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Life cycle assessment (LCA) of Kangamiut Seafood products

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Preface

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CONTENTS

1 Introduction

This report presents a detailed cradle-to-consumer life cycle assessment (LCA) screening of fish products sold by Kangamiut Seafood products. Kangamiut Seafood is a trading company and is not directly involved in fishing operations, however the activities of their suppliers and other affected systems are included in the product life cycles.

In addition, carbon offsetting potential for Kangamiut Seafood is included as part of the assessment.

The study covers a wide range of environmental impacts, including greenhouse gas (GHG) emissions (i.e. carbon footprint), nature occupation, respiratory effects, eutrophication etc. The LCA addresses both direct land use changes (dLUC), indirect land use changes (iLUC), and in connection makes use of recent developments in land use changes (LUC) modelling to include GHG emissions. The primary focus is on GHG emissions.

The LCA model has a flexible design, which allows future updates, such as calculating results every year in the future, to be carried out with a minimum of extra work.

2 Goal and scope

The purpose of the study is to carry out a high-level cradle-to-consumer screening LCA of Kangamiut Seafood's products, with focus on greenhouse gas emissions. Further, the purpose is to identify and investigate improvement options and to provide recommendations on how Kangamiut Seafood can reduce the environmental impact per unit of product. The LCA results are based on the following main life cycle stages: fishery, transport/wholesale, processing and distribution to end-user markets.

The following Kangamiut Seafood products are included in this assessment:

1. Atlantic Cod
2. Cooked & peeled prawns
3. Shell-on prawns

The LCA is carried out according to the standards ISO 14040:2006 and ISO 14044:2006, using the same methodology as applied for the consequential model of the ecoinvent database. Exceptions to this include the lack of a critical review of the study and an incomplete assessment of all uncertainties.

The LCA has its focus on GHG emissions, but results for 13 other impact categories are also included.

The modelling approach is based on linking the foreground data provided by Kangamiut Seafood to EXIOBASE hybrid as the background database.

The results are presented as a detailed hotspot analysis (main contributing processes in the life cycle). Improvement options are mapped according to the influence of Kangamiut Seafood.

Further, a number of GHG reductions by use of offsetting are investigated. These are: nature conservation, carbon sequestration in seaweed farms and power purchase agreement to invest in Chinese wind power. These are explained in further detail in **section 7**.

This LCA follows the procedure as defined by the ISO standards, where the assessment is divided into four phases, as seen in **Figure 2.1**:

1. Definition of goal and scope
2. Life cycle inventory (LCI)
3. Life cycle impact assessment (LCIA)
4. Life cycle interpretation

The four phases of an LCA are not consecutive. The actual process is iterative, but the LCA study is reported and structured in the same order as the phases above.

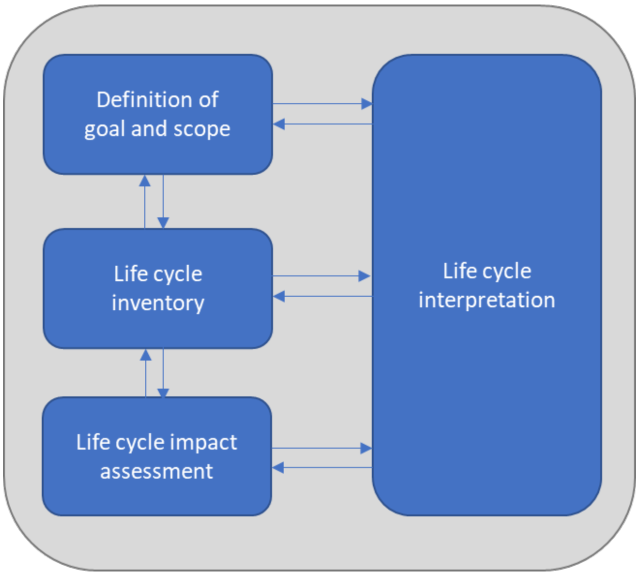

Figure 2.1: Stages of a life cycle assessment. The process is iterative, as indicated by the arrows.

Temporal scope

All provided data from Kangamiut Seafood refer to operations during the whole year of 2020.

Geographical scope

This LCA covers the following product life-cycle stages and their respective location:

- Landing of wild-caught fish in the North Atlantic Ocean.
- Aquaculture systems in Norway and South-East Asia.
- Processing sites in China, Poland, Portugal and Morocco.
- Distribution to end-user markets (modelled as Denmark).

2.1 Functional unit

Results are presented for a functional unit of 1 kg of each included seafood product:

- 1 kg of fileted Atlantic Cod
- 1 kg of Cooked and peeled prawns
- 1 kg of Shell-on prawns

For the carbon offsetting analysis, the following functional units are used:

- Nature conservation of 1 ha of Brazilian rainforest and Indonesian peatland respectively.
- 1 ha of seaweed aquaculture for the purpose of carbon sequestration.
- Sponsoring a 1 MW wind turbine in coastal China.

2.2 Life cycle inventory model

The study applies a consequential approach to modelling in life cycle inventory in accordance with allocation hierarchy of the international standards for LCA: ISO 14040 (2006) and 14044 (2006) and further defined in Weidema et al. (2009).

Consequential modelling is a cause-effect based approach to the definition of system boundaries in LCA (Sonneman and Vigon 2011), and it is characterised by the modelling of by-products through system expansion and by including only unconstrained suppliers in the market mixes[1]. Consequential modelling is used when the study is aimed for decision support and when results are aimed at representing a change in demand for the product at focus in the LCA.

Consequential LCA answers the question: "*what is the impact of a choice?*". This choice could be to buy or produce a product (compared to not buying or producing the product), or to implement an improvement option. Consequential LCA is relevant when companies/decision makers want to know the impacts of their actions. Attributional LCA answers the question: "*what are the impacts from a specific part of the product life cycle?".* The specific part is chosen based on normative allocation and cut-off rules.

When system expansion is applied, it is important to distinguish between determining (reference) products, by-products and materials for treatment. Reference products are characterised by being the ones for which the demand determines the production volume of the activity, while by-products and materials for treatment are produced regardless of the demand.

2.3 Life cycle impact assessment (LCIA)

LCA calculations are performed for the functional unit of:

Method

The method used for LCIA is the Stepwise 2006 method, version 1.7. The method is described and documented in Annex II in Weidema et al. (2008) and in Weidema (2009) and updates for nature occupation in Schmidt and de Saxcé 2016). The characterization module of Stepwise is based on a combination of the Impact 2002+ method (Jolliet et al. 2003) and the EDIP 2003 method (Hauschild and Potting 2005). The weighting module is documented in Weidema (2009). The indicators in the Stepwise method are explained in '**Appendix 2: Explanation of units in the Stepwise LCIA method'**. Interpretation of results and conclusions are based on characterised results. However, more detailed contribution analyses are presented only for the impact category: global warming.

The full environmental impact of Kangamiut Seafood's products is captured by considering a comprehensive set of environmental impact categories:

- Global warming
- Nature occupation
- Respiratory inorganics
- Respiratory organics
- Human toxicity, carcinogens
- Human toxicity, non-carc.
- Ecotoxicity, aquatic
- Ecotoxicity, terrestrial
- Acidification
- Eutrophication, aquatic
- Eutrophication, terrestrial
- Photochemical ozone, vegetat.
- Non-renewable energy
- Mineral extraction

[1] https://consequential-lca.org

Biogenic carbon and methane and LCIA for global warming

By default, the results for global warming do not include biogenic CO_2 uptake and emissions, except for CO_2 emissions that are related to land use changes.

CO_2 caused by land use changes (see **section 3.1**) are modelled as accelerated CO_2 emissions. The global warming effect of this is calculated by use of time-dependant GWP. This is described in Schmidt et al. (2015).

The characterisation factors in the Stepwise method follows IPCC (2013). However, for methane these are corrected according to Munoz and Schmidt (2016). This means that the characterisation factors for CH_4 (fossil) is corrected from 30 to 30.5 kg CO_2-eq./kg CH_4, and for CH_4 (biogenic) it is corrected from 28 to 27.75 kg CO_2-eq./kg CH_4.

Modelling of nature occupation in the consequential model

Nature occupation in Stepwise 1.7 (Schmidt and de Saxcé 2016) is modelled consistently with the modelling of iLUC (see **section 3.1**). This means that distinction is made for the aggregated nature occupation impact between direct and indirect impacts. Further, the indirect impacts are modelled as accelerated denaturalisation, as described in Schmidt and De Saxcé (2016).

3 Life cycle inventory: Foreground and background systems

The unit processes in the product system are either located in the foreground or background system. The foreground system includes the final Kangamiut Seafood products and all their inputs and outputs. The foreground system is further described in chapter 4 and 5.

The background system includes all unit processes that are not included in the foreground system (production of fuels, electricity, machinery, etc.).

3.1 Background database

Background data are used to include upstream emissions and resources related to the in- and outflows mapped in the foreground system, e.g. emissions associated with the production of electricity.
The method used is a consequential LCA model for which all data are obtained from the EXIOBASE v3.3.16 database.

EXIOBASE is a global hybrid multi-regional environmentally extended input output (IO) database. The EXIOBASE v3 database (http://www.exiobase.eu/) is the product of four large EU funded projects under the 6th and 7th framework programmes: FORWAST (http://forwast.brgm.fr/), EXIOPOL (http://www.feem-project.net/exiopol/), CREEA (http://www.creea.eu/) and DESIRE (http://fp7desire.eu/). EXIOBASE can be used for national level footprints (http://www.exiobase.eu/index.php/9-blog/27-creea-booklet) as well as a background LCI database for detailed product LCAs and corporate footprints. The advantage of using an IO-database instead of a process database, such as ecoinvent, is that it operates with a cut-off criterion at 0% and that it has a much more complete geographical scope than any process database. Further, the hybrid version of EXIOBASE, which is used in the current study, has been constructed from supply-use tables using the by-product technology assumption, which is identical to substitution in LCA (Suh et al. 2010).

The newest hybrid version of EXIOBASE (version 3.3.16) has the following characteristics:

- Product flows in hybrid units: EUR, kg, MJ.
- 43 countries, 5 Rest-of-the-world regions
- Base year: 2011
- 164 activities/products (this is equivalent to LCA processes in a conventional LCA database)
- 34 emissions, 22 resources, land use, water
- Employment per three skill levels

The used version of EXIOBASE is documented in two core papers: Stadler et al. (2018) and Merciai and Schmidt (2017a). In the sections below, different central components of the EXIOBASE are further elaborated.

When linking to flows in the background system, average suppliers to the national markets are used, including specified import shares from other countries, and country-specific recycling rates and waste management data. The linking to activities in EXIOBASE can be done in both physical units (mass or energy) and in monetary units.

The principle of linking between the foreground and the background data is illustrated in **Figure 3.1** below.

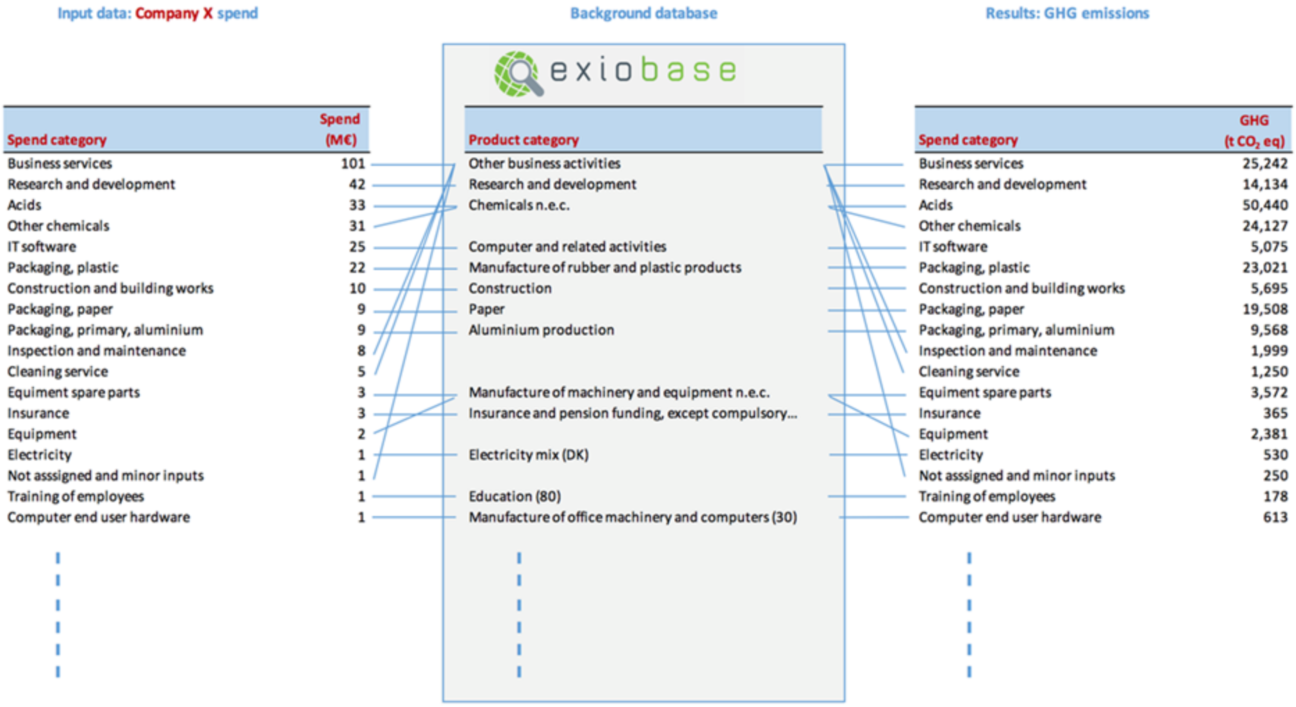

Figure 3.1: Illustration with fictive numbers of the principle of linking expenditure categories and EXIOBASE product categories to obtain estimates of average GHG emissions per expenditure category.

3.2 Indirect land use changes (iLUC)

According to IPCC (2020), 11% of global GHG emissions (GWP100) are caused by CO_2 emissions from land use changes. iLUC is relevant, whenever an activity uses land. This affects the overall pressure on land in use, hence it will have an overall effect on the boundary between land in use (productive land and land under human facilities) and nature (unproductive land). In LCA studies of fish production, inclusion of iLUC emissions is important due to the animal feed used in the affected aquaculture systems. This animal feed is largely based (or affects) agricultural production, which causes changes in the global market for land. Additionally, the background processes used in EXIOBASE include the entire economy which means many iLUC effects occur beneath the surface within the background data as industries overlap. Lastly, iLUC is relevant for nature conservation initiatives analysed for carbon offsetting in **section 7.1**.

We use a model for iLUC proposed by Schmidt et al. (2015). This model has been used for a large number of LCA studies and carbon footprints[2] and the model is rated as the best among a comparison of six major LUC models by De Rosa et al. (2016). The ranking considers completeness, impact assessment relevance, scientific robustness, and transparency. The current study uses version 4.3 of the iLUC model, which is integrated in the multi-regional hybrid input-output model Exiobase v3 (Merciai and Schmidt 2017a,b; Schmidt and De Rosa 2018). The applied iLUC model has been and is currently being developed through an initiative lead by 2.-0 LCA consultants: The 2.-0 iLUC club (http://lca-net.com/clubs/iluc/). The initiative is supported by more than 25 partners including large multinational companies, national research centres, NGOs and universities. The partners are located in 11 different countries in Europe, Asia, North America and Australia.

The iLUC model has several key characteristics that make it superior to many of the other models:

[2] See list of examples of application areas at: https://lca-net.com/projects/show/indirect-land-use-change-model-iluc/

- It is applicable to all crops (also forest land, range land, built land etc.) in all regions in the world.
- It avoids arbitrary allocation/amortization of transformation impacts.
- It is based on modelling assumptions that follow cause-effect relationships consistent with the way any other links between LCA-processes are modelled.

1 ha*year average global arable land is associated with 1.27 t CO_2-eq. (calculated with the EXIOBASE v3.3.13 implementation of the iLUC model).

According to Schmidt et al. (2015), the cause of land transformation is a change in the demand for land. The mechanism linking land use change to changes in demand for land is illustrated in **Figure 3.2**. The figure uses the example of adding a demand for land for rapeseed in Denmark of 1 ha*year. It appears from the figure that the land use effects can be divided into direct and indirect land use changes. This is further explained in the following.

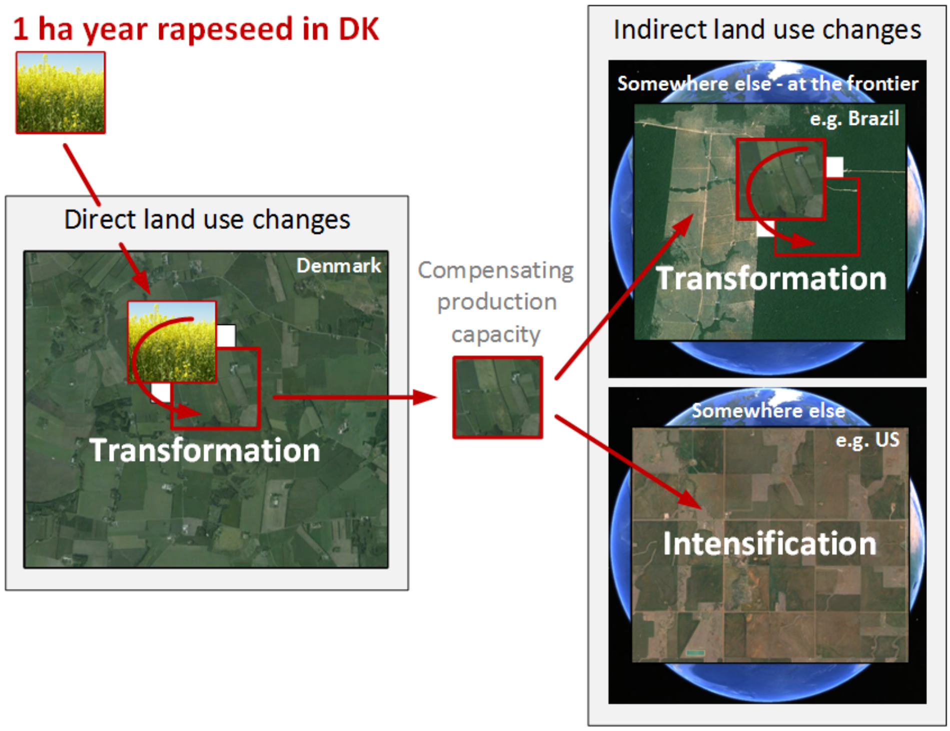

Figure 3.2. Illustration of the effects of adding a demand for land in Denmark of one hectare*year. The effects include indirect transformation of land and intensification to compensate for the production capacity in Denmark that is now no longer available due to being occupied by the new demand.

Direct land use changes (dLUC)

In the example in **Figure 3.2**, the direct land use change is the effect of changing from a reference situation to rapeseed. The reference situation is the current marginal use of the affected land, which will be arable land in most cases (Schmidt et al. 2015).

Obviously, any arable cropping will affect arable land, but also many other human activities are located on arable land, so that when demanding land for buildings, infrastructure, sites for resource extraction, etc., arable land is often affected. An example is the use of land for a residential house in an urban area. This change in demand for land will put equivalent pressure on the boundaries of the urban area that will likely expand into the surrounding arable land.

Most often, the impacts of direct land use changes are small, because the carbon stock and biodiversity hosted on the land are similar for the specific use and for the reference. When the crops under study are associated with a carbon stock that is equal to the reference in that country, then the direct land use changes are not associated with any change in carbon stock. However, if the crops under study stores more carbon than the reference, then the crops under study contribute to an increase of stored carbon in crops in that country. This is the case of oil palm (which is affected in the current study), which stores more carbon than reference, which will be the average of arable land in Indonesia and Malaysia, excluding oil palm because that is the crop that expands.

Indirect land use changes (iLUC)

As illustrated in **Figure 3.2**, the indirect consequence of the direct land use change is the occupation of production capacity somewhere else to compensate for the production capacity now occupied by the additional demand. According to Schmidt et al. (2015), this compensation is partly expansion of arable land at the agricultural frontier, and partly intensification of land already in use. The use of land by the crop under study is what is considered as dLUC, while the supply of new land caused by the need for compensating the production capacity of the land required by the new demand is considered as iLUC. The link between the supply-side and the use-side of land is further elaborated in the next section.

Supply and use of land linked via the global market for land

The iLUC model described in Schmidt et al. (2015) assumes there is a global market for land. To be more precise, the market is not mainly concerned with the area of land but rather its production capacity. Hence, all countries that expand their arable land supplies land into this market as well as all countries that intensify their existing productive land supply arable land into the global market for arable land. This supply-side to the global market for land is illustrated in **Figure 3.3**.

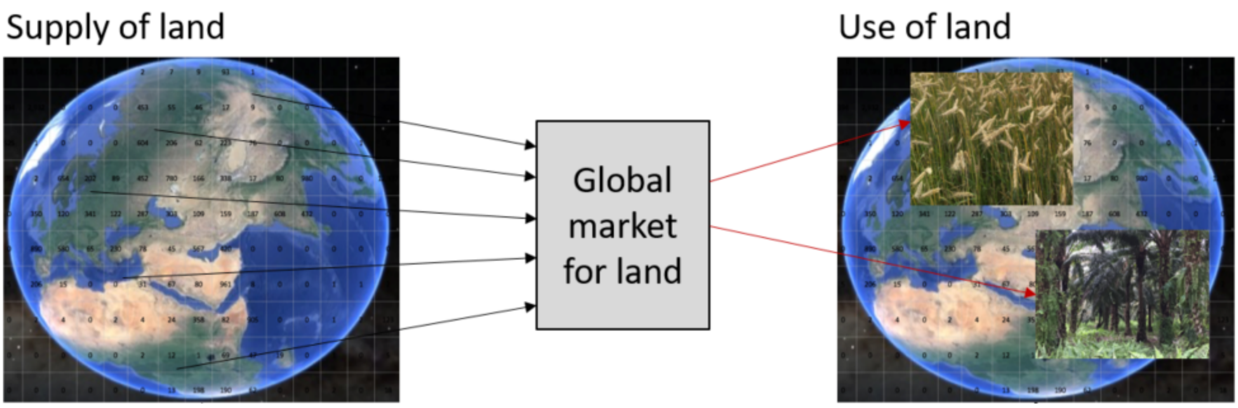

Figure 3.3. Illustration of the global supply and demand of land (Schmidt and De Rosa 2018).

The supply-side of land is modelled using the Exiobase model, and the approach and data are described in Schmidt and De Rosa (2018) and Merciai and Schmidt (2017b).

The supply of land in the applied iLUC model is modelled by using data in the multi-regional hybrid input-output model Exiobase (Merciai and Schmidt 2017a). The integration of the iLUC model in Exiobase is described in Merciai and Schmidt (2017b) and Schmidt and De Rosa (2018). The land market modules of the model contain data on time-series of land use data and agricultural production data for all countries. The Exiobase data allow identifying the land supplied by each country, by expansion of the cultivated area as well as by intensifying existing agricultural land and linking the production trends with the land use trends. In Exiobase, the complete global economy is divided in 47 countries and regions, and each of them is divided in 164 industrial sectors. The agricultural and land use module in Exiobase make use of FAOSTAT (2018), which provide time series on area and production per crop. To have comparative yields, all crops are converted to dry matter. These data allow modelling the global supply of land (**Figure 3.3**) to the global market for land, distinguishing between land expansion (land transformation) and land intensifications (increased production per unit of land). Analogously, the demand side is modelled for every country using land for crop cultivation, pasture, forestry and other purposes.

Adjustment for differences in potential productivity

To calculate how much land that needs to be compensated from occupying 1 ha*year in a specific country/region, its productivity must be adjusted for. Schmidt et al. (2015) use the potential net primary production (NPP_0) for this adjustment. Hence, the adjustment factor is calculated as the actual NPP_0 divided by the global average NPP_0 for arable land. When this adjustment is done, the unit is changed from ha*year to ha*year-equivalents, where 1 ha*year-equivalent refer to land with average global potential productivity.

The potential productivity of arable land in different countries is based on high resolution maps that allow to determine how much iLUC is induced by using land in different regions. For example, 1 ha arable land in Indonesia gives a potential productivity that is 1.9 times greater than in EU28, hence the induced iLUC emissions from 1 ha in Indonesia is 1.9 times higher than in EU28. The data used to determine national average potential productivity of arable land relative to global average arable land is a detailed overlay analysis in GIS, with the following data sources:

- 10 x 10 km grid of potential net primary production (NPP_0) (Haberl et al. 2007)
- 0.05 x 0.05 km grid of land cover data (Friedl et al. 2010)
- National borders

Different land markets

Schmidt et al. (2015) operate with different markets for land: 1) Arable land, 2) Intensive forest land, 3) Extensive forest land, and 4) Grassland. This delimits land types with different potential uses. The potential uses represent the reference for each land type, e.g. grassland in the dry Brazilian Cerrado, which is to a large extent used for cattle grazing, cannot be used for forestry or arable cropping because it is too dry for these purposes. Therefore, a change in the use of these grasslands will not have any indirect effects on the markets for forest land or arable land. Similarly, forest land in some countries may not be fit for arable cropping because the land is too cold, rocky or hilly for that purpose. Therefore, the use of this land will only affect the market for forest land. Sometimes land is used for less productive purposes (economically) than the land's potential use, e.g. when potential arable land in Indonesia and Malaysia is used for extensive forestry. In this case, using this land will still affect the market for arable land. (Schmidt and de Saxcé 2016)

The markets for land are defined in **Table 3.1**.

Table 3.1. Different markets for land (based on Schmidt et al. 2015)

Markets for land	Description
Market for arable land (fit for arable and other)	Fit for arable cropping (both annual and perennial crops), for intensive or extensive forestry, and pasture.
Market for forest land (fit for intensive/extensive forestry and grazing)	Fit for forestry and pasture, but unfit for arable cropping e.g. because the soil is too rocky or because the climate is too cold. Forest land may also be used for other uses, e.g. livestock grazing.
Market for grassland (fit for grazing)	Too dry or cold for forestry and arable cropping. Grassland is most often used for grazing.

Temporal aspects: Avoiding amortization of land transformation

A challenge when modelling land use changes is that transformation of land (in unit ha), e.g. from forest to oil palm, is not proportional with FFB production (which is proportional with land occupation in unit ha*year). A common approach to overcome this is to amortize (allocate) impacts related to land transformation over a normatively defined period of time, e.g. 20 years. This approach is used in several LCA and carbon footprint guidelines, e.g. the PEF guideline, the GHG protocol, PAS2050 and the PalmGHG.

However, this approach does not reflect a cause-effect relationship, the amortization period is arbitrarily defined, and by allocating historical land use change impacts to current oil palm cultivation it implies a causality that goes backwards in time (current demand for crops causes deforestation 20 years ago), which is obviously not possible in reality.

The applied iLUC model overcomes this problem by modelling land transformation as accelerated denaturalisation (Schmidt et al. 2015). This approach models the observed and current relationships only: that deforestation is taking place as long as the demand for land grows and as long as deforestation is not stopped. To grow the functional unit under study in an LCA, the indirect effect could be an additional demand for 1 ha*year. When this demand is added to the background demand causing the current deforestation, the effect is that in year 0, an additional hectare of deforestation is taking place, while after one year when the functional unit is produced, the cleared land can be handed over to the next crops, which can then be grown without deforestation. The handing over of the land after 1 year thus avoids 1 ha deforestation. The net effect of the additional demand for 1 ha*year is thus an acceleration of 1 ha deforestation by 1 year, i.e., the deforestation that would have taken place in year 1 is now taking place in year 0 because of the demand for the functional unit under study. When moving deforestation and associated CO_2 emissions in time, the impact on global warming can be calculated by using the time-dependent global warming potential. This is further described in Schmidt et al. (2015). Further, the impact on nature occupation (biodiversity) can be modelled as occupation in units of PDF*ha*year. This is because moving land transformation in time is the same as occupation.

3.3 Electricity

LCI data for the production of electricity is available in EXIOBASE v3.3.16. The EXIOBASE data for electricity is described in Merciai and Schmidt (2017b). The determination of the electricity mixes follows the same approach as described in Schmidt et al. (2011), which has recently also been applied in the consequential version of ecoinvent 3.5.

Table 3.2 shows the applied electricity mixes as of EXIOBASE.

Table 3.2. Marginal electricity mixes as of EXIOBASE v3.3.16b2 in the countries involved in the product system. Exiobase region abbreviations: DK = Denmark, NO = Norway, CN_TW = China & Taiwan, PL = Poland, PT = Portugal, WA = rest of Asia, WF = rest of Africa.

Source	DK	NO	CN_TW	PL	PT	WA	WF
Coal			74%			75%	
Natural gas		46%	4%	15%	25%	14%	68%
Nuclear			2%			3%	
Hydropower		43%	14%	3%	6%		22%
Wind power	70%	9%	4%	29%	55%	1%	1%
Oil							7%
Biomass	30%	2%	2%	53%	11%	7%	
Solar photovoltaic	<1%		<1%		2%		
Geothermal					1%		2%
Sum	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

4 Life cycle inventory: General activities

This chapter describes the life cycle inventory modelling for general activities relevant for the LCA of Kangamiut Seafood's products.

4.1 Fuels and combustion emissions

Emission factors, densities and calorific values are available for all relevant fuels in the product system, as shown in **Table 4.1.**

Table 4.1: Emission factors, densities and calorific values for relevant fuels in the product system (Nielsen et al. 2016; Nielsen et al. 2018; Schmidt and De Saxcé 2016).

Parameter	Unit	Fuel oil	Diesel	Natural gas	Coal	Biomass
Properties						
Density	kg/m³			0.8		
Calorific value	GJ/t	42.7	43.1	49.54	24.33	19
Emission factors						
Carbon dioxide	kg/GJ	74	74	56.95	94.17	
Methane	kg/GJ	0.003	0.003	0.0017	0.0009	0.015
NMVOC	kg/GJ	0.0008	0.0008	0.002	0.0012	0.01
Dinitrogen monoxide	kg/GJ	0.0006	0.0006	0.001	0.0014	0.004
Carbon monoxide	kg/GJ	0.015	0.015	0.015	0.01	0.24
Nitrogen oxides	kg/GJ	0.15	0.15	0.055	0.03	0.09
Sulfur dioxide	kg/GJ	0.023	0.023	0.0003	0.009	0.025
Particulates, <2.5 um	kg/GJ	3.50E-07	3.33E-07	6.98E-08	3.56E-07	3.38E-05

Upstream LCI data for production of fuels are obtained from the EXIOBASE database.

4.2 Transport

Data for transport in the life cycles of the different products is provided by Kangamiut Seafood. The unit of transport used in this study is tkm (distance multiplied with mass of transported goods).

Transport by lorry is modelled using the EXIOBASE activity: 'Other land transport [country]'. The EXIOBASE transport activities are given with transport in monetary units and fuel inputs in mass unit. Hence, for the EXIOBASE transport activities the fuel use per transport service can be calculated as kg diesel/EUR transport. The corresponding proportion in units of kg diesel/tkm is identified in the ecoinvent database. By combining these two proportions, the reference flows of the EXIOBASE road transport activities can be converted to tkm.

Transport by ship is modelled in a similar fashion, however instead based on the EXIOBASE activity: 'Sea and coastal water transport [country]'.

The emissions related to the production of diesel as well as the combustion emissions are described in the sub-section above '**Fuels and combustion emissions**'.

Kangamiut Seafood has provided data on transport on different life cycle stages of their products (fishery, processing, distribution to end-user markets). The data is provided in units of total transported kilometres, which is converted into tkm when inserted into the model. Transport related to by-product to users is not included on the assumption that this matches the substituted product's transport.

4.3 Markets for feed energy and feed protein

Animal feed is relevant for this study for two main reasons: Firstly, marginal production of fish in aquaculture uses animal feed. Secondly, fish offal is used to produce animal feed.

As a condition of the consequential model, all by-products of animal feed are modelled using substitution. EXIOBASE does not include specific activities that represent global markets for animal feed. Therefore, this modelling is made specifically for this purpose, while still linking to EXIOBASE to cover inputs of fertilisers, chemicals, fuels etc.

Feed constitutes two main components: protein and energy. This section describes the marginal sources of feed protein and energy, which are substituted by the animal feed by-products. I.e. it is described which crops and downstream processing are influenced by a change in demand for marginal feed protein and energy, and how this is modelled.

Inputs to feed markets: The consequential model reflects the consequences of a change in demand for feed by identifying the marginal suppliers, i.e. the most likely crop/feed type to be affected by a change in demand for protein and energy respectively. The applied modelling of feed divided into proteins and energy feed reflects the way that farmers design the feed mix to have a balanced protein/feed ratio. Small speciality feed components, such as vitamins and minerals, are regulated by adding these to the ration, separately. Since the quantities of these are small, they are not accounted for in the current study. The modelling approach is similar to the one used in the consequential version of ecoinvent 3, and it is documented in e.g. Schmidt and Weidema (2008), Schmidt et al. (2009), Schmidt (2010) and Schmidt (2015). Assuming that the markets for protein and feed energy are global and independent (Schmidt and Weidema 2008; Schmidt 2015a), cereal grain is identified as the marginal feed type for feed energy and soybean meal as the marginal feed type for protein (Schmidt 2015a).

Because protein feed such as soybean meal also contains energy, the feed protein production has a by-product of energy that affects the market for feed energy. Vice-versa, feed energy crops such as maize grains contain protein, thus the feed energy production generates a by-product of protein that affects the protein market. These links create a loop in the life cycle inventory modelling: demand for protein partially displaces energy, which in turn displaces some protein etc. This algebraic problem is solved using standard LCA calculations, where the by-products are represented as negative inputs to LCA activities. For more details, see (Schmidt et al. 2009).

The crop types and their country of origin for the marginal feed protein and energy types are identified based on production data from FAOSTAT (2018). According to FAOSTAT (2018), the three most widely used grain crops globally are maize, wheat and barley, which are all grown in several countries. In order to identify the countries that primarily respond to increased demand in the global market, we calculate the increase in production in the period 2012-2016 by linear regression for all countries and rank the countries according to the highest increase rate (slope). Consistent with the methodology, to identify marginal suppliers in LCA (Weidema et al. 2009, Weidema 2003), the marginal producers/countries for each crop are the most competitive suppliers. Here we use the increase rate of crop production as an indicator for the competitiveness for country.

Table 4.2 shows that maize grown in the United States is the crop with the largest annual production increase, followed by Russian wheat, Argentinian maize and Ukrainian wheat. Together these four grain crops account for more than 63% (=39 + 14 + 6.9 + 4.2) of the annual production increase in 2012-2016, as presented in the column 'Share of change'. The amounts of grain crops identified in FAOSTAT (2018) have been converted to gross energy by using **Equation 4.1**:

Equation 4.1

$$GE\ [MJ] = Fat\ [kg] \times 36.6[MJ/kg] + Crude\ protein\ [kg] \times 24.1\ [MJ/kg] + Carbohydrates\ [kg] \times 18.5\ [MJ/kg]$$

The fat, crude protein and carbohydrate contents of crops are obtained from Møller et al. (2005).

The percentage distribution presented in the column on the right is used to calculate the average marginal grain crop.

The countries with the highest increase rate of soybean cultivation are US and Brazil. Soybeans in the US and Brazil are the crops that primarily respond to changes in demand for protein in the global market. The life cycle inventory in the model is based on 52% soybeans from USA and 48% soybeans from Brazil.

Table 4.2. Crops responding to changes in demand for feed energy (grain crops) and feed protein (protein crops).

Crop, country	Unit	Annual production increase (2012-2016)	Share of change	Applied supply mix
Grain crops				
Maize, USA	PJ gross energy	373	39%	61%
Wheat, Russia	PJ gross energy	132	14%	22%
Maize, Argentina	PJ gross energy	67	7%	11%
Wheat, Ukraine	PJ gross energy	41	4%	7%
Other, increase	PJ gross energy	577	60%	
Other, decrease	PJ gross energy	-228	-24%	
Total			**100%**	**100%**
Soybean				
Soybean, USA	Million t crude protein	3.14	37%	52%
Soybean, Brazil	Million t crude protein	2.85	33%	48%
Other, increase	Million t crude protein	2.97	35%	
Other, decrease	Million t crude protein	-0.38	-4%	
Total			**100%**	**100%**

The LCI data for the global market for feed protein and feed energy are shown in **Table 4.3**.

Table 4.3. Life cycle inventories for feed protein and feed energy. The LCI data for the crops mentioned in this table are described in **Table 4.4**.

Flows	Unit	Feed protein {GLO} Transforming soybean meal to feed protein	Feed energy {GLO} Transforming wheat and maize to feed energy
Output: reference flow			
Feed protein, crude protein	kg	0.468	
Feed energy, gross energy	MJ		1.00
Output: by-products			
Feed protein, crude protein	kg		0.0052
Feed energy, gross energy	MJ	18.0	
Inputs			
Maize {US}	kg		0.0353
Wheat {RU}	kg		0.0132
Maize {AR}	kg		0.0064
Wheat {UA}	kg		0.0041
Soybean meal {US}	kg	0.524	
Soybean meal {BR}	kg	0.476	

LCI data for crops: For each of the six crops in **Table 4.3** (soybean meal is obtained from soybean) life cycle inventory data are established. This includes determination of inputs (e.g. fertiliser, diesel, land, irrigation), outputs (crops and emissions). The input of land is linked with the indirect land use change model, which is integrated in the EXIOBASE database The LCI data for the six crops is presented in **Table 4.4**. The input of land in **Table 4.4** is referred to as market for arable land.

The amount of fertiliser used per hectare for each crop in the countries mentioned in **Table 4.3** is calculated by a top-down approach, by distributing the total fertiliser consumption in the relevant countries for 2015, on the agricultural area (IFA 2018). The distribution is crop specific, thus based on crop-specific harvested areas from FAOSTAT (2018) for the individual countries. Different crops require different amounts of fertiliser. Therefore, for each of the relevant countries, a crop-specific distribution key, based on data from IFA (2002), is used. Data on diesel consumption is based on Cederberg et al. (2009) and data on irrigation is drawn from the ecoinvent database (2017). Yields for 2016 are calculated by regression of yield data for 2012-2016 from FAOSTAT (2018). Emissions are calculated according to IPCC (2006) tier 1, which takes account of crop-specific yields, fertiliser inputs and crop residues, from which a detailed N-balance is established.

The datasets for irrigation are based on ecoinvent (2017): “Irrigation {RoW}| processing” and includes 0.24 kWh electricity and 0.018 kg agricultural machinery per m^3 water. The datasets are created for US, RU, AR (represented by EXIOBASE region WL) and UA (represented by EXIOBASE region WE).

Table 4.4. Life cycle inventories for crops involved in the inputs to the marginal global markets for feed protein and feed energy in **Table 4.3**. All data are shown for 1 ha*year.

Flows	Unit	Maize {US} Maize cultivation	Wheat {RU} Wheat cultivation	Maize {AR} Maize cultivation	Wheat {UA} Wheat cultivation	Soybean {US} Soybean cultivation	Soybean {BR} Soybean cultivation
Reference flow							
Output: Crop	kg	11,406	2,710	7,610	4,317	3,494	3,000
Inputs: Energy							
Diesel	MJ	2,898	3,306	2,898	3,306	1,709	1,709
Lubricants and hydraulic oil	MJ	1.10	1.10	1.10	1.10	1.10	1.10
Inputs: Nutrients and chemicals							
Urea	kg N	85.3	1.69	32.3	18.8	17.1	8.13
Ammonium nitrate	kg N	107	32.3	0	39.0	21.3	2.02
Calcium ammonium nitrate	kg N	0	0	1.13	3.98	0	0.36
Ammonium sulphate	kg N	8.95	3.35	1.62	0.67	1.79	1.73
Phosphate rock	kg P_2O_5	0	13.6	0	13.5	0	1.91
Phosphate fertiliser	kg P_2O_5	49.8	0	27.3	0	42.7	59.3
Potassium chloride	kg K_2O	51.2	6.21	0.24	13.8	54.0	68.0
Potassium sulfate	kg K_2O	2.35	1.37	0	0	2.48	0.14
Input: Irrigation							
Irrigation (US)	m^3	2,792					
Irrigation (RU)	m^3		935				
Irrigation (AR)	m^3			1,181			
Irrigation (UA)	m^3				1,490		
Input: Transport							
Road transport {US}	tkm	0.735				0.306	
Road transport {RU}	tkm		0.121				
Road transport {AR}	tkm			0.139			
Road transport {UA}	tkm				0.195		
Road transport {BR}	tkm						0.295
Input: land, link to iLUC model							
Market for arable land	ha-eq.	1.02	0.93	1.32	0.98	1.02	1.33
Input: Capital goods and services							
Maize cultivation capital goods and services {US}	ha*year	1					
Wheat cultivation capital goods and services {RU}	ha*year		1				
Maize cultivation capital goods and services {AR}	ha*year			1			
Wheat cultivation capital goods and services {UA}	ha*year				1		
Soybean cultivation capital goods and services {US}	ha*year					1	
Soybean cultivation capital goods and services {BR}	ha*year						1
Emissions							
Ammonia	kg	23.8	4.40	4.08	7.36	4.72	1.39
Carbon dioxide	kg	138	2.72	52.0	30.3	27.5	13.1
Dinitrogen monoxide	kg	5.76	1.41	1.81	2.25	1.62	0.96
Nitrogen oxides	kg	1.47	0.36	0.47	0.58	0.42	0.25
Nitrate	kg	376	93	121	149	108	65.2

Table 4.5. Life cycle inventories applied for the inputs to crop cultivation in **Table 4.4**. The LCI data behind the activities in the right column are referenced in 'Appendix 1: Bridge table between foreground and background database'.

Inputs	LCI applied
Diesel	See **section 4.1**
Lubricants and hydraulic oil	See **section 4.1**
Urea	Link to: N-fertiliser, urea, as N
Ammonium nitrate	Link to: N-fertiliser, ammonium nitrate, as N
Calcium ammonium nitrate	Link to: N-fertiliser, ammonium nitrate, as N
Ammonium sulphate	Link to: N-fertiliser, ammonium sulphate, as N
Phosphate rock	Link to: P-fertiliser, rock phosphate, as P_2O_5
Phosphate fertiliser	Link to: P-fertiliser, triple superphosphate, as P_2O_5
Potassium chloride	Link to: K-fertiliser, potassium chloride, as K_2O
Potassium sulphate	Link to: K-fertiliser, potassium chloride, as K_2O
Irrigation (US)	See text above
Irrigation (RU)	See text above
Irrigation (AR)	See text above
Irrigation (UA)	See text above
Road transport {US}	Link to: Road transport {US} 16-32 t truck
Road transport {RU}	Link to: Road transport {RU} 16-32 t truck
Road transport {AR}	Link to: Road transport {AR} 16-32 t truck
Road transport {UA}	Link to: Road transport {UA} 16-32 t truck
Road transport {BR}	Link to: Road transport {BR} 16-32 t truck
Market for arable land	Link to: Market for arable land {GLO}
Maize cultivation capital goods and services {US}	Link to: Maize cultivation capital goods and services {US}
Wheat cultivation capital goods and services {RU}	Link to: Wheat cultivation capital goods and services {RU}
Maize cultivation capital goods and services {AR}	Link to: Maize cultivation capital goods and services {AR}
Wheat cultivation capital goods and services {UA}	Link to: Wheat cultivation capital goods and services {UA}
Soybean cultivation capital goods and services {US}	Link to: Soybean cultivation capital goods and services {US}
Soybean cultivation capital goods and services {BR}	Link to: Soybean cultivation capital goods and services {BR}

LCI data for soybean meal: Soybean meal is co-produced with soybean oil in the soybean mill. An increase in demand of soy protein results in an increased availability of soybean oil in the global market, which affects the production of the marginal supplier of oil, i.e. palm oil (Schmidt and Weidema 2008; Schmidt 2014; Schmidt 2015a). This means that the palm oil system is also affected by changes in the demand for protein. The affected palm oil is the industry average of RBD palm oil. LCI data for this are presented in Schmidt and De Rosa (2020). Similarly, because grain crops contain proteins, a change in demand for feed energy causes a change in availability of protein as a by-product, affecting the production of soymeal and subsequently palm oil. The correlation between the product systems for feed protein, feed energy and vegetable oil are described in detail in Dalgaard et al. (2008) and Schmidt and Weidema (2008).

LCI data for soybean meal production and refining of soybean oil are presented in

Table 4.**6.** The table shows that the soybean oil mills produce soybean meal (reference flow) and crude soybean oil as a material for treatment. It is a material for treatment because it needs refining before it is substitutable on the market for vegetable oil and thereby become a by-product that will substitute alternative production. The refinery step is needed to ensure substitutability because crude oils have different contents of free fatty acids, e.g. 1 kg CPO (containing 5% free fatty acids) is not substitutable with 1 kg crude rapeseed oil or soybean oil. When the crude soybean oil is treated in the refinery, the by-product outputs substitute refined palm oil and PFAD.

Table 4.6. Life cycle inventories for the soybean meal involved in the inputs to the marginal global market for feed protein shown in Table 4.3.

Flows	Unit	Soybean meal {US} Soybean oil mill	Soybean meal {BR} Soybean oil mill	Crude soybean oil {US, BR} Treatment refinery	LCI data
Reference flow					
Output: Soybean meal	t	0.773	0.773		
Input: Crude soybean oil {US, BR}	t			1	Crude soybean oil {US, BR} Treatment of CSBO in soybean oil refinery
Input: Feedstock					
Soybean {US} Soybean cultivation	t	1.00			**See Table 4.4**
Soybean {BR} Soybean cultivation	t		1.00		
Output: Materials for treatment					
Crude soybean oil {US}	t	0.192			Crude soybean oil {US, BR} Treatment of CSBO in soybean oil refinery
Crude soybean oil {BR}	t		0.192		Crude soybean oil {US, BR} Treatment of CSBO in soybean oil refinery
Landfill of bleaching earth {ID}	kg			5.79	ID data for landfill has been used: Link to: Landfill of bleaching earth {ID}
Landfill of oil loss {ID}	kg			5.00	ID data for landfill has been used: Link to: Landfill of oil loss {ID}
Output: By-products that substitute alternative production					
Palm oil	t			0.983	Schmidt and De Rosa (2020)
Palm fatty acid distillate (PFAD)	t			0.012	
Input: Energy					
Natural gas	MJ	5.71-06	5.71E-06		Link to: Natural gas {ID&MY} Fuel and combustion
Fuel oil	MJ	3.40-06	3.40E-06	5.73E-06	Link to: Fuel oil {ID&MY} Fuel and combustion
Electricity {US}	kWh	12.2		14.5	Link to: Electricity {US} market
Electricity {BR}	kWh		12.2	14.5	Link to: Electricity {BR} market
Input: Water					
Water {US}	m^3	0.104		1.37E-02	Link to: Water {US}
Water {BR}	m^3		0.104	1.37E-02	Link to: Water {BR}
Input: Transport					
Road transport {US}	tkm	200		1.38	Link to: Road transport {BR} 16-32 t truck
Road transport {BR}	tkm		200	1.38	Link to: Road transport {BR} 16-32 t truck
Input: Material use					
Caustic Soda, as 100% conc.	kg			2.10	Link to: Caustic Soda, as 100% conc {ID&MY}
Phosphoric acid, as 100% conc.	kg			0.800	Link to: Phosphoric acid, as 100% conc {ID&MY}
Bleaching earth	kg			9.00	Link to: Bleaching earth {ID&MY}
Sulphuric acid, as 100%	kg			1.90	Link to: Sulphuric acid, as 100% conc {ID&MY}
Input: Capital goods and services					
Soybean mill capital goods and services {US}	t	1			Link to: Soybean mill capital goods and services {BR}
Soybean mill capital goods and services {BR}	t		1		Link to: Soybean mill capital goods and services {US}
Soybean oil refinery capital goods and services	t			1	This is already included with the input in the oil mill stage because the oils and fats sector in EXIOBASE includes both the milling and the refinery processes.

5 Life cycle inventory: Kangamiut Seafood products

This chapter presents the life cycle inventory summaries for the included Kangamiut Seafood products.

As the carrying capacity of global ecosystems of wild fish are fully exploited (FAO, 2020), this LCA considers wild-caught fish a constrained resource. This means it is not possible to increase the volume of landed fish, and for this reason, landing of wild-caught fish cannot satisfy an increase in consumer demand of fish products.

Figure 5.1 shows that the output of capture fisheries has been stable for the last 30 years, while the increases in fish production volumes is entirely originating from an increase in aquaculture. As seen on the figure, aquaculture accounted for nearly half of all fish production in 2018.

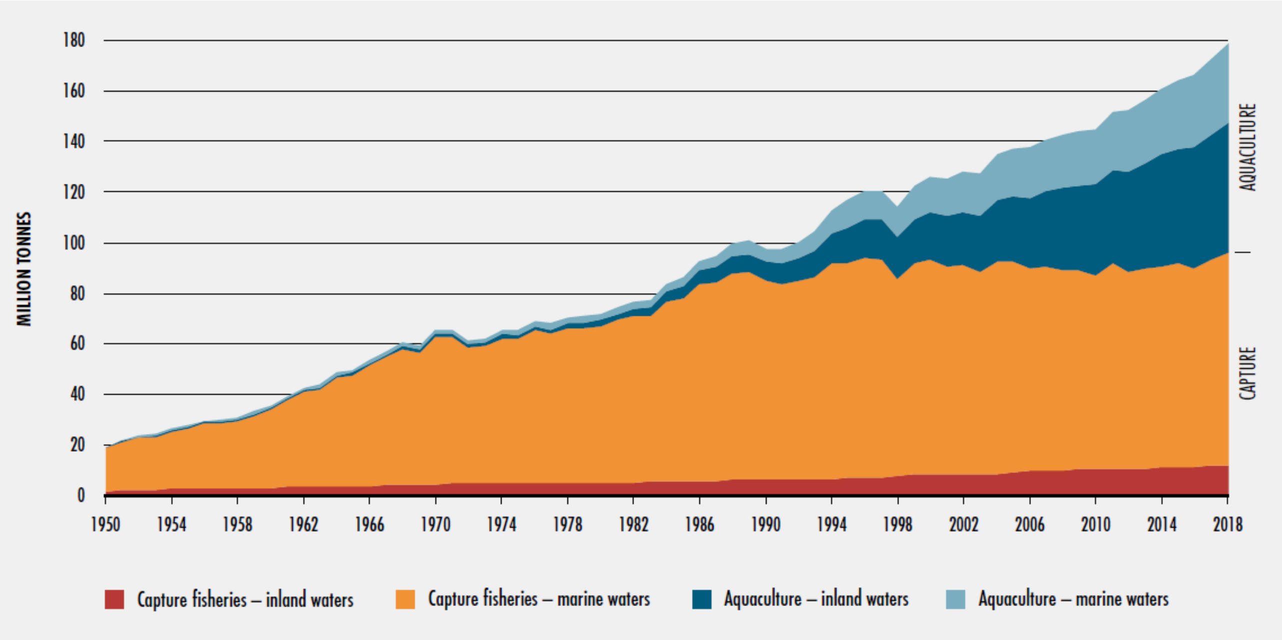

Figure 5.1: World capture fisheries and aquaculture production (in FAO, 2020). The capture fisheries have remained stable from the mid-1990s approximately. The increase in fish supply since then has almost entirely been from aquaculture production.

Thus, when calculating the environmental footprint of Kangamiut Seafood's products, this LCA includes the consequential aquaculture production of fish as this type of production has seen considerable growth in recent decades (FAO, 2020) and is identified as able to satisfy increased consumer demands through an increase in production. This means that the consequence of increasing demand of fish products, such as by a consumer purchasing Kangamiut Seafood's products, is an increase in production in aquaculture systems.

5.1 Inventory of Kangamiut Seafood product: Atlantic Cod

This section documents the inventory data used to model the Kangamiut Seafood product: Atlantic Cod.

As explained above, wild-caught fish is a constrained resource. Thus, the consequence of demanding one additional functional unit (1 kg) of fileted Atlantic Cod is a corresponding increase in in aquaculture. In this case, aquaculture of Atlantic salmon is modelled as increasing its production to satisfy new demand. This is based on the assumption that freshwater and saltwater fish fulfil different functions on the market. On this assumption, an increase in demand caused by the purchase of cod would be met with the increased production of saltwater fish. Salmon is among the fastest growing aquaculture species in the world (FAO, 2020a) and for this reason it is modelled as the flexible supplier that will increase its production to meet the higher demand.

Norway is the largest global producer of aquacultural salmon (FAO, 2013) as well as the fastest growing (FAO, 2020a), and as such, data for Norwegian salmon aquaculture is modelled as the marginal production system.

This constrained nature of landing of wild-caught cod means that only a specific number of fish can be caught every year. As explained, this means that no more fish can be caught to satisfy an increase in demand, however it also means that if Kangamiut Seafood's suppliers do not catch cod, the fish quotas' allowed number of cod will be caught regardless by someone else. For this reason, when Kangamiut Seafood's suppliers catch wild cod, the effect is that another company is displaced from doing so. Thus, the environmental performance of Kangamiut Seafood suppliers is relevant as it must be compared to the alternative supplier that would otherwise catch the fish. Here, any beneficial comparison results in the displacement of a worse alternative, whereas a worse comparison would displace an environmentally superior alternative. Thus, this comparison to the average is a central aspect of how Kangamiut Seafood can influence the environmental footprint of their products.

Consequently, this means the product system for Kangamiut Atlantic Cod includes the following inputs: Increase in production from salmon aquaculture, landing and processing activity from Kangamiut Seafood's partners and lastly, the displacement (negative input) of the average landing and processing activities of cod.

Figure 5.2 shows the product system used to model Kangamiut Seafood Atlantic Cod.

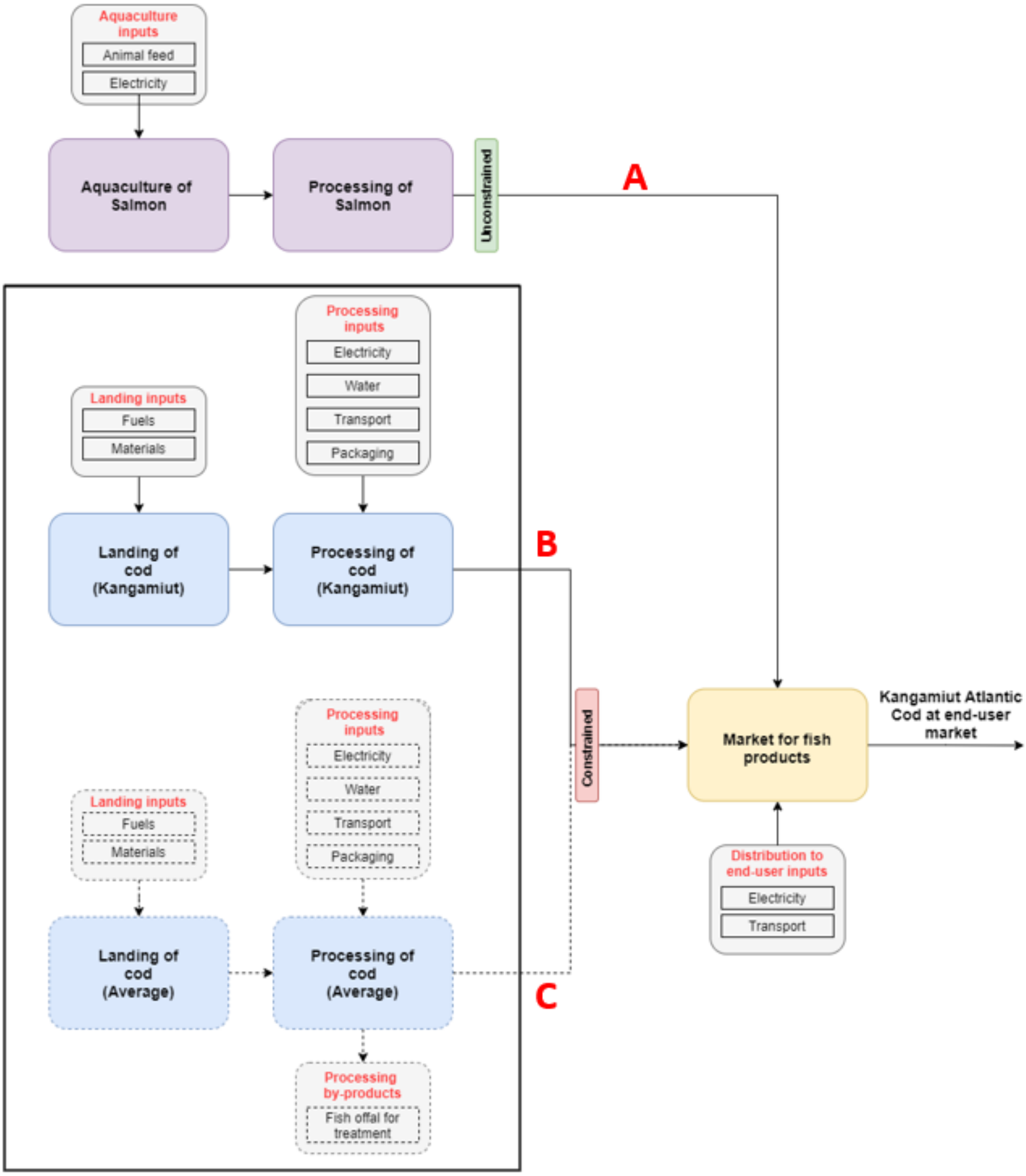

Figure 5.2: Product system for Kangamiut product: Atlantic Cod.

In **Figure 5.2,** A represents the flow of fileted salmon from aquaculture. B represents the fileted Cod from Kangamiut Seafood suppliers, while C represents the displaced average landing and processing value chain. Thus, the effect of demanding a Kangamiut Seafood product can be represented as: A + B – C. Additionally, inputs of electricity and transport related to the end-user market are included.

For the purpose of this study, the landing and processing operations performed by Kangamiut Seafood's suppliers are considered to be representative of the market average operations. This assumption is driven by a lack of data of what constitutes average operations as well as the fact that this is Kangamiut Seafood's first efforts to reduce the environmental impact of their value chain. Additionally, Kangamiut Seafood is a trading company and not itself a producer of seafood products, which means that without buying from specific suppliers, they can also be said to buy average market products.

For these results, this means that the emissions caused by Kangamiut Seafood's landing and processing are cancelled out by the displacement of the average activities that would have otherwise occurred. Thus, the overall environmental impact of the final product is hugely influenced by the market reaction of the marginal salmon aquaculture, which increases its production to meet increased demand caused by consumer purchase of the final Kangamiut Seafood product.

However, any improvements made by Kangamiut Seafood to the activities of their suppliers will displace a worse alternative, meaning environmental benefit is obtained. This is further investigated in **section 6.3**.

Electricity usage in salmon aquaculture

Electricity usage in salmon aquaculture has been estimated based on a production weighted average of external studies on Norwegian salmon aquaculture. This identified electricity usage includes both the hatchery (producing smolts) and the growing stage (producing full grown salmons) and takes into account the ratio of input of kg smolt pr. kg live-weight salmon. Using these sources, the production of 1 kg of live-weight salmon through Norwegian aquaculture has an input of 0.53 kWh of electricity. **Table 5.1** shows the sources, the electricity usage statistics provided within them, and the production volume assessed which was used to calculate the weighted average. The total life-cycle electricity usage is obtained through own calculations of different numbers of electricity use at different stages in the sources.

Table 5.1: Weighted average calculated from different sources of electricity consumption in Norwegian salmon aquaculture.

Electricity usage (kWh/kg live-weight salmon)	Production volume in source (tonnes)	Source
0.61	1,236,354	SINTEF (2017)
0.37	626,000	Pelletier (2009)
Weighted average:		
0.53		

These sources are based on aggregated data from various types of salmon aquaculture systems. A separate study for a specific salmon aquaculture farm in Iceland identified a life cycle electricity consumption of 0.6 kWh/kg live-weight salmon (Ingolfsdottir et al, 2013), which indicates that the number obtained through the weighted average is a realistic one.

Feed composition: Atlantic salmon

Table 5.2 shows the feed conversion rates (FCR) and feed composition for Atlantic salmon, the marginal aquaculture species modelled for Kangamiut Atlantic Cod.

Table 5.2: Feed conversation rate (Fry et al, 2018) and feed composition for Atlantic salmon.

	Atlantic salmon
FCR	
Feed conversion rate	1.3
Feed	
Source	FAO (2020b)
Wheat, meal	11.4%
Corn gluten meal	5.6%
Soybean meal	7.8%
Brewer's yeast	1.6%
Vitamins	1.0%
Minerals	1.0%
Fish meal	40.3%
Fish oil	17.9%
Fish soluble concentrate	1.0%
Poultry offal	7.6%
Blood meal	1.0%
Feather meal	3.8%
Total	**100%**

Aquaculture of salmon

Table 5.3 shows the inventory for salmon from aquaculture.

Table 5.3: Inventory for Salmon Aquaculture, normalised to a reference flow of 1 kg whole salmon output.

Flows	**Unit**	**Aquaculture of salmon**
Output: reference flow		
Whole fish, salmon	kg	1
Inputs		
Electricity mix {NO}	kWh	0.5304
Soybean meal {GLO}	kg	0.1014
Wheat, meal {ID}	kg	0.1479
Corn gluten meal {NO}	kg	0.0728
Feed brewer's yeast {GLO}	kg	0.0208
Vitamins {CN_TW}	kg	0.0130
Minerals {NO}	kg	0.0130
Feed fish meal {GLO}	kg	0.5239
Fish oil as feed {GLO}	kg	0.2330
Fish soluble concentrate {GLO}	kg	0.0130
Offal (poultry) {GLO}	kg	0.0988
Feed blood meal {GLO}	kg	0.0130
Feather meal {GLO} Feed protein and feed energy	kg	0.0494

Table 5.4 shows the inventory for processing of salmon to make salmon filet. The modelling of this processing activity is based on the ones used in The Big Climate Database (Concito, 2021). For this LCA, it is assumed that the processing takes place in Norway, which is reflected in the background data used.

The skinless fillet portion of salmon is 0.58 kg pr. kg whole fish salmon (Fry et al, 2018). Thus, 1.724 kg of whole fish salmon is required for 1 kg of salmon filet. The fish offal treatment for Norwegian salmon processing is modelled in the fashion as shown later in **Table 5.7**, albeit with Norwegian background data.

Table 5.4: Inventory for processing of salmon.

Flows	Unit	Processing of salmon
Output: reference flow		
Salmon filet	kg	1
Inputs		
Salmon from aquaculture (See **Table 5.3**)	kg	1.724
Inputs: Electricity		
Electricity mix {NO}	kWh	0.152
Inputs: Transport		
Road transport, tkm {NO} 16-32 t truck	tkm	0.4
Outputs: Material for treatment		
Fish offal for treatment {NO}	kg	0.724

Landing of cod

The fuel and material inputs to landing of cod are based on data provided by Kangamiut Seafood. As mentioned, this is assumed to be equivalent the average landing activity. The environmental benefits of improving this activity for Kangamiut Seafood's suppliers is described in **section 6.3**.

Data provided by Kangamiut Seafood for marine diesel and lubricants is given in litres, while the relevant background processes work in units of mass. To convert from volume to mass, a density of 0.87 kg/L is used for diesel (ILO.org, nd) and a density of 0.825 kg/L for lubricant oil (Noria Corporation, nd).

As referenced in the data provided by Kangamiut Seafood: The cod is gutted and headed after landing. E-mail correspondence with Kangamiut Seafood revealed that the offal from heading and gutting is not sent for treatment and instead discarded into the ocean. For this reason, this offal from gutting and heading is not included in the product system of this LCA.

Data for bycatch were also provided by Kangamiut Seafood, although they are not included in this study's product system. This is due to the fact that the bycatch species are also part of fishing quotas as well as on the assumption that these bycatch species have dedicated fishing activities which also have their own bycatch. Thus, it is assumed that the bycatches of these activities substitute each other. With more detailed bycatch data for each relevant bycatch species, a more precise modelling of these interrelations and following substitutions of other activities would have been possible, although this data was not available.

Table 5.5 shows the inventory for landing of cod. Background data for Denmark is used for this activity.

Table 5.5: Inventory for landing of cod stage.

Flows	Unit	Landing of cod	Background data
Output: reference flow			
Whole fish, cod	kg	1	Reference flow
Inputs: Fuels			
Marine diesel	kg	0.375	Fuel, diesel {DK} Fuel and combustion
Lubricants	kg	2.37E-03	Lubricants and hydraulic oil {DK} Fuel
Inputs: Materials			
Superbags	kg	5.33E-03	64 Manufacture of rubber and plastic products {DK}
Plastic bags/wrapping	kg	7.14E-05	64 Manufacture of rubber and plastic products {DK}
Pallets	kg	7.14E-03	50 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials {DK}

Processing of cod

The inputs to processing of cod is also based on data provided by Kangamiut Seafood. As with the landing activity, this processing is also assumed to be equal to the average cod processing activity.

As the provided data for processing included packaging materials, these materials are modelled as originating from the country where the processing takes place. By request of Kangamiut Seafood, the packaging inputs for the processing sites in Poland and Portugal have been scaled down in accordance with difference in production volume using the processing site in China as a point of reference.

Table 5.6 shows the connected EXIOBASE processes for the packaging materials.

Table 5.6: Corresponding EXIOBASE processes for packaging materials used in cod processing.

Material	LCI data
Packaging material plastic (CN_TW)	64 Manufacture of rubber and plastic products {CN_TW}
Packaging material plastic (PL)	64 Manufacture of rubber and plastic products {PL}
Packaging material plastic (PT)	64 Manufacture of rubber and plastic products {PT}
Packaging material boxes (CN_TW)	54 Paper {CN_TW}
Packaging material boxes (PL)	54 Paper {PL}
Packaging material boxes (PT)	54 Paper {PT}

Fish offal from the processing stage is modelled as a material for treatment. Treatment of fish offal is modelled as having a by-product of fish meal (84%) and fish oil (16%) (Silva et al, 2018). These outputs are converted to dry matter using the EXIOBASE dry matter ratio for fish products: 0.2 kg dm pr. kg fish product. Thus, an input of 1 kg fish offal has a total output of 0.2 kg dry matter by-products.

Table 5.7 shows the inventory for treatment of fish offal. A process is shown for every processing location for cod.

Table 5.7: Inventory of waste treatment of unspecified fish offal in the different processing countries for cod.

Flows	Unit	Treatment of unspecified fish offal (CN_TW)	Treatment of unspecified fish offal (PL)	Treatment of unspecified fish offal (PT)
Output: reference flow				
Waste treatment (offal)	kg	1	1	1
Inputs				
Fish offal for treatment	kg	1	1	1
Inputs: Fuels				
Fuel, diesel {CN_TW} Fuel and combustion	kg	0.008		
Fuel, diesel {PL} Fuel and combustion	kg		0.008	
Fuel, diesel {PT} Fuel and combustion	kg			0.008
Inputs: Electricity				
Electricity mix {CN_TW}	kWh	0.005		
Electricity mix {PL}	kWh		0.005	
Electricity mix {PT}	kWh			0.005
Inputs: Materials				
63 Chemicals nec {CN_TW}	kg	0.235		
63 Chemicals nec {PL}	kg		0.235	
63 Chemicals nec {PT}	kg			0.235
Inputs: Transport				
Road transport, tkm {CN_TW} >32 t truck	tkm	0.04		
Road transport, tkm {PL} >32 t truck	tkm		0.04	
Road transport, tkm {PT} >32 t truck	tkm			0.04
Outputs: by-products				
Fish meal	kg	0.168	0.168	0.168
Fish oil	kg	0.032	0.032	0.032

These by-products of fish meal and fish oil outputs substitute alternative unconstrained production. Fish meal is modelled as substituting animal feed whilst fish oil is modelled as substituting palm oil.

Fish meal substitutions are based on protein and energy content of the fish meal, which substitutes the marginal sources of protein and energy respectively. Soybean meal is identified as the marginal source of protein and wheat/maize for energy. This is explained in further detail in **section 4.3.**

Table 5.8 shows the substitutions from the two by-products. The negative inputs refer to avoided production.

Table 5.8: Substitutions from fish offal by-products.

Flows	Unit	Fish meal	Fish oil
Output: reference flow			
Output of by-product	kg	1	1
Inputs			
Feed protein {GLO} Transforming soybean meal to feed protein	kg	-0.621	
Feed energy {GLO} Transforming wheat and maize to feed energy	MJ	-20.5	
RBD palm oil {ID&MY} Palm oil refinery, average	kg		-1

Transport processes for the processing stage have been converted from monetary to physical units using the method described in **section 4.2**. The transport inputs for the processing stage take into account all transport of product from the landing harbour to the processing site.

Data for inputs of water in the processing stage were given by Kangamiut Seafood in m^3. This was converted to monetary units using water input data found in EXIOBASE to match the reference flow in monetary of the relevant EXIOBASE process: 113 Collection, purification and distribution of water. This was done for all 3 relevant countries.

Table 5.9 shows the full inventory for processed cod (filet).

Table 5.9: Inventory for processed cod. The flows are scaled to a reference flow of 1 kg of fileted cod.

Flows	Unit	Cod, processing (China)	Cod, processing (Poland)	Cod, processing (Portugal)
Output: reference flow				
Fileted cod	kg	1	1	1
Input:				
Landing of cod (see Table 5.5)	kg	1.429	1.429	1.429
Inputs: Electricity				
Electricity mix {CN_TW}	kWh	0.5		
Electricity mix {PL}	kWh		0.5	
Electricity mix {PT}	kWh			0.5
Inputs: Resources				
113 Collection, purification and distribution of water {CN_TW}	EUR2011	0.006		
113 Collection, purification and distribution of water {PL}	EUR2011		0.012	
113 Collection, purification and distribution of water {PT}	EUR2011			0.024
Inputs: Materials				
Packaging material plastic (CN_TW)	kg	0.010		
Packaging material plastic (PL)	kg		0.010	
Packaging material plastic (PT)	kg			0.010
Packaging material boxes (CN_TW)	kg	0.109		
Packaging material boxes (PL)	kg		0.109	
Packaging material boxes (PT)	kg			0.109
Inputs: Transport				
Sea transport, tkm {GLO} transoceanic ship	tkm	24.5	24.5	24.5
Road transport, tkm {CN_TW} 16-32 t truck	tkm	0.157		
Road transport, tkm {PL} 16-32 t truck	tkm		0.157	
Road transport, tkm {PT} 16-32 t truck	tkm			0.157
Output: Material for treatment				
Fish offal for treatment (CN_TW)	kg	0.429		
Fish offal for treatment (PL)	kg		0.429	
Fish offal for treatment (PT)	kg			0.429

Final product at end-user market: Kangamiut Atlantic Cod

For the distribution to end-user market stage, inputs for transport and electricity for storage of frozen products are included. Data for transport is provided by Kangamiut Seafood. Electricity consumption for storage of frozen products is estimated as 20 kWh/t of product (FAO, 2015).

The inputs related to transport at the distribution to end-user market stage refer to all transport of product from the processing site to the end-user market destination. The inputs of road transport for China, Poland and Portugal refer to truck transport from the processing site to shipping harbour in the respective country, while road transport in Denmark refers to the final transport to end-user markets (modelled as Denmark for the purpose of this study).

Table 5.10 shows the total inputs for the functional unit: 1 kg of Kangamiut Atlantic Cod at end-user market. The production volume difference between processing sites has been used as a guideline of how much of a share each processing site contributes to 1 kg of final Kangamiut Atlantic Cod product.

Table 5.10: Inventory for 1 kg of final product: Kangamiut Atlantic Cod.

Flows	Unit	Kangamiut Atlantic Cod
Output: functional unit		
Kangamiut Atlantic Cod at end-user market	kg	1
Inputs		
Salmon filet from aquaculture (see **Table 5.3**)	kg	1
Fileted cod (processing), China (see **Table 5.9**)	kg	0.72
Fileted cod (processing), Poland (see **Table 5.9**)	kg	0.21
Fileted cod (processing), Portugal (see **Table 5.9**)	kg	0.07
Displaced fileted cod (average landing and processing)	kg	-1
Inputs: Electricity for freezing		
Electricity mix {DK}	kWh	0.02
Inputs: Transport to end-user market		
Sea transport, tkm {GLO} transoceanic ship	tkm	16.1
Road transport, tkm {CN_TW} 16-32 t truck	tkm	0.080
Road transport, tkm {PT} 16-32 t truck	tkm	0.007
Road transport, tkm {PL} 16-32 t truck	tkm	0.023
Road transport, tkm {DK} 16-32 t truck	tkm	0.25

5.2 Inventory of Kangamiut Seafood products: Cooked and peeled prawns & Shell-on prawns

This section documents the inventory data used to model the following Kangamiut Seafood products: Cooked and peeled prawns and Shell-on prawns.

These two prawn products are modelled in a very similar fashion with the key difference being the required processing for cooked and peeled prawns. For this reason, these products are modelled almost identically with the only difference being the required processing for one product.

As with cod, landing of wild-caught prawns is considered constrained. For this reason, the consequence of increasing demand for prawn products is modelled as the marginal production of 1 kg of giant tiger prawn through aquaculture. This aquacultural production commonly takes place in South-East Asia (FAO, 2009) and is modelled using EXIOBASE data for rest-of-world Asia (WA).

As previously explained, when Kangamiut Seafood's supplier lands cold-water prawn, this displaces the landing activity that would otherwise have occurred to reach the limits of fish quotas. Therefore, the environmental effect of landing (and processing) relates to how Kangamiut Seafood's suppliers perform compared to the average, they are displacing. As with cod, the activities of Kangamiut Seafood's suppliers are considered average and the effect of improving these activities are described in **section 6.3**.

Figure 5.3 on the next page shows the product system used to model Kangamiut cooked and peeled prawns.

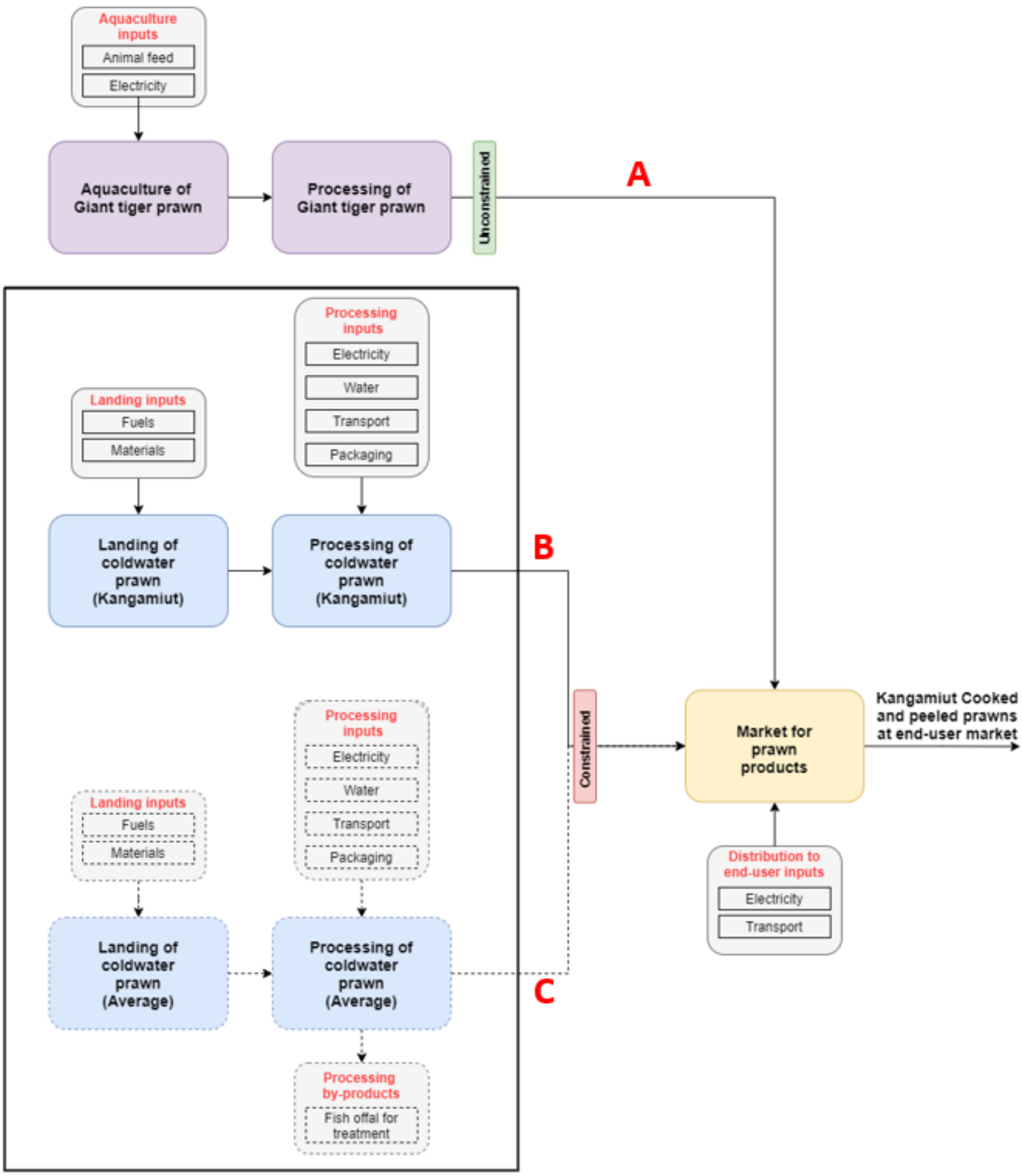

Figure 5.3: Product system for Kangamiut product: Cooked and peeled prawns.

As in **Figure 5.2**, in **Figure 5.3** A represents the marginal increase in aquaculture, B represents the value chain built using data provided by Kangamiut Seafood while C represents the displaced average landing. Thus, the same logic applies: A + B – C.

Figure 5.4 shows the product system used to model Kangamiut shell-on prawns.

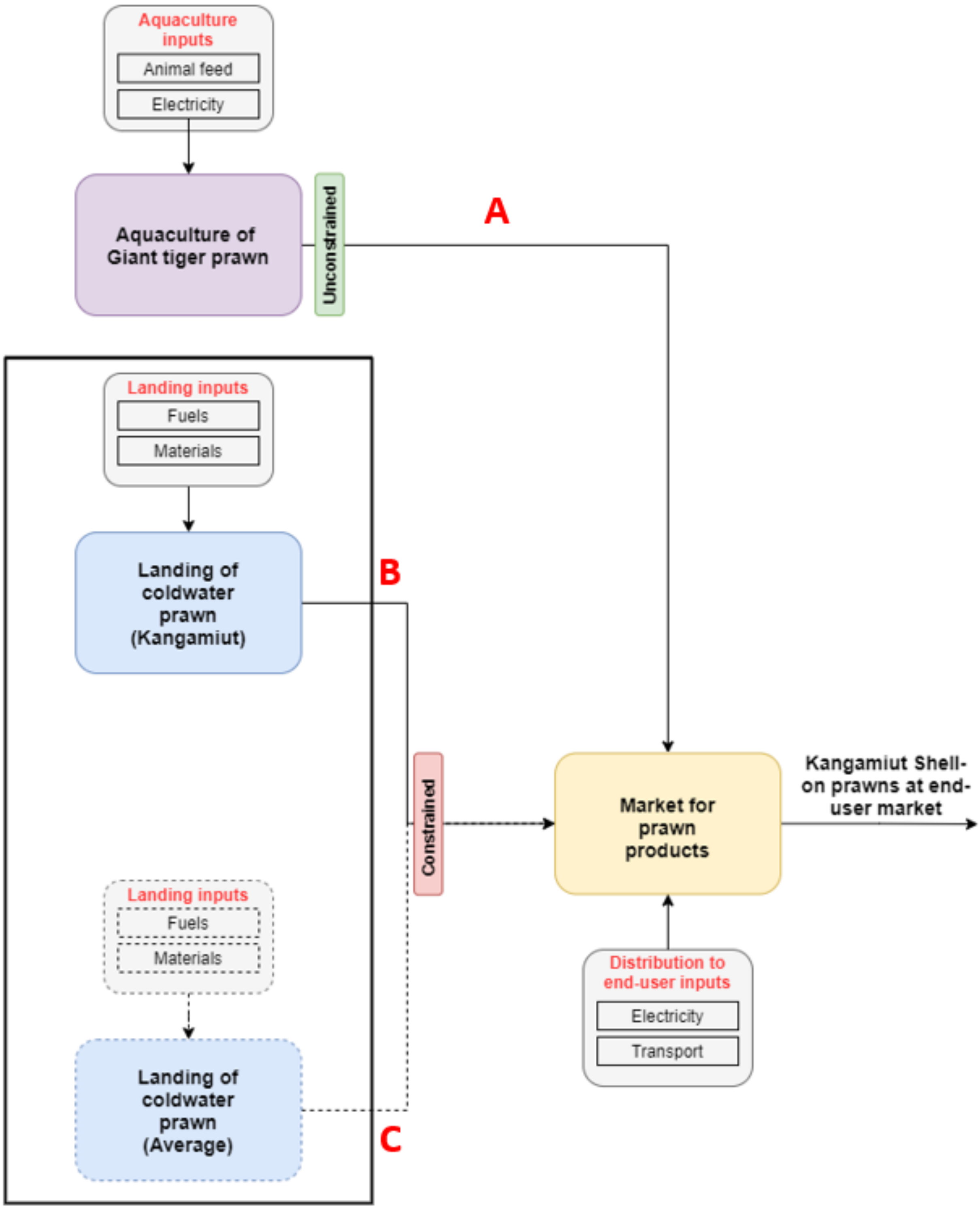

Figure 5.4: Product system for Kangamiut shell-on prawns.

Here, A, B, and C represents the same as above, meaning the same modelling logic applies: A + B – C.

Electricity usage in Giant tiger prawn aquaculture

Electricity usage for aquaculture of prawns is based on data from external sources. As with salmon aquaculture, this data also considers both the hatchery and growing stages. The electricity usage is based on the sum of the hatchery data and a production weighted average of 3 farms (which have data for electricity).

This is shown in **Table 5.11** below.

Table 5.11: Weighted average calculated from different sources of electricity consumption in SEA giant tier prawn aquaculture.

Electricity usage (kWh/kg live-weight prawn)	Production volume in source (tonnes)	Source
3.005	59618	Mungkung (2005) Farm 1
1.120	38333	Mungkung (2005) Farm 2
1.282	47180	Mungkung (2005) Farm 4
Weighted average:		
1.947		

Feed composition: Giant tiger prawn

Table 5.12 shows the feed conversion rates (FCR) and feed composition for giant tiger prawn, the marginal aquaculture species modelled for Kangamiut Seafood's prawn products.

Table 5.12: Feed conversion rate (Fry et al, 2018) and feed composition for Giant tiger prawn.

	Giant tiger prawn
FCR	
Feed conversion rate	1.7
Feed	
Source	FAO (2020f)
Wheat, meal	15.5%
Wheat, bran	6.3%
Wheat, gluten	3.8%
Wheat, middling	7.5%
Soybean meal	17.3%
Soybean oil	0.8%
Soy lecithin	0.4%
Lupine kernel meal	12.2%
Fish meal	18.1%
Fish oil	1.8%
Fish soluble concentrate	0.8%
Squid oil	0.8%
Squid meal	5.5%
Shrimp meal	6.1%
Shrimp head meal	3.1%
Total	**100%**

Aquaculture of giant tiger prawn

Table 5.13 shows the inputs for 1 kg of giant tiger prawn from aquaculture.

Table 5.13: Inventory for aquaculture of giant tiger prawn, normalised to a reference flow of 1 kg whole fish giant tiger prawn.

Flows	Unit	Aquaculture of giant tiger prawn
Output: reference flow		
Whole fish, giant tiger prawn	kg	1
Inputs		
Electricity mix {WA}	kWh	1.947
Soybean meal {GLO}	kg	0.294
Wheat, meal {WA}	kg	0.263
Wheat, bran {WA} Cultivation of wheat	kg	0.108
Wheat, gluten {WA} Cultivation of wheat	kg	0.065
Wheat, middlings {WA} Cultivation of wheat	kg	0.127
Soy lecithin {GLO} Market for oil and fat	kg	0.006
Feed lupine kernel meal {CN_TW} Feed protein and feed energy	kg	0.208
Feed fish meal {GLO} Feed protein and feed energy	kg	0.308
Fish oil as feed {GLO} Market for oil and fat	kg	0.031
Fish soluble concentrate {GLO} Feed protein and feed energy	kg	0.013
Squid oil {GLO} Market for oil and fat	kg	0.013
Feed squid meal {GLO} Feed protein and feed energy	kg	0.094
Feed shrimp meal {GLO} Feed protein and feed energy	kg	0.104
Feed shrimp head meal {GLO} Feed protein and feed energy	kg	0.052
Soybean oil {GLO} Market for vegetable oils	kg	0.013

As with salmon, inventory data for processing of giant tiger prawn is also based on the models used in The Big Climate Database (CONCITO, 2021). The inventory for processing of giant tiger prawn is shown in **Table 5.14**. This processing is assumed to take place in rest-of-Asia (WA) and as such uses background data for this region.

Table 5.14: Inventory for processing of giant tiger prawn.

Flows	Unit	Processing of salmon
Output: reference flow		
Processed giant tiger prawn	kg	1
Inputs		
Giant tiger prawn from aquaculture (See **Table 5.13**)	kg	2.5
Inputs: Electricity		
Electricity mix {WA}	kWh	0.650
Inputs: Transport		
Road transport, tkm {WA} 16-32 t truck	tkm	0.40
Inputs: Transport		
Fuel, natural gas {WA} Fuel and combustion, energy unit	MJ	8.641
Outputs: Material for treatment		
Fish offal for treatment {WA}	kg	1.5

Landing of prawns

This section describes the modelling of the activity of landing of cold-water prawns.

As with cod, data for landing of prawns is provided by Kangamiut Seafood. As explained in sub-section **Landing of cod**, diesel and lubricant oils are converted to mass units to match the unit of the background processes.

Bycatch for prawns is also not included on the same assumption as stated in sub-section **Landing of cod**.

As with cod, this is also assumed to be representative of the average activity.

Table 5.15 shows the inventory for landing of cold-water prawns.

Table 5.15: Inventory for landing of prawns.

Flows	Unit	Landing of coldwater prawns	LCI data
Output: reference flow			
Whole fish, cold-water prawn	kg	1	Reference flow
Inputs: Fuels			
Marine diesel	kg	0.47	Fuel, diesel {DK} Fuel and combustion
Lubricants	kg	9.913E-04	Lubricants and hydraulic oil {DK} Fuel
Inputs: Materials			
Superbags	kg	9.925E-03	64 Manufacture of rubber and plastic products {DK}
Cartons	kg	9.989E-02	54 Paper {DK}

Processing of prawns

This section describes the modelling of processing of prawns, which is relevant for the Kangamiut product: ‘Cooked and peeled prawns’. The product: ‘Shell-on prawns’ has no processing.

The inputs to processing of prawns is also based on data provided by Kangamiut Seafood. As with cod, the packaging materials included in the processing activity is modelled as originating in the processing location – in this case Morocco (modelled as WF (Rest of Africa)).

Fish offal from prawns is modelled as unspecified fish offal in the same manner as explained in **sub-section ‘Processing of cod’**, although with WF specific processes in EXIOBASE as background data.

Table 5.16 shows the inventory for processing of prawns.

Table 5.16: Inventory for processing of prawn. Flows are scaled to a reference flow of 1 kg prawns in brine.

Flows	Unit	Prawn, processing
Output: reference flow		
Prawns in brine	kg	1
Input:		
Landing of coldwater prawn (see **Table 5.15**)	kg	3.130
Inputs: Electricity		
Electricity mix {WF}	kWh	1.00E-04
Inputs: Resources		
113 Collection, purification and distribution of water {WF}	EUR2011	1.31E-04
Inputs: Materials		
Packaging material plastic (WF)	kg	0.046
Inputs: Transport		
Sea transport, tkm {GLO} transoceanic ship	tkm	14.869
Road transport, tkm {WF} 16-32 t truck	tkm	0.157
Output: Material for treatment		
Fish offal for treatment (WF)	kg	2.130

Final products at end-user market: Kangamiut cooked and peeled prawns & Kangamiut shell-on prawns

This section describes the modelling of the distribution to end-user market stage.

For this stage additional data for transport and electricity for freezing storage is included. As in **sub-section ' Final product at end-user market: Kangamiut Atlantic** Cod', transport data is provided by Kangamiut Seafood and electricity use for storage of frozen products is estimated as 20 kWh/t of product.

The inputs related to transport at the distribution to end-user market stage refer to all transport of product from the processing site to final end-user market destination. The inputs of road transport for WF refers to truck transport from the processing site to shipping harbour in Morocco, while road transport for Denmark refers to the final transport to end-user market destination after shipping (once again modelled using background data for Denmark).

Table 5.17: Inventory for Kangamiut Seafood prawn products at end-user market stage.

Flows	Unit	Kangamiut cooked and peeled prawns	Kangamiut shell-on prawns
Output: functional unit			
Kangamiut cooked and peeled prawns at end-user market	kg	1	
Kangamiut shell-on prawns at end-user market	kg		1
Inputs			
Prawns in brine (processing) (see **Table 5.16**)	kg	1	
Landing of coldwater prawns (see **Table 5.15**)	kg		1
Displaced processed prawns (average landing and processing)		-1	
Displaced shell-on coldwater prawns (average landing)	kg		-1
Processed giant tiger prawn (from aquaculture)	kg	1	
Raw giant tiger prawn (from aquaculture)	kg		1
Inputs: Electricity			
Electricity mix {DK}	kWh	0.02	0.02
Inputs: Transport			
Sea transport, tkm {GLO} transoceanic ship	tkm	11.7	14.72
Road transport, tkm {WF} 16-32 t truck	tkm	1.597E-2	
Road transport, tkm {DK} 16-32 t truck	tkm	0.176	0.5

6 Life cycle impact assessment (LCIA)

This chapter presents the results of the LCA for the included Kangamiut Seafood products. All results refer to the functional unit of 1 kg of product. The primary result is for GHG emissions although results for 13 additional impact categories are also included.

Overall characterised results are presented in **section 6.1.** Detailed contribution analyses for the impact category of global warming are presented in **section 6.2**.

6.1 Overall characterised results

This section presents the overall results for all impact categories. **Table 6.1** shows the characterised results for the assessed Kangamiut Seafood products.

Table 6.1: Characterised results: environmental impacts for Kangamiut Seafood's products.

Impact category	Unit	Atlantic Cod	Cooked and peeled Prawns	Shell-on Prawns
Global warming, fossil	kg CO_2-eq.	3.427	13.281	4.549
Nature occupation	PDF*m²*year	2.446	3.300	1.326
Respiratory inorganics	kg $PM_{2.5}$-eq.	0.005	0.017	0.006
Respiratory organics	pers*ppm*h	0.002	0.006	0.002
Human toxicity, carcinogens	kg C_2H_3Cl-eq.	0.039	0.113	0.023
Human toxicity, non-carc.	kg C_2H_3Cl-eq.	0.016	0.034	0.014
Ecotoxicity, aquatic	kg TEG-eq. w	9.401	-9.955	-4.735
Ecotoxicity, terrestrial	kg TEG-eq. s	8.866	21.311	6.828
Acidification	m² UES	0.537	1.904	0.706
Eutrophication, aquatic	kg NO_3-eq.	0.124	0.410	0.163
Eutrophication, terrestrial	m² UES	1.885	5.488	2.142
Photochemical ozone, vegetat.	m²*ppm*hours	21.896	65.741	21.835
Non-renewable energy	MJ primary	28.050	96.621	30.557
Mineral extraction	MJ extra	0.004	0.008	0.002

Figure 6.1 includes a visualisation of GHG emissions for the different Kangamiut Seafood products.

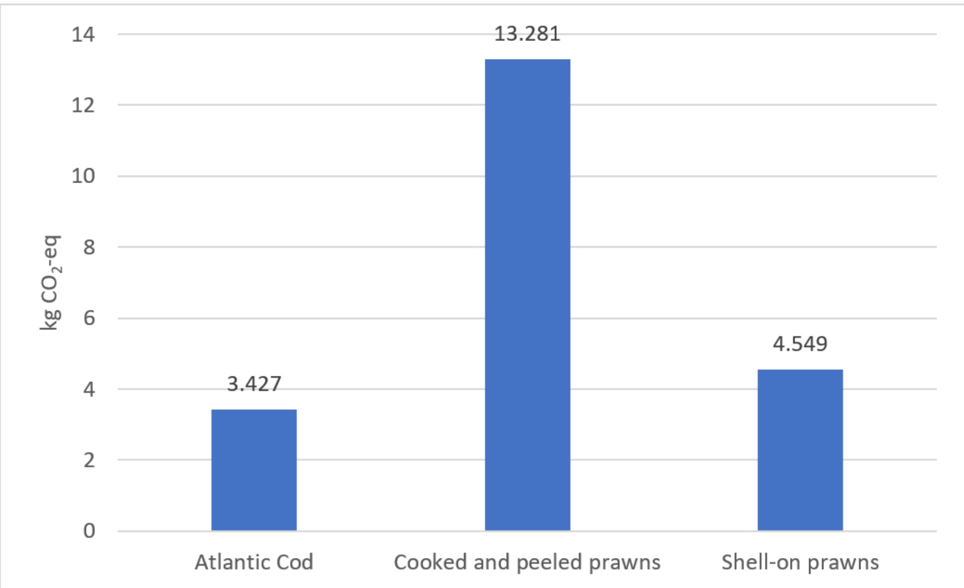

Figure 6.1: Visualisation of results for GHG emissions (per kg product) for the assessed Kangamiut Seafood products.

6.2 Contribution analysis: Kangamiut Seafood products

This section presents a contribution analysis of the GHG results of the assessed Kangamiut Seafood products based on consequential modelling.

Firstly, the contribution analysis divides share of the carbon footprint into the different life cycle stages. Secondly, the most important inputs the major life cycle stages are identified, with a focus on the stages which Kangamiut Seafood can influence.

With the results of this contribution analysis, Kangamiut Seafood can identify how to prioritize improvements of aspects within their influence. This provides the basis for **section 6.3**, in which the effect of improvements to the hotspots identified in this contribution analysis are investigated.

Atlantic Cod:

Table 6.2 shows the contribution analysis for the Kangamiut Seafood product: Atlantic Cod.

Only the life cycle stages which can be influenced by Kangamiut Seafood are presented in detail. For this reason, inputs related to fileted salmon from aquaculture are not shown in detail. The 'displacement' contributions seen below refer to the avoided average landing and processing. The sum of all the non-displacement activities (e.g. materials and fuels in landing stage) represents the total impact from Kangamiut Seafood's supplier operations. Thus, it cancels out with the displaced average on the assumption that they are the same, which results in a total carbon footprint of 0 for both the landing and processing stage.

Table 6.2: Contribution analysis for Kangamiut Atlantic Cod.

Life Cycle Stage	Contribution	Emissions (kg CO_2-eq)
Landing of cod		
	Materials (landing equipment)	0.063
	Fuels	2.209
	Displacement of average landing activity	-2.272
	Total landing of cod stage	**0**
Processing of cod		
	Electricity	0.428
	Transport	0.485
	Waste treatment	0.255
	Materials (packaging)	0.654
	Resources (water)	0.025
	Displacement of average processing activity	-1.848
	Total processing of cod stage	**0**
Distribution to end-user market		
	Salmon filet from aquaculture	2.814
	Electricity	0.001
	Transport	0.612
	Total distribution to end-user market stage	**3.427**
All stages		
Total		**3.427**

As indicated by **Table 6.2**, most of the carbon footprint for this product stems from the marginal salmon from aquaculture, which meets the increase in demand. This means a large share of the carbon footprint of Atlantic Cod is outside the influence of Kangamiut Seafood. However, fuel usage during landing of cod also represents a major share of emissions and can potentially be influenced by Kangamiut Seafood. Any improvements here could have a large influence on the carbon footprint as the displaced average landing would then be worse performing compared to Kangamiut Seafood's supplier.

Cooked and peeled prawns:

Table 6.3 shows the contribution analysis for the Kangamiut Seafood product: Cooked & peeled prawns.

As with Atlantic Cod, only the life cycle stages which can be influenced by Kangamiut Seafood are presented in detail. As before, the displacement contributions refer to the avoided activities resulting from Kangamiut Seafood's suppliers landing and processing the prawn instead of someone else.

Table 6.3: Contribution analysis for Kangamiut cooked and peeled prawns.

Life Cycle Stage	Contribution	Emissions (kg CO_2-eq)
Landing of cold-water prawns		
	Materials (landing equipment)	1.117
	Fuels	6.016
	Displacement of average landing activity	-7.133
	Total landing of cold-water prawns stage	**0**
Processing of prawns		
	Electricity	4.52E-05
	Transport	0.277
	Waste treatment	0.490
	Materials (packaging)	0.463
	Resources (water)	3.62E-05
	Displacement of average processing activity	-1.230
	Total processing of prawns stage	**0**
Distribution to end-user market		
	Processed giant tiger prawn from aquaculture	12.869
	Electricity	0.001
	Transport	0.411
	Total distribution to end-user market stage	**13.281**
All stages		
Total		**13.281**

As shown in **Table 6.3**, the vast majority of the carbon footprint for cooked and peeled prawns is caused by the marginal aquaculture of giant tiger prawn which is outside the influence of Kangamiut Seafood. However, as with Atlantic Cod, fuel consumption during landing constitutes a substantial source of emissions where any improvements would result in the displaced average landing being noticeably worse and thereby providing environmental benefits.

Shell-on prawns:

Table 6.4 shows the contribution analysis for the Kangamiut Seafood product: Shell-on prawns.

Once again, only the life cycle stages which can be influenced by Kangamiut Seafood are presented in detail. As before, the displacement contributions refer to the avoided activities resulting from Kangamiut Seafood's suppliers landing and processing the prawn instead of someone else.

Table 6.4: Contribution analysis for Kangamiut shell-on prawns.

Life Cycle Stage	Contribution	Emissions (kg CO_2-eq)
Landing of cold-water prawns		
	Materials (landing equipment)	0.357
	Fuels	1.922
	Displacement of average landing activity	-2.279
	Total landing of cold-water prawns stage	**0**
Distribution to end-user market		
	Aquaculture of giant tiger prawn	3.710
	Electricity	0.001
	Transport	0.837
	Total distribution to end-user market stage	**4.549**
All stages		
Total		**4.549**

As seen in **Table 6.4**, the vast majority of the carbon footprint of shell-on prawns is once again caused by the marginal aquaculture of giant tiger prawn, which is outside the influence of Kangamiut Seafood. The highest contributor within the influence of Kangamiut Seafood is the fuel use during landing, which makes it the obvious aspect in which an improvement could reduce the carbon footprint of the product.

6.3 Improvement analysis for Kangamiut Seafood suppliers

In this section, improvement initiatives to the environmental performance of Kangamiut Seafood's suppliers are investigated.

As explained throughout this report, the activities of Kangamiut Seafood's suppliers are assumed to be representative of the average activity. This assumption is made due to a lack of data for the average processes and on the basis of Kangamiut Seafood now looking into potential improvements to be made.

Thus, this section will use fictional scenarios to exemplify the environmental benefits of improving these activities. These scenarios are based on the results of the contribution analysis, in which hotspots for these activities were identified.

As fuel consumption during the landing activity constitutes the majority of the carbon footprint from the activities Kangamiut Seafood can control, this indicates an obvious hotspot to focus on. Thus, the effect of reducing diesel consumption during the landing activities is the focus for this improvement analysis.

New contribution analyses are presented for all 3 products, all with 10% reduced diesel consumption. This is an arbitrary reduction that only serves the purpose of showcasing the effect on the carbon footprints of the products.

Table 6.5 shows the updated contribution analysis for Atlantic Cod in a scenario with 10% reduced diesel consumption during landing.

Table 6.5: Contribution analysis and results for Atlantic Cod with 10% reduced diesel consumption.

Life Cycle Stage	Contribution	Emissions (kg CO_2-eq)
Landing of cod		
	Materials (landing equipment)	0.063
	Fuels	2.052
	Displacement of average landing activity	-2.272
	Total landing of cod stage	**-0.220**
Processing of cod		
	Electricity	0.428
	Transport	0.485
	Waste treatment	0.255
	Materials (packaging)	0.654
	Resources (water)	0.025
	Displacement of average processing activity	-1.848
	Total processing of cod stage	**0**
Distribution to end-user market		
	Salmon filet from aquaculture	2.814
	Electricity	0.001
	Transport	0.612
	Total distribution to end-user market stage	**3.427**
All stages		
Total		**3.206**

The new result for Atlantic Cod is 3.206 kg CO_2-eq, which represents a 6.45% decrease in total carbon footprint. By improving the efficiency of the landing activity, the displacement of the average landing activities results in a net avoided GHG emissions, which results in a total GHG emission contribution from landing of -0.220 kg CO_2 eq./kg filleted cod.

Table 6.6 shows the updated contribution analysis for Cooked and peeled prawns in a scenario with 10% reduced diesel consumption during landing.

Table 6.6: Contribution analysis and results for Cooked and peeled prawns with 10% reduced diesel consumption.

Life Cycle Stage	Contribution	Emissions (kg CO_2-eq)
Landing of cold-water prawns		
	Materials (landing equipment)	1.117
	Fuels	5.415
	Displacement of average landing activity	-7.133
	Total landing of cold-water prawns stage	**-0.602**
Processing of prawns		
	Electricity	4.52E-05
	Transport	0.277
	Waste treatment	0.490
	Materials (packaging)	0.463
	Resources (water)	3.62E-05
	Displacement of average processing activity	-1.230
	Total processing of prawns stage	**0**
Distribution to end-user market		
	Processed giant tiger prawn from aquaculture	12.869
	Electricity	0.001
	Transport	0.411
	Total distribution to end-user market stage	**13.281**
All stages		
Total		**12.679**

The new result of 12.679 kg CO_2-eq represents a decrease of 4.53% in total carbon footprint. By improving the efficiency of the landing activity, the displacement of the average landing activities results in a net avoided GHG emissions, which results in a total GHG emission contribution from landing of -0.602 kg CO_2 eq./kg cooked and peeled prawn.

Table 6.7 shows the updated contribution analysis for Shell-on prawns in a scenario with 10% reduced diesel consumption during landing.

Table 6.7: Contribution analysis and results for Shell-on prawns with 10% reduced diesel consumption.

Life Cycle Stage	Contribution	Emissions (kg CO_2-eq)
Landing of cold-water prawns		
	Materials (landing equipment)	0.357
	Fuels	1.730
	Displacement of average landing activity	-2.279
	Total landing of cold-water prawns stage	**-0.193**
Distribution to end-user market		
	Aquaculture of giant tiger prawn	3.710
	Electricity	0.001
	Transport	0.837
	Total distribution to end-user market stage	**4.549**
All stages		
Total		**4.357**

The new result of 4.357 kg CO_2-eq represents a decrease of 4.22% in total carbon footprint. By improving the efficiency of the landing activity, the displacement of the average landing activities results in a net avoided GHG emissions, which results in a total GHG emission contribution from landing of -0.193 kg CO_2 eq./kg shell-on prawn.

From these new results, it is clear that improvements to the diesel consumption during landing can have a significant effect on the carbon footprint of the products. It is evident that any other improvements unrelated to diesel can further reduce the climate impact of the products, although less so due to the significance of emissions from diesel consumption.

7 Carbon offsetting possibilities for Kangamiut Seafood

This chapter presents three different options for carbon offsetting for Kangamiut Seafood:

- Nature conservation of South American rainforest and Indonesian peatland
- Carbon sequestration in seaweed
- Power purchase agreement (PPA) through investments in Chinese wind power

The climate effects of such initiatives are calculated to support decision making for Kangamiut Seafood when choosing among different carbon offsetting initiatives based on their climate change mitigation potential. This chapter does not include detailed LCAs of the different carbon offsetting options, but only screening LCA results.

The purpose is therefore to provide a frame of reference to Kangamiut Seafood, when considering carbon offsetting options and their costs. This way, Kangamiut Seafood can explore the cost efficiency of different options available to them on the basis of these results, and thus guide decisions towards achieving the highest GHG emissions reduction.

7.1 Nature conservation of South American rainforest and Indonesian peatland

The carbon offsetting example involves conserving an area of land in the South American rainforest, and thus protecting it from deforestation. This has the goal of preventing the forest's carbon stock being released into the atmosphere as CO_2 emissions.

For this reason, the way of modelling the benefits of such an initiative is to calculate the benefits of postponing the deforestation that would otherwise happen due to the current observed trend of deforestation. This postponement benefit is calculated using the time-dependent characterization factor of 0.00772 for accelerated CO_2 emissions described in Schmidt et al (2015).

Due to the current trend of deforestation, conserving forest area has the consequence of pushing production of new land-equivalents elsewhere to satisfy market demand for yields. As mentioned in **section 3.2**, this is achieved through a mixture of deforestation to produce new land and intensification of currently used land. Thus, the total environmental ramifications of nature conservation, and thereby effectively removing land from the market, must include this downstream consequence.

Put briefly, this means nature conservation can be viewed as redirecting production of land equivalents somewhere else. This is visualised in **Figure 7.1**.

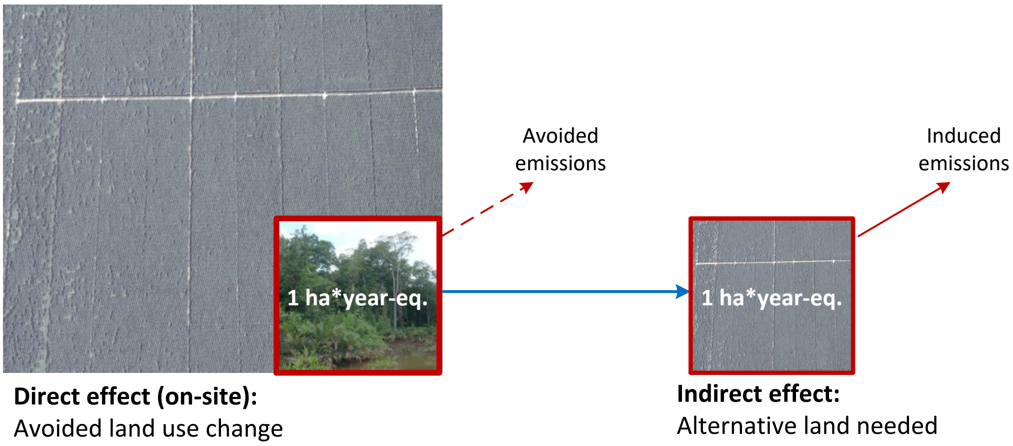

Figure 7.1: Direct and indirect effect of nature conservation. Here illustrated as nature conservation in an oil palm cultivation. Pictures: Oil palm field (Google Maps 2014) and nature (Nature conservation reserve in United Plantations Berhad Indonesia, picture taken by Jannick H Schmidt).

This nature conservation example is modelled as two different scenarios with the following functional units:

- Conservation 1 ha of Brazilian rainforest.
- Conservation of 1 ha of Indonesian peatland.

Results are given for 1, 10, 50 and 100 years of continuous nature conservation.

Brazilian rainforest:

The above-ground biomass content of 1 ha of tropical rainforest in South America is approximately 300 tonnes dry matter per hectare (IPCC, 2006). Additionally, the ratio of below-ground biomass to above-ground biomass is 0.37 for tropical rainforests (IPCC, 2006). This results in a total biomass weight of 411 t dm per hectare of Brazilian rainforest. As the ratio of carbon content to biomass is 0.47 t C / t dm biomass (IPCC, 2006), this results in a carbon stock of 193.17 tonnes of carbon per hectare of rainforest.

It is assumed that the biomass content of this fully grown forest is stable, meaning that an equal amount of carbon stock is gained through growth of new biomass and lost through decomposition and decay of old biomass.

Converting carbon stock to CO_2 is done by multiplying with the ratio of molecular weight of carbon dioxide to carbon (44/12). This results in 708.29 t CO_2 for the 1 ha of rainforest, which corresponds to the emissions that would occur if the land was deforested.

As mentioned, the benefit of this nature conservation is calculated by modelling it as postponing these emissions to a later point in time. Postponing 1 kg of CO_2 by 1 year reduces the climate impact to 0.99228 CO_2-eq, when using the time-dependent characterisation factor of 0.00772. Thus, a climate benefit of -0.00772 kg CO_2-eq is achieved by postponing the emission by 1 year.

Similarly, the benefit of conserving the rainforest carbon stock for 1 year at a time can be calculated by multiplying the potential CO_2 emissions from deforestation with the same characterisation factor of 0.00772. This results in a benefit of -5.468 t CO_2-eq for conserving the forest for 1 year. This benefit accumulates every year the carbon stock is conserved as this means delaying deforestation for another year each time.

When calculating the consequences of pushing production of land-equivalents elsewhere as a result of nature conservation, the common factor of comparison is the productivity of the land. Thus, it is required to compare the 1 ha of South American rainforest with the global average productivity of 1 ha of arable land, which is the assumed category of land for this example. The unit for this global average is 1 production weighted hectare year (or ha year-eq). To obtain data for this comparison to the global average, **Figure 7.2** is used as a guideline.

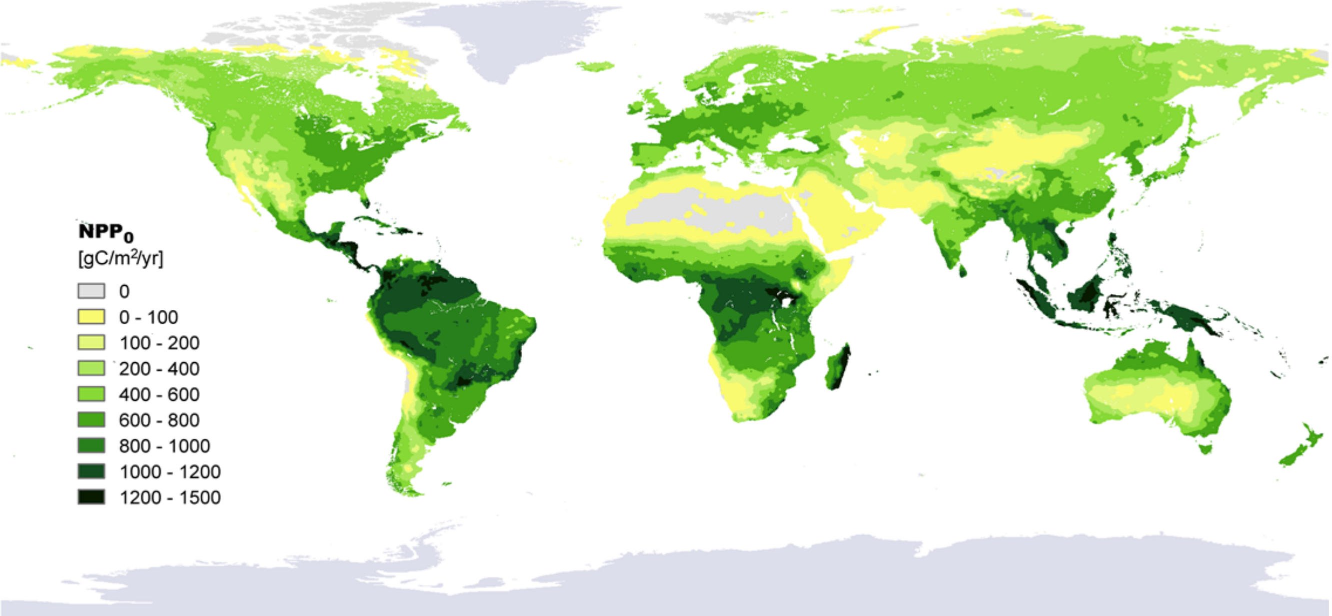

Figure 7.2: Overview of the net primary production of land in different areas of the globe (Haberl et al, 2007)

As seen on **Figure 7.2**, most of the Amazon rainforest is within the NPP_0 value of 800 – 1200 g C/m^2/year. For this reason, an estimate value of 1000 is used.

Since the average NPP_0 value of 1 ha arable land is 568 g C/m^2/year (Haberl et al, 2007), this means the difference can be calculated by dividing the two. This results in 1.761 ha year-eq which corresponds to the amount of land that must be produced elsewhere as a consequence of conserving the 1 ha of Brazilian rainforest.

Thus, the key element to consider is the benefits of preserving the carbon stock content of 1 ha of Brazilian rainforest compared to the emissions relating to the additional production of 1.761 ha year-eq of land per year.

This can be modelled as occupying 1.761 ha year-eq of arable land in the iLUC model presented in **section 3.2**. This indirect effect will occur every year the nature is conserved as this prolongs the occupation.

Table 7.1 presents nature conservation results for different points in time.

Table 7.1: Overview of results from nature conservation of 1 ha of Brazilian rainforest at different year intervals.

	Benefit from nature conservation ($t\ CO_2$-eq)	Induced iLUC emissions ($t\ CO_2$-eq)	Total climate effect ($t\ CO_2$-eq)
Year 1	-5.468	2.280	**-3.188**
Year 10	-54.680	22.796	**-31.88**
Year 50	-273.40	113.98	**-159.42**
Year 100	-546.80	227.96	**-318.84**

Indonesian peatland

The second scenario involves conserving the carbon stock of peatland in Indonesia and thereby postponing emissions relating to the release of its carbon stock. For this scenario, 1 ha of dense 10-meter-thick peat soil is used. The calculation for this scenario follows the same logic, the benefits of conserving the carbon stock is calculated as postponing the emissions to a later point in time.

Thick (10 m) peatland has an approximate carbon stock of 3,000 –7,000 t C/ha (Agus & Subsika, 2008), estimated in this case to be the average of 5000 tonnes of carbon. Using the same conversion as above, this equates to 18,333 t CO_2 which represents the emissions related to releasing this carbon stock. Using the time dependent characterisation factor for CO_2 of 0.00772, the benefit for postponing these emissions by one year results in -141.53 t CO_2.

To calculate the effects of pushing the land market somewhere else, **Figure 7.2** is once again utilised to indicate land productivity levels. Here, Indonesia is in the 1,000 to 1,500 t C/m^2/year range. Thus, the value utilised for this scenario is 1,250 t C/m^2/year. This corresponds to a global average of 2.201 ha year-eq on the arable land market, which must be produced somewhere else.

Thus, the overall climate effects of this nature conservation initiative can be calculated. This is shown in **Table 7.2**.

Table 7.2: Results for conservation of 1 ha of Indonesian peatland.

	Benefit from nature conservation (t CO_2-eq)	Induced iLUC emissions (t CO_2-eq)	Total climate effect (t CO_2-eq)
Year 1	-141.53	2.85	**-138.68**
Year 10	-1,415	28.49	**-1,386**
Year 50	-7,076	142.46	**-6,934**
Year 100	-14,153	284.92	**-13,868**

Table 7.2 shows that both the benefits from nature conservation and the resulting iLUC emissions are higher. However, the increase in iLUC emissions is dwarfed by the much higher increase in climate benefits. Overall, conserving 1 ha of Indonesian peatland for 100 years results in a climate benefit that is approximate 43 times higher compared to conservation of 1 ha of Brazilian rainforest.

7.2 Seaweed farming for carbon sequestration

Seaweed farming is another opportunity to mitigate climate change through carbon offsetting. Seaweed is an attractive option due to its CO_2 sequestration possibilities. Especially so because seaweed slowly falls into the deep sea after death where the carbon content of the biomass is stored for centuries. This way, the eventual release of CO_2 into the atmosphere from biomass decomposition and decay is avoided by instead storing it in the ocean. This makes it fundamentally different to land-based forest carbon sequestration as the market for land is not affected unlike in the previous example of nature conservation, which means induced iLUC effects are avoided.

This is evidently an advantage for climate change mitigation, although adverse effects in other impact categories could result from this. For instance, increasing the amount of seaweed going into the deep ocean might impact the deep ocean ecosystem and by extension biodiversity. These potential trade-offs are not addressed in this assessment.

To calculate the carbon offsetting possibilities of seaweed, it is necessary to determine its carbon sequestration potential. This is obviously dependent on several factors such as species, geography et cetera.

A review of scientific literature on the topic is used to obtain general information on the carbon sequestration potential of seaweed. The carbon sequestration potential values found in external sources vary greatly depending on the study. Most of the identified studies mention a reliance on assumptions to obtain carbon sequestration values, which could be a contributing factor to the high variations. For the purpose of this study, results are provided for different values found in different sources.

This large variation in carbon sequestration values evidently brings large uncertainty to the results. The superficial nature of this carbon offsetting example means this is not addressed although a dedicated LCA covering the topic in detail would take this into account. This large variation also indicates that considerations of seaweed species, geography and more is an important factor for efficiently using seaweed for carbon offsetting.

The functional unit for this seaweed offsetting screening is defined as: 1 ha of coastal seaweed aquaculture for the purpose of carbon sequestration for 1 year at a time.

The superficial nature of this screening means that processes for planting of seaweed or potential maintenance are not included. Instead, the focus is solely on the carbon sequestration potential.

Additionally, it is assumed that the seaweed will grow and sequester the same amount of CO_2 every year. It is assumed that all dead and decomposing seaweed enters the deep sea where the CO_2 is stored for hundreds of years.

Based on Chung et al (2013), 66% of seaweed enters the deep ocean where the carbon contents are stored. The remaining 33% take part in various other natural processes such as being eaten by herbivores or entering the detritus food chain cycle (Chung et al, 2013). Thus, a factor of 0.66 is used to indicate how much of the sequestered carbon end up in the deep ocean without being re-released into the atmosphere in the near future. Chung et al (2013) also notes a lifespan of approximately 5 years and thus the first reference year in these results is year 5. Additional results are shown for year 10, 50 and 100.

The carbon sequestration results are shown in **Table 7.3** using different sources for carbon sequestration potential.

Table 7.3: Climate effect of seaweed farming for different points in time. Different sources for carbon sequestration potential of seaweed are used for separate results.

Carbon sequestration potential (t CO_2/ha/year)	Year 5 (t CO_2)	Year 10 (t CO_2)	Year 50 (t CO_2)	Year 100 (t CO_2)	Source
10	-33	-66.0	-330.0	-660.0	Chung et al (2013)
15	-49.50	-99.0	-495.0	-990.0	Duarte et al (2017)
57.64	-190.21	-380.42	-1902	-3804	Mashoreng et al (2019)
74.93	-247.27	-494.54	-2472	-4945	Fakhraini et al (2020)

It is evident that the variation in carbon sequestration levels between sources have large implications on the results, meaning that any seaweed carbon offsetting initiative must consider and evaluate different options thoroughly.

The results show that there are significant climate benefits to be found using seaweed. Based on these general screenings, it appears that the climate mitigation effect of 1 ha of seaweed farming outperforms nature conservation of 1 ha of Brazilian rainforest but does not outperform conservation of 1 ha of thick Indonesian peatland.

Another potentially interesting angle is the use of seaweed as biofuel, thereby substituting alternative fuels. Here, the carbon sequestration in the deep sea would not occur and instead any potential climate benefit would relate to the avoided production and combustion of alternative fuels. An assessment of this, however, is not included in this screening.

7.3 Power purchase agreement of Chinese wind energy

The third and final option for carbon offsetting for Kangamiut Seafood in this report is based around a power purchase agreement (PPA) focused on increasing the capacity of wind energy in China. China is chosen as an example based on its high share of fossil fuels in its marginal electricity mix (see **Table** 3.2) and because the Chinese electricity market is relevant elsewhere in this study.

A power purchase agreement involves investing in energy production capacity. This differs from other similar initiatives such as renewable energy certificates, where no such investment into increased production capacity exists.

From a consequential LCA perspective, this is a key distinction as investing into new capacity changes the long-term marginal electricity mix of the country in question, which is how consequential LCA calculates environmental impact from electricity. For countries such as China where the long-term marginal electricity mix still involves a large share of fossil fuels (primarily coal), this can support a transition to lower carbon footprint electricity production sources in the future.

For the purpose of this screening, it is assumed that any investment in wind energy will replace coal power in the marginal mix.

The functional unit for this PPA carbon offsetting example is defined as follows: Sponsoring a 1 MW wind turbine with an annual electricity output of 2,986 MWh a year in coastal China.

The annal output of the 1 MW wind turbine varies depending on the average wind speeds. These vary greatly depending on the region, although an approximate value of 7 m/s is used for coastal China (drr.ikcest.org, 2021). The assumed annual output of a 1 MW wind turbine with annual average wind speeds of 7 m/s is 2,986 MWh (Renewablesfirst.co.uk, nd). Following the previous assumption of displacement of coal power capacity, this means 2,986 MWh will be moved from coal to wind power in the long-term marginal electricity mix of China.

In order to calculate the climate effect of this change, the difference in climate impact between producing 2,986 MWh of electricity from coal power and wind power is calculated. The background EXIOBASE processes for coal and wind power in China/Taiwan are used as the basis for this comparison.

Table 7.4 shows the comparison in emissions between wind and coal power and the result of switching between them.

Table 7.4: Emissions from the production of 2986 MWh of electricity from coal and wind respectively and the result of changing from coal to wind power.

	t CO_2-eq	Background data
Coal power	4242	96 Production of electricity by coal {CN_TW}
Wind power	603.42	100 Production of electricity by wind {CN_TW}
Result from change	**-3639**	

Thus, the annual climate effect of this change in China's long-term marginal electricity mix is -3639 t CO_2-eq, due to the lower climate impact of wind compared to coal for the same output of electricity. Over its lifespan this annual effect will occur multiple times as long as coal power capacity is the replaced source in the long-term marginal electricity mix. For this reason, any changes in the current trends of marginal sources which make up the additional installed electricity production capacity in China will also change the annual results.

To showcase this point, a PPA investing in a wind turbine in Denmark would only replace another windmill which means that no or negligible effects would be achieved. Thus, such a PPA must always be measured against the trends seen in the marginal mix. This also means making results for many years only increases the uncertainty. For instance, it is very unlikely that China's current long-term marginal mix is the same in 50 years. Thus, results are not shown for different time intervals like in the other carbon offsetting examples.

Regional considerations could also be included in the context of a Chinese wind power PPA. As mentioned, annual average wind speeds are important for the electricity output of the wind turbine which influences how much coal power capacity is replaced. Additionally, a more local analysis of China's regional long-term marginal electricity mixes could be useful to identify the areas where any additional coal power capacity is most likely to be substituted by the new wind turbine.

8 Interpretation and conclusions

This section presents the interpretation and the conclusion of the study. The overall results for Kangamiut Seafood's products are discussed and main conclusions are drawn, focusing on GHG emissions.

The objective of this LCA is to provide consequential information on the environmental footprint, with a focus on GHG emissions, of the following Kangamiut Seafood products:

- Atlantic Cod
- Cooked and peeled prawns
- Shell-on prawns

The functional unit, i.e. the reference to which results are presented, is defined as 1 kg of product at end-user market of the three included Kangamiut Seafood products listed above.

8.1 Results per kg of Kangamiut Seafood product

The GHG results for the three Kangamiut Seafood products are summarised in **Table 8.1**. The results in the table refer to the functional unit of 1 kg of each product at end-user market.

Table 8.1: Characterised GHG results for the included Kangamiut Seafood products.

Impact category	Unit	Atlantic Cod	Cooked and peeled Prawns	Shell-on Prawns
Global warming, fossil	kg CO_2-eq.	3.427	13.281	4.549

It appears from **Table 8.1** that both the prawn products both have a higher carbon footprint than Atlantic Cod, even though shell-on prawns require no processing. This can mostly be attributed to the marginal market reaction of aquaculture, where the GHG emissions related to 1 kg of giant tiger prawn from aquaculture are more than 3 times higher than 1 kg of salmon from aquaculture.

This difference can mostly be attributed to the vast difference in electricity consumption in the two aquaculture systems. Electricity usage accounts for 53% of the carbon footprint for giant tiger prawn aquaculture, but only 11% for salmon aquaculture.

Additionally, the long-term marginal electricity mix for rest-of-Asia (WA) includes a higher share of polluting energy sources compared to Norway, which means electricity usage has a higher carbon footprint for this region. Thus, both the increase in electricity consumption and the higher emission factor for rest-of-Asia contribute significantly to this difference.

The carbon footprint of giant tiger prawn aquaculture is also the main reason for the vast difference in results between the two prawn products. This is caused by the higher required input of 3.13 kg landed prawns pr. 1 kg of cooked and peeled prawn compared to the 1 kg to 1 kg ratio of shell-on prawns. This also means that the marginal reaction of increased giant tiger prawn aquaculture is higher for the cooked and peeled prawn product.

The results obtained in this study deviate from similar results found in The Big Climate Database (CONCITO, 2021), by CONCITO and 2.-0 LCA consultants. Although the applied LCA methodology is similar, The Big Climate Database is a more superficial study of each product and is based on more general industry data. Additionally, new data sources were identified for relevant processes. An example of this is electricity usage in salmon and prawn aquaculture, where the newer data sources used in this study deviate from the ones used in The Big

Climate Database which has implications for the GHG emissions results. For prawns, another difference with The Big Climate Database is the ratio of whole fish prawns to processed prawns. Here, 2.5 kg of prawns is used for an output of 1 kg of processed prawns, while the data provided by Kangamiut Seafood indicate an input of 3.1k kg of prawns for the same output of 1 kg of processed prawns. This data deviation has large implications on the results for cooked and peeled prawns in this study, although it is at the same time offset by the lower electricity consumption in giant tiger prawn aquaculture. The end result is a similar climate impact between this study and the one found in The Big Climate Database.

8.2 Improvement options for Kangamiut Seafood

The contribution analysis presented in **section 6.2** revealed that a large share of the carbon footprint of the products stems from the marginal reaction of aquaculture systems and is thus outside the influence of Kangamiut Seafood. Additionally, fuel usage during landing activities represents a large source of emissions, which is within the influence of Kangamiut Seafood. As described throughout the report, any improvements to these constrained landing and processing activities would mean a more beneficial comparison to the displaced average landing and processing activity that would otherwise occur. Thus, fuel consumption during landing is the obvious hotspot within the influence of Kangamiut Seafood to focus on if the goal is a reduction of climate impact for the studied products.

In **section 6.3**, the effect of reducing diesel consumption during landing by 10% was analysed. This resulted in a 6.45% decrease in carbon footprint for Atlantic Cod, a 4.53% decrease for Cooked and boiled prawns and lastly a 4.22% decrease for Shell-on prawns. This indicates that improvements to the activities of Kangamiut Seafood's suppliers can potentially have significant effects on the carbon footprint of their products, even though a major share of the products' carbon footprint is related to aquaculture which is outside the influence of Kangamiut Seafood.

For this reason, the efforts of Kangamiut Seafood are recommended to be best directed at scrutinizing the activities of the suppliers in their value chain to ensure a comparison as beneficial as possible with the displaced average activity. While the improvement analysis in this LCA focused specifically on fuel consumptions during landing due to its high emission significance, it is evident that several other smaller improvements are also relevant to consider. The contribution analysis presented in this LCA can provide perspective on how different inputs should be prioritised in this regard based on their environmental significance.

8.3 Carbon offsetting options for Kangamiut Seafood

By request of Kangamiut Seafood, options for carbon offsetting were also examined in this study. Here, 3 options were analysed: Nature conservation, seaweed carbon sequestration and a power purchase agreement (PPA) focused on wind energy in China.

A screening for each option was presented in **section 8.3**. These serve the purpose of decision-making guidance for Kangamiut Seafood by functioning as a point of reference of how to maximize climate change mitigation.

For nature occupation, two options were analysed: 1 hectare of Brazilian rainforest and 1 hectare of Indonesian thick peatland. Here, the nature conservation of Indonesian peatland vastly outperformed the rainforest due to the significantly higher carbon stock in the peat soil. After a 100-year period, the result was -318.84 t CO2-eq for conservation of Brazilian rainforest was and -13,868 t CO2-eq for conservation of Indonesian peatland.

The screening of seaweed carbon sequestration was based on 1 ha of seaweed aquaculture. Seaweed has the advantage of storing about 66% of its carbon in the deep ocean and thus removing it from the atmosphere for hundreds of years. Different sources for the carbon sequestration potential of seaweed were used and results were presented for each one. Overall, the results after 100 years ranged between -660 and -4,945 t CO2-eq, which revealed considerable climate change mitigation effects which outperformed conservation of the Brazilian rainforest although not the Indonesian peatland.

The PPA screening was conducted based on a functional unit of a 1 MW wind turbine in coastal China. Unlike the other screenings, results were not shown at different points in time. This is because the calculated results are based on the wind turbine substituting coal power in the long-term marginal mix of China. Thus, any changes in the marginal electricity mix of China could result in coal power no longer being the vast majority of increased capacity. This means that results based on the wind turbine substituting coal might not be representative of the future. The result of this screening showcased a climate effect of -3,639 t CO_2-eq for 1 year caused by this change in China's long-term marginal electricity mix.

Overall, these carbon offsetting results are based on a variety of different scenarios that might exist in very different contexts which influence their applicability. For instance, conserving 1 hectare of peatland might be much more expensive for Kangamiut Seafood compared to investing in 1 ha of seaweed aquaculture, which could result in seaweed aquaculture being a better investment. Therefore, these results merely give a frame of reference for Kangamiut Seafood to judge how they can optimally invest in effective initiatives. The results can also be scaled up or down, e.g. for 0.1 or 10 hectare of nature conservation.

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Appendix 1: Bridge table between foreground and background database

Appendix table 1: Overview of common activities and corresponding background database activities.

Common activity name	Activity name in background database
Used for inputs to foreground system	**Exiobase v3.3.16b2**
Road transport, km {DK} 16-32 t truck	122 Other land transport {DK} (product market, hybrid units, purchaser price)
Road transport, km {CN_TW} 16-32 t truck	122 Other land transport {CN_TW} (product market, hybrid units, purchaser price)
Road transport, tkm {NO} 16-32 t truck	122 Other land transport {NO} (product market, hybrid units, purchaser price)
Road transport, km {PL} 16-32 t truck	122 Other land transport {PL} (product market, hybrid units, purchaser price)
Road transport, km {PT} 16-32 t truck	122 Other land transport {PT} (product market, hybrid units, purchaser price)
Road transport, tkm {WA} 16-32 t truck	122 Other land transport {WA} (product market, hybrid units, purchaser price)
Road transport, km {WF} 16-32 t truck	122 Other land transport {WF} (product market, hybrid units, purchaser price)
Sea transport, km {GLO} transoceanic ship	124 Sea and coastal water transport {DK} (terminated incl cap)
Fuel, diesel {CN_TW} Fuel and combustion	57 Petroleum Refinery {CN_TW} (product market, hybrid units, purchaser price)
Fuel, diesel {PL} Fuel and combustion	57 Petroleum Refinery {PL} (product market, hybrid units, purchaser price)
Fuel, diesel {PT} Fuel and combustion	57 Petroleum Refinery {PT} (product market, hybrid units, purchaser price)
Fuel, diesel {WA} Fuel and combustion	57 Petroleum Refinery {WA} (product market, hybrid units, purchaser price)
Fuel, diesel {WF} Fuel and combustion	57 Petroleum Refinery {WF} (product market, hybrid units, purchaser price)
Fuel, natural gas {WA} Fuel and combustion, energy unit	22 Extraction of natural gas and services related to natural gas extraction, excluding surveying {WA} (product market, hybrid units, purchaser price)
Lubricants and hydraulic oil {DK} Fuel	57 Petroleum Refinery {DK} (product market, hybrid units, purchaser price)

Appendix 2: Explanation of units in the Stepwise LCIA method

This appendix briefly explains the impact categories included in the applied LCIA method: Stepwise 2006 (version 1.7). The original version is described in Weidema et al. (2008). Updates regarding nature occupation are described in Schmidt and de Saxcé (2016). If no literature reference is given in the table, this means that the information is obtained from Weidema et al. (2008).

Appendix table 2: Explanation of the impact categories in the LCIA method Stepwise 2006.

Impact category	Unit	Original source		Explanation
		EDIP 2003	Impact 2002+	
Global warming	kg CO_2-eq	x		The unit is GWP100 (kg CO_2 equivalents) based on the fifth IPCC Assessment report (IPCC 2013).
Nature occupation	m^2 agr.land		x	The unit 'm^2-equivalents arable land', represents the impact from the occupation of one m^2 of arable land for one year. According to Schmidt et al. (2015), a change in demand for 1 ha*year land has the effect that denaturalisation of one hectare is moved one year closer. According to Weidema et al. (2008, p 157), arable land hosts only 20% of the species compared to the number in nature at full relaxation. Therefore, one ha*year arable land corresponds to 0.8 BAHY (biodiversity adjusted hectare years).
Acidification	m^2 UES	x		The unit expresses the area of the ecosystem within the full deposition area (in Europe) which is brought to exceed the critical load of acidification because of the emission (area of unprotected ecosystem = m^2 UES). The impact indicator is based on modelling of deposition in Europe. (Hauschild and Potting 2005, p47)
Eutrophication, aquatic	kg NO_3-eq	x		The aquatic eutrophication potentials of a nutrient emission express the maximum exposure of aquatic systems that it can cause. The aquatic eutrophication potentials are expressed as N- or P-equivalents. (Hauschild and Potting 2005, p 73-74)
Eutrophication, terrestrial	m^2 UES	x		Same as for acidification.
Photochemical ozone, vegetat.	m^2*ppm*h	x		The impact is expressed as the accumulated exposure (duration times exceed threshold) above the threshold of 40 ppb times the area that is exposed because of the emission. The threshold of 40 ppb is chosen as an exposure level below which no or only small effects occur. The unit for vegetation exposure is m^2*ppm*hours. (Hauschild and Potting 2005, p 93)
Respiratory inorganics	kg $PM_{2.5}$-eq		x	The impact on human health related to respiratory inorganics is expressed as equivalents of particles ($PM_{2.5}$).
Respiratory organics	pers*ppm*h	x		The category covers the impact on human health from photochemical ozone formation. The impact is expressed as the accumulated exposure above the threshold of 60 ppb times the number of persons which are exposed because of the emission. No threshold for chronic exposure of humans to ozone has been established. Instead, the threshold of 60 ppb is chosen as the long-term environmental objective for the EU ozone strategy proposed by the World Health Organisation, WHO. The unit for human exposure is pers*ppm*hours. (Hauschild and Potting 2005, p 93)
Human toxicity, carcinogens	kg C_2H_3Cl-eq		x	The impact on human health related to carcinogens is expressed as equivalents of chloroethylene (C_2H_3Cl). The Impact2002+ method determines the damage on human health in terms of DALY (disability adjusted life years). Since there is no real mid-point for human toxicity, the Impact2002+ method has chosen C_2H_3Cl-eq. as a reference substance. (Jolliet et al. 2003)
Human toxicity, non-carc.	kg C_2H_3Cl-eq		x	Same as for human toxicity, carcinogens
Ecotoxicity, aquatic	kg TEG-eq w		x	The impact on ecosystems related to ecotoxicity is expressed as equivalents of chloroethylene triethylene glycol (TEG) into water. The Impact2002+ method determines the damage on ecosystems in terms of PAF (potentially affected fraction). Since there is no real mid-point for ecotoxicity, the Impact2002+ method has chosen TEG-eq. into water as a reference. (Jolliet et al. 2003)

Ecotoxicity, terrestrial	kg TEG-eq s		**x**	Same as for ecotoxicity, aquatic
Ozone layer depletion	kg CFC_{11}-eq		**x**	The unit is equivalents of CFC11 which is an important contributor to ozone layer depletion.
Non-renewable energy	MJ primary		**x**	Total use of primary non-renewable energy resources measured in MJ.