From Fish to Fish – Evaluating the Socio-Environmental Consequences of the Vietnamese Fishmeal Industry

A life Cycle Assessment and Product Chain Organisation Analysis of the Production of Vietnamese Fishmeal

Master's Thesis in Industrial Ecology

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Division of Environmental Systems Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Typical Vietnamese trashfish destined for reduction delivered via transhipment boat then reduced into fishmeal. Photos by author.

Chalmers Reposervice
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To Margot, thank you

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Abstract

The rapidly growing aquaculture industry in Vietnam has increased the demand for wild fish as a raw material for fishmeal and fishoil in processed feeds. While fishmeal and fishoil can be produced from fish by-products, in Vietnam it is generally produced from small pelagic fish or bycatch from local capture fisheries, otherwise known as 'trashfish'. These fisheries have been associated with a range of negative environmental interactions, including disturbance of sea-floor ecosystems, poor energy efficiency, and reduction of juvenile fish. Moreover Edwards et al., (2004) review of Vietnamese fishmeal production reported that several of the fish stocks used were already overexploited and a recent report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) states that there will be no exploitable fish stocks in South East Asia by 2048 if current fishing practices continue.

As such, this study explored these environmental impacts using Life Cycle Assessment (LCA) and Product Chain Organisation (PCO) methodologies, with primary data collection in key parts of the fishmeal supply chain. This allowed for quantitative (LCA) and qualitative (PCO) representation of the status of the industry to be assessed, and for key Life Cycle Inventory data to be made publicly available.

The results from the LCA conducted show that the Vietnamese Large trawl fishing vessels (Anchovy trawlers) have the largest environmental impact for the Life Cycle Impact categories assessed in this study (Global Warming potential, Eutrophication, Acidification and Photochemical Oxidisation) relative to the functional unit of 1 tonne of Vietnamese fishmeal produced. The reason for this impact is a result of the quantity of trashfish this vessel class supplies to the fishmeal industry along with the fuel consumption per kg trashfish landed compared to the other vessel classes assessed. Along with this, when compared to other Vietnamese LCA studies that have used Peruvian or Danish fishmeal as a proxy, up to a 5x increase in environmental impact (based on impact categories assessed) can be seen in Vietnamese fishmeal.

The results from the PCO indicate the important role middlemen play within the Vietnamese fishmeal industry with relation to, among others, the quality of trashfish that will be utilised for fishmeal production processes and the logistical support they provide. Moreover, it was seen that there are great sustainability improvements that could be made using the middlemen as a vector into the industry.

This thesis's major flaw is that it lacks good biodiversity impact assessments that could be used as a baseline for comparison into the future. It is therefore suggested that the attention of further studies should be focused on environmental consequences of utilising trashfish for fishmeal and the subsequent biodiversity/ecosystem implications that these capture fisheries are associated with.

Keywords: Fishmeal, Trashfish, Life Cycle Assessment, Product Chain Organisation (PCO), Vietnamese Fisheries, Aquaculture.

Abstract ở Tiếng Việt

Ngành nuôi trồng thủy sản phát triển nhanh chóng ở Việt Nam đã làm tăng nhu cầu cá hoang dã làm nguyên liệu cho bột cá và dầu cá trong thức ăn chế biến. Trong khi bột cá và dầu cá có thể được sản xuất từ các sản phẩm phụ từ cá, ở Việt Nam, nó thường được sản xuất từ cá biển nhỏ hoặc cá chép từ nghề đánh cá địa phương, hay còn gọi là 'cá tạp'. Những ngư trường này đã được kết hợp với một loạt các tương tác môi trường tiêu cực, bao gồm cả xáo trộn hệ sinh thái đáy biển, hiệu quả năng lượng kém và giảm số lượng cá mới trưởng thành. Hơn nữa, Edwards và cộng sự (2004) trong đánh giá sản lượng bột cá của Việt Nam đã báo cáo rằng một số lượng cá được sử dụng đã bị khai thác quá mức và một báo cáo gần đây của nền tảng chính sách khoa học liên chính phủ về dịch vụ sinh thái và đa dạng sinh học (IPBES) cho rằng sẽ không có cổ phiếu khai thác cá ở Đông Nam Á vào năm 2048 nếu các hoạt động đánh bắt hiện tại tiếp tục. Như vậy, nghiên cứu này đã khám phá những tác động môi trường này bằng cách sử dụng phương pháp Đánh giá vòng đời (LCA) và Tổ chức chuỗi sản phẩm (PCO), với việc thu thập dữ liệu chính trong các phần chính của chuỗi cung ứng bột cá. Điều này cho phép đại diện định lượng (LCA) và định lượng (PCO) về tình trạng của ngành được đánh giá, và những Dữ liệu chính về Vòng đời được công khai. Các kết quả từ LCA được tiến hành cho thấy các tàu đánh bắt cá lớn của Việt Nam (tàu đánh bắt cá cơm) có tác động môi trường lớn nhất đối với các loại tác động của chu trình sống được đánh giá trong nghiên cứu này (tiềm năng hâm nóng toàn cầu, phú dưỡng, axit hóa và quá trình oxy hóa quang hóa) liên quan đến đơn vị chức năng 1 tấn bột cá của Việt Nam được sản xuất. Lý do cho tác động này là kết quả của số lượng cá tạp mà lớp tàu này cung cấp cho ngành công nghiệp bột cá cùng với mức tiêu thụ nhiên liệu trên mỗi kg cá tạp đã được đánh bắt so với các loại tàu khác được đánh giá. Các kết quả từ PCO cho thấy vai trò 'trung gian' quan trọng trong ngành công nghiệp bột cá Việt Nam liên quan đến chất lượng của cá tạp sẽ được sử dụng cho quy trình sản xuất bột cá. Hơn nữa, đã có những nhìn nhận rằng có những cải tiến bền vững tuyệt vời có thể được thực hiện bằng cách sử dụng các trung gian như là một vector vào ngành công nghiệp. Điểm yếu chính của luận án này là thiếu các đánh giá tác động đa dạng sinh học tốt có thể được sử dụng làm cơ sở để so sánh trong tương lai. Do đó, đề xuất sự chú ý nghiên cứu sâu hơn về các hậu quả môi trường của việc sử dụng cá tạp cho bột cá và sự đa dạng sinh thái / hệ sinh thái có liên quan đến việc khai thác thủy sản này.

Từ khóa: Bột cá, Cá tạp, Đánh giá vòng đời, Tổ chức chuỗi sản phẩm, Nghề cá Việt Nam, Nuôi trồng thủy sản

Preface

This master’s thesis goes towards the degree of Environmental Science at the University of Gothenburg but has been undertaken as a stand-alone thesis subject at Chalmers University of Technology due to the technical capacity and expertise of their Environmental Systems Analysis Division which has a strong focus on Life Cycle Assessment.

The thesis opportunity came about via postdoctoral researcher, Patrik Henriksson of the Stockholm Resilience Centre, whereby there was a data gap identified in Vietnamese LCA aquaculture studies relating to Vietnamese fishmeal production. Consequently, the outcome of this report has been to address this data gap and for further (particularly aquaculture LCA’s) research to be undertaken that incorporates the data obtained.

The data for this thesis was collected during 4 months of field work in Vietnam during August-December 2017 with close cooperation and generous help from the Vietnamese Research Institute for Aquaculture No.2 (RIA2).

Acknowledgments

I would like to thank my two supervisors that have made this thesis a reality. Firstly, immense gratitude goes toward Henrikke Baumann, my Chalmers supervisor and examiner. From our first fika you showed faith in me and provided me with support whenever it was needed, often at short notice. Secondly, I would like to thank my external supervisor, Patrik Henriksson, for allowing me the opportunity to work on my dream project and have fun along the way. You have been a friend and mentor since our first contact and I have greatly enjoyed learning from you-saying thank you doesn't come close.

A large thank you also goes to my now friends at The Research Institute for Aquaculture No. 2, for providing me with on the ground assistance and a solid work base whilst conducting field work in Vietnam. Without your support this project would simply not have been possible. Of special mention is Mr. Lam, Mr. Bay and Mr. Phung-the hours you spent and the knowledge you passed onto me has been invaluable and I hope the report reflected this.

For the hours spent together drinking countless 'cà phê sữa đá' and for your knowledge with Vietnamese aquaculture and fisheries, a big thank you goes to Dien Lam Son, my translator and friend. I hope we can have more adventures in the future.

A generous thank you also goes toward Mr. Thong. Your support and knowledge of the Vietnamese fishing industry has been invaluable for this project. The data you generously salvaged from your damaged computer was of great help and increased the overall representativeness of the Vietnamese fishing industry in the data analysis.

For their time and expertise, thank you to all the people involved in the interviews and livelihoods surrounding the Vietnamese fish reduction sector. I was shown how great Vietnamese generosity can be and it will stick with me forever.

Not to be forgotten are all the beautiful creatures that are ground up into the fish powder that was the study of this thesis. You were in my mind the whole way.

A thank you also goes towards WorldFish Center and all the beautiful people I was lucky enough to spend time with in Penang while I was there at the latter part of this thesis. It was an experience that allowed me to learn a great deal and to meet some fantastic people trying to make this world a better place. Of mention is Sharon Suri, Matt Roscher (Dark decadence), Elyssa, Lauren Banks, Shanali Pethiyagoda, Nathalie Bax, Baby Ella, Maniam, Suren, and my cheeky housemate, now great friend-Thong Trinh.

I would also like to thank my family, particularly Stephen Muecke. I cannot express my gratitude in words for how much your support has meant to me. I can only hope that in the future that my actions reflect the faith you have had in me-I will try my best.

Lastly, I would like to thank my mother, for showing compassion to all living things on this beautiful blue, green and increasingly grey planet - no matter how big or small, everything is equal.

List of Abbreviations

ASC - Aquaculture Stewardship Council

BAP - Best Aquaculture Practice

BRU - Biological Resource Required

CO2eq - Carbon Dioxide Equivalent

FAO - Food and Agricultural Department of the United Nations

FETP - Freshwater Eco-Toxicity Potential

FGF - Falling-gear Fishery

Global GAP - Good Aquaculture Practice

GHG – Greenhouse Gas

GWP - Global Warming Potential

HDPE - High-density Polyethylene

IEA - International Energy Agency

IFFO RS - International Fish-Meal Fish-Oil Organisation Responsibly Assured

IPBES- the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

ISO - International Standards Organisation

IUU - Illegal, Unreported, and Unregulated Fishing Practices

JSC - Joint Stock Company

LCA - Life Cycle Assessment

LCI - Life Cycle Inventory

LCIA - Life Cycle Impact Assessment

LCT - Life Cycle Thinking

LTF - Large-trawler Fishery

MARD - Ministry of Agriculture and Rural Development

MC - Monte Carlo

METP - Marine Eco-Toxicity Potential

PCO - Product Chain Organisation

PPR - Primary Production Required

RIA - Research Institute for Aquaculture

SEAFDEC - South East Asian Fisheries Development Center

SEAT - Sustainable Trade in Ethical Aquaculture

SETAC - Society of Environmental Toxicology and Chemistry

SGF- Surrounding-gear Fishery

STF - Small-trawler Fishery

TETP - Terrestrial Eco-Toxicity Potential

UNEP - United Nations Environment Program

Viet GAP - Vietnamese Good Aquaculture Practice

VND - Vietnamese Dong

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1. Introduction

Global capture fisheries are believed to have reached their capacity with the Food and Agriculture Organisation of the United Nations (FAO, 2016) reporting that global captures have remained relatively static since the late 1980's, with 93.4 million tonnes captured in 2014 (excluding aquatic plants). During this time, there has been a surging demand for fishery products. Growth in the global supply of fish for human consumption has outpaced population growth, with current per capita consumption increasing from 9.9 kg in the 1960's to 20.1 kg as of 2014 (FAO, 2016).

This increase in global supply has been met with a milestone reached in 2014 whereby the aquaculture sector's contribution to the supply of fish for human consumption overtook that of wild-caught fish for the first time (FAO, 2016). This rate of growth in aquaculture is equal to about 8.8 percent since 1970 compared to 2.8 percent for terrestrial farmed food; with early 1950's annual production recorded at 1 million tonnes and has since grown steadily to 73.8 million tonnes with an estimated first-sale value of US $160.2 billion (FOA, 2016).

The vast expansion of aquaculture has been brought about by expanding and intensifying production systems, which has resulted in large demand and dependence on wild capture fisheries for fishmeal and oil production, increased energy consumption, and a range of other environmental impacts related to agri-food production (Tacon, 2008; Deutsch, L. et al., 2007; Oyinlola, M. A., et al., 2018)

Along with global capture fisheries, the FAO (2016) reports that global fishmeal production was 15.8 million tonnes in 2014, down from the peak production in 1994, producing 30.1 million tonnes globally. The large oscillations in fishmeal production are contributed to the El Niño phenomenon that affects anchoveta catches, particularly from Peru, the world's largest fishmeal source, and stricter management measures in place for anchoveta landings and other species normally utilised for reduction (FAO, 2016).

Fishmeal prices reached historic highs in 2014 due to increased demand and a decrease in production due to the oscillations caused by the El Niño phenomenon, with 2015 Peru and Chile recording the lowest export volumes in six years (FAO, 2016). Overall the prices are expected to remain high into the future because of sustained demand from the aquaculture sector (FAO, 2016).

1.1 Aquaculture and fishmeal industry In Vietnam

55% of global aquaculture is dependent upon external feed inputs or natural food organisms that are produced in the culture systems; with the remaining 45% being made up of aquatic plants and bivalve mollusks that live off dissolved nutrients and planktonic organisms (Tacon and Metian 2008). The use of wild fish in aquaculture feeds has been a major concern for the aquaculture sector, being subject to environmental (global warming emission, biodiversity implications) and socioeconomic arguments (Naylor, et al., 2000; Cao, et al., 2015).

The rapidly growing aquaculture industry in Vietnam has increased the demand for wild fish as a raw material for fishmeal and fishoil in processed feeds (which is shown in figure 1, the dramatic increase in fishmeal production). While fishmeal and fishoil can be produced from fish by-products, in Vietnam it is generally produced from small pelagic fish or bycatch from local capture fisheries, otherwise known as 'trashfish' (Edwards, 2004). These fisheries have been associated with a range of negative environmental interactions, including disturbance of sea-floor ecosystems, poor energy efficiency, and reduction of juvenile fish. Moreover Edwards et al., (2004) review of Vietnamese fishmeal production reported that several of the fish stocks used were already overexploited and a recent report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) states that there will be no exploitable fish stocks in South East Asia by 2048 if current fishing practices continue (IPBES, 2018).

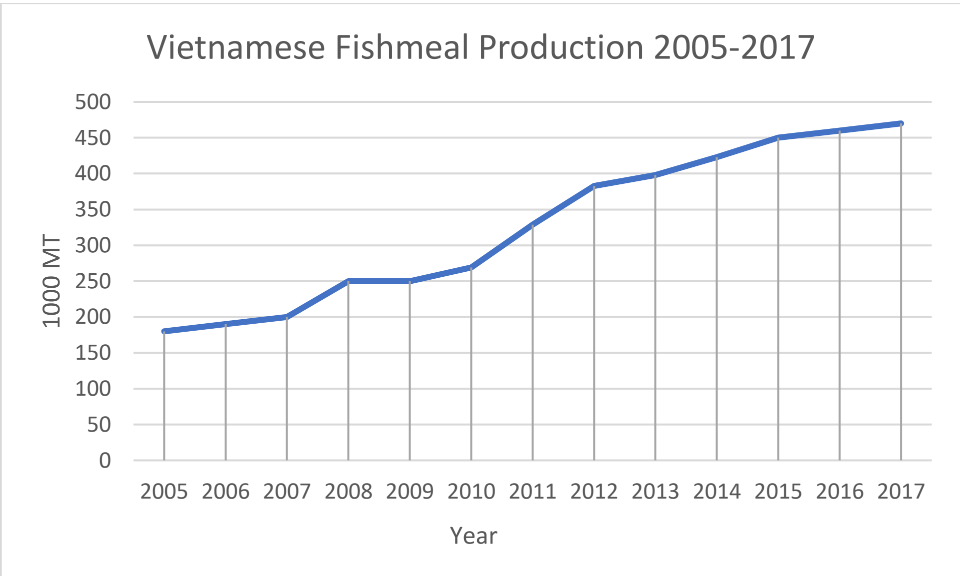

Figure 1. Graphing showing Vietnamese fishmeal production from 2005-2017. Data sourced from Index Mundi

Henriksson et al., (2015), has subsequently later performed an exploratory Life Cycle Assessment (LCA) on three types of capture fisheries serving the Vietnamese fishmeal industry (small-scale, large-scale, and broodstock fishery), and concluded that a wide variety of species were caught (incl. marine finfish, crabs, jellyfish, and shrimp) using highly energy inefficient fishing methods. However, no up-to-date study exists for Vietnam's fish reduction industry, despite a surge in demand from the Vietnamese aquaculture industry over the last decade.

Earlier research of the Vietnamese aquaculture industry provides some answers but does not provide a coherent analysis of the relatively unknown industry. Along with Henriksson's et al., (2015) LCA, there have been a handful of other LCAs that have taken place assessing the Vietnam Aquaculture industry (please see: Huysveld et al., 2013; Nhu et al., 2015; Bosma et al., 2011; Hong et al., 2009; Phong, 2010; and FAO, 2017); However, besides Henriksson et al.'s LCA, these studies have used no data on domestically produced fishmeal in their modelling, which is relevant to especially finfish farming in Vietnam. Instead, the abovementioned studies used proxy fishmeal data from Peru or Denmark (as part of the LCAFood database from 2003). These proxies- Danish and particularly Peruvian fishmeal-are considered the most energy efficient sources of fishmeal in the world (Freon and Avadi 2014, LCAfood.dk).

Given the reliance on capture fisheries and fishmeal production for aquaculture expansion, it is important to research this industry. Therefore, this study seeks to address this data gap by conducting interviews with actors in the Vietnamese fish reduction supply chain to gather relevant information and data to assess the current, largely unknown status of the fish reduction industry within Vietnam. A range of techniques discussed in the methodology section, namely, Product Chain Organisation and LCA will be employed to answer specific research questions that will help fill these data gaps in the industry.

1.2 Aim and objective

The aim of this thesis was to present an updated evaluation of Vietnam's fish reduction industry via two methodologies: A Product Chain Organisation approach to understand what factors are influencing the fishmeal industry (in the form of actors, companies, etc.) and a quantitative Life Cycle Assessment (LCA) to identify environmental impacts related to the production of fishmeal. The objective of this research is to provide a sound scientific basis of the Vietnamese fish reduction industry to foster its improvements in the future and to add to the data pool of Life Cycle Inventory, so it can be of use to other LCA practitioners via easily assessable first-hand data.

1.3 Research questions

To meet the aim and objective of this research, three research questions have been formulated to steer this study in a common direction throughout the period of this thesis:

I) Who and what are the main actors and drivers involved in the Vietnamese fish reduction industry and how are they organised?

II) What are the environmental impacts of the Vietnamese fish reduction industry and how do these compare to other countries?

III) What are the environmental hot-spots in the Vietnamese fish reduction industry, and how could these be addressed, and change be implemented?

The key methodological choices that have been made for answering these questions will be discussed in the next section.

2. Project Design and Methodology

Below is a description of the methods that have been used to answer the research questions of this thesis. To meet these methodical requirements, a trip to Vietnam for data collection between the 1st of September 2017 to 20th December 2017 was needed.

2.1 Life Cycle Assessment

LCA is a process whereby the whole value chain of a product/service is evaluated in a quantitative manner to assess, *inter alia*, the most efficient way of shrinking the environmental consequences of a products production (Baumann, H., & Tillman, A. M. 2001). The framework dates back more than forty years, with companies such a Coca-Cola being early adaptors of LCA methods to determine the environmental consequences of different packaging solutions (PET compared to glass bottles) (Hunt, R. G et al., 1996). In the following decades, LCA has become more common in environmental standards, labelling schemes, policy and legislation (Guinée, J. B et al., 2011), and is now supported by its own ISO standard (ISO 14044, 2006). The usage of LCA allows for a 'cradle-to-grave' approach and thus permits the analysis of environmental impacts from initial emissions from the extraction of raw materials, to the end of life of those materials. However, due to LCA's 'goal and scope' phase, for some studies a 'cradle-to-gate' approach may be implemented, whereby the use and end of life stages of the product are not subject to assessment (ISO 14044, 2006). In relation to fisheries and aquaculture, this is a tool to promote more sustainable food products, and to displace any detrimental environmental 'hot spots' in the production chain.

An LCA can explore one or several impact categories, such as energy use, global warming, ozone depletion, abiotic resource use, acidification, eutrophication, ecotoxicological impacts, photochemical oxidant formation, human work environment, or any other quantifiable factor. Various new and creative impact categories have also been developed to suit the need of aquatic-based LCAs, including seafloor destruction and net primary production required (biotic resource use) becoming more common in seafood system studies (Langlois, J., et al., 2014; Cashion, T., et al., 2016; Pelletier, N.L., et al., 2007; Emanuelsson, A., et al., 2014; Vázquez-Rowe, I., et al., 2012).

The LCA approach has its strengths in that it can be used to assess the broad range of environmental interactions (inputs and outputs) that take place within the Vietnamese fish reduction industry in a quantitative manner. However, to conduct an LCA, a Life Cycle Inventory (LCI) must first be undertaken of parts of a system that previously there is no, or little data available. This is discussed in section 3.1 along with data collection for PCO as they can be interlinked as qualitative understandings and descriptions are important in LCI to comprehend practitioners reasoning and judgments when it comes to validity of final findings.

2.2 Product Chain Organisation

Product Chain Organisation (PCO) is a method using life cycle thinking (LCT) for structuring organisational studies of product chains (Baumann, 2012). As figure 2 shows, PCO has similarities with the LCA method, but distinguishes itself by focusing on the organisational structure of product chains rather than the environmental information collected along the technical processes of the chain (Baumann, 2012). In other words, PCO is structured along the actors, utilities, companies, etc. involved along the production chain, which are the catalysts that enable the product to "flow" from its origin to final disposal/use. The understanding and analysis about the interrelations and objectives within product chains is important in being able to achieve sustainability goals within the management of such production systems. In this respect, the PCO method might be more accessible for social and management scholars than LCA is (which mainly puts analysis in the hands of engineers) and can therefore result in the addition of 'new issues and perspectives in life cycle management and product governance' (Baumann, 2012).

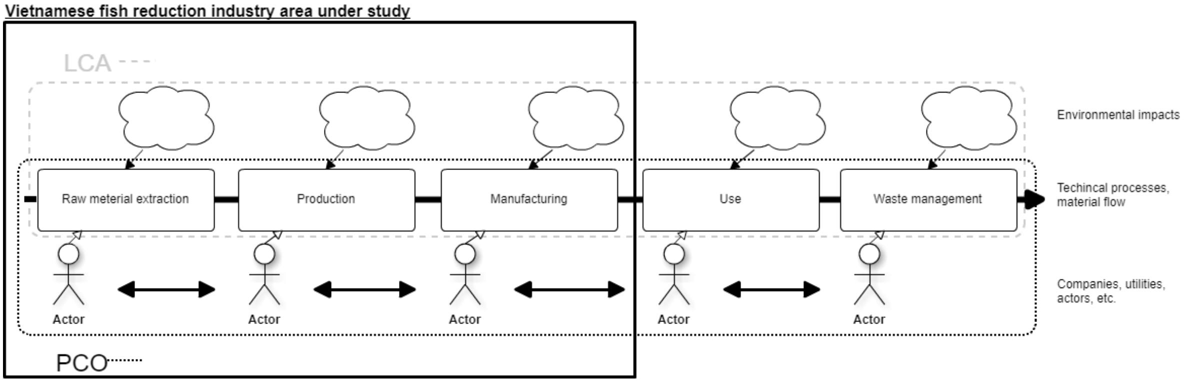

Figure 2. Illustration explaining the relationship between LCA and PCO. Both follow the technical processes but PCO focuses on actors, companies, utilities, etc. and LCA focuses on environmental impacts. (Figure has been adapted from Baumann, 2012)

With the PCO approach utilised for the Vietnamese fish reduction industry, it will allow for previously unknown or under-identified linkages within the product chain of wild capture fisheries through to fishmeal production.

2.3 Scoping review of impact categories specific to fisheries

A brief scoping literature search was undertaken to assess what impact categories would be suitable for the present study and was reflected upon after LCI data has been consolidated. The more 'generic' impact categories have not been included in this review as they are readily included in all LCA's and can be easily searched and understood.

Biological resource use (BRU) / Primary Production Required (PPR). A review of the marine biotic resource use metric was undertaken by Cashion et al., (2016), with some important methodological and terminological advances being made. From a terminology standpoint, Cashion et al., (2016) states that the term primary production required (PPR) should be used because of *"the specificity with which it refers to what it quantifies, rather than the ambiguity of the biotic use term*." The indicator for PPR is kg C with the emphasis behind PPR being that wild harvest of fish stocks directly effects pelagic and benthic ecosystems. This can be related to stock assessments and status, with the FAO (2010), reporting that regularly stocks are under their regeneration threshold worldwide, with half being fully exploited and a quarter being overexploited, depleted, or recovering from depletion. Along with the direct effects of over-exploitation of fish stocks, there are also secondary environmental consequences, which has implications across trophic levels and the food chain. Furthermore, the FAO (2010) reports that there is a decline of average trophic level of landed fish species, which means that marine ecosystems are relying on fish which are lower in marine food webs (Langlois et al., 2014). In relation to the Vietnamese fishmeal industry, PPR is an important impact category indicator because it can quantify the amount of primary production necessary for fishmeal and oil products and the resulting effects it has on those ecosystems. It is also important to recognise that harvesting the products of primary production will have different consequences for different ecosystems. Cashion et al., (2016), has developed a method which incorporates source-species and ecosystem specific values, which will allow for 'far greater resolution of PPR than when employing global values', however it relies on harvest and ecosystem specific data availability.

Seafloor effects / Seafloor impact potential. Seafloor effects represent an important specific impact category for fishery related LCAs. The basis behind the impact category is that when bottom trawling is conducted, the seafloor is swept by trawls and the habitat is destructed. To quantify this impact, the trawled area is divided per functional unit landed (Ziegler et al., 2003). Seafloor ecosystems are however, spatially heterogeneous, which results in trawling in one place having a variable environmental impact than in another. Further LCA methodology progress has been made by Nilsson and Ziegler (2006) which tries to increase the impact categories robustness by increasing seafloor types assessed and by differentiating between different benthic communities and their associated resilience to disturbance.

Discard reporting/global discard index or bulk mass discarded. According to researchers at the Research Institute of Aquaculture No. 2, no discarding of catches takes place in Vietnam, so this impact category has not been assessed in this literature review.

Aquatic and Terrestrial Ecotoxicity. Ecotoxicity is an impact category that can be split into a variety of sub-categories such as Freshwater Eco-Toxicity Potential (FETP), Marine Eco-Toxicity Potential (METP) and Terrestrial Eco-Toxicity Potential (TETP). The importance of the Impact category(s) is that it contributes to conditions toxic to flora and fauna. Regarding aquatic eco-toxicity potential, a large amount of studies have used 1,4-dichlorobenzene (1,4 DCB) as the category indicator. However, with recent understandings of the toxicity potential of anti-fouling paint emissions, Thrane (2004), Ziegler et al. (2003), Thrane (2004a) and Hospido and Tyedmers (2005) have all used impact categories that do not use the common indicator and thus have implemented novel approaches such as volume of polluted water by copper-based anti-fouling paints used on the hulls of fishing vessels.

Socio-economic impact. Recently within the LCA sphere, there has been greater emphasis in incorporating socio-economic factors such as social welfare into impact categories (Cao et al., 2013). Heller & Koeleian (2003) have proposed some social and economic indicators at each life cycle stage for agri-food systems which could be adapted to meet the seafood system, with indicators including land conversion rate, farm profitability, average wages, quality of life and worker satisfaction. Furthermore, the UNEP and SETAC (2009) have also developed guidelines for social life cycle assessment to address a range of social issues, but it is still a relatively lacking impact category compared to others within LCAs.
Of note, this impact category is important, however this report also utilises a PCO methodology that already focuses more heavily on socio-economic impacts and dynamics, so this impact category has not been included in the LCA.

2.4 Goal and scope

The Goal of this LCA is related back to this thesis's research questions, particularly question 2 and partly question 3-I.e. What are the environmental impacts of the Vietnamese fish reduction industry and what hotspots can be targeted for improvement.

The overall scope of this LCA is the Vietnamese fishmeal industry and its related input product chains (such as fisheries, electricity, agriculture, etc), thus it does not look at downstream processes of what happens after the production of fishmeal and those related environmental impacts. The intended application of the study is to add to the data pool of specific Unit Process data to the Vietnamese fishmeal industry as it is relatively under studied. The audience of the report is then majorly aimed at individuals who can utilise this LCI dataset for further analysis of the sector going into the future and utilise the data for comparisons with different fishmeal production regions/practices.

The critical review of the data obtained, and subsequent analysis has been achieved during reviews by the two supervisors of this thesis. Raw data is available online with this thesis for others wishing to assess the validity of the data and findings.

2.4.1 Functional Unit

The functional unit for this study is 1 tonne packaged fishmeal, at plant

2.4.2 System Boundaries

The system boundary was set via following similar aquaculture and fishmeal based LCAs (see for example Freon and Avadi, 2014 and Henriksson, 2015), and has be altered accordioning to data available. The system boundary of the current study can be seen in diagram form further down in the report in figure 4.

2.4.3 CMLCA software and Ecoinvent data

CMLCA V.5.2 software was used to solve the LCA matrix. Primary data were evaluated using Microsoft Excel, and supporting data were retrieved from the ecoinvent V2.2 database. The ecoinvent database was also used as a base for processes specific to Vietnam that have been modelled. For example, the Vietnamese electricity mix has been calculated based upon the International Energy Association (IEA) data, and those numbers have been used as supplements to coal and oil electricity generation upon ecoinvent's data on Czech Republic power plants because they have a similar combustion efficiency as South East Asian countries.

2.4.4 Handling of primary and secondary data

LCA outcomes are subject to, *inter alia*, a range of outcomes related to different methodological choices made by practitioners, with studies describing identical systems experiencing an order of magnitude difference in assessment impacts (de Koning et al. 2009; Williams et al. 2009; de Silva et al 2010). Examples include systems boundary setting, inclusion of capital goods, and characterisation factors (Henriksson et al. 2011). The consequence of this is additional dispersion around averages that have needed to be made when opportunistically seeking LCI data most relevant to the processes in question (UNEP 2011) creating inventory uncertainty. In the case of this report, an example of this additional dispersion, is when horizontal averaging has been used for the averages of agricultural rice production data. Since the Vietnamese fishmeal industry is to date relatively understudied, primary data representing the whole industry is scarce and secondary data on unit processes not directly related to the fishmeal industry in question has been used in some instances. To handle this, the protocol produced by Henriksson et al. (2014) for horizontal averaging of unit process data-including estimates for uncertainty, has been used to deal with these issues because it incorporates dispersion from inherent uncertainty, spread and unrepresentativeness into the input parameters for the LCA program used-CMLCA. Furthermore, to try and minimise aleatoric uncertainty, the largest sample size possible was used (multiple surveys) and then later assessed using Monte Carlo analysis to average out the uncertainty over a large number (1000) of MC runs.

2.4.5 Allocation

The main allocation method that has been used in modelling conducted was physical/mass allocation. A supplementary economical allocation was also conducted and used as a sensitivity analysis between the two allocation methods. This is discussed in more detail in the sensitivity analysis section of the report.

2.4.6 Land use, maintenance and construction

For this LCA, maintenance and construction phases have not been included due to previous studies due to the large amount of time that has to be invested in calculating the total input in relation to the small impact that is considered (Ayer, Tydmers 2009). Land use has also not been considered due to the lack of data corresponding to what was present at the fishmeal factory before.

3. Findings and Analysis: Life Cycle Assessment

3. Life Cycle Inventory

3.1 Data collection

Primary data collection was conducted in the Vietnamese provinces of Cà Mau, Bạc Liêu, Kiên Giang, Sóc Trăng, Bến Tre, and Trà Vinh during the 1st of September and the 20th of December 2017. Not all provinces visited for data collection provided suitable LCI data or no LCI data were collectable. This lack of data collection can be somewhat attributed to the European Commission issuing Vietnam with a yellow card in the middle of the data collection period, 'over insufficient action to fight illegal fishing' (http://europa.eu/rapid/press-release_IP-17-4064_en.htm), and subsequently many Vietnamese businesses became not willing to talk, even if many interview questions did not touch on this subject.

All quantitative data have been collected from structured interviews (see appendix 1) within key parts of the Vietnamese fish reduction supply chain, with managers, technicians, fishermen, and vessel owners. Interviews ranged from 30 minutes to 90 minutes, with permitted voice recordings taken to be referred to later if needed. The interview data collection questionnaires (separate questionnaires for capture fisheries, middlemen, and fish reduction plants) were based upon previous LCA studies of the Vietnamese aquaculture sector/other South East Asian aquaculture sectors (Henriksson, Doctoral Thesis, 2015), and subsequently adapted when further understanding of the fish reduction industry specific to Vietnam was identified during initial research (the iterative process of LCA studies). All interviews were translated into Vietnamese, and a Vietnamese translator with specific knowledge of the Vietnamese fisheries and aquaculture sectors was used in all interviews.

Supplementary primary data specific to the Vietnamese trawl fisheries in Kiên Giang province were provided by Thong Ba Nguyen, based on his PhD thesis on the Socio-economic study of the trawl fishery in Kiên Giang (Thong, 2014), and were used as unit process data for catch statistics and fuel consumption, once back calculations and conversions were undertaken.

The diagram in figure 4 has been produced to describe key processes that have been modelled within this current LCA. Included is also an indication of actors involved in the PCO analysis (Please refer to appendix 1 for a full table of actors). The diagram is also to be used as a referral back to Unit process data descriptions that follow the product chain (by using the codes in the top right of the boxes).

3.2 Data sensitivity

As discussed elsewhere in this report, the sensitivity of some topics relating to the Vietnamese fishing and related industries has meant that I have decided to keep interview sources confidential; for without their insights and generosity, none of this information would have been made available. A map of data collection area is presented in figure 3 below.

3.3 Data Collection Locations

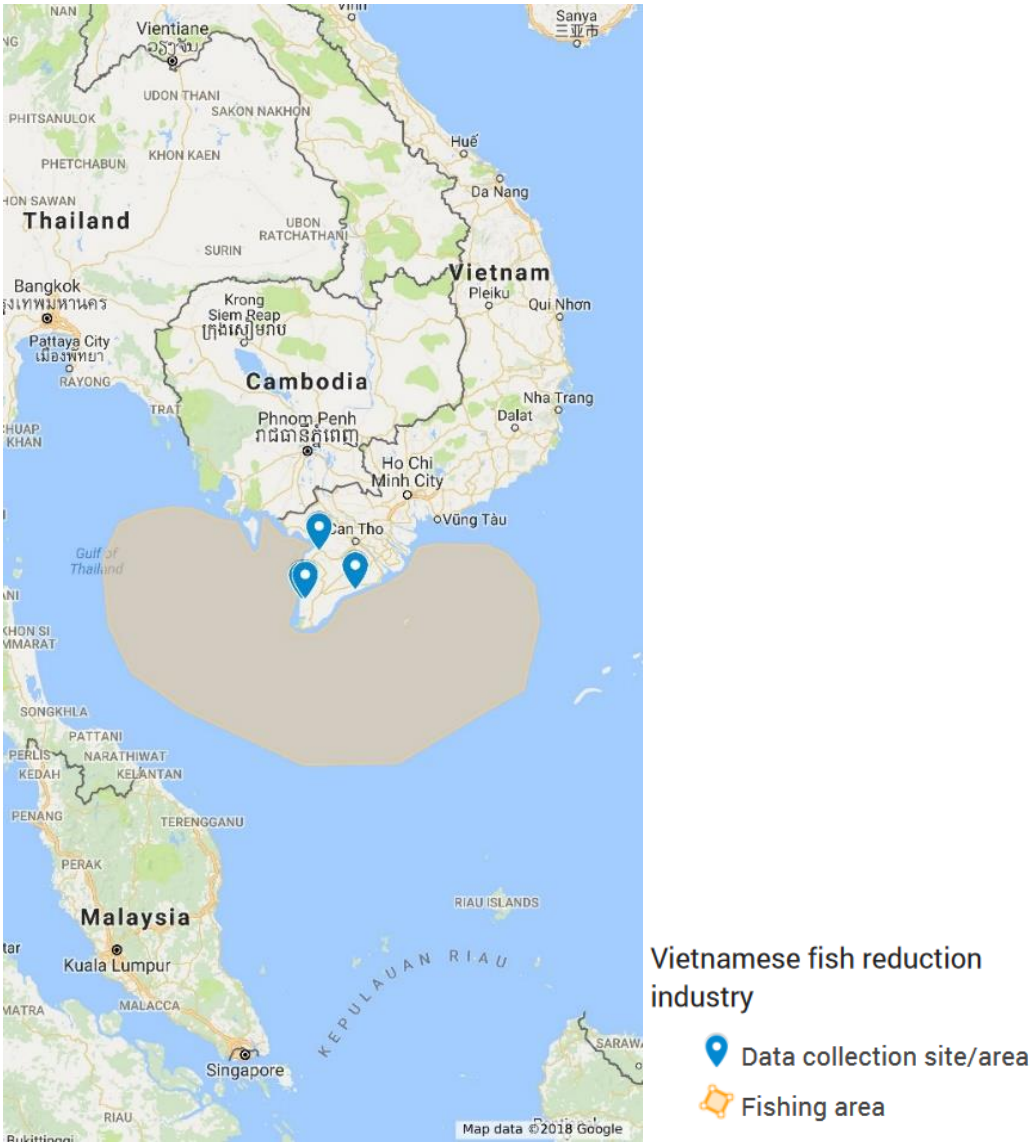

Figure 3. Approximate data collection locations and the fishing area that was identified to be fished from data collection interviews in 2017

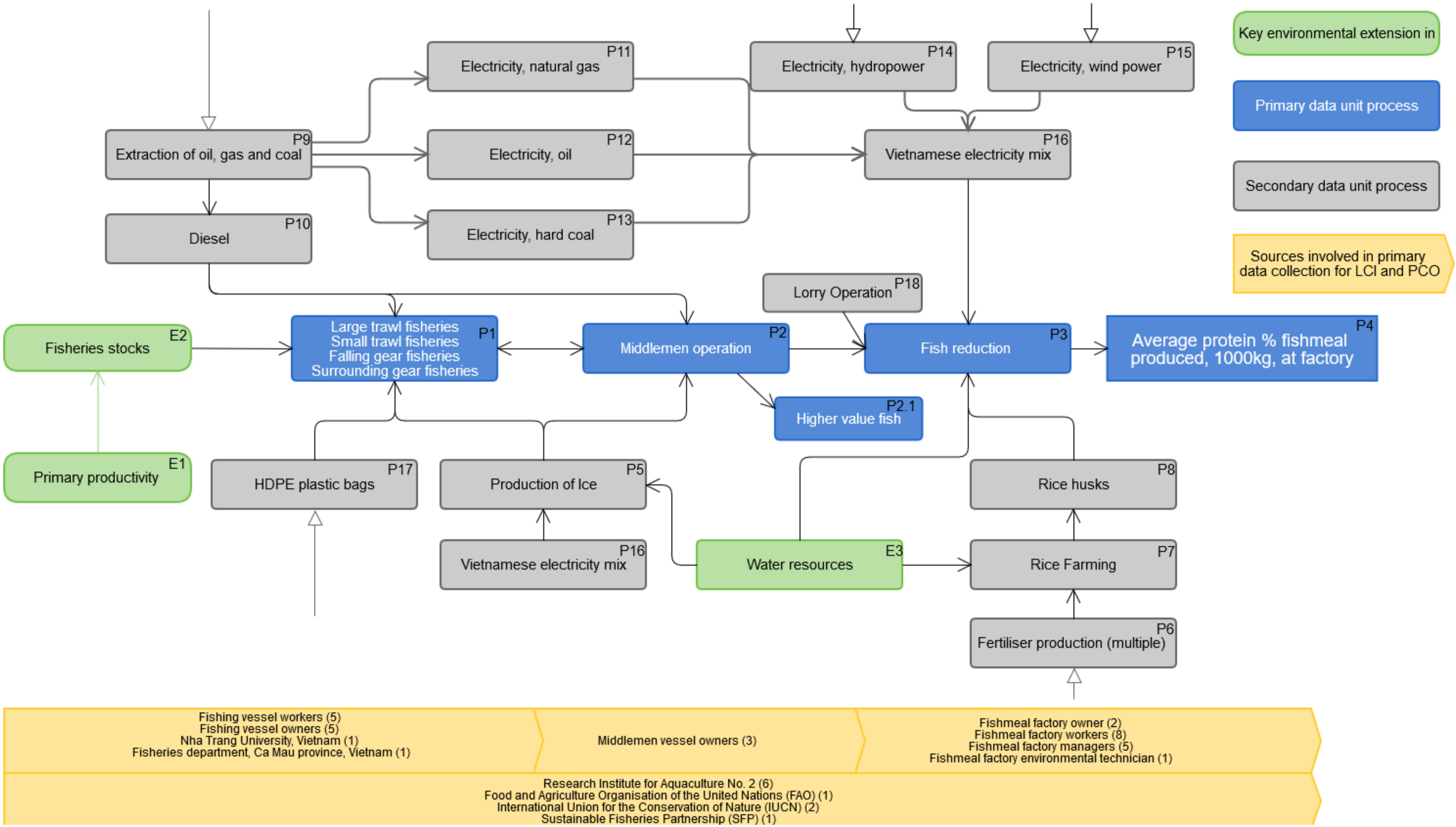

Figure 4. A diagram showing the processes and products involved in the Vietnamese fish reduction industry. Included are the sources involved in data collection for the Life Cycle Inventory and Product Chain organisation. Codes in process/product boxes have further explanation in on the next page. Arrows not filled-in are demonstrating upstream processes. Process diagram does not include wastes or environmental emissions. The Process and Product identifier both start with P, while environmental inputs start with E.

3.4 Primary productivity and fisheries stocks (E1-E2)

No official data could be collected on the primary productivity of the region fished or the status of the stocks that where fished (especially those species used for reduction) that could be of practical use within LCA modelling. It was included in the model the weight of biological inputs as an 'environmental flow'.

3.5 Fishing data (P1)

A total number of eight primary interviews for vessel data were collected. All the interviews took place in Son Doc, Cà Mau province (The Mekong Delta), with the first interview being arranged by personal contacts with employees from the Research Institute for Aquaculture No. 2, a Vietnamese governmental department, and then a 'snowball' of interviews from friends of interviewees (Atkinson, R., & Flint, J. 2001). Some vessel owners had up to six vessels, but data collected corresponded to two of their vessels that caught the most trashfish as time did not permit for more vessel data collection in these instances.

The supplementary data provided by Thong Ba Nguyen were collected in 2015 for a report on the socio-economic study on the trawl fishery in Kiên Giang (Thong 2015) consists of 18 vessels. Fuel use data were presented in monetary values and were converted to kg/diesel using values obtained in late 2017 during primary data collection. Also, conversions such as catch per year from catch per trip have also been calculated to suit this report's current LCI database.

LCI data for vessel construction was not able to be obtained and is not included in this LCA.

3.5.1 Trips per month/year for fishing vessels

For data collection regarding to trips per year, it is assumed that: one 20-day long trip is made per month, 11 months out of the year, for all vessels that did not report elsewise (please refer to LCI which data shows trip data in greater details). This assumption has been made based on primary data collection, whereby most fishing vessels conducted a 20-day fishing trip per month, for 11 months of the year (thus 1 month off). Of note is that 'Otter trawlers' (shrimp trawls) operate 4-5 days per trip, with an average of 23 active fishing days per month (Thong, 2015). Anchovy pair trawlers had trip durations ranging from 15-20 days and fished ten months of the year, and fished once per month (Thong, 2015).

3.5.2 Catch statistics

Most of the vessel owners interviewed owned multiple vessels (ranging from one to eight vessels owned). Many fishing vessels operate at night time, especially to catch squid, but per trip catches can be up to 95% fish and crustaceans used for reduction (See table 1). Many of these vessels have verbal contracts/agreements with middlemen that collect all catches approximately every 24 hours that then further on sell them. The verbal contract/agreements with middlemen is extremely flexible, because if a middlemen vessel is not there to collect fresh catch, the fishers will sell to another middleman.

Table 1. Table showing the percentages of trash fish in different vessel classes catch

Vessel type	Range of data (%)	Average % trashfish of total catch
Large trawlers	88 – 95	87
Small trawlers	9 – 51	27
Falling gear	55 – 80	72
Surrounding gear	40 – 50	43
Unweighted combined vessel average		**57**

Although there are regulations regarding Vietnamese fishing practices, none of the interviewees stated that they adhere to these rules, mainly because there is no enforcement and they do not even know what the rules are.

3.6 Middlemen data (P2)

A total of three middlemen data interviews were conducted, of which all took place in Son Doc, Cà Mau province. The middlemen vessel data collection consisted of two vessels that are similar to the Vietnamese fishing vessels that data had been gathered on (wooden built and 22m in length), and one larger, 32m steel vessel. The steel vessel acted as a mobile 'processing plant', capable of processing and freezing fish for direct sale. The steel vessel is considered unusual in traditional Vietnamese middlemen processes but is seen as the possible future of the industry (Pers comm, middlemen vessel owner, 2017), and has been included in LCI data and subsequent calculations.

With the middlemen sector being an important part of the Vietnamese fisheries and fish reduction industry, modelling for inputs in processes plays a distinctive role for understanding environmental impacts of the production of fishmeal. The middlemen vessels transport fuel, ice, and food to fishing vessels, and buy fish to take back to the port and fishmeal factories. Per trip middlemen vessels on average visit 7-10 fishing vessels, over seven days, conducting 3-4 trips per month (based on primary data collection, 2017)

3.7 Middlemen modelling method

Because middlemen vessels visited on average 7-10 vessels of different gear types, no data were able to be collected on how much fuel, ice or food was distributed to these different individual vessels corresponding to gear types. This problem has been dealt with by calculating the diesel required to transport the above-mentioned products to the vessels and turning it (the middlemen input process) into an 'artificial' product/ input. It is assumed that vessels that are visited more frequently, receive a greater share of the middlemen products/inputs. For example, the Small trawl fishing vessels have a much greater input from middlemen vessels than larger trawlers, because middlemen vessels are visiting them more frequently to collect high value shrimp and other fish (including trashfish)-Thus when modelling the data, it is assumed that small trawlers have received greater inputs (See appendix for calculations).

For modelling purposes, a process of 'transportation vessel' has also been made as to differentiate between the action of middlemen inputting into the fishing process and taking away (collecting catch landings and taking them to fishmeal plant).

3.8 Fishmeal data (P3)

A total of five fishmeal plants were visited for data collection. Interviews took place in Cà Mau and Bạc Liêu provinces. All five factories differed in raw product input capacity and actual input, with ranges between 21,900 to 213,160 t/year maximum capacity and 10,950 to 199,837.5 t/year actual reduction (see table 2). For LCA modelling regarding production numbers, fishmeal factory 4, with it reducing almost three times the amount as the second largest producer, was not included due to difficulties in confirming the numbers given in the interview. Moreover, it was not known at the time of data collection, but it was assumed that fishmeal factory 1 and 3 run the same brand of fish reduction machinery because they have the same maximum fish capacity a year.

Table 2. Fishmeal plant maximum capacity of production vs actual reduction quantities

Fishmeal factory	Maximum fish capacity/year (t)	Actual reduction raw fish/year (t)
1	73,000	21,000
2	36,500	13,500
3	73,000	21,900
4	213,160	199,837
5	21,900	10,950

3.9 Agricultural rice production data (P6-P8)

The fuel used for combustion to heat the boiler in all fishmeal plants visited was rice husks. Rice husk and rice bran are by products from rice grain production. The quantity of rice husk required to produce one tonne fishmeal was gathered from primary data collection in interviews (N=5), with an average of 1,270 kg rice husk per t fishmeal (1.27:1). Unit process data for Vietnamese rice farming were derived from the SEAT annex report and is specific to Vietnam (http://media.leidenuniv.nl/legacy/d35-annexreport.pdf)

3.10 Electricity Mix (P9-P16)

Electricity production shares were determined on an annual average and on the level of net production calculated from the International Energy Agency (IEA) with latest numbers for 2015. The electricity generation was based upon power plants in Czech Republic from the ecoinvent V2.2 database, as they were assumed to have similar technology as those in South East Asian countries. Figure 5 shows the relative contributions which have been used in the current LCA modelling.

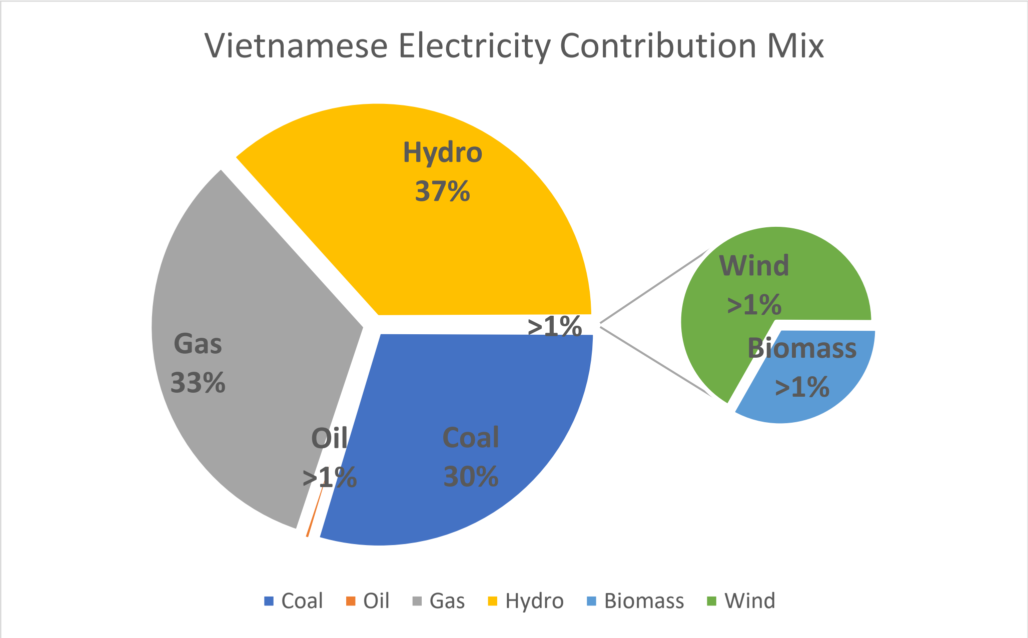

Figure 5. Illustration of the contributions that different electricity generation sources have in the overall Vietnamese mixed used in the present LCA. Data taken from IEA with data for 2015

3.11 Infrastructure (Various processes)

The infrastructure, specifically fishmeal plant building data has been neglected in this study because time and resource requirements for data collection did not make it possible.

3.12 Ice production data (P5)

No ice producing businesses agreed to interviews for unit process data collection, or any interview, so modelling has been based upon it takes 2.5-2.7 kWh to produce 40-50 kg ice (SEAT annex report), with electricity input from the modelled Vietnamese energy mix.

3.12.1 Ice on board fishing and middlemen vessels

Monetary values were the only data available for ice used onboard, conversions were based on primary data collection at the end of 2017 that 50kg blocks of ice are 12,000vnd (0.43 euro).

3.13 Diesel use on-board fishing and middlemen vessels (P1-P2)

Not all data collected for diesel consumption were in kg diesel, with monetary value or litres being the most common unit. To convert these numbers, a conversion factor of 14,400 vnd/litre (0.52euro) was used, based on primary data interview results from the end of 2017. It was also assumed that one litre of diesel equals 0.85 kg (N. N. Greenwood, A. 199; FAO, 2017).

The sulphur content of the diesel used could not be established during interviews, nor from literature data.

3.14 Plastic bag production and use on vessels (P1 and P17)

It was observed and noted in interviews that most fishing vessels used plastic bags to store trashfish for ease of storage and to keep the overall weight of fish caught (no fish juices lost). Primary data interviews conducted at the end of 2017 gives an average of 8kg capacity of trashfish per bag. This value has then been used to calculate total plastic bag use/year for capture fisheries vessels, with 5.5 grams of High-density polyethylene (HDPE) per 8kg capacity plastic bag.

The plastic bag input has been modelled using the ecoInvent 2.2 database because it was not possible to source plastic bag production data specific to Vietnam. It is also important to note that some upstream processes (such as rice production, have not included the use of plastic bags in modelling)

3.15 Price of different fish species (P1-P3)

The price of the different major fish species, i.e. shrimp, 'mixed fish', 'trashfish' and squid has been based upon primary data collected at the end of 2017 and data from Thong (2015). Where there was observed fluctuations in price among vessels, middlemen and fishmeal factories, the average for that part of the value chain has been used; i.e. some fishermen state that they receive 4,000-8,000 vnd per kg of trash fish, so the value of 6,000 vnd (0.21euro) was used for modelling within CMLCA. This is further discussed later in the report because it tells an interesting story of the supply chain.

3.16 Trash fish transport via lorry (P18)

For the LCA it was assumed that all fish is offloaded directly to the fishmeal plant via either the fishing vessel or middleman vessel. This assumption is being made because out of all the interviews, only 1 fishmeal company occasionally got trash fish supplied to them via a small lorry driving a total of 3-5km from the local port. Because of the irregularity of this type of transport and the short distance it is used, it was not modelled.

3.17 Proportions of different protein content fishmeal's to Vietnams country fishmeal mix

The final country mix which has been made up of different quantities of different protein percentage fishmeal's, this has been calculated from primary data collection on fishmeal factories total average production of 5 different fishmeal's (50-55, 60, 62, 65 and 67% protein). These class totals were then divided by the sum to get the average proportion of each fishmeal class to go into the country mix. Attention must be paid to the fishmeal plants that not all produced five different fishmeal's. Many produced two or three, and many did not know how much they produced of each class, hence in those specific cases the quantity was averaged out over all five classes used for this LCA.

It is to be noted that these proportions do not affect the environmental impact, but just used to understand a general Vietnamese country fishmeal.

The pricing of different fishmeal classes has also been calculated from primary data collection at the end of 2017, with data from fishmeal factory owners, managers and technical employees.

4. Life Cycle Inventory Results

4.1 Fisheries results

Vessel classes have been devided based on gear type used for fishing practices identified in interviews in the months September-December 2017, and by data colleced by Thong (2015). Vessel gear types in use are: Large trawlers (demersal and pelagic) (LTF), Small trawlers (otter/shrimp trawlers) (STF), Falling gear (FGF), and Surrounding gear vessels (purse seine)(SGF).

4.2 Weighting of fisheries vessel classes

No data while conducing the LCA could be found on the contributions of vessel classes to total fisheries landings that go towards fish reduction industy. This has resulted in weighting of vessel class contributions to the fish reduction industry based upon average yearly catches of For explanation, from interview data, supplemented by data from Thong (2015), the Large trawl gear fishery on average has a annual trashfish catch of 473 t/vessel/year, whereas Small trawl fisheries catch 12.336 t/vesel/year, which results in a much smaller contribution to the fish reduction industry. See table 3 for contributions to fish reduction per tonne.

Table 3. A Table showing how vessel class contributions have been divided for the input into the fish reduction industry. Note: The values for 'kg contribution to trashfish mix in fleets interviewed/Thong 2015 data' have been used to also scale 'mixed fish', 'squid', and 'shrimp' catches from different fleets, so the correct proportions are accounted for.

Vessel gear type	Average tonne trashfish catch/year	Proportion out of total between vessel classes	Percentage out of total	kg contribution to trashfish mix	Weighted kg Diesel/t trashfish
Small trawler	12.335	0.01	1.1%	11.49	18
Large trawler	473.208	0.44	44%	440.79	144
Falling gear	336	0.31	31%	312.98	69
Purse seine	252	0.23	23%	234.73	59
Total/year	**1073.544**	**1**	**1**	**1000**	**290**

4.3 Fuel use

The fuel use between the vessel classes for catching a tonne of trashfish varied considerbly. Large trawl gears required on average 250kg diesel/t trashfish, Small trawlers 1,520 kg diesel/t, Falling gear 147 kg diesel/t, and Surrounding gear requiring 179 kg diesel/t trashish caught.

When weighted between classes for contribution to the trashfish industry, the average kg diesel to catch 1000kg trashfish is 290kg (333.5ltrs diesel) for this present study (See table 4).

Table 4. A table showing the diesel use required to catch 1000kg of trashfish between different vessel classes

Vessel gear type	kg Diesel/1000kg trashfish	Contribution to mix	Weighted kg diesel/1000kg trashfish
Small trawler	1597	1.1%	17.6
Large trawler	327	44%	144
Falling gear	224	31%	69.6
Surrounding	256	23%	59
Total kg diesel	2406		290.2
Total ltr diesel	2827		333.7

Different quality fishmeal's, based on percentage of protein content, varying from 50-67%, were produced from fish reduction plants visited for data collection (see table 5 for contributions). These contributions were weighted together based on production quantities gathered from interviews and were used to produce a 'Vietnamese country fishmeal mix' profile average for LCA purposes.

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Table 5. A table showing different protein content fishmeal's and quantities produced at all fish reduction factories interviewed. Many interviewees did not know exact contributions over the year because the fish reduction process is highly variable because of raw input freshness, species composition, and mechanical equipment processes used for reduction; thus, averages were made.

Interview	Fishmeal's produced	% Protein content	Production/year(t)	% of total production
1	3	50-55	-	0
		60	2,581.250	50
		62	1,290.625	25
		65	1,290.625	25
		67	-	0
2	3	50-55	-	0
		60	675.000	20
		62	-	0
		65	1,350.000	40
		67	1,350.000	40
3	4	50-55	-	0
		60	1,520.833	25
		62	1,520.833	25
		65	1,520.833	25
		67	1,520.833	25
4	3	50-55	-	0
		60	18,231.750	33.33
		62	18,231.750	33.33
		65	18,231.750	33.33
		67	-	0
5	4	50-55	1,773.600	60
		60	492.647	16.66
		62	492.647	16.66
		65	492.647	16.66
		67	-	0

5. LCA results

The Life Cycle Impact Assessment results have been based on physical/mass allocation procedures, with economic allocation also being used for sensitivity analysis. Results are specific to the year of 2017.

5.1 Life Cycle Impact Assessment

The initial Life Cycle Impact Assessment (LCIA) conduced was based upon mass allocation of 1 tonne of trashfish at the port/fishmeal factory and subsequent Monte Carlo analysis within CMLCA.

A literature review was conducted at the start of this thesis on impact categories that may have been suitable in line with the goal and scope of the study. Due to data requirments and the time frame of this thesis, not all suitable impact categories, specifically relating to the fisheries sector, have been assesed. The lack of data avalible for these impact categories hinders the actual environmental assessment of this industry, and it is further discussed later in this report.

The Impact categories included in the current LCA are global warming potential, acidification potential, photochemical oxidation potential, and eutropication potential. First the results of the contributional analysis are shown, followed by Monte Carlo analysis.

5.2 Contributional Analysis

The results from the contributional analysis for the impact categories assessed (figures 6-9), show that the burning of diesel in fishing vessels is the largest contributer to global warming (54%), Eutrophication (39%) and Acidification (51%); while rice straw burning is the largest contributer for Photochemical oxidisation (26%). Of interest is the burning of diesel in transportation vessels (the middlemen sector), which is the second largest contributor to GWP and acidification potentials, with 30% and 27%, respectivly; For Eutrophication and Photochemical oxidation, burning of diesel in transportation vessels are both the third largest contributions with 21% and 12%, in that order.

These results also show, if the two key fisheries sectors, that is, the act of fishing and middlemen transportation, are assessed together, they constistute 84% contributions to GW, 78% to Acidification, 60% to Eutrophication, and 33% to Photochemical oxisation to the functunal unit of 1000kg fishmeal produced.

5.2.1 GWP

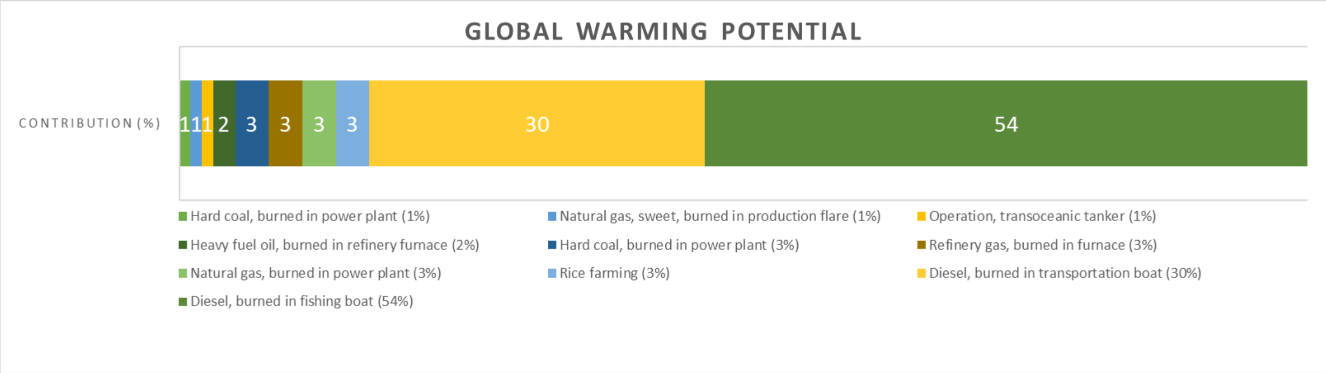

Figure 6. Percentage GWP contributions to 1000kg Vietnamese fishmeal. Made up of contributions from carbon dioxide, nitrogen oxides, and methane (biogenic) emissions. Does not include negative emissions amounting to 13% from Nitrox oxides emissions to 13% from Nitrox oxides emissions to air from diesel burned in fishing boat (-8%), and diesel burned in transportation boat (-5%).

5.2.2 Eutrophication

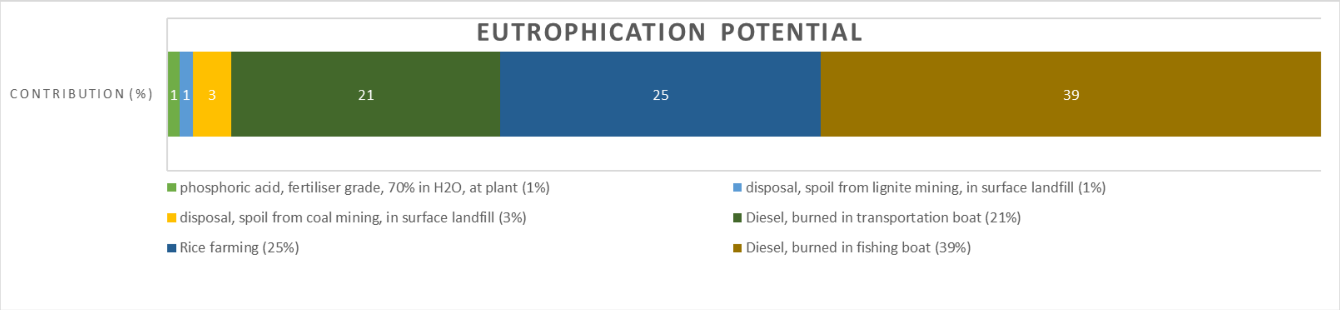

Figure 7. Percentage eutrophication potential contributions to 1000kg Vietnamese fishmeal. Made up of contributions from phosphate (marine water), phosphate (fresh water), nitrogen oxides, and nitrate emissions.

5.2.3 Acidification

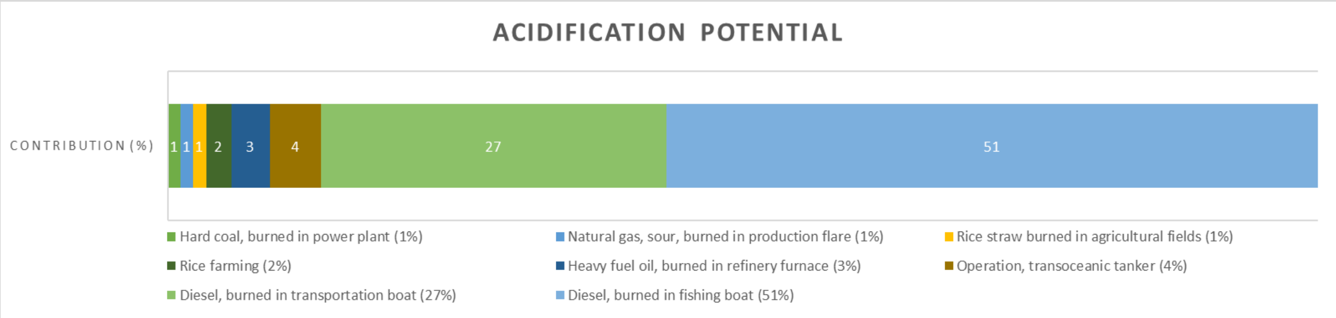

Figure 8. Percentage Acidification potential contributions to 1000kg Vietnamese fishmeal. Made up of contributions from sulfur dioxide, ammonia, and Nitrogen oxide(s) emissions.

5.2.4 Photochemical oxidation potential

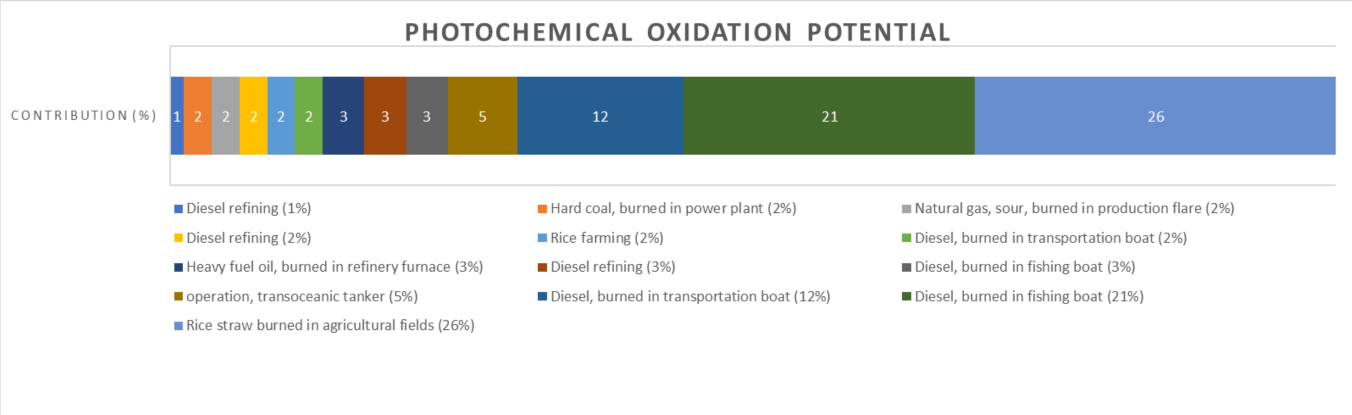

Figure 9. Photochemical oxidation potential contributions to 1000kg Vietnamese fishmeal. Made up of contributions from sulfur dioxide, butane, pentane, hexane, carbon monoxide, and methane (biogenic) emissions.

5.3 Fishing vessel/gear type Monte Carlo Results

After analysing the results of the contributional analysis, 1,000 Monte Carlo (MC) iterations where conducted on the four vessel classes to understand their individual contributions to the impact categories assessed and their uncertainties. For the initial MC, modelling a tonne of trashfish onboard each vessel class was undertaken and then weighted contributions from each vessel class were also assessed, with Large trawl fisheries contributing 1693kg, Small trawlers 44.2, Falling gear 1201kg and Surrounding gear 902kg (to add upto the 3,850kg trashfish required for 1000kg fishmeal).

5.3.1 Global Warming potential

The global warming potential results from the LCIA for 1000kg trashfish, onboard vessel (see figure 10), indicate that Small trawlers had the highest GWP impact potential with 1700kg CO2eq, up 35% from the second largest emitter, Large trawls with 1,105kg CO2eq, followed by Falling gear with 583kg CO2eq, and Surrounding gear with 542kg CO2eq.

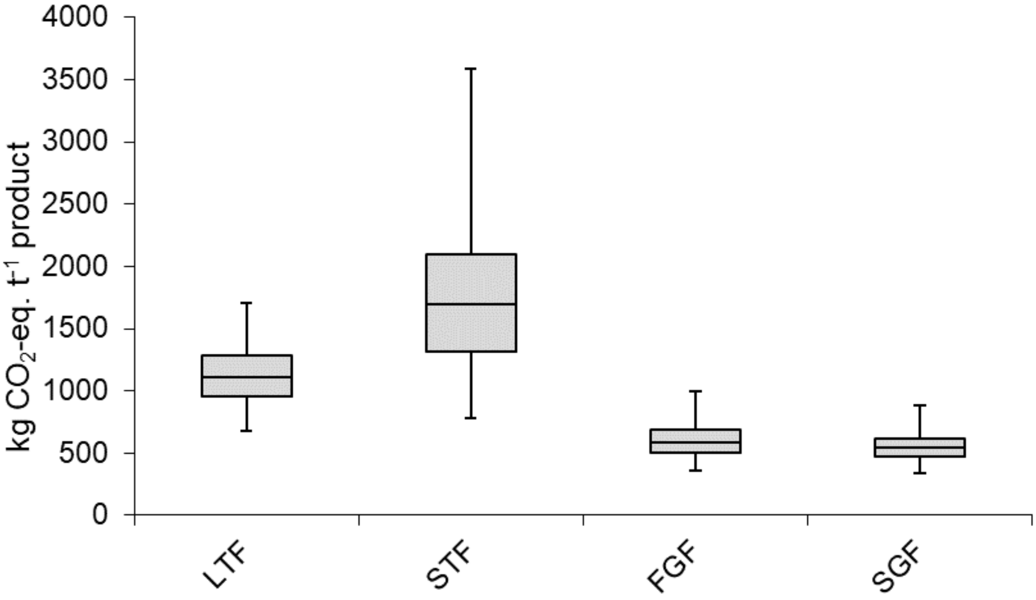

Figure 10. Greenhouse gas emissions resulting from the process of fishing one tonne of trashfish, delivered to the port/fishmeal factory for each vessel/gear class. Box-and-whisker plot of the GHG emissions associated with fish from Large trawlers (N=112), Small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

As figure 11 shows, when vessel contribution calculations have been included into trashfish quantities that go toward the fish reduction industry (refer back to table 2), including the fish reduction ratio needed to produced 1000kg fishmeal (3.85:1), the impacts are different. Large trawlers exibit the greatest GWP potential with 1,870kg CO2eq and small trawlers conversly contribute 73kg CO2eq – a 96% difference. Falling gear and Surrounding gear contributing 708 kg CO2eq and 480 kg CO2eq, respectively.

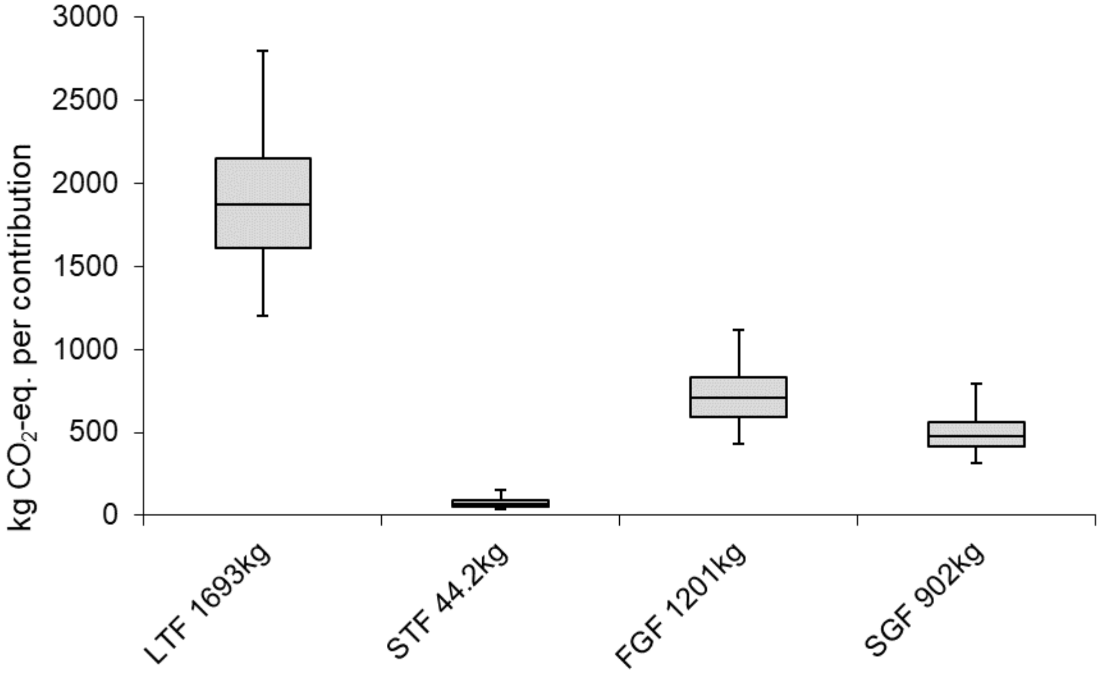

Figure 11. Box-and-whisker plot of the GHG emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Vessel class contributions (in kg of trashfish) have been included: Large trawl fisheries contribute 1693kg trashfish, small trawl fisheries 44.2kg, falling gear fisheries 1201kg, and surrounding gear fisheries contribute 902kg. Delivered to the port/fishmeal factory. Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

5.3.2 Acidification Potential

The Acidification potential results from the LCIA for 1000kg trashfish, onboard vessel (see figure 12), show that Small trawl fisheries contribute the highest impact with 13kg SO_2-eq, Large trawlers 9kg SO_2-eq, falling gear 5kg SO_2-eq and Surrounding gear 4kg SO_2-eq.

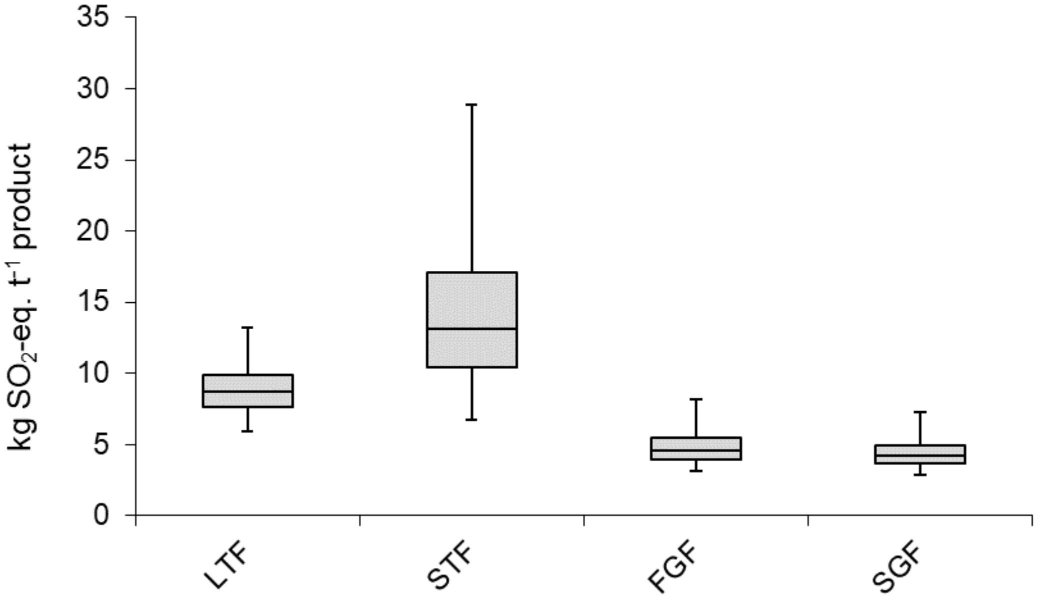

Figure 12. Sulphur dioxide equivalent (SO2-eq) emissions resulting from the process of fishing one tonne of trashfish, delivered to the port/fishmeal factory for each vessel/gear class. Box-and-whisker plot of the SO2-eq emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

Acidification results when contributions have been made, as shown in figure 13, indicate Large trawl fisheries contribute 15kg SO_2-eq, Small Trawl 1kg SO_2-eq, Falling gear 6kg SO_2-eq, and Surrounding gear contributing 4kg SO_2-eq to the overall produciton of 1000kg fishmeal.

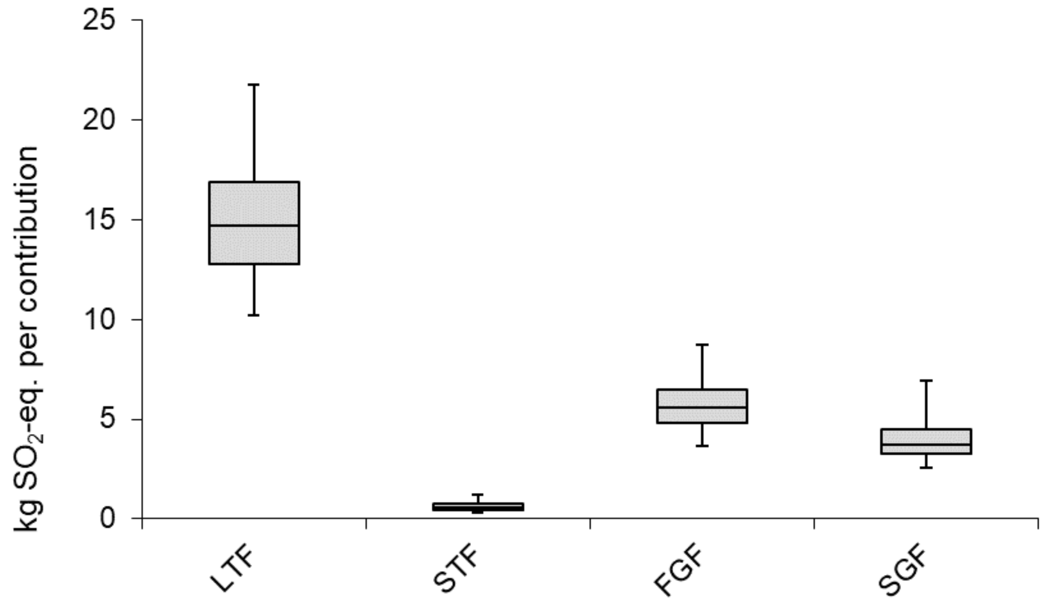

Figure 13. Sulphur dioxide equivalent (SO2-eq) emissions for 4 different gear types. Vessel class contributions (in kg of trashfish) have been included: Large trawl fisheries contribute 1693kg trashfish, small trawl fisheries contribute 44.2kg, falling gear fisheries contribute 1201kg, and surrounding gear fisheries contribute 902kg. Delivered to the port/fishmeal factory. Box-and-whisker plot of the $SO_{2\text{-}eq}$ emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

5.3.3 Photochemical oxidation potential

The Photochemical oxidation potential results from the LCIA for 1000kg trashfish, onboard vessel (see figure 14), indicate that Small trawlers had the highest Photochemical ocidation impact potential with 0.3 kg ethylene-eq, followed by Large trawls 0.19 kg ethylene-eq, Falling gear kg ethylene-eq, and Surrounding gear 0.1 kg ethylene-eq.

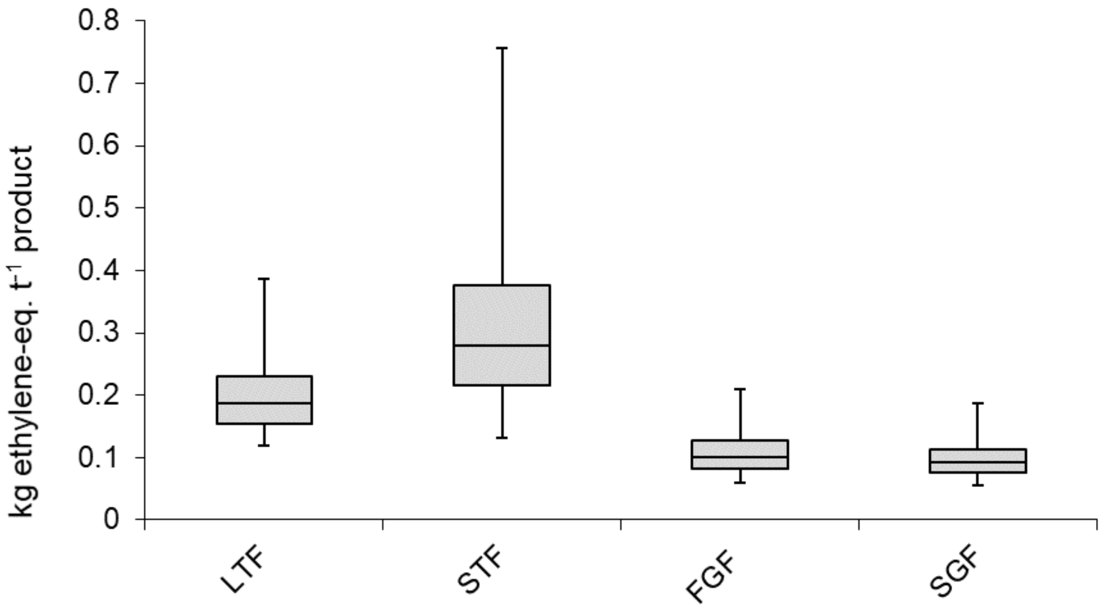

Figure 14. Ethylene equivalent emissions resulting from the process of fishing one tonne of trashfish, delivered to the port/fishmeal factory for each vessel/gear class. Box-and-whisker plot of the Ethylene equivalent emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

When weighted contributions have been made, the results show Large trawls contribute 0.31 kg ethylene-eq, Small trawls 0.01 kg ethylene-eq, Falling gear 0.12 kg ethylene-eq, and Surrounding gear contributing 0.08 kg ethylene-eq (figure 15).

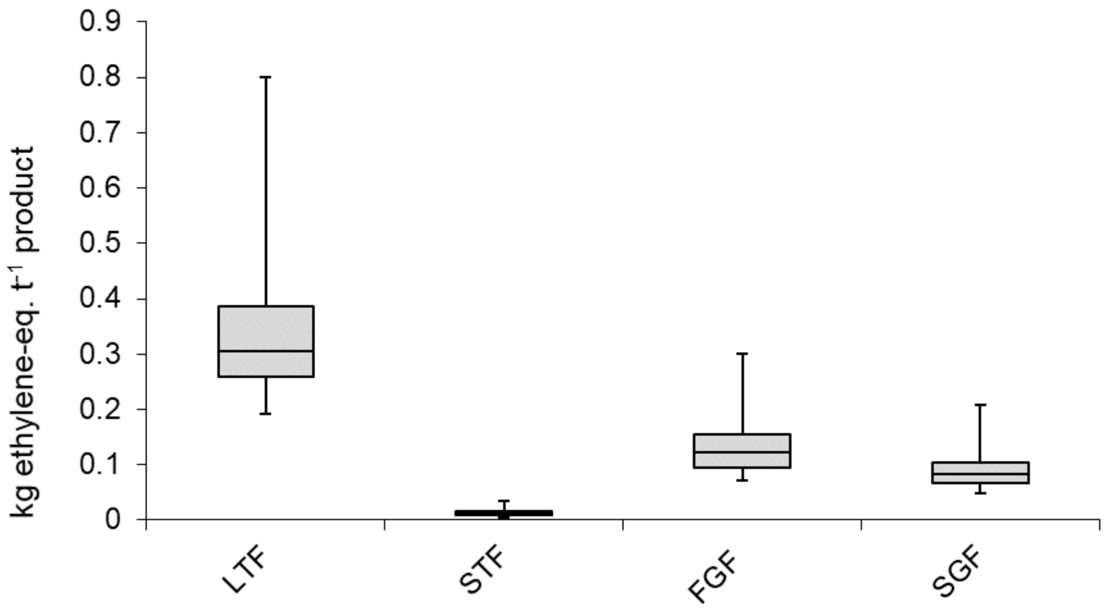

Figure 15. Ethylene equivalent emissions for 4 different gear types. Vessel class contributions (in kg of trashfish) have been included: Large trawl fisheries contribute 1693kg trashfish, small trawl fisheries contribute 44.2kg, falling gear fisheries contribute 1201kg, and surrounding gear fisheries contribute 902kg. Box-and-whisker plot of the Ethylene equivalent emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

5.3.4 Eutrophication potential

Eutrophication potential results for 1000kg of trashfish, onboard vessel, indicated in figure 16 show Small trawlers contribute the highest impact with 3 kg PO4 eq, followed by Large trawlers with 2 kg PO4 eq, and Falling gear and Surrounding gear being similar with 1 kg PO4 eq.

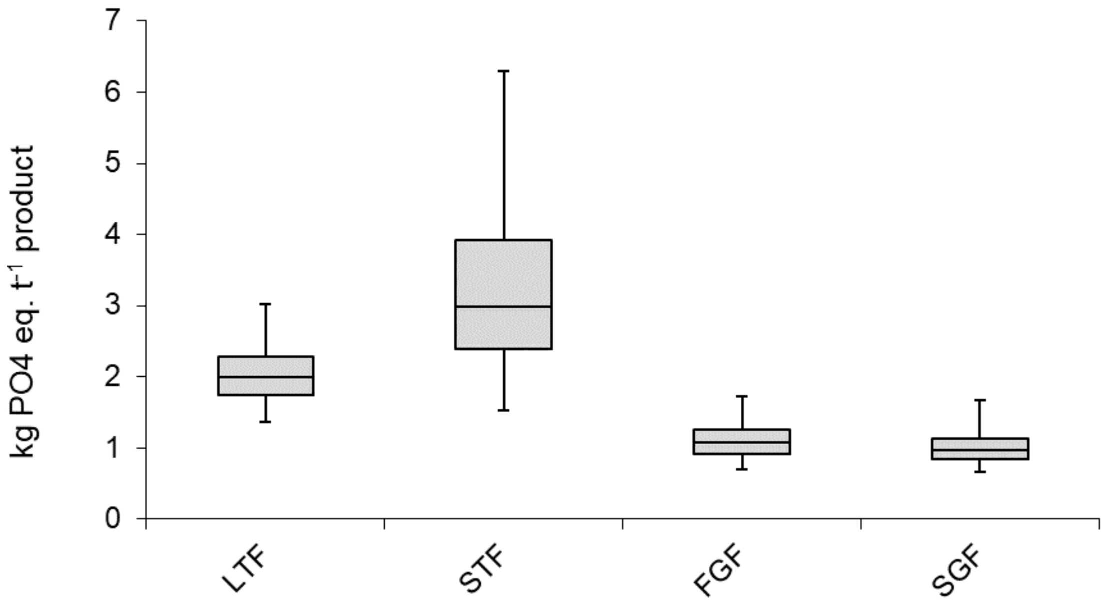

Figure 16. PO4 equivalent emissions resulting from the process of fishing one tonne of trashfish, delivered to the port/fishmeal factory for each vessel/gear class. Box-and-whisker plot of the PO4 equivalent emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

When weighted contributions have been made, the results show Large trawls contribute 1.49kg PO4 eq. Small trawls 0.021kg PO4 eq., Falling gear 0.372kg PO4 eq, and Surrounding gear contributing 0.08kg PO4 eq (Figure 17).

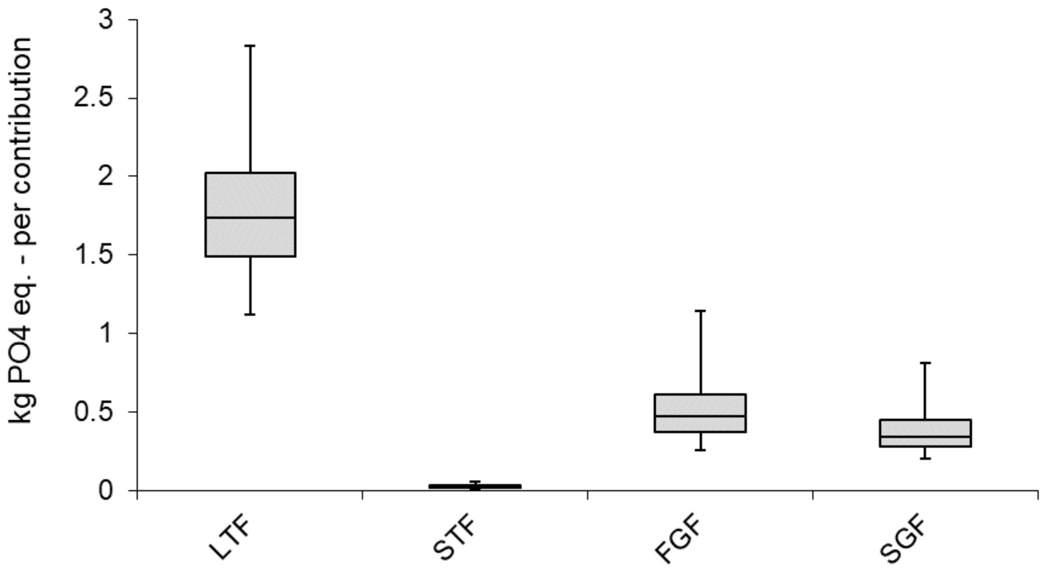

Figure 17. PO4 equivalent emissions for 4 different gear types. Vessel class contributions (in kg of trashfish) have been included: Large trawl fisheries contribute 1693kg trashfish, small trawl fisheries contribute 44.2kg, falling gear fisheries contribute 1201kg, and surrounding gear fisheries contribute 902kg. Box-and-whisker plot of the PO4 equivalent emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

5.4 Overall fisheries results

As figures 6 to 17 show, across all Impact category classes, the impact potential between different gear types is relativley the same. This is resulting from the combustion of diesel being the largest contributor to all impact categories that have been assessed in this LCIA, which is in line with findings from similar studies such as Tyedmers (2000), Troell et al. (2004), and Papatryphon et al. (2004).

6. LCA Discussion

6.1 Comparison with Peruvian and Danish fishmeals

It was touched upon at the start of this report that many LCAs conducted on Vietnamese aquaculture systems did not use fishmeal data specific to Vietnam. It was thus seen as important to conduct comparisons between the LCI data used in those reports, and the data from this present LCA. Below are the results of the contributional analysis for GWP of Peruvian, Danish and Vietnamese fishmeal production followed by Monte Carlo analysis for all impact categories assesed in this study.

6.1.2 Contributional analysis between countries

The results in figures 18-20 show that the fisheries sector in Vietnam (including middlemen transportation), contirbute 84% to GWP, whereas the fisheries sector in Peru and Denmark contribute 25% and 55%, respectively. The contributions that make up both a large proportion of Peruvian and Danish fishmeal is the natural gas used in the cooking process at the fishmeal plants (54% for Peru and 28% for Denmark). This is in strong contrast to the 3% contribution rice farming has, which is the fuel source for the cooking process of Vietnamese fishmeal.

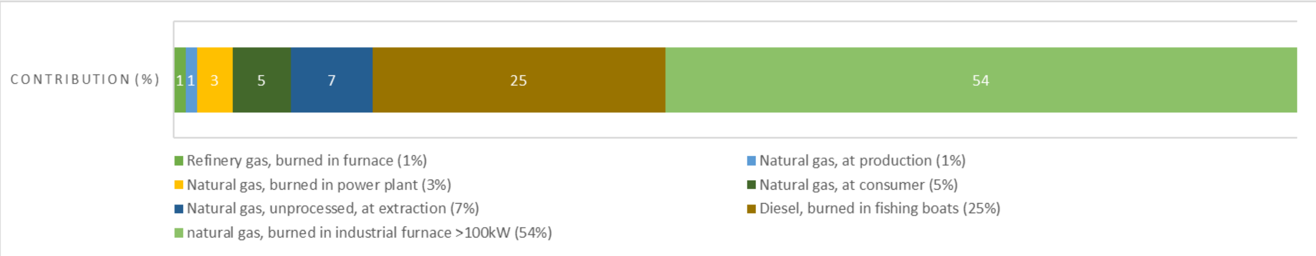

Figure 18. Peruvian fishmeal. Percentage contributions to GWP of 1000kg fishmeal. Made up of contributions from carbon dioxide and methane (fossil) emissions. Does not include the negative emissions effects from nitrogen oxide (-4%).

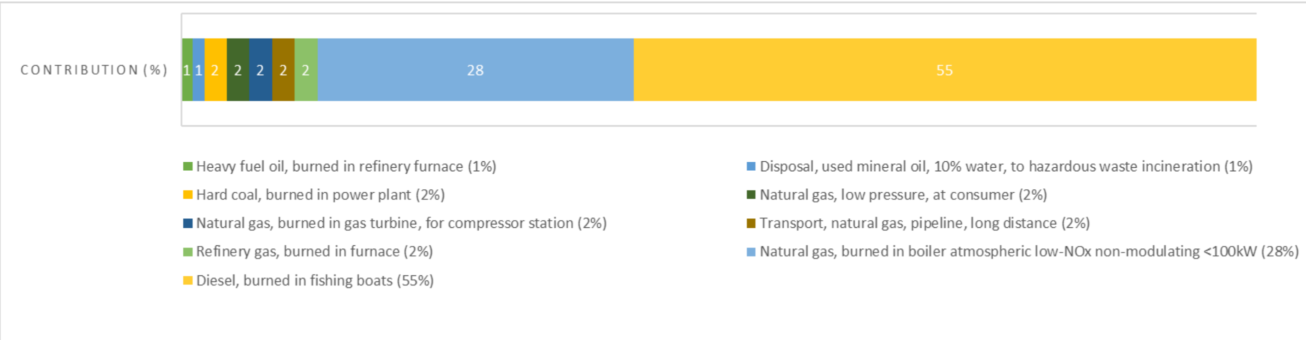

Figure 19. Danish fishmeal. Percentage GWP contributions to 1000kg fishmeal. Made up of contributions from carbon dioxide and methane (fossil) emissions. Does not include the negative emissions effects from nitrogen oxide (-8%).

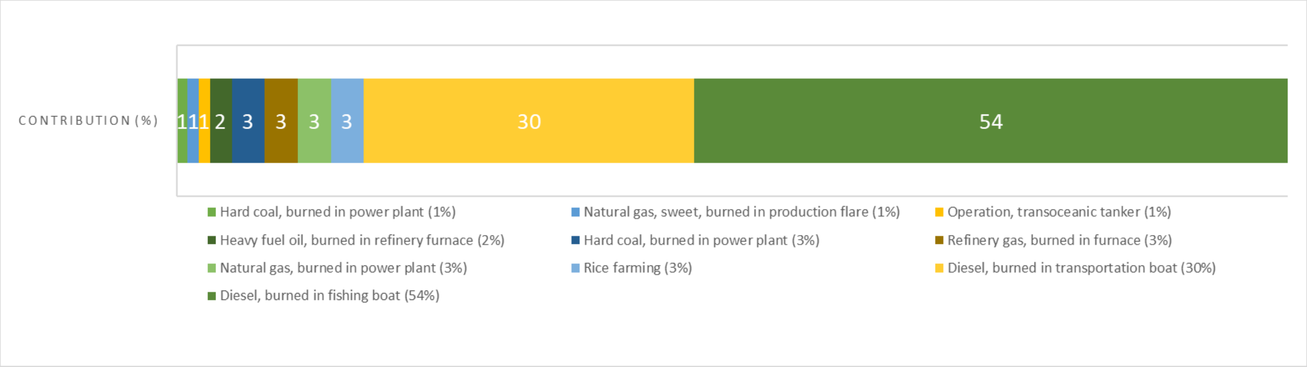

Figure 20. Vietnamese fishmeal. Percentage GWP contributions to 1000kg fishmeal. Made up of contributions from carbon dioxide, nitrogen oxides, and methane (biogenic) emissions. Does not include negative forcing emissions amounting to 13% from Nitrox oxides emissions to air from diesel burned in fishing boat (-8%), and diesel burned in transportation boat (-5%).

6.1.3 Country fishmeal comparison Monte Carlo results

6.1.3.1 Global Warming Potential

As figure 21 indicates, for the final product of 1 tonne of fishmeal, at plant, Vietnamese fishmeal has the highest GWP with 3,380 kg CO_2-eq, followed by Danish fishmeal contributing 1020 kg CO_2-eq, and Peruvian with the lowest GWP, contributing 717 kg CO_2-eq.

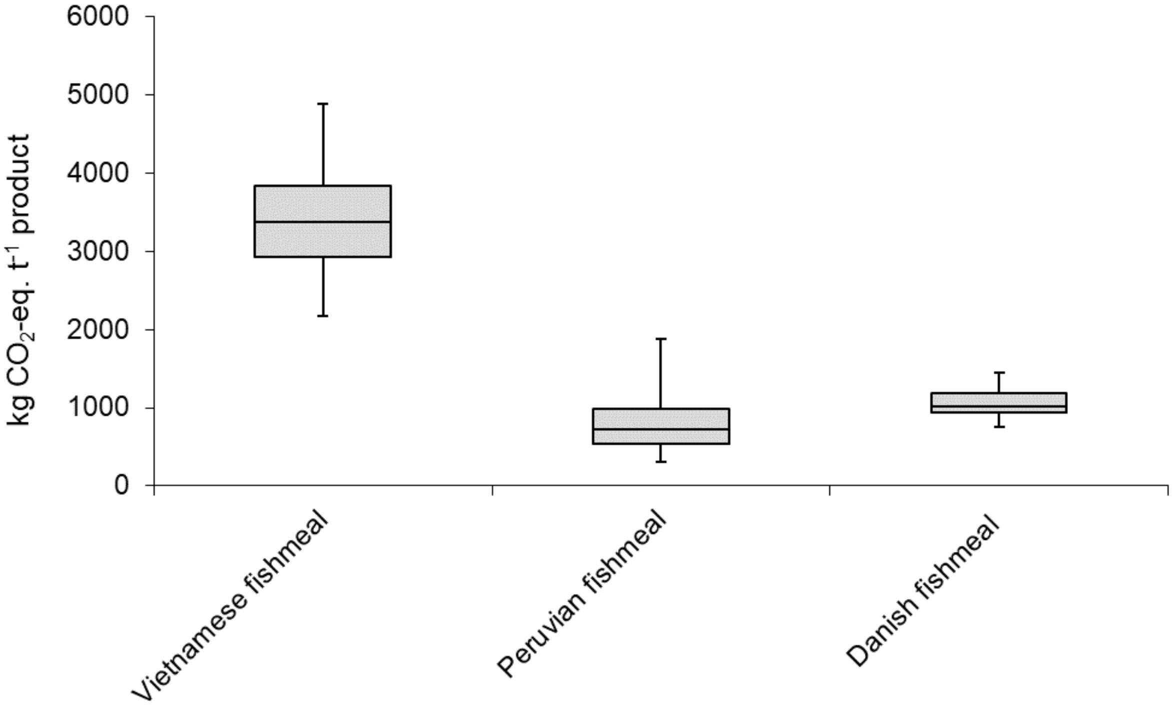

Figure 21. Greenhouse gas emission comparison for one tonne of 3 different country fishmeal's, at fish reduction plant. Vietnam N= 5, Peru N=1, Denmark N=1 (lcafood.dk). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10^{th} and 90^{th} percentiles (whiskers). Based on mass allocation.

6.1.3.2 Acidification Potential

As figure 22 indicates, for the final product of 1 tonne of fishmeal, at plant, Vietnamese fishmeal has the highest acidification potential with 26kg SO_2-eq, and Peruvian and Danish fishmeal both contributing 6kg kg SO_2-eq.

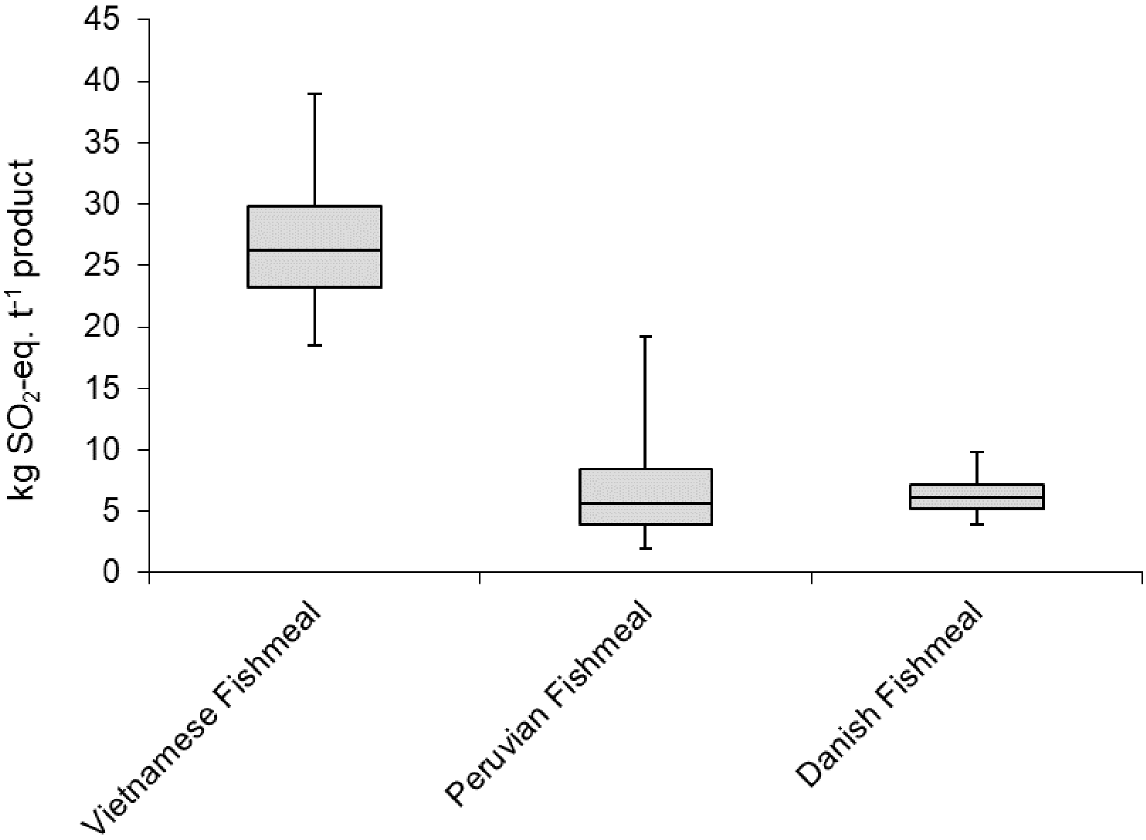

Figure 22. Sulphur dioxide equivalent (SO2-eq) emission comparison for one tonne of 3 different country fishmeal's, at fish reduction plant. Vietnam N= 5, Peru N=1, Denmark N=1 (lcafood.dk). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

6.1.3.3 Photochemical oxidation potential

The results for photochemical oxidation potential (see figure 23) show that 1000kg Vienamese fishmeal contributes 0.77kg ethylene-eq, followed by Peruvian fishmeal 0.22 ethylene-eq, and then Danish fishmeal with 0.17 ethylene-eq.

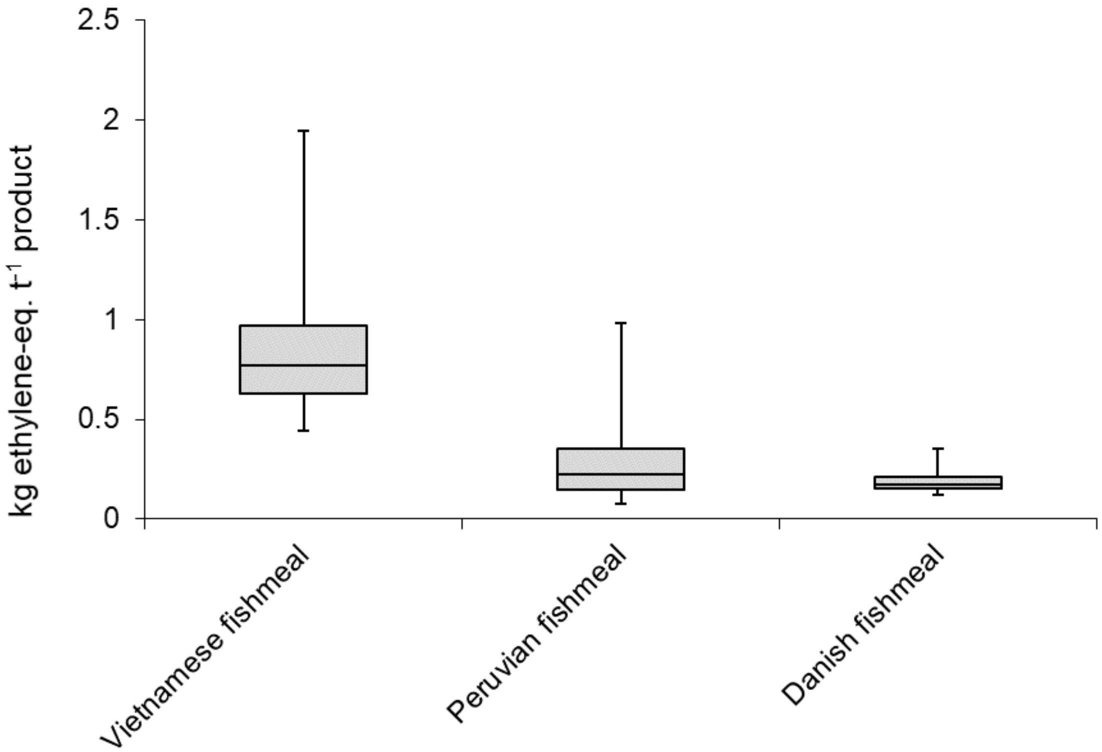

Figure 23. Ethylene equivalent emission comparison for one tonne of 3 different country fishmeal's, at fish reduction plant. Vietnam N= 5, Peru N=1, Denmark N=1 (lcafood.dk). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

6.1.3.4 Eutrophication Potential

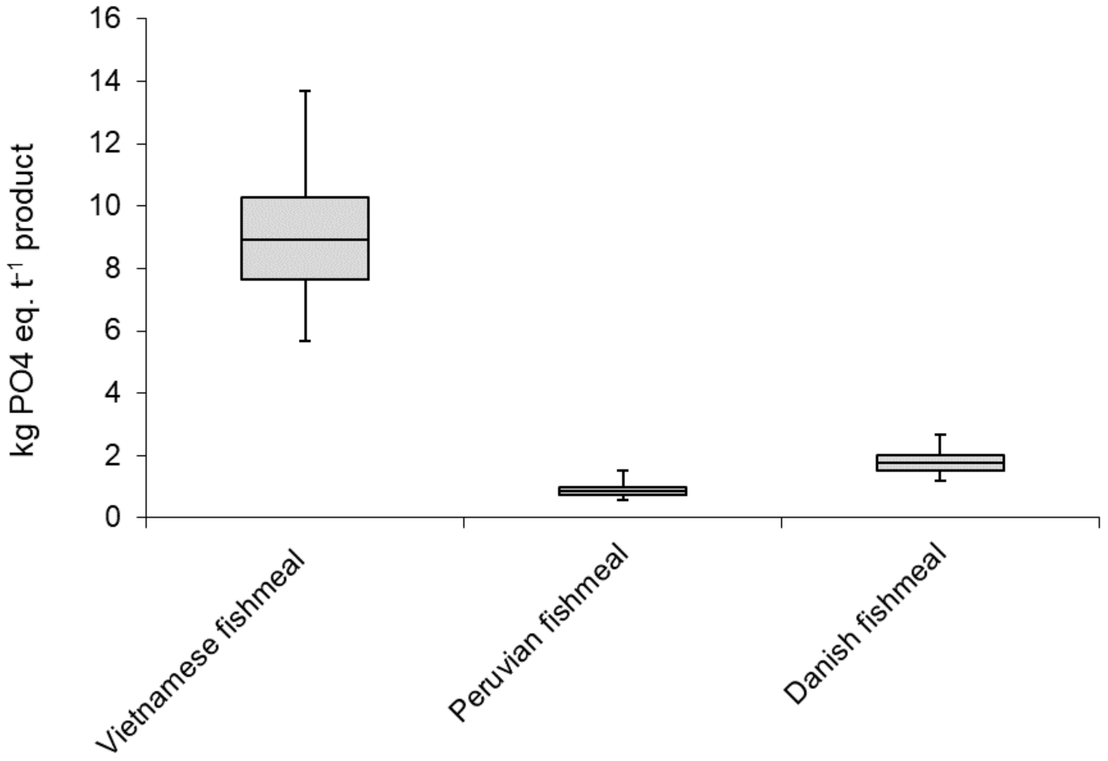

Figure 24. PO4 equivalent emission comparison for one tonne of 3 different country fishmeal's, at fish reduction plant. Vietnam N= 5, Peru N=1, Denmark N=1 (lcafood.dk). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on mass allocation.

These results indicate that during previous LCA studies, particularly on Vietnamese aquaculture systems, the environmental impact has been under-represented, due to using either Peruvian or Danish fishmeal data as a proxy for Vietnamese fishmeal. When looking at the GWP data as previously indicated in figure 21, aquaculture LCA studies that would use Peruvian fishmeal LCI data although assessing systems that would utilise Vietnamese fishmeal, the environmental impact would be underrepresented by up to 5x the GWP (717kg CO_2-eq instead of 3,380kg kg CO_2-eq).

6.2 Sensitivity analysis

6.2.1 consequential analysis

As indicated by interviews, a previous fuel source was coal for some plants, but due to the low cost of rice husk, and complaints from some neighbouring residents to certain fishmeal plants about air quality, all plants now use rice husk, an agricultural low-value by-product of rice farming. To understand the impacts this change may have had, a basic sensitivity analysis was undertaken to understand the consequences of using a different combustion fuel in the fishmeal cooking process.

As figure 25 shows, for the impact categories chosen in this study there was a marked decrease in percentage contribution impact for coal combustion compared to rice husk combustion when related to Eutrophication emissions (30.9% down to 3.4%) and Photochemical oxidisation (30% down to 12.5%). Upon further analysis, the contribution is due to the rice farming processes, in particular, the burning of rice straw as an agricultural waste on farms.

Both GWP and Acidification potentials remained relatively similar between fuel alternatives. Rice husk burning contributed 4.7% to GWP compared to 6.7% for coal combustion, and 4.9% to Acidification compared to 8.3% from burning of coal. This however could be explained to due the allocation method used (mass), and the way rice farming was modelled in the current LCA. It is also important to note at this point that further impact categories, such as a particulate matter impact category, would be advantageous for such comparisons between fuels; because clearly coal is not usually seen as the 'cleanest' combustion source (Demirbas, A. 2004).

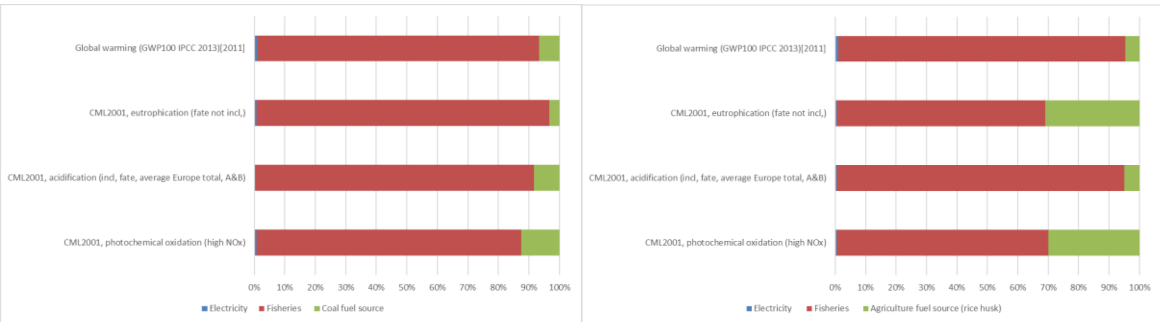

Figure 25. A simplified contribution graph showing key inputs to fishmeal production with coal substituted (left) with rice husk as a fuel source(right) for combustion during the cooking process. Fishery sector includes middlemen inputs.

6.2.2 Economical allocation

Economical allocation was also conducted for the GWP impact category to see how this changed the contribution between different vessel classes because they catch different quantities of various fish species with different economic value. To see the results of economical allocation of the other impact categories, please contact the author.

As the Monte Carlo results in figure 26 show, compared to mass allocation (figure 10), trawl fisheries with economic allocation for 1000kg trashfish on vessel have the greatest GWP of 555kg CO_2-eq, 71% more than Small trawls with 323kg CO_2-eq, followed by Falling gear with 211kg CO_2-eq and Surrounding gear with 205kg CO_2-eq. The economic allocation does not affect the relative differences between Falling gear or Surrounding gear compared to mass allocation (of note, actual CO_2-eq emissions are lower with economical allocaiton).

The reversal of greater GWP between large trawl fisheries when using economic allocation is due to the sheer volume of trashfish that the large trawlers catch, avg 473,208kg/year, compared to small trawlers catching, on average, 12,335kg/year.

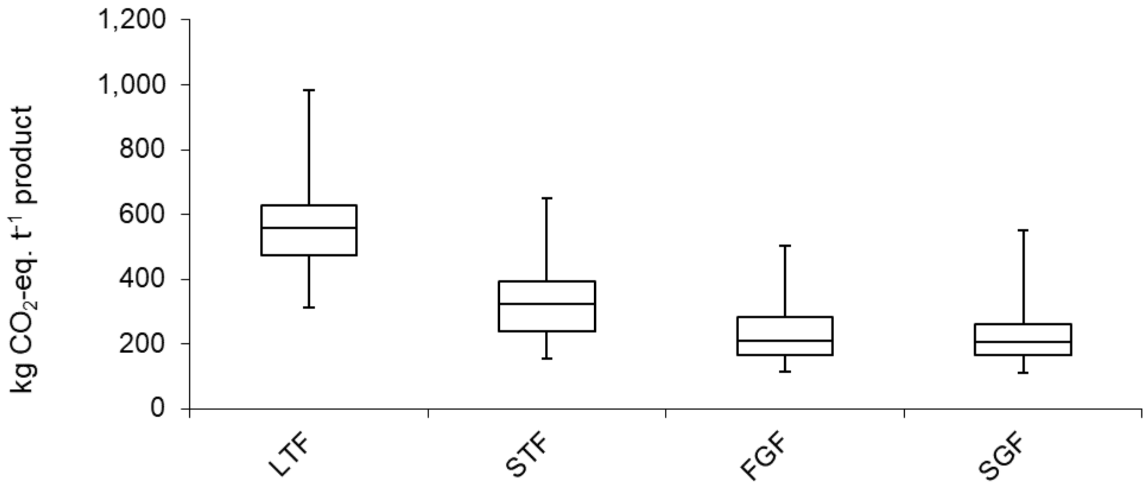

Figure 26. Greenhouse gas emissions resulting from the process of fishing one tonne of trashfish, delivered to the port/fishmeal factory for each vessel/gear class. Box-and-whisker plot of the GHG emissions associated with fish from large trawlers (N=12), Small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on Economical allocation.

When weighted economical allocation occurred, as is shown in figure 27, the relative differences between each vessel class remained the same as mass allocation, but as before the overall GWP is lower. For example, large trawlers under mass allocation have a GWP of 1,870 kg CO_2-eq, whereas under economic allocation they contribute half of that with 945 kg CO_2-eq (49.5% decrease).

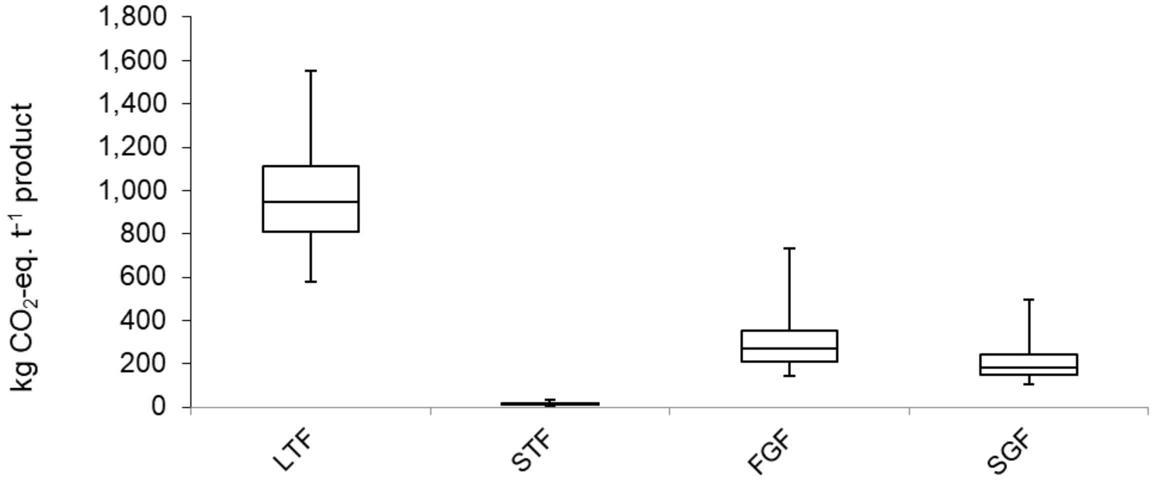

Figure 27. Greenhouse gas emissions for 4 different gear types. Vessel class contributions (in kg of trashfish) have been included: Large trawl fisheries contribute 1693kg trashfish, small trawl fisheries contribute 44.2kg, falling gear fisheries contribute 1201kg, and surrounding gear fisheries contribute 902kg. Delivered to the port/fishmeal factory. Box-and-whisker plot of the GHG emissions associated with fish from large trawlers (N=12), small trawlers (N=7), Falling gear vessels (N=6), and Surrounding gear vessels (N=3). Indicated are the median, the 25th percentile and the 75th percentile (box), and the 10th and 90th percentiles (whiskers). Based on economical allocation.

7. Findings and Analysis: Product Chain Organisation

The goal of using the PCO methodology in this report was to answer research question 1: 'Who and what are the main actors and drivers involved in the Vietnamese fish reduction industry and how are they organised?'

The identification and the analysis in this section of the report is based upon the interviews conducted whilst data collection for the LCA was undertaken. Supplementary understanding of the industry was gained in-between official interviews, with various occasions spending time with different industry actors related to the Vietnamese Fishmeal industry on an informal basis over 4 months in Vietnam.

The PCO provides an overview of the structure of the companies and actors that have been identified and are currently present around the fishmeal industry, and their influence/purpose. A diagram, shown in figure 28, has been created to represent different actors that have a role in different parts of the technical flow of the supply chain. The diagram is useful as a guide to refer to when reading the subsequent PCO section.

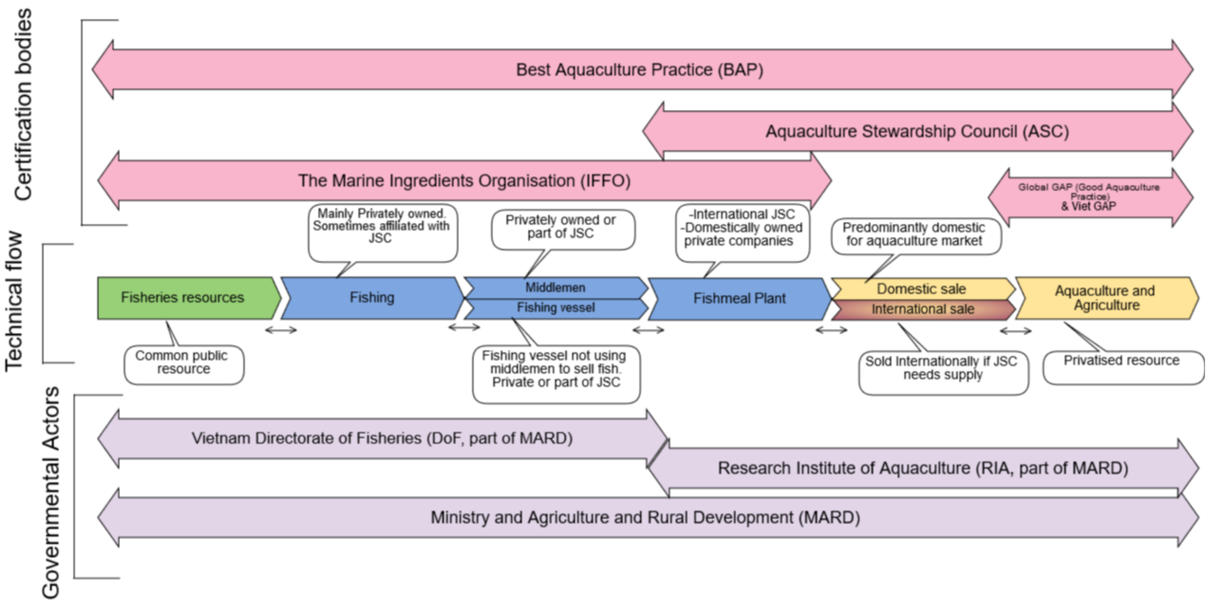

Figure 28. A diagram showing the actors that have been identified in this PCO study. The product flow after international sale is not included as it is out of scope of this report. The arrows between parts of the product chain indicate that there is a 'flow' of actor relationships between them that is dynamic. JSC=Joint Stock Company. Figure by author.

7.1 Relationship between actors

The main demand for fishmeal (mainly incorporated into aquafeed mixes) in Vietnam is the booming aquaculture sector, currently the fourth largest in the world (FAO, 2016). Although the scope of this report does not specifically deal with the aquaculture industry, it is still important to understand because it is what drives the environmental consequences that are identified within the LCA conducted. Thus, this exploration is seen as important for the applicability of this report as a useful document when in the context of trying to improve the environmental and socio-economic impacts of this industry.

Out of the 5 fishmeal plants interviewed, 1 company was solely Vietnamese owned, while the other 4 were Joint Stock Companies (JSC) with partners from either France, Korea, The Netherlands or Malaysia. Most domestic fishmeal produced at these companies stayed within Vietnam to supply the aquaculture industry; However, particularly for 1 of the companies, if demand for fishmeal was needed elsewhere in their company production process, such as aquafeed manufacture, the fishmeal would be sent overseas.

In many instances, the JSC's had substantial influence across the whole supply chain when dealing with fish reduction. 2 fishmeal companies interviewed had their own middlemen business or a transportation vessel (from herein will be called transportation vessel to avoid confusion) that acted in a similar way to the independently owned middlemen vessels. These transportation vessels owned by the JSC's often only collected from specific fishing vessels that they either owned or provide some sort of support/input to. This support may have been in the form of a loan for the buying of the fishing vessel by a captain or providing free maintenance of the vessel when needed. In return to the financial assistance from the JSC's, the fishing vessel is required to sell exclusively to that JSC.

In some cases, an independent middleman (not connected to an JSC) will have similar arrangements made with fishing vessels, whereby they have a verbal contract that they will be responsible for collecting the vessels catches. However, in many instances the vessel owners stated that if the middlemen vessel they had agreements with was not there to collect the catch, the would sell it to the first middlemen vessel to arrive to their vessel. This has resulted in many middlemen vessels actively following fishing vessels, so they can immediately take the landings.

Along with the verbal contracts between middlemen and fishermen, there was also instances of verbal agreements between fishmeal plants and middlemen. These verbal agreements are in place to ensure consistent supply of fish to the fishmeal plant and a set price for the fishing vessels fish. In 1 interview, the interviewee stated that they now exclusively receive fish from one middlemen owner (who owned multiple vessels), because the quality of the fish was much better compared to getting supplied fish in a haphazard way from other middlemen vessels or fishing vessels (resulting in a higher quality fishmeal).

Out of all the interviews conducted, none of these agreements where on paper-all were verbal, and most where deemed appropriate to break on occasion if one actor thought it appropriate. These verbal contracts also play an interesting role, as mentioned above, for the pricing of capture fisheries products and their prices; the subsequent tracking of the supply chain based on prices becomes difficult, as each verbal contract has its own agreements. This also relates to economical allocation methods in LCA, discussed elsewhere in this report.

To sum up this section, it can be seen that there are large actors at one end of the supply chain, usually in the form of a JSC, that in many instances has varying degrees of control over the whole fishmeal industry. These large JSCs can appear to have a large amount of power over the industry, but the involvement of independent middlemen still plays a crucial and large role in the collection and distribution of trashfish to the fishmeal plants, with many cases the middlemen being the important bridge between a good quality raw product for reduction-so with fishmeal plants aiming for a quality product, it is a necessity to use these middlemen services.

7.2 Certification Schemes

The role of certification bodies was identified by internet searches and via questioning interviewees about their ideas on the sustainability of the industry and if they were under any type of certification. It becomes clear in the coming paragraphs that sustainability schemes are present but have little impact on the fish reduction industry.

7.2.1 IFFO

The IFFO Responsibly Supply Assured (IFFO RS) is a Global Standard for the fishmeal and fish oil (FMFO) industry. Presently there is one fishmeal plant in Vietnam that has the IFFO RE certification for some or all their fishmeal products (https://www.iffors.com/statistics, date accessed: 27.05.2018). The certification is issued by Global Trust Certification Ltd and is validated through continual assessment. The key requirements for meeting the IFFO RS standard include:

- Eradication of Illegal, unregulated and unreported fishing material being used as IFFO RS approved raw material;
- Ensure that whole fish used in the production of marine ingredients are sourced from responsibly managed fisheries;
- Ensure the safe manufacture of marine ingredients; and
- To have effective traceability systems in place to ensure that the IFFO RS compliant marine ingredients can be traced back to the approved IFFO RS raw material fishery.

7.2.2 Best Aquaculture Practice

Along with IFFO RS, Best Aquaculture Practice (BAP) assesses the whole supply chain when it comes to aquaculture products, unlike some other certification schemes which just look at the final product (i.e. not about the sustainability/traceability of the aquaculture feed). At present official figures could not be obtained on how many products/companies have received BAP certification within Vietnam due to a membership profile being needed on the BAP website (https://bapcertification.org/CertifiedFacilities). However, judging from the interactive map available on their website with business locations under/undergoing BAP certification, it is around 80. With multiple aquaculture companies and products under BAP certification, then it can also be assumed that multiple FMFO plants that supply these aquaculture companies meet the BAP standards for responsible supply and sourcing of raw ingredients; However, this information could not be verified.

7.2.3 ASC, Global GAP and Viet GAP

Along with the above-mentioned certification schemes, present in Vietnam is also Aquaculture Stewardship Council (ASC), Global GAP (Good Aquaculture Practice), and Viet Gap. ASC, one of the world's largest certification schemes, works towards transforming aquaculture, using market mechanisms, into a environmentally sustainable and socially responsible industry along the supply chain. The global GAP and Viet GAP is more geared towards focusing on export markets in reassuring and promoting the Aquaculture sector, particularly regarding product safety, environmental impact, and the health, safety and welfare of workers and animals.

During data collection, it was asked whether a certification scheme was held by the vessel or fishmeal plants. From responses from fishing vessels, none were under certification, and only 1 interviewee knew what a certification scheme was; and out of fishmeal factories interviewed, 1 was under a certification scheme, but it was not related to the sustainable fishmeal production, only the food safety standards of the final product (HACCP certification) – all other fishmeal plants interviewed likewise did not know what certification was.

It is clear that certain certification schemes are around when it comes to the fish reduction sector (and its related industry), but from the findings in this PCO, it seems that they play a minimal role in the production of fishmeal-most actors have not heard of them or are not actively wanting certification if they do know of them. Moreover, it is interesting that the schemes identified do play a larger role in downstream processes from fishmeal production, such as aquaculture, even though this industry relies heavily on these fishmeal inputs.

7.3 Governmental Actors

There are various governmental bodies that have a relation to the Vietnamese Fishmeal industry and its related product chains. For this PCO data collection, it was identified that 3 governmental actors have the greatest influence/involvement within the fishmeal sector: mainly, The Ministry for Agriculture and Rural Development (MARD); The Department of Fisheries (under MARD) and; The Research Institute(s) for aquaculture (under MARD)(there are 3).

These governmental bodies are spread out through Vietnam with provincial, and district departments. The highest body is MARD, and it is responsible for the governance, promotion of both the aquaculture and agriculture industries in Vietnam and all that they encompass. MARD has 63 provincial department offices.

Of the departments under MARD which are key to the fish reduction industry are the Department of Fisheries and the Research institute for aquaculture. As their names suggest they are both responsible for their subsequent place in the product chain; however, the Research institute is not so much a law enforcement body, unlike MARD and the Department of Fisheries.

Further study is needed on the influence these actors have with regards to the sustainability of the industry, as the complex governmental bodies in Vietnam make this a difficult sector to map.

8. Discussion

8.1 Vessel gear types in use

With regards to the results obtained from the LCA conducted, it is clear Small trawl vessels (shrimp/otter trawlers) have a large energy consumption per kg fish landed in the terms of diesel burned (1.6kg diesel to 1kg trashfish), however the gear type is more selective in species compared to other fishing methods and catches less quantity. On average 27% trashfish per landing compared to 87% for Large trawlers.

It was thus important in this LCA that weighting of vessel class contributions was undertaken, because if only equal ratios from each vessel class where incorporated into the model, then Small trawl vessels would receive the greatest environmental impact – when in reality they play a relatively small role in the fish reduction industry compared to Large trawlers, Falling gear and Surrounding gear vessels, as indicated earlier in this report.

Another important factor that was common on all vessel classes assessed, was the mesh net sizes in use. Many interviews stated that mesh sizes have gradually been decreasing, with meshing "comparable to that of a mosquito net being used" (Vessel owner, pers com, 2017). This is clearly of concern as having mesh sizes this small effectively voids any selection of species that pass through the net. As evident from fishmeal plant visits, this un-selectivity is present in the trashfish that arrives in plastic bags-with many juvenile high value species being present in the bags.

Along with the current selectivity of species and sizes of species caused by mesh sizes chosen, according to Thong (2015), storage and haul times are too long, so fish initially suitable for human consumption is no longer suitable and eventually sold as trashfish to fishmeal plants. With the continued increased in price for trashfish, stemming particularly from aquaculture and fish sauce sector growth, it will be tough/difficult to curb these practices using such small mesh sizes (albeit it already does not comply with the Regional Guidelines for Responsible Fishing Operations in South East Asia set forth by the South East Asian Fisheries Development Centre, SEAFDEC in 1999) (Nguyen 2013).

A study conducted by Nguyen Xuan Thi et al., (2014) found that 35-48 percent of landings by trawl fisheries in Kien Giang are lost due to a loss of quality during the trawling process, which is resulting from improper handling practices and preservation methods of fish while at sea. Further elaboration in a report produced by Thong Ba Nguyen (Thong, 2015) also focusing on the Kien Giang fishing industry, contributes much of this loss due to trawling techniques, particularly the long duration of individual trawls: "the average duration of each trawling haul now is about 7-8 hours, therefore, the fish entering the net in the first couple of hours will be spoiled already once taken to the deck of the vessel (Thong, pers.comm., 15 September 2017).

8.2 Vietnamese fuel use compared to other key fisheries

As shown in table 6, the fuel use required to catch 1t of trashfish in Vietnam, 1t anchoveta in Peru 1t Sandeel in Denmark, and 1t global average for reduction fisheries, all of which have been used in the modelling of this reports LCA (besides the global average), have been compared to other capture fisheries around the world. It was deemed important to place the modelled Vietnamese trashfish industry fuel consumption into comparison with these other fisheries, considering many species that are utilised for reduction could also be used for direct human consumption. As mentioned earlier, the result for the Vietnamese fuel consumption has been gained with weighting of different vessel class contributions to the industry, so it will not represent the true fuel consumption. However, this result can be used as a baseline for comparison of fuel use data in the trashfish industry in coming years if the same vessel class weighting procedure is undertaken.

Table 6. Fuel use in litres for different fisheries. Sources: a: Primary data (2017); b: Danish lcafood database (2001); c: Avadí, Á et al. (2014); and d: Parker, R. W. et al. (2018)

Main fishery targets	Gear	Time frame	Location of fishery	Fuel use intensity (litres/tonne)
Vietnam trashfish average	Trawl, Otter, Surrounding, Falling	2017	SW & SE Vietnamese waters	333a
Danish Sand eel	Trawl	Early 2000's	North Sea	42b*
Peruvian anchoveta	Purse seine	2008-2010	SW Pacific	19c
Global average for reduction fisheries	Various	2018	Global	82d

*data are 20% lower than the national average due to the fishing season of data collection being exceptionally productive

8.3 Species used for fishmeal production-biodiversity implications

Unlike the fish reduction sectors in Peru or Denmark that utilise a single species of fish for reduction (anchoveta for Peru and sandeel for Denmark), the Vietnamese fish reduction industry relies on the supply of local trashfish, comprised of over 100 different species (please refer to appendix 2 for a complete list of species). These vessels have previously fished for the economical purpose of landing higher value mixed fish, such as squid, shrimp and octopus, while still catching trashfish as by-catch. However, interviews with fishermen in Son Doc, Cau

Mau province stated that they now have some vessels that exclusively fish for trashfish because they are more abundant, and prices have been increasing - landings of higher value species are seen as a bonus (Vessel owners, pers.comm., 2017).

It was a common response that catches have declined 50-70% over the past 20 years and catch composition has changed with an increase in trashfish in landings (due to overfishing of higher value species which are usually higher on the trophic level than the majority of trashfish species-resulting in less grazing pressure on trashfish). Furthermore, the vessel owners state that the decline in catches up to 70% has not been detrimental because the price of fish has increased substantially over that time. However, it is important to note that official Vietnamese fisheries catch statistics over that 20-year time period (1997-2017) have increased from 1315 thousand tonnes, to 3163 thousand tonnes (General Statistical Office of Vietnam, 2017) indicating a large increase of fishing effort or incorrect assessments gathered from interviewees.

8.4 Fishmeal reduction ratio

The fish to fishmeal ratio, 3.85:1 that was used in this report was based upon LCI data collection from five fishmeal plants. This ratio contrasts with some of the largest reduction plants in the world having larger ratios, such as the Danish TrippleNine plant, having a ratio of 4.66:1 (LCAfood database). A reason behind this may be that the Danish plant also produces 0.21g fish oil to 1kg fishmeal (0.21:1), whereas the Vietnamese plants do not separate the fish oil from the fishmeal. If calculations are made to incorporate the 0.21 fish oil into the fishmeal ratio, then the Danish ratio drops to 3.68:1. The same for these instances are also assumed to be likewise in the Peruvian sector, which is reaching the technical limit of 4.21:1 (Avadi, pers comm., 2017).

The reasons behind the worse fishmeal ratio in Vietnam, when compared to Denmark and Peru (when calculations have been made to incorporate fishmeal, as mentioned above), can be due to the type of species used for reduction, the quality of the fish (storage conditions), moisture content, and the machine type and operation procedures. Some fishmeal plant owners stated that they only clean the cooker once a year, and this is not only unhygienic but also would cause for a worse fish to fishmeal ratio due to a build-up of residues. Applying different management approaches, such as regular cleaning of fishmeal cookers/steamers during the production of fishmeal can thus be a viable, low cost mechanism of increasing the efficiency of fishmeal produced within Vietnam, in turn lowering environmental impacts.

8.5 Middlemen, sustainability and certification

The key role of middlemen in the Vietnamese fishing industry, with most fish bought and sold having a direct connection to them at some part of the supply chain to them, has many consequences for the sustainability and possible certification of parts of the fishing, fishmeal and further aquaculture industries.

This key role was explored more because during data collection for this thesis, Vietnam was given a “yellow card” by the European Commission, as a warning sign of Vietnam being identified as a “non-cooperating country with regards to illegal, unreported and unregulated (IUU) fishing practices” (European commission press release, Brussels, 23 October, 2017). This warning can put the focus on middlemen processes as they are a key factor in the industry and would have contributed to this yellow card being issued.

When the middlemen vessels collect fish landings from fishing vessels out at sea, they typically collect from 7-10 different vessels and the fish is then mixed together and then sold at the port or fishmeal factory. Based on own assumptions, this mixing of fish from different sources makes it virtually impossible to trace the source of fish, i.e. whether it has been caught using sustainable methods or not.

The middlemen in the Vietnamese industry clearly play a large role in the perpetuation and continuation of IUU practices due to the lack of traceability they create in the supply chain; and if this “yellow card” is to be withdrawn then the current business-as-usual approach will not be successful. However, instead of the middlemen being considered a hindrance with regards to the sustainability of the industry, they could potentially be a vessel for rapid, far reaching change in a more sustainable direction for Vietnamese fisheries and consequent food production systems (particularly aquaculture) that rely on such fisheries.

Clearly further research is needed to understand these dynamics within the industry, but if these middlemen where targeted regarding sustainability practices (such as incentives, possibly via certification, from only collecting fish from vessels that utilise good fishing practices), it could cause a dramatic shift due to them having such an ingrained role in the Vietnamese fisheries supply chain.

8.6 LCA and PCO as tools

Utilising both LCA and PCO methodologies allowed for complimentary analysis of the Vietnamese fishmeal industry. The LCA was a useful analytical tool for assessing a range of environmental interactions and the PCO allowed for the discovery of actor relations behind these technical flows. However with regards to the LCA, it does not cover all the environmental consequences with the production of fishmeal and author judgments have a large impact on the results. An example of this is the biodiversity indicator that is lacking within the current LCA conducted-due to lack of data the true environmental consequences are not fully incorporated or apprehended.

These weaknesses are important to be addressed within the current study, however, the value of conducting the LCA, with more qualitative discussion around such limitations still allows for it to be a useful tool as an indicator of the overall environmental impact of Vietnamese fishmeal production industry as there is such little knowledge around it presently.

8.7 Sources of error and limitations

Although most fishmeal plants in Vietnam are located within the Mekong Delta, there are other plants and associated fisheries in additional provinces of Vietnam that where not visited for this thesis. However, as fuel combustion in vessels was the largest contributor to LCA impact categories, it can be assumed the results would have been similar if time permitted for data collection of fishmeal plants in other provinces.

Many of the processes in the present study have also been retrieved from the Ecoinvent database which is predominantly based on European examples and production methods. Using this database in modelling clearly is not ideal, but as many other studies have used the same Ecoinvent data, perhaps it allows them to be more comparable because the uncertainty for that data is shared between studies.

Some of the practices described for different sectors of the value chain of this report could deviate from the common practice in Vietnam, or across the Mekong delta, due to practices differing on individual and provincial levels, such as fertiliser used in rice production. The reporting of these numbers by interviewees could also be incorrect due to pressure placed upon them from external or internal forces such as the Joint Stock Companies that are entwined with international interests.

9. Conclusions

- A change in gear types used could reduce the environmental impact by reducing fuel consumption by almost half.
- LCA impacts, particularly GWP are as much as 5x higher than previous studies used for Vietnamese Aquaculture LCAs (in relation to fishmeal inclusion)
- Middlemen should be used as a vector for certification schemes/sustainability improvements within the industry
- Further effort needs to be put in by local governmental departments on enforcement of sustainable fishery practices and record keeping

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Appendices

Appendix 1. Table of actors involved in the present study.

Actor	Function	Number of representatives	Location	Type of data collection	Type of contact	Data collection
Fishing vessel workers	Private actor	5	Ca Mau, Ben Tre, Rach Gia, Bac Lieu, Can Tho, Vietnam	Structured interview, dialogue & port visits	Meetings	Recording or notes
Fishing vessel owners	Private actor	5	Ca Mau, Rach Gia, Bac Lieu, Can Tho, Vietnam	Structured interview, dialogue and & port visits	Meetings	Recording and notes
Head of fisheries for Ca Mau province	Governmental body	1	Ca Mau, Vietnam	Structured interview	Meeting	Recording & notes
Fishmeal factory owners	Private actors	2	Ca Mau and Bac Lieu	Structured interview, factory visits	Meetings	Recording & notes
Fishmeal factory workers	Processor	8	Ca Mau and Bac Lieu	Dialogue	Meetings	notes
Fishmeal factory managers	Processor	5	Ca Mau and Bac Lieu	Structured interview	Meetings	Recording, notes
Fishmeal factory environmental technician	processor	1	Ca Mau	Structured interview and dialogue	Meeting	Recording, notes
'Middlemen'	Buyer/trader	3	Ca Mau, Bac lieu, Kiên Giang	Structured interview and dialog	Meetings	Recording or notes
Research Institute for Aquaculture No. 2	Governmental body	6	Vietnam, various locations	Dialogue,	Meetings & emails	Notes/publication data
Sustainable Fisheries Partnership	Non-profit	1	Vietnam	Dialogue	Emails	notes
Food and Agriculture Organisation	International organisation	1	Vietnam	Dialogue	Individual interaction	Notes/publication data

of the United Nations					and emails	
International Union for the Conservation of Nature (IUCN)	International organisation	2	Ho chi Minh City, Vietnam	Dialogue	Individual interaction	Notes
Nha Trang University	Educational institution	1	Nha Trang, Vietnam	Dialogue	Email	Notes/publication data

Appendix 2. List of fish species used for reduction in Vietnam. Table sourced from Edwards et al., (2004)

Scientific name	English name	Vietnamese name	Location
Mollusca	**Mollusc**	**Nhuyen the**	
Hyriopsis cumingii	Fresh water oyster	Trai nuoc ngot	C
Sanguinolaris diphos	?	Phi	C
Ostrea sp	Oyster	Hau	C
Pteria martensii	Penguin wing oyster	So giay	C
Bilaglobosa swatson	Golden snail	Oc vang	C
Pila polita	Apple snail	Oc buou	C
Loligo spp	Squid (small size, gut)	Muc (nho, ruot)	SW
Crustacea	**Crustacean**	**Giap xac**	
Penaeidea	Penaeid shrimp (small)	Tom nho	N, C
Calappa sp	Crab (small)	Cua nho	N, C, SW
Portunus spp	Swimming crab (small)	Ghe nho	N, C, SW
Echinodermata	**Echinoderms**	**Da gai**	
Holodeima spp	Lolly fish	Hai sam	C
Holothuria vagabunda	Black sea cucumber	Hai sam den	C
Diadema setosum	Black sea urchin	Cau gai den	C
	Marine fishes	**Ca bien**	
Rajiformes	**Order Rajiformes**	**Bo ca duoi**	
Dasyatis spp	Sting ray (gut)	Duoi (ruot)	SW
Clupeiformes	**Order clupeiformes**	**Bo ca trich**	
Stolephorus spp	Anchovy	Com	C, SW
Clupea leiogaster	Sardine	Trich	SW
Thrissa mystax	Moustached thryssa	Lep	C
Clupanodon spp	Gizzard shad	Moi	SW
Scopelifomes	**Order Scopeliformes**	**Bo ca den**	
Saurida spp	Lizard fish	Moi	N, C, SE
Anguilliformes	**Order Anguilliformes**	**Bo ca chinh**	
Muraenesox cinereus	Silver conger eel	Lat	C
Beloniformes	**Order Beloniformes**	**Bo ca kim**	
Hemirhamphus far	Half break	Kim bong	N, C
Cyselurus spp	Flying fish	Chuon	C, SW
Mugiliformes	**Order Mugiliformes**	**Bo ca doi**	
Shyraena jello	Giant sea pike	Nhong	SW
Perciformes	**Order Perciformes**	**Bo ca vuoc**	
Otholithes argentius	Croaker	Op	N
Johnius goma	Croaker	Uop	N, C, SW
Upeneus spp	Goat fish	Phen	N, SE
Siganus spp	Rabitfish	Dia	N
Decapterus spp	Scad	Nuc	N, C, SW
Scomber spp	Mackerel	Bac ma	SW
Rastrelliger brachisoma	Short-body mackerel	Ba thu	SW
Selaroides leptolepis	Yellow-stripe trevally	Chi	SW
Fomio niger	Black pomfret	Chim den (nho)	SW
Psenes indicus	Indian pomfret	Chim An Do	C
Priacanthus macracanthus	Red bigeye	Son thoc	SE
Leiognathus spp	Pony fish	Liet	C, SW

Appendix 3. Data collection example

Capture fisheries for Vietnamese fish reduction industry

Please complete the following survey to the best of your ability. If no exact number is known, then record the best-known estimate based on personal expertise, and please note down that it is an estimate.

All survey data will be held in confidence.

1. **Survey and interview details**

1.1 Survey details

Survey Number	Year of reference	Date collected
CF*:		

*Capture Fisheries

1.2 Port location:

Country	Area (District), Port name
Vietnam	

GPS Coordinates					
East			North		

1.3 Interviewee / manager / owner details:

Business name	
Role in business – e.g skipper	
Full name	
Tel. number / email	

1.4 Explanation of the company/business:

E.g. a brief description of size of the company, history, etc.

1.5 Fishing locations:
Most fished spots if multiple vessels are under question

GPS location		Distance from port	Unit	Days per year spent fishing this site	Number of trips to this site
East	North				

2. **Fishing practices and cost details***
   *Costings are to be conducted if time permits.
   2.1 Vessel Information

Vessel information		
	V1	V2
Vessel type (steel, wooden, etc.)		
Vessel length (m)		
Vessel width (m)		
Vessel height (m)		
Days spent fishing per year		
Year of purchase		
Price paid in VND		
Present value (VND)		
Expected life time (# of years)		
Expenditure on maintenance over lifetime (VND)		

2.2 Engine Information

Engine information		
	V1	V2
Type		
Power (HP)		
year of purchase		
price paid VND		
Present value VND		
expected life time (#years)		
expenditure on maintenance over lifetime		

2.3 Major equipment

Major equipment		
	V1	V2
Generators		
Fuel consumption/hour		
Fuel type		
Freezers		
Electricity consumption/hr (kWh)		
Electric winches		
Average number of uses per year		
Other Equipment:		
Other Equipment:		
Other Equipment:		

2.4 Gear and fishing effort

There are two sections (e.g V1, V1) to be used in the instance two different types of gears are implemented at different periods of fishing.

Please include 'Middlemen' sales in these numbers if necessary

***Gear* and fishing effort**				
	V1	V1	V2	V2
Item (e.g long line, otter trawl)				
Length/size of trawl/long lone etc				
Material				
Number of Hauls per day				
Time for individual haul (hr)				
Number of fishing days per trip				
Mean trip catch (kg)				
Discard at sea (kg)				
Number of trips per month				
Number of operating months per year				
Fishing effort (hrs / year)				
Total catch (kg / year)				

3. **Species caught and other catches**
   3.1 Type of species caught, including bycatch
   *To be conducted if time permits

Species	Quantity (kg/year)	Price (VND)*	By boat (V1, V2)
1)			
2)			
3)			
4)			
5)			
6)			
Unknown/unidentified species			
	Total:		

3.2 Type and quantity of plastic and other debris also collected when fishing

Plastic	Quantity (kg/year)	Collected by which gear type?	By boat (V1, V2)
1) Bottles			
2) Plastic bags			
3) Coral			
4) Sea weed/aquatic plants			
5)			
6)			

3.3 What is done with the plastic and other debris that is hauled in with fishing catches? e.g. returned overboard?

4. **Energy**
   4.1 Energy sources
   Average Energy source/year

Energy Source	Total	Units e.g litres a day / year.	Total price	Remarks
Diesel				
Gasoline				
Propane/LPG				
Coal				

4.2 Energy consumption
Average energy consumption rank

Consumption	Diesel	Petrol	Propane/LPG	
Fishing (e.g trawling)				
Travel to fishing grounds				
Generators				
Freezers				
Ice made on board				

5. Other inputs

5.1 Chemical inputs

Substance	Use	Quantity	Unit/year	Price VND
	Antifouling			
HCFC R22	Coolants			
'other' CFC's	Coolants			
Lubricants	Engine			
Engine oil	Engine			
Cleaning agents				
Paint				

5.2 Packaging /year

Material	Quantity	Unit	Price (VND)
Ice			
Containers (fish storage)			
Salt			
Plastic			

6. Sale of catch

Sales Type		unit
Time from landing to sale		
Intermediate cold/frozen storage?		
Distance to market		(km)
Time to market		
Time until middleman collection at sea		
Proportion of landings to feed production		(%)

7. Transportation

Purpose of transporting (e.g. from port to market)	Type of transport (e.g. lorry)	type of fuel used (diesel, etc)	Refrigerated? Yes/no	Distance (km)	Total price (local currency)
Port to fishmeal factory					
Port to market					
Port to storage					

8. Labour

	No.	Avg. h/day	Days/yr	Total price	Unit	Other benefits
Family members						
Full-time labour						
Part-time labour						

9. Disposal of by-catch and by-products: methods and costs description

10. What sort of trouble do you have with waste getting caught in your nets, how do you deal with this problem? E.g. plastic debris

11. **Does anything go towards waste management? E.g. is there anything dumbed over board during a trip? If so, what?**

12. **Processing of fish on board**
    Is there any processing of fish on board the vessel, such as beheading of shrimp before freezing?

More PCO oriented section

13. **What is your perception on the status/condition of your fishing ground(s)?**

14. **From your local expertise, what do you believe are areas within this fishery that could be improved to decrease environmental impact?**

15. **Who do you trade with/who are your buyers? E.g. Do you have any written or verbal agreements with middlemen or fishmeal companies to which you supply your trash fish, if so, what do they entail?**

16. Are you under any sustainability certification schemes or are the people that you supply fish to under these schemes? For example, do you, or are you trying to meet the requirements of IFFO RS (International fish-meal fish-oil organisation) assured standards? Please explain.

17. Do you actively record/report your catch data? if so, who do you supply this information too and what is it for?

18. What is your understanding over sustainability for fisheries and what issues do you see as important regarding the sustainability of your fishing industry?

19. What have been some sustainability measures taken, or put upon you (E.g. by government legislation or certification standards) since you have been fishing? What do you see as future sustainability measures which might be implemented in the industry?

20. How do your catches change during different times of the year?

21. Additional Comments

Thank you for helping to complete this survey,

Charles Horsnell

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