FAO Fisheries and Aquaculture Circular No. 1044 FIE/C1044 (En)

ISSN 2070-6065

LIFE CYCLE ASSESSMENT OF SOUTHERN PINK SHRIMP PRODUCTS FROM SENEGAL

An environmental comparison between artisanal fisheries in the Casamance region and a trawl fishery based in Dakar

Copies of FAO publications can be requested from:
Sales and Marketing Group
Communication Division
FAO
Viale delle Terme di Caracalla
00153 Rome, Italy
E-mail: publications-sales@fao.org
Fax: (+39) 06 57053360
Web site: http://www.fao.org

FAO Fisheries and Aquaculture Circular No. 1044 FIE/C1044 (En)

LIFE CYCLE ASSESSMENT OF SOUTHERN PINK SHRIMP PRODUCTS FROM SENEGAL

An environmental comparison between artisanal fisheries in the Casamance region and a trawl fishery based in Dakar

by

Friederike Ziegler
Swedish Institute for Food and Biotechnology
Gothenburg, Sweden

John Lucas Eichelsheim
Intervenir pour le développement écologique de l’environnement en Casamance
Ziguinchor, Senegal

Andreas Emanuelsson
Swedish Institute for Food and Biotechnology
Gothenburg, Sweden

Anna Flysjö
Swedish Institute for Food and Biotechnology
Gothenburg, Sweden

Vaque Ndiaye
Centre de recherches océanographiques de Dakar-Thiaroye
Dakar, Sénégal

Mikkel Thrane
Aalborg University
Aalborg, Denmark

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2009

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of FAO.

ISBN 978-92-5-106302-6

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders. Applications for such permission should be addressed to:
Chief
Electronic Publishing Policy and Support Branch
Communication Division
FAO
Viale delle Terme di Caracalla, 00153 Rome, Italy
or by e-mail to:
copyright@fao.org

© FAO 2009

PREPARATION OF THIS DOCUMENT

This FAO Fisheries Circular is based on a study carried out as a collaboration between the Fisheries and Aquaculture Department at the Food and Agriculture Organization of the United Nations (FAO), the Swedish Board of Fisheries, the Swedish Institute for Food and Biotechnology (SIK), Intervenir pour le développement écologique de l’environnement en Casamance (IDEE Casamance) and Centre de recherches océanographiques de Dakar-Thiaroye (CRODT).

The main aim of the study was to quantify the environmental impacts caused by a Senegalese shrimp product from fishing to market by performing a life cycle assessment (LCA) of the artisanal fishery for southern pink shrimp in the Casamance region. Secondary aims were to compare the different fishing methods (artisanal and industrial) from an environmental point of view.

This circular was prepared by Ms Friederike Ziegler (Swedish Institute for Food and Biotechnology), Mr John Lucas Eichelsheim (IDEE Casamance), Mr Andreas Emanuelsson (Swedish Institute for Food and Biotechnology), Ms Anna Flysjö (Swedish Institute for Food and Biotechnology), Mr Vaque Ndiaye (Centre de recherches océanographiques de Dakar-Thiaroye) and Mr Mikkel Thrane (Aalborg University).

Support for the study has been provided through the Swedish International Development Cooperation Agency (Sida)-funded FAO FishCode TECPRO Project and the Swedish Board of Fisheries.

Ziegler, F.; Eichelsheim, J.L.; Emanuelsson, A.; Flysjö, A.; Ndiaye, V.; Thrane, M.
Life cycle assessment of southern pink shrimp products from Senegal. An environmental comparison between artisanal fisheries in the Casamance region and a trawl fishery based in Dakar.
*FAO Fisheries and Aquaculture Circula*r. No. 1044. Rome, FAO. 2009. 29p.

ABSTRACT

Life cycle assessment (LCA) of two Senegalese seafood products exported to Europe has been undertaken based on the functional unit of one kilogram of product (frozen whole shrimps, independent of size) plus the accompanying packaging at the point of import to Europe, i.e. transported by boat to Vigo, Spain. The products are exchangeable on the European market, but the way they reach this market from the fishery over processing is very different. One product is produced through on-board processing on demersal trawlers based in Dakar fishing at sea in FAO fishing zone 34 (eastern central Atlantic), then landed and stored before being exported to Europe. The other product originates in artisanal fisheries in the Casamance River in southern Senegal. Fishing takes place to similar extents by the two fishing methods: Mujas, a fixed trawl set in the deepest part of the river from a canoe, and Félé-félé, a type of driftnet managed by three men in a canoe. The shrimps are landed and transported to a processing plant in Ziguinchor where they are washed, packed and frozen before land transportation to Dakar, storage and finally shipment to Europe. The three fisheries included (trawl, Mujas and Félé-félé) were shown to have highly different catch compositions. Each fishing method has advantages and drawbacks from a biological point of view, i.e. proportion of discard, landed bycatch and small shrimps in the catch. LCA results showed major differences between the two final products, with regard to resource use and environmental impact, depending on their origin. For the product originating in trawling, fishing was the most important activity in all categories of environmental impact. For the product originating in the artisanal fishery, fishing was the most important activity from a biological point of view. In contrast, processing and storage dominated the two categories: global warming and ozone depletion potential. The main areas to improve regarding these categories in the production chain of the trawled product are the use of fuel and refrigerants on board, while the main areas for improvement in the chain of the artisanal product are the use of energy and refrigerants in the processing plant and the energy source used by the plant. Both on board the trawlers and in the mainland processing of artisanal shrimps, considerable amounts of refrigerants with a high global warming and ozone depletion potential are used to freeze the shrimp products. In both chains, transportation was found to be of minor importance. Increased traceability and labelling is also desirable to enable active consumer choices between products.

CONTENTS

Page

FIGURES

TABLES

ACKNOWLEDGEMENTS

We would like to thank IDEE Casamance and CRODT and their staff who were involved in the study for all their help with the data collection. Likewise, numerous anonymous sources have been most helpful providing us with data including fishermen, government officials, fishing vessel owners, staff at the processing plant and many more. We would also like to thank the Swedish Board of Fisheries and the FAO Fisheries and Aquaculture Department for taking the initiative to this project and the Swedish International Development Cooperation Agency (Sida) for funding the work.

ACRONYMS AND ABBREVIATIONS

CPUE	catch per unit of effort
CRODT	centre de recherches oceanographiques Dakar-Thiaroye
EPD	environmental product declaration
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
IPCC	UN Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	life cycle analysis
LPUE	landings per unit of effort
Sida	the Swedish International Development Cooperation Agency
SIK	Swedish Institute for Food and Biotechnology
UNEP	United Nations Environment Programme

1. INTRODUCTION

1.1 The area

The Casamance is the southernmost region of Senegal located north of Guinea-Bissau and south of Gambia in West Africa (Figure 1). The Casamance River, 250 km long, is a rich source of aquatic resources providing the basis for the livelihood of local communities along the river. The capital of the region, Ziguinchor, is located along the river 75 km from the coast. The Casamance River is a hypersaline estuary, as the freshwater inflow is less than the loss through evaporation, salinity becomes higher than in the sea. Up to 1969 the estuary of the Casamance was only very slightly hypersaline (40‰ in June, at 80 km from the mouth). But where salinity did not exceed 1‰ in 1969, it reached 70‰ in 1984. At the end of the 1986 dry season salinity reached 170‰ at a location 220 km from the sea. In the dry season, the deficit of freshwater plus high evaporation leads to the formation of a salt plume which travels upstream, like a piston, at a speed of 0.1 to 0.5 cm/s. (FAO, 1995)

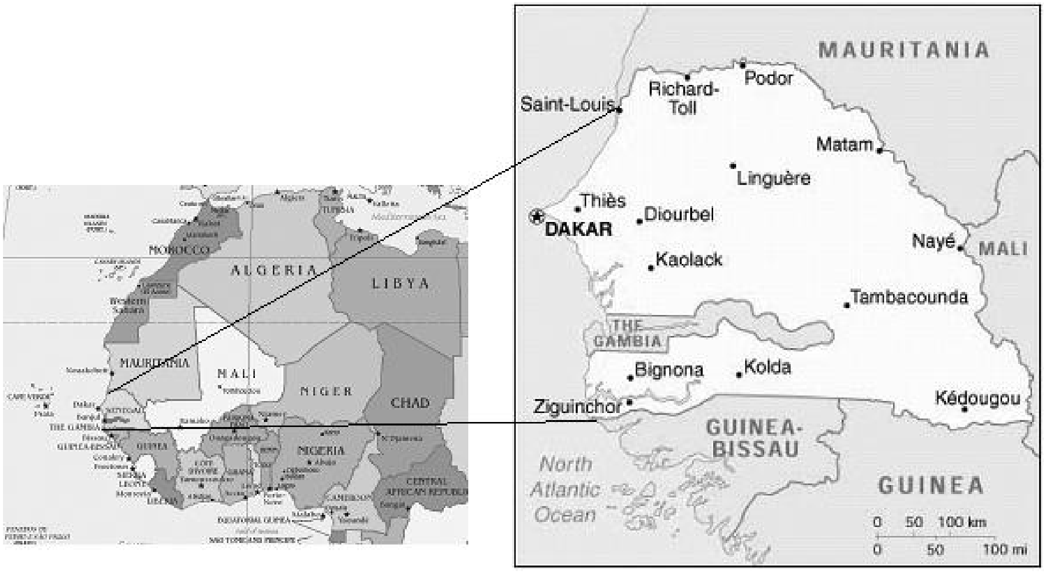

Figure 1*:* Location of Ziguinchor along the Casamance River in southern Senegal

1.2 The shrimp

The southern pink shrimp (*Penaeus notialis*) occurs in estuaries and coastal waters of West Africa from Mauritania to Angola, where it inhabits muddy sand bottoms at depths ranging from 2–100 m. The shrimp stock occurring in the Casamance estuary has its spawning grounds in the sea off the coast of Senegal and Guinea-Bissau. After hatching and metamorphosis to various larval stages in the sea, juveniles migrate upstream in shallow areas of the river to feed and grow in the nutrient-rich mangrove areas that are found along the entire river. Three months later, adult shrimps migrate back to the sea in the central and deepest part of the river to spawn (Garcia and Le Reste, 1981; L'Homme and Garcia, 1984**).** While the fishery takes place all year round, landings peak in September-November after the rainy season (June to September). Salinity in the river is due to high evaporation especially in the shallow areas and is a limiting factor for spawning. This pattern has changed over time as salinity has increased due to an increasingly dry climate since the 1960s. Previously the shrimps spawned when salinity peaked; now spawning occurs when salinity is relatively low (Le Reste, 1995). It seems that the shrimps manage two spawning cycles before the salinity increases too much, as there is a second, smaller, peak in the fishery in February-March.

1.3 The two shrimp fisheries

1.3.1 The Casamance fishery

Traditionally shrimp fisheries in the Casamance have been undertaken for subsistence purposes only, deploying moderately efficient fishing methods and regulation between fishing villages initiated by the local population (IDEE Casamance, 2007). Around 90 fishing villages and 6–8 000 fishermen and their families depending on the shrimp fishery are located along the Casamance River (IDEE Casamance, 2007) as well as a number of employees at the processing plants (perhaps 100). During the last decades, the number of fishermen has grown as many people have moved from inland areas, both from within Senegal but also from neighbouring countries, to the river and started to fish. Fishing pressure, therefore, has probably increased during this period Due to the short life cycle and migration pattern of the shrimps, the two fisheries (the fishery at sea described further below and the artisanal fishery in the Casamance) are exploiting the same stock but in different parts of its life cycle and, hence, are connected. No estimates of catch per unit of effort (CPUE) in the Casamance fisheries have been documented so far. However, CPUE at sea, i.e. in the trawl fishery, decreased by over 90 percent between 1970 and 2005 (UNEP, 2002; Anon 2007)

There are mainly two artisanal fishing methods in use today (Figure 2):

1. **Félé-félé.** Nets used in intermediate parts of the river, around 120 m long and 1–2 m deep with 12 mm meshes (24 mm when stretched), trailed by canoes and actively managed by three men.
2. **Mujas**. Pairs of filtering trawl-like nets placed by one man on each side of an anchored canoe in the deepest part of the river during low tide, i.e. the fishery is powered by the tidal current that brings the large shrimps migrating towards the sea.

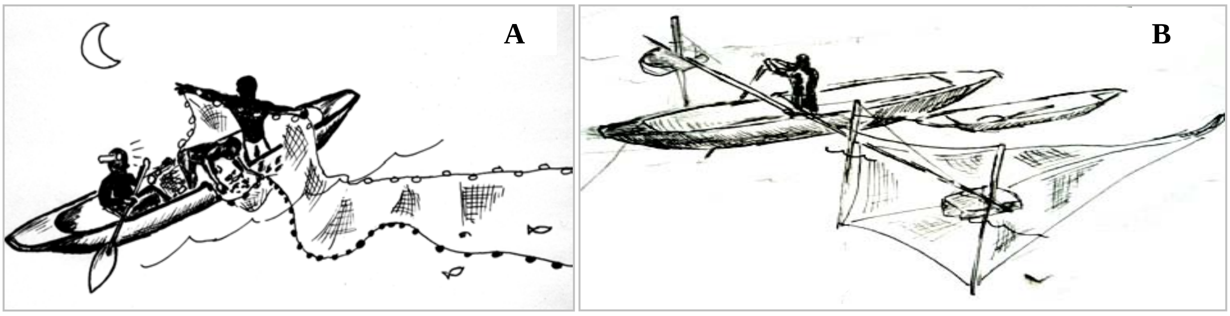

Figure 2*:* The two most common artisanal fishing methods in the Casamance: a) Féle-félé and b) Mujas nets (moudiasse). Sketches by Andreas Emanuelsson.

A type of beach seines, **Xuus** nets, are also used in shallow areas, but these represent only a small part of total catches and were therefore not included in the present study. As reliable data on the distribution between the two gear types with regard to landings is currently not available, the study is based on the assumption that Félé-félé and Mujas account for equal quantities with regard to total landings, i.e. including both fish and shrimps.

Reported landings in the Casamance varied between 800 and 1 200 tonnes between 2000 and 2006 (IDEE Casamance, 2007). Total artisanal pink shrimp landings (including the Casamance region) represent on average 60 percent of total pink shrimp landings in Senegal which varied between 2 500 and 3 600 tonnes between 2004 and 2006. Consequently, around 40 percent, or 1 100-1 600 tonnes are fished in the trawl fishery described below (DPCA, Diarra Dioup, unpublished data**).**

The shrimp fishery in the Casamance is theoretically regulated by a system of fishing permits, by a minimum stretched mesh size of 24 mm and by a ban on pull nets and the capture, possession and trading of shrimps smaller than caliber 8 (i.e. >200 individuals/kg). This ban on landing small shrimps indirectly gives a minimum legal size. In addition, and perhaps more importantly, an unofficial traditional system of respecting each other's fishing zones and rules exists between villages. This system has in part been put aside, with the growing number of fishermen moving to the area and introducing new gear types. Some overlap exists with regard to what parts of the river are used by the different gear types which causes some conflict.

1.3.2 The Dakar fishery

The Dakar-based fisheries are more large-scale. Vessels are diesel-driven and demersal trawls are used by the around 30 trawlers active in this fishery. The boats go out to fish during so called “mares”, i.e. months. During a mare, a boat is out fishing for about 25 days. Fishing goes on all year, so a vessel can make around 10 mares a year. Most vessels are owned by foreign, European, companies.

A trawler employs around 10 people so altogether the trawl fishery occupies around 300 crew members. As stated earlier the trawl fishery lands about 40 percent of the shrimps landed in Senegal. The minimum legal mesh size in the trawl fishery is 50 mm, but most of the shrimps are caught with a mesh size of 60 mm. The entry to the fishery is limited as trawlers need to hold a licence but there are no limitations for those licensed in terms of catches or effort. There is also a spatial regulation allowing larger trawlers to trawl outside six nautical miles from the coast. Due to the decreasing catch per unit effort since the 1970s mentioned above, a discussion about decreasing the number of licences is ongoing.

2. OBJECTIVE OF THE STUDY

The main aim of the present study was to quantify the environmental impacts caused by a Senegalese shrimp product from fishing to market by performing a life cycle assessment (LCA) of the artisanal fishery for southern pink shrimp in the Casamance region. Secondary aims were to compare the different fishing methods (artisanal and industrial) from an environmental point of view. Biological effects of the different fishing methods were included in the analysis and an additional goal was to attempt to quantify a few socio-economic indicators.

3. LCA – GENERAL METHODOLOGY

LCA is an environmental assessment tool to quantify environmental impact throughout the entire life cycle of a product or process. The life cycle of a product means from raw material extraction over production, transportation and use phases to waste treatment (Figure 3). The method was originally developed to assess industrial production systems in the 1960s and has not until the 1990s been applied to food production systems. Since then, however, the number of researchers in this field and the number of published case studies has grown quickly which has led to development of the methodology to cover types of environmental impact that are typical for food production such as land use and biodiversity. LCA studies can both be carried out as research projects in which case purposes can include mapping the overall environmental impact of a product and showing which activities are important and which are not (from a purely environmental point of view). Improvement options are always identified. In some cases two alternative products are compared with regard to environmental impact and customers on any level can in such cases use LCA results to make a conscious choice of what to buy. The outcome of research projects is generally published and will hence get more or less widely spread. Many LCAs are also carried out as consultancies in which case the commissioner decides how results are used. Companies can use LCAs internally to improve their own environmental performance (i.e. decrease use of energy or water, change the type of energy, refrigerant or packaging material used) or to make sure their sourcing strategy for raw materials is an environmentally sound one. Another situation when doing an LCA is wise is before planned changes are implemented (e.g. a change of raw material, recipe, packaging material, energy source etc.) since it will tell whether the change, in a life-cycle perspective is a sound on or not. This applies also to authorities in charge of environment since many of their (financial and other) ways to support certain types of production will have environmental consequences, negative consequences if the wrong type of production is supported. A company that has done an LCA can also use the results to communicate the environmental performance to its customers, either by qualitative or quantitative statements.

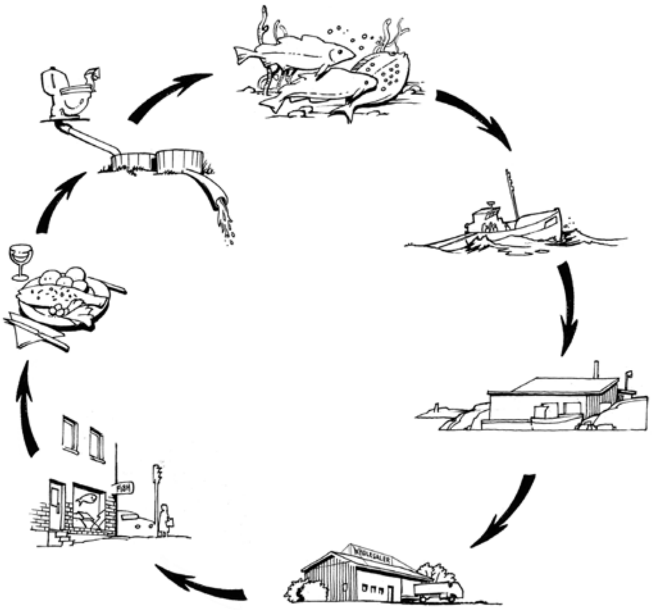

Figure 3*:* The life cycle of a seafood product

LCA methodology is standardized by ISO (ISO, 2006a; ISO, 2006b) in the ISO 14040 series. A related standard, ISO 14025, concerns environmental product declarations (EPDs) which is one way to communicate environmental performance by providing a number of environmental indicators, based on LCA results. This quantified and science-based way of communicating environmental performance is by ISO classified as the highest level (Type 3) type of ecolabelling.

The performance of an LCA is divided into four main parts (Figure 4):

1. Goal and scope definition,
2. Inventory analysis,
3. Impact assessment and
4. Interpretation of results

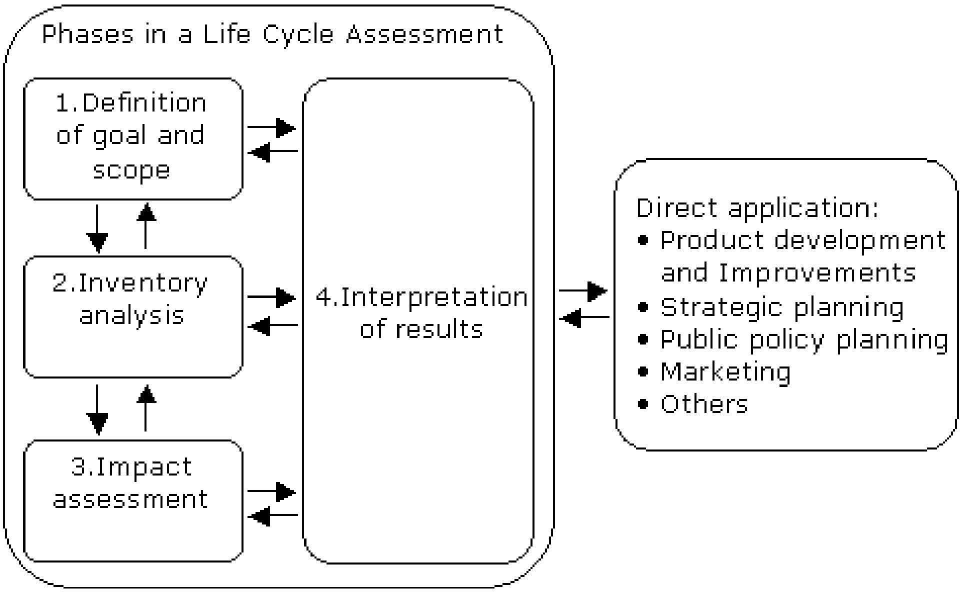

Figure 4*:* The four steps in life cycle assessment and possible applications of results

3.1 Definition of goal and scope

In the goal and scope definition, the system to be studied and the purpose of the study is defined. System boundaries are chosen, preferably reflecting the boundary where the human interference with nature due to the production of that particular product starts, i.e. normally starting with extraction of raw materials and ending with waste treatment. However, a more limited life cycle can also be studied where this is relevant.

3.2 Inventory analysis

The inventory analysis consists of the gathering of data about the resource use, energy consumption, emissions and products resulting from each activity in the production chain. The production chain, or system studied, can be divided into the foreground and the background system. The foreground system contains the most important parts of the studied system for which specific data need to be gathered. The background system contains production of packaging materials and other supply materials, electricity, transports and waste treatment. All in- and outflows are then calculated on the basis of a unit of the product to be studied called the functional unit. The choice of this unit should represent the function of the product. From some activities, more than one product may be the outcome. In such cases, the total environmental impact is often divided between the main product and by-products, a procedure known as allocation in LCA methodology. Allocation is based on the most relevant relationship between the main product and by- products in each case, e.g. mass, energy content or economic value. Another approach is to include the by-products in the system and separately assess another production system for this product, which can then be subtracted from the original system in order to obtain results for the main product. This latter approach is called system expansion and is recommended by ISO.

The first result of an LCA is a matrix of inventory results (hundreds or thousands of inputs and outputs), where the calculated values for each phase of the life cycle and also the total values are presented for a number of categories of substances like resources from ground, resources from water, emissions to air, emissions to water and products.

3.3 Impact assessment

In order to simplify this table and to get an idea of what kind of environmental impact the emissions cause, characterisation methods are used which weight together all emissions causing for example global warming, acidification, toxicity, eutrophication, photochemical ozone formation and stratospheric ozone depletion. For example in the category global warming potential (GWP) the different emissions contributing to the category are multiplied by their impact indicator, which are developed and updated by the UN Intergovernmental Panel on Climate Change (IPCC), and then added up to give one single result in that category, measured in carbon dioxide equivalents. They hence relate the global warming potential of each emission to the impact of carbon dioxide and this is done in the same way for the other categories (acidification is measured in sulphur dioxide equivalents, eutrophication in nitrate equivalents, etc.). Characterization together with qualitative assessment of types of environmental impact that cannot be characterized is called impact assessment. Qualitative assessment means that when no reliable method to quantify a category of environmental impact exists or data is lacking, it can be assessed qualitatively (e.g. land and seafloor use, biodiversity, discard).

Table 1: Current impact indicators for a number of greenhouse gases (IPCC, 2007)

Important greenhouse gas emissions	**Global warming potential (kg CO_2 equivalents/kg)**
CO_2 (carbon dioxide)	1
CH_4 (methane)	25
N_2O (dinitrogen monoxide)	298
Refrigerant HCFC 22 (known as R22)	1 810
Refrigerant HFC 404a (known as R404a)	3 700

3.4 Normalization, weighting, interpretation and sensitivity analysis

Normalization and weighting are optional steps aiming at relating the environmental impact of the studied activity to other activities in society and comparing the different types of environmental impact to each other.

Whether these steps are performed or not depends on the goal and scope of the study. After the impact assessment and in some cases normalisation and weighting has been completed, interpretation of results follows along with identification of key figures and initial assumptions (that are presented in the goal and scope section) as well as a sensitivity analysis in order to finalize the LCA. In the sensitivity analysis, key figures are varied and the dependence of the results on certain data is analysed in relation to the quality of those data. There are many good handbooks explaining step-by-step how to perform an LCA (Baumann and Tillman, 2004; Hauschild and Wenzel, 1997; Wenzel *et al*., 1997)

4. LCA METHODOLOGY SPECIFIC TO THE PRESENT STUDY

4.1 System boundary

The studied system starts with production of supply materials for the respective fisheries, e.g. fuel and gear material. Fishing is presumed to be undertaken by Félé-félé and Mujas nets (50 percent each with regard to total landings) due to the low importance of Xuus nets in total shrimp landings. In the case of the artisanal fishery, the shrimps are landed in the villages along the river shore, where they are bought and transported by several traders to the processing plants in Ziguinchor by a pick-up (Figure 4, chain on the left), sometimes also directly to Dakar. Processing of the main product means cleaning, packaging and freezing (unpeeled and head-on). By-products in the processing plant are small shrimps from the same fisheries as well as fish originating in other fisheries, that are sent (iced on trucks) to the main plant of the processing company, located in M'bour close to Dakar, for processing (peeling/filleting and freezing). The fish and small shrimps sent to M'bour for peeling are not included in the studied chain. Likewise, the finished, large-shrimp products are taken frozen from Ziguinchor to M'bour on trucks (367 km), where they are stored for a short period before being transported to Dakar (83 km) and further to Vigo, Spain, on large container freighters (3 234 km). Currently, around 80 percent of the Casamance shrimps are exported to Europe (IDEE Casamance, 2007), in 2007 mainly to the United Kingdom and Spain (Exportation des expéditeurs, 2008). The study ends at the point of import, i.e. no further transport, storage, preparation or waste treatment is included, mainly due to the lack of data and the fact that the chains to be compared are identical from the point of export. The transport to Europe was included (even though it is the same in the two chains) as the role of long-distance food transports is often debated.

In the case of the trawl fishery, processing, including packaging, is done at sea (Figure 5, chain to the right). The products are landed and taken for storage in Dakar where they are stored for, on average, 1–2 months. From there, the same type of transport on container freighters takes the product to the European market. The main markets for shrimp product from trawl fisheries are Greece, Portugal and France.

Production and maintenance of boats and fishing gear was excluded due to expected low contribution per functional unit in combination with difficulties in obtaining useful data on these matters.

4.1.1 Functional unit

The functional unit in the present study is one kilogram of frozen, whole, pink shrimps packed in a plastic bag inside a cardboard box, delivered to the port of Vigo, Spain. The shrimps originate either in the Dakar-based trawl fishery or in the Casamance artisanal fishery, assumed to be done by equal use of Mujas and Félé-félé nets with regard to total landings.

4.1.2 Allocations

Two allocation situations arose in this study. In the fishing phase, several species are landed together and the allocation between them has been done on an economic basis, i.e. their proportion of the total value of landings. Especially in the trawl fishery, the amount of landed by-catch terms of weight is considerable, while the economic importance of it is much less important. Therefore, it is assumed that the shrimps are the driving force of this fishery rather than the fish that is also landed. In the processing plant, shrimp products are produced from large shrimps. The small shrimps and fish from other fisheries are merely sent on ice to the processing plant in M'bour. Therefore, separation of the resource use between the products was done rather than allocating the burdens.

Instead of splitting the energy use of the whole plant between the products produced according to their proportion of total production in terms of mass or economic value (which would be the process in case of mass or economic allocation), the specific energy use to make ice and the energy use for freezing were determined since these are used for specific products only. Since the fish (and only the fish) is transported on ice, almost all "ice energy" was subtracted from the total. Since the shrimps are the only products frozen at the plant, all the "freezing energy" (50 percent of total) was designated to them. In the sensitivity analysis, the alternative option to let the large shrimps account for 100 percent of energy and water use was tested in order to see how much difference this would make.

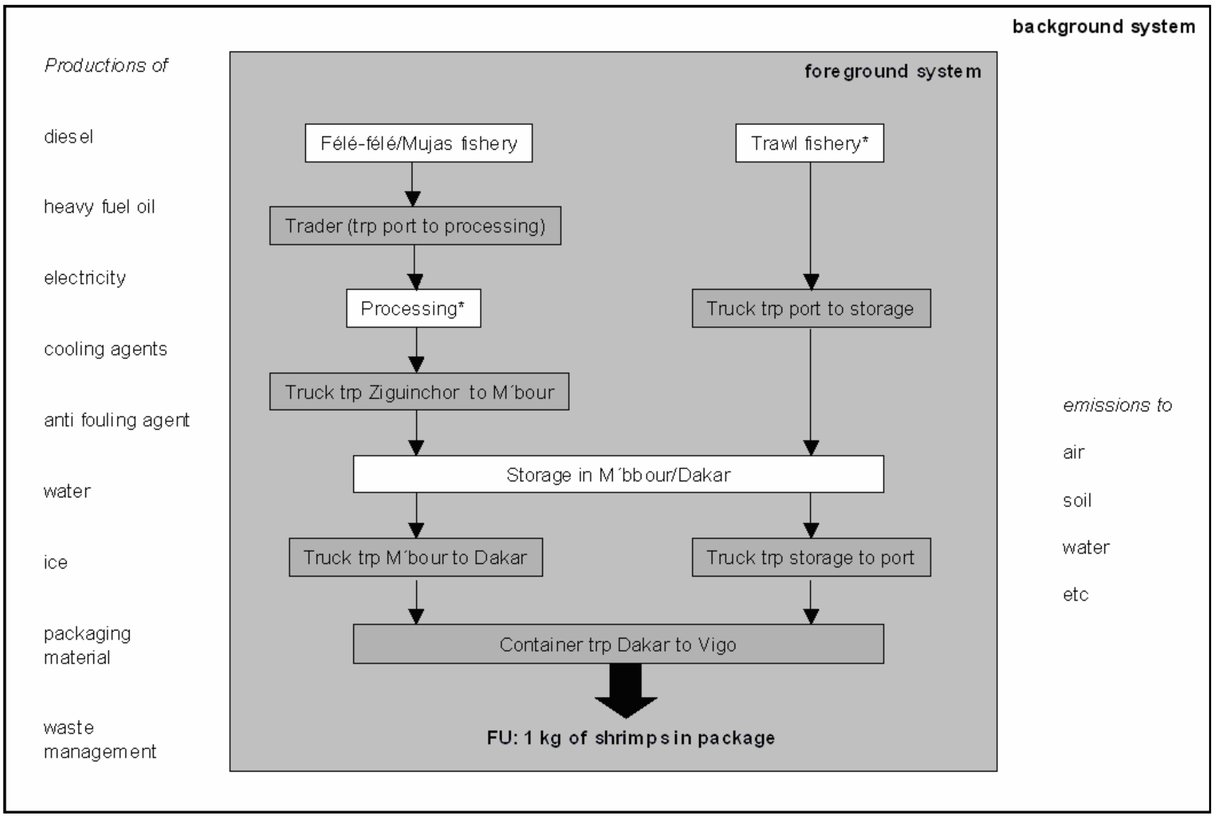

Figure 5: Flowcharts for the studied chains. Shaded area represents the foreground system and the white area the background system

4.1.3 Data inventory

Data inventory of the foreground system in the Casamance was undertaken by local experts (IDEE Casamance and CRODT) in collaboration with the Swedish-Danish LCA team (SIK and Aalborg University) from November to December 2007. Relevant authorities and organisations were visited and existing documentation regarding the stock and the fishery gathered. Data for the Casamance fishery was collected by visiting fishing villages, interviewing fishermen and inspecting their catches upon landing. Analysis of around 30 landings in two fishing villages (around Ziguinchor and Bangangha, around 20 km upstream from Ziguinchor), constitute the basis for the biological part of the present analysis Fishermen were either requested beforehand to bring the entire catch ashore and sort it into landing and discard there or they were asked to estimate the weight and species discarded. A total of 32 samples were collected and analysed, approximately half mujas and half félé-félé (the number of useful samples varied somewhat for the different variables investigated).

To our knowledge, there is no historical data available. The Ziguinchor fishermen often travel a considerable distance downstream so the true distance between fishing sites is larger than 20 km. Conversations with the fishermen provided the data for the more typical LCA data like amount of materials used for fishing gear, fuel used, etc.

Traders buying shrimps and taking them to the processing plants were also interviewed. Two processing plants in Ziguinchor were visited and technical staff answered questions with regard to production, logistics and the use of e.g. energy, refrigerants, packaging material, freshwater etc. Here, shrimps are sorted into eight size classes, so called calibers classified according to the number of shrimps per kilogram. Caliber 8 is the smallest legal size with 120-200 shrimps/kg, (see Appendix 1 for caliber classification). Data for the background system, e.g. production of packaging materials, fuels and transports was taken from database Ecoinvent v.2.0[1] Electricity production in the Casamance was modelled based on information from Senelec, the local producer.

In Dakar, the data inventory was undertaken in collaboration with a shrimp biology expert from Centre de recherches océanographiques de Dakar-Thiaroye (CRODT) from December 2007 to January 2008. With regard to the fishery, data from the two largest trawling companies was used. These two companies operate 15 and 4 shrimp trawlers, respectively and so 19 out of the total number of vessels of 30 were covered. The largest company alone accounts for around 60 percent of the Senegalese-trawled shrimp landings. Representatives of the companies provided data on landings, fuel use, use of refrigerants and logistics after landing. Information on the composition of different energy sources in average Senegalese electricity production (used in the present study for electricity use in the Dakar region) was found on the web site of the International Energy Agency.

4.1.4 Method for Impact Assessment

The impact assessment method chosen is CML 2001 (Guinée, 2002) and the categories studied are Global Warming Potential, Acidification Potential, Eutrophication Potential, Photochemical Ozone Creation Potential, Ozone Depletion Potential, Human toxicity, Terrestrial toxicity, Marine Aquatic Toxicity and Terrestrial Ecotoxicity and Energy as these categories were considered to be the most relevant ones for the chains studied. The category Global Warming Potential was updated with the new characterisation factors according to IPCC 2007. For energy the method Cumulative Energy Demand in SimaPro was used. The LCA was carried out in LCA software SimaPro v.7 (SimaPro 2007).

5. RESULTS AND DISCUSSION

The results are divided into two parts**:** i) inventory results and ii) characterized results from the LCA.

Inventory results include the results obtained regarding the biological aspects mentioned above as well as results of the LCA data inventory for important resources used along the chains (e.g. fuel and refrigerants).

Characterized results include the latter (“traditional” LCA data) after impact assessment and these are presented both for the fishing phase alone (i.e. per kilogram of shrimps landed) and per kilo of product transported to Europe (the functional unit). Due to uncertainties in parts of the material, the results should primarily be used to identify important activities from an environmental point of view and improvement options, rather than comparing the absolute level of each figure, especially with other production systems. We are confident that there is a clear difference between the product originating in the artisanal and trawl fishery. However, the exact level of impact in each category is surrounded by a high level of uncertainty.

5.1 Inventory results

5.1.1 Fisheries

Size composition shrimps

As is evident from Tables 2 and 4, the catch composition for the three fishing methods differed considerably. The proportion of small shrimps caught at sea (by trawls) is much smaller than in the artisanal fisheries, which is quite natural considering the life-cycle of the species. Almost half of the catch in the Félé-félé fishery consists of small shrimps, i.e. shrimps of caliber 8 and undersized (>120 individuals per kilogram). Mujas fishing has a small size ratio in between the other two methods with an average of 12 percent of the catch being small. This was the composition found in the samples which were collected during a shrimp peak

---

[1] A Swiss life cycle data database

season in November-December 2007 and we do not know how representative this composition is for the average félé-félé catch in the Casamance over the whole year.

Table 2: Catch composition for the three shrimp fishing methods

Gear	**Percentage of total catch**			
	Discard	**Fish bycatch**	**Small shrimps**	**Large shrimps**
Mujas	36	18	12	34
Félé-félé	12	8	46	34
Trawl	35	57	1	7

Landed fish bycatch

Another major difference is the difference in the fish by-catch landed, which represents more than half of the catch in the trawl fishery in terms of weight (representing 54 percent of the value of landings, with shrimps representing 46 percent). The proportion of fish landed in the artisanal fisheries is much smaller in terms of weight, and even lower in terms of value (fish 5 percent and shrimps 95 percent of value of landings). The difference is both related to the species and the sizes caught. In the river small individuals of commercial species are caught who have a lower value compared to the bycatch in trawl fishing. See Table 3 for the most common bycatch species landed in artisanal fisheries (this information is not available for the trawl fishery).

Discard

The proportion of catch discarded was similar in Mujas and in the trawl fishery and smaller in the Félé-félé fishery. It should be mentioned that the discard in the artisanal fisheries to a considerable part consist of swimming crabs, as opposed to the discard in the trawl fishery which according to interviews with trawl skippers and crew largely consists of undersized specimens of commercial fish species, many of which are considered to be in a highly overexploited condition (UNEP, 2002).

The data was analysed statistically by undertaking analyses of variance (ANOVAs) including the variables location (Ziguinchor or Bangangha) and the fishing method (Mujas or Félé-félé) with small-size ratio, bycatch ratio, mean shrimp catch and discard ratio as the dependent variables. No significant interactions were found between locations and fishing methods and all parameters showed significant differences between fishing methods.

Table 3*:* Most common species in landed bycatch

Species	**Félé-félé**	**Frequency found in by-catch (%)**	**Mujas**	**Frequency found in by-catch (%)**
No. 1	*Calinectes* spp. – Swimming Crabs	51	*Etmalosa fibriata* – Bonga Shad	32
No. 2	*Eucinostomus melanopterus* – Flagfin Mojarra	22	*Calinectes spp* – Swimming Crabs	27
No. 3	*Liza* spp. – Fam. Mullets (Mugilidae)	6.4	*Pseudolithus elongatus* – Bobo Croaker	13
No. 4	*Etmalosa fibriata* – Bonga Shad	5.7	*Elops lacerata* – West African Lady Fish	11
No. 5	*Elops lacerate* – West African Lady Fish	4.6	*Brachydeuterus auritus* – Big Eye grunt	5.5

Table 4*:* Landed small shrimps, landed bycatch (other species) and discard (in kilogram per kilogram of large shrimps landed).

Fishery	Landed small shrimps	Landed by-catch	Discard
Félé-félé	1.30	0.25	0.13
Mujas	0.38	1.20	0.55
Trawl	0.09	7.00	5.40

5.1.2 Seabed/river bottom impact

Félé-félé nets are not set on the bottom, but are operated like drift nets near the surface. Mujas nets are set on the bottom, but are not moved and so the bottom impact of the two artisanal fishing methods is considered to be very low to negligible. The seabed impact of demersal shrimp trawls was roughly estimated by asking trawlers for information on trawl width opening, length and width of trawl boards, speed during trawling, average time of a haul and average LPUE (landings per unit effort). The trawls were set in pairs, each trawl with an opening width of around 22-26 m and equipped with two trawl boards 2-3 m long. Excluding the chains that connect the trawl and trawl boards to each other and to the boat, but assuming that the full width of the trawl and the trawl boards has seabed contact, the width is 58 m (24+24+(2.5*4)) times 2.5 knots (4.6 km/h) which gives and impacted area per hour trawled of 0.27 km^2. An average of 15 hours trawled per day during a 25-day fishing trip, landing 4.700 kg of shrimps (46 percent of the value) and 35 000 kg of fish (54 percent of value) gives an average seafloor area impacted of 10 100 m^2 per kg of shrimps landed (using economic allocation). That area corresponds roughly to one hectare.

5.1.3 Fuel use in fishery

Some canoes in the artisanal fishery are operated with outboard engines, but they constitute a small fraction. The Mujas fishermen do not use any fuel at all and only about 10 percent of Félé-félé fishery is engine-driven, using around 10 litres of gasoline per day to land approximately 16 kilogram of shrimps or around 0.63 litre of gasoline per kilo of shrimps. This gives an estimated average petrol use of 0.063 litre/kg shrimps for Félé-félé nets and 0.046 litre/kg artisanal shrimps on average (50 percent Félé-félé, 50 percent Mujas). There is considerable uncertainty around these figures, however, which is why they have been varied in the sensitivity analysis further down. The fuel use in the Dakar fishery, on the contrary, was much higher, 9.8 litres/kg shrimps, which includes the energy used for processing, i.e. washing, packaging and freezing. Note that economic allocation is used to allocate the fuel use between shrimps and fish landed (as described on page 9), this makes a big difference (the fuel use per kilogram of mixed catch landed was 2.6 litres/kg). Shrimps represented on average 12 percent in weight, but 46 percent by value of the landed catch.

5.1.4 Refrigerants

The refrigerant used onboard the trawlers is R22, an HCFC with high ozone depletion potential and a high global warming potential (Table 1). The amount refilled per year divided by total landings and using economic allocation between shrimps and fish gives that around three grams are used per every kilogram of shrimps landed. Artisanal fisheries do not use refrigerants in the fishing phase, but they do at the processing plant. It is the same refrigerant as that used on the trawlers (R22) in combination with R404a of HFC type, which has a lower ozone depletion potential, but a higher global warming potential (Table 1). The amounts used (and emitted) are 0.07 g R22 and 0.5 g R404a per kilogram of shrimps produced.

5.1.5 Anti-fouling

Anti-fouling substances are not used in the artisanal fishery. The canoes dry up on the beach between fishing trips, which kills and removes settling marine organisms. In the Dakar fishery, copper-based paints of various brands are used. Four of them were checked in terms of chemical content and since their content of active ingredients was fairly similar (30-40 percent Cu(I)O), one of them was chosen for the calculation of aquatic emissions of copper. For copper and xylene, the active ingredient and a solvent, 100 percent of the applied amount (0.05 grams of paint/kg) was assumed to be emitted to water.

5.1.6 Batteries

Batteries were only used in the artisanal fisheries. As fishing is often undertaken at night, flashlights are used for orientation. The use of batteries in the Félé-félé fishery was said to be two D-size batteries per three days and the use in the Mujas fishery was two D-size batteries per week. The battery type used was alkaline with a low content of mercury and they were deposited on land (on the beach) after they were unloaded. It was very difficult to find a reliable estimate on the mercury content of these batteries, hence a very conservative estimate of 0.025 percent (in weight) was used to assess the amount emitted. The battery production was excluded due to lack of data both on the composition of the batteries and LCA data for battery production, hence these data are both uncertain and incomplete and the figures are most likely underestimated.

5.1.7 Water and ice in the processing plant

The total amount of water used at the processing plant during a year was 7 683 m^3. Subtracting the amount of water used to produce the 3 650 tonnes of ice (4 015 m^3) produced in a year leaves 3 478 m^3 of water used for other purposes such as washing the shrimps and cleaning the facilities. Shrimps are washed with bisulphite, around 0.05 litre/kg of shrimps, the use of bisulphite, however, could not be included due to lack of data. As the factory produces 190 tonnes of large-shrimp products (as well as 161 tonnes of small shrimps and 253 tonnes of fish), the water use per kilogram of product (allocation based on mass) is around six litres per kilo of product. The use of ice in the chains studied is limited to the transport from the ports in the Casamance to the processing plants and the transportation of the small shrimps and fish from Ziguinchor to M'bour where these are peeled/processed. The amount of ice used for transport from port to the processing plant was included (2 kg/kg shrimps) as well as the one kg/kg shrimps used for de-icing at the processing plant. The ice used to transport the small shrimps to M'bour was excluded as the focus of the study is the larger shrimps.

5.1.8 Electricity production

Electricity production in the Casamance region was found to be based entirely on combustion of heavy fuel oil with a sulphur content of 4 percent hydropower and biofuels contributed with 11 and 12 percent respectively in the average Senegalese electricity production (75 percent oil and 2 percent natural gas). On this basis, this distribution was also used in the case of electricity use in the Dakar region (storage of shrimps before export). Grid losses of 18 percent were assumed in both cases based on information found on the website of the International Energy Agency. In the processing plant, 7.3 MJ were used per kilo of shrimps processed, during storage an additional 5.3 MJ were used.

5.1.9 Gear material

Among the artisanal fishing methods, the estimation of the use of gear materials that could be done indicated considerably higher use in the Félé-félé fishery than in the Mujas fishery. The life-time of Mujas nets was on the order of decades, while the life-time of Félé-félé nets was 3–5 years. The average weight of Félé-félé nets was 55 kg consisting of cotton and stones used as weights (50 percent of the weight is cotton, 50 percent stone). An average daily catch of 16 kg of shrimps and 180 fishing days per year give an average annual catch of 2 880 kg of shrimps. A life-time of 4 years means that 2.5 g of cotton are used per kilogram of shrimps caught in the Félé-félé fishery. Due to the longer life-time of Mujas nets and their lower weight compared to a Félé-félé net (20 kg), it is concluded that less material is used for gear in the Mujas fishery per kilo of shrimp landed, despite the lower daily catch in this fishery. Still the contribution of this input is assumed to be very small and it is therefore left out of the analysis.

5.2 Characterized (LCA) results

All the above mentioned different data were inserted into the LCA software SimaPro 7.1.6. The data were then complemented with the so called background data for example for truck and boat transports involved, the packaging material, electricity production and many other supply materials that are used in the chains. The model adds, subtracts, multiplies and divides all the figures to:

i. correspond to the functional unit

ii. to classify all those emissions contributing to the respective category of environmental impact (global warming, eutrophication etc.)

iii. characterize them, i.e. multiplying them with the impact indicator of each emission e.g.) in order to obtain one result per environmental category.

5.2.1 Overall results

In Figure 6 the overall results of the LCA for all categories are presented (details in Table 5). When looking at the results it should be realized that processing takes place on board of the trawlers and that for a correct comparison *"fisheries"* in Trawling should be compared with *"fisheries and processing"* in artisanal fisheries. Efforts have been made to find out how much of the energy use is due to processing and how much is due to fishing, but this has not been possible to do in a reliable way.

The characterized LCA results are shown for the fishing phase, per kilogram of shrimps landed and for the full life-cycle (per kilogram of product delivered to Vigo from artisanal and industrial fisheries) for all categories.

LCA results showed major differences between the two final products, with regard to resource use and environmental impact, depending on their origin. The product that stems from the trawl fishery requires much more resources and leads to more environmental impact than does the product from artisanal fisheries. For the product originating in trawling, fishing (processing included) was the most important activity in all categories of environmental impact. For the product originating in the artisanal fishery, fishing was the most important activity from an ecological point of view. In contrast, processing and storage dominated all other, more typical LCA categories of environmental impact.

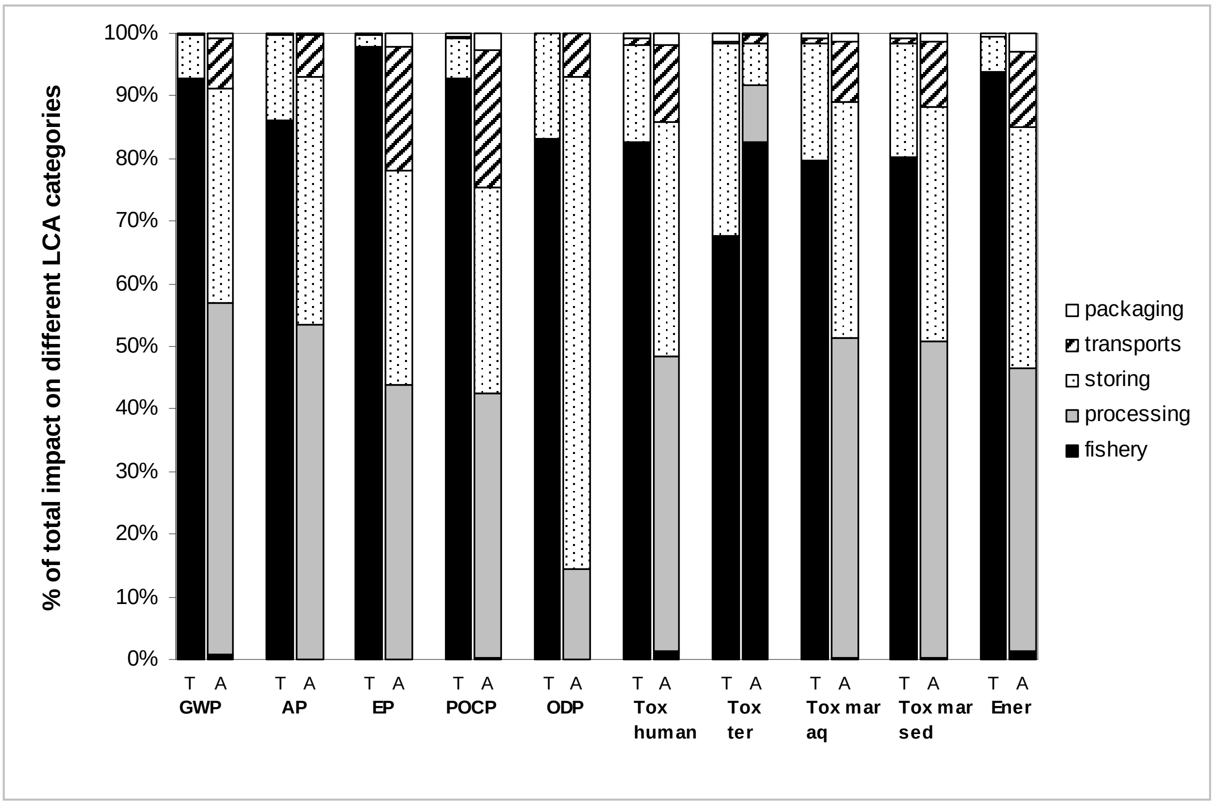

Figure 6: Relative results of impact assessment. T = trawl, A = artisanal for different activities in the chain. The impact categories studied are global warming (GWP), acidification (AP), eutrophication (EP), photochemical creation (POCP), ozone depletion (ODP), human toxicity (Tox human), terrestrial ecotoxicity (Tox ter), marine aquatic ecotoxicity (Tox mar aq), marine sediment ecotoxicity (Tox mar sed) and energy (Ener).

Table 5: The results from the lifecycle impact assessment presented per functiona unit (1 kg of shrimps) for the impact categories included, where CO_2e means carbon dioxide equivalents. Processing is zero for trawled shrimps because processing is done in the fishing phase.

		fishery	**processing**	**storing**	**transports**	**packaging**	**TOTAL**
GWP (CO_2e)	trawled	3.53E+01	-	2.66E+00	4.68E-02	5.72E-02	3.81E+01
	artisanal	6.60E-02	4.36E+00	2.66E+00	6.19E-01	5.72E-02	7.76E+00
AP (SO_2e)	trawled	2.86E-01	-	4.47E-02	1.01E-03	2.14E-04	3.32E-01
	artisanal	1.26E-04	6.04E-02	4.47E-02	7.77E-03	2.14E-04	1.13E-01
EP (NO_3e)	trawled	4.54E-02	-	8.70E-04	8.78E-05	5.69E-05	4.64E-02
	artisanal	2.42E-06	1.12E-03	8.70E-04	5.04E-04	5.69E-05	2.55E-03
POCP (C_2H_4e)	trawled	1.42E-03	-	9.83E-05	6.30E-06	7.69E-06	1.53E-03
	artisanal	1.13E-06	1.25E-04	9.83E-05	6.55E-05	7.69E-06	2.98E-04
ODP (CFC11-e)	trawled	2.70E-04	-	5.44E-05	6.46E-09	5.54E-09	3.24E-04
	artisanal	4.81E-08	9.95E-06	5.44E-05	4.80E-06	5.54E-09	6.92E-05
tox (human) (benzene-e)	trawled	1.76E+00	-	3.28E-01	2.63E-02	1.55E-02	2.13E+00
	artisanal	1.14E-02	4.14E-01	3.28E-01	1.08E-01	1.55E-02	8.77E-01
tox (terrestial) (benzene-e)	trawled	1.88E-03	-	8.54E-04	7.71E-06	3.71E-05	2.78E-03
	artisanal	1.04E-02	1.14E-03	8.54E-04	1.57E-04	3.71E-05	1.26E-02
tox (marine aq.) (benzene-e)	trawled	3.43E+00	-	8.12E-01	3.56E-02	2.93E-02	4.30E+00
	artisanal	3.33E-03	1.09E+00	8.12E-01	2.03E-01	2.93E-02	2.14E+00
tox (marine sed.) (benzene-e)	trawled	4.00E+00	-	8.99E-01	4.69E-02	3.50E-02	4.98E+00
	artisanal	4.03E-03	1.21E+00	8.99E-01	2.44E-01	3.50E-02	2.39E+00
energy (MJ-e)	trawled	4.52E+02	-	2.73E+01	7.50E-01	2.02E+00	4.82E+02
	artisanal	8.62E-01	3.19E+01	2.73E+01	8.47E+00	2.02E+00	7.06E+01

Because of uncertainties in some of the material, the *results should primarily be used to identify important activities from an environmental point of view*. A summary of results of comparisons between the three fisheries in the different environmental impact categories with an estimate of data quality/variation/ uncertainty is presented in Table 6.

5.2.2 Global warming potential

As is evident from Figure 7a, the difference in global warming potential (GWP) between artisanal and industrial fisheries is enormous due to the use of 9.8 l of diesel fuel and 2.7 g of refrigerant R22 in the trawl fishery as opposed to 0.05 litre of fuel and no use of refrigerants in the fishing phase in the artisanal fisheries. It must be kept in mind, though that processing is included in the trawl fishery, which explains part of the difference. Over 35 kg of CO_2e are emitted per kilogram of shrimps landed in the trawl fishery, 0.2 kg in the félé-félé fishery and no global warming emissions at all in the mujas fishery.

When processing is included to make the figures more comparable, the artisanal fishery causes emissions of 4.4 kg (Figure 7b).When the life-cycle after landing is added, the artisanal product causes emissions of 7.8 kg CO_2e per kilogram of product and the industrially fished product 38 kg CO_2e per kilogram. The major contributions to global warming emissions from the artisanal product are caused by energy- and refrigerant-related emissions in processing and storage. Actually, this represents the only published LCA result for a seafood product where processing and storage have led to larger contributions compared to fishing, perhaps reflecting that seafood production chains from artisanal fisheries have not previously been studied using LCA methodology.

Table 6: Summary of results of comparisons between the three fisheries in the different environmental impact categories included (+ means overall better environmental performance, - means overall less good environmental performance), main factors influencing the result (both positive and negative) in text in each box and an estimate of data quality/variation/uncertainty.

Environmental Impact category	**Félé-félé fishery**	**Mujas fishery**	**Trawl fishery**	**Data quality/ Uncertainty**
Global warming	+ cooling agents, oil-based electricity	+ cooling agents, oil-based electricity	- fuel use in fishing, cooling agents, less oil-based electricity	good data on use of energy and cooling agents in processing and in trawl fishing, rather large uncertainty of fuel use in félé-félé fishery
Eutrophication	+ oil-based electricity	+ oil-based electricity	- NO_x from fuel use in fishing	good data on energy use in processing and fishing
Acidification	+ high sulphur fuel oil for electricity	+ high sulphur fuel oil for electricity	- less oil-based electricity, but high fuel use in fishing	good data on energy use in processing and fishing
Aquatic toxicity	+ no anti-fouling	+ no anti-fouling	- anti-fouling	high variation in fuel use data and estimations on emissions and content of copper
Terrestrial toxicity	- mercury batteries	- mercury batteries	+ no mercury batteries	good data on battery use, estimations on mercury content and emissions
Target stock impact	- high proportion small size	+ intermediate proportion small size	+ low proportion small size	data valid for peak shrimp season
Discard	+ low proportion of by-catch and discard	- large proportion of by-catch and discard	-- very large proportions of by-catch and discard	data valid for peak shrimp season
Seafloor impact	+ no bottom impact	+ no bottom impact	- major seafloor impact	annual average data of good coverage

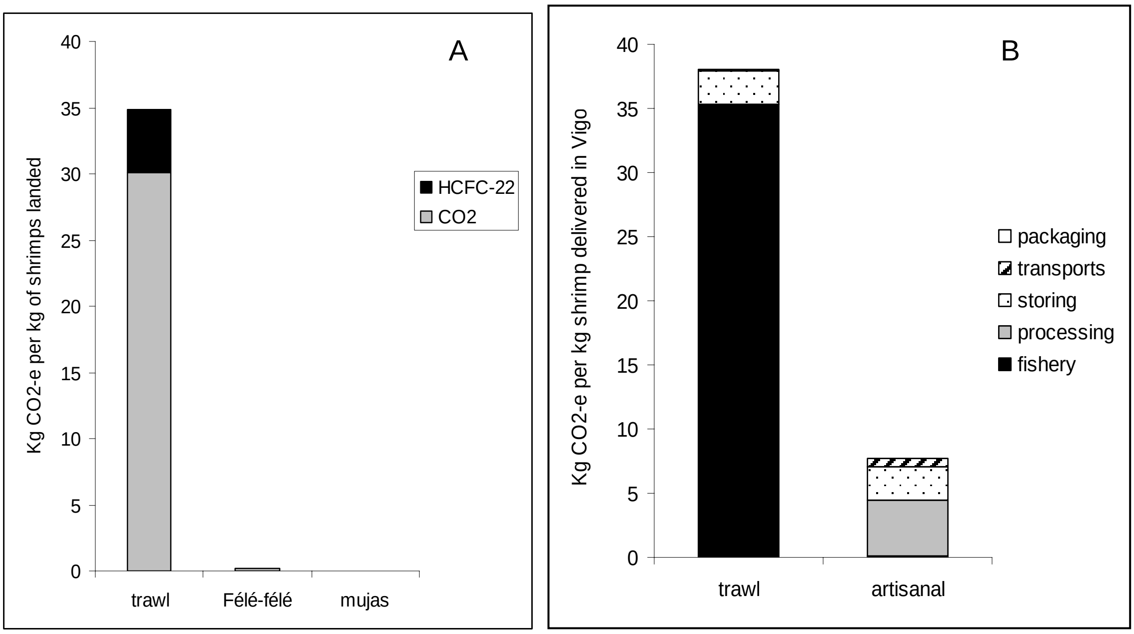

Figure 7: Global warming emissions caused by a) a kilogram of shrimps landed by the three fishing methods, b) a kilogram of shrimp product delivered in Vigo (Spain) and fished either in artisanal fisheries or in the trawl fishery indicating contributions of different life-cycle phases.

5.2.3 Acidification potential (AP)

In the acidification category, the impact of the industrially fished product is three times higher than the artisanal one. The diesel fuel used in the trawl fishery has a sulphur content (0.4 percent) only 10 percent of the heavy fuel oil used for electricity production in the Casamance (4 percent), otherwise the difference would be even greater. The combustion and production of these fuels explain the main part of the acidification caused throughout the chains. Shipment also plays a role.

5.2.4 Eutrophication potential (EP)

The difference with regard to eutrophication is considerably larger and this category is dominated by emissions of nitrous oxides from combustion of fossil fuels in both chains.

5.2.5 Photochemical ozone creation potential (POCP)

The formation of ozone is largely correlated to the use of gasoline and to the production of fossil fuels: gasoline, diesel as well as heavy fuel oil. Gasoline in the chains studied only occurs in the félé-félé fishery stemming from the use of outboard engines. The diesel is used on the trawler and for transports and heavy fuel oil is used for electricity production. This is the category where transports score highest (almost 20 percent of the artisanal products emissions).

5.2.6 Ozone depletion potential (ODP)

A refrigerant with a high ozone depletion potential, R22, is used both onboard the trawlers and in the processing plant on land. At the processing plant, two refrigerants are used, one for ice-making (R22), of which only the very low amount used for shrimps is allocated to the products and one for freezing and maintenance (R404a) which is entirely allocated to the shrimps. R 22 is also used at the storage in Dakar which gives the highest contribution to ODP in the artisanal chain. R22 has a high ODP and GWP, while R404a has zero ODP, but an even higher GWP compared with R22. Therefore R22 dominates this category while R404a is important in the category GWP.

5.2.7 Toxicity categories (human, terrestrial, marine aquatic, marine sediments)

Artisanal fisheries score 50–60 percent lower in all toxicity categories compared to the trawl fishery with the exception of terrestrial toxicity which is higher for the artisanal product. This is due to the emission of mercury to soil from the batteries used. Many of the toxic emissions also originate from the production of fossil fuels. For the trawlers, the aquatic emissions of copper ions from the anti-fouling paint, accounts for a considerable part of the aquatic toxicity results.

5.2.8 Energy use

The global warming potential of the trawled product was about five times higher than that of the artisanal product, which was also considerable. The relation between the fisheries regarding energy use is similar to the relation between the fisheries regarding global warming. The production chain from artisanal fisheries required about 15 percent of the energy of the industrial product chain (the figure was 20% for GWP). This similarity in result in the categories GWP and energy use reflects the fact that the energy use throughout the two chains to a large extent is fossil fuel-based. Had the energy used for processing, e.g. to a higher degree been based on hydro- or nuclear power, then the GWP result of the artisanal chain would have been lower, while the energy result would have been the same.

6. SENSITIVITY ANALYSIS

Based on these results, a number of issues were identified that were varied in the sensitivity analysis in order to analyse the dependence of results and conclusions on these in relation to their uncertainty. These were:

1. The proportion of shrimps produced by Mujas and Félé-félé fishing to the processing plant (assuming shrimp landings are distributed 50–50 between the fishing methods rather than that total landings are distributed 50–50 between the fishing methods, which was the case in the base case). Because of the differing catch composition of the fishing methods this makes a difference.
    - **Results**: As some of the boats in the Félé-félé fishery use engines and the Mujas do not, the environmental impact is (around one third) higher for all categories when the share of Félé-félé shrimps in the artisanal product is increased to 50 percent (looking at the fishing stage only). The only impact category where the result does not favour Mujas is terrestrial exotoxicity, because of the mercury batteries. The overall environmental impact looking at the whole chain is very small though (less than 0.5 percent higher) if more Félé-félé is used, except for terrestrial exotoxicity, which is around one percent lower.
2. The proportion of outboard engines among Félé-félé boats (decreased from 10% to 5% or increased to 100 percent)
    - **Results:** Assuming that a lower proportion of Félé-félé fishermen use outboard engines (5 percent instead of 10 percent) implies a negligible difference at the product level in global warming potential, while increasing the proportion to 100 percent, as a kind of worst case future scenario, would lead to a 10 percent increase in global warming potential at the product level. At the fishery level (i.e. per kilogram of landed shrimps) the impact of the changed use of outboard engines is of course much greater and total impact is directly related to the frequency of engines.
3. The mode of transport between port and processing plant (from small truck to pickup) and load factor of the truck (percent loaded of total loading capacity).
    - **Results**: Efficient transports are important, i.e. not to have a bigger truck/car than what is needed for the transport. The “worst-case” scenario analysed, a pick-up only transporting 200 kg of shrimps per day using 25 litres of fuels, compared to the “base-case” (which was a small truck with a relatively high proportion loaded), implies a difference of around 10 percent of the overall results for GWP. Also, for the pick-up one third of the fuel was petrol instead of diesel, which gave a higher contribution to most impact categories, especially POCP that meant 95 percent higher impact of the overall results
4. Letting the shrimps account for 100 percent of electricity and water use at the processing plant instead of 50 percent (that were said to be due to the ice production for the other products)
    - **Results**: For the artisanal fishery processing is the stage with the highest environmental impact, except for ozone depletion potential (ODP) (where storing has the highest impact). Assuming a “worst case”, where the large shrimps take the whole environmental burden

from the processing plant (i.e. all energy and refrigerant use for ice production is allocated to the large shrimps), the environmental impact increases by between[2] 35 percent (GWP) and 60 percent (ODP), depending on the impact category. The relatively higher contribution to ODP depends on the refrigerant used in the processing phase (R22). Emissions of R22 contribute to ODP as opposed to the other refrigerant (R404a) also used in the processing plant, which does not contribute to ODP, but which has twice the contribution of R22 to GWP.

5. Allocating the energy and refrigerant use for processing based on mass instead of the manual split between frozen products (large shrimps) and iced products (Fish and small shrimps to be peeled).
   - ➢ **Results:** When mass allocation is used instead to divide the environmental burden between the products in the processing plant (frozen shrimps, and small shrimps and fish on ice), the environmental impact is around 25 percent (32 percent for GWP) less compared to the base case[3], except for ODP which increases by 4 percent.
6. Allocating the energy and refrigerant use for storage based on mass instead of economic value
   - ➢ **Results:** If mass allocation would be applied in the storage phase instead of economic allocation, the environmental impact would decrease by up to 60 percent (ODP) for the artisanal shrimps. GWP, AP, EP and POCP would decrease by between 10 percent and 20 percent for artisanal. For trawled shrimps the result would not decrease as much: 13 percent for ODP, 10 percent for AP, 5 percent for GWP and POCP and 1 percent for EP. As storage represents a larger share of the environmental impact for the artisanal shrimps, it is logical that the decrease is also larger.
7. Testing another method of characterisation especially regarding the toxicity categories (from CML 2001 to EDIP 2003 and IMPACT 2002)
   - ➢ **Results**: There are differences between the impact assessment methods that make it difficult to compare them, especially some categories. However, the overall conclusions are that even if the magnitude of the results changes, trawling still gives the highest environmental impact for all categories, with the exception of toxicity in some cases. The artisanal fishery gave the highest contribution to terrestrial toxicity (CML 2001) and Ecotoxicity soil (EDIP 2003) and human toxicity water (EDIP 2003), while trawl fishery gave the highest contribution in all cases for Impact 2002. It is a fact though that toxicity is one of the more difficult impact categories within the LCA methodology and the category with the most inconsistencies when using the different methods. The results, depend on how different substances are weighted to each other (similar to how global warming emissions are weighted in Table 1).
8. Letting the processing plant use a renewable energy source (solar energy) and environmentally harmless refrigerants.
   - ➢ **Results**: In a future scenario, where the processing plant and ice production plants in the Casamance use solar energy for electricity production and an environmentally harmless refrigerant (NH_3), the global warming emissions of the artisanal product decrease drastically to less than 4 kilogram of CO_2e/kg and these would mainly be related to the storage in M'bour and transports. Whether or not this scenario is realistic is not judged here, but the example shows the potential of designing the chain on land of artisanal seafood products in an environmentally efficient way.

7. CONCLUSIONS

For all impact categories studied, the shrimps from the trawled fishery have a higher environmental burden, except for terrestrial toxicity, where artisanal fisheries have higher results because of the use of mercury-containing batteries. The main impact of the trawled shrimps occurs at the fishing stage, which also includes processing and packaging. The use of fuel and refrigerants in the trawl fishery is very high and although there may be ways to decrease the fuel use onboard (Hassel *et al*., 2001), the type and amount of refrigerants used may be an easier improvement to achieve in the short-term.

---

[2] Terrestrial ecotoxicity only increased with 8%

[3] Terrestrial ecotoxicity would decrease with over 60%

Artisanal shrimps scored very low in terms of resources used for fishing and the processing phase dominated the same categories as the trawling: energy, GWP and ODP. The source of energy used (and of course the amount) is very important for this result and an important improvement option would be to change from using average Casamance electricity to renewable energy sources. The use of refrigerants at the processing plant and storage was important from a global warming and ozone depletion perspective and a switch to less harmful refrigerants and/or decreased leakage represents important improvement option regarding in this respect. Looking at a future scenario, where the processing plant and ice production plants in the Casamance use solar energy for electricity production and an environmentally harmless refrigerant (NH_3), the global warming emissions of the artisanal product would decrease drastically to less than 4 kilogram of CO_2e/kg (half of today's emissions) and these would mainly be related to the storage in M'bour and transports. Whether or not this scenario is realistic is not judged here, but the example shows the potential of designing the chain on land of artisanal seafood products in an environmentally efficient way. Moreover, the use of mercury-free batteries and the collection of used batteries should be encouraged[4]**.** Providing fishermen with environmentally friendly batteries could be an option.

On the biological side, stock assessment and relating fishing effort to its outcome is the basis of sustainable fishing practices. The use of a selectivity device, such as a species-selective grid, could be very favourable both in the trawl fishery and in the Mujas fishery, decreasing the amount of discard and fish by-catch. That would decouple the fish-fishery from the shrimp-fishery and make it possible to optimize each of them. An increase in mesh size in both artisanal fisheries could also decrease the catches of undersized fish, something already suggested by the fishermen. The netting used today is of a "mosquito net type". Also, in artisanal fisheries, a spatial regulation could improve the catch composition of the Félé-félé fishery. If it were conducted further upstream, a smaller proportion of small shrimps would be caught as the shrimps migrate upstream in the areas where Félé-félé nets are set.

8. LESSONS LEARNT

At the seminar at the FAO Department for Fisheries and Aquaculture when the results were presented, the suggestion came up to include a section about our experiences from this project, resulting in this section of "lessons learnt".

The study would have been impossible to undertake without the collaboration with the local partners; IDEE Casamance and CRODT, which hence was a crucial factor especially for the data collection. Sufficient time in field to find the necessary data was another crucial factor, likewise a highly motivated and engaged team. It was difficult to estimate how much time in field would be necessary and we ended up having the LCA team in Senegal for two weeks and the Master student studying the biological aspects and completing the LCA data inventory staying for two months. Questionnaires, e-mails and phone calls which are common means for data inventory in industrialized countries would not have worked here so the site visits by the team were absolutely necessary. A number of differences both between countries and between organisations had to be overcome and handled. These differences were linguistic, administrative as well as cultural. All in all, we think it worked out well even if some mistakes were done along the way.

What would we have done differently today? Perhaps a project start meeting at FAO would have been useful to meet and plan the work and get everybody on the same page. It would definitely have been good to have the same people doing the inventory and the analysis and writing. This was, though, not possible. Of course, more time in field would have been useful, but was not possible either for several reasons. A critical reviewer could have followed the work closely throughout the project period, this has shown to been very useful in other projects. We did involve one external expert with experience of doing LCA of Asian shrimp aquaculture in the planning of the project, and, since she could not take on the final review of the report, had to find another reviewer to read the report. This was not an ideal way to solve this. For the Master student it would probably have been easier if we had planned the work for one biology student and one LCA student so that the two of them would have spent about the same amount of time in field.

---

[4] Actually, this has already happened since the first results of this project were presented. The artisanal fishermen started collecting the batteries, sending them to disposal.

The project is pioneering in the sense that it is an LCA study of a product from a developing country that is exported to Europe. It has been a very inspiring and rewarding project for all of the LCA team who are most interested in continuing this type of work assessing the environmental performance as well as advantages and opportunities for improvement of food production in developing countries.

9. REFERENCES

Anon., 2007. Impacts de la legislation sur la resource et les systemes de peche. Ministère du developpment rural et de l'agriculture. Institut Sénégalais de recherches agricoles.

Baumann, H. and Tillmann, A. M. 2004. The hitch-hikers guide to LCA. Studentlitteratur.

Emanuelsson, A. 2008. Bycatch and discard in Senegalese artisanal and industrial fisheries for southern pink shrimp (*Penaeus notialis*) B.Sc. thesis Göteborg University, Dept. of Zoology/SIK.

Exportation des expéditeurs. 2008. Shrimp export figures to different countries in weight and value. Data from Senegalese customs.

FAO. 1989. Yield and nutritional value of the commercially more important fish species. FAO Fisheries Technical Paper 309. Accessible at: www.fao.org/DOCREP/003/T0219E/T0219E05.htm

FAO. 1995. Effects of riverine inputs on coastal ecosystems and fisheries resources. FAO Fisheries Technical Paper 349, 133p.

Garcia, S.M. and Le Reste, L. 1981**.** Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. FAO Fisheries Technical Paper 203, 224pp.

Guinée, J., Gorree. M., Heijungs, R., Huppes, H., Kleijn, R., de Koning, A., van Oers, L., Wegener Sleeswijk, A., Suh, S., Udo de Haes, H., de Bruijn, H., van Duin, R. and Huijbregts, M. 2002. Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. Dordrecht: Kluwer Academic Publishers.

Gulland, J.A. and Rothschild, B.J. 1984. (eds.), Penaeid shrimps: their biology and management. Fishing News Books, Farnham, UK, pp. 111-144.

Hassel, K., Farstad, A. and Standal, D. 2001. Fiskerinaeringens muligheter til å bidra til oppfyllelse av Kyoto-avtalen (The possibilities for the fishing sector to contribute to fulfilment to the Kyoto agreement, in Norwegian) SINTEF Fisheries and Aquaculture Report No. 830011.00. 54p.

Hauschild, M. and Wenzel, H. 1997. Environmental Assessment of Products. Chapman & Hall, London.

IDEE Casamance. 2007. Eco-labelling and value chain promotion of the Casamance shrimp fishery. Achieving sustainability through fisheries co-management and market incentives. Funding proposal.

IPCC. 2007. Climate Change 2007. IPCC Fourth Assessment Report. The Physical Science Basis.

ISO. 2006a. Environmental management – Life cycle assessment – Principles and framework. ISO 14040:2006(E). International Organization for Standardization. Geneva. Switzerland

ISO. 2006b. Environmental management – Life cycle assessment – Requirements and guidelines. ISO 14044:2006(E). International Organization for Standardization. Geneva. Switzerland.

ISO. 2006b. Environmental management – Life cycle assessment – Requirements and guidelines. ISO 14044:2006(E). International Organization for Standardization. Geneva. Switzerland.

Le Reste, L. 1995. Pluviométrie et captures des crevettes *Penaeus notialis* dans l'estuaire de la Casamance (Sénégal) entre 1962 et 1984. Aquatic living resources (5): 233-248

L'Homme, F. and Garcia, S. 1984. Biologie et exploitation de la crevette Penaeide au Sénégal.

Mungkung, R.T. 2005. Shrimp aquaculture in Thailand: Application of Life Cycle Assessment to support sustainable development. PhD Thesis, Center for Environmental Strategy, School of Engineering, University of Surrey, UK.

Mungkung, R.T. Udo de Haes, H.A. and Clift, R.**T.** 2006. Potentials and limitations of Life Cycle Assessment in setting ecolabelling criteria: A case study of a Thai shrimp aquaculture product. Int. J.LCA **11**(1): 55-59.

Samb, B., M'Baye, A., Deme, M., Thiam, D., Sarre, A., Fall, M., Barry, M., Ngom, F. and Diouf, K. 2007. Impacts de la législation sur la ressource systèmes de pêche. ISRA, Institute sénégalais de recherches agricoles.

SimaPro7. 2007. PRé Consultants. Amersfoort. the Netherlands. www.pre.nl

Thrane, M. 2004. Energy consumption in the Danish fishery. Identification of key factors. J. of Ind. Ecol. 223-239.

Tyedmers, P. 2001. Energy consumed by North Atlantic Fisheries. pp. 12- 34

Tyedmers, P. Watson, R. and Pauly, D. 2005. Fueling global fishing fleets. Ambio 34(8): 619-622

UNEP. 2002. Support policies to Senegalese fisheries in: *Policy implementations and Fisheries Resource Management: lesson from Senegal*, by Dahou, K., Tiers Monde, E., Dème, M. United Nations Environment Programme, Geneva, 97p.

Wenzel, H., Hauschild, M. and Alting, L. 1997. Environmental Assessment of Products, Chapman & Hall.

APPENDIX

Price paid by industry for different calibers (sizes) of shrimps and related weight and length

Calibre	Maximum No. of shrimps/kg	Value (FCFA per kg)	Max weight (g)	Minimum weight (g)	Maximum carapax length (mm)	Minimum carapax length (mm)
1	20	7 050	>50	50	>43	43
2	30	5 600	50	33	43	37
3	40	2 000	33	25	37	33
4	60	1 275	25	17	33	29
5	80	975	17	13	29	26
6	100	675	13	10	26	24
7	120	575	10	8.3	24	22
8	200	450	8.3	5.0	22	18
Undersized	>200	-	5.0	>0	18	>0

ISBN 978-92-5-106302-6 ISSN 2070-6065

9 789251 063026

I0910E/1/06.09/360