vessel's energy usage is an special area of focus. This paper describes how one important environmental aspect of fishing, energy used by the fishing vessel, is measured for each species fished by the Norwegian fishing fleet.

1.1 Life cycle assessment (LCA)

LCA is a standardised method (ISO 14040 2006; ISO 14044 2006), that is developed for industrial production (Graedel and Allenby 1995). LCA follows the product from raw material extraction, through material production, production, consumption and waste handling, and provides information on a range of environmental aspects of the product (Guinée 2001). Adjustments are made for using LCA of food products from agricultural production (Ceuterick et al. 1998) and also fish food product (Ziegler 2001). LCA recognises the industrial aspects of modern fishery with accompanying energy and material flows, where especially fuel usage in the fishing phase is important (Hospido and Tyedmers 2005).

1.2 Environmental product declaration (EPD)

There are several different environmental labelling schemes for sea food, but many focus on the ecological/biological aspects only. Type III Environmental product declarations (EPD) require a LCA according to the ISO14040-series (ISO 14025 2006). EPD for fish food products include many different impact categories, i.e. global warming potential, energy use, marine eco-toxicity potential and eutrophication in addition to fishery specific aspects such as fishing gear applied and sea floor use (Schau 2006). Type III EPD, for short EPD, requires an approval of the LCA and a third party verification of the declaration (Fet and Skaar 2006), such that the information has credibility among the interested parties. LCA results are complex, and a standardised way of communicating the results to the stakeholders, for example by using an EPD, could facilitate the overall goal of better environmental performance for fish food production.

An EPD is normally of one specific product. Norwegian fishing vessels usually target several different fish species, and also get different species as by-catch. As the consumer or other purchasers of the product may be more interested in the potential environmental consequences of the specific product offered, and not that of the fishing vessel, specific information for one species seems like a reasonable need. Different species may have very different value chains. Making an EPD for only one species, instead of many different species, would facilitate the work of conducting the LCA where the product is followed from cradle to grave.

2. Material and method

2.1 Material

From 1966 to 2004, a committee (Budsjettnemda) set down by the Norwegian Directorate of Fisheries and Statistics has conducted profitability investigations of Norwegian fishing vessels (8 meters length over all and above) operating year-round. Beginning in 2005, this investigation was undertaken by the Norwegian Directorate of Fisheries (Fiskeridirektoratet 2006). Investigations from 2001 and onward, also surveyed[1] the fuel usage of the fishing vessel in addition to pure financial data (Aasheim and Steinseide 2005). The Norwegian law orders the recipient of this questionnaire to fill it out and reply. The data on fuel consumption was merged with the catch registry of the Norwegian Directorate of Fisheries. These vessels accounted for 85 % of the total Norwegian catch in 2001 and increased to 94.1 % in 2004 (Budsjettnemnda for fiskenæringen 2004; Fiskeridirektoratet 2006).

A Microsoft Excel spreadsheet and the built-in Visual Basic application have been used to organize and analyse the data. Table 1 shows vessel group and operating code and the prices that have been used to estimate missing fuel data. Only data for year 2004 are shown due to limited space. The input data for the year 2001 – 2003 are of the same magnitude.

[1] For a throughout description of sampling technique, see i.e. (Fiskeridirektoratet 2006)

Table 1: Aggregated data for each vessel group or operating code* for the year 2004

Group of vessel	operating code*	Number of vessels in operating code*	Number of vessels that have reported fuel usage in litre	Average fuel price [NOK/l]	Mixed fish caught [kg]	Fuel usage [l]	Specific fuel usage for mixed fish [l kg^{-1}]
1	001	55	46	3.44	2.86×10^6	3.95×10^5	0.138
2	002	208	159	3.24	2.21×10^7	3.42×10^6	0.155
3	003	37	27	2.95	8.60×10^6	1.61×10^6	0.187
4	004	21	16	2.66	1.10×10^7	2.28×10^6	0.207
5	005	32	22	3.58	6.00×10^7	1.96×10^7	0.327
6	006 007	6 6	6 5	2.35 2.12	6.44×10^7	3.17×10^7	0.492
7	008 009	11 12	10 10	2.37 2.25	7.67×10^7	4.71×10^7	0.614
8	010	14	9	2.33	3.63×10^7	2.11×10^7	0.581
9	011 012	3 9	3 6	3.62 3.25	3.68×10^5	2.62×10^5	0.711
10	013 014 015	22 9 8	17 7 5	2.89 2.94 2.89	5.71×10^6	3.74×10^6	0.655
11	016	6	6	2.10	1.25×10^7	2.46×10^7	1.968
12	017	8	6	2.39	1.71×10^7	9.21×10^6	0.540
13	018 019	4 15	3 13	3.38 2.46	3.43×10^6	2.87×10^5	0.084
14	020 021 022	9 11 17	7 8 15	2.87 2.54 2.75	3.84×10^7	3.44×10^6	0.089
15	023	46	38	2.39	1.03×10^8	1.04×10^7	0.102
16	024 025	21 7	17 6	1.99 2.30	1.79×10^8	2.40×10^7	0.134
17	026	38	24	2.19	9.09×10^8	9.14×10^7	0.101
18	027	27	18	2.39	1.48×10^8	2.14×10^7	0.144
Grand Total		662	509				

* The operating code is a second grouping of the fishing fleet in addition to vessel groups used by the Norwegian Directorate of Fisheries to divide the fishing fleet into similar vessels depending on size of vessel, fishing gear used and species caught.

2.2 *Method*

The fish catch data can be presented as a matrix **A** with the mass *a* caught of the different fish species *j* by the different fishing vessels *i* and **Y** is the matrix with the fuel use *y* of the fishing vessel *i*. A special case with three fishing boats catching two species could be presented as:

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \end{pmatrix} \text{ and } \mathbf{Y} = \begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix}$$

The first column in matrix **A** represents catch of species 1 and the second column, the catch of species 2. The first row in matrix **A** represents the catches of fishing boat 1, the second row the catches of fishing vessel 2 and so on.

The fuel use y_{ij} for species j caught by fishing vessel i can be found by allocating the fuel y_i of fishing vessel i on the fish species j as described by eq. (1):

$$y_{ij} = \frac{a_{ij}}{\sum_j a_{ij}} \cdot y_i \qquad (1)$$

where i = 1 … m, and m is the number of fishing vessels. The average fuel for all fishing vessels $\bar{y}_j$ allocated to species j is given by eq. (2):

$$\bar{y}_j = \frac{\sum_i \frac{a_{ij}}{\sum_j a_{ij}} \cdot y_i}{m} \qquad (2)$$

where i = 1 … m. [2] The average mass caught for all fishing vessels $\bar{a}_j$ of fish species j is given by eq. (3):

$$\bar{a}_j = \frac{\sum_i a_{ij}}{m} \qquad (3)$$

where i = 1, … m.
By dividing the average fuel $\bar{y}_j$ allocated to species j (eq. 2) by the average mass of fish species j, $\bar{a}_j$ given by eq. (3), the specific average fuel consumption $\bar{x}$ for fish species j, $\bar{x}_j$, can be found by eq. (4):

$$\bar{x}_j = \frac{\bar{y}_j}{\bar{a}_j} = \frac{\sum_i \left(\frac{a_{ij}}{\sum_j a_{ij}} \cdot y_i\right)}{\sum_i a_{ij}} \qquad (4)$$

where i = 1,2, …, m fishing vessels, j = 1,2,3,… n fish species, a_{ij} = mass of fish species j caught by fishing vessel i and y_i = annual fuel usage of fishing vessel i.

3. Results

Table 2 shows the specific fuel usage for different species and the number of vessels that caught this species in the year 2001 to 2004. The grand total specific fuel usage for all species and fishing vessels are also included. All species that have been reported are included in the table, except where there are so few vessels catching one species that the anonymity of the fishing vessel could be jeopardized. In such cases, the species are aggregated in the generic categories *other marine fish* or *other species*.

[2] For species 1, $\bar{y}_1$ in the special case is given by: $\bar{y}_1 = \frac{\frac{a_{11}}{a_{11}+a_{12}} \cdot y_1 + \frac{a_{21}}{a_{21}+a_{22}} \cdot y_2 + \frac{a_{31}}{a_{31}+a_{32}} \cdot y_3}{3}$

Table 2: Species and specific fuel consumption (litre fuel per kg catch) for the year 2001 – 2004 and the number of vessels (N) reporting catch of the species are shown.

Species	2001 Specific fuel usage [l kg^{-1}]	2001 N	2002 Specific fuel usage [l kg^{-1}]	2002 N	2003 Specific fuel usage [l kg^{-1}]	2003 N	2004 Specific fuel usage [l kg^{-1}]	2004 N
Anglerfish/monkfish (*Lophius piscatorius*)	0.32	383	0.46	334	0.34	327	0.28	364
Argentines (*Argentina spp*)	0.24	22	0.20	14	0.20	15	0.18	13
Atlantic cod (*Gadus morhua*)	0.42	420	0.39	418	0.44	377	0.39	452
Atlantic herring (*Clupea harengus*)	0.10	204	0.11	216	0.12	193	0.12	220
Atlantic redfishes (*Sebastes spp*)	0.30	12	0.85	12	0.60	12	0.85	19
Atlantic wolfish (= Catfish) (*Anarhichas lupus*)	0.34	372	0.39	315	0.38	323	0.46	337
Beaked redfish (*Sebastes mentella*)	0.56	55	0.57	45	0.53	38	0.55	45
Blue ling (*Molva dypterygia*)	0.35	130	0.42	115	0.37	122	0.32	467
Blue whiting (*Micromesistius poutassou*)	0.10	118	0.11	113	0.10	105	0.12	143
Brill (*Scophthalmus rhomus*)	2.70	29	0.84	16	2.34	29	2.55	30
Capelin (*Mallotus villosus*)	0.10	133	0.11	142	0.11	131	0.13	22
crustacean/mussel/mollusc	0.11	11	0.12	33	0.12	15	0.06	13
Deepwater prawn (*Pandalus borealis*)	1.14	85	1.14	74	1.30	87	1.25	96
Dover sole (*Solea solea*)	3.14	17	1.01	14	2.75	25	2.71	27
Edible crab (*Cancer pagurus*)	0.17	10	0.10	5	0.19	13	0.15	23
European lobster (*Homarus gammarus*)	0.50	24	0.26	12	0.22	12	0.21	20
European sprat (*Sprattus sprattus*)	0.10	22	0.07	9	0.11	12	0.07	9
Greater forkbeard (*Phycis blennoides*)	0.39	459	0.39	445	0.39	409	0.33	453
Golden redfish (*Sebastes marinus*)	0.46	463	0.45	428	0.37	402	0.42	465
Greenland halibut (*Reinhardtius Hippoglossoides*)	0.51	396	0.57	380	0.46	375	0.47	447
Haddock (*Melanogrammus aeglefinus*)	0.45	579	0.46	529	0.48	505	0.44	570
Hake (*Merluccius merluccius*)	0.39	198	0.29	158	0.40	175	0.30	200
Horse mackerel (*Trachurus trachurus*)	0.11	203	0.11	188	0.11	180	0.12	213
King crab (*Paralithodes camtscatica*)	0.15	17	0.16	21	0.15	23	0.16	48
Lemon sole (*Microstomus kitt*)	1.28	56	0.19	51	1.40	55	0.90	62
Ling (*Molva molva*)	0.38	462	0.39	430	0.37	410	N.A	N.A.
Lumpfish (*Cyclopterus lumpus*)	0.12	29	0.10	38	0.13	45	0.13	44
Mackerel shark (*Lamna nasus*)	0.26	30	0.23	27	0.27	42	0.22	38
Moras (*Moridae*)	0.37	14	0.40	8	0.39	7	N.A	N.A.
Northern wolffish (*Anarhichas denticulatus (latifrons)*)	0.39	47	0.38	34	0.36	35	0.37	35
Norway lobster (*Nephrops norvegicus*)	1.59	57	0.65	43	1.09	58	0.89	69
Norway pout (*Trisopterus esmarkii*)	0.11	27	0.11	22	0.14	13	0.15	18
Plaice (*Pleuronectes platessa*)	2.67	189	0.85	161	2.20	172	1.96	183
Pollack (*Pollachius pollachius*)	0.28	335	0.34	302	0.33	293	0.27	327
Roughhead grenadier (*Macrourus berglax*)	0.45	31	0.46	21	0.40	21	0.43	25
Roundnose grenadier (*Coryphaenoides rupestris*)	0.63	16	0.53	14	0.62	14	0.39	15
Saithe (*Pollachius virens*)	0.40	635	0.47	620	0.45	573	0.41	644
Sandeels (*Ammodytes spp*)	0.08	36	0.09	34	0.13	27	0.15	24
Skate/Thornback ray (*Raja batis/Raja clavata*)	0.48	241	0.52	204	0.47	215	0.44	242
Skates and rays. nei.(*Rajiformes*)	0.44	154	0.42	113	0.31	122	0.33	152
Spoted sea cat (*Anarchicas minor*)	0.41	180	0.40	174	0.34	152	0.35	179
Spurdog (*Squalus acanthias*)	0.25	143	0.29	110	0.28	133	0.23	164
Turbot (*Psetta maxima*)	2.82	112	0.95	76	2.40	85	2.40	98
Whiting (*Merlangius merlangius*)	0.56	86	0.41	75	0.51	75	0.31	71
Witch (*Glyptocephalus cynoglossus*)	1.53	46	0.59	35	1.23	55	0.96	61
Wolffishes (*Anarhichas spp*)	0.39	34	0.38	19	0.32	30	0.32	39
Other marine fish	0.29	229	0.22	213	0.40	173	0.42	214
Other species	0.17	29	0.11	28	0.17	31	0.17	17
Grand Total	**0.170**	**656**	**0.175**	**637**	**0.193**	**607**	**0.198**	**662**

The lowest specific fuel usage is used for catching pelagic species such as Horse mackerel, Atlantic herring and Blue whiting (all 0.12 l kg^{-1} in 2004), Capelin (0.13 l kg^{-1}) and by-catch species Crustaceans/Mussel/Mollusc (0.06 l kg^{-1} in 2004) and European sprat (0.07 l kg^{-1} in 2004). At the other end are energy intensive species such as Dover sole (2.71 l kg^{-1}), Brill (2.55 l kg^{-1}) and Turbot (2.40 l kg^{-1}). Also Plaice (1.96 l kg^{-1}) and Deepwater prawn (1.25 l kg^{-1}) are relatively high energy intensive species. Frequently caught species like Atlantic cod (0.39 kg^{-1}), Haddock (0.44 kg^{-1}) and Saithe (0.41 kg^{-1}) are found in the mid range.

The variation from year to year is surprisingly small for most species, except for Atlantic redfish, Brill, Dover sole, European lobster, Lemon sole, Norway lobster, Plaice and Turbot. The average specific fuel consumption for all species for all fishing vessel shows also small variation, but an increase from the year 2001 to 2004 of 16.4 % is recognisable.

4. Discussion

The data and results are from Norwegian fishing vessels, fishing mainly in the North Atlantic. Other nations' fishing vessel targeting the same stock and with similar fishing gear underlying the same management scheme are believed to show comparable results with corrections for different distances to harbour. The method applied for finding the results, can be applied by other nations' fishing fleets, as long as the data are available.

When the results are communicated to the purchaser of fish, either through the EPD or another way, it is believed that the more environmentally sound fish species, i.e. those using less fuel, should experience an increased demand. This in turn may lead to a higher price paid for low fuel species in the market.

4.1 Data quality

The fuel data are reported by the vessel owner, and it has not been possible to cross check these data against other sources directly. This may be a source of error. However, for each of the operating codes, the fuel expenses (given in Norwegian kroner, NOK) divided by volume of fuel (given in litre) was calculated using the expenditure of fuels oils in the approved financial statement and the fuel usage reported by the vessel owners. The resulting price [NOK l^{-1}] seems reasonable for all vessel codes. The data used for 2004 can be found in table 1.

Finding fuel based on expenditure for fuel and lubrication oil for those that do not indicate fuel usage, is not straight forward. It is especially problematic where the ratio *Fuel expenses* / *Fuel* is based on very few vessels. I decided to use the operating code, to have a systematic way of doing the estimate and basing the estimate on similar vessels. The numbers of vessels that are missing fuel usage are small compared to the number of vessels that reported fuel usage (see table 1 column 3 and 4 for the year 2004). The bias of the results is therefore considered small; insignificant for species where the number of fishing vessels reporting catch of this species is large ($N > 100$), but larger for other species caught by few vessels ($N < 30$).

4.2 Reasons for varying specific fuel usage of the different species

Targeting shoaling species, which leads to large quantities of fish in one haul, could lead to lower specific fuel usage than other non-shoaling fish. The composition of fishing gears used to catch different species would influence the specific fuel usage of the species. The difference between passive and active fishing gear are believed to be large (Ziegler and Hansson 2003; Thrane 2004). Different sort of vessels that are targeting the different species could also explain different fuel use (Thrane 2004). Vessel specification of breadth/length ratio, installed propulsion power size, and hull form and size, influence the energy use of the fishing vessel and thereby can be a reasons for differences between species (Ellingsen and Pedersen 2004). The distance from harbour to fish stock will also have an impact on the fuel usage. Fish stock that is caught close to the shore would have, ceteris paribus, a lower specific fuel usage than fish stock that is targeted a long distance from the home harbour (Hospido and Tyedmers 2005). The stock size could impact the fuel usage (Fletcher 1992), which is related to the variations in the availability of fish (Huse et al. 2002. p. 78; Tyedmers et al. 2005). Availability is also dependent on whether the species is governed by a quota system or not. The Blue whiting fishery was, for the data period covered, a free access fishery. Quotas were introduced in 2005. It will be interesting to observe how the fuel usage for blue whiting is affected by the change from open access to a quota system. According to anonymous sources in the Norwegian fishing industry, the specific fuel usage for blue whiting has been nearly reduced by 50 % after the quota was introduced. But official data for 2005 and 2006 are not yet available. The fishery management scheme is also believed to have an influence on the fuel use intensity.

Future research should investigate how much each of these factors impacts the fuel usage.

5. Conclusion

This paper has shown that the fuel usage of different species caught by the Norwegian fishing vessels varies considerably, with up to a factor of 42 between different species. This statement needs to be taken into consideration when LCA of fish food products are conducted. Because EPDs usually are for one product only, a scientific way of allocating the fuel usage of different species is crucial when preparing EPD. The method used here for finding the specific fuel consumption is through allocation of the fuel reported by each vessel each year 2001 to 2004 included on the reported catch measured in kilogram of each species from about 650 fishing vessels. There are various factors that in sum lead to large variations of the specific fuel usage for different species.

Future research should investigate what factors influence the energy used by the fishing vessel and potential ways to reduce this, such that the environmental profiles of fish food products can be improved. This paper has presented data and methods for the fuel usage of the fishing vessel. This is only one, however important, environmental aspect of the fish food product. Fishing and the production and handling of fish food product involve a range of different environmental aspects that are required to be considered in the LCA and EPD.

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Aasheim, T. and A. K. Steinseide (2005). Drivstofforbruk og fangst i fiskeflåten (Letter about fuel use and catch of the Norwegian fishing fleet sent to E M Schau). Bergen.

Appendix F

Example of an EPD for Atlantic herring

and

Product category rules (PCR) for preparing an environmental product declaration (EPD) for product group wild caught fish - Draft

A slightly different version of the PCR draft was published in January 2006 by the EPD Foundation Norway:
Schau, EM (2006). "Product category rules (PCR) for preparing an Environmental Product Declaration (EPD) for Product Group Wild caught fish -Draft." ISO/DIS 14025 Environmental Declarations Type III Oslo, EPD Foundation Norway. Retrieved 23 Jan 2006, from URL http://www.nho.no/files/NPCR06FishEN.pdf

Environmental Declaration ISO/CD 14025 Type III

Producer; Anonymous [for this purpose]

EPD

Norwegian Environmental Product Declarations

NEPD no.: XXX
Approved, date: DD.MM.YYYY
Valid until, date: DD.MM.YYYY

This declaration has been compiled by:

Erwin M. Schau
Department of Industrial Economics and Technology Management, NO-7491
NTNU, Trondheim, Norway

[Picture to be inserted here]

Statement from certificate body:

This declaration has not been approved

Information about the producer:

Name of production unit
Place
Contact person: N. N
Phone: + xxxxxxx
E-mail:

Figure 1: Atlantic Herring

Global warming potential	2.14 kg CO_2-equivalent	Fish consumption:	3.03 kg (round fish, target species)
		Total by-catch:	32.9 g (Mainly Saithe and Blue whiting)
Total energy consumption	37.0 MJ		
Fishing gear type	Purse seine and pelagic trawl	Total discard to sea:	0 (Due to legal requirement in Norway, discard is not allowed)

Product specification: Species name: *Clupea harengus* (scientific) Atlantic herring (trade name)
Origin of catch: North East Atlantic, landed in Norway

Functional unit: 1 kg fillet
From 3.03 kg landed fish on deck.

Life cycle stage included: This environmental declaration includes the whole life cycle of the product, from raw material extraction to consumption.

Assumed market region: European Union

Product specification: 100 % filet from Atlantic herring, no preservative or additive, packaged in cardboard and plastic (PET).

CONSUMPTION OF RESOURCES

Material resources

Table 1: Consumption of Material Resources

Information	Name	value	Unit
Renewable resources	Fish	3.06	kg
Renewable resource	Water*	82.7	kg
Renewable resources	Timber	0.137	kg
Non renewable resources	Copper ore (0.14%)	25.6	g
Non renewable resources	Iron ore	14.8	g
Non renewable resources	Limestone (calcium carbonate)	9.84	g
Non renewable resources	Heavy spar (barytes)	2.98	g
Non renewable resources	Chromium ore	2.17	g
Non renewable resources	Bauxite	2.08	g
Non renewable resources	Zinc - copper ore (4.07%-2.59%)	1.41	g
Non renewable resources	Nickel ore (1.6%)	1.04	g

* Household consumption of water not included

Land use, sea floor use and fresh water consumption

Land use and sea floor use has not been quantified in this study. The fishing gear used are not in contact with the sea floor. Water consumption is included in table 1, except for household consumption.

Energy resources

Table 2: Energy consumption specified for the different energy carriers.

Category	Resource	value	Unit
Non renewable energy resources	Crude oil	16,3	MJ
Non renewable energy resources	Hard coal	3,45	MJ
Non renewable energy resources	Lignite	3,43	MJ
Non renewable energy resources	Natural gas	2,34	MJ
Renewable energy resources	Hydro power	5,17	MJ
Renewable energy resources	Renewable fuels	1,03	MJ
Renewable energy resources	Wind power	56,8	kJ
Renewable energy resources	Wood	37,2	kJ
Renewable energy resources	Solar energy	26,6	kJ

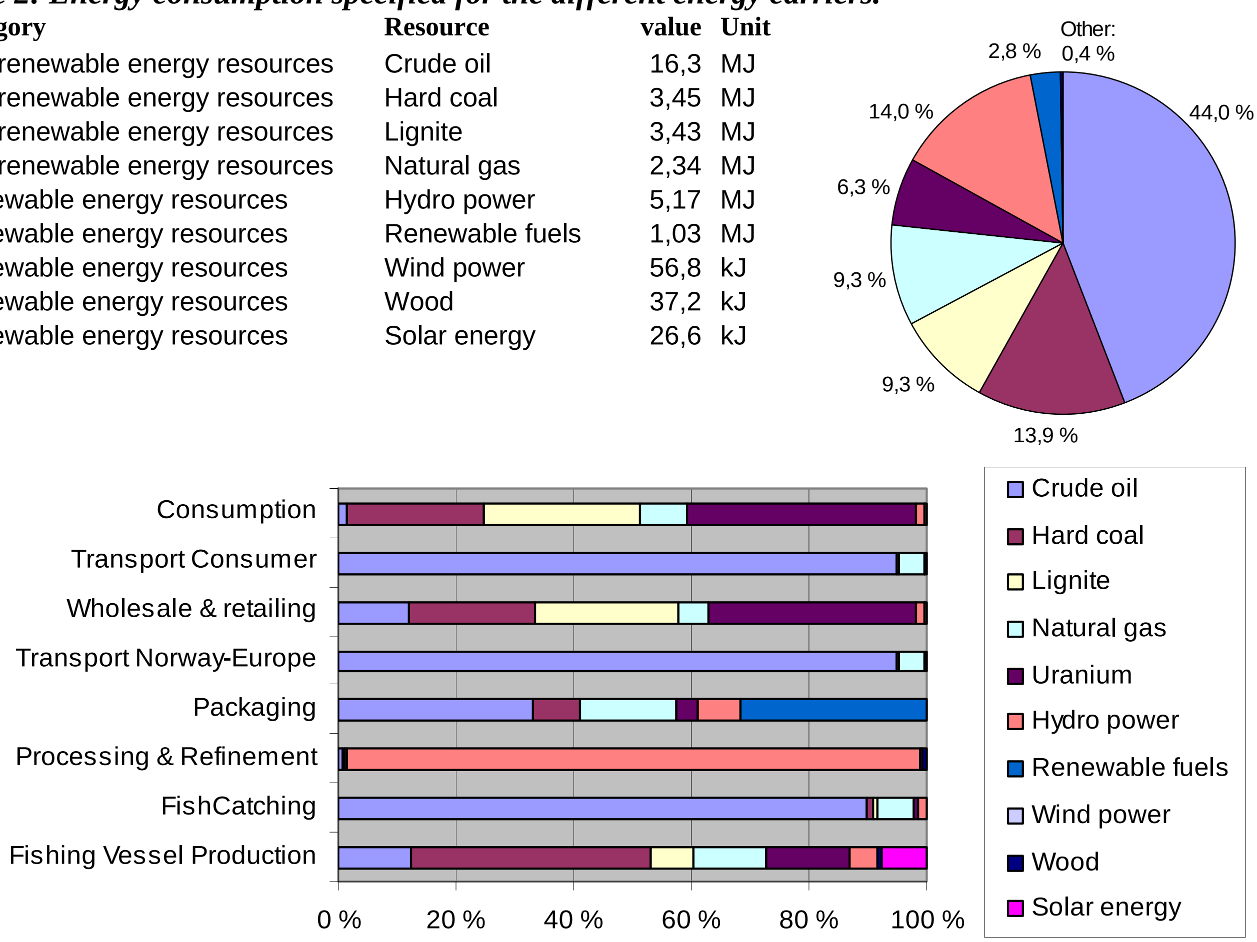

Figure 2: Percentage of the different energy carriers, total and per life cycle stage.

Emissions and environmental impacts

Table 4: Environmental impacts.

Impact category	Total
Acidification Potential (AP) [g SO_2-Equiv.]	17.1
Eutrophication Potential (EP) [g Phosphate-Equiv.]	4.4
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	2.14
Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]	67.2
Ozone Layer Depletion Potential (ODP) [mg R11-Equiv.]	0.836
Photochem. Ozone Creation Potential (POCP) [g Ethene-Equiv.]	2.03
Radioactive Radiation (RAD) [DALY]	3.56E-09

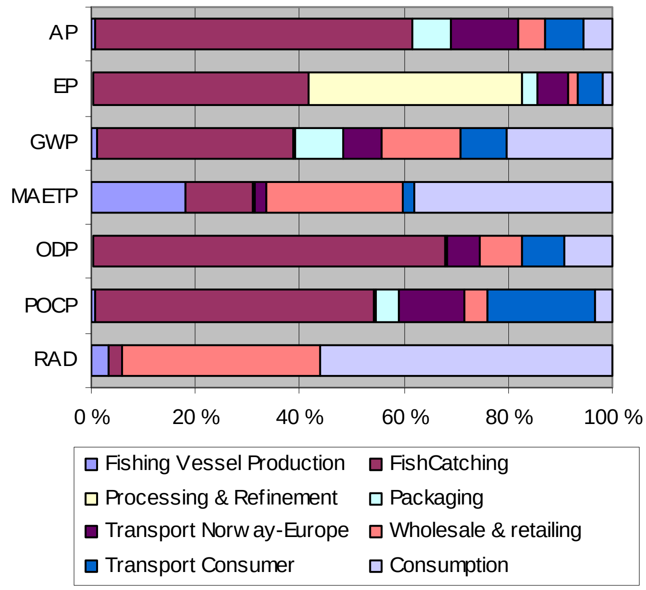

Table 5: Waste and largest emissions to air and water on a weight basis.

Emission	Compartment	quantity	unit
CO_2	Emission to air	2038	g
NOx	Emission to air	18.9	g
SO_2	Emission to air	3.84	g
Non methane VOC	Emission to air	3.27	g
CO	Emission to air	2.76	g
Methane	Emission to air	2.60	g
Dust	Emission to air	653	mg
Nitrous oxide (laughing gas)	Emissions to air	0,0545	mg
Chloride	Emission to fresh water	11.5	g
Chemical oxygen demand (COD)	Emission to fresh water	4.28	g
Sodium	Emissions to fresh water	2.03	g
Sulphate	Emissions to fresh water	1.75	g
Chemical oxygen demand (COD)	Emissions to sea water	81.1	g
Fatty acids (calculated as total C)	Emissions to sea water	1.92	g
Copper ion (Cu++/Cu+++)	Emissions to sea water	22.9	µg
Xylene (isomers; dimethyl benzene)	Emissions to sea water	10.7	µg
Consumer waste	Waste	18.0	g
Hazardous waste	Waste	17.6	g
Radioactive waste	Waste	1.81	g

Table 6: By-catch and discard

Type	Species	quantity	unit
By-catch	Saithe *(Pollachius virens)*	20.9	g
By-catch	Blue whiting *(Micromesistius poutassou)*	10.7	g
By-catch	Haddock *(Melanogrammus aeglefinus)*	1.36	g

Other fishery specific environmental aspects

The total catch of Atlantic Herring is considered to be within safe biological limits.

Additional information

The consumption phase reflects an average German consumer where data have been taken from (Wiegmann et al. 2005). The consumer can significantly influence the results by the choice of transport mode, technical equipment (e.g. gas or electric cooker), efficiency of and storing time in refrigerator and deep freezer and the electricity energy sources.

Some adjustment has been made for the material choice in the fishing vessel, because specific data for all materials do not exist. This adjustment and assumptions has been made by experienced life cycle assessment practitioners. In such cases, similar materials from the GaBi 3.0 life cycle inventory databases have been used.

Recycling and waste handling

Residuals can be composted.

Methodological Decisions

The analyses of the fishing vessel is a "cradle to gate"-analyses, which means that all processes from raw material extraction and production are included. Infrastructure, like the construction of the processing plant and the production of the transport means are not included in the analyses; for these only the operation phases of their life cycles are included.

In Figure 2, the upper level of the production system is illustrated. The doted lines indicate generic data, whereas strong lines are data collected specific for this EPD.

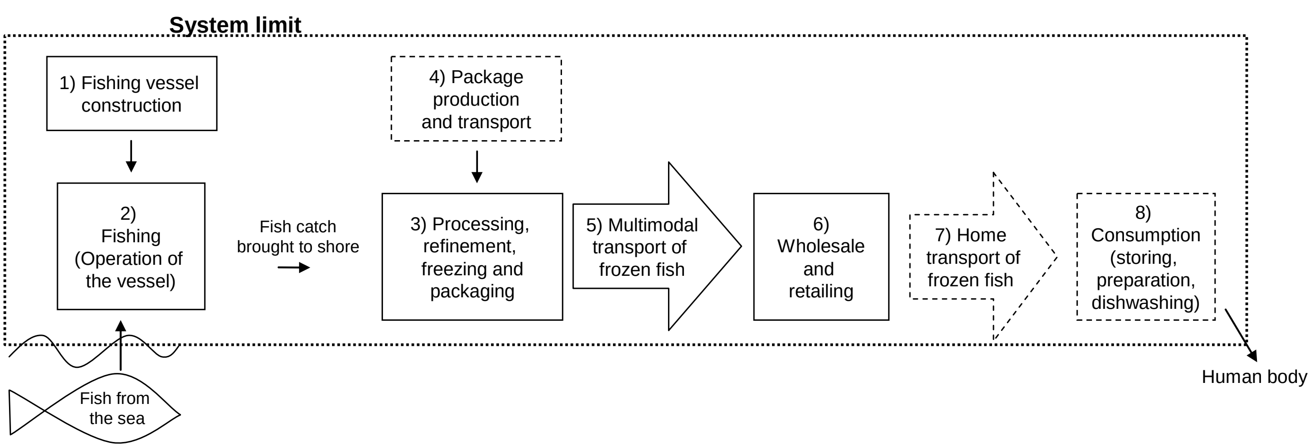

Figure 2: Upper level illustration of the production system investigated

Cut-off criteria

Processes and activities that contribute to less than 1 % of the total environmental impact for any impact category are permitted to be omitted according to the PCR.

Excluded processes
Detergent has been omitted. The one used in the fishing phase is more than 90 % biodegradable. The environmental impacts of detergent throughout the life cycle of the fish food product are considered neglectable.

Allocation rules
Allocation in the fishing phase has been done on basis of the mass of the fish. This is motivated by the quota system, which is based on mass of the fish and limits the fishery. Another allocation method may influence the results considerably.

Data quality
50.4 % of the total mass in the inventory are from specific data and 49.6 % from generic data.

References

Documentation of all underlying processes would be available on request. Questions about method choices and data basis should be directed to the compiler of this declaration.

Wiegmann K, Eberle U, Fritsche U, Hünecke K. Datendokumentation zum Diskussionspapier Nr. 7 ("Umweltauswirkungen von Ernährung - Stoffstromanalysen und Szenarien"). Darmstadt/Hamburg: Öko-Institut e.V. - Institutt für Angewandte Ökologie; 2005 September 2005. 51 pp.

PCR Wild caught fish, draft December 2005. URL: http://www.epd-norge.no

Product Category Rules (PCR)

for preparing an Environmental Product Declaration (EPD) for Product Group

Wild caught fish

Table of contents:

1. General information

These Product Category Rules are intended for wild caught fish, a subcategory of fish food product. The rules apply to wild caught fish, defined as a food product intended for human consumption or a processed or unprocessed feed for other animals intended to be used for human food consumption. Other functions that the product may provide are not considered herein.

Only wild caught fish that comes from fisheries with a fishery management plan based on regular scientific advice on sustainable exploitation are considered for this Product Category Rules.

This document specifies the requirements for the LCA study and for the format and content of the EPD itself. Recognising the global aspects of the fishing industry, the geographical coverage is global.

The PCR document has been prepared by Erwin Meissner Schau at SINTEF Fisheries and aquaculture and the Norwegian University of Science and Technology in accordance with ISO/CD 14025 and the Norwegian adaptation of this standard (NEPD 2004).
The EPD and criteria are meant as a supplement and complement to other eco-labelling scheme like KRAV and MSC and other organic and or biological schemes, even there may be overlap in some fields.

2. Product description

The product or range of product will be identified as a product where the edible contain of the product is more than 95 % (weight) fish.

The packaging following the product should be included in the analysis.

The relevant impact categories are listed in section 9.

In accordance with the “Requirements for an International EPD scheme”, similar products (i.e. products with different additive ingredients) can be included in the same declaration provided that the range of variation within each impact category does not exceed ±5 %. The non quantified impact categories have to be the same.

3. List of materials, chemical substances and fishery specific environmental aspects

The materials and substances listed below must be reported in the environmental product declaration (EPD). The emissions listed in b1 and b2 are the emissions that are considered to be the most relevant from the fishing industry.

a) Product specifications, consisting of:
   1. Species (common name and Latin name) and origin of catch
   2. Ingredients composition, in gram per functional unit (FU) and in percentage of weight landed fish on deck.
b) Emissions (sorted by main phases of the life cycle – see fig. 1):
   1. Emissions to air, in gram per FU, including:

        i. Fossil CO_2
        ii. CH_4
        iii. N_2O
        iv. NO_x
        v. SO_x
        vi. HC
        vii. CO
        viii. NMVOC
        ix. Dioxins
        x. Heavy metals (specified)
    2. Emissions to water, in gram per FU, including:
        i. Phosphates
        ii. Nitrates
        iii. Dioxins
        iv. Heavy metals (specified)
    3. Wastes, in gram per FU, sorted by:
        i. Material recycling.
        ii. Incineration with energy recovery.
        iii. Incineration without energy recovery.
        iv. Disposal.
        v. Hazardous waste.
c) Fishery specific environmental aspects
    1. Fishing gear type used
    2. Sea floor use
        i. If active fishing gears are used on the sea bottom, the swept area per FU should be reported.
    3. By-catch
        i. Mass and species of by-catch per FU should be reported
    4. Discard
        i. Mass and species of discard per FU should be reported
    5. Lost fishing gears
        i. If fishing gears are lost and not found and collected within 24 hours, type of fishing gear and size should be reported.

4. Functional unit

The functional unit for the life cycle assessment is 1 kg fish delivered to the main target audience (e.g. consumer) of the EPD document. This main target audience has to be named.

The EPD shall provide information for the entire physical product. Aggregated results for the net mass content of the packaging shall be reported. The reported mass must be clearly specified on the front page of the EPD.

5. System boundaries

The entire life cycle is to be covered. This includes all industrial processes from raw material extraction and production, processing, use and maintenance, transportation, and disposal. Rules on how recycling processes should be handled are described in detail in chapter 7, Allocation rules.

In general, production of capital goods, infrastructure, and personnel related activities are not included, with the exception of the fishing vessel that should be included. Personnel related activities on the fishing boat can be included. This should be clearly described in the description of the system boundaries.

Naturally occurring consumption and release of CO_2 are not included. This is to avoid counting of CO_2 in the natural cycle. Emissions linked to the depletion of natural resources (e.g. fish stocks depletion or deforestation) such that the natural CO_2-cycle is influenced, are not considered to be part of the natural cycle and should be included.

A flow chart like figure 1 should be used to illustrate the system boundaries. If the EPD does not cover the entire life cycle (cradle to grave) this shall be clearly stated on the front page of the EPD. Alternative statements for the following system boundaries are:

AEF: This declaration covers environmental impacts throughout the product life cycle, from raw material extraction to packaging and disposal, inclusive.

AEG: This declaration covers environmental impacts from raw material extraction to consumption, inclusive. The declaration does not cover packaging and rest product disposal, and is therefore not comparable to declarations that cover the entire product life cycle.

A: This declaration covers environmental impacts from raw material extraction to production, inclusive. The declaration does not cover retailing, consumption and disposal, and is therefore not comparable to declarations that cover the entire product life cycle.

D: This declaration is a module environmental product declaration. It covers the fishing vessel/gear maintenance, fishing and fishing vessel/gear disposal. Raw material extraction and production, retailing, consumption and disposal are not included.

Processes that are not included should be indicated by solid drawn lines, while processes that are not included should be indicated by stippled lines.

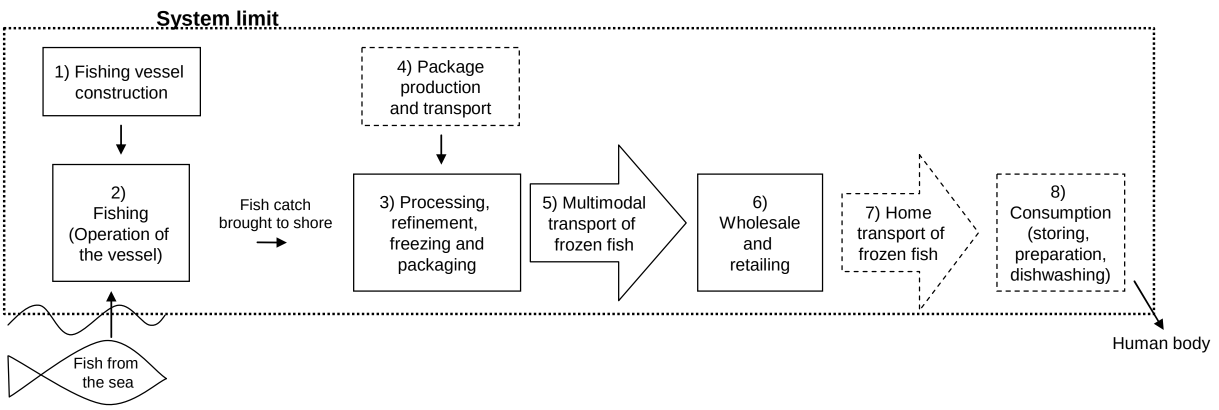

Fig 1: Example of flow chart of system for indicating system boundaries (arrows indicate eventual transport and/or intermediate storing)

6. Cut-off rules

Processes and activities that contribute to less than 1 % of the total environmental impact for any impact category are allowed to be omitted from the inventory analysis.
By-catch species that constitutes less than 1 % of the mass of the target species and are not in the IUCN Red List can be omitted from the specification in the EPD.

Components and materials of composition similar to the major components (>20 weight %) in the inventory list may be assumed to have the same environmental impact in percent as their weight percentage, and may therefore be excluded on weight basis alone.

7. Allocation rules

Allocations should where possible be avoided by system expansion or dissagregation. Deviation from this rule should be explained. If there is not possible to avoid allocation, then the system under study should be investigated for physical relationship, that could be basis for allocation. If that is not possible, then the following methods of allocation are preferred:

- Multi-output processes: Allocation based on the economical relationships between the output products.
- Multi-input processes: Allocation based on physical relationships (e.g. mass balances).
- Open loop recycling: No allocation should be made for materials subject to recycling. The recycling processes are included when recycled materials are used as inputs. Outputs subject to recycling are regarded as outputs to the next life cycle.

Deviation from these allocation rules must be documented and reasoned for.

8. Units

SI units shall be used for both the LCA and the EPD.

9. Calculation rules and data quality requirements

Specific data should always be used in the upstream phases (extraction, production of materials, production of main inputs and fishing). Information from databases may be regarded as specific data, if they fulfil the following requirements:

1. Representative of the geographical area, i.e. from areas with same legislative framework and same energetic mix.
2. Technological equivalence.
3. Boundaries towards nature, i.e. data shall report all the quantitative information (resources, emissions, etc.) necessary for the EPD redaction.
4. Boundaries towards technical systems must be identical.

Generic data for the downstream processes; retailing, consumption and sewage treatment are preferred. The generic data should relate to the geographical region where the phases involved are most likely to happen.
Data on by-catch should be calculated on the basis of good and representative sampling.

Data should represent annual averages from a specific year. Deviation from this must be specified in the EPD. Impact assessment categories and calculation methods are listed in Table 1.

Table 1 – Impact assessment categories and calculation methods.

	Impact assessment category	Calculation method
1.	Global warming potential (GWP 100 years) [gram CO_2-eq.]	CML 2001
2.	Ozone layer depletion potential (ODP, steady state) [gram CFC11 (R11)-eq.]	CML 2001
3.	Acidification potential (AP) [gram SO_2]	CML 2001
4.	Photochemical ozone creation potential (POCP) [gram ethen-eq.]	CML 2001
5.	Eutrophication potential (EP) [gram phosphate-eq.]	CML 2001
6.	Marine aquatic ecotoxicity [gram 1,4-DB eq.]	CML 2001

10. Parameters to be declared in the EPD

The following parameters must be declared in the EPD:

a) Material resources, sorted by:
    a) Virgin renewable resources:
        i. Fish
            1. Mass wet round weight
            2. Net primary production
        ii. Other virgin renewable resources
    b) Recycled renewable resources.
    c) Virgin non-renewable resources.
    d) Recycled non-renewable resources
b) Land usage and sea floor usage
c) Energy consumption:
    a) Fossil fuels
    b) Nuclear fuels
    c) Renewable fuels
    d) Miscellaneous fuels (surplus heat, incineration of waste)
d) Impact assessment categories, as specified in section 9.
e) Emissions, wastes and fishery specific environmental aspects, as specified in section 3b and c.

11. Recycling and waste handling declaration

A recycling declaration may include information on aspects that are important for the understanding and appreciation of the recycling properties of the packaging following the product and waste handling of residual product. The recycling declaration may also include information about the dismantling of packaging and reuse of materials.

- Information on suitable procedures for recovery of selected parts of the entire products
- Information on a proper handling of the product as waste at the end of its life cycle, (i.e. fish bones composting, recycling of packaging)

12. Other environmental information

This part should include:

1. List of products in the inventory assessment from suppliers with certified environmental management system, if any.
2. List of products in the inventory assessment from suppliers with environmental declarations (Type I, II or III), if any.

Information may be included on aspects how the product should be handled during storing and consumption to reduce environmental impacts. Other factors such as noise, visual impact, risk related issues, HSE (i.e. accidents) may also be included in this section. If the product or part of it is in an eco-labelling scheme, this information can be included here.

13. References

The EPD shall refer to:

- The national/regional guidelines for Environmental Product Declarations.
  - Norway: NEPD Næringslivets Stiftelse for Miljødeklarasjoner (2004): Retningslinjer for Næringslivets Stiftelse for Miljødeklarasjoner. Oslo: NEPD.
  - Sweden: Requirements for Environmental Product Declarations, EPD, (MSR 1999:2) published by the Swedish Environmental Management Council at www.environdec.com
- The relevant PCR document.
- The underlying LCA report. There has to exist an open version of the LCA report.
- Other documents that verify and complement the EPD.

14. EPD format

The format of the environmental product declaration shall be structured as follows:

1. Front page:
   a) Picture of product
   b) Manufacturer's name and contact information.
   c) Information on the EPD programme operator.
   d) Date of certification and period of validity.
   e) Functional unit.
   f) Key environmental parameters:
      i. Global warming potential
      ii. Total energy consumption
      iii. Fishing gear type used
      iv. Total by-catch
      v. Total discard
2. Product specifications, as described in section 3a.
3. Material resources, sorted by:
   a) Virgin renewable resources:
      i. Fish
      ii. Other virgin renewable resources
   b) Recycled renewable resources.
   c) Virgin non-renewable resources.
   d) Recycled non-renewable resources
4. Land usage and sea floor usage.
5. Energy consumption:
   a) Fossil fuels
   b) Nuclear fuels
   c) Renewable fuels
   d) Miscellaneous fuels (surplus heat, incineration of waste)
6. Impact assessment categories, as specified in section 9.
7. Emissions, wastes and fishery specific environmental aspects, as specified in section 3b and c.

8. Recycling and waste handling declaration
9. Methodological information:
    a) Criteria for including flows.
    b) Statement on excluded processes.
    c) Allocation rules.
    d) Data quality (percentage specific/generic data).
    e) Graphical presentation of product system.
10. Additional information, as specified in section 12.
11. References, as specified in section 13.

Appendix G

Overview Norwegian fisheries and management

Fisheries

This annex includes a brief overview of the fisheries management in Norway and the organisations involved, important Norwegian fish species and different fishing gears used.

Fish provides food and income for millions of people (FAO Fisheries Department, 2007), a resource fishers harvest without needing to sow. Fishing is a form of gathering from nature and can be compared to hunting, and as such known since the earliest days of mankind (von Brandt, Borgstrom et al., 2009).

Fisheries are important for Norway with its 22 000 km coast line and one of the most productive marine areas in the world. Norway was in 2002 the tenth largest producer of captured fish in the world (FAO Fisheries Department, 2004), but the country was the second largest export nation of sea food, exporting to more than 150 countries worldwide (Fiskeri- og kystdepartementet, 2006). The fishing industry plays an important role in the Norwegian economy (Directorate of Fisheries, 2009) and in particular in rural districts along the coast (Almås, 1999; Rolstadås, 2006).

G.1. Fisheries management in Norway

The Norwegian fisheries have a significant impact on the Norwegian society, and are a tool to maintain settlement in the coastal areas. Therefore, it is important to manage the fisheries resources to be profitable and avoid overexploiting the natural resources.

The Norwegian fishery management has four equal objectives (The Royal Norwegian Ministry of Fisheries, 1998). This is to secure:

1) Protection of the resources base
2) Maintenance of the settlement pattern,
3) Provide safe and good employment opportunities
4) Real wage capacity increase

More concretly, this translates to the following objectives (Fiskeridepartementet, 1992):

1) Rational and biologically correct harvesting of the resources
2) As much raw material as possible should be used for human food
3) Promote the quality of Norwegian fish products
4) Promote a suitable structure of the fish industry
5) Strengthen the knowledge of the fish industry and develop vital local fishery communities
6)Contribute to make the social condition in the fishery industry equals to other industry

Norwegian fishery policy and regulation

The objective of the fishery management is to provide the basis for fishery policy and regulation.

The primary law in the Norwegian regulation of fishery, the Norwegian Participation Act of 1999 (Deltakerloven, 1999), states that only active fishers can own a fishing vessel. When a company owns a fishing vessel, the majority of the stock holders must be fishers. An exception to the rule is given to fish processing companies to ensure raw material for the production, e.g. in the fresh fish trawling fleet (Fiskeridepartementet, 1998).

There are many stakeholders in the Norwegian fishery management. Figure G1 shows a few and how these are, according to Norwegian policy-making tradition, involved in setting the fish quotas. The agency and activity management that leads to the final allocation of fishing quota to different fleet groups (Figure G1) is initiated by a consultation about the state of the fishery resource and fishery management.. The Institute of Marine Research, the International Council for the Exploration of the Seas (ICES) and the Norwegian Directorate of Fisheries provide the necessary data for a special committee (The territorial limit committee – Sjøgrenseutvalget), which is composed of representatives from different ministries and the University of Oslo and prepares the Norwegian strategy for the negotiation with other countries (Mikalsen and Jentoft, 2003).

Most Norwegian fish stocks are shared with other countries, such that bilateral and multilateral agreements on total quota provide the basis for the Norwegian quota. National regulation of the fisheries is done by regulation of the input factor and quotas. The regulating council allocates the quota to different fleet groups and the directorate of fisheries issues the licences and permissions. Finally, the coast guard takes part in the operative control of the fisheries operation at sea together with the regional fishery office of the directorate of fisheries, while the fish cooperative controls the landing of the fish. Figure G1 shows the different actors and how they influence the fishing quota (Riksrevisjonen, 2004).

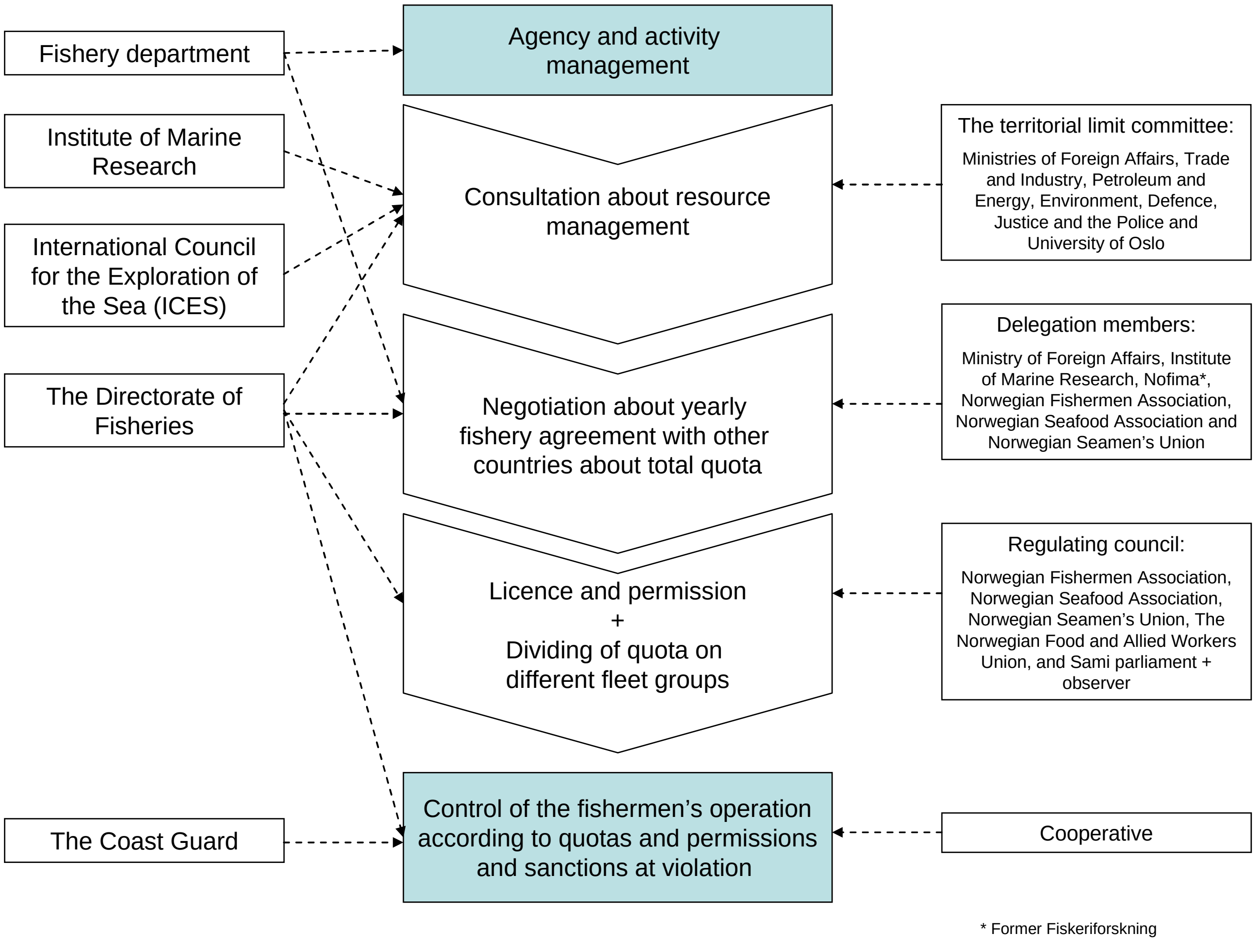

Figure G1: Process of the Norwegian regulation and involved actors [Based on (Riksrevisjonen, 2004)]

The main goal of the fishery regime is to contribute to a desired progress of total harvesting, harvesting pattern, capacity and cost development, ratio between the inshore fishing and deep-sea fishing, ratio between land production and on-board production and regional distribution (Fiskeridepartementet, 1998).

One of the main threats to these goals is the excess capacity of both the international (Gréboval, 1999) and Norwegian fishing fleets (The Royal Norwegian Ministry of Fisheries, 1998; Standal and Aarset, 2001; Fiskeridepartementet, 2003; Riksrevisjonen, 2004). The excess capacity is a threat to both the fish resources and to the economics of the fishery. Despite reduced number of fishing vessels, the catch capacity is generally increasing as a result of larger catch efficiency.

The authorities use the following mechanisms to reduce the capacity (Fiskeridepartementet, 1998):

- Regulation of access to carry out commercial fishing
- Fees, for example a yearly fee for the fishing vessel registration

- Decommission incentives for fishing vessels financed by the industry itself

The Norwegian fishery is divided into vessels with and without licences. Another main division of the fleet is into a coastal fishing fleet and deep-sea fishing fleet (>27.5 meters length[1]) based on size of the vessel. The two groups satisfy different fishery political goals (Fiskeridepartementet, 1998).

G.2. Important fish species in Norwegian fisheries

Fish is a healthy food product with a range of valuable nutrients (Julshamn, Utne et al., 1978; Nordic Council of Ministers, 2003). The nutritional content of fish varies between different species, fish parts and the season caught (Torry Research Station, 1989; Frimodt, 1995).

According to the Directorate of Fisheries (2005) the total Norwegian catch of wild fish amounted to 2 700 000 tonnes live weight in 2004. Of this, Atlantic cod accounted for 231 000 tonnes while all groundfish species together (including Atlantic cod), amounted to around 606 000 tonnes. Even though the pelagic species dominate total landings, accounting for 1 850 000 tonnes, Atlantic cod was the most important species economically with a total value of 2.8 billion NOK (Directorate of Fisheries, 2005).

Table G1 shows some important Norwegian fish species, their Norwegian name, scientific name and were available the quantity and value of the catch in the decade 1998-2007.

[1] For some part of the fishing fleet, this limit is set to 20 meter.

Table G1: Important fish species in Norwegian fishery, name, quantity and value of catch 1998-2007 (Statistics Norway, 2009)

			1998 - 2007	
Trade name	Norwegian name	Scientific name	Quantity. Tons live weight	Value [1 000 NOK]
Atlantic herring	Sild	*Clupea harengus*	7 138 494	19 145 942
Blue whiting / Poutassou	Kolmule	*Micromesistius poutassou*	6 519 852	5 691 514
Atlantic cod	Torsk/skrei	*Gadus morhhua*	2 347 202	30 500 859
Saithe / Pollack	Sei	*Pollachius virens*	2 071 411	9 962 092
Capelin	Lodde	*Mallotus villosus*	1 965 026	2 299 533
Mackerel	Makrell	*Scomber scombrus*	1 553 118	11 180 112
Sand eel	Tobis	*Ammodytes tobianus*	1 166 273	961 833
Haddock	Hyse/kolje	*Melanogrammus aeglefinus*	617 321	6 023 246
Northern prawn	Reke	*Pandalus borealis*	570 449	8 057 287
Norway pout	Augepål	*Trisopterus esmarkii*	224 013	167 256
Golden redfish	Uer	*Sebastes marinus*	208 083	1 497 381
Horse mackerel / Scad	Hestmakrell	*Trachurus trachurus*	195 805	608 948
Tusk / torsk	Brosme	*Brosme brosme*	170 066	1 410 630
Ling	Lange	*Molva molva*	166 324	2 110 741
Greenland halibut / Turbot	Blåkveite	*Reinhardtius hippoglossoides*	140 654	2 431 304
Catfish / Wolfish	Steinbit	*Anarchichas lupus*	78 751	395 808
Halibut	Kveite	*Hippoglossus hippoglossus*	9 945	396 324
Salmon / Atlantic salmon	Laks,sjøaure	*Salmo salar*	N.A.	N.A.
Sea trout	Sjøørret	*Salmo trutta*	N.A.	N.A.

G.3. Important fishing gears in Norwegian fisheries

The first known fishing equipment included spears, stone-tipped arrows, traps of wood, vines or stone. As woven material evolved this could be used for finer and stronger lines for hooks and netting. The introduction of sail power increased the range of the fishing vessels. The development of steam power increased the capability to haul nets and bring catch aboard (Jennings, Kaiser et al., 2001).

There are two main groups of fishing equipment – passive fishing gears where the target species move into or towards the fishing gears themselves – and active fishing gears which are propelled or towed toward the fish. This section gives an overview of important fishing gears used in modern Norwegian fisheries.

G.3.1 Passive fishing gears

Passive fishing gears are gears where the fish actively move into the gears. An important property for passive fishing gear is the soak time. Fishers have to know this and the interaction with different currents in the sea. To get the best catch, static gear is often orientated across migration routes of the target fish species. For a good quality catch it is important to tend the gears frequently (daily) to avoid damage from other fish and other animals (Jennings, Kaiser et al., 2001).

Line - hooks

Lines consist of a length of line, rope or wire with shorter lengths of line with hooks at one end. A fishing line is a very effective traditional fishing gear. The fish are attracted to the hook, usually with bait. There are different line types distinguished by the number and way the hooks are connected to the line. For the autoline, the baiting and hook handling is done mechanically and is most often found on larger seagoing vessels (Fuglerud, 2003). Floating long lines are used to fish pelagic species (Royal Commission on Environmental Pollution, 2004).

Gill net (Set net)

Gill nets have their name from the main way they capture fish: When the fish try to swim through the net, they get snagged by their gill operculi, fins or by their scales. Gill nets are very selective for particular size class of fish. Small fish are able to swim through and oversized fish are too large to penetrate the net to get trapped. The gill nets have a foot-rope and headline with floats. At the ends they are buoyed and anchored and stretch out to form a barrier. They are set in different places of the water column, from the bottom to the surface. When shooting gillnet, the tide has to be taken into account. Gillnet can be up to 50 km long, combining series of panels of meshes, but international legislation limits nets to maximum 2 km to prevent too much by-catch of turtles, seabirds and dolphins (Jennings, Kaiser et al., 2001).

Monofilament nylon is the material used in most nylon nets. It is invisible in water and long-lasting (Jennings, Kaiser et al., 2001). However, this is also a threat. When fishing gears are lost, they will still continue fishing - so called ghost fishing (Valdemarsen, 2001; Huse, Aanondsen et al., 2002).

Traps and pots

Traps are a primitive fishing technology, that use some sort of guiding, i.e. a wall of net or sticks and the trap with one or more chamber, from which the catch can not escape. Pots work much in the same way as traps, but are made of a rigid frame with a mesh covering with an entrance (Jennings, Kaiser et al., 2001). Traps and pots can be furnished with bait to attract the prey.

G.3.2 Active fishing gears

Active fishing gears need to be towed or propelled towards the fish. In Norway, a special licence is needed for fishing with active fishing gears, trawl, shrimp trawl and purse seine (Fiskeridepartementet, 1998).

Trawls

Trawl is an active fishing method where a fishing net is towed after the fishing vessel to catch fish (Galbraith, Rice et al., 2004). The otter trawl has its name from the otter board which held the wings of the net open by hydrodynamic forces. The net is vertically held open by a series of buoys on the headline and weighted foot rope. The otter trawl and the warps have a herding effect on the fish. The weight and size of the otter board and buoys together with the towing speed determine the fishing depth (Jennings, Kaiser et al., 2001).

Otter trawls are either used for bottom trawling (demersal trawling) after prawn or demersal fish such as cod and whiting, or in mid-water trawling (pelagic trawl) for species such as herring and mackerel. The rock hopper trawls have a ground rope fitted with rubber discs that can be more than 50 cm in diameter and heavy (> 10 kg each) metal bobbins. Another variant of the rock hopper, the street sweeper gear, has round brushes instead of bobbins (Jennings, Kaiser et al., 2001).

The otter trawl size is constrained by the power of the engine, winches for net hauling and size of the vessel (Jennings, Kaiser et al., 2001). A pelagic trawl can be huge, a vertical net opening of 90–180 m (Wenneck, Falkenhaug et al., 2008) and a mouth area of 15 000 m^2 (Valdemarsen, 2001) are typical dimensions for large mid-water pelagic trawls.

Otter trawls can be operated by two vessels. This is called pair-trawling. It is also possible to twin-rig. That is when one vessel is fishing with two otter trawls (Jennings, Kaiser et al., 2001). The latter is used in Norwegian fisheries mainly in the shrimp fishery and is called double trawl (Valdemarsen, 2001; Schau, Ellingsen et al., 2009).

A factory trawler is a large fishing vessel trawling for fish and with a processing, and possible also refinement, factory onboard with the possibility of freezing fish products at sea (Pike, 2009).

Seines

Seines are encircling nets, another type of active fishing gear. The nets are set and circled around the fish and drawn closer to the boat. Fish are in good condition because they spend little time in the cod end compared to the trawling fisheries (Jennings, Kaiser et al., 2001).

The purse seine has its name from the purse wire used to close the net at the bottom of the net. Purse seine mainly targets species with schooling behaviour such as anchovies, tunas and mackerel. Purse seines can be very large. There are often too many fish in the net to drag it onto the boat, consequently, the fish are scooped up using pan nets, brailers or, common today, pumped into the boat (Jennings, Kaiser et al., 2001). In Norway, the hauling of the purse seining is usually performed with the triplex device and a second transport block, which make it possible to operate the purse seine with large catches, in rough weather conditions and with few crew members (3-5 on the largest purse seiners) to handle the purse seine (Valdemarsen, 2001).

Danish seine was originally a flat fish trawl, a passive fishing gear where the fishing vessel anchored and stayed there (therefore passive) while drawing in the net. However, with the development of increased propulsion power and stronger ropes, the fishing vessel is no longer anchored, but can actively draw the (now much larger) Danish seine (Hauge, 2008). Therefore, Danish seine can be considered an active fishing gear, which may impact the sea bottom considerably. Danish seines are used for cod, saithe, haddock, European place, and flounder.

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Appendix H

Eco-labels and stakeholders

Results from a small e-mail survey about the stakeholders to fish food products eco-labels among existing eco-labels.

A small e-mail survey regarding the eco-labels existing for Norwegian sea food products - as of December 2010 (Norsk Sjømat, 2010) was conducted to gain insight into the target stakeholder groups of eco-labels for FFP. The survey was sent to the directors of the eco-labelling organisations for KRAV, MSC and FoS. Responses were received from Brand, the Baltic Commercial Officer at MSC; Bray, Director at FoS; and Hällbom, Director of Regulatory Affairs at KRAV. They were asked to rate the importance of different stakeholder groups for their own eco-label in addition to rate how important, in their opinion, these stakeholders are for other eco-labels.

How important are the following target groups?
Please rate the following groups from 0 to 3, where 0 is not important at all to 3, very important.

Table H.1: Rating of different stakeholders groups for different eco-labels

Respondent:	Brandt, Marine Stewardship Council (MSC)					Hällbom, KRAV					Bray, Friend of the Sea (FoS)				
Rating for: / Target groups:	Own label (MSC)	Carbon Footprint (CFP)	KRAV	FoS	EPD	Own label (KRAV)	Carbon Footprint	MSC	FoS	EPD	Own label (FoS)	Carbon Footprint	MSC	EPD	SUM ALL
Regular consumer	3	3	3	1	1	3	1	2	2	1	3	1	2	1	27
Environmentally councious consumers	3	2	3	1	3	3	3	3	3	2	3	2	2	2	35
Animal protection right consumers	2	1	2	2	0	3	1	1	1	1	2	2	2	1	21
Organic food consumer	1	3	3	2	3	3	1	1	1	1	2	2	2	2	27
Restaurants guest	3	2	1	0	1	3	1	2	1	1	2	0	2	1	20
Restaurants owners	3	2	1	0	2	2	2	2	2	1	2	0	2	0	21
Retailers (purchasers)	3	3	3	1	2	3	3	3	3	3	3	1	2	1	34
Retailers (management)	3	2	3	1	3	3	3	3	3	2	3	1	2	1	33
Fishers	3	1	2	2	0	3	1	2	2	1	3	1	2	0	23
Fishing vessels owner	3	2	2	2	2	3	2	3	3	1	3	1	2	0	29
Fish food processors	3	1	3	2	3	3	3	3	3	2	3	1	2	1	33
Investors (general)	2	3	1	1	2	1	1	2	1	2	1	0	2	1	20
Banks	0	2	0	0	1	1	1	2	1	1	1	1	2	0	13
Insurance companies	0	3	0	0	1	1	1	1	1	2	1	1	2	1	15
Non-governmental organisation (NGO) (general)	2	3	2	2	2	2	1	2	1	1	2	3	0*	1	24
Environmental NGOs	3	3	3	2	3	3	3	3	1	3	2	3	0*	3	35
Authorities	3	3	2	1	3	2	2	2	1	2	2	1	2	1	27

* Acording to Bray (FoS) MSC has never taken into considerations NGOs complaints about their certified fisheries

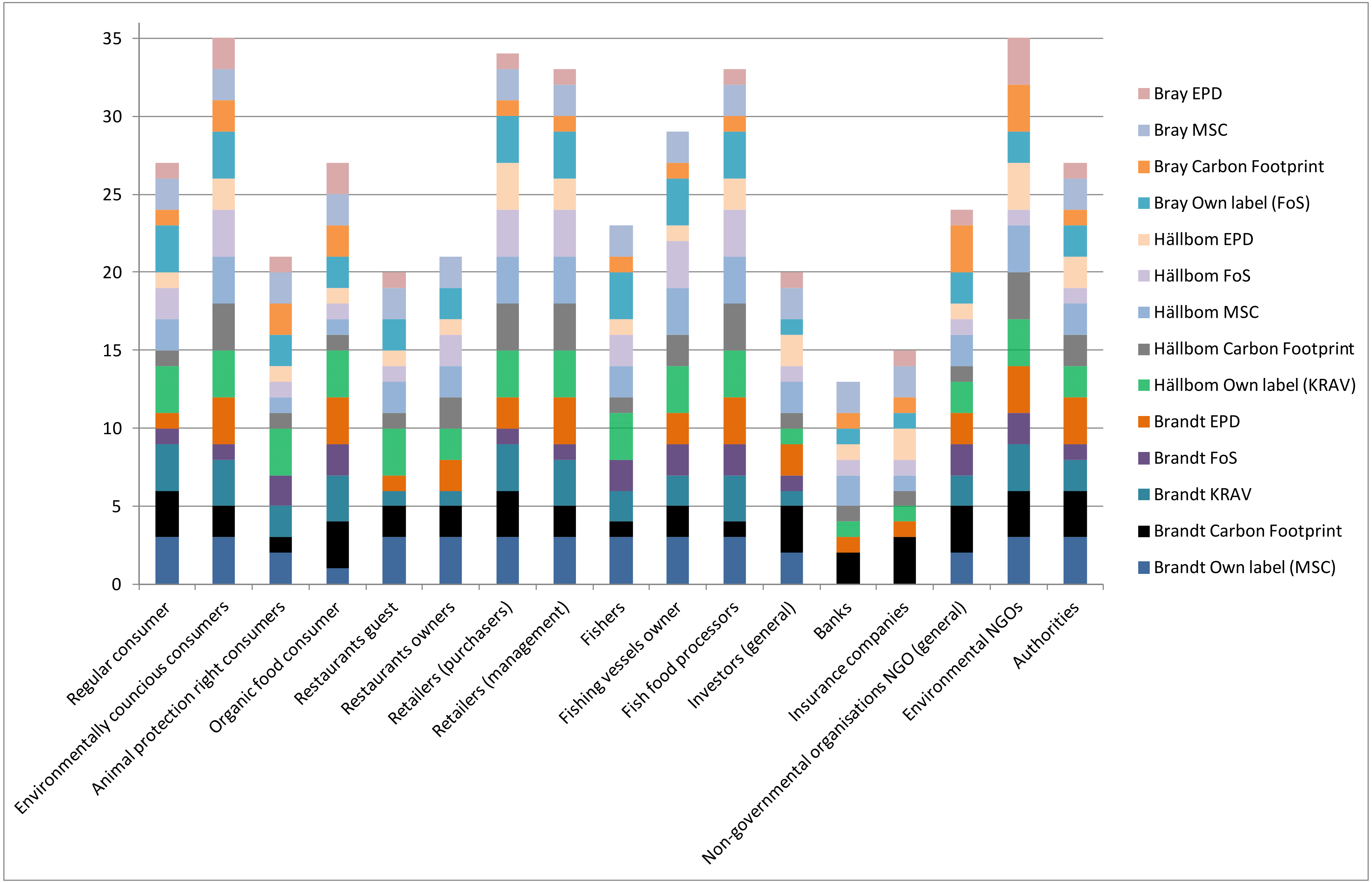

Figure H.1: Results from a small e-mail survey about the importance of stakeholders to fish food products eco-labels among existing eco-labels (A high number on the y-axis indicates a high relevance)

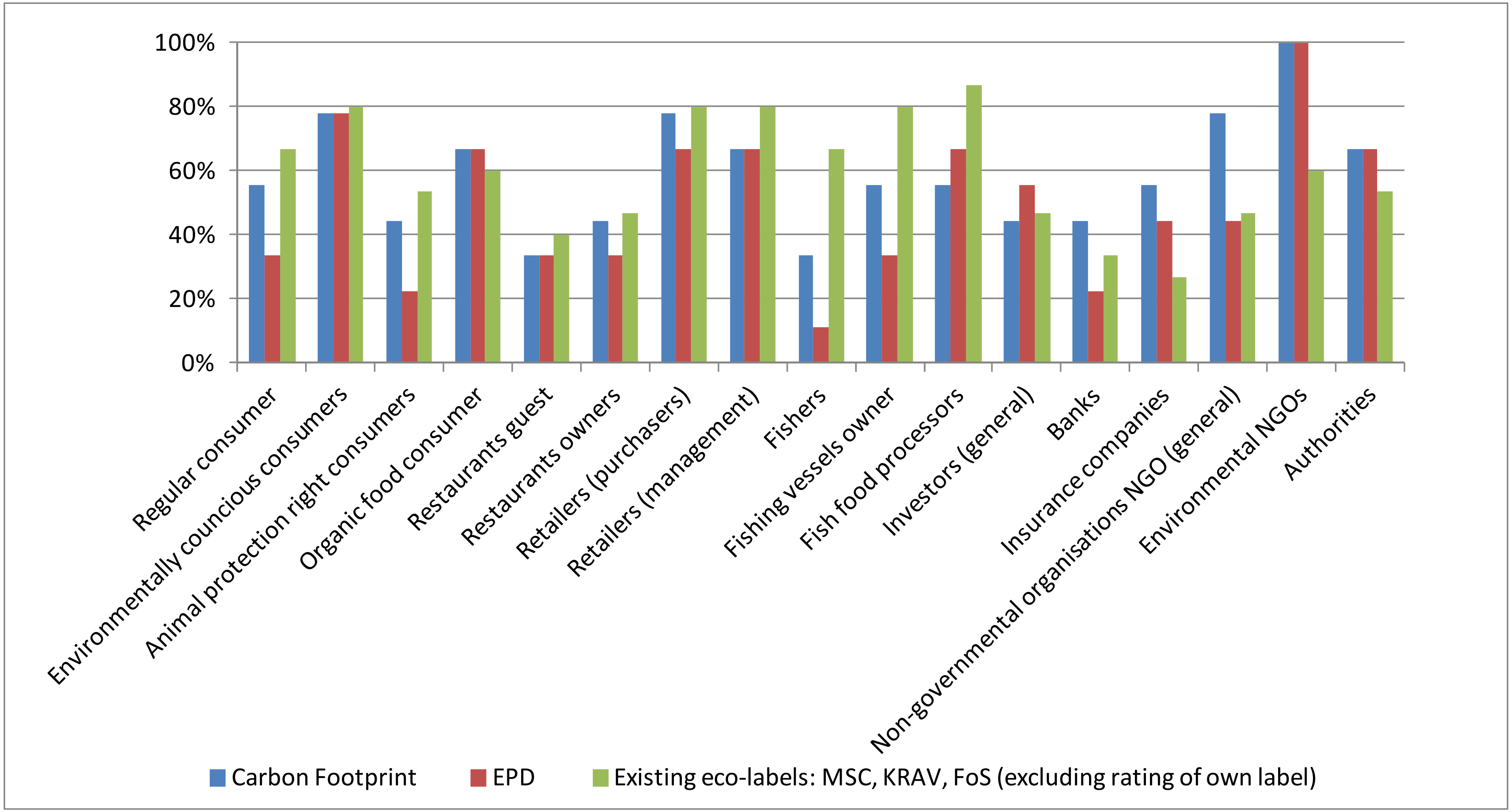

Figure H.2: Stakeholders to potential new labels (Carbon Footprint and EPD) compared to existing labels (MSC, KRAV, FoS), where the y-axis indicates degree of relevance (0 = not at all important, to 100 % very important)