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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

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Summary

Life Cycle Assessment 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 catch zone 34 (eastern central Atlantic), then landed and stored before export 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 shipment to Europe. The three fisheries included (trawl, mujas and félé-félé) were shown to lead to highly different catch compositions. Each fishing method has advantages and drawbacks from a biological point of view, i.e. proportion of discard, landed by-catch 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, processing and storage dominated the two categories global warming and ozone depletion potential while fishing was the most important activity from a biological point of view. The main areas to improve regarding global warming and ozone depletion potential in the production chain of the trawled product are reducing the use of fuel and refrigerants onboard, while the main areas for improvement in the chain of the artisanal product are reducing the use of energy and refrigerants in the processing plant as well as replacing the energy source used. Both onboard 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. From a biological point of view, spatial regulation of the artisanal fisheries that would make the artisanal fishery take place upstream rather than downstream, would be advantageous. The introduction of mesh size regulations would likewise be favourable, as would the introduction of selectivity devices in the trawl and mujas fisheries. Stock assessment and any limitations of fishing effort resulting from this constitute the basis of sustainable fishing practices. Increased traceability and labelling is also desirable to enable active consumer choices between products.

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Acknowledgements

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1. Background

This study was carried out as a collaboration between the Fisheries and Aquaculture Department at the Food and Agricultural Organization of the United Nations (FAO), the Swedish Board of Fisheries, the Swedish Institute for Food and Biotechnology (SIK), IDEE Casamance and Centre de Recherches Oceanographiques Dakar-Thiaroye (CRODT). The biological part of the study also resulted in a B.Sc. thesis where that part is presented in more detail Emanuelsson (2008). The present report starts with a background description of the area, species and fisheries as well as the studied production chains. The aim of the study is presented followed by an outline of the methodology used. The results and discussion are combined, in order to explain the assumptions made within the study, and divided into two parts: inventory results and results from the impact assessment. Sensitivity analysis, improvement options, conclusions and lessons learnt conclude the report.

1.1 The area

The Casamance is the southernmost region of Senegal located north of Guinea Bissau and south of Gambia in West Africa (Fig. 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.

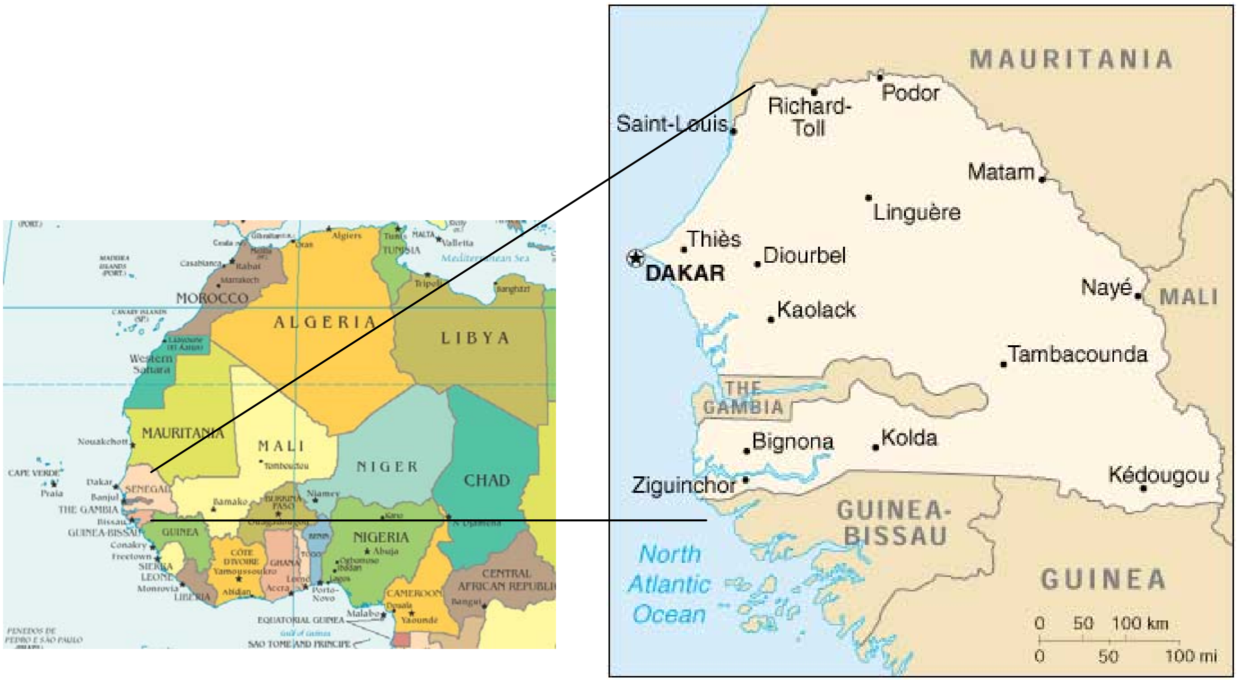


Figure 1: *Location of Ziguinchor along the Casamance River in southern Senegal*

1.2 The species

The southern pink shrimp (*Penaeus notialis*) occurs in estuaries and coastal waters of West Africa from Mauretania to Angola, where it inhabits muddy sand bottoms at depths ranging from 2-100m. 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 (L'Homme and Garcia 1984, Garcia and Le Reste 1981). 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 higher than in the sea due to high evaporation especially in the shallow areas and high salinity 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 fisheries

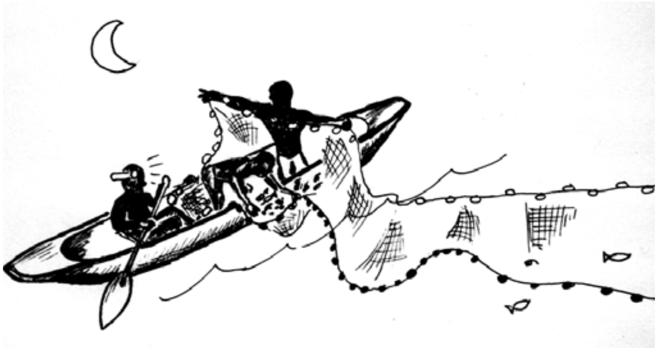
The Casamance fishery
Traditionally shrimp fisheries in the Casamance have been undertaken for subsistence purposes only, deploying moderately efficient fishing methods and regulation between fishing villages initiated by the local population has been sufficient to keep the stock viable (IDEE Casamance). Around 90 fishing villages and 6-8.000 fishermen depend on the shrimp fishery are located along the Casamance River (IDEE Casamance 2007) as well as a number of employees at the processing plants (around 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 as is indicated by decreasing catch per unit effort (CPUE) data, (UNEP 2002, Anon. 2007) in the trawl fishery at sea. 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 are therefore connected. No estimates of CPUE in the Casamance fisheries have been documented so far. According to the two references mentioned above, however, CPUE at sea, i.e. in the trawl fishery, decreased by over 90% between 1970 and 2005 (UNEP, 2002, Anon. 2007).

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

- 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.

- 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.

a)



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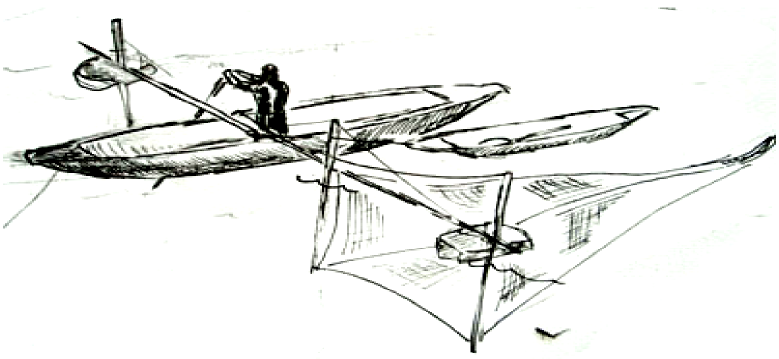


Figure 2: *The two most common artisanal fishing methods in the Casamance: a) Féle-félé and b) Mujas nets (moudiasse) (Sketches by Andreas Emanuelsson).*

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 quantitites 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% of total pink shrimp landings in Senegal which varied between 2.500 and 3.600 tonnes between 2004 and 2006. Consequently, around 40%, or 1.100-1.600 tonnes are fished in the trawl fishery described below (DPCA, Diarra Dioup unpubl.).

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 inofficial 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.

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% 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 ever since the 1970s mentioned above, a discussion about decreasing the number of licences is ongoing.

2. Aim

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. Methods

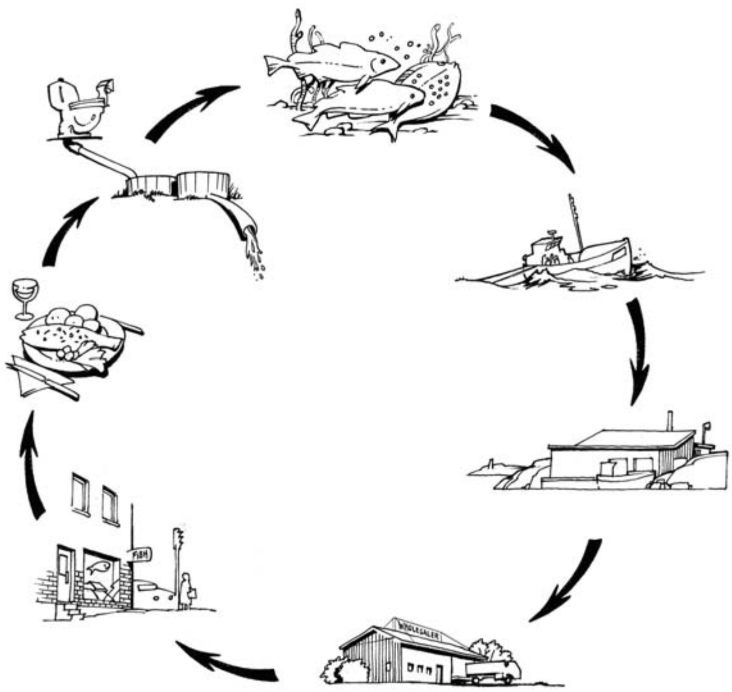
3.1 LCA methodology general

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 (Fig. 3a). 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 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 support conscious choices about what to purchase. 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 one 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 inefficient types of production are 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.

LCA methodology is standardised 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 eco-labelling.

The performance of an LCA is divided into four main parts: i) Goal and scope definition, ii) Inventory analysis, iii) Impact assessment and iv) Interpretation of results (Fig. 3b).

a)



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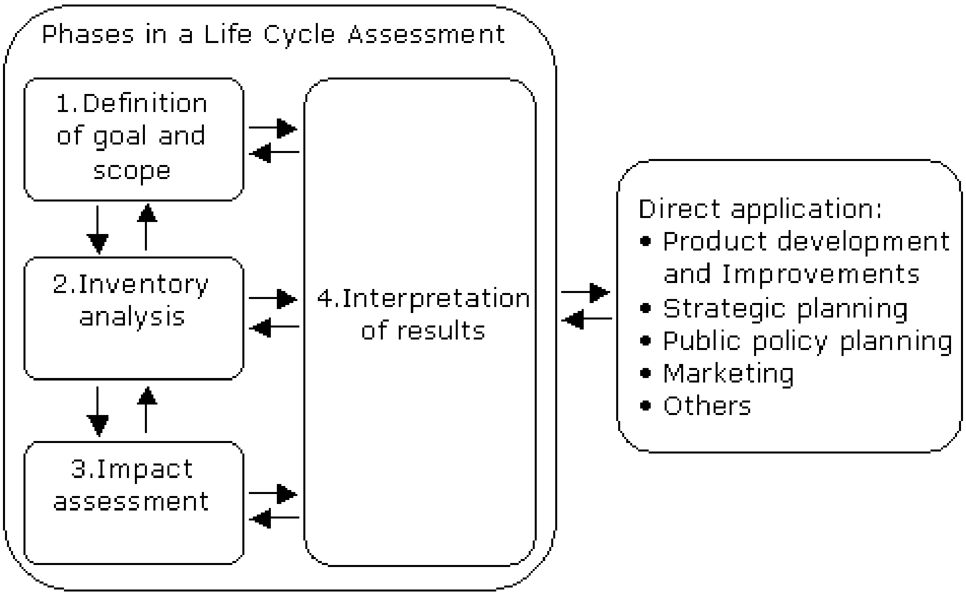


Figure 3: *a) The life cycle of a seafood product, illustration by Jürgen Asp. b) The four steps in Life Cycle Assessment and possible applications of results*

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.

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 supply materials and services such as packaging 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. Another approach, recommended by ISO, 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.

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.). Characterisation together with qualitative assessment of types of environmental impact that cannot be characterised 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)	1810
Refrigerant HFC 404a (known as R404a)	3700

Normalisation, Weighting, Interpretation and Sensitivity analysis
Normalisation 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 finalise 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 & Tillman 2004, Hauschild & Wenzel 1997, Wenzel et al.1997).

3.2 LCA methodology specific to the present study

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% 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 rivershore, where they are bought and transported by several traders to the processing plants in Ziguinchor by a pick-up (Fig. 4, chain to 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% of the Casamance shrimps are exported to Europe (IDEE Casamance 2007), in 2007 mainly to the UK and Spain (Exportation des expediteurs, 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, food miles, is often debated.

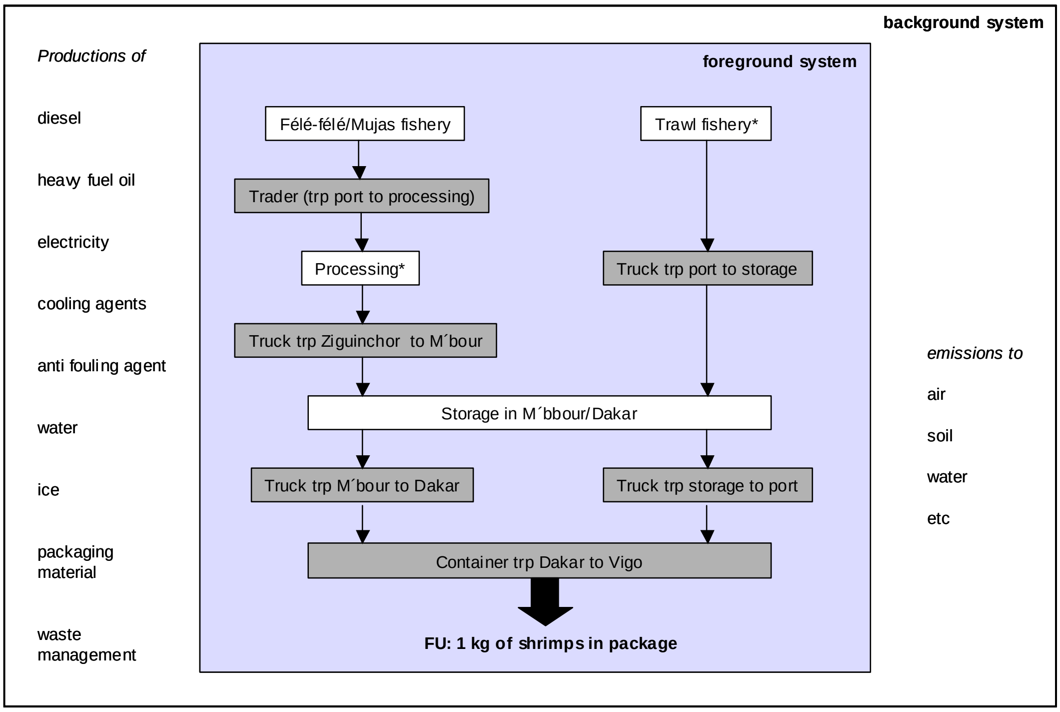
In the case of the trawl fishery, processing, including packaging, is done at sea (Fig. 4, chain to the right). The products are landed and taken for storage in Dakar where they are stored for, on average, 1-2 months. From there, the same type of transport on container freighters takes the product to the European market. The main market for shrimp product from trawl fisheries are Greece, Portugal and France (Exportation des expediteurs, 2008).

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.

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 fish 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: The specific energy use to make ice and the energy use for freezing were determined since these are used for specific products only. Since 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% of total) was designated to them. In the sensitivity analysis, the alternative option to let the large shrimps account for 100% of energy and water use was tested in order to see how much difference this would make.



* including packaging and freezing

Figure 4: *Flowcharts for the studied chains (grey boxes = transports). Shaded area represents the foreground system and the white area the background system.*

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 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 (around half félé-félé and half mujas, the number of useful samples differed somewhat for the 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 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 Oceanographiques 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 so 19 out of the total number of vessels of 30 were covered. The largest company alone accounts for around 60% 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 for electricity use in the Dakar region) was found on the website of the International Energy Agency.

Biological aspects assessed

In addition to the characterised LCA results, the biological aspects: target stock impact, discard and seafloor impact are partly quantified and discussed, based on field data gathered. The target stock impact was described based on available literature and interviews. With regard to discard, fishermen were either instructed 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. Length distribution of landed shrimps was measured (carapax length) and landed by-catch was identified to species or genus and weighed, as were the landed shrimps. The seabed impact of demersal shrimp trawls was roughly estimated roughly 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). Artisanal fishing methods were considered not to cause seafloor impact. More detail on methodology regarding the biological aspects can be found in Emanuelsson (2008).

[1] A Swiss life cycle data database.

Socioeconomic aspects assessed
Two socioeconomic indicators were quantified along the two production chains (artisanal and trawled), namely working hours and revenue. This was done by asking fishermen and to some extent the staff at the processing plant about working hours in relation to amount produced and revenue. Information from shrimp traders as well as official statistics and information about consumer prices in Spanish supermarkets constitute the basis for the analysis of the shrimp value chain. It should be mentioned that this is not normally a part of LCAs, it was not initially a part of the project and is only due to our experience and interest in this field. Hence, the effort that has been put on these aspects is not as structured and planned as in the other areas and the results therefore by no means represent a complete picture of the topic (an alternative is to take it out completely).

Method for Impact Assessment
For the third of the four steps mentioned in Figure 3b, a method has to be chosen for the Impact Assessment and which environmental impact categories to include. In this case, the method chosen was developed by the Institute of Environmental Sciences (CML) at Leiden University, the Netherlands. The method is called CML 2001 and it was updated with 2007 IPCC indicators for global warming potential. As an alternative, the method IMPACT 2002 was tested in the sensitivity analysis on the basis of its toxicity categories which were assumed to be important due to the use of anti-fouling substances in the trawl fishery and the use of mercury containing batteries in the artisanal fishery. The categories included were 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 LCA was carried out using LCA software SimaPro v.7.1.6.

4. Results and discussion

The results are divided into two parts: inventory results and characterised results from the LCA. **Inventory results** include the results obtained regarding the biological and socioeconomic aspects mentioned above as well as results of the LCA data inventory for important resources used along the chains (e.g. fuel and refrigerants). **Characterised results** include the latter ("traditional" LCA data) after impact assessment and these are presented both for the fishing phase alone (i.e. per kg of shrimps landed) and per kg 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. Table 5 intends to summarise the result of the comparison between the three fisheries by indicating a plus or a minus in each category and the main activities contributing to the result in that category and fishery are listed.

4.1 Inventory results

As evident in Figure 5, the catch composition for the three fishing methods differed considerably.

Size composition shrimps

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 kg). Mujas fishing has a small size ratio in between the other two methods with an average of 12% of the catch being small.

Landed by-catch

Another major difference is the difference in the fish by-catch landed, which represents more than half of the catch[2] in the trawl fishery in terms of weight (representing 54% of the value of landings, with shrimps representing 46%). 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% and shrimps 95% 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 by-catch in trawl fishing. See Table 2 for the most common by-catch species landed in artisanal fisheries (this information is not available for the trawl fishery). It should be noted that in Figure 5, the discard is included. The discard has no value, but represents a considerable part of the catch in terms of weight. Looking at the landings of the trawl fishery rather than the catch, the value distribution is equal (46% shrimps and 54% fish) but the weight distribution is rather different: 12% shrimps and 88% fish.

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). Swimming crabs are not known to be overexploited.

[2] Catch-discard=landing=target catch+ by-catch

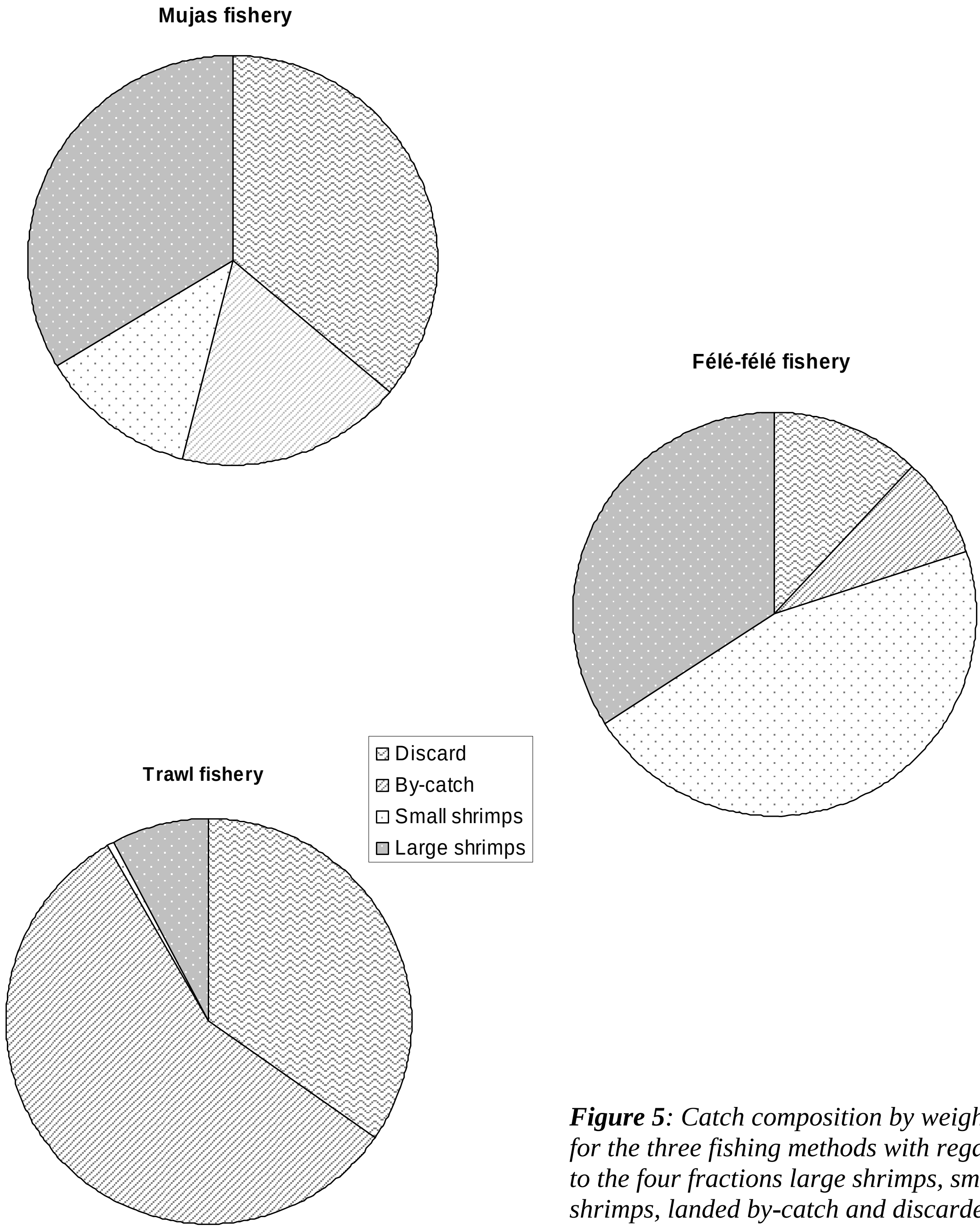


Figure 5*: Catch composition by weight for the three fishing methods with regard to the four fractions large shrimps, small shrimps, landed by-catch and discarded catch.*

The biological 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, by-catch 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, some (small-size ratio and mean catch) also between locations.

***Table 2**: Most common species in landed by-catch*

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 3:** Landed small shrimps, landed by-catch (other species) and discard* ***per kilogram of large shrimps landed**.*

Fishery	Landed small shrimps (kg)	Landed by-catch (kg/kg s)	Discard (kg)
Félé-félé	1.3	0.25	0.13
Mujas	0.38	1.2	0.55
Trawl	0.09	7.0	5.4

To conclude this section about the biological aspects studied, each fishery has its own very specific pattern of catch composition. Mujas, the fixed nets, essentially catch larger shrimps but also have both a higher discard and by-catch rate. Félé-félé, the drift nets, on the other hand, catch much smaller shrimps with lower by-catch and discard rates. Trawls catch larger shrimps, but have high rates of both fish-bycatch and discard. As mentioned earlier, more detail can be found in the B.Sc. thesis, resulting from the same project, focussing on the biological aspects (Emanuelsson 2008). Table 3 summarises the biological results of the study.

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 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% of the value) and 35.000 kg of fish (54% of value) gives an average seafloor area impacted of 10100 m^2 per kg of shrimps landed (using economic allocation). That area corresponds roughly to one hectar. This figure gives an indication about the scale of the impact. The actual effects of this impact depends of course on the distribution of the impact geographically (i.e. whether the same area is trawled many times or the impact is evenly distributed over the area) and the sensitivity of the marine habitat impacted. A seabed of sand or cobble has a higher resilience to trawl impact than e.g. muddy seabeds or coral reefs (Collie et al. 2000).

Socioeconomic aspects
As an extension of this study, an attempt was made to quantify two socio-economic indicators. Focus was on the primary part of the production chain, i.e. the fishery, but also on the trader (taking the shrimps from the landing sites to the processing plants) and to some extent the processing plant. Data for the rest of the chain would be very useful and interesting (i.e. transports, wholesale etc), but since the socioeconomic part was originally not a part of the project, which was planned as a purely environmental study. Therefore the few data that could be obtained regarding socioeconomic aspects while gathering environmental data are only to be viewed as a complement and the analysis is not claimed to be complete. The indicators chosen were working hours and revenue, they were chosen because it was possible to find data (not necessarily because they were the optimal indicators) and because they are both in different ways relevant in order to draw conclusions about the socioeconomic impact of the different fisheries. The indicators were also related to the functional unit, to make comparison between the different fishing methods possible. The revenue is also presented as share of final consumer price to illustrate the value added through the chain.

The mean catch of days fishing is a lot higher for the félé-félé, but calculated per person (since three men are operating the félé-félé net and only one person the mujas net) mujas is most effective of the artisanal methods, even more when the actual working hours are accounted for see Figures 6a) and b). A normal working day for a fisherman is about 15 hours on a trawler, 6 hours for mujas and 15 hours (of which 3 hours are fixing the nets etc) for félé-félé. Typically the fisherman in the artisanal fishery works all days, as compared with 25 days per month in the trawl fishery. Adjusting for that, the average working day is 12.5 hours for trawling.

Fig. 6 a)

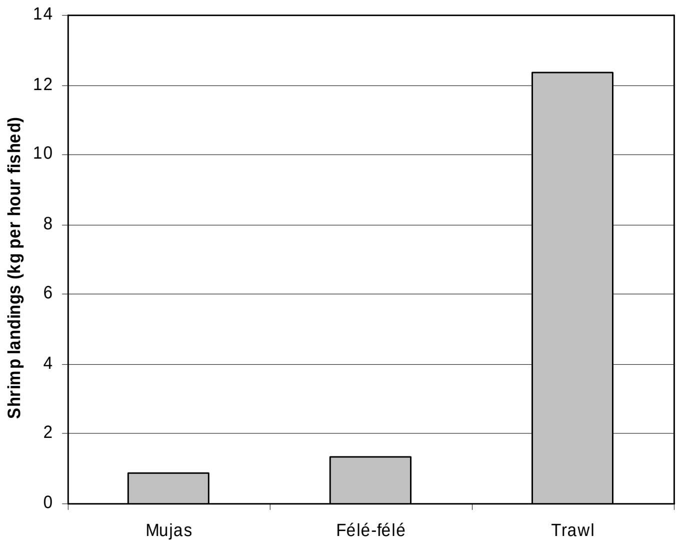


Fig. 6 b)

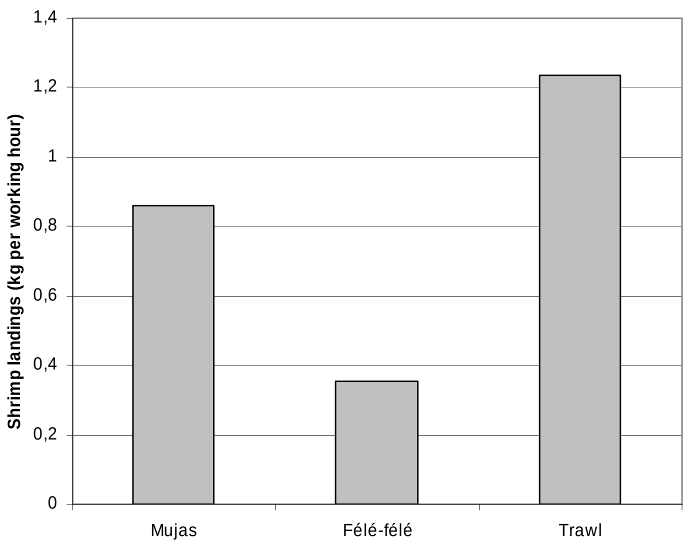


Figure 6*: Shrimps landings per a) hour fished -from a biological point of view and b) per working hour- from a socioeconomic point of view*

Figure 6b shows the amount of shrimps landed by hour and person. Calculating the person hours worked per kg of shrimps landed instead, it gives 0.08 hours for trawl, one hour for mujas and three hours for félé-félé. The range is considerable depending on variable landnings.

The fisherman in the Casamance area (artisanal fishery) is paid per landed amount of shrimp and fishermen using mujas are usually paid more than the ones fishing with félé-félé as their shrimps are, on average, larger. The shrimps are typically bought by a "trader", collecting all shrimps to sell to the processing plants. The plant pays depending on the size of the shrimps (prices for different sizes are presented in the Appendix). The results from interviews showed that the price per kilo obtained by the mujas fishermen was 50% higher per kg compared to the félé-félé fishermen.

The average revenue per working hour and person for mujas is 0.9 euro and for félé-félé 0.2 euro meaning that the amount revenue per person and day is 5.5 euros for mujas and 3.3 for félé-félé, as shown in Fig. 7.

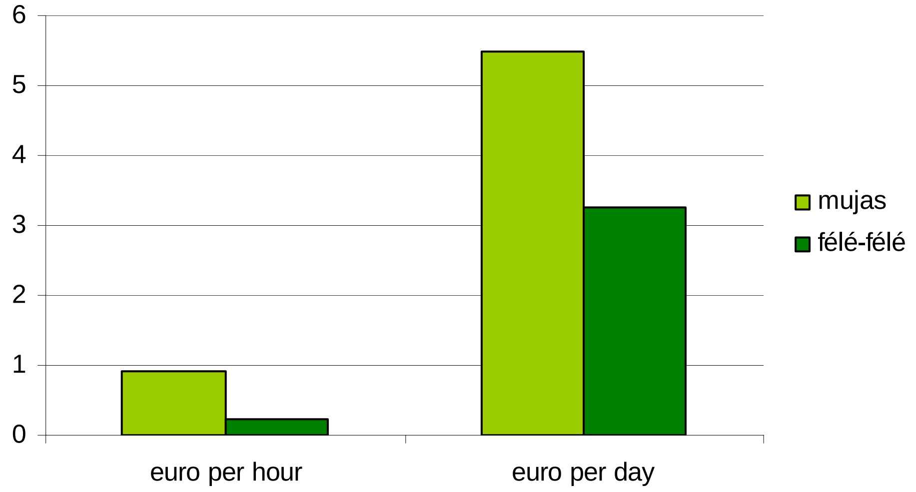


Figure 7: *Revenue per working hour and day for mujas and félé-félé respectively.*

The products coming from the trawl fishery and the artisanal fishery respectively differ: The output from the trawl fishery is frozen shrimps packed in boxes (as processing takes place onboard), while the shrimps from the artisanal fishery are unprocessed. As a consequence, the products are not comparable at the point of landing and the price paid for the trawled shrimps is considerably higher than for the artisanal ones. In addition, the average shrimps from the trawl fishery are larger which also contributes to the higher price.

Figure 8 shows the value of trawled and artisanal shrimps respectively. The fishery for the trawled shrimps also includes freezing and packaging (so 'fishery', 'trader' and 'processing' in the case of artisanal are comparable to 'fishery' for trawl). The value per kg of shrimps is double for the trawled shrimps compared to the artisanal, as there is a higher proportion of large shrimps. As a consequence, the final consumer price for the artisanal shrimps is assumed to be half of those trawled. For the trawled shrimps, the final consumer price (in a supermarket in Spain[3]) is estimated at 15 euros per 2 kilo-box and for the artisanal 7.5 euros per 2 kilo-box.

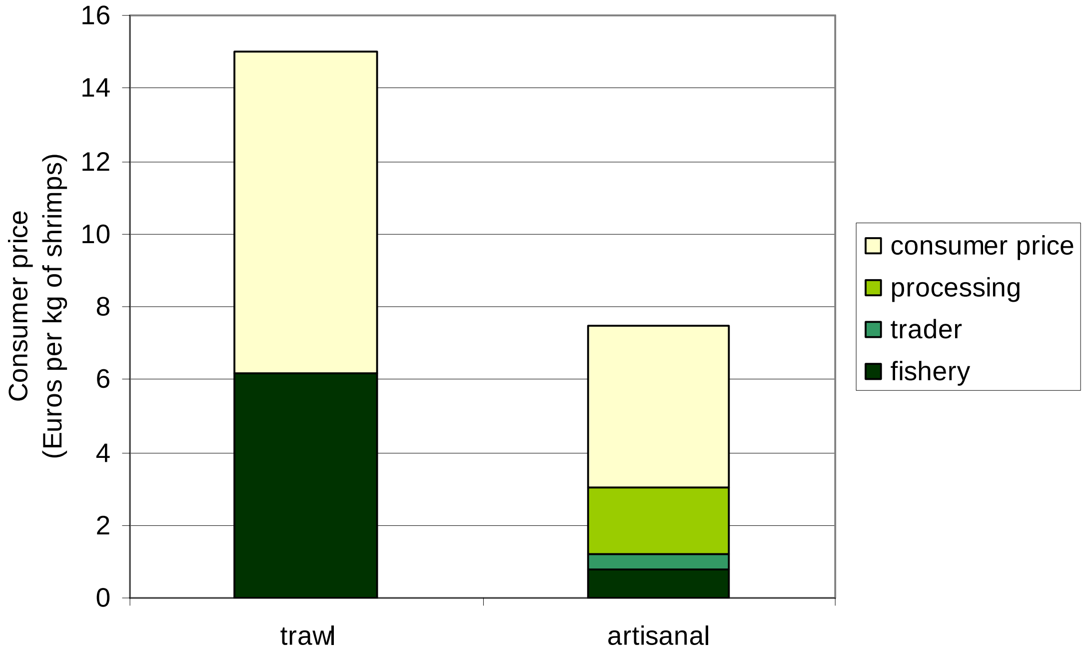


Figure 8: *Value of shrimps at fishery stage, trader, processing and final consumer price for trawled and artisanal shrimps respectively.*

Data for costs could not be obtained, which is why it has not been possible to calculate or even estimate the net profit in the different stages. The figures used in this section are based on interviews which of course entails a great deal of uncertainty, but the results still can give an indication about the input of labour and value distribution along the chain.

It can be mentioned that, since the artisanal shrimp fishery in the Casamance employs 6-8000 fishermen altogether landing 800-1200 tonnes of shrimps annually, while the trawl fishery lands 1100-1600 tonnes of fish employing around 300 trawl crew members. These figures show that a tonne of shrimp landed in the artisanal fishery provides livelihood to seven artisanal fishermen, while a tonne landed in the trawl fishery provides livelihood to 0.2 fishermen (i.e. landing of five tonnes of shrimps are needed to support one trawl fisherman).

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% of félé-félé fishery is engine-driven, using around 10 l of gasoline per day to land approximately 16 kg of shrimps or around 0.63 liter of gasoline per kg of shrimps.

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[3] The final consumer price differs a lot depending on the size of the shrimps. The price chosen here is estimated based on prices in supermarkets in Spain.

This gives an estimated average petrol use of 0.063 l/kg shrimps for félé-félé nets and 0.046 l/kg artisanal shrimps on average. 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 l/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 pages 11 and 13), this makes a big difference (the average fuel use per kg of mixed catch landed was 2.6 l/kg). Shrimps on average represented 12% in weight, but 46% by value of the landed catch.

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 0.07g R22 and 0.5 g R404a per kg of shrimps produced.

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, one of them was chosen for the calculation of aquatic emissions of copper. For copper and xylene, the active ingredient (CuO) and a solvent, 100% of the applied amount (0.05grams of paint/kg shrimps) was assumed to be emitted to water.

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% (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.

Water and ice in the processing plant
The total amount of water used at the processing plant during a year was 7683 m^3. Subtracting the amount of water used to produce the 3650 tons of ice (4015 m^3) produced in a year leaves 3478 m^3 of water used for other purposes such as washing the shrimps and cleaning the facilities. Shrimps are washed with bisulphite, around 0.05l/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 tons of small shrimps and 253 tonnes of fish), the water use per kg of product (allocation based on mass) is around six litres per kg 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.

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%. Hydropower and biofuels contributed with 11 and 12% respectively in the average Senegalese electricity production (75% oil and 2% 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% were assumed in both cases due to information found at the IEA website. In the processing plant, 7.3 MJ were used per kg of shrimps processed, during storage an additional 5.3 MJ were used.

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% of the weight is cotton, 50% 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 kg 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 (20kg), it is concluded that less material is used for gear in the mujas fishery per kg of shrimp landed, despite the lower daily catch in this fishery. Due to lack of data on cotton production, however, the use could not be evaluated further.

4.2 Characterised (LCA) results

The data were inserted into the LCA software SimaPro 7.1.6 where a model had been built of the two production chains. 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 calculates the results to 1) to correspond to the functional unit and 2) to classify all those emissions contributing to the respective category of environmental impact (global warming, eutrophication etc.) and 3) characterise them, i.e. multiplying them with the impact indicator of each emission (see Table 1 for global warming e.g.) in order to obtain one result per environmental category. The characterised LCA results are shown for the fishing phase (per kilogram of shrimps landed in the three fisheries) for some categories (Fig. 9) and for the full life-cycle (per kilogram of product delivered to Vigo from artisanal and industrial fisheries) for all categories (Fig.10 and Table 4).

Because of uncertainties in some of the material, the *results should primarily be used to identify important activities from an environmental point of view*, as mentioned earlier.

Overall (all categories)

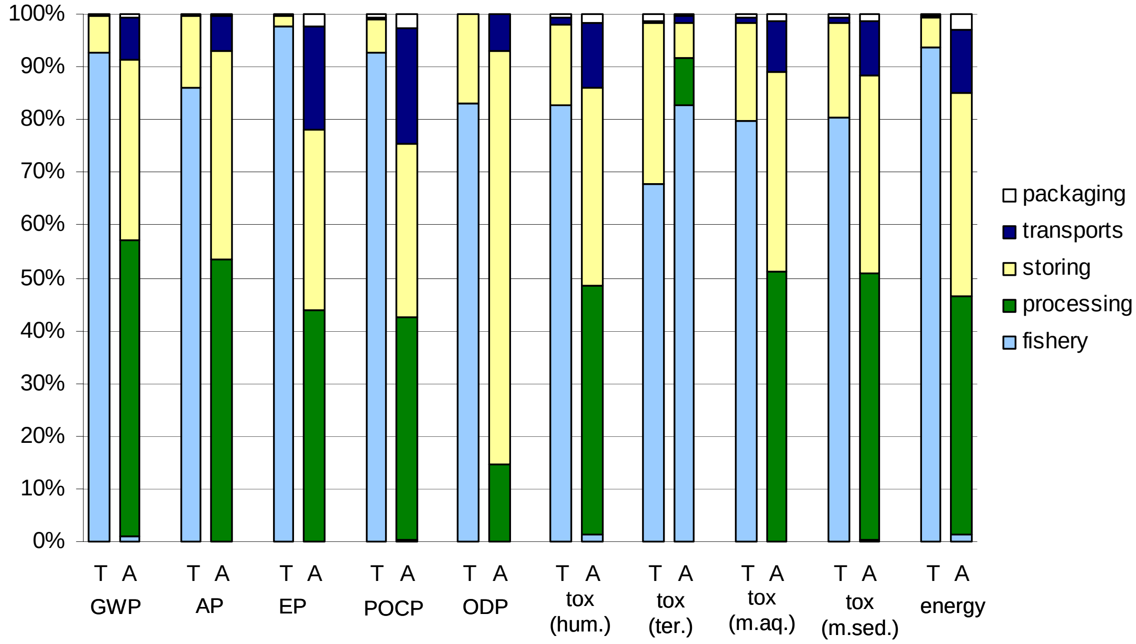


Figure 10: *Relative results of impact assessment T= trawl, A=artisanal for different activities in the chain. The impact categories studied are global warming, acidification, eutrophication, photochemical creation, ozone depletion, human toxicity, terrestrial ecotoxicity, marine aquatic ecotoxicity, marine sediment ecotoxicity and energy.*

Table 4: The results from the lifecycle impact assessment presented per FU (1 kg of shrimps) for the impact categories included, where CO_2e means carbon dioxide equivalents etc. Processing is zero for trawled shrimps because processing is done in the fishing phase.

		fishery	processing	storing	transports	packaging	**TOTAL**
GWP (kg 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 (kg 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 (kg 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 (kg 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 (kg 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) (kg 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) (kg 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.) (kg 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.) (kg 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**

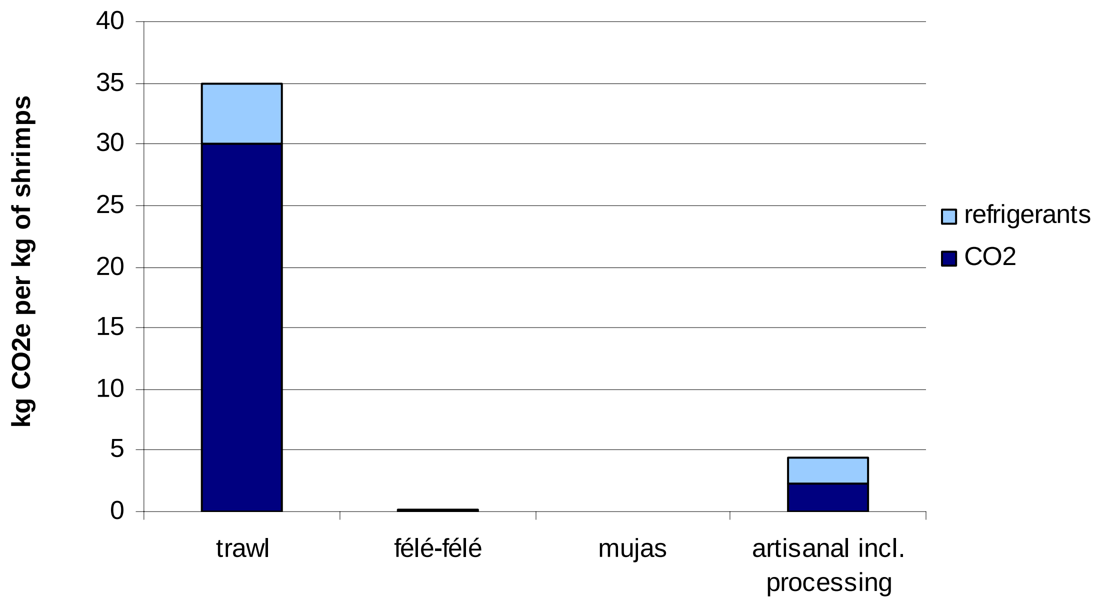
Table 5: Summary of results of comparisons between the three fisheries in the different environmental impact categories included (+ means overall better environmental performance, - means overall less good environmental performance), main factors influencing the result (both positive and negative) in 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

Global Warming Potential

As is evident from Figure 7, 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 l 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 kg 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 (Fig. 9a).When the life-cycle after landing is added, the artisanal product causes emissions of 7.8 kg CO_2e per kg of product and the industrially fished product 38 kg CO_2e per kg. 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.

9a)



9b)

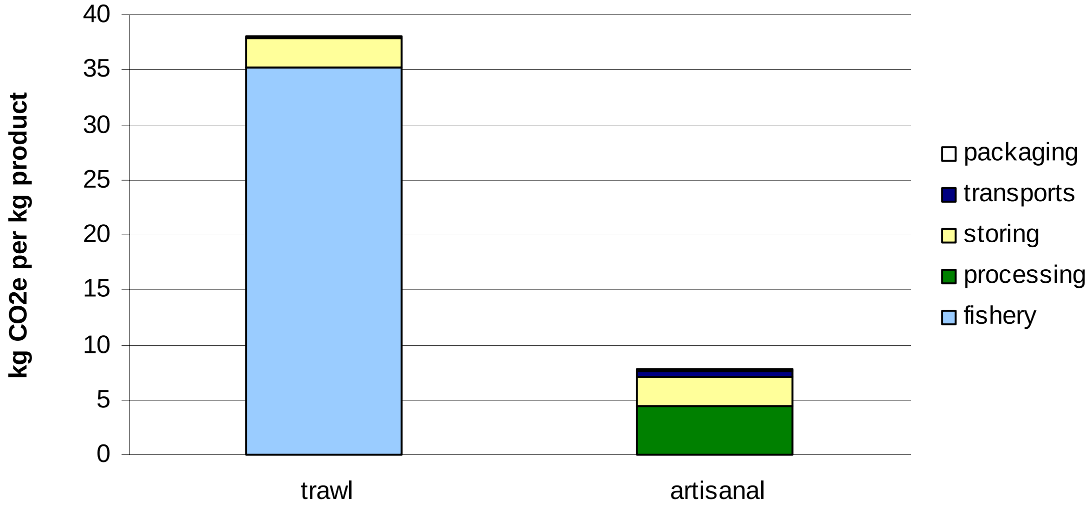


***Figure 9**: Global Warming Potential caused by a) a kilogram of shrimps landed by the three fishing methods, b) a kilogram of shrimp product delivered to Vigo and fished either in artisanal fisheries or in the trawl fishery indicating contributions of different life-cycle phases.*

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%) only 10 percent of the heavy fuel oil used for electricity production in the Casamance (4%), 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.

Eutrophication Potential (EP)
The difference with regard to eutrophication is considerably larger and this category is dominated by emissions of nitrogen oxides from combustion of fossil fuels in both chains.

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% of the artisanal products emissions).

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. 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.

Toxicity categories (human, terrestrial, marine aquatic, marine sediments)
Artisanal fisheries score 50- 60% lower in all toxicity categories 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.

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% 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.

4.3 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.

2) the proportion of outboard engines among félé-félé boats (decreased from 10% to 5% or increased to 100%)

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).

4a) letting the shrimps account for 100% of electricity and water use at the processing plant instead of 50% (that were said to be due to the ice production for the other products)

4b) 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).

5) allocating the energy and refrigerant use for storage based on mass instead of economic value

6) testing another method of characterisation especially regarding the toxicity categories (from CML 2001 to EDIP 2003 and IMPACT 2002)

7) Letting the processing plant use a renewable energy source (solar energy) and environmentally harmless refrigerants.

8) Assuming there were product losses in the chains and that the two chains differed with regard to this aspect.

The result of each aspect was studied in the impact categories influenced most by this specific aspect. The results are outlined below.

1) 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% (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% higher) if more félé-félé is used, except for terrestrial ecotoxicity, which is around one percent lower.

2) Assuming that a lower proportion of félé-félé fishermen use outboard engines (5% instead of 10%) implies a negligible difference at the product level in global warming potential, while increasing the proportion to 100%, as a kind of worst case future scenario, would lead to a 10% increase in global warming potential at the product level. At the fishery level (i.e. per kg 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) 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% 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% higher impact of the overall results.

4a) 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[4] 35% (GWP) and 60% (ODP), depending on the impact category. The relatively higher contribution to ODP depends on the refrigerant used in the processing

[4] Terrestrial ecotoxicity only increased with 8%

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 as high a contribution to GWP compared to R22.

4b) When mass allocation is used instead to divide the environmental burden between the products in the processing plant (frozen shrimps, small shrimps and fish on ice), the environmental impact is around 25% (32% for GWP) less compared to the base case[5], except for ODP which increases by 4%.

5) If mass allocation would be applied in the storage phase instead of economic allocation, the environmental impact would decrease by up to 60% (ODP) for the artisanal shrimps. GWP, AP, EP and POCP would decrease by between 10% and 20% for artisanal. For trawled shrimps the result would not decrease as much: 13% for ODP, 10% for AP, 5% for GWP and POCP and 1% 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 here.

6) 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 inconsistences 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).

7) 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 kg 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.

8) Due to the lack of data on product waste (i.e. marketable product that is wasted on its way from the fishery to the consumer) it was assumed to be negligible. This makes sense since the product is only followed until transport to the wholesaler and product waste is often highest in the last life cycle phases consumer and retailer. Moreover, the products are frozen immediately after processing which also typically leads to low product losses. However, if it was e.g. 5%, then 5% more shrimps would have to be fished, processed and transported in order to get a kilo of the product to Europe (and consequently, all impacts would increase by 5%). More importantly, if the product losses should differ between the two chains, this could have a significant impact on the

[5] Terrestrial ecotoxicity would decrease with over 60%

results. This is important to keep in mind even if it cannot be assessed quantitatively due to lack of data on this matter.

4.3 Improvement options

Based on the results presented above, a number of options that would considerably improve the environmental performance of the studied products can be identified. The improvement options suggested below only concern environmental aspects, as this is the focus of the study. They do hence not reflect what is feasible from political, socioeconomic, or other perspectives.

Improvement options in the fishery

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 optimise each of them. 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. An additional advantage of this would be a decreased need for the use of outboard engines which accounted for the main part of the environmental impact in the LCA impact categories of artisanal fisheries in the fishing phase. The engines are used to fish further downstream and never used to fish upstream. The use of outboard engines in félé-félé fishing should therefore be discouraged both due to the biological impact of fishing further downstream and due to the emissions from fuel combustion resulting from having to reach fishing locations further away. Moreover, the use of mercury-free batteries and the collection of used batteries should be encouraged[6]. Providing fishermen with environmentally friendly batteries could be an option. 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”. Regarding the more typical LCA resources and environmental impact types, the use of fuel and refrigerants in the trawl fishery is very high. Although there are certainly 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.

Improvement options after landing

For the trawled shrimps, processing and packaging is done at sea and included in the fishing stage, which explains (probably a minor) part of the difference between the fisheries in energy use, global warming potential and ozone depletion potential. Artisanal shrimps scored very low in term of resources used for fishing and the processing phase dominated the same categories (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

[6] Actually, battery collection has already been implemented since the inventory was completed.

a switch to less harmful refrigerants and/or decreased leakage represents important improvement option regarding in this respect.

Consumer pressure increasingly requires traceability schemes and on this basis, traceability and labelling of the products in terms of their originating in artisanal or industrial fisheries, perhaps even to distinguish between the félé-félé and mujas fisheries would be desirable to make active consumer choices possible.

Comparisons with other shrimp production systems

Fuel use in north Atlantic shrimp (*Pandalus borealis*) trawl fisheries have been reported to be in the range of 1.2 l/kg (Thrane 2004) and 0.7-2.3 l/kg (Tyedmers 2001). The former used economic allocation, the same method used in the present study, the latter mass allocation. The fuel use reported in Tyedmers (2001) would have been higher if the difference in value between shrimp and fish catch had been taken into account. Shrimp trawl fisheries in general seem to be energy-intensive (Thrane 2004, Tyedmers et al. 2005) and the studied shrimp trawl fishery in Senegal is no exception. The use of fuel per kg of shrimps landed is very high independent of which method of allocation is used.

Both the trawled and the artisanal shrimps are much higher with regard to global warming emissions than tropical farmed shrimps (<5kg CO_2e/kg including the whole chain from feed production to the consumer) (Mungkung 2005, Mungkung 2006) due to several factors, which are explained below. High productivity of intensive farming systems and the fact that economic allocation is used to allocate between food and feed fish caught in the same fishery, which places much less environmental burden on the shrimp feed than would other allocation methods. The same method of allocation is used in the Senegal shrimp fishery to separate the environmental burden between fish and shrimps and leads to higher impact being placed on the shrimps compared to the fish landed in parallel than would other methods.

5. Conclusions

There are major differences between the artisanal fishery and the trawl fishery in all environmental impact categories included. Trawling uses much more fuel and refrigerants and leads to much higher amounts of landed fish by-catch, discard and seabed impact than do the artisanal methods.

Since processing is done onboard the trawlers it is not completely fair to compare the fishing phase alone. The difference decreases when processing on land is added to artisanal fishing but still the trawl fishery leads to five times higher global warming emissions than artisanal fishing including processing. Transports and packaging only contribute a minor part to the overall result in both chains. The most important biological improvement options for the trawl fishery in addition to performing stock assessment and relating the fishing effort to its results, consist in implementation of more selective gears that separate the shrimp and fish catches from each other. Exchanging the refrigerants used onboard from so called synthetic (e.g. HCFCs and HFCs) to natural ones (e.g. NH_3 and CO_2) would result in considerable improvements in the categories ozone depletion potential and global warming potential.

There was a considerable difference between the two artisanal fishing methods studied as well, with the félé-félé fishery landing a much higher proportion of small sized shrimps. Mujas fishing has a smaller proportion of small shrimps, but has a higher proportion of discard and fish by-catch (both with a very low value). The introduction of selectivity devices in the gear represents an improvement option for the mujas fishery. However, a considerable part of the discard is constituted by swimming crabs which are much less problematic from a biologic point of view, than the discard in the trawl fishery which consists of fish species believed to be over-exploited (UNEP 2002). The proportion of small shrimps increases with fishing taking place further downstream and, in addition, outboard engines are used to reach these fishing locations. Regulating the félé-félé fishery spatially to areas upstream, where the proportion of smaller size classes is lower and which would decrease the need to use engines would be beneficial both from a biological and from an LCA perspective. The only category where artisanal fisheries had higher results than the industrial was in the category terrestrial toxicity, which was because of the use of mercury-containing batteries that were disposed on the beach. The use of less harmful types of batteries and the collection after use therefore represents an improvement option in this aspect. The most important post-landing activities are processing and storage with the use of fossil-based energy and refrigerants. Exchanging the energy source and type of refrigerants used and decreasing the amounts used represent important improvement options. Artisanal fisheries create more livelihood for fishermen per tonne of shrimps landed than does the trawl fishery.

Consumer pressure requires traceability and therefore traceability and labelling of the products as to origin in artisanal or industrial fisheries, perhaps even to distinguish between félé-félé and mujas fishery would be desirable to make active consumer choices possible.

6. 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 from local and national authorities. 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 industrialised 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 an external expert with experience of doing LCA of shrimp aquaculture in the planning of the project, but since she could not make the final review of the report, had to find another reviewer. 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.

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. Assessing the environmental performance as well as advantages and opportunities for improvement of food production in developing countries has been very inspiring and rewarding.

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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	7050	>50	50	>43	43
2	30	5600	50	33	43	37
3	40	2000	33	25	37	33
4	60	1275	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