LCA of 22 frozen food products and their alternatives

Third Party Technical Report

PRé

Fact-based sustainability

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This report is a shortened version of the full ISO report that was reviewed by the review panel.

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Executive summary

Goal of the study

Nomad Foods, Europe's leading frozen food company, is interested in learning more about the potential trade-offs between a frozen food supply chain and one using alternative preservation methods. For example, while a frozen supply chain requires energy for both the initial freezing and frozen storage during the life cycle, there are possible benefits in terms of food preservation, such as less food waste due to the low-perishable nature of frozen food. This study examines these potential trade-offs to determine if there are significant differences between frozen and non-frozen food products in terms of environmental impact.

To analyse this, the environmental impact of 22 frozen food products is compared to their alternatives (equivalent products using other preservation methods, such as fresh products, jars and cans). These products are from the product categories: fish, plant-based proteins and vegetables. To ensure that differences in environmental impact between the frozen food product and its alternative stem solely from the preservation method and not from other factors, the ingredient composition, manufacturing efficiencies, ingredient distribution route, and location of consumption remain constant. More specifically, the most notable differences between the frozen products and their alternatives will be inherent differences in the product creation, temperature of transport vehicles, the storage, and food loss and waste.

In parallel, this study also reports the carbon footprint (life cycle climate change impact) of the 22 Nomad Foods frozen products for sale and consumption in one specific country per product.

The study was executed to conform to ISO 14040/44: 2006 and has been externally reviewed by an independent review panel.

Scope of the study

To calculate the environmental impact of the 22 products and their alternatives, Life Cycle Assessment (LCA) was used. The scope of this study is cradle to grave, meaning it includes all life cycle stages, from the farming and wild capture of raw ingredients to consumed product, including end-of-life of the package and any non-consumed food product. Primary data from 2019 was collected from Nomad Foods and its suppliers for processes which are under Nomad Foods' direct or operational control. Primary data was also collected for upstream manufacturing processes which were anticipated to have a considerable contribution (e.g. wild capture of fish) and from retailers for food loss and waste percentages. Secondary data was sourced primarily from Life Cycle Inventory (LCI) databases (in order: ecoinvent v3.7.1 (87%), Agri-footprint 5.0 (7%), World food LCA database (5%) and AGRIBALYSE 3.0 (1%)), and supplemented with data from relevant literature and the Product Environmental Footprint (PEF) method where appropriate.

For the comparison of the potential environmental impact of the 22 frozen food products with their alternatives, the unit of analysis (i.e. the functional unit) was 3 portions of consumed product (since an average OECD household consists of 2.6 people). For the calculation of the carbon footprint of the 22 frozen products, a functional unit of 1 kg of consumed product was used, since kg CO_2eq./ kg is a common unit for the carbon footprint of food products.

The main impact category assessed in this study is global warming potential (i.e. the carbon footprint). While they are not used for detailed analysis, the full range of other impact categories from the EF 3.0 impact assessment method are also calculated to identify potential trade-offs.

To determine the importance and sensitivity of the various modelling approaches that were used and assumptions that were made, a series of sensitivity analyses were performed on storage time, retail and consumer electricity source, consumer preparation and packaging size of the alternative product.

Results

The carbon footprint of Nomad Foods' 22 products are reported individually further on in this report.

The relative contribution of life cycle stages to the carbon footprint varies slightly for different products and product types.

- In most cases, **ingredient production** is the most contributing life cycle stage in terms of carbon footprint. This means cultivation of the vegetables, catching of the fish or, in the case of the Atlantic Salmon fillet, farming the fish. For fish products, the main impact comes from the catching operations of the fish itself (for wild-caught fish) or for fish feed (for farmed fish). For plant-based products, the main contributors to the carbon footprint within the cultivation varies with common sources being fuel-use during planting and harvesting, land-use change, herbicide and pesticide production, and irrigation efforts.
- The relative contribution of **manufacturing** to the carbon footprint varies between the products. For the Green Cuisine products (vegetarian burger, falafel and chicken-less nuggets), it has a significant contribution to the overall carbon footprint, while for the pure vegetable products it does not. The fish products lie somewhere in the middle, with manufacturing being a bigger or smaller contributor to the overall carbon footprint depending on each case. The impact of this stage is mainly driven by the energy use, where the share of renewable electricity sources in the electricity mix used by the factory has a large influence.
- **Packaging** has a fairly low contribution to the carbon footprint of most of the products under study, with the exception of jarred and canned products. Many of the frozen products are packaged in a cardboard and/or thin plastic film that has a relatively low impact.
- For the products under study, **distribution** between the factory and retail distribution centre, mostly does not have a large impact to the overall carbon footprint
- **Storage at retail and the consumer** is a significant contributor to the carbon footprint of most products under study, with the share of renewables in the electricity mix determining the extent of the impact.
- In the screening study leading up to this study, it became clear that the **food loss and waste percentages** at retail and the consumer have a significant effect on the overall result. To acknowledge the importance of these numbers and their relative uncertainty, the results are shown with the default food loss and waste percentages in general, but a *tipping point* is calculated as well. This tipping point calculation keeps the food loss and waste at retail and consumer fixed for the frozen product and varies the food loss and waste at retail and consumer for the alternative product independently. The tipping point occurs where the carbon footprint of the two products is equal, thereby representing the value of food loss and waste where the conclusion of the comparison changes from one product having a higher or lower carbon footprint than the other to them being numerically equal.
- For most products in this study, the **consumer preparation** has a noticeable contribution to the overall carbon footprint. In many cases it is still a relatively low share though. The

main products where consumer preparation has a larger contribution to the overall carbon footprint is when the product is prepared in the oven. This impact is among others influenced by the local electricity mix.

Since retail and consumer can have a big share of the environmental impact of a product, environmental impact studies of food products and labels based on these, should include the whole life cycle (cradle-to-grave) instead of excluding the retail, consumer and end-of-life life cycle stages (cradle-to-gate).

Main differences between frozen versus other preservation methods.

The results and corresponding interpretation steps provided insights into the differences in carbon footprint between the frozen and non-frozen food product. In general, from this study, it can be concluded that there are four main factors that determine whether the carbon footprint of a frozen product is higher or lower than that of an alternative, when the carbon footprints of the production phases are assumed to be identical. These factors are not necessarily main contributors to the impact, but they are the main source of difference between the frozen and non-frozen products. They are as follows:

1. The electricity mix used by retail and consumer. An energy mix with a lower carbon footprint per kWh is beneficial for frozen products. The products included in this study use the average country electricity mix in the country of consumption. Over time, these mixes are expected to move in the direction of lower carbon footprint, thereby moving in favour of the frozen product.
2. The number of days the consumer keeps the frozen product in their freezer. A shorter freezer storage time is beneficial for the carbon footprint of frozen products.
   In this study, a frozen storage time of 30 days is used based on default values of the PEF method [1]. If the carbon footprint of electricity mixes is lower, the sensitivity to the frozen storage days is less significant.
3. The amount of food loss and waste at retail and consumer. If the food loss and waste of the alternative product is higher than that of the frozen product, whether this is due to high perishability, low turnover or other reasons, the carbon footprint of the frozen product is more likely to be favourable. Since the amount of food loss and waste can influence the outcomes of the comparison, data on this should be specific to the product and the preservation method.
4. The inherent carbon footprint of the product itself. If the production of the product (i.e. the ingredients cultivation and manufacturing) has a higher carbon footprint, the effect of wasting this product will also be higher. So, a change in the food loss and waste percentage of products with a relatively high production (at the point of leaving the factory) carbon footprint will have a larger absolute effect than the same change for a product with a relatively low production carbon footprint. Since the food loss and waste percentages are in general lower for frozen food products, the frozen food product is more likely to have a lower carbon footprint than its alternative if the inherent carbon footprint of the product is high.

Limitations of the study

While this study attempted to be as accurate and detailed as possible, limitations still exist, as in any LCA study. Most notably, there are limitations in the selection of the alternative products, the secondary data sources used and modelling approaches. The concluding statement is expressed with these limitations in mind.

Conclusions

Considering the results, interpretation, sensitivity analysis and uncertainty assessments, **this study shows that when it comes to carbon footprint, there is no general advantage or disadvantage to using frozen food products compared to products using alternative preservation methods. However, it does support the hypothesis that when food loss and waste rates in the retail and consumer stages are lower for a frozen product compared to a non-frozen alternative, this may compensate for the additional energy use caused by a frozen supply chain when looking at carbon footprint.**

This conclusion is based on the overall conservative approach that was used in this study on multiple fronts, meaning that the differences stem solely from the preservation method and not from other factors such as the ingredient composition, processing efficiencies, ingredient distribution route, and location of consumption. This means the carbon footprint of the ingredients production phase is assumed to be identical for both the frozen and non-frozen alternative. As a result, the differences between the frozen products and their alternatives will be inherent differences in the product processing, temperature of transport vehicles, the storage processes and food loss and waste.

Conclusions on all impact categories:

This study mainly investigated the carbon footprint of the products. The results and uncertainty assessment have shown that the carbon footprint is not always a good representation of the results on other impact categories. So, conclusions based on the carbon footprint cannot be generalized to overall environmental impact.

In many of the studied products, the trend as to which product has a lower impact - the frozen or the alternative - is fairly constant when looking at the other impact categories. However, without exception there are trade-offs in all products under study. The main impact categories that often show a contradicting trend are ozone depletion, freshwater eutrophication, land use and water use. Further research could look further into these trade-offs.

Terms and definitions

Acidification – Environmental Footprint impact category that addresses impacts due to acidifying substances in the environment. Emissions of NO_x, NH_3 and SO_x lead to releases of hydrogen ions (H^+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.

Alaska pollock – The Alaska pollock or walleye pollock (*Gadus chalcogrammus*) is a marine fish species of the cod genus Gadus and family Gadidae. It is a semi-pelagic schooling fish widely distributed in the North Pacific, with largest concentrations found in the Bering Sea. [2]

Allocation – An approach to solving multi-functionality problems. It refers to 'partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems'[3].

Alternative product - Equivalent product using other preservation method such as fresh products, jars and cans.

Aquaculture Stewardship Council (ASC) - World's leading certification scheme for farmed seafood – known as aquaculture. The ASC label only appears on food from farms that have been independently assessed and certified as being environmentally and socially responsible.

Atlantic cod - The Atlantic cod (*Gadus morhua*) is a benthopelagic fish of the family Gadidae. It is found mainly in the North Atlantic Ocean. It is also commercially known as cod or codling. [4]

Atlantic salmon - The Atlantic salmon (*Salmo salar*) is a species of ray-finned fish in the family Salmonidae which is the largest salmon and can grow up to a meter in length. It is found in the northern Atlantic Ocean and in rivers that flow into this ocean. [5]. Because fish stocks of this salmon are not at sustainable levels, currently Atlantic salmon is mainly farmed (by aquaculture).

Attributional approach - This is the most commonly applied type of LCA. In case of multi-functionality, attributional thinking implies that impacts are allocated between products inside the system boundary. In consequential LCA, co-products would instead be assumed to replace other products outside the system boundaries, thereby crediting the product with avoided (negative) impacts.

Background process – Refers to those processes of the Organisations supply chain for which no direct access to information is possible. For example, most of the upstream supply-chain processes and generally all processes further downstream will be considered part of the background process. [1]

Carbon footprint – net amount of GHG emissions and GHG removals, expressed in CO_2 equivalents [7]

Cape Hake - *Merluccius capensis* (shallow-water Cape hake) and *Merluccius paradoxus* (deep-water Cape Hake) is a ray-finned fish in the genus Merluccius, found in the south-eastern

Atlantic Ocean, along the coast of South Africa and Namibia. It is a long, lean fish with a large head, similar in appearance to the European hake. [8]

Chickpea - The chickpea or chick pea (*Cicer arietinum*) is an annual legume of the family Fabaceae, subfamily *Faboideae*. [9]

Climate change - All inputs or outputs that result in greenhouse gas emissions. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale.

Company-specific data – Refers to directly measured or collected data from one or multiple facilities (site-specific data) that are representative for the activities of the company. It is synonymous with 'primary data'. To determine the level of representativeness a sampling procedure can be applied.

Cradle to Gate – A partial product supply chain, from the extraction of raw materials (cradle) up to the when it leaves the manufacturer ('gate'). The distribution, storage, retail, use stage and end of life stages of the supply chain are omitted.

Cradle to Grave – A product's life cycle that includes raw material extraction, processing, distribution, storage, retail, use (by the consumer), and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.

Data quality – Characteristics of data that relate to their ability to satisfy stated requirements[3]. Data quality covers various aspects, such as technological, geographical, and time-related representativeness, as well as completeness and precision of the inventory data.

Ecotoxicity, freshwater – Environmental footprint impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem.

EF 3.0 – Life cycle impact assessment method from the most recent version of the Product Environmental Footprint (PEF) method [1]. This impact assessment method is assembled by the European Commission based on the state-of-the art science per impact category

ELCD- European reference Life Cycle Database. Comprises data from EU level business associations. The publication was discontinued on the 29th of June 2018

Elementary flow – Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.

Eutrophication – Nutrients (mainly nitrogen (N) and phosphorus (P)) from sewage outfalls and fertilised farmland accelerate the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass. Three Environmental Footprint impact categories are used to assess the impacts due to eutrophication: Eutrophication, terrestrial; Eutrophication, freshwater; Eutrophication, marine.

Foreground process - Refers to those processes of the Organisation life cycle for which direct access to information is available. For example, the producer's site and other processes operated by the Organisation or contractors (e.g. goods transport, head-office services, etc.) belong to the foreground system. [1]

Functional unit - quantified performance of a product system for use as a reference unit [3]

Food loss and waste - Any food intended for human consumption that ends up not being consumed by humans. The inedible parts of a food product (e.g., bones, pits/stones) are not included because it is assumed that 100% of the frozen products analysed as produced are intended for human consumption.

Global warming potential – Capacity of a gas to influence radiative forcing, expressed in terms of a reference substance (for example, CO_2-equivalent units) and specified time horizon (e.g. GWP 20, GWP 100, GWP 500, for 20, 100, and 500 years respectively). It relates to the capacity to influence changes in the global average surface air temperature and subsequent change in various climate parameters and their effects, such as storm frequency and intensity, rainfall intensity and frequency of flooding, etc.

Green Cuisine – A Nomad Foods brand name for products in the plant-based category. See 'meat replacement'.

Human toxicity – cancer – EF impact category that accounts for adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer.

Human toxicity – non-cancer – EF impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionizing radiation.

Impact category – Environmental problem with clear boundaries. LCA is used to express the environmental impact of the product in specific impact categories.

Input flows – Product, material or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products[3].

Intermediate product – Output from a unit process that is input to other unit processes that require further transformation within the system [3]. An intermediate product is a product that requires further activities before it is saleable to the final consumer.

ISO – International Organization for Standardization, develops and publishes International Standards.

Ionizing radiation, human health – EF impact category that accounts for the adverse health effects on human health caused by radioactive releases.

JRC – Joint Research Centre. European Commission's science and knowledge service, providing scientific evidence throughout the whole policy cycle.

Land use – EF impact category related to use (occupation) and conversion (transformation) of land area by activities such as agriculture, forestry, roads, housing, mining, etc. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (changes in quality multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (changes in quality multiplied by the area).

Life Cycle Assessment (LCA) - LCA measures the potential impacts on the environment associated with the life cycle of a product, process, or service. It typically includes every part of the life cycle, the so-called life cycle stages.

Life Cycle Impact Assessment (LCIA)- phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product [3] In this phase, the LCI is converted into environmental impact.

Life Cycle Inventory (LCI) – The combined set of exchanges of elementary, waste and product flows in an LCI dataset.

Life Cycle Inventory (LCI) dataset – A document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory. An LCI dataset could be a unit process dataset, partially aggregated or an aggregated dataset.

Meat replacement – plant-based protein meant to resemble or be a substitute for meat

Marine Stewardship Council (MSC) - International non-profit organization that recognises and rewards efforts to protect oceans and safeguard seafood supplies for the future. They use an ecolabel and fishery certification program to contribute to the health of the world's oceans by recognizing and rewarding sustainable fishing practices.

Multi-functionality – If a process or facility provides more than one function, i.e. it delivers several goods and/or services ('co-products'), then it is 'multifunctional'. In these situations, all inputs and emissions linked to the process will be partitioned between the product of interest and the other co-products according to clearly stated procedures.

North Pacific Hake - The North Pacific hake, Pacific hake, Pacific whiting, or jack salmon (*Merluccius productus*) is a ray-finned fish in the genus Merluccius, found in the northeast Pacific Ocean from northern Vancouver Island to the northern part of the Gulf of California. [10]

OECD – Organisation for Economic Co-operation and Development. This organisation works to build better policies for better lives. 38 countries are a member of this organisation.

Output flows – Product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases [3].

Ozone depletion – EF impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).

Pea - The pea is the small spherical seed or the seed-pod of the pod fruit *Pisum sativum* [11]

Photochemical ozone formation – EF impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts, and manmade materials through reaction with organic materials.

Practitioner of study – Individual, organization or group of organizations that performs the study.

Primary data – This term refers to data from specific processes within the supply-chain of the company applying the study. Such data may take the form of activity data, or foreground elementary flows. Primary data are site-specific, company-specific (if multiple sites for the same product) or supply-chain-specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material/product balances, stoichiometry, or other methods for obtaining data from specific processes in the value chain of the company applying the LCA. In this Guidance, primary data is synonym of 'company-specific data' or 'supply-chain specific data'.

Product category – Group of products (or services) that can fulfil equivalent functions.

ReCiPe – Life cycle impact assessment method developed by RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability. The 2016 version is used in the sensitivity on ozone depletion described in section *7.1.2* [12]

Reference flow – Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit [3].

Resource use, fossil – EF impact category that addresses the use of non-renewable fossil natural resources (e.g. natural gas, coal, oil).

Resource use, minerals and metals – EF impact category that addresses the use of non-renewable abiotic natural resources (minerals and metals).

Secondary data – This refers to data not from specific processes within the supply-chain of the company applying the LCA. This refers to data that is not directly collected, measured, or estimated by the company, but sourced from a third-party life-cycle-inventory database or other sources. Secondary data includes industry-average data (e.g., from published production data, government statistics, and industry associations), literature studies, engineering studies and patents, and can also be based on financial data, and contain proxy data, and other generic data. Primary data that go through a horizontal aggregation step are considered as secondary data.

Spinach - Spinach (*Spinacia oleracea*) is a leafy green flowering plant. [13]

Supply-chain – This term refers to all of the upstream and downstream activities associated with the operations through all life cycle stages, including the use of sold products by consumers and the end-of-life treatment of sold products after consumer use.

System boundary – Definition of aspects included or excluded from the study. For example, for a 'cradle-to-grave' LCA, the system boundary includes all activities from the extraction of raw materials through the manufacture, distribution, storage, use, and disposal or recycling stages

Unit process dataset – Smallest element considered in the life cycle inventory analysis for which input and output data are quantified [3].

Waste – Substances or objects which the holder intends or is required to dispose of [3].

Water use – This term represents the relative available water remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived (see also http://www.wulca-waterlca.org/aware.html).

1 Introduction

Nomad Foods is Europe's leading frozen food company, with a portfolio of iconic brands such as Birds Eye, Findus, iglo, Ledo and Frikom. It manufactures, distributes and sells a range of branded frozen food products across 22 European countries with the United Kingdom, Italy, Germany, Sweden and France representing the five largest markets. Nomad Foods' products span across the frozen food category and predominantly focus on fish, vegetables, potatoes, and plant-protein.

Nomad Foods is committed to continuous improvement aligned to its global sustainability strategy and targets. It is in this light that Nomad Foods asked PRé Sustainability to conduct an ISO study conforming to the 14040/44:2006 [3] standard with a comparative life cycle assessment of 22 of frozen products from three product categories and their alternatives, i.e. equivalent products using other preservation methods.

This third-party report summarises the larger report written for the purpose of ISO review and is intended to disseminate both the results and the used methodology of the executed ISO study. The third-party report is set up to align with the ISO 14040/44 requirements for third-party reports.

Sharing the methodology and results in this level of detail has several purposes:

- **Illustrate the importance of including the whole life cycle in LCAs of food products.** Many food LCAs and environmental labels adopt a cradle-to-gate approach, excluding the distribution, retail, and consumer stage. However, the results of this ISO study show that the retail and consumer stage cause a significant share of the environmental impact of the products under study. Based on this, Nomad Foods wants to advocate for cradle-to-grave LCA studies (including all life cycle stages) in the food industry instead of cradle-to-gate.
- **Demonstrate that the carbon footprint of frozen food products is equal to (or can even be better than) alternatives.** There is a perception that frozen foods have a higher carbon footprint than products using other preservation methods, since they require energy for freezing. However, this study shows that this can be compensated for by lower food loss and waste resulting from a frozen supply chain. With lower food loss and waste, less "extra" food needs to be produced (e.g. including planting/catching, harvesting, manufacturing and packaging) to compensate for this loss and less waste processing is needed, offsetting the additional frozen activities.
- **Highlight the need for reliable food loss and waste data.** Since the difference in food loss and waste can influence the results of the comparison, reliable and specific data on this is needed. However, many sources use generic data on food loss and waste or for specific product groups. To properly compare different products, food loss and waste data should be specific to the product and preservation methods.

2 Goal of the study

The goal of this study is twofold:

1. Compare the environmental impact of 22 frozen food products with equivalent products which use other preservation methods. This information is intended to inform consumers and both internal and external stakeholders about potential differences in environmental impacts between frozen foods and alternatives. The focus will be on global warming potential.

   This study is intended to support comparative assertions intended to be disclosed to the public.

   The reason for carrying out this study is that as a frozen food company, Nomad Foods is interested in learning more about the potential trade-offs between a frozen food supply chain and using alternative preservation methods. For example, while a frozen supply chain requires energy for both the initial freezing and frozen storage during the life cycle, there are potential benefits in terms of food preservation. This study is designed to shed light on these potential trade-offs and determine if there are significant differences between frozen and non-frozen food products in terms of environmental impact.

   For this purpose, a functional unit of **3 portions** will be used. The reasoning for this is explained in section *3.2 Functional unit*.

2. Report the carbon footprint (global warming potential) of the 22 frozen products. This information is intended to inform consumers and both internal and external stakeholders about the carbon footprint of the specific products.
   This does not include the communication of a comparative assertion to the public. Which means based on this study, a comparison across frozen products is not possible.

   The reason for carrying out this study is that external stakeholders are becoming increasingly interested in the potential impact on climate change of their food products and Nomad Foods wants to provide them with insight into the carbon footprints of its products.
   For this purpose, a functional unit of **1 kg** will be used. The reasoning for this is explained in section *3.2 Functional unit*.

3 Scope of the study

3.1 Systems under study

This study includes the products from the product groups fish, vegetables and plant-based protein. These product groups were selected by Nomad Foods because they are the leading product groups in terms of volume sold, and they are sold in most of the markets they operate in. Each product group contains sub-categories defined by Nomad Foods, as specified below.

Fish

- Fish fingers and coated fish
- Natural fish
- Recipe fish

Vegetables

- Peas
- Spinach
- Prepared vegetables
- Natural vegetables
- Vegetable mix for soups

Plant-based protein

- Meat alternatives
- Falafel

The 22 products selected by Nomad Foods to represent these product categories are listed in Table 1. They were selected to ensure all of the sub-categories were covered, as well as representing a large share of sales volumes: the products under study include some of the biggest volume single products.

For each product, the country of consumption is included in Table 2. The country of consumption influences for example the transportation used and electricity mix at the retail and consumer phases.

In addition to Nomad Foods products, the study includes an alternative product for each of these. The selection of these alternatives is discussed in section *3.3 Selection of alternatives*.

To ensure that differences in environmental impact between the frozen food product and its alternative stem solely from the preservation method and not from other factors. The ingredient composition, manufacturing efficiencies, ingredient distribution route, and location of consumption remain constant. More specifically, this means the carbon footprint of the ingredients production phase is assumed to be identical for the frozen and non-frozen alternative, and therefore the most notable differences between the frozen products and their alternatives will be inherent differences in the product manufacturing, temperature of transport vehicles, the storage temperatures and food loss and waste. This is done to take a conservative approach to the differences between frozen and alternative products, meaning that it removes potential benefits of frozen products resulting from for example centralised large scale manufacturing and the ability for ingredients to be available year-round. Any differences will be solely due to the frozen/non-frozen supply chain.

As a result of keeping the ingredients production phase the same for both products, there is a possibility that some potential downsides of frozen food products are eliminated as well, such as the need for longer transport routes to the centralized production facilities. However, most of Nomad Foods' vegetables production sites are localised as close to the ingredient origin as possible and therefore this effect is expected to be small. For example, the factories processing peas and spinach are located centrally in Nomad Foods' own pea and spinach growing regions, respectively. The main factory for manufacturing fish is also located next to one of the main European ports.

3.2 Functional unit

For the comparison of the potential environmental impact of the 22 frozen food products with their alternatives, a functional unit of 3 portions is used. Although for some products, e.g. fish bake (Schlefi), consumers are likely to prepare a single pack instead of three portions, the functional unit is preferred to be consistent throughout the study. The three portions are chosen since an average OECD household consists of 2.6 people [15]. The reference flows that were used are listed in Table 1.

For the alternative products, an equal pack size to frozen was assumed in most cases. However, in certain cases the pack size of frozen products is not feasible for the alternative products due to the shelf life. For example, a pack of 800 gr. of frozen peas can easily be split into multiple meals of 3 portions, but a pack of 800 gr. of fresh peas significantly exceeds the amount of portions needed and is not a likely alternative. In such cases, an existing pack size was selected that is closest to holding 3 portions.

The portion sizes as indicated on the packaging of the Nomad Foods products are used. These can vary between similar products and are not always related to the packaging size. For example, the chicken less nuggets come in a pack of 250 grams, while a single portion is 100 grams. In case of discrepancies between the portion size and the pack size, the portion size is used as leading, even if this means not a complete number of packs is used, this is done for both the frozen products and their alternatives.

A functional unit based on nutritional content might possibly have been a better solution, but this comes with many challenges. For example, there are several different systems to determine overall nutritional value based on the various contributors (calories, vitamins, etc.) and no consensus on what the best approach is. Therefore, portion size is used as a basis here to represent a typical amount of the product consumed, with the portion size kept the same for the frozen and non-frozen food product.

The number of portions considered is relevant for the preparation stage. For example, heating up an oven to prepare 1 portion or 3 will affect the overall potential environmental impact of the product. For this study, it is assumed that all the food products are prepared with 3 portions at a time, hence the decision to reflect this in the functional unit as well.

For the calculation of the carbon footprint (life cycle climate change impact) of the 22 frozen products, a functional unit of 1 kg of product is used. This is done to provide a common basis for all food products that can be scaled to different portion sizes easily.

Table 1 – List of the 22 products (3 portions)

Product	Reference flow (3 portions)	Pack size frozen	Pack size alternative
Alaska Pollock fish fingers	450 gr. (15 pc)	450 gr. (15 pc)	equal to frozen
Battered Alaska Pollock fish fingers	420 gr. (15 pc)	364 gr. (13 pc)	450 gr.
Atlantic Cod fish fingers	336 gr. (12 pc)	840 gr. (30 pc)	450 gr.
North Pacific Hake fish fingers	300gr. (12 pc)	450 gr. (18 pc)	equal to frozen
South African Cape Hake fillet	270 gr. (3pc)	360 gr. (4 pc)	equal to frozen
Atlantic Cod loins	280 gr. (3 pc)	280 gr. (3 pc)	equal to frozen
Atlantic Salmon fillet	375 gr. (3 pc)	500 gr. (4 pc)	450 gr.
Fish bake (schlefi)	570 gr.	380 gr.	equal to frozen
Fish gratin	810 gr.	540 gr.	equal to frozen
Vegetarian burger	300 gr. (3 pc)	200 gr. (2 pc)	equal to frozen
Vegetarian chicken nuggets	300 gr.	250 gr.	equal to frozen
Falafel	270 gr.	450 gr.	equal to frozen
Garden peas	240 gr.	800 gr.	175 gr. drained (can/jar) 250 gr. (fresh)
Extra fine peas	300 gr.	750 gr.	230 gr. drained (jar)
Cream spinach	500 gr.	700/750 gr.	500 gr.
Leaf spinach	450 gr.	500 gr.	equal to frozen
Italian vegetable mix	480 gr.	480 gr.	equal to frozen
Honey-glazed parsnips	240 gr.	500 gr.	equal to frozen
Red cabbage with apple	450 gr.	750 gr.	400 gr. (jar)
Vegetable mix for steaming	390 gr.	540 gr.	equal to frozen
Minestrone mix	300 gr.	1000 gr.	600 gr.

3.3 Selection of alternatives

Besides the 22 products from Nomad Foods, this study also includes alternatives used for comparison in this study. Selection of these alternatives is a critical part of the study, since the comparisons are highly dependent on the choices made here. To make the selection process as fair and transparent as possible, a decision tree was set up. This decision tree is shown in Figure 1.

The goal of the decision tree is to end up with an alternative that is both fully comparable to the frozen product and as close to reality as possible. Here, it's most preferable that this is a real-world product (option 1 in decision tree). In several cases, the ideal alternative product is not available on the market, so a theoretical alternative is determined. This is done in incremental steps as described in the decision tree so that the theoretical alternative stays as close to reality as possible.

For clarity, the step in the decision tree that was used to come to the selection of the alternative is mentioned in brackets in Table 2.

Please note that any brands associated with the example pictures of the alternatives are irrelevant, since no particular brand was used and production data from Nomad Foods was used to model the non-frozen products as well.

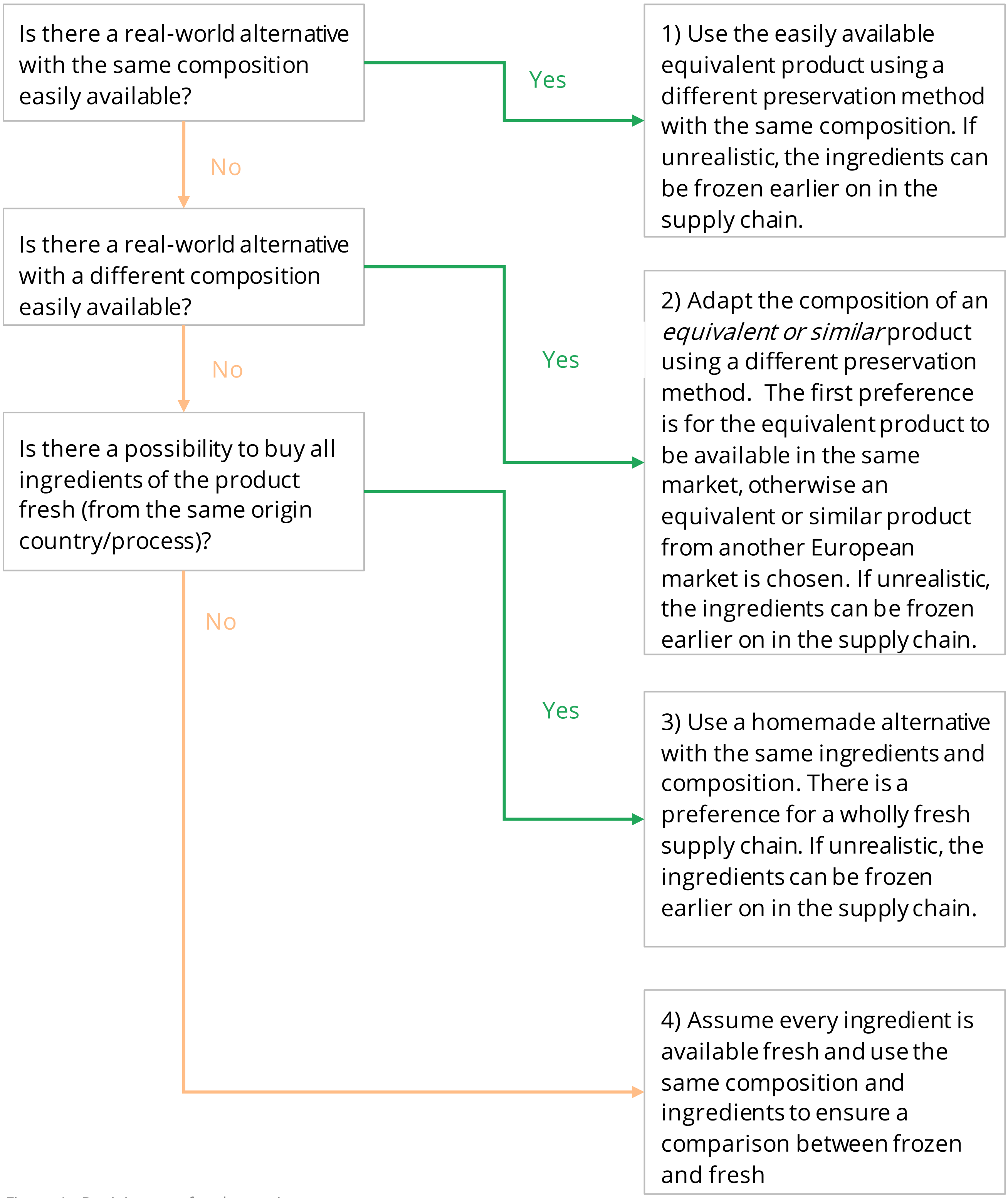
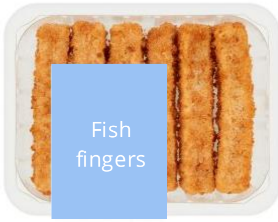
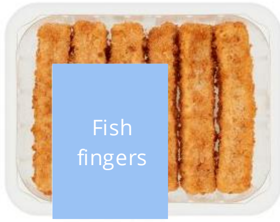


Figure 1 - Decision tree for alternatives

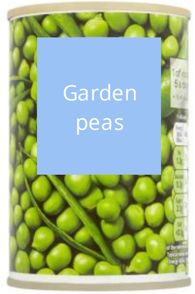
Table 2 - The 22 products and their alternatives

Product category	Product under study (frozen)	Alternative (number decision tree)	Ingredients	Country of consumption
Fish – Fish fingers and coated fish	Alaska Pollock fish fingers (frozen) *450 g, 15 fish fingers*  	Ready-made Alaska Pollock fish fingers (2) *450 g, 15 fish fingers*  	65% fish content 35% coating MSC certified wild captured Alaska pollock manufactured into fish fillet blocks Breadcrumbs	Germany
	Battered Alaska pollock fish fingers (frozen) *364 g, 13 fish fingers*  	Ready-made battered Alaska Pollock fish fingers (2) *450 g, 13 fish fingers*  	58% fish content 42% coating MSC certified wild captured Alaska pollock manufactured into fish fillet blocks Batter	Germany
	Atlantic cod fish fingers (frozen) *840 g, 30 fish fingers*  	Ready-made Atlantic cod fish fingers (2) *450 g, 30 fish fingers*  	58% fish content 42% coating MSC certified wild captured Atlantic cod manufactured into fish fillet blocks Breadcrumbs	United Kingdom

	North Pacific Hake fish fingers (frozen) *450g, 18 fish fingers* 	Ready-made North Pacific Hake fish fingers (2) *450g, 18 fish fingers* 	60% fish content 40% coating MSC certified wild captured North Pacific hake manufactured into fish fillet blocks Breadcrumbs	Italy
Fish – Natural fish	Frozen South African Cape Hake fillet *360g, 4 pieces* 	Chilled South African Cape Hake fillet (1) *360g, 4 pieces* 	MSC certified wild captured Cape hake	Italy
	Frozen Atlantic cod loins *280g, 3 pieces* 	Chilled Atlantic cod loins (1) *280g, 3 pieces* 	MSC certified wild captured Atlantic cod manufactured into fish loins	Sweden

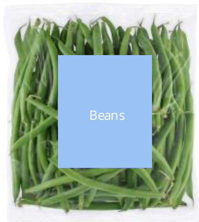
	Frozen Atlantic salmon fillet *500g, 4 pieces* 	Chilled Atlantic salmon fillet (1) *450g, 4 pieces* 	ASC certified farmed Atlantic salmon manufactured into fish fillet	Sweden
Fish – Recipe fish	Schlefi (fish bake) Bordelaise, crunchy (frozen) *380g* 	Homemade fish bake using chilled fish of the same species (3) *380g* 	MSC certified wild captured Alaska pollock manufactured into fish fillet blocks With bordelaise topping, made of breadcrumbs	Germany
	Frozen fish gratin *540g* 	Fresh fish gratin using chilled fish of the same species (2) *540g* 	Fish sauce with among others macaroni and 30 % fish content MSC certified wild captured Atlantic cod manufactured into fillet blocks and mince blocks With breadcrumbs topping	Norway

Green cuisine – Meat alternatives	Frozen vegetarian Burger *200g, 2 burgers* 		Chilled pea-protein burger (1) *200g, 2 burgers*	60% rehydrated pea protein	United Kingdom
	Frozen chicken nuggets alternative (plant-based) *250g* 		Chilled pea-protein nuggets (1) *250g*	29% rehydrated pea protein Covered in breadcrumbs	United Kingdom
Green cuisine – Visible veg	Frozen falafel *450g* 		Chilled falafel (1) *450g*	61% chickpeas Covered in a spiced dry mix	Sweden

Vegetables – Peas	Frozen garden peas *800g*  	 	Canned garden peas (1) *290g (175g drained weight)*	100% peas (F grade)	United Kingdom
		 	Jarred garden peas (1) *350g (175g drained weight)*		
		 	Fresh Garden peas (1) *250g*		

	Frozen extra fine peas *750g* 	Jarred extra fine peas (1) *330g (230g drained weight)* 	100% peas (A grade)	Italy
Vegetables - Spinach	Frozen cream spinach *700g* 	Homemade cream spinach using chilled spinach (3) *500g bag of fresh spinach with fresh cream from a plastic container* 	84% spinach with 16% cream sauce	Germany

Frozen cream spinach *750g* 	Homemade cream spinach using chilled spinach (3) *500g bag of fresh spinach with fresh cream from a plastic container*  	84% with 16% cream sauce	Germany
Frozen spinach (full-grown leaf spinach) *500g* 	Chilled spinach (baby leaf spinach) (3) *500g* 	100% spinach	Germany

Vegetables - Prepared vegetables	Frozen Italian vegetable mix *480g* 	Homemade fresh vegetable mix (3)   	93% vegetables (21% green beans, 18% peppers, 17% carrots, 16% zucchini, 11% onions, and 10% broccoli) from various European countries, oils, herbs, and broth.	Germany
	Frozen roast parsnips, honey glazed *500g* 	Homemade roast fresh parsnips, honey glazed (3)  	84% parsnips from Belgium with 11% palm oil, 4% coating and 1% honey.	United Kingdom

	Frozen apple red cabbage *750g* 	Jarred red cabbage with apple (2) *400g* 	75.1% Red cabbage, 20.3% Apple, Rapeseed.	Germany
Vegetables - natural vegetables	Frozen vegetable mix for steaming *540g* 	Homemade fresh vegetable mix for steaming (4) *540g* 	47% Carrots, 30% Peas and 23%.	United Kingdom
Vegetables - Soups	Frozen mix for minestrone *1000g* 	Chilled minestrone mix soup from fresh vegetables (4) *1000g* 	Carrots (11.1%) courgettes (10%), cabbage (6%), tomatoes (10%), pumpkin (4.8%), celery (7%), chard (5.5%), green beans (14%), leek (3.5%), peas (5.5%), potatoes (18.7%) red onion (2%), basil and parsley.	Italy

3.4 Impact assessment method

The main impact category assessed in this study is global warming potential. The reasons for focusing on this impact category are as follows:

- Climate change is an issue of concern for an increasing number of people.
- Nomad Foods has set ambitious carbon reduction targets and is interested in better understanding the potential impacts of a frozen supply chain.
- Consumers are increasingly interested in carbon footprints, and some are starting to include it in their decision-making.

While they are not used for detailed analysis, a wide range of other impact categories is calculated as well. These are used for identifying potential trade-offs.

The impact assessment method used in this study is EF 3.0 from the most recent version of the Product Environmental Footprint (PEF) method [1]. This impact assessment method is assembled by the European Commission as a result of a consensus process based on the state-of-the art science per impact category. Due to their subjective and uncertain nature, no normalization, grouping or cross-category weighting has been applied.

The 16 impact categories (environmental impacts) used in this method are given in Table 3. Please note that LCIA results are relative expressions and do not predict impacts on category endpoints, such as human health, ecosystem quality or resource depletion, exceeding of thresholds, safety margins or risks.

Table 3 - Impact categories of the EF 3.0 method

EF impact category	Impact category indicator	Unit	Characterization model
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2 eq	Baseline model of 100 years of the IPCC (based on [16])
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	Steady-state ODPs [17]
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 [18]
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 [18]
Particulate matter	Impact on human health	disease incidence	PM method recommended by UNEP [19]
Ionizing radiation, human health	Human exposure efficiency relative to 235U	kBq 235U eq	Human health effect model as developed by Dreicer et al. 1995 [20]

Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model [21] as implemented in ReCiPe 2008
Acidification	Accumulated Exceedance (AE)	mol H+ eq	Accumulated Exceedance [22]
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance [22]
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model [23] as implemented in ReCiPe 2008
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model [23] as implemented in ReCiPe 2008
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 [18]
Land use	Soil quality index[1] Biotic production Erosion resistance Mechanical filtration Groundwater replenishment	Dimensionles s (pt) kg biotic production kg soil m3 water m3 groundwater	Soil quality index based on LANCA [24][25]
Water use	User deprivation potential (deprivation-weighted water consumption)	m3 world eq	Available WAter REmaining (AWARE) as recommended by UNEP, 2016 [19]
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	CML 2002 [26], [27]
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	CML 2002 [26], [27]

[1] This index is the result of the aggregation, performed by JRC, of the 4 indicators provided by LANCA model as indicators for land use.

3.5 System boundary

The system boundaries indicate which aspects (life cycle stages, processes, activities, emissions, land uses and resource extractions) of the product's life cycle are included in the assessment.

The scope of this study is cradle to grave, meaning it includes all life cycle stages from the farming and wild capture of raw ingredients to consumed product, including end-of-life of the packaging and any non-consumed food product. A simplified flowchart is provided in Figure 2, including indications for what parts of the lifecycle primary data is generally used.

An initial screening study of Alaska Pollock fish fingers and peas indicated that refrigerant leaks in production are not relevant to the overall environmental impact (maximum of 0.7% of the carbon footprint). This was confirmed by a more expansive study of the fish fingers, which was peer reviewed according to ISO 14067 in 2021. As a result, this data point has been excluded from the remaining products in this study. Note that refrigerant leakage in the factories has still been included in the Alaska Pollock Fish Fingers product and its alternative. Still refrigerant leaks occurring at the fisheries and in retail have been included in the study.

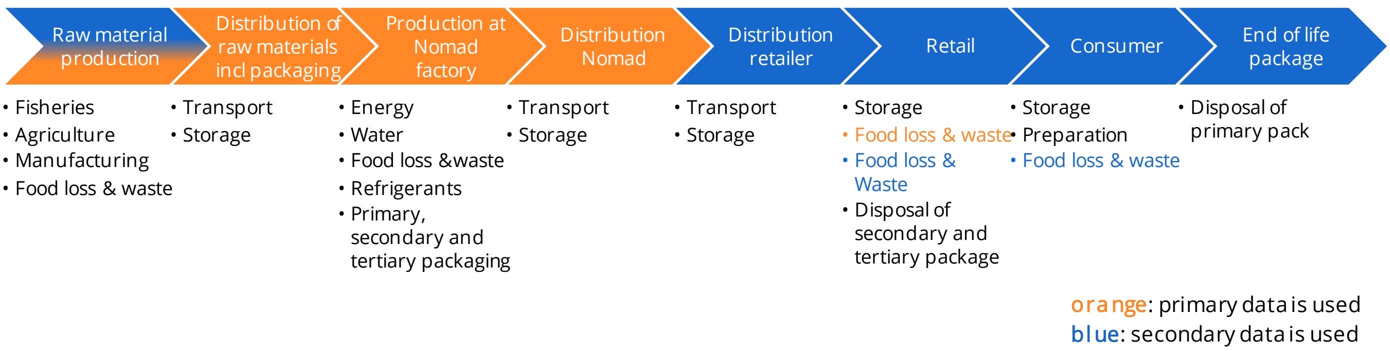


Figure 2 - System boundaries of the study

4 Data sources and data quality requirements

4.1 Primary and secondary data

Site-specific data is collected for all individual processes where Nomad Foods has financial or operational control. Capital goods is included in the background data. In the foreground processes they are estimated based on similar background processes.

4.2 Data sources

The following databases are used to source the background data:

- ecoinvent 3.7.1 with the "Allocation, cut-off by classification" system model [28]. This version is selected to match the allocation procedures outlined elsewhere in this document. This database does not contain regionalized land use or water flows. Land use and water use are therefore included on a generic basis.

The following three databases also do not contain regionalized land use flows. Land use is therefore included on a generic basis. The databases do include regionalized water flows though.

- Agri-footprint 5.0, economic allocation [29]. For those processes where Agri-footprint is more specific, this database will be used. The version using economic allocation is used to be consistent with the allocation procedures for this study. Some processes in this database use other data in the background (e.g. ELCD for electricity and transport).
- World food LCA database [31]. This database is used for datasets on the preparation of food. It is based on ecoinvent cut-off and thus matches the allocation procedures used in this study.
- AGRIBALYSE 3.0. [30]. When there was no appropriate process in ecoinvent or Agri-footprint, a process was chosen from AGRIBALYSE if available. It follows the same methodological rules as ecoinvent 3.5 and uses ecoinvent as its background database, therefore it is assumed to be compatible with ecoinvent 3.7.1.

As an indication of the relative contribution of each of these databases to the overall models, the following number of processes has been used form each database:

- ecoinvent 3.7.1: 3089 processes (87%)
- Agri-footprint 5.0: 232 processes (7%)
- World food LCA database: 191 processes (5%)
- AGRIBALYSE 3.0: 33 processes (1%)

Some impact categories (e.g. water scarcity and land use) require regionalised datasets. In foreground processes, regionalised flows were used. However, the spatial resolution of the different background datasets is not consistent. Agri-footprint, for example, often has a higher regional resolution than ecoinvent. This is not foreseen to be a cause of concern because the aim of the study is to provide accurate carbon footprint results, and simply flag any possible trade-offs in the other impact categories. Meaning, that when non-regionalized data is used, the inaccuracies will be present in both the frozen product and for the alternative, therefore not influencing the conclusions drawn.

This data is accessed through SimaPro 9.2[32], which is also used for the modelling and calculations in this study.

Additional data is gathered from published literature. One important literature source used is the PEF Guide [1]:

- The PEF guide provides default average values for various life cycle stages. These values are used for stages in the life cycle not directly influenced by Nomad Foods, e.g. the use stage. When required, secondary data sources are used to supplement this PEF data, for example, cooking instructions for the homemade equivalent products. These secondary data sources are outlined in the data collection phase.

4.3 Data quality requirements

The Pedigree matrix [33] is used for judging the data quality of each frozen product and its alternative, so that a similar data quality of the frozen product and its alternative can be assured. The same matrix is used to quantify data uncertainty in the ecoinvent database version 3.7.1 [28], the main background database used in this study.

Data quality is assessed according to five indicators:

- Reliability
- Completeness
- Temporal correlation
- Geographic correlation
- Technological correlation

For each of these indicators, a score between 1 (best) and 5 (worst) is assigned. This is done according to the categorization provided in the Pedigree matrix.

4.4 Timeframe for the study

The timeframe for this study is the year 2019. Wherever possible, data specific to this year and covering this entire year is used. This is especially the case for the primary data used. If data covering other/older time periods is used, this is reflected in the data quality score. This applies mostly to the background data used, which has a wide range of time periods that the data stems from.

Nomad Foods deems 2019 to be representative of an average production year and the results of this study are therefore considered to be applicable until major changes in the life cycle occur. These changes might include changes to Nomad Foods' production, as well as relevant factors outside of Nomad Foods, such as energy efficiency of cooling and freezing, and consumer behaviour in relation to food loss and waste.

4.5 Geographic boundary for the study

For this study, the products were each modelled for sale and consumption in one specific country, as indicated in the product overview. These countries were selected based on the market where the product is sold the most.

This study is meant to represent the specific countries in which each of the included products are consumed. These countries are all part of the European market, since this is where Nomad Foods operates.

The main factors in the modelling affected by the selected country are:

- Transport distance from the factory to the Nomad Foods distribution centre
- Transport distance from the Nomad Foods distribution centre to the retail distribution centre
- Electricity mix used in retail for cooling/freezing
- Electricity mix used at home for cooling/freezing
- Electricity mix used at home for preparation

Food loss and waste percentages are not differentiated per consumption country in this study.

While this study therefore covers the main sales and consumption location of each of the products, there can be some variations when consumption takes place in a different country, especially if the electricity mix is different.

5 Allocation procedures

In this study, the attributional approach was taken. In the primary data, where allocation can be avoided by subdividing the processes, this was done. For the remaining cases, allocation was used to determine what part of the impacts are attributed to the products under study. Table 4 shows the allocation approaches that were used at different parts of the supply chain. These are explained in more detail in the sections of this chapter.

For the used background data, the data providers have determined how multi-functionality was dealt with. The 'cut-off by classification' version of ecoinvent was used, which uses allocation factors to handle co-products and by-products. The same applies to the Agri-footprint database. For more detail on this and the approaches used by the other background data providers, refer to their respective methodology reports as referenced in section *4.2* Data sources.

Table 4 - Overview of allocation methods used

Topic	Allocation method used
Fisheries: target catch and by-catch	Mass allocation
Fisheries: fillet and co-products	Economic allocation
Factory: Multiple products on one factory line	Mass allocation to indicate throughput
Factory: Multiple product lines within one factory	Mass allocation as proxy for space occupied
Factory: Refrigerant use (Alaska Pollock Fish Fingers only)	Operational time of factory lines
Storage	Volume and storage time-based allocation
End of life	Cut-off (0-100) approach

5.1 Allocation in multi-output processes

In multi-output processes (agricultural production and separating different parts of animal and plant input), economic allocation will be applied as a default. Any deviations, due to another approach being more accurate in a certain case or due to data gaps, will be reported along with the reason for deviating.

5.1.1 Target fish and bycatch

To ensure high data quality, primary data was collected from Nomad Foods' fish suppliers on both the manufacturing and the catching operations. Depending on the fish species, there can be multiple catch areas and data was received for a different number of vessels. In some cases, this primary data was expanded on with secondary data. This section, focuses on the allocation approaches used.

In this study, the applied allocation between target fish and bycatch is mass allocation. The main rationale for this is because the fisheries are quota-limited, rather than economically driven.

If the choice in fish catch would be driven by economic incentive, this would mean that the fisheries would prefer to catch the fish with the higher value and spend most of their catching efforts on that. However, with a quota (i.e. a maximum amount of fish which can be caught and/or landed) fishers do not have control over the amount and species proportions of fish they can catch. Because there is an upper limit to the number of fish which can be caught/landed of each species, the catching amount is primarily driven by the quota rather than the economic incentive. Discussions with wild caught fish suppliers confirm that they fish until the quota is reached, and then move on to target other species. This forms the basis for using mass allocation as the default allocation approach.

For the Atlantic Salmon, allocation between target fish and bycatch is not required, because the Salmon is farmed (i.e. 100% of impacts are allocated to the Atlantic Salmon).

5.1.2 Fillet and co-products

Economic allocation based on revenue is used for allocating the impacts between the fillet block/fillet and the co-products. This can be considered as a similar process to cattle and pig slaughterhouse activities, for which the European Commission prescribes economic allocation in the PEF method [1]. For some species, price data was available for the manufactured fish and co-products, either from primary data or literature [34], however lack of data for other species meant that assumptions had to be made.

5.1.3 Multiple products on one factory line

In case multiple products are produced on the same factory line, mass allocation is used. This is in part because economic values of various products at factory level are difficult to obtain. In addition, mass allocation is considered to be a valid approach, since the products produced on the same line require similar manufacturing steps and are expected to be of comparable value.

5.1.4 Multiple product lines in one factory

When certain factory inputs cannot be reported per production line (such as the energy used for cooling the factory space and lighting), mass allocation will be applied. In this case, the mass produced per production line is used as a proxy for the space occupied by each line, as it is not feasible to determine the space occupied per production line in this study.

5.1.5 Storage

In case other products than the frozen products are stored in the same (cold) storage space, the allocation is based on volume and time (m^3-days), following the guidelines of the PEF [1].

5.2 Allocation at end-of-life

For allocation at end-of-life, the cut-off approach is *primarily* used [35]. This is used in both the background databases and the foreground processes to ensure consistency.

According to the cut-off approach, environmental impacts arising from collecting, processing and storing the material after use to make it reusable, are not attributed to the waste product. The underlying philosophy of this approach is that primary (first) production of materials is allocated to the primary user of a material. If a material is recycled, the primary producer does not receive any benefit or burden for the provision of recyclable materials. Similarly, energy generated from incineration of waste is not attributed to the provider of the waste, but to the user of the energy.

For glass, aluminium and steel, the cut-off approach is deemed not appropriate, and the closed loop approximation is used instead. The cut-off approach is suitable for materials where there is limited market demand for the recycled material. For example, there is minimal market demand for recycled plastic, partially explained by the relative low cost of virgin plastic, and the polymer degradation of plastic when recycled. In contrast, there is a high market demand for recycled glass, aluminium, and steel. For example, there is a high market demand for recycled glass, because virgin glass is energy intensive to make, and the use of recycled glass drastically reduces the energy requirements (consequently, making it the cheaper alternative). Additionally, recycled glass, steel and aluminium are capable of maintaining their quality.

If the cut-off approach were to be used for glass, aluminium and steel, the benefit associated with providing these recycled materials to the market would be disregarded. Using the closed-loop approximation method means that there are no inputs and outputs associated with using the recycled input of glass, aluminium, or steel, and when these materials are provided to the recycling, the associated benefits and burdens are accounted for. For the products with a minimal market demand (i.e. plastic), it is appropriate that no benefit is associated with providing the materials to the recycling system.

Aluminium, glass and steel are used in packaging of the alternatives in jars and cans. For interpretation purposes, the benefits and burdens of the material recycling are grouped in the packaging phase.

For waste that is not recycled, such as materials going to landfill or incineration, the impacts are assigned to the respective functional unit.

Food loss and waste in **production** is monitored carefully by Nomad Foods and is modelled based on the exact waste amounts and destinations from each factory.

Treatment of food loss and waste at both **retail** and **consumer** is modelled as the EU market mix for biowaste included in ecoinvent, meaning it is partially incinerated (45%), partially industrially composted (36%), and partially sent to anaerobic digestion (19%). Industrial composting and anaerobic digestion can be considered as recycling in this context, so any emissions associated with the collection and processing at end of life are out of scope. As a result, only greenhouse gas emissions related to incineration are included in the model.

For the consumer waste, it is possible that even when there is the option to collect biowaste separately, some of it may still end up with municipal solid waste. As a result, a fraction is expected to end up in landfill, where anaerobic digestion may create methane emissions, which are a much more potent greenhouse gas than carbon dioxide. However, there was no data available on the split between what percentage of household waste ends up in biowaste collection and what ends up in municipal solid waste. Since higher food loss and waste impacts will affect the products with higher food loss and waste numbers (i.e. the non-frozen products) more, it was decided to model a situation of 100% biowaste. This makes the difference between the frozen and non-frozen products smaller instead of bigger. In addition, in several of the countries included in this study, the fraction of municipal solid waste that ends up in landfill is fairly small, as can be seen in Table 5. The effect of food waste ending up in municipal solid waste is therefore also fairly small.

Packaging waste at the consumer is modelled as municipal solid waste as included in ecoinvent. The emissions associated with landfilling, incineration and open burning are all included in the model. The percentages for the various end of life destinations as included in ecoinvent are listed in Table 5.

Table 5 - Municipal solid waste destinations

Country	Landfilling	Incineration	Open burning
Germany	0.6 %	99.4 %	0.01 %
United Kingdom	34.8 %	64.8 %	0.4 %
Norway	8.1 %	91.8 %	0.1 %
Sweden	1.2 %	98.8 %	0.01 %
Italy	55.2 %	44.1 %	0.7 %

6 Specific modelling approaches

Several challenges were encountered during the modelling and specific approaches were devised to deal with these challenges. These approaches are documented in this section. The approaches that are most relevant for the results are checked with a sensitivity analysis.

6.1 Overview of differences between frozen and alternative products

This section gives an overview of the differences between how frozen, chilled, and ambient were modelled, with reference to where in the report further details can be found.

Table 6 - Overview of the ways in which frozen, chilled and ambient food products are modelled throughout the value chain

	Frozen	Chilled	Ambient
Transport temperature	Between the factory and the retailer, all transport is with a **frozen** lorry From retail to consumer, the transport is ambient Refer to section *6.8*	Between the factory and the retailer, all transport is with a **chilled** lorry From retail to consumer, the transport is ambient Refer to section *6.8*	Between the factory and the retailer, all transport is with a **regular** lorry From retail to consumer, the transport is ambient Refer to section *6.8*
Raw materials / agriculture	Based on Nomad Foods primary data	Based on Nomad Foods primary data (i.e. the same as the frozen products). *With the exception of leaf spinach and cream spinach products where the raw materials for fresh spinach differ slightly. Refer to section 6.5 for more details*	
Upstream raw material processing	Upstream materials are modelled based on how they arrive at Nomad Foods (e.g. if the raw materials come to Nomad Foods as frozen, the processes are adapted to account for upstream freezing of materials)	Upstream plant-based materials are modelled assuming all **arrive at the factory chilled** Upstream fish materials are modelled assuming all **are frozen until reaching Europe** and are then defrosted passively. Note that for some products, a purely fresh version	Upstream materials are modelled assuming all **arrive at the factory ambient**

		does not exist in Europe (e.g. Alaska Pollock).	
Factory manufacturing	Using Nomad Foods primary data	Factory manufacturing is kept as close as possible to the frozen manufacturing, but adjustments were made based on key product differences, such as, different preparation states (i.e. raw, cooked, blanched etc.) and different final packed temperature requirements. Refer to section *6.4* and *6.7*	
Packaging material, size and volume (has influence on factors throughout value chain)	Using Nomad Foods primary data	Different packaging is used for alternative products. Selected based on section *3.3*	
Distribution storage (temperature, duration and volume factor)	Using Nomad Foods primary data	Using PEF data for chilled storage as described in section *6.8*	Using PEF data for ambient storage as described in section *6.8*
Retail storage (temperature, duration and volume factor)	Using PEF data for frozen storage as described in section *6.8*	Using PEF data for fresh storage as described in section *6.8*	Using PEF data for ambient storage as described in section *6.8*
Retail waste	Using primary data for products based on the product category where possible.	Using primary data for chilled products based on the product category where possible.	Using primary data for ambient products based on the product category where possible.
Consumer storage (temperature, duration and volume factor)	Using PEF data for frozen storage as described in section *6.8*	Using PEF data for chilled storage as described in section *6.8*	Assuming zero impact from storage as described in section *6.8*
Preparation (time and method – dependent on decision tree)	Preparation time and method is based on Nomad Foods product packaging	The preparation method is kept the same as the frozen product *when feasible,* and the cooking times are adjusted to account for the different preparation requirements. Refer to section *6.10*.	
Consumer waste	Using secondary data for *frozen* products based on product categories where possible.	Using secondary data for *chilled* products based on product categories where possible.	Using secondary data for *ambient* products based on product categories where possible.

6.2 Modelling primary fisheries data

Nomad Foods' main fish suppliers were engaged to gather primary data on fishing operations and processes. The data collected for fishing operations was primarily the fuel usage, refrigerant usage and catch volumes. The data collected was mainly the energy requirements for processing and the mass breakdown of the co-products.

Data on capital goods, lubricating oil, and antifouling paint are based on secondary data.

Atlantic Salmon that is used in the Atlantic Salmon fillet is farmed. Data was collected on fish feed production (produced on-site) and for open net-pen salmon farming and manufacturing.

6.3 Modelling primary cultivation data

Primary data was used for the cultivation of red cabbage, leaf spinach and garden peas. The data provided includes the yield, field size, fertilizer use, fuel use, pesticide use, irrigation, and $CaCO_3$ use. Data was provided for the growing period within 2019.
For this primary data, pesticide emissions are modelled as per the HFCR v1.0 [36]. This states that 90% of active ingredients applied are emitted to the soil, 9% to the water and 1% to the air.

To model the Nitrogen (N) and Phosphorus (P) emissions from fertilizer application, the alternative approach to nitrogen modelling is adopted, from section 4.4.1.5. from PEF [1]. This approach is chosen because of limited data availability on field characteristics.

The contribution of fertilizer and pesticides to the overall environmental impact is very different for the three products (between 2 and 30%), the assumptions made for modelling the cultivation phase, these are as follows:

- The fraction of synthetic fertilizer and manure lost to leaching and runoff as NO_3 (i.e. the leaching factor) is assumed to be 30%.
- The fraction of synthetic fertilizer N applied to soils that volatilizes as NH_3 and NO_x is assumed based the alternative approach described in PEF. Different fractions are used for urea, ammonium nitrate, other chemical fertilizers, and manure.
- Nitrogen in soil from mineralization and atmospheric deposition is estimated, based on the difference calculated between the N balance and N loss, assuming the minimum of 30% N leaching.
- Assuming soil and crop residue N is 0% lost.
- N content of harvested product is taken from external sources [37], [38], [36]
- Assumed density of UAN is 1.28kg/L [39]
- Assuming zero N in soil from crop residues.
- Assuming 1kg/L of pesticide
- A generic dataset for the production of pesticides is used

6.4 Manufacturing of non-frozen products

To ensure equal data quality and not let the efficiency of Nomad Foods' manufacturing facilities affect the comparison between the frozen and alternative products, the primary manufacturing data of the Nomad Foods frozen products is used for the alternative products as well. To account for the alternatives not being frozen and possibly being in a different state than the frozen product (i.e. raw vs cooked), adjustment values are applied to the manufacturing data.

The temperature adjustments are made based on the temperature difference between the product temperature after manufacturing and the final temperature of the product when leaving the factory. For example, garden peas are chilled during distribution and thus begin manufacturing at a temperature of 3°C. For frozen peas, the temperature is then reduced to -20°C, while the non-frozen alternative the temperature remains at 3°C. This results in a different amount of electricity used for this final step. It is assumed that all other manufacturing steps remain the same for both the frozen and non-frozen products. The electricity use for the canning and jarring manufacturing itself and the sterilisation of the jars are thus not included in this study.

The temperature difference between the product after manufacturing and the final temperature of the product when leaving the factory is used as a basis for determining the electricity reduction for non-frozen products. This data is assumed to be linear with the desired temperature difference and is therefore scaled up or down based on the required temperature difference.

In addition, in some cases there is a difference in the state of the frozen and non-frozen product that needs to be adjusted for. For example, frozen leaf spinach is blanched in the factory, after which it is frozen. In contrast, chilled leaf spinach is packed raw. So not only is an adjustment needed for not reducing the temperature to freezing, but an adjustment is also needed for not cooking the product during manufacturing. Similar to the cooling adjustment, this blanching adjustment is also made based on temperature difference.

In all instances, when additional cooling is required, the electricity consumption is adjusted linearly based on temperature differences.

The adjustments are based on the following temperatures:

- All chilled items are chilled to 3°C.
- All frozen products are frozen to -20°C
- Ambient products (such as those in jars or cans) are assumed to have no active cooling in the factory. They are filled hot and cool down passively.
- Food products which are boiled or fried prior to chilling or freezing assumed to have an initial temperature of 80°C.
- Food products which are pre-blanched prior to chilling or freezing assumed to have an initial temperature of 70°C.
- Food products which are raw/uncooked prior to chilling/freezing are assumed to have an initial temperature of 8°C.

By using primary manufacturing data from Nomad Foods for both the frozen and non-frozen products as many differentiating factors as possible are taken out of the equation, focusing only on the inherent differences between frozen and non-frozen. In return, the adjustment values do introduce an amount of uncertainty into the model, which will be assessed during the sensitivity and uncertainty analyses. The contribution of these adjustments to the overall results will determine if the adjustments are adequate for the purpose. An additional relevant parameter would be the duration of cooking times (e.g. difference in duration of cooking times would likely differ between pre-cooking and pre-blanching), however the granularity of factory data available does not allow for this to be accounted. This will be taken into consideration in the interpretation.

6.5 Modelling differences in spinach cultivation

For red cabbage and garden peas, the form of vegetable is the same for the frozen and fresh alternative. Therefore, the same crop is used for modelling the frozen and fresh alternative. However, for spinach the form is different; spinach which is bought fresh has a smaller leaf size than spinach which is to be frozen, which has the largest of all marketed leaf sizes [40]. The spinach which is to be sold frozen is therefore grown for longer periods than the spinach to be sold fresh, so needs to be modelled accordingly.

Table 7 shows an overview of the data found on the differences in spinach cultivation in literature. Table 8 shows an overview of how this information was used to represent the difference in the cultivation of fresh versus frozen spinach in the model (all other cultivation processes which are not mentioned in this overview are assumed to remain constant between the fresh and frozen spinach).

Table 7 - Literature overview on difference between frozen and fresh spinach production

	Fresh bunched spinach	Clipped fresh market spinach (sold in salad mixes)	Spinach to be manufactured/frozen	Source
Pre-plant or at planting	22 kg N /ha	22 kg N /ha	22 kg N/ha	[40]
Topdress or water run application #1	22-34 kg N/ha *(28 kg N/ha mean)*	22-34 kg N/ha *(28 kg N/ha mean)*	22-34 kg N/ha *(28 kg N/ha mean)*	[40]
Topdress or water run application #2	*Not required*	*Not required*	22-34 kg N/ha *(28 kg N/ha mean)*	[40]
N removed by harvesting of product	N removed by harvesting fresh spinach is 22-45 kg N per ha. *(33.5 kg N/ha mean)*		Double the N removed as harvesting fresh spinach. As frozen spinach is harvested at a more mature stage *(67 kg N/ha mean)*	[40]
Harvesting method	Hand-harvested for bunched spinach	Mechanical harvested (cutter bar)	Mechanical harvested (cutter bar)	[40]
Harvesting time	32-62 days after planting	26-50 days after planting) (teenage) *(38 days mean)*	48-90 days after planting *(69 days mean)*	[40]
Yield	1300 to 4800 cartons (of minimum net weight 9kg) per ha = 11.7ton / ha 43.2 ton / ha		Leaf size and thickness significantly greater	[40]

		20.8 ton/ha *Based on spinach for the fresh market*	36.2 ton/ha *Based on spinach for manufacturing*	[41]
Post-harvest handling		Clipped just above the root, transported to packing facility to be cooled, washed, sorted and bagged.		[40]
		After clipping, the roots are still in the field so the plant can continue growing another 1-2 times	After clipping, the roots are still in the field so the plant can continue growing another 1-2 times	[41] [40]

Table 8 - Differences implemented in the model for fresh versus frozen spinach

	Fresh	Frozen	
Fertilizers	50 kg N/ha (based on Table 7)	78 kg N /ha (based on *Table 7*)	N applied for Fresh is 64% less per ha than N applied for Frozen. This is applied to the UAN, CAN, lime and KornKali applied. The fuel usage for fertilizing is also scaled to be 64% lower for fresh spinach
Yield	20.8 ton/ha	36.2 ton/ha	Yield is 57% lower for fresh than for frozen spinach
Land occupation			With a shorter growing period, land occupation is assumed to be 55% lower for 1kg of fresh spinach than 1kg of frozen spinach
Plant protection	Assumed to be the same given no literature could be found on the differences		
Harvesting method	Fuel usage assumed to be the same for harvesting, unless harvested by hand		
N in harvested crop	N content in the harvested product per ha is assumed to be 50% lower for fresh spinach than that of frozen spinach based on Table 7.		
Irrigation	Assumed to be correlated with the growth time, therefore is 55% lower for fresh than frozen		

6.6 Differences in upstream processing of raw materials

For multiple products, Nomad Foods sources the raw materials pre-cooked and/or pre-frozen. With the secondary datasets mostly providing data on raw foods, the energy and material requirements for pre-cooking and freezing the raw materials still needs to be accounted for.

To determine the inputs and outputs associated with these steps, the inputs and outputs of several background datasets that were available in both a frozen and non-frozen version were compared. The difference between these datasets was taken to represent the additional inputs and outputs needed to provide raw materials pre-frozen and applied to all datasets where a pre-frozen version was not available. In addition, refrigerant use was added to the created pre-frozen datasets based on data from the PEF guidance [1].

For pre-cooked (blanched) raw materials coming into the Nomad Foods facilities, a dataset from the Agribalyse database on blanching was used.

6.7 Manufacturing of homemade products

It is assumed that for the homemade products, the only impacts in the factory manufacturing phase for the fresh vegetables come from the packaging. It is assumed that the fresh vegetables essentially go directly from the farm to the distribution centre with only a packaging step in between, given that no further preparation (e.g. chopping, peeling etc) is required. There is no granular primary data on the electricity required for the packaging phase from Nomad Foods since this data is integrated with the factory line data. Therefore, data from one of Nomad Foods' co-packers covered in this study is used. This co-packer did provide granular data, so the packaging step could be separated.

6.8 Distribution and storage

Each of the frozen products and their alternative take the same distribution route, with the same distances being used for both. Throughout distribution, products are stored at a national distribution centre (DC) of Nomad Foods and a retailer DC before arriving at the retailer. The times spent in storage differ between the frozen products and their alternatives. Fresh products are often distributed more seasonally, whereas frozen products are distributed throughout the year. Consequently, frozen foods are stored for longer periods. Primary data is used for the average storage time of products at the Nomad Foods DCs, accounting for the longer storage period at the Nomad Foods DC. At the retail DC, storage times are taken from the PEF [1], which accounts for frozen products being stored for longer periods.

For storage at retail, Nomad Foods retail experts were consulted to gain insights into modern supermarkets (days spent in cold rooms, days spent on display and proportion of open and closed fridge and freezers). Energy use is taken from literature. An interesting data point is that the literature reference shows that the energy use for the chilled cold room is higher than for the freezer. This could be due to the volume differences between the two types of storage, with the literature reference indicating the freezer room having a much larger volume than the chilled room. Refer to [42] for further details on how the energy consumption at retail was calculated.

6.9 Food loss and waste

This study addresses the full life cycle of the included products from cradle to grave. This means the food loss and waste (FLW) throughout the life cycle needs to be included to come to an accurate representation of the potential environmental impact. The food loss and waste numbers are one of the main differentiating factors to the comparison of the frozen product and its alternative and is therefore expected to have a significant influence on the overall results. Because of this, the data used for this is of high importance.

6.9.1 Definition of food loss and waste

Different classifications of food loss and waste exist, with a common split being that into categories such as avoidable, possibly avoidable and unavoidable food [WRAP] or edible, questionably edible and inedible food [NRDC]. These categories are meant to indicate that not all food loss and waste can be prevented. Bones, pits, inedible peels and other parts may be typically part of food purchased, but were never expected to be consumed by humans. Some food parts may be considered edible by some people but not by others, covering many things from potato peels to chicken feet. These fall under the category of 'possibly avoidable' or 'questionably edible' food loss and waste.

The definition of food loss and waste used in this study is:

"Any food intended for human consumption that ends up not being consumed by humans"

This definition is flexible to the possibly avoidable food loss and waste, since it can be determined on a per product basis which part is intended for human consumption in the market that it is being sold in.

Food loss and waste can occur throughout the entire life cycle, from cultivation to the final consumption. An overview of the various occurrences of food loss and waste is provided in

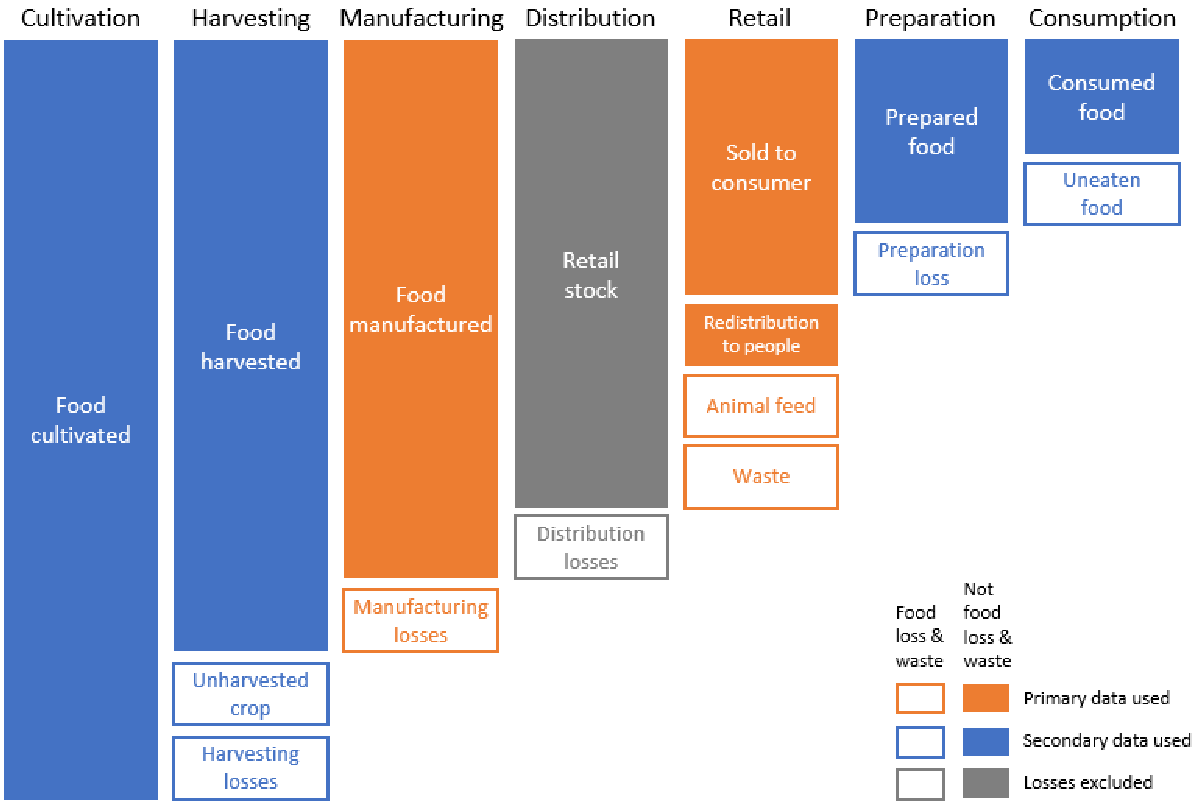


Figure 3. The image is not scaled to the amount of food loss and waste occurring, but illustrates that for a certain amount of consumed food, the various losses throughout the value chain stack up to require a larger amount of food to be cultivated. The figure illustrates which pathways are

considered food loss and waste in this study, shown by a coloured outline. Most notably, redistribution to people is not considered food loss and waste since it is still used for human consumption. Food used as animal feed however, is considered as food loss and waste even though it is excluded from the definition many use for the purpose of meeting SDG Target 12.3 (to reduce food loss and waste).

In addition,

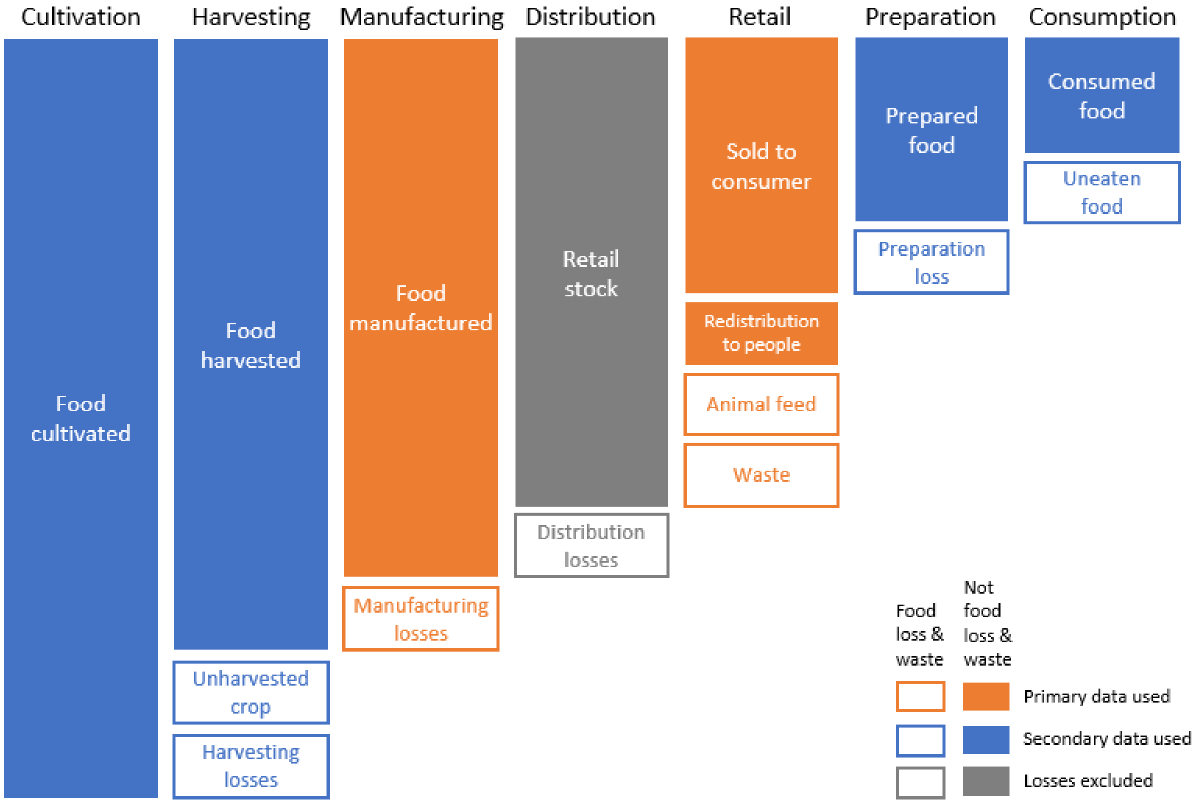


Figure 3 indicates through which data sources each of the various types of food loss and waste are covered. As shown, the cultivation and harvesting losses are covered by the background databases used. Datasets representing the food products leaving the farming stage are selected to capture this. In those cases where cultivation and harvesting were modelled with primary data, the food loss and waste was also covered by primary data. Manufacturing losses are covered by the primary data received from Nomad Foods' factories and the destinations of the losses are specified in this data as well. For distribution losses to retail, no data was available. Since this is expected to be low, it has been excluded from this study and zero losses are modelled in this stage. For retail and consumer losses, the data used is described in more detail in the following sections.

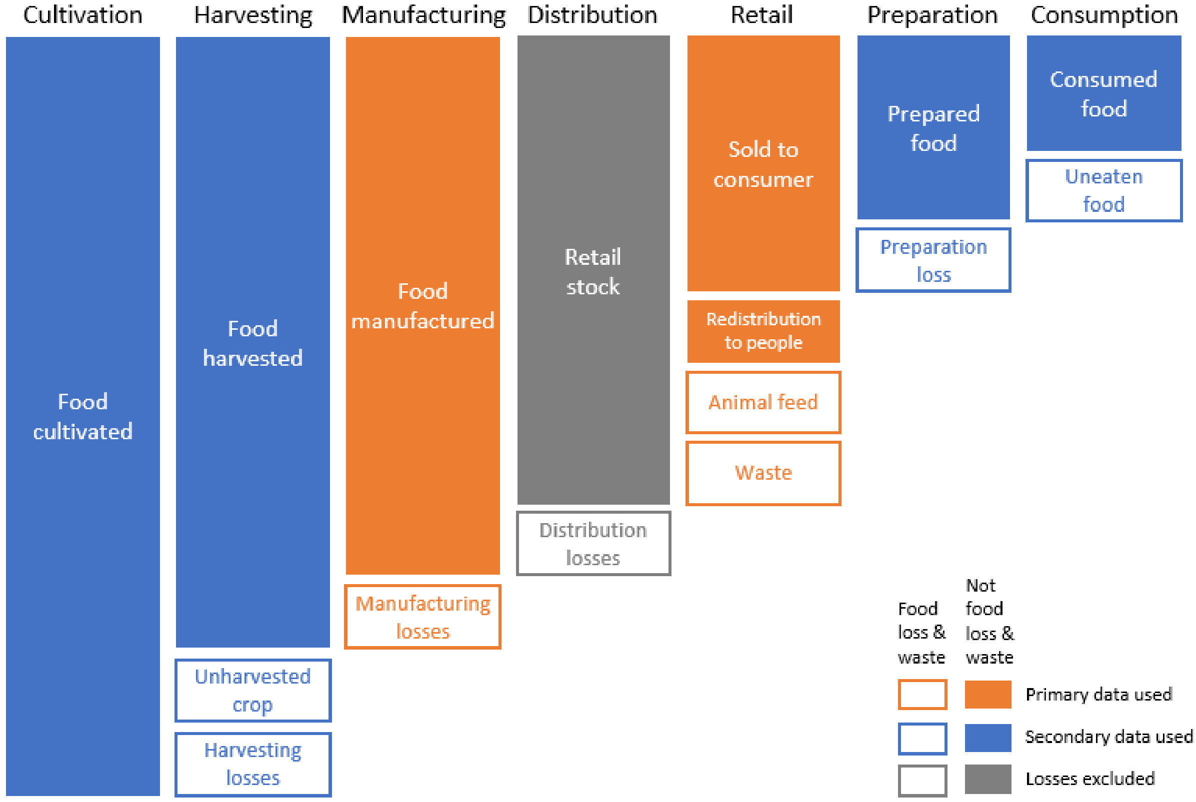


Figure 3- Illustration of food loss and waste throughout the value chain, including data sources

Throughout the study, it became clear that accurate and detailed data on food loss and waste at the retail and consumer stage is difficult to find. Available reports on the topic often focus on the absolute amounts of waste, for examples in tons per year, without relating it back to the total amount stocked or purchased. In addition, the definitions of food loss and waste in these reports vary and it is not always clear if for example food products from retail going to animal feed are considered a food loss or not.

An additional complication in relation to this study is that there are not many studies available that make a distinction between various preservation methods, i.e. the difference in food loss and waste between frozen, canned or jarred, ambient or chilled products. However, various studies refer to shelf life as a main influencing factor on the amount of food loss and waste. As an example, a study by the Thünen Institute states that common reasons for food loss and waste in retail are expired shelf life, visual damage to the food or packaging, and overstocking [43]. A report from WRAP on household food loss and waste specifies 48% of avoidable waste was described by the consumer as 'not being used in time' [44]. Since there is a big difference in shelf life between various preservation methods, it can be expected there is also a significant difference in the associated food loss and waste.

6.9.2 Data for food loss and waste at retail

Three literature sources were identified that specify food loss and waste percentages in retail for one or more specific preservation methods. These are the following:

- The report from the European Commission on the **Product Environmental Footprint** [1] method specifies default food loss and waste percentages for both retail and consumer.

There is some distinction included between product groups, such as fruits and vegetables, meat and meat alternatives, and dairy products. A specific product group for prepared manufactured frozen meals is also included. Data is mainly sourced from an FAO report from 2011, supplemented with expert judgement. However, for some data points, no source is provided.

- A study by **Caldeira et al.** [45] on food availability in the EU provides food loss and waste data for both retail & distribution and household consumption of fresh foods, split into various high level product groups.
- An elaborate report and data set by the **USDA** provides food availability estimates per year for many specific products and various preservation methods [46]. Further analysis of the data showed however that many of the data points for both retail and consumer were equal across all products and preservation methods and likely to be based on a single source number. These numbers also deviated significantly from any other values found, so in the end it was decided to exclude this reference from the study in agreement with the external review panel. The only exception are the numbers provided by USDA for chilled spinach. These are very specific and thus appear to be specifically collected for spinach. In addition, they are in line with the trend set by the other numbers.

Nomad Foods also reached out to various retailers across Europe. During the course of this study, primary data was received from four retailers. The level of detail provided by the retailers varied, as well as the detail on the specific definitions of food loss and waste used, but covered a wide range of supermarkets.

No single source covers all products and geographies included in this study and various levels of detail are provided. Therefore, an overview of the numbers provided by the various sources was created to determine if there were any outliers and to come to a final conclusion on a reasonable set of food loss and waste numbers to use for retail. This overview showed that each of the sources covers a different selection of the products under study, so a combination had to be made. There is a fairly large variation in the food loss and waste numbers from the various sources, so it was decided to use the mean value of the numbers available. The resulting calculated averages are summarized in Table 9.

Table 9 - Used percentages of food loss and waste in retail

	Frozen	Chilled	Canned/jarred
Alaska Pollock fish fingers	0.4 %	4.8 %	n/a
Battered Alaska pollock fish fingers	0.4 %	4.8 %	n/a
Atlantic cod fish fingers	0.3 %	5.4 %	n/a
North Pacific Hake fish fingers	0.4 %	4.8 %	n/a
South African Cape Hake fillet	0.7 %	4.8 %	n/a
Atlantic cod loins	0.3 %	5.4 %	n/a
Atlantic salmon fillet	0.3 %	4.0 %	n/a
Schlefi (fish bake)	0.6 %	4.3 %	n/a
Fish gratin	0.6 %	5.0 %	n/a
Vegetarian Burger	0.4 %	3.9 %	n/a
Chicken nuggets alternative	0.5 %	2.7 %	n/a
Falafel	0.5 %	4.9 %	n/a
Garden peas	0.5 %	5.5 %	0.4 %
Extra fine peas	0.5 %	n/a	0.4 %
Cream spinach	0.4 %	9.6 %	n/a
Leaf spinach	0.4 %	9.6 %	n/a
Italian vegetable mix	0.5 %	8.1 %	n/a
Roasted parsnips	0.4 %	9.1 %	n/a
Red cabbage with apple	0.7 %	n/a	0.5 %
Super Sunshine Steam Mix	0.5 %	4.9 %	n/a
Mix for minestrone	0.5 %	7.8 %	n/a

6.9.1 Data for food loss and waste at consumer

For the consumer stage, only secondary data was available for food loss and waste. A number of different sources was identified. The first three were also covered in the retail section, since they provide data on both the retail and consumer stages. An overview:

- The report from the European Commission on the **Product Environmental Footprint** [1] method as per above
- A study by **Caldeira et al.** [47] on food availability in the EU as per above
- An elaborate report and data set by the **USDA** as per above. These numbers deviated significantly from any other values found, so in the end it was decided to exclude this reference from the study.
- A publication by **Janssen et al.** [48] looked specifically into consumer food loss and waste of products with different preservation methods. The study was conducted in the Netherlands. A selection of products was included in the study, including some of the specific products included in this LCA such as fish fingers and spinach. For products not specifically included in the study, it was possible to find suitable proxies within the other products covered.
- A publication by **Martindale et al.** [49] specifically compares the fraction of food purchases wasted by consumers between fresh and frozen food. The area under study is Austria. The categories used are quite broad (vegetables, meat, fish, etc.), however the categories of fish fingers and spinach specifically were covered.
- A report by WRAP UK [50] specifies the percentages of purchases wasted by the consumer split between avoidable and possibly avoidable waste for various food groups.

It mainly covers fresh or chilled products, no separate category for frozen foods is included.

Similar to the retail data, no single source covers all products and geographies included in this study and various levels of detail are provided. In addition, the methods used to collect and report food loss and waste by consumers varies considerably across these sources. Values from the USDA are excluded from the calculation of the average value per product, as mentioned before. The resulting calculated averages are summarized in Table 10.

Table 10 - Used percentages of food loss and waste at consumer

	Frozen	Chilled	Canned/jarred
Alaska Pollock fish fingers	4.5 %	7.1 %	n/a
Battered Alaska pollock fish fingers	4.5 %	7.1 %	n/a
Atlantic cod fish fingers	4.5 %	7.1 %	n/a
North Pacific Hake fish fingers	4.5 %	7.1 %	n/a
South African Cape Hake fillet	1.8 %	6.8 %	n/a
Atlantic cod loins	1.8 %	6.8 %	n/a
Atlantic salmon fillet	1.8 %	6.8 %	n/a
Schlefi (fish bake)	2.1 %	7.1 %	n/a
Fish gratin	2.1 %	7.1 %	n/a
Vegetarian Burger	3.0 %	8.5 %	n/a
Chicken nuggets alternative	3.0 %	8.5 %	n/a
Falafel	3.0 %	8.5 %	n/a
Garden peas	2.0 %	16.5 %	3.2 %
Extra fine peas	2.0 %	n/a	3.2 %
Cream spinach	1.4 %	16.5 %	n/a
Leaf spinach	1.4 %	16.5 %	n/a
Italian vegetable mix	2.2 %	11.3 %	n/a
Roasted parsnips	2.6 %	17.2 %	n/a
Red cabbage with apple	2.6 %	n/a	3.6 %
Super Sunshine Steam Mix	2.3 %	11.3 %	n/a
Mix for minestrone	2.1 %	11.3 %	n/a

6.10 Consumer preparation

6.10.1 Nomad Foods product preparation

For the Nomad Foods frozen products, the preparation method and cooking times are used from the package recommendations. If more than one preparation method is suggested, an equal proportion of preparation methods are assumed. For example, if the package states the consumer can either bake or fry a product, it is assumed that 50% is baked and 50% is fried. It is possible for consumers to deviate from the preparation methods described on the packaging. For example, consumers may choose to fry peas instead of boil or microwave them. However, no detailed data on this is available.

In some cases, the Nomad Foods packaging states specifically for how much of the product the preparation method is intended for (e.g. for frozen garden peas, the microwaving time is specified for 500g of peas). When this is explicitly stated, the preparation is modelled on the basis of the grams specified. When the amount of product for the associated preparation methods is *not* specified, it is assumed that the preparation method is for **three servings** of product. The serving size for the frozen and alternatives is assumed to be the same. The mass of three servings of each product is specified in Table 1.

Where a time range is given, an average is taken. For example, a time range of 5-7 minutes is modelled as 6 minutes.

6.10.2 Alternative product preparation

An inherent difference between the frozen product and its alternative is often the preparation of the product. The time taken to cook frozen food is longer than chilled food which needs to be accounted for. As outlined in section *6.4*, an adjustment is made in the manufacturing phase to account for the different state (i.e. raw or cooked) of the product and its alternative. Similarly, this needs to be accounted for in the consumer preparation in order to compare two cooked products, i.e. if less energy is required in the manufacturing phase for the alternative because it is raw instead of cooked, additional energy is required in the preparation phase to fully cook the product.

Figure 4 shows the decision tree which outlines the process for determining the preparation of the alternative product.

The following examples illustrate how the decision tree is used.

- *North Pacific Hake Fish Fingers:* The frozen product is pre-cooked, and the package states to bake in the oven or grill in the pan. The alternative product is also pre-cooked, so the frozen and alternative product are in the same state. The package does not state to thaw the fish fingers before preparation. This leads to decision 2; the same preparation method is used, and the cooking time is adjusted so that the difference in time required to cook frozen food versus chilled food is accounted for.
- *Extra fine peas:* The frozen product is pre-blanched, and the jarred peas are cooked, therefore they are in a different state. It is realistic to assume the jarred peas could also be microwaved or boiled, leading to decision 4. A recipe is found for preparing the jarred peas using the same preparation methods.

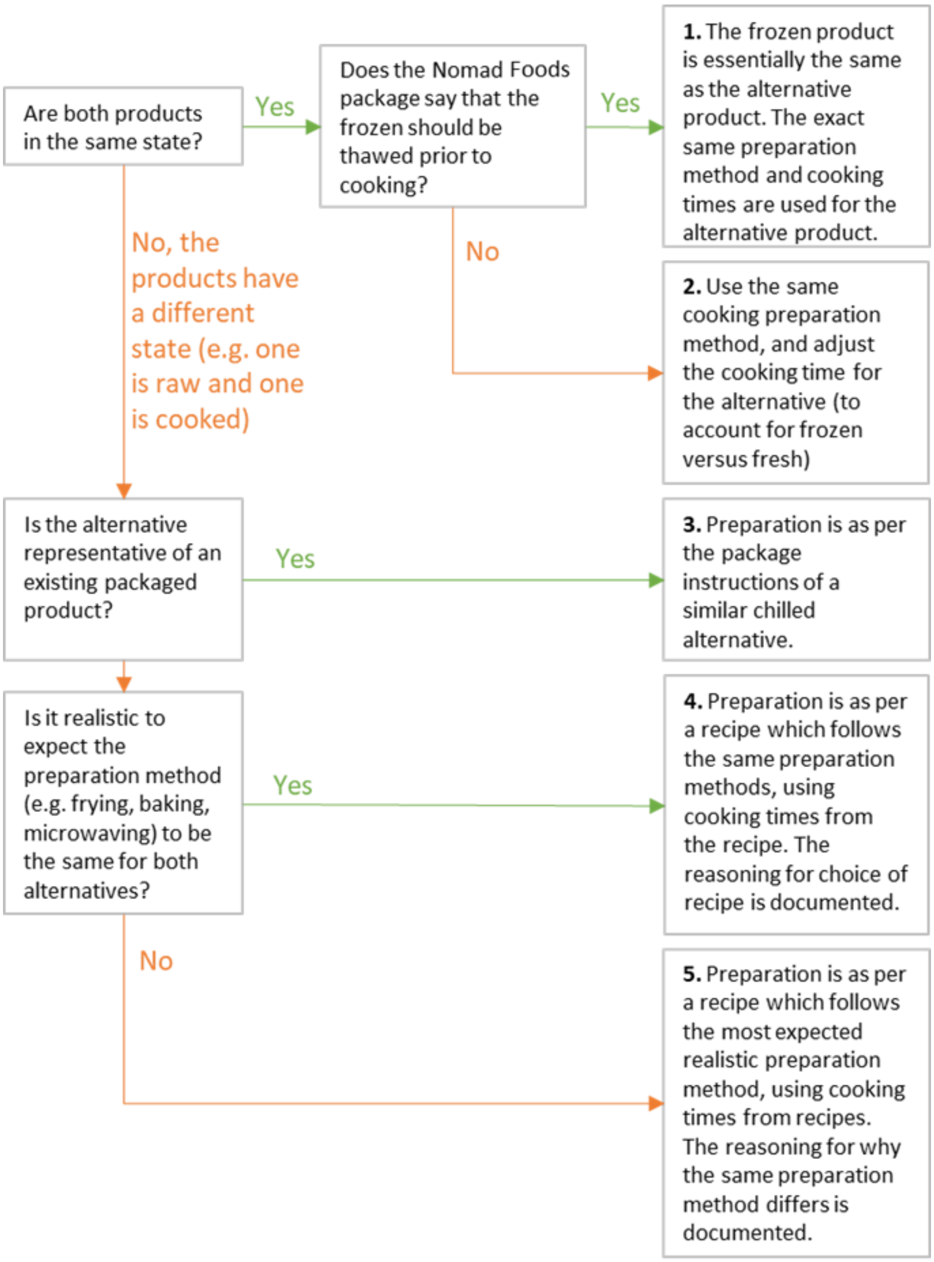


Figure 4 - Decision tree for consumer preparation of the alternative product

Because the temperature difference between frozen and cooked is greater than the temperature difference between chilled or ambient and cooked, cooking frozen food in the same state will fundamentally take longer. Therefore, when Decision 2 is selected, an adjustment of cooking time is required. There is limited scientific literature to determine the difference in cooking times. Thus, in this study instead of having a fixed difference in cooking times, the difference per product is calculated. The boiling and frying processes used as a basis for the preparation include the energy for heating both the food and any water needed for boiling. Based on the initial temperature and the specific heat capacity of the food [51] the required energy to heat the food is calculated. The time to heat the food is then calculated based on this required energy and the power of the stove.

7 Results and interpretation

The results are calculated on a wide range of impact categories. The interpretation mainly goes into detail on global warming potential, i.e. the carbon footprint. The wide range of impact categories is used to determine the existence of trade-offs and attention points, but no detailed analysis is performed on these impact categories.

Based on the interpretation detailed in the results document, the section below describes overall insights when looking at the carbon footprint of all products together.

Please note that these results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

7.1 Numerical comparison of frozen vs. alternative

7.1.1 Carbon footprint

An overview of the calculated numerical carbon footprint results is shown in Table 11. These results are displayed per three portions, with portion size varying between the products. The values are therefore only comparable between the frozen and alternative product, not between different products.

Please note that conclusions cannot be drawn on these numerical values alone. Sensitivity and uncertainty analysis of the results is addressed in chapters *8* and *9*. Final conclusions are discussed in chapter *10*.

Table 11 – Numerical carbon footprint results (per 3 portions), a green number in frozen or alternative means its carbon footprint is lower than that of the other one. A green number in relative difference means that the carbon footprint of the frozen product is lower than of its alternative.

Product	Frozen (kg CO_2eq. per 3 portions)	Alternative (kg CO_2eq. per 3 portions)	Relative difference (negative number means frozen is lower)
Alaska Pollock fish fingers	1.95	2.05	-4.7%
Battered Alaska pollock fish fingers	1.93	1.90	1.4%
Atlantic cod fish fingers	1.57	1.64	-4.3%
North Pacific Hake fish fingers	0.82	0.84	-2.4%
South African Cape Hake fillet	1.55	1.58	-1.8%
Atlantic cod loins	1.62	1.71	-5.4%
Atlantic salmon fillet	2.80	2.99	-6.2%
Schlefi (fish bake)	2.46	2.65	-7.4%
Fish gratin	2.10	2.24	-6.4%
Vegetarian Burger	0.84	0.89	-5.4%
Chicken nuggets alternative	0.84	0.87	-2.9%
Falafel	0.67	0.75	-10.2%
Garden peas	0.29	0.52/0.45/0.3*	-43.6%/-35.1%/-2.0%
Extra fine peas	0.67	0.81	-17.5%

Cream spinach 700gr.	0.93	1.26	-25.9%
Cream spinach 750gr.	0.91	1.26	-27.9%
Leaf spinach	0.73	0.86	-15.6%
Italian vegetable mix	0.99	0.87	14.3%
Roasted parsnips	0.81	0.71	13.4%
Red cabbage with apple	0.60	0.91	-33.7%
Super sunshine mix	0.46	0.47	-0.4%
Minestrone mix	0.64	0.54	15.1%

*jarred/canned/chilled

The initial numerical results show that for the 22 products under study, in many cases the carbon footprint of the frozen and alternative product(s) are very close together. This is especially the case for the battered Alaska Pollock fish fingers, the North Pacific Hake fish fingers, South African Cape Hake fillet, chicken nugget alternative, chilled garden peas, and the super sunshine mix, where in all cases the frozen product has a numerical carbon footprint that is a mere 1 to 3% different from that of the alternative product. Even before a detailed sensitivity and uncertainty analysis, it is fairly clear that there is no clear difference between these frozen products and the alternatives in terms of carbon footprint. If any of the numerical differences can be considered significant between the frozen product and the alternative requires further investigation of the results through sensitivity and uncertainty analysis.

When looking purely at the numerical values, there are 4 products where the numerical carbon footprint of the frozen product is higher than for the alternative product, ranging from 1% for the battered Alaska Pollock fish fingers to 15% for the Minestrone mix. For the remaining 18 products, the frozen product has a lower numerical carbon footprint of the frozen product than that of the alternative, ranging from 0.4% for the super sunshine mix to 44% for jarred garden peas. How significant these differences are and if a clear conclusion can be drawn on whether a product has a lower carbon footprint than its alternative will need to be investigated in the sensitivity and uncertainty analyses.

7.1.2 Broad range of impact categories

As mentioned before, while the focus of the study is on climate change, a broad range of impact categories was considered to investigate trade-offs between climate change and other impact categories. In the full report used for ISO review, these results were provided for all products under study. For this third-party report, three case studies are used to illustrate these results.

Figure 5 and Table 12, Table 13, and Table 14 show the results for all analysed impact categories for one product per analysed product group.

Figure 5 - Characterized results for different impact categories for the frozen product and its alternative(s). The highest impact is scaled to 100% and the other products are relative to that.

Table 12 - Characterized results for all impact categories for 1 kg of Alaska Pollock Fish Fingers

Impact category	Unit	Frozen	Frozen [%]	Fresh	Fresh [%]
Climate change	kg CO_2 eq	4.33	95%	4.54	100%
Ozone depletion	kg CFC11 eq	1.27E-05	89%	1.42E-05	100%
Ionising radiation	kBq U-235 eq	0.32	100%	0.31	97%
Photochemical ozone formation	kg NMVOC eq	0.04	93%	0.04	100%
Particulate matter	disease inc.	3.80E-07	93%	4.11E-07	100%
Human toxicity, non-cancer	CTUh	5.39E-08	95%	5.70E-08	100%
Human toxicity, cancer	CTUh	3.24E-09	97%	3.35E-09	100%
Acidification	mol H+ eq	0.06	93%	0.06	100%
Eutrophication, freshwater	kg P eq	2.05E-03	100%	1.89E-03	92%
Eutrophication, marine	kg N eq	0.02	94%	0.02	100%
Eutrophication, terrestrial	mol N eq	0.17	93%	0.18	100%
Ecotoxicity, freshwater	CTUe	95.01	96%	99.29	100%
Land use	Pt	56.89	92%	61.89	100%
Water use	m3 depriv.	0.50	85%	0.59	100%
Resource use, fossils	MJ	46.27	93%	49.60	100%
Resource use, minerals and metals	kg Sb eq	3.73E-05	68%	5.49E-05	100%

Table 13 - Characterized results for all impact categories for 1 kg of Vegetarian burger

Impact category	Unit	Frozen	Frozen [%]	Fresh	Fresh [%]
Climate change	kg CO_2 eq	2.80	95%	2.96	100%
Ozone depletion	kg CFC11 eq	2.54E-07	23%	1.09E-06	100%
Ionising radiation	kBq U-235 eq	0.88	100%	0.68	77%
Photochemical ozone formation	kg NMVOC eq	8.08E-03	90%	8.95E-03	100%
Particulate matter	disease inc.	1.18E-07	87%	1.35E-07	100%
Human toxicity, non-cancer	CTUh	5.88E-08	93%	6.34E-08	100%
Human toxicity, cancer	CTUh	2.27E-09	89%	2.55E-09	100%

Impact category	Unit	Frozen	Frozen [%]	Fresh	Fresh [%]
Acidification	mol H+ eq	0.01	92%	0.02	100%
Eutrophication, freshwater	kg P eq	6.41E-04	95%	6.77E-04	100%
Eutrophication, marine	kg N eq	0.01	91%	0.01	100%
Eutrophication, terrestrial	mol N eq	0.05	91%	0.05	100%
Ecotoxicity, freshwater	CTUe	101.56	92%	110.24	100%
Land use	Pt	128.94	93%	139.12	100%
Water use	m3 depriv.	0.21	73%	0.29	100%
Resource use, fossils	MJ	43.14	100%	42.90	99%
Resource use, minerals and metals	kg Sb eq	2.73E-05	59%	4.60E-05	100%

Table 14 - Characterized results for all impact categories for 1 kg of Garden Peas

Impact category	Unit	Frozen	Frozen [%]	Jarred	Jarred [%]	Canned	Canned [%]	Fresh	Fresh [%]
Climate change	kg CO_2 eq	1.22	56%	2.16	100%	1.88	87%	1.24	58%
Ozone depletion	kg CFC11 eq	1.62E-07	61%	2.64E-07	100%	1.74E-07	66%	1.16E-07	44%
Ionising radiation	kBq U-235 eq	0.61	100%	0.28	47%	0.33	54%	0.60	99%
Photochemical ozone formation	kg NMVOC eq	3.10E-03	38%	8.17E-03	100%	6.50E-03	80%	3.08E-03	38%
Particulate matter	disease inc.	3.81E-08	19%	1.97E-07	100%	1.33E-07	67%	3.95E-08	20%
Human toxicity, non-cancer	CTUh	1.39E-08	11%	2.91E-08	24%	1.22E-07	100%	1.46E-08	12%
Human toxicity, cancer	CTUh	6.77E-10	4%	1.39E-09	8%	1.71E-08	100%	7.55E-10	4%
Acidification	mol H+ eq	4.68E-03	31%	0.02	100%	0.01	70%	4.93E-03	33%
Eutrophication, freshwater	kg P eq	2.11E-04	38%	3.38E-04	61%	5.53E-04	100%	2.06E-04	37%

Impact category	Unit	Frozen	Frozen [%]	Jarred	Jarred [%]	Canned	Canned [%]	Fresh	Fresh [%]
Eutrophication, marine	kg N eq	1.30E-03	45%	2.92E-03	100%	2.26E-03	77%	1.31E-03	45%
Eutrophication, terrestrial	mol N eq	0.01	39%	0.03	100%	0.02	76%	0.01	41%
Ecotoxicity, freshwater	CTUe	2750.23	83%	2804.01	85%	2811.10	85%	3295.34	100%
Land use	Pt	102.88	83%	117.12	94%	107.95	87%	124.19	100%
Water use	m3 depriv.	0.23	46%	0.42	83%	0.51	100%	0.24	47%
Resource use, fossils	MJ	24.92	81%	30.86	100%	27.82	90%	24.65	80%
Resource use, minerals and metals	kg Sb eq	8.51E-06	12%	2.01E-05	29%	6.95E-05	100%	8.20E-06	12%

For Alaska Pollock Fish Fingers, the numerical carbon footprint of the frozen product is lower than the alternative. Looking at all impact categories, the same general trend is seen. Meaning that the frozen product performs *slightly* numerically better on most impact categories, with the exception of two out of 16 impact categories (ionizing radiation and freshwater eutrophication) where the chilled alternative performs *slightly* numerically better. The most noticeable difference is in the impact category minerals and metals resource use, where the impact of the chilled product is >30% higher than the frozen product, mainly due to the PET used in the primary package.

For the vegetarian burger, the numerical carbon footprint of the frozen product is numerically lower (but not significantly so) than the chilled alternative. Looking at all impact categories, the impact of the frozen product is numerically lower (but not significant) than the one of the fresh one for most categories, with some exceptions. The frozen product has a noticeably higher impact for ionizing radiation (mainly due to higher electricity use at the consumer stage) whilst the fresh product as a considerably higher impact on ozone depletion and minerals and metals resource use (mainly due to PET packaging).

For garden peas, the numerical carbon footprint of the frozen product is significantly lower than the canned and jarred alternatives, and similar to the fresh alternative. Looking at all impact categories, a similar trend is seen with the jarred and canned products having a higher impact than frozen on all impact categories with the exception of ionizing radiation where frozen has the highest impact (due to higher electricity usage). When comparing to the fresh alternative, the two products have a similar impact on most impact categories, whilst the fresh has a more noticeably higher impact on freshwater ecotoxicity and land use. Human toxicity cancer and non-cancer and mineral and metals resource use are a lot higher for canned peas.

Note: for Ozone Depletion the main source of differentiation is due to the lack of a characterization factor of N_2O in the EF3.0 method. A sensitivity analysis with ReCiPe shows a *fairly small relative difference, meaning conclusions on this impact category should be treated with caution.*

7.2 Identification of significant life cycle stages

To identify the most significant life cycle stages, the carbon footprint results are grouped into the different life cycle stages (Figure 6 and Table 15).

- **Ingredients**: Production of ingredients, including transport to the factory.
- **Manufacturing**: All activities that happen at the factory, including electricity, natural gas, on-site waste and the treatment of it, and the activities related to packaging the product. In case the ingredient is delivered to Nomad Foods pre-blanched or pre-frozen, this is also part of the manufacturing group.
- **Packaging**: Packing materials, including their transport to the factory.
- **Distribution**: Transport from the factory to the Nomad distribution centre, storage at the distribution centre, transport to the retail DC and storage at the retail DC.
- **Retail storage**: Electricity and coolant use in the retail cold room and on the retail floor.
- **Retail waste**: Waste treatment of transport packaging, product losses and waste treatment of product losses. This includes ingredients, manufacturing, packaging and distribution of the product losses.
- **Consumer transport**: Transport from the retailer to the consumer.
- **Consumer storage**: Electricity use for storage at the consumer.
- **Consumer preparation**: Electricity and gas use at the consumer to cook the food product, as well as any capital goods included in the background databases.
- **Consumer waste**: Waste treatment of primary packaging and product losses. This includes all upstream processes required to compensate for the product losses at the consumer.

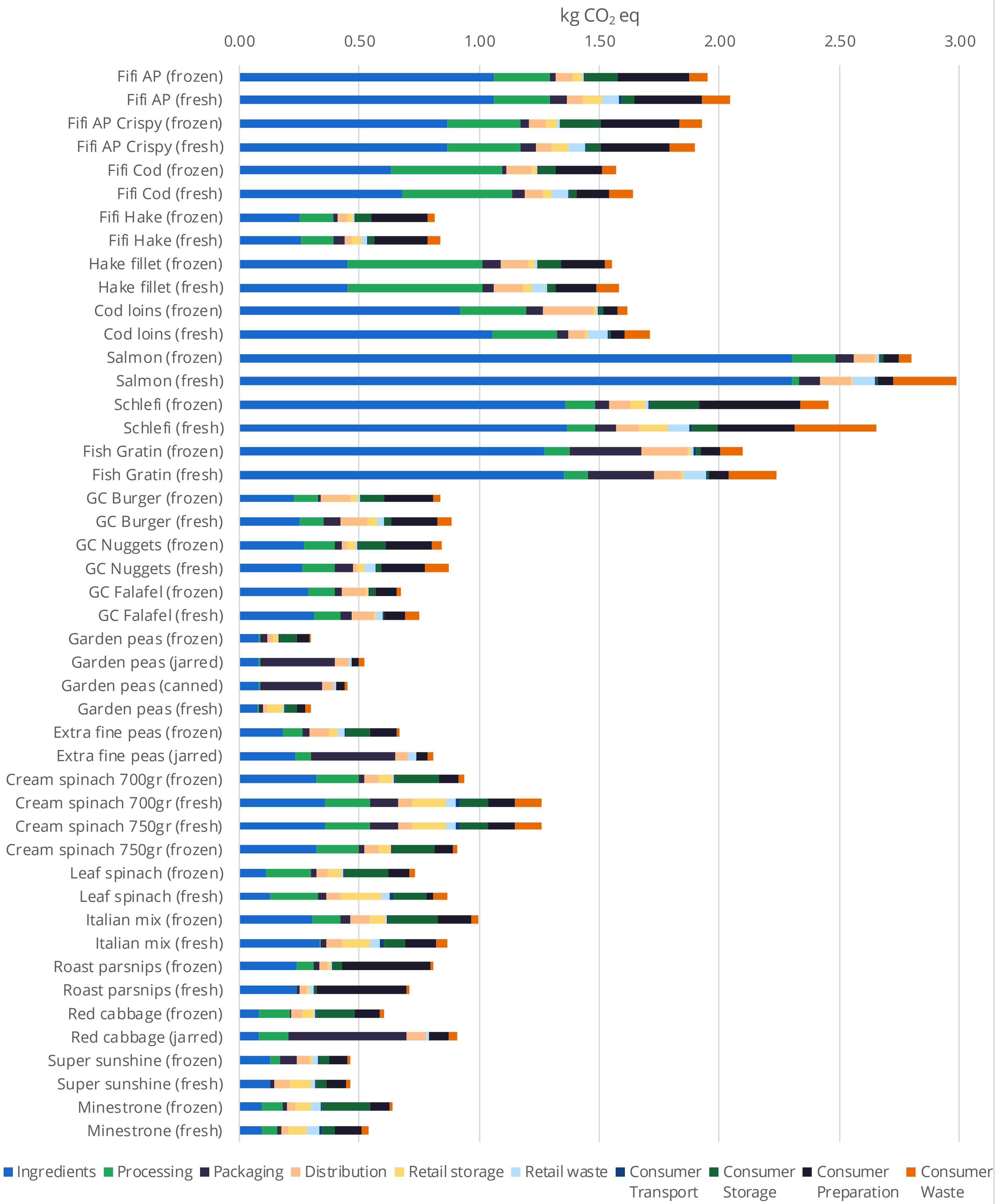


Figure 6 - Carbon footprint per life cycle stage for three portions of the product

Table 15 - Carbon footprint per life cycle stage for three portions of the product in kg CO_2eq.

	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer Transport	Consumer Storage	Consumer Preparation	Consumer Waste	Total
Fifi AP (frozen)	1.06	0.24	0.02	0.07	0.04	7.31E-03	4.23E-03	0.14	0.30	0.07	1.95
Fifi AP (fresh)	1.06	0.23	0.07	0.06	0.08	0.08	6.66E-03	0.06	0.28	0.11	2.05
Fifi AP Crispy (frozen)	0.87	0.31	0.03	0.07	0.05	7.15E-03	5.19E-03	0.17	0.33	0.09	1.93
Fifi AP Crispy (fresh)	0.87	0.30	0.07	0.06	0.07	0.07	6.66E-03	0.06	0.29	0.10	1.90
Fifi Cod (frozen)	0.63	0.46	0.02	0.10	0.02	4.85E-03	3.38E-03	0.07	0.19	0.06	1.57
Fifi Cod (fresh)	0.68	0.46	0.06	0.07	0.04	0.07	5.33E-03	0.03	0.14	0.10	1.64
Fifi Hake (frozen)	0.25	0.14	0.02	0.04	0.02	3.29E-03	2.82E-03	0.07	0.23	0.03	0.82
Fifi Hake (fresh)	0.26	0.13	0.05	0.03	0.04	0.03	4.32E-03	0.03	0.22	0.05	0.84
Cape Hake fillet (frozen)	0.45	0.56	0.08	0.11	0.02	0.01	3.08E-03	0.10	0.18	0.03	1.55
Cape Hake fillet (fresh)	0.45	0.56	0.05	0.13	0.03	0.06	3.87E-03	0.03	0.17	0.09	1.58
Atl. Cod loins (frozen)	0.92	0.28	0.07	0.21	9.00E-03	6.18E-03	6.45E-03	0.02	0.06	0.04	1.62
Atl. Cod loins (fresh)	1.06	0.27	0.05	0.07	0.01	0.08	6.62E-03	4.41E-03	0.06	0.11	1.71
Atl. Salmon (frozen)	2.30	0.18	0.08	0.09	6.02E-03	0.01	4.35E-03	0.01	0.07	0.05	2.80
Atl. Salmon (fresh)	2.30	0.03	0.09	0.13	8.04E-03	0.09	5.95E-03	3.68E-03	0.07	0.26	2.99
AP Schlefi (frozen)	1.36	0.12	0.06	0.09	0.06	0.01	6.40E-03	0.21	0.42	0.12	2.46

	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer Transport	Consumer Storage	Consumer Preparation	Consumer Waste	Total
AP Schlefi (fresh)	1.36	0.12	0.09	0.09	0.13	0.09	0.01	0.10	0.32	0.34	2.65
Atl. Cod Fish Gratin (frozen)	1.27	0.10	0.30	0.19	0.01	0.02	0.01	0.01	0.08	0.09	2.10
Atl. Cod Fish Gratin (fresh)	1.35	0.10	0.27	0.11	0.01	0.09	0.01	3.63E-03	0.08	0.20	2.24
GC Meatless Burger (frozen)	0.23	0.10	0.01	0.12	0.03	6.86E-03	4.66E-03	0.09	0.21	0.03	0.84
Meatless Burger (fresh)	0.25	0.10	0.07	0.11	0.04	0.03	5.32E-03	0.03	0.19	0.06	0.89
GC Chicken less Nuggets (frozen)	0.27	0.13	0.03	0.02	0.04	4.82E-03	5.37E-03	0.11	0.20	0.04	0.84
Chicken less Nuggets (fresh)	0.27	0.13	0.08	0.02	0.03	0.04	4.38E-03	0.02	0.18	0.10	0.87
GC Falafel (frozen)	0.29	0.11	0.03	0.10	6.25E-03	3.99E-03	4.48E-03	0.02	0.09	0.02	0.67
Falafel (fresh)	0.31	0.11	0.05	0.09	6.63E-03	0.03	4.34E-03	2.88E-03	0.09	0.06	0.75
Garden peas (frozen)	0.08	0.01	0.03	0.02	0.02	4.74E-03	3.55E-03	0.07	0.05	2.73E-03	0.29
Garden peas (jarred)	0.08	9.78E-03	0.31	0.06	X	6.50E-03	8.09E-04	X	0.03	0.02	0.52
Garden peas (canned)	0.08	9.78E-03	0.26	0.05	X	0.01	7.00E-04	X	0.03	0.01	0.45
Garden peas (fresh)	0.07	9.67E-03	0.01	0.02	0.06	9.19E-03	8.34E-03	0.04	0.04	0.02	0.30
Extra fine peas (frozen)	0.18	0.08	0.03	0.08	0.03	0.03	4.01E-03	0.10	0.11	0.01	0.67
Extra fine peas (jarred)	0.23	0.07	0.35	0.06	X	0.04	7.91E-04	X	0.04	0.03	0.81
Cream spinach 700gr (frozen)	0.32	0.18	0.02	0.06	0.06	5.33E-03	5.71E-03	0.18	0.08	0.02	0.93

	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer Transport	Consumer Storage	Consumer Preparation	Consumer Waste	Total
Cream spinach 700gr (fresh)	0.36	0.18	0.12	0.05	0.14	0.04	0.02	0.12	0.11	0.11	1.26
Cream spinach 750gr (frozen)	0.32	0.18	0.02	0.06	0.05	5.08E-03	5.33E-03	0.17	0.08	0.02	0.91
Cream spinach 750gr (fresh)	0.36	0.18	0.12	0.05	0.14	0.04	0.02	0.12	0.11	0.11	1.26
Leaf spinach (frozen)	0.11	0.19	0.02	0.05	0.06	4.42E-03	5.73E-03	0.18	0.09	0.02	0.73
Leaf spinach (fresh)	0.13	0.20	0.04	0.06	0.18	0.03	0.02	0.13	0.03	0.05	0.86
Italian Veg mix (frozen)	0.30	0.12	0.04	0.08	0.06	6.76E-03	6.37E-03	0.20	0.14	0.03	0.99
Italian Veg mix (fresh)	0.33	5.91E-03	0.03	0.06	0.12	0.04	0.01	0.09	0.13	0.05	0.87
Roast parsnips (frozen)	0.24	0.07	0.02	0.04	0.01	9.29E-03	1.90E-03	0.04	0.37	0.01	0.81
Roast parsnips (fresh)	0.24	1.21E-03	6.47E-03	0.03	0.01	0.01	2.06E-03	0.01	0.38	0.01	0.71
Red cabbage (frozen)	0.08	0.13	3.81E-03	0.05	0.05	7.09E-03	4.85E-03	0.16	0.11	0.02	0.60
Red cabbage (jarred)	0.08	0.12	0.49	0.08	X	0.01	1.10E-03	X	0.08	0.04	0.91
Super sunshine (frozen)	0.13	0.04	0.07	0.05	0.01	0.02	2.14E-03	0.04	0.07	0.02	0.46
Super sunshine (fresh)	0.13	1.50E-04	0.02	0.06	0.09	0.02	3.40E-03	0.04	0.08	0.02	0.47
Minestrone (frozen)	0.09	0.09	0.02	0.03	0.06	0.04	7.82E-03	0.20	0.09	8.37E-03	0.64
Minestrone (fresh)	0.09	0.07	0.02	0.03	0.08	0.06	0.04	0.06	0.11	0.03	0.54

7.2.1 Ingredients

In most cases, ingredient production is the most contributing life cycle stage in terms of carbon footprint. This means cultivation of the vegetables, catching of the fish or, in the case of the Atlantic Salmon fillet, farming the fish. For the different types of products, there are different factors that influence the overall carbon footprint of this stage.

For wild fish, the main carbon footprint impact comes from the catching operations. Due to the catching locations of the fish species, this often involves sailing vast distances to get to the catching location and sailing additional distances across the fishing grounds. This results in the use of marine diesel. Some of the wild fish species included in this study (Alaska Pollock and North Pacific Hake) are caught with trawlers and swim in large schools. They are therefore relatively easy to catch compared to other fish species that require for example, bottom trawling and more travel to locate (i.e. Atlantic Cod and Cape Hake). Another important factor contributing to the carbon footprint of the catching operations is the refrigerant use to store the caught fish. Most fleets have upgraded or are in the process of upgrading to more modern refrigerants with a more limited impact. However, some fisheries still use refrigerants with a significant impact on climate change.

For the farmed fish in this study (Atlantic Salmon), the main contributor to the carbon footprint is the production of fish feed. This impact mainly stems from the soy included in the fish feed. The proportion of marine protein in the fish feed is much larger but has a lower carbon footprint.

For vegetables, the causes of the carbon footprint contribution within the cultivation varies. Common sources are fuel use during planting and harvesting, land-use change, herbicide and pesticide production and irrigation efforts.

7.2.2 Manufacturing

The relative contribution of manufacturing to the carbon footprint varies between the products. For the Green Cuisine products (vegetarian burger, falafel and chicken-less nuggets), it has a significant contribution to the overall carbon footprint, while for the pure vegetable products it does not. The fish products lie somewhere in the middle, with manufacturing being a bigger or smaller contributor to the overall carbon footprint depending on the case.

The carbon footprint of manufacturing is mainly determined by the energy use, in the form of electricity or heat. The various products are made in different factories, located in different countries, so the varying electricity mix also affects the overall contribution to the carbon footprint of manufacturing.

The contribution of manufacturing to the carbon footprint is very similar between the frozen products and their alternatives, with the alternative typically having a slightly lower impact. This is a direct consequence of the decision that was made at the start of this project to assume similar manufacturing efficiencies for both the frozen products and their alternatives. The reason for this decision was to strip out as many other influencing factors as possible, so that the main differences between the frozen product and its alternative would be directly related to it being frozen or not. In addition, no detailed data on differences between frozen and non-frozen production was available.

This was modelled in the study by using the same manufacturing data for both the frozen product and its alternative, with reductions made to accommodate the lower energy use needed to chill products instead of freezing them. Since this is only a small fraction of the overall manufacturing, the resulting difference to the carbon footprint is fairly small. The exception to this is the Atlantic Salmon, where primary data suggested that the fresh alternative has a much lower manufacturing impact.

In reality, it is quite possible that the factories operated by Nomad Foods are more efficient than others. They produce very large amounts of product and do so in centralized factories, which are highly optimized towards the types of tasks they focus on. These factories have been in operation for decades and have been optimized over those years to be as efficient as possible. Smaller scale or less optimized production is likely to have a higher carbon footprint per product. It is also possible that highly efficient production is an inherent benefit to frozen food production and that producers relying on fresh supply need to be more flexible and can therefore operate less optimized. These effects are not included in these results.

7.2.3 Packaging

Packaging has a fairly low contribution to the carbon footprint of most of the products under study. The exception is those cases where jars or cans are used, which require more energy intensive production processes. For the other products, the main difference in packaging impact between the frozen and alternative product usually stems from the use of plastics (PET) trays in the packaging for the non-frozen product. This has a higher impact in terms of carbon footprint than the cardboard and thin plastic film that is used for many of the frozen products. Which could be considered a potential benefit of frozen foods.

Another contributing factor to differences in the carbon footprint is in the amount of packaging material in relation to the amount of food it contains. For the alternative products, a packaging size was selected that is as close to three portions as possible. The frozen products however are often sold in larger pack sizes since the remainder can easily be kept for another time. As a result, the ratio of packaging material to content is more favourable for the frozen products. This can also be considered an inherent benefit of frozen foods.

7.2.4 Distribution

For the products under study, distribution typically does not have a large impact to the overall carbon footprint. The differences between the frozen and alternative products here stem mainly from the need for temperature control during transport. Depending on the product, frozen, chilled or ambient trucks are used.

The ratio of packaging material to food content is also relevant here, since the packaging weight per three portions to be transported is also affected.

Please note that there are assumed to be no product losses in the distribution stage. While there are likely to be some losses that occur, for example due to damaged boxes or temperature control failing, the amounts of these losses are expected to be low and should therefore not influence the results in a significant way. It is also expected that these losses would be similar for both the frozen and alternative products, if not perhaps higher for the alternative products due to their higher sensitivity to temperature changes. Assuming them to be equal for both frozen and alternative products can therefore be considered a conservative approach.

7.2.5 Refrigeration in retail and at consumer

Storage at retail and the consumer is a significant contributor to the carbon footprint of most products under study, the obvious exception being those that are stored at ambient temperature (namely jarred and canned products). This contribution stems from both the electricity use and refrigerant leaks. For the frozen products, the storage carbon footprint tends to be higher at the consumer stage, where a storage time of 30 days is assumed compared to 9 days in retail. For the chilled products, the storage carbon footprint tends to be higher at retail, where a storage time of 6 days is modelled compared to 4 days at the consumer.

An important differentiation in terms of retail storage for frozen products and their alternatives is that frozen retail storage is assumed to be 95% in closed display cabinets and 5% in open display cabinets, while chilled storage is 50% in closed display cabinets and 50% in open display cabinets. Open cabinets use more energy than closed ones and this difference in fraction of open and closed cabinets therefore affects the contribution of retail storage. It is worth noting however, that the difference in energy use is not as extreme as one might expect (a factor 1.3 was used for closed vs. open) due to the need for anti-condensation heaters on the doors.

Another distinguishing factor with regards to the storage to the carbon footprint of frozen products and alternatives is the volume factor applied. Since frozen products are typically stored more efficiently in both retail and consumer than chilled products, the space occupied is modelled as two times the packaging volume. For chilled products, this space occupied is modelled as three times the packaging volume.

Finally, a very important influencing factor on the carbon footprint of retail and consumer storage is the electricity mix that is used. A large variation can be seen in the contribution of this stage based on which country is used as the consumption location. For example, the products sold in Norway have a significantly lower carbon footprint contribution from retail and consumer storage due to the high share of renewable energy sources in their national grid mix. If the electricity mix in the country of consumption has relatively high emissions, the impact of the retail and consumer storage is amplified.

7.2.6 Food loss and waste

In the screening study leading up to this study, it became clear that the food loss and waste percentages at retail and the consumer have a significant effect on the overall result. While the retail food loss and waste data is largely based on primary data from retailers, there is still a fair amount of uncertainty associated with these numbers, for example due to data gaps, and high variability between sources. The consumer food loss and waste data is only based on secondary data sources and has a significant uncertainty associated with it. The sensitivity of the results to other food loss and waste numbers is tested in the sensitivity analysis (Chapter *8*).

7.2.7 Preparation

For most products in this study, the preparation has a significant contribution to the overall carbon footprint. In most cases it is still a fairly low share though. The main products where consumer preparation has a larger contribution to the overall carbon footprint is when the product is prepared in the oven. This is mainly due to the preheating of the oven. The assumption of preparing three portions is relevant here, since preparing only one portion at a time, and therefore preheating the oven for each single portion, would significantly affect the results.

The preparation methods are mostly the same for the frozen products and their alternatives and are therefore not expected to significantly influence the comparison between these products in terms of carbon footprint. However, if a consumer were to decide on a different preparation method based on whether the product is frozen or not, this could affect the comparison between the carbon footprint of the frozen product and its alternative.

Just like for storage, the electricity mix of the consumer is relevant here as well. For the purposes of this study, oven preparation was assumed to be electric and stove-top preparation was split between gas and electricity. If the consumer lives in a country with an electricity mix with relatively low emissions, a reduction in the total carbon footprint is expected to be seen.

7.3 Identification of significant substance contributions

7.3.1 Carbon footprint

As a case study, substance contributions to the carbon footprint of two frozen products were calculated, one vegetable product (leaf spinach) and one fish product (Alaska Pollock fish fingers). The results are shown in percentages in Table 16 and Table 17. The percentage listed under 'Total' indicates the contribution of the individual substances to the overall carbon footprint and add up to 100 vertically. The percentages listed under the life cycle stages are relative to the total of that particular substance and therefore add up to 100 horizontally.

For both products, fossil carbon dioxide is the main contributor to all life cycle stages. For leaf spinach, dinitrogen monoxide is an important contributor to the ingredients stage. This flow is a common output of agricultural processes. For the Alaska Pollock fish fingers, there are more contributions in the main flows coming from CFCs related to cooling and refrigeration. Both leaf spinach and the Alaska Pollock fish fingers have a flow of HFC-134a occurring in the retail storage phase, but for the fish fingers there are also significant flows of HCFC-22 and CC-12. These refrigerants are used on board the fishing vessels and leakage occurs over time. The contribution of methane emissions at end of life is not significant in these two cases, since there is no landfilling occurring for the biowaste occurring at retail, and the percentage of landfilling of consumer waste is limited in the countries under study. In countries of consumption where there is more landfilling, this contribution is expected to be higher.

Table 16 – Substance contribution for global warming potential of frozen leaf spinach

Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Carbon dioxide, fossil	Air	%	80.7	15.7	17.6	3.2	5.2	8.3	3.3	0.9	28.7	13.5	3.7
Dinitrogen monoxide	Air	%	10.1	89.5	1.3	0.5	0.4	0.9	0.6	0.1	3.2	1.5	2.0
Methane, fossil	Air	%	5.1	10.0	38.6	5.0	3.3	6.2	1.3	0.6	21.6	12.4	1.0
Carbon dioxide	Air	%	1.5	98.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.4
Methane, biogenic	Air	%	1.0	1.0	30.3	0.8	3.7	9.4	1.0	0.1	32.5	18.8	2.6
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	%	0.5	0.0	0.0	0.0	0.6	98.9	0.5	0.0	0.0	0.0	0.0
Methane	Air	%	0.3	98.0	0.0	0.0	0.0	0.0	0.4	0.3	0.0	0.0	1.4

Carbon dioxide, land transformation	Air	%	0.3	3.6	0.8	71.9	0.7	3.5	0.6	0.1	12.2	5.5	1.1
Sulphur hexafluoride	Air	%	0.3	3.2	1.6	2.5	1.7	15.2	0.4	0.3	52.7	22.2	0.2
Carbon monoxide, fossil	Air	%	0.2	46.8	9.3	2.7	5.3	4.3	3.1	0.9	15.0	11.2	1.3

Table 17 – Substance contribution for global warming potential of frozen Alaska Pollock fish fingers

Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Carbon dioxide, fossil	Air	%	72.1	46.9	12.9	1.2	2.9	2.6	1.4	0.3	8.9	19.1	3.8
Methane, chlorodifluoro-, HCFC-22	Air	%	13.6	92.3	3.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	4.3
Dinitrogen monoxide	Air	%	3.9	74.4	9.1	0.3	0.4	0.7	0.5	0.0	2.3	7.6	4.6
Methane, fossil	Air	%	3.2	24.9	28.0	3.6	2.1	2.8	0.9	0.3	9.6	25.1	2.8
Carbon dioxide	Air	%	2.3	83.0	8.4	0.0	0.0	0.0	0.4	0.0	0.0	4.1	4.1
Carbon dioxide, land transformation	Air	%	1.6	77.4	8.4	3.4	0.1	0.2	0.4	0.0	0.6	5.5	4.0
Methane, dichlorodifluoro-, CFC-12	Air	%	0.9	92.2	3.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	4.3
Methane, biogenic	Air	%	0.9	15.0	31.4	5.8	0.4	3.0	0.6	0.0	10.5	26.9	6.4
Ethane, pentafluoro-, HFC-125	Air	%	0.4	7.8	86.0	0.0	0.0	1.6	0.4	0.0	0.0	0.0	4.2
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	%	0.4	23.2	38.6	0.0	0.5	34.4	0.5	0.0	0.0	0.0	2.8
Methane	Air	%	0.3	82.7	8.5	0.0	0.0	0.0	0.4	0.1	0.0	4.2	4.1
Carbon monoxide, fossil	Air	%	0.2	60.6	10.7	0.6	2.8	1.2	1.4	0.3	4.3	14.5	3.6
Sulphur hexafluoride	Air	%	0.1	7.4	1.4	2.2	1.2	7.8	0.3	0.1	27.0	52.0	0.6

7.3.2 Other impact categories

For the substance contribution on all impact categories, the frozen garden peas are used as a case study. Table 18 shows the substance contribution per impact category in percentages, with the cut-off set at 1%. This means that only substances contributing 1% or more to that impact category are shown. The exception to this is water use, where the list is very long, so only the 10 most contributing water flows are shown. In the table, the percentage listed under 'Total' indicates the contribution of the individual substances to the overall impact on that impact category and add up to 100 vertically. The percentages listed under the life cycle stages are relative to the total of that particular substance and therefore add up to 100 horizontally.

Table 18 - Substance contribution for all impact categories of frozen garden peas

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Climate change	Carbon dioxide, fossil	Air	%	77.5	17.7	3.8	9.3	5.3	8.6	3.8	1.5	29.7	19.5	0.8
	Carbon dioxide	Air	%	11.5	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Methane, fossil	Air	%	5.1	18.9	3.1	22.1	3.0	6.2	1.7	0.9	21.5	21.5	1.0
	Methane, biogenic	Air	%	2.2	5.1	0.2	28.2	0.1	0.2	57.6	0.0	0.8	4.3	3.5
	Dinitrogen monoxide	Air	%	1.3	37.2	4.9	6.9	2.5	6.4	3.6	0.8	22.3	12.9	2.6
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Ozone depletion	Methane, bromo-, Halon 1001	Air	%	33.3	0.0	0.0	97.2	0.0	0.0	0.5	0.1	0.2	0.1	2.0
	Methane, bromotrifluoro-, Halon 1301	Air	%	26.7	23.8	2.0	8.6	22.7	1.8	18.1	5.9	6.2	9.1	1.7
	Methane, bromochlorodifluoro-, Halon 1211	Air	%	25.2	17.9	3.0	4.8	1.4	11.0	0.3	0.1	38.1	22.9	0.6
	Methane, trichlorofluoro-, CFC-11	Air	%	5.7	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	%	3.1	3.1	0.1	0.2	0.7	84.9	0.4	0.1	6.9	3.4	0.1
	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	%	3.0	92.2	2.7	0.0	0.0	0.0	0.5	0.0	0.0	2.8	1.9
	Methane, dichlorodifluoro-, CFC-12	Air	%	1.4	63.4	1.9	0.9	0.2	24.4	0.5	0.1	4.8	2.5	1.3

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Ionising radiation	Carbon-14	Air	%	49.7	18.6	0.9	1.0	1.9	12.3	0.9	0.3	42.7	21.0	0.5
	Radon-222	Air	%	48.3	14.7	0.7	1.5	1.1	13.2	0.2	0.1	45.6	22.6	0.4
	Cesium-137	Water	%	1.2	77.9	2.3	0.1	0.2	2.8	0.4	0.0	9.8	4.8	1.6
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Photochemical ozone formation	Nitrogen oxides	Air	%	70.5	19.2	1.6	10.1	11.7	6.8	9.4	1.6	23.6	14.8	1.2
	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	%	11.7	19.6	1.7	25.1	12.1	3.2	9.7	3.5	10.9	12.5	1.6
	Nitrogen dioxide	Air	%	7.6	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Sulphur dioxide	Air	%	5.2	38.7	1.7	8.8	3.5	6.2	2.7	1.3	21.4	14.6	1.1
	Carbon monoxide, fossil	Air	%	1.3	17.4	1.7	13.8	10.0	4.4	8.1	3.0	15.1	25.4	1.2
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Particulate matter	Particulates, < 2.5 um	Air	%	68.2	30.8	1.5	13.3	13.3	3.4	11.2	1.8	11.7	11.3	1.6
	Sulphur dioxide	Air	%	20.8	60.3	2.2	9.4	2.9	2.5	2.6	1.1	8.6	8.7	1.6
	Nitrogen oxides	Air	%	5.3	20.9	1.9	12.0	16.2	4.6	13.4	2.1	16.0	11.4	1.6
	Ammonia	Air	%	4.3	37.7	1.6	12.2	1.1	5.7	2.0	0.5	19.6	14.1	5.5
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Human toxicity, non-cancer	Arsenic	Water	%	24.2	14.8	2.9	7.8	1.9	10.6	2.5	1.2	36.9	20.2	1.1
	Mercury	Air	%	17.5	26.8	4.8	8.1	3.3	6.0	3.6	0.9	20.6	24.8	1.1
	Carbon monoxide, fossil	Air	%	7.0	17.4	1.6	13.8	10.0	4.4	8.1	3.0	15.1	25.5	1.2
	Lead	Air	%	6.5	18.6	1.1	6.4	13.9	4.7	11.1	2.5	16.2	24.3	1.0
	Lambda-cyhalothrin	Air	%	6.5	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Chloride	Water	%	6.0	80.1	3.7	2.2	2.4	0.7	3.1	0.7	2.3	2.8	2.0
	Lead	Soil	%	3.8	56.6	4.7	6.3	5.1	3.3	4.2	0.4	11.4	6.3	1.6
	Mercury	Soil	%	3.1	81.9	7.8	2.8	0.1	0.6	0.6	0.1	2.0	2.3	1.9
	Pendimethalin	Soil	%	3.0	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Zinc	Soil	%	2.4	39.7	3.0	2.8	12.0	4.9	9.6	0.9	16.8	8.9	1.4

	Carbon monoxide, biogenic	Air	%	1.6	14.1	1.3	4.9	1.2	11.8	3.1	0.1	40.9	21.6	1.0
	Cadmium	Soil	%	1.5	31.9	1.7	10.8	2.3	8.0	1.6	0.4	27.9	14.4	1.0
	Carbon disulphide	Air	%	1.5	11.9	1.2	5.9	1.3	11.3	0.9	1.2	39.2	26.6	0.4
	Acrolein	Air	%	1.4	20.3	0.7	3.9	30.5	0.3	24.5	15.7	1.0	1.4	1.7
	MCPB	Soil	%	1.3	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Arsenic	Air	%	1.1	21.9	1.6	6.7	3.1	6.0	2.7	1.1	20.9	35.0	0.9

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Human toxicity, cancer	Chromium	Air	%	25.7	6.8	0.9	4.4	0.4	1.6	0.3	0.5	5.4	79.4	0.3
	Chromium VI	Water	%	22.6	25.2	5.0	9.5	5.2	5.5	4.6	4.5	18.9	20.4	1.2
	Benzo(a)pyrene	Air	%	13.6	18.1	2.0	8.3	5.4	4.2	4.4	3.6	14.6	38.5	0.9
	Formaldehyde	Air	%	9.7	25.6	1.4	18.4	9.2	2.0	9.1	3.4	7.0	22.5	1.3
	Arsenic	Water	%	6.7	14.8	2.9	7.8	1.9	10.6	2.5	1.2	36.9	20.2	1.1
	Chromium VI	Soil	%	5.7	4.4	0.7	0.7	0.4	15.2	0.1	0.1	52.5	25.9	0.1
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	%	4.4	30.2	3.5	5.1	1.2	7.3	3.0	1.0	25.4	22.5	0.9
	Mercury	Air	%	3.0	26.8	4.8	8.1	3.3	6.0	3.6	0.9	20.6	24.8	1.1
	Chromium	Water	%	1.8	72.8	3.1	5.8	1.6	1.5	1.6	0.6	5.4	5.8	1.9
	Chromium	Soil	%	1.4	24.7	2.2	22.1	2.2	5.4	2.1	0.6	18.7	21.0	0.8

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Acidification	Sulphur dioxide	Air	%	55.3	38.7	1.7	8.8	3.5	6.2	2.7	1.3	21.4	14.6	1.1
	Nitrogen oxides	Air	%	34.5	19.2	1.6	10.1	11.7	6.8	9.4	1.6	23.6	14.8	1.2
	Ammonia	Air	%	6.3	39.3	1.7	9.8	1.0	5.8	2.1	0.4	20.1	13.5	6.2
	Nitrogen dioxide	Air	%	3.7	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Eutrophication, freshwater	Phosphate	Water	%	98.5	19.1	1.9	13.4	2.1	8.6	1.5	1.0	29.7	21.7	0.9
	Phosphorus	Water	%	1.3	71.0	2.1	21.7	0.2	0.1	0.7	0.2	0.5	1.5	1.9

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Eutrophication, marine	Nitrogen oxides	Air	%	65.2	19.2	1.6	10.1	11.7	6.8	9.4	1.6	23.6	14.8	1.2
	Nitrate	Water	%	18.0	55.5	4.8	14.5	0.5	2.8	3.9	0.2	9.7	6.4	1.7

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
	Ammonium, ion	Water	%	8.8	62.1	6.0	19.0	0.2	0.2	8.1	0.2	0.8	1.7	1.8
	Nitrogen dioxide	Air	%	7.0	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Eutrophication, terrestrial	Nitrogen oxides	Air	%	79.9	19.2	1.6	10.1	11.7	6.8	9.4	1.6	23.6	14.8	1.2
	Ammonia	Air	%	11.4	39.3	1.7	9.8	1.0	5.8	2.1	0.4	20.1	13.5	6.2
	Nitrogen dioxide	Air	%	8.6	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Ecotoxicity, freshwater	Lambda-cyhalothrin	Water	%	88.4	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Pendimethalin	Water	%	6.0	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Sulphur	Soil	%	2.2	94.6	2.8	0.0	0.0	0.0	0.5	0.0	0.1	0.0	2.0
	Sulphur	Water	%	1.3	94.5	2.7	0.2	0.1	0.0	0.5	0.0	0.0	0.0	2.0
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Land use	Occupation, agriculture	Raw	%	89.9	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Occupation, forest, intensive	Raw	%	5.5	10.9	0.5	25.0	0.9	9.8	0.3	0.1	34.0	17.7	0.8
	Occupation, traffic area, road network	Raw	%	1.3	23.9	1.1	8.2	30.7	0.7	25.0	3.5	2.4	2.6	1.8
	Transformation, to annual crop, non-irrigated	Raw	%	1.1	0.2	0.0	96.4	0.1	0.1	0.6	0.0	0.4	0.2	1.9
	Transformation, from annual crop, non-irrigated	Raw	%	-1.1	-0.2	0.0	-96.4	-0.1	-0.1	-0.6	0.0	-0.4	-0.2	-1.9
Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Water use	Water, turbine use, unspecified natural origin, RoW	Raw	%	9117.0	9.4	0.9	9.3	1.5	4.6	1.4	1.2	15.8	55.5	0.5
	Water, turbine use, unspecified natural origin, GB	Raw	%	2114.0	14.0	0.7	0.1	1.0	13.6	0.1	0.0	47.2	22.9	0.3
	Water, turbine use, unspecified natural origin, FR	Raw	%	1022.8	15.5	0.9	5.6	1.5	11.9	0.7	0.2	41.1	21.9	0.7

	Water, turbine use, unspecified natural origin, CN-SC	Raw	%	693.5	16.8	1.2	41.4	6.6	3.6	5.7	4.4	12.3	6.4	1.5
	Water, turbine use, unspecified natural origin, ES	Raw	%	453.9	24.5	2.2	29.6	2.1	2.8	1.7	0.9	9.8	25.2	1.3
	Water, ES	Water	%	-459.9	-24.5	-2.2	-29.6	-2.1	-2.8	-1.7	-0.9	-9.8	-25.1	-1.3
	Water, CN-SC	Water	%	-693.7	-16.8	-1.2	-41.4	-6.6	-3.6	-5.7	-4.4	-12.3	-6.5	-1.5
	Water, FR	Water	%	-1037.8	-15.5	-0.9	-5.5	-1.5	-11.9	-0.7	-0.2	-41.2	-21.9	-0.7
	Water, GB	Water	%	-2241.0	-14.1	-0.7	-0.1	-1.0	-13.6	-0.1	0.0	-47.1	-22.9	-0.3
	Water, RoW	Water	%	-9179.4	-9.4	-0.9	-9.6	-1.6	-4.5	-1.4	-1.2	-15.7	-55.2	-0.5

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Resource use, fossils	Gas, natural/m3	Raw	%	36.4	17.7	3.2	8.0	1.6	10.2	0.5	0.2	35.4	22.6	0.6
	Uranium	Raw	%	29.5	14.4	0.7	2.0	1.1	13.1	0.2	0.1	45.5	22.6	0.4
	Oil, crude	Raw	%	12.9	16.7	0.8	33.6	17.7	1.3	14.5	4.8	4.5	4.3	1.8
	Coal, hard	Raw	%	9.9	15.5	0.9	9.3	2.3	10.5	1.4	0.9	36.2	22.3	0.6
	Energy, from gas, natural	Raw	%	3.2	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Energy, from uranium	Raw	%	2.9	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Energy, from oil	Raw	%	2.3	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0
	Energy, from coal	Raw	%	1.2	94.8	2.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.0

Impact category	Substance	Compartment	Unit	Total	Ingredients	Manufacturing	Packaging	Distribution	Retail storage	Retail waste	Consumer transport	Consumer storage	Consumer preparation	Consumer waste
Resource use, minerals and metals	Tellurium	Raw	%	69.0	12.8	1.3	6.4	1.3	12.2	1.0	1.2	42.3	21.0	0.5
	Gold	Raw	%	7.2	22.2	1.2	14.6	4.2	6.6	3.5	12.3	22.8	11.7	0.9
	Copper	Raw	%	7.1	13.5	1.3	6.8	1.4	12.0	1.1	1.4	41.5	20.6	0.5
	Silver	Raw	%	4.5	15.4	1.1	6.8	5.1	9.7	4.1	6.8	33.6	16.5	0.7
	Chromium	Raw	%	3.3	6.2	0.8	3.2	0.2	1.3	0.2	0.5	4.4	82.9	0.2
	Molybdenum	Raw	%	2.2	12.0	1.2	5.9	1.3	11.4	0.9	1.2	39.4	26.3	0.5
	Lead	Raw	%	2.0	23.8	1.6	8.8	7.1	6.4	5.7	7.0	22.1	16.4	1.0
	Selenium	Raw	%	1.8	12.8	1.3	6.3	1.3	12.2	1.0	1.2	42.3	21.0	0.5

7.4 Completeness and consistency

7.4.1 Completeness check

All life cycle stages and processes included in the scope are covered for all products in this study. However, during the execution of the study, several data gaps were encountered. These were mainly handled with additional research and/or more primary data collection. The main occurrences of data gaps were as follows:

- **Food loss and waste data**. It became clear fairly early on that there was limited data available on food loss and waste data at both retail and consumer level. The importance of this data for the reliability of the study was also clear, so extensive further research was done to collect additional data. Multiple additional rounds of literature research were done, starting with articles in scientific journals but branching further out to for example governmental institutions, NGOs and universities. In addition, several experts from research institutes and universities were contacted to inquire if more data was available, either publicly available or proprietary. In the meantime, Nomad Foods reached out to their retail customers across Europe with the request for primary data on retail food loss and waste. This was a long-term activity, involving many direct conversations with retailers to explain the type of data needed and the used definitions of food loss and waste. At the point of writing this report, four retailers had provided primary food loss and waste data, which made a very big difference in the reliability of the study. In the end, there was no one best source for either retail or consumer food loss and waste, and numbers vary significantly across sources. As a result, averages from all available data sources were used to represent the best currently available data and the addition of primary data improves the data quality significantly.
- **Spinach cultivation differences**. While most ingredients are the same for the frozen and non-frozen products, this is not the case for spinach. Frozen spinach is manufactured and can therefore have a very large leaf size, while fresh spinach has a smaller leaf size. Spinach intended to be sold frozen is therefore grown for longer periods than spinach to be sold fresh. Nomad Foods had provided primary data for cultivation of their spinach, but no data on the cultivation of fresh spinach was available. Since this is an inherent difference between the frozen and non-frozen product, additional research was done to determine the differences in cultivation. Several literature sources were found that describe the difference and these were used to model an adjusted version of the Nomad Foods spinach data.
- **Manufacturing**. Primary data for manufacturing of the Nomad Foods' products was provided for this study. However, since Nomad Foods only produces frozen products, primary manufacturing data of the non-frozen alternatives was not available. Since the intention of the study was to strip out any differences not directly related to the preservation method used, basically comparing to a situation where the non-frozen product was made in the same factory and with the same efficiencies, the primary factory data of the frozen products needed to be adjusted to be representative for the non-frozen products. Several approaches for this were discussed, including extrapolation of average manufacturing data from other sources, but finally the approach taken involved an adjustment to the energy required for manufacturing based on the temperature difference between the product after manufacturing and the final temperature of the

product when leaving the factory. For example, garden peas are chilled during delivery to the factory and thus begin processing at a temperature of 3°C. For frozen peas, the temperature is then reduced to -20°C, while the non-frozen alternative the temperature remains at 3°C. This results in a different amount of electricity used for this final step.

- **Preparation.** Similar to the factory manufacturing, primary data on the preparation methods and cooking times for the Nomad Foods' products was available, but not for the alternative products. Several approaches were considered, including using published recipes for comparable products. However, the approaches were difficult to standardize across all 22 products included in the study. In the end, an approach in line with that of the adjustment of factory manufacturing was used, where the same data as for the frozen products was used but with a change in cooking time based on the starting temperature of the product. This can be applied consistently across all products and is based on physical attributes of the products, therefore reducing variability.

7.4.2 Consistency check

The following subjects are important to check in order to determine whether the assumptions, methods and data are aligned with the goal and scope:

- **The data quality along the life cycle.** There is a variation in data quality in different stages of the life cycle. The full production stage and, for several products, the agricultural stage are modelled with high quality primary data. For the remainder of the products, the agricultural stage is modelled with secondary data. The retail and consumer stages however have a lower data quality.
  Despite these variations, the data quality is consistent across the frozen product and its alternative, and a reasonable data quality is achieved as discussed using the Pedigree matrix in chapter *9* on uncertainty assessment.
- **Background data sources.** Background data from several different databases was used in this study. While the main qualifiers of these databases (i.e. handling multi-functionality and end of life allocation) are consistent, there are still likely to be small differences in how these various databases handle their data collection process.
- **Food loss and waste data sources.** Data from multiple sources was combined to determine the food loss and waste percentages used in this study for retail and consumer. While special attention was paid to ensuring the definitions of food loss and waste were in line with each other, each of these data sources collected their data in a different way and presented it in various levels of detail.
- **Spinach data sources.** To model the differences in spinach cultivation between the different leaf sizes, two data sources were used. The methodologies seem to be in line, but the full background information on how some numbers were obtained is not given. There is some unclarity about a possible discrepancy between the yield and N removed numbers in these papers, but without additional background information it is unclear if this discrepancy is due to the use of different data sources or an inherent difference in the cultivation process. This could affect the nitrogen balance and with that direct emissions of nitrogen from the cultivation and thereby have an effect on the carbon footprint.
- **Regional and temporal differences.** All primary data uses 2019 as the reference year and covers the entire year. Primary data is collected from the areas that are under study. For some background data, proxies had to be used since exact regions were not available.

Since comparable regions were available (for example Belgium instead of the Netherlands), the effect of this is expected to be minor.

- **Allocation and system boundary.** Allocation rules for multi-functionality, specifically for factory wide data, have been selected based on the most appropriate approach for the situation and are clearly documented in the report. Some small differences in system boundaries occur, but this pertains mainly to infrastructure contributions, which are expected to be minor.
- **Impact assessment.** The impact assessment steps of classification and characterization have been applied consistently across all products and flows. However, as in any life cycle assessment study, there are flows included in the inventory that are not covered by the impact assessment method used. Specifically for the water use and land use impact categories, the lack of regionalized data means the results are very uncertain.

8 Sensitivity analysis

To determine the importance of and sensitivity of the various modelling approaches that were used and assumptions that were made, a series of sensitivity analyses was performed. The topics were selected based on the main contributors to the overall impact and the reliability of the data sources. Depending on the topic of the sensitivity analysis and its applicability to the products under study, it is either done on one product or a selection of several products with at least one from each of the product groups.

The sensitivity analyses performed are:

- Food loss and waste percentages at retail and consumer
- Days in consumer storage
- Electricity mix at retail and consumer
- Preparation in general
- Preparation method
- Oven roasting of parsnips
- Defrosting fish
- Packaging size

In this third-party report, two topics are reported in detail: the days in consumer storage, and the packaging size.

8.1 Food loss and waste at retail and consumer

Since food loss and waste at retail and consumer stages have a relative high uncertainty, this sensitivity looks at the influence of different food loss and waste numbers on the results.

Any variation in food loss and waste numbers in retail and at the consumer will affect the carbon footprint quite significantly, especially in case of products that have a relatively high carbon footprint associated with its ingredients and manufacturing, such as the fish and Green Cuisine products. While the numerical contribution varies from product to product, a variation in the food loss and waste numbers can often sway the comparison one way or another in terms of carbon footprint.

To acknowledge the importance of these numbers and their relative uncertainty, and how they can influence the results a tipping point is calculated as well (Table 19). This tipping point calculation keeps the food loss and waste at retail and consumer fixed for the frozen product and varies the food loss and waste at retail and consumer for the alternative product independently. The tipping point occurs where the carbon footprint of the two products is equal, thereby representing the value of food loss and waste at which the frozen and non-frozen product are equal in carbon footprint The tipping points indicate above which percentage of food loss and waste for the alternative, the frozen product has a lower carbon footprint. If the tipping points are lower than the food loss and waste rates currently assumed, the frozen product has a lower carbon footprint than the alternative. If the tipping point is negative, the frozen product will have a lower carbon footprint than its alternative even if the alternative has a 0% food loss and waste. For example, for Alaska Pollock fish fingers (Fifi AP) the tipping point at retail is 2.6% meaning that at a fresh food loss and waste percentage higher than this, the frozen product has a lower carbon footprint than its alternative. Since this 2.6% is lower than the currently assumed 4.8% frozen Alaska Pollock fish fingers have a lower carbon footprint than its alternative.

Table 19 – Tipping points for the food loss and waste percentages of the alternative

	Currently assumed at retail	Tipping point retail	Currently assumed at consumer	Tipping point consumer
Fifi AP	4.8	2.6	7.1	4.9
Fifi AP Crispy	4.8	5.4	7.1	7.8
Fifi Cod	5.4	3.2	7.1	5.0
Fifi Hake	4.8	3.0	7.1	5.9
Hake fillet	4.8	3.9	6.8	6.0
Cod loins	5.4	3.0	6.8	4.4
Salmon	4.0	1.1	6.8	4.1
Schlefi	4.3	0.9	7.1	4.8
Fish Gratin	5.0	3.0	7.1	3.5
GC Burger	3.9	1.3	8.5	5.9
GC Nuggets	2.7	1.2	8.5	8.4
GC Falafel	4.9	0.2	8.5	4.1
Garden peas jarred	0.4	-35.1	3.2	-29.4
Garden peas canned	0.4	-23.7	3.2	-12.7
Garden peas fresh	5.5	-0.7	16.5	6.8
Extra fine peas	0.4	-7.3	3.2	-4.3
Cream spinach 700gr	9.6	-7.9	16.5	2.0

Cream spinach 750gr	9.6	-9.4	16.5	0.6
Leaf spinach	9.6	1.9	16.5	9.2
Italian mix	8.1	14.9	11.3	18.0
Roast parsnips	9.1	21.7	17.2	29.8
Red cabbage	0.5	-14.6	3.6	-11.5
Super sunshine	4.9	4.7	11.3	11.1
Minestrone	7.8	16.9	11.3	19.8

8.2 Days in consumer storage

The current assumption is that the consumer keeps the frozen product in their freezer for 30 days based on PEF [1]. Seeing as consumer storage is a significant contributor to the potential environmental impact, a sensitivity analysis was done to determine the consequences of keeping the product in the freezer longer or shorter. In this analysis, varying storage times are used for the frozen product while the storage time of the alternative product is kept constant at 7 days.

Figure 7 shows the effect of changing the storage days on the carbon footprint

Figure 7 – Sensitivity analysis on influence of days of consumer storage on carbon footprint of 1 kg of product

The results of this analysis show that the comparison between the frozen product and its alternative is highly dependent on the number of days the frozen product is stored. How strong the effect of shorter or longer storage is depends on two main factors: the volume of the packaging and the electricity mix used by the consumer.

For the products assessed in this sensitivity analysis, tipping points were calculated. Assuming all other factors remain the same (for example food loss and electricity mix at consumer), a storage time for the frozen product below this tipping point results in a lower numerical carbon footprint for the frozen product than for the alternative. A storage time at the consumer above this number of days means the numerical carbon footprint of the frozen product is higher than the alternative. For roasted parsnips the tipping point is a negative number which means that the carbon footprint of the frozen product is higher for all storage times, partly because the storage of non-frozen parsnips is ambient and does not require energy.

The overview of these tipping points is shown in Table 20.

Table 20 - Tipping points consumer storage days

Product	Tipping point frozen storage days
Alaska Pollock fish fingers	45 days
Leaf spinach	46 days
Falafel	120 days
Roasted parsnips	-60 days
Super sunshine mix	44 days

8.3 Packaging size

For all the alternative products in this study, a packaging size was chosen that is as close as possible to three serving sizes. This is done because the shelf life of the product is limited for the non-frozen products, especially after the packaging has been opened. While the contribution of packaging to the overall carbon footprint is relevant for most products, it is mostly not a significant driver of the difference between the frozen and non-frozen product. The exception to these are the jarred and canned products, where the packaging material is the main driver of the difference. Therefore, a sensitivity analysis is done to determine what the comparison would look like when a larger packaging size is used for the non-frozen products. Since the jarred products showed the biggest contribution of packaging, these were used as a case study.

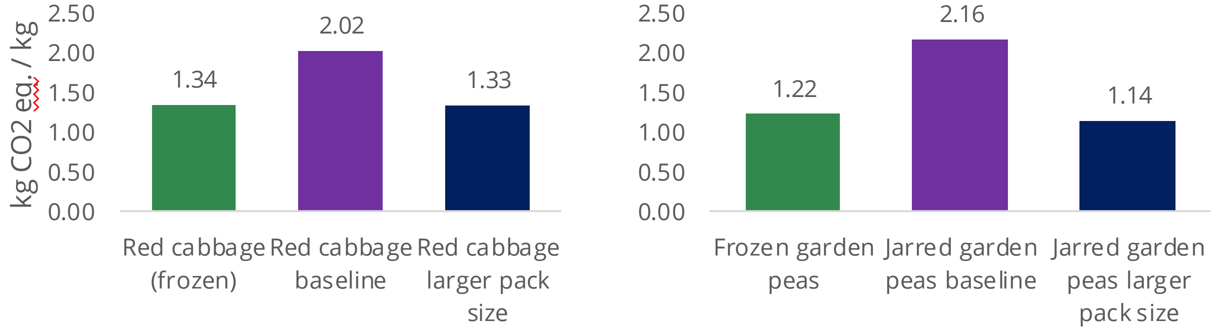


Figure 8 - Sensitivity analysis on effect of larger pack size on the carbon footprint of red cabbage and garden peas

The results (Figure 8) show that using a larger pack size significantly reduces the carbon footprint per 3 portions of the jarred products, with a reduction of 35% for the jarred red cabbage and a reduction of 46% for the jarred garden peas. This brings the total carbon footprint of these jarred products very close to that of the frozen products they are being compared to. The packaging size of the jarred and canned alternative products can therefore affect the conclusion of the comparisons: if a large jar or can is used and the full contents are consumed, for example by eating the same product two days in a row, there is no longer a significant difference in carbon footprint between the frozen and non-frozen product. But if the amount of food loss and waste at the consumer increases due to using a larger packaging size, this may no longer be the case.

8.4 Other sensitivity analysis

Changing the electricity mix at retail and with the consumer can influence the comparative conclusions drawn. For example, frozen falafel has a lower carbon footprint than the chilled falafel when using the Swedish grid mix, Norwegian grid mix, and 100% solar electricity. In contrast, the frozen falafel has a higher footprint when using the German, Italian and British grid mixes. Since frozen products use more electricity, a different electricity mix makes the frozen products more sensitive to changes in electricity mix than on its alternative. The benefits of using a cleaner electricity mix are more obvious when making the switch at the consumer's home than at retail.

To determine the sensitivity of the model to **preparation in general,** the amount of preparation included in the model has been changed. This has a higher impact on the carbon footprint of the frozen product than that of the alternative. For leaf spinach an increase in preparation of 50% increases the carbon footprint with 5.6% for frozen and 5.2% for fresh. For Alaska Pollock Fish fingers the results change with 7.6% for frozen and 6.8% for fresh. The carbon footprint of falafel increases with 5.7% for frozen and 5.2% for fresh.

Changing the **proportions of the different preparation methods** does not influence the conclusions of the comparison in carbon footprint for Alaska Pollock Fish Fingers. The frozen fish fingers have a lower carbon footprint than the chilled ones for all three analysed scenarios (50-50% frying-baking, 100% frying and 100% baking). The total carbon footprint of the product does increase when using only oven baking and decreases when using frying only. The oven baking of the product thus has a higher carbon footprint than the frying. This is mainly due to the pre-heating of the oven.

Increasing the oven time of the homemade roasted parsnips does not influence the conclusions of the comparison in carbon footprint to the frozen alternative. The homemade roasted parsnips have a lower carbon footprint than the frozen ones for all scenarios (from the default 27.5 minutes up to 45 minutes). The carbon footprint of the homemade product does increase when increasing the oven time. However, even when doubling the oven time, the carbon footprint of the homemade roasted parsnips does not reach the carbon footprint of the frozen parsnips.

If a consumer does not **defrost the salmon fillet**, but cooks it directly from the freezer, the carbon footprint increases with 0.05%. This small increase does not lead to a change in the results of the comparison. Even when cooking the fillet directly from frozen, the frozen salmon fillet has a lower carbon footprint than the fresh salmon fillet.

9 Uncertainty analysis

To assess the uncertainty associated with the results, a Monte Carlo simulation was performed. A lognormal scale was assigned to all relevant input values. The Pedigree matrix was used to determine the standard deviation associated with each data point by providing a score on each of the following five indicators:

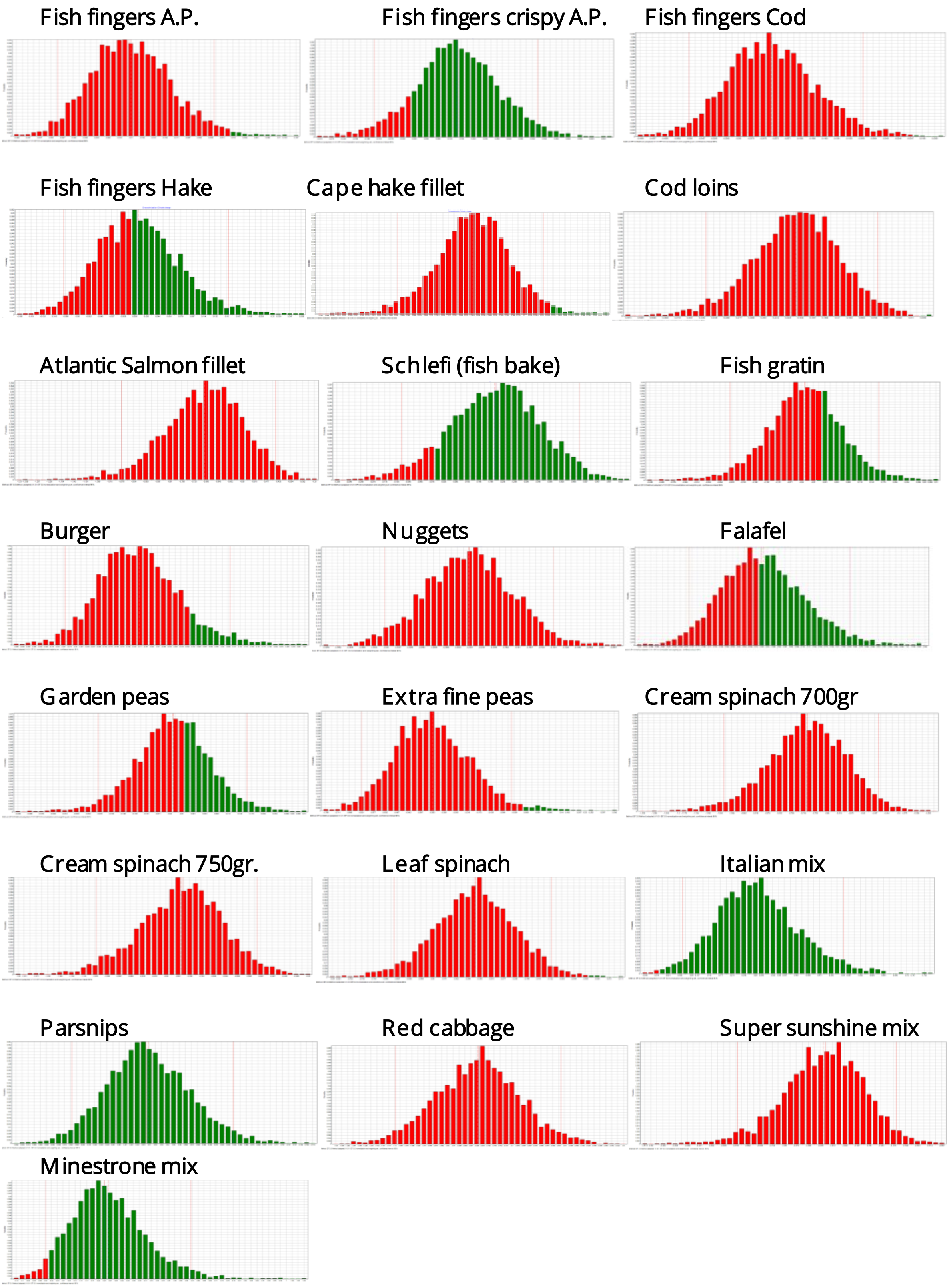
- Reliability
- Completeness
- Temporal correlation
- Geographic correlation
- Technological correlation

The background databases used in this study include data quality scores for all datapoints as well, following this same procedure. Due to the time needed to assign the scores in the model, not all Pedigree scores were included in the model and therefore in the Monte Carlo calculations. To determine if scores were excluded from the model, the main consideration was relevance to the results. The scores that were excluded fall under one of these categories:

- The score applied to a datapoint with a very low contribution to the carbon footprint. For example, the transport distance from the retailer to the consumer.
- The score both indicated a low uncertainty and applied to a datapoint shared by both the frozen product and its alternative, therefore not having an important effect on the comparison. For example, the ingredient composition of the products under study.

To summarize the results of the uncertainty assessment, Figure 9 shows a high-level overview of the carbon footprint comparisons of all products included in this study. Red coloured bars indicate the runs in which the frozen product had a lower carbon footprint than the alternative, while green bars indicate the runs in which the alternative product had a lower carbon footprint than the frozen product.

Figure 9 - Carbon footprint uncertainty results of all products under study



Red bars: Carbon footprint of the frozen product is lower than that of the alternative product
Green bars: Carbon footprint of the alternative product is lower than that of the frozen product

10 Conclusions

Taking into account the results, interpretation, sensitivity analysis and uncertainty assessments, this chapter discusses the conclusions of this study. The focus here is on the carbon footprint.

With regards to the full range of impact categories included in the EF3.0 method, the focus on the carbon footprint is not necessarily a good representation of the comparison on the other impact categories. Trade-offs occur in all products under study, where in one impact category the frozen product has a lower impact than the alternative, and in another it is the other way around. The conclusions in this report focus on the carbon footprint results, but it is important to note that any overall conclusion about potential environmental impact as a whole will require a prioritization between the impact categories, as well as a more detailed analysis on all included impact categories, to be able to come to a final conclusion.

An important factor to remember when interpreting the results is that for the frozen food products and their alternatives, the differences stem solely from the preservation method and not from other factors such as the ingredient composition, manufacturing efficiencies, ingredient distribution route, and location of consumption. This means the carbon footprint of the ingredients production phase is assumed to be identical for both the frozen and non-frozen alternative. As a result, the differences between the frozen products and their alternatives will be inherent differences in the product manufacturing, temperature of transport vehicles, the storage temperatures and food loss and waste. All the life cycle efficiencies for Nomad Foods' products are described in detail in section *10.1.2*

10.1 Important contributing factors

The results and corresponding interpretation steps provided insights into the main contributing factors to the carbon footprint of the products under study. These are discussed here. Please note that these contributing factors are not necessarily also those that have a large contribution to the overall carbon footprint. Instead, they are those factors where important differences occur between frozen and non-frozen products, thereby affecting the comparison between them.

10.1.1 Selection of alternative

The selection of the alternative product to compare to the frozen product can influence the result of the comparison. Selecting small packaging sizes for the alternatives can make the frozen product appear more favourable than it is. In addition, assuming various approaches for the supply chain of the alternative can affect the conclusion as well. For example, if one assumes that chilled Cape Hake fillet was never frozen during its life cycle then it would need to be transported by airplane, which comes with a significant increase in carbon footprint. Therefore, the chilled Cape Hake fillets were assumed to be frozen for transport and defrosted in Europe. This is quite common for chilled fish and therefore gives a fairer basis for comparison. Because of the importance of selecting the alternative fairly, the selection process was documented as transparently as possible, and the way decisions were made was documented in a decision tree.

10.1.2 Life cycle efficiencies

Whenever possible, similar efficiencies were assumed for both the alternative and frozen product. For example, the same manufacturing energy was used for both frozen and chilled fish fingers, with only an adjustment made based on the energy difference for freezing or chilling. This was done to focus any differences occurring between the frozen product and its alternative solely on the inherent difference between a frozen and non-frozen supply chain. The numerical differences shown in the results are stripped of any other contributing factors.

However, many of the efficiencies Nomad Foods has built up over the years may not apply to the alternative products in reality. For example, the ability that Nomad Foods has to manufacture frozen food products at scale using dedicated production lines or even dedicated factories is relatively unique to the business. It is not expected that smaller scale producers can match these efficiencies. Therefore, the actual carbon footprint of the alternative products is likely to be higher than calculated in this study.

In addition, some of the alternative products are theoretical, meaning they do not actually exist on the market today. An example is the minestrone mix, whose ingredients are not all available in their fresh form at the same time during the year.

An overview of the potential advantages given to the alternative products as a result of focusing the differences solely on the frozen vs. alternative supply chain is given in Table 21.

Table 21 – Advantages given to the alternative products

Product	Advantages given to the alternative product
ALL PRODUCTS	The same production efficiencies are assumed for the alternative products as for the Nomad Foods' products. This is likely not realistic, since Nomad Foods has dedicated production lines and even dedicated factories for manufacturing specific products, and have optimised these over the span of several decades.
ALL PRODUCTS	Because the split between consumer waste before and after preparation was unknown, consumer food loss and waste is modelled before preparation. As a result, the effect of the food loss and waste percentage applied is smaller. This is because the impact associated with cooking food that goes uneaten is not taken into account.
ALL FISH PRODUCTS except salmon	The chilled fish is assumed to be frozen upstream to allow for efficient transport to Europe. Once in Europe, the fish is defrosted and sold as a chilled product. This is a common approach, but there are also cases where chilled fish has never been frozen and therefore needs to be flown in from remote catching and manufacturing locations. Air transport is expected to significantly increase the carbon footprint. The only exception to this is the Atlantic Salmon, which is farmed in Europe and assumed to be never frozen.
ALL AGRICULTURAL PRODUCTS except spinach	The non-frozen vegetables are assumed to be grown the same way as the frozen vegetables, with the exception of spinach. In reality, Nomad Foods works directly with a large amounts of their growers, and has optimized agricultural practices and the locations of their manufacturing facilities to ensure optimal

	efficiency. As a result, the carbon footprint of their agricultural production is likely to be lower than that of alternative products.
Atlantic Salmon fillet	The same salmon supplier is used to model the frozen and chilled salmon products. In reality, the company supplying Nomad Foods' Atlantic Salmon is highly optimized and has been working towards lowering the environmental impact of their salmon for many years. They have tackled one of the main contributors to the environmental impact of farmed salmon, the fish feed, by setting up their own fish feed production facilities on site. It is therefore likely they are on the favourable end of the scale in terms of farmed Atlantic Salmon production.
Garden peas	Chilled / fresh garden peas are only available for a limited time period every year and are therefore not always a real alternative for frozen garden peas.
Minestrone mix	The ingredients in Nomad Foods' minestrone mix are not all in season at the same time. In reality there could therefore not be chilled mix for sale that contains the same ingredients.

10.1.3 Packaging

Both the type of packaging and the packaging size are a relevant factor for determining if a frozen product has a lower carbon footprint than the alternative or not. Packaging material is relevant here (paper, plastic, glass, metal). The other important factor in relation to packaging is packaging size. Using larger pack sizes (i.e. more product mass per product unit) means less packaging impact per serving of food product. But there is of course a close relation to consumer behaviour and food loss and waste here, as buying large packages of products with a relatively short shelf life may result in more losses when consumers do not fully consume a product before it becomes (or appears to be) no longer edible.

10.1.4 Country of consumption

Both the default results and the sensitivity analysis show that the country of consumption is an important factor in determining if a frozen product has a lower carbon footprint than the alternative or not. A different country of consumption means a different electricity mix, which affects retail storage, consumer storage and preparation. The effect of this can go as far as to changing the conclusion which product has a lower carbon footprint.

10.1.5 Consumer behaviour

The behaviour of the consumer is very important to determining if a frozen product has a lower carbon footprint than the alternative or not. This affects multiple factors. First of all, the storage time at home can affect the conclusion. The default results and the sensitivity analyses show that if the consumer stores the frozen product for a relatively short amount of time (the default is 30 days), this can result in the carbon footprint being lower for the frozen product than for the alternative in many cases. However, if that same frozen product is stored by the consumer much longer, such as six months to a year, the frozen product can easily have a higher carbon footprint as a result.

The preparation method the consumer uses also makes a difference. If the method of preparation used for frozen and alternative products remains the same then this is of little influence to the comparison, even though the total carbon footprints may change. However, if a consumer tends to use different preparation methods for frozen and alternative products, this could change the conclusion in terms of which product has a lower carbon footprint overall.

Another very important factor in terms of consumer behaviour is in relation to food loss and waste. This really is a driving factor in terms of whether the frozen product has a lower carbon footprint than the alternative or not. This can also vary largely between individuals and can be affected by many different factors.

10.1.6 Food loss and waste

As mentioned in relation to several previous topics, the rate of food loss and waste is a very important factor that can influence if a frozen product has a lower carbon footprint than the alternative or not. This is the case for both the retail and consumer stages, though in general food loss and waste at the consumer's home appears to be higher than at retail.

At retail, there are many different factors that come into play when it comes to reducing food loss and waste. The percentage of losses for frozen products at retail is already quite low (below 1%), so the main challenge appears to occur for products with a shorter shelf life and that are more prone to damage. Reducing food loss and waste is an important improvement point for retail. Any advances that are made, either by individual retailers, certain chains or the sector as a whole, would alter the footprint of a frozen product and/or its alternative. Therefore, in the future, it is possible that the comparisons as presented in this report are no longer applicable.

An important factor to consider when looking at the food loss and waste in relation to the carbon footprint is the impact of producing the product itself. If the production of the product (i.e. the ingredients cultivation and manufacturing) has a higher carbon footprint, the greenhouse gas emissions associated with food loss and waste of that product will also be higher than that of products with a lower carbon footprint for its production. So a change in the food loss and waste percentage of products with a relatively high cradle-to-gate carbon footprint will have a larger absolute effect than the same change for a product with a relatively low production carbon footprint. Therefore, for the products with a relatively high production carbon footprint, smaller differences in the food loss and waste between a frozen and non-frozen product can make a significant difference.

10.1.7 Impact categories

An important factor to determine if a frozen product has a lower environmental impact than the alternative or not is the choice of impact categories to look at. As was shown by the analysis of the results on the full range of EF3.0 impact categories and the corresponding uncertainty assessment, the carbon footprint is not necessarily a good representation for the overall environmental impact.

In many of the studies products, the trend as to which product has a lower impact, the frozen or the alternative, is fairly constant. However, without exception there are trade-offs in all products under study. The main impact categories that often show a contradicting trend are ozone depletion, freshwater eutrophication, land use and water use. The choice of impact categories should be carefully considered before drawing any overall conclusions.

10.2 Limitations

This study has calculated the carbon footprint of 22 Nomad Foods products using primary data for processes under their operational control, and also for some processes beyond their operational control. These results provide valuable insights to the main contributors to the carbon footprint in the product value chains, providing a direction on where to target sustainability efforts. The comparisons made provide novel insights to the trade-offs between the carbon footprint of frozen food products and alternative preservation methods.

While this study was attempted to be as accurate and detailed as possible, limitations still exist. An overview of the most important limitations in relation to the results and intended purpose is provided here.

10.2.1 Products under study

The products under study represent a selection of frozen food products. They were selected by Nomad Foods because they have the highest sales volume. Nomad Foods often has the highest market share in the markets it operates in (frozen fish, vegetables and plant-based proteins in the selected European markets), so it can be expected that the findings from this study represent a good window to these products in these markets. However, no further research for this study was done in respect of frozen food sub-categories outside fish, vegetables and plant-based proteins

The products under study were investigated in relation to specific regions. As shown in the sensitivity analysis, the country of consumption can influence the results significantly and any country-specific results presented here may not be generally applicable to other countries of consumption.

The functional unit used for this study refers to a consumption of three portions that are prepared at once. Since preparation is an important contributor to the overall impact, it is not necessarily possible to expand any conclusions to other consumption scenarios.

The alternative products that the frozen products are compared to are selected following a transparent methodology, but it is very possible that the selection of a different alternative would lead to a different conclusion. For example, as seen in this study, comparing to jarred or canned products tends to result in the frozen product having a lower carbon footprint. While the alternatives were selected to be the most common options in the areas under study, this may not be the case in other regions.

Limited data was available on the production, manufacturing, and packaging of the alternatives. Consequently, assumptions and generalizations had to be made. It should be noted that a conservative approach was used when making decisions on any assumptions or generalizations, aiming to ensure the frozen products do not receive any questionable advantages.

10.2.2 Data sources

Secondary data was used for several parts of the life cycle. This data was sourced from several databases and varies in terms of how well it represents the products under study. For example, data in these databases may be extrapolated from older data, which comes with a certain amount of uncertainty. This was addressed in the uncertainty assessment, but in general the representativeness of the background data can be limited.

In addition, there may be consistency issues across the background data, since several different databases were used. These databases are compatible in all major aspects, like the approach to multi-functionality, but inconsistencies can still occur.

While the amount of primary data that is included in this study for the fisheries, is good, sourcing accurate data on the prices of the various co-products proved to be challenging since suppliers were not keen to share this sensitive information. Even in secondary data there was not much detail available on this. The most suitable assumptions possible were made, but this is an important data gap. However, since it is an equal data gap for both the frozen and alternative products, it is unlikely to affect the comparison between them significantly.

While consumer behaviour is identified as an important contributing factor to the results, limited consumer data was available for inclusion in this study. Background data had to be used or assumptions had to be made on storage time, preparation methods and food loss and waste.

10.2.3 Modelling approaches

Many of the raw material ingredients do not include any post-harvest handling, such as washing and sorting. When this is left out of the study due to limited data availability it is an equal data gap for both the frozen and alternative products, it is unlikely to affect the comparison between them significantly.

The model only includes the preparation methods outlined on the packaging of the frozen food products. In case these methods were not suitable for the alternative product, adjustments were made. But if the majority of consumers deviates from these suggested methods, the preparation impacts can change significantly. This is also the case for individual users looking to apply the results of this study to themselves.

10.2.4 Impact assessment

This study mainly investigates the carbon footprint of the products. The results have shown that the carbon footprint is not always a good representation of the results on other impact categories. So conclusions based on the carbon footprint do not automatically apply to other impact categories.

Certain impact categories included in the EF3.0 method require regionalized input data to fully capture the potential environmental impact, specifically land use and water use. Not all used databases include regionalized input data for these flows, meaning their impact is only included on a less detailed and therefore less representative level. This is specifically the case for land use and water use, for which the results should be seen as very uncertain. In addition, the impact categories have varying levels of uncertainty associated with them. For example, the inherent uncertainty of the USETox impact assessment method is acknowledged by the authors of that method.

Investigation of the results on all impact categories showed an anomaly in the ozone depletion category. Big differences were seen between the frozen and alternative products of a factor four or five. Further research and a sensitivity check with the ReCiPe 2016 Midpoint (H) method showed that this is because the EF3.0 method does not include a characterization factor for N_2O in relation to ozone depletion potential. N_2O emissions commonly occur from agricultural processes and while certain substance flows (specifically Halon 1001) do increase by a factor 5 between the frozen and alternative products, the relative contribution of N_2O is much larger.

Therefore, using the ReCiPe 2016 Midpoint (H) method, which does include a characterization factor for N_2O, the difference between the frozen and alternative product is minimal.

10.2.5 Data validity

It is important to note that the results are derived from data which are subject to change over time, or when more accurate data becomes available. For example, if electricity mixes change significantly or big changes occur in food loss and waste at retail and consumer, the results and corresponding interpretation may no longer be valid.

10.3 Concluding statement

The results of this study show that when it comes to carbon footprint, there is no general advantage or disadvantage to using frozen food products compared to products using alternative preservation methods, However, it does support the hypothesis that in terms of carbon footprint, when food loss and waste rates in the retail and consumer stages are lower for a frozen product compared to a non-frozen alternative, this may compensate for the additional energy use caused by a frozen supply chain.

This conclusion is based on the overall conservative approach that was used in this study on multiple fronts, meaning that the differences stem solely from the preservation method and not from other factors such as the ingredient composition, manufacturing efficiencies, ingredient distribution route, and location of consumption. This means the carbon footprint of the ingredients production phase is assumed to be identical for both the frozen and non-frozen alternative. As a result, the differences between the frozen products and their alternatives will be inherent differences in the product manufacturing, temperature of transport vehicles, the storage temperatures and food loss and waste.

10.3.1 Determining factors

In general, it can be concluded that there are four main factors that determine whether the carbon footprint of a frozen product is higher or lower than that of an alternative, when the carbon footprint of the production phase are assumed to be identical. These factors are not necessarily main contributors to the impact, but they are the main source of difference between the frozen and non-frozen products. They are as follows:

- The electricity mix used by retail and consumer. An electricity mix with a lower carbon footprint per kWh is beneficial for frozen products.
  The products included in this study use the average country electricity mix in the country of consumption. Over time, these mixes are expected to move in the direction of lower carbon footprint, thereby moving in favour of the frozen product.
- The amount of time the consumer keeps the frozen product in their freezer. A shorter freezer storage time is beneficial for frozen products.
  It is unclear if the 30 days of frozen storage assumed in this study is an accurate representation of reality. The reality can be higher or lower. However, as the carbon footprint of electricity mixes becomes lower, the sensitivity to the frozen storage days becomes less significant.
- The amount of food loss and waste at retail and consumer. If the food loss and waste of the alternative product is higher than that of the frozen product, whether this is due to

high perishability, low turnover or something else, the carbon footprint of the frozen product is more likely to be favourable. Due to the influence of the food loss and waste on the results of the comparison, data on specific products and preservation methods should be used.

- The inherent carbon footprint of the product itself. If the production of the product (i.e. the ingredients cultivation and manufacturing) has a higher carbon footprint, the greenhouse gas emissions associated with food loss and waste of that product will also be higher than that of products with a lower carbon footprint for its production. So a change in the food loss and waste percentage of products with a relatively high production carbon footprint will have a larger absolute effect than the same change for a product with a relatively low production carbon footprint. Therefore, for the products with a relatively high production carbon footprint, smaller differences in the food loss and waste between a frozen and non-frozen product can make a significant difference.

10.3.2 Spinach products

Based on the sensitivities discussed above, no comparative assertions are made on each of the 22 products included in this study. However, one set of products that is worth to call out specifically in these conclusions is the spinach products. When looking at the numerical values, listed in Table 22, the differences in numerical carbon footprint between the frozen and chilled alternative products are quite substantial, ranging in relative differences from 15% to 28%.

Table 22 - Carbon footprint of spinach products

	Frozen (kg CO_2eq. per 3 portions)	Alternative (kg CO_2eq. per 3 portions)	Relative difference (negative number means frozen is lower)
Cream spinach 700gr.	0,93	1,26	-28%
Cream spinach 750gr.	0,91	1,26	-26%
Leaf spinach	0,73	0,86	-15%

The leaf spinach has the smallest relative difference in carbon footprint of the three spinach products. This product was included in the sensitivity analyses on consumer storage, electricity mix and preparation. As a result, tipping points were calculated for the storage days and food loss and waste numbers. These are listed in Table 23.

These numbers show that the main assumptions used for the leaf spinach are at a comfortable distance from the tipping points. For the two cream spinach products, the distances to the tipping points are even larger. In fact, even if retail food loss is 0% for the chilled spinach, the frozen cream spinach products still come out favourable in terms of carbon footprint.

In addition, the results covering the full set of EF3.0 impact categories show that the potential impact of the frozen product is lower than the alternative amongst most impact categories. Out of 28 sub-impact categories, which contribute to the 16 impact categories, there are only 3 where the frozen spinach products have a higher potential impact than the alternative. These are freshwater eutrophication, land use and water use.

Table 23 - Comparison to tipping points leaf spinach

	Current assumption	Tipping point
Consumer storage days of the frozen product	30 days	46 days maximum
Retail food loss and waste of the alternative	9.6%	2.0% minimum
Consumer food loss and waste of the alternative	16.5%	9.3% minimum

Based on this information, from this study it can be concluded that when it comes to carbon footprint, there is an advantage to frozen spinach products compared to chilled spinach products. The additional energy caused by a frozen supply chain is compensated by a lower amount of food waste, more efficient packaging and storage volume compared to chilled spinach, and the possibility to use more efficient agricultural practices to grown full leaf spinach instead of smaller leaf sizes.

This conclusion is based on the overall conservative approach that was used in this study on multiple fronts, meaning that the differences stem solely from the preservation method and not from other factors such as the ingredient composition, manufacturing efficiencies, ingredient distribution route, and location of consumption. This means the carbon footprint of the ingredients production phase is assumed to be identical for both the frozen and non-frozen alternative. As a result, the differences between the frozen products and their alternatives will be inherent differences in the product manufacturing, temperature of transport vehicles, the storage temperatures and food loss and waste.

11 External review

As required by the ISO 14040/44 standards, this study has been reviewed by an external review panel consisting of three members. An addendum to this full report was made later, and approved by the same review panel on the 28th of October 2022.

Please note that the panel reviewed the full version of the report, of which this third-party report represents a shortened version. The review statement applies to the full version of the report.

11.1 Review panel

The review panel was set up to cover both extensive LCA expertise as well as knowledge of the food supply chain in general and food loss and waste in particular. Prof. Dr. Matthias Finkbeiner served as the chair of the review panel, with Prof. Dr. Greg Thoma and Kai Robertson serving as the other two members. The reviewers act and were contracted as independent experts, not as representatives of their affiliated organization.

Prof. Dr. Matthias Finkbeiner served as the chair of the review panel. He is currently Chair of Sustainable Engineering and Managing Director of the Department of Environmental Technology at Technical University Berlin as well as Guest Professor at the Chinese Academy of Agricultural Sciences. He was Chair of the ISO-Committee and member of the International Life Cycle Board (ILCB) of the UNEP´s Life Cycle Initiative. He is the Editor in Chief of the International Journal of Life Cycle Assessment. He serves on the Advisory Board of the Institut Bauen und Umwelt e.V. (IBU) as Europe's leading organisation for environmental product declarations in the building sector. He also served on the Advisory Board of the German Ecolabel Blue Angel. Earlier in his career, he was Manager for Life Cycle Engineering at the Design-for-Environment Department for Mercedes-Benz Cars at Daimler AG. He holds an MBA in Sustainability Management and further degrees in Environmental Science, Environmental Economics and Environmental Law.

Prof. Dr. Greg Thoma is currently Professor of Chemical Engineering at the University of Arkansas. He served as director for research and is currently senior advisor to The Sustainability Consortium. The Consortium is focused on measuring and improving the sustainability of consumer goods, including food. He has represented the Sustainability Consortium on the United Nations Environment Program/Society of Environmental Toxicology and Chemistry Lifecycle Initiative board of directors assisting in coordination of international efforts to mainstream life cycle management in the consumer goods sector. Dr. Thoma's research focuses on the application of chemical engineering principles to find solutions to environmental problems. He is currently lead investigator for a number of life cycle initiatives in the food and agriculture sector.

Kai Robertson is currently a Senior Corporate Sustainability Advisor at KOR Consulting. Among other roles, she serves as Lead Advisor to the Food Loss & Waste Protocol, which developed the Food Loss and Waste Accounting and Reporting Standard. This standard enables countries, companies, and others to report in a transparent, practical, and consistent manner how much food is lost and wasted and identify where it occurs. In the past, she served as Director of Business & Industry, Food and Agriculture at WWF, Director of Food & Agriculture at Conservation International, where she was involved in shaping Wal-Mart's environmental sustainability strategy, and Manager/Director at the Food Marketing Institute. She holds an MBA from the Kellogg Graduate School of Management at North-western University.

11.2 Review process

The study was reviewed in two stages: first an initial review of the goal and scope, after which the full report was finalized and delivered. Second, a review of the complete report was done, including the updated goal and scope, data description, results interpretation and conclusions.

The comments and recommendations from the reviewers were delivered in table form, where they were classified into various categories (general, editorial or technical). Responses were given to each comment, as well as a description of any changes made as a result.

A plausibility check of the life cycle inventory (LCI) model was performed by Prof. Dr. Greg Thoma. The assessment or verification of individual data and datasets are outside the scope of the review.

The main changes that resulted from the reviewers' comments included adding more detailed descriptions on the used modelling approaches, expanding on the section covering food loss and waste, adding additional data sources and detail to the used food loss and waste numbers at retail and consumer, and expanding on the discussion of the results and interpretation. In addition, the wording of the report was adapted to make it clear that the focus is on the carbon footprint.

11.3 Review statement

After the review process was completed, the external review panel provided the following critical review statement about this study. Please note that this review statement applies to the full version of the report, of which this third party report is a shorted version.

COMPARATIVE LIFE CYCLE ASSESSMENT OF 22 NOMAD FOODS FROZEN FOOD PRODUCTS AND ALTERNATIVES

Commissioned by*:* Nomad Foods Europe Limited, Feltham, United Kingdom

Prepared by: PRé Sustainability B.V., Amersfoort, Netherlands

Review panel: Prof. Dr. Matthias Finkbeiner (chair), Germany
Prof. Dr. Greg Thoma, United States of America
Kai Robertson, United States of America

References ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework
ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines
ISO/TS 14071 (2014): Environmental Management - Life cycle assessment - Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Scope of the Critical Review

The review panel had the task to assess whether

- the methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,

- the technological coverage of the industry in the prevalent LCA study is representative of current practice,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review was performed concurrently to the study according to paragraph 6.3 of ISO 14044, because the study is intended to be used for comparative assertions intended to be disclosed to the public. This review statement is only valid for this specific report in its final version 2.3 dated 11.02.2022.
Outside the scope of this review were

- the verification of assumptions and calculations made for the frozen food alternatives, food loss and waste rates, retail and consumer storage, as well as food preparation.
- an analysis of the LCA model and
- the verification of individual LCI datasets

Review process

The review process was coordinated between Nomad Foods, PRé Sustainability and the chair of the review panel. As a first step in the review process, the panel members were selected based on their specific LCA and food loss and waste expertise.

After the review panel was established, a kick-off call was held on 21.10.2021. In this call, the details of the review process were agreed, and an outline of the goal and scope of the study was presented by PRé Sustainability. The first draft of the goal and scope report was submitted to the panel after the meeting. The review panel provided 129 comments of general, technical and editorial nature to the commissioner by 05.11.2021. Responses to the reviewer comments were delivered together with the first draft of the final report on 06.12.2021. A revised goal and scope text was provided as part of the draft final report.

The review panel provided 146 comments on the draft final report of general, technical and editorial nature and sent them to the commissioner by 19.12.2021.

A critical review panel meeting with Nomad Foods and PRé Sustainability (web conference) was held on 06.01.2022 to address the comments that needed additional information or agreement on how they should be implemented.

PRé Sustainability provided a comprehensively revised report and documentation on the implementation of the review comments on 12.01.2022. The majority of critical issues and many of recommendations of the review panel were addressed in a proper manner. As the revised report contained a significant amount of changed and new text, the panel provided a further set of 23 comments. PRé Sustainability addressed them before the conclusion of the critical review process.

The final version 2.3 of the report dated 11.02.2022 was provided on 15.02.2022.

The review panel acknowledges the unrestricted access to all requested information as well as the open and constructive dialogue during the critical review process.

The contributions of the panel members were consistent, complementary and without any conflicting views. The comments during the process and this review statement were approved unanimously.

General evaluation

Nomad Foods is the largest frozen food company in Europe and manufactures, sells and distributes a range of branded frozen food products across 13 European countries with the United Kingdom, Italy, Germany, Sweden and France representing their five largest markets. This study provides a comparative life cycle assessment of 22 of their frozen products from three product categories with their alternatives, i.e. equivalent products using other preservation methods. The product group Fish included, fish fingers and coated fish, natural fish and recipe fish. The product group Vegetables included peas, spinach, prepared vegetables, natural vegetables and vegetable mix for soups. The product group Plant-based protein included meat alternatives and falafel.

The breadth and depth of the scope of the study were demanding for both LCA practitioners and reviewers as these different product groups covered a broad range of different raw material production processes (from agriculture to fishing), different storage and food loss/waste scenarios at retail and consumer stage, different types of packaging and different food preparation methods. The methodology and scope description as well as analysis and interpretation of the results are documented in a report of nearly 300 pages. The flowcharts for each of the products and the associated LCIA results are presented in a separate document of about 200 pages.

Another outstanding feature of the study is detailed collection of primary data from the manufacturing at Nomad including inbound as well as outbound logistics until the retail stage. Primary data were included in the study even for raw material production of a significant number of agricultural and fishery products.

The study was performed in a professional manner using state-of-the-art methods. The study results and conclusions are reported in a comprehensive manner including transparent documentation of its scope and methodological choices. Several issues were studied in sensitivity analyses.

The feedback provided by the review panel was constructively considered and led to a significant improvement of the report. The following aspects should be noted for a proper interpretation of the results and for potential future updates of the study:

- Alternative product data: the study transparently documents and justifies the choice of the product alternatives selected for each of the frozen food options. Nonetheless, the choice of different types, packaging and sizes of the alternatives may lead to different results.
- Impact assessment: the study provides quantitative results for all 16 impact categories of the EF 3.0 method, but a more detailed result analysis in terms of contributions and sensitivities was only performed for the global warming potential. A full analysis of all impact categories with the same level of detail for all 22 products is obviously challenging. However, future product-specific updates based on the models developed here would allow for a comprehensive discussion of the full set of impact categories and as a consequence, even more detailed product-specific conclusions.
- Food loss and waste rates: the study transparently notes the limitations inherent in identifying appropriate food loss and waste rates at the retail and consumer stages. Improvements in the granularity, and accuracy, of food loss and waste rates for the Nomad products as well as alternative products would improve the representativeness and accuracy of the results. Moreover, as noted in the study, the rate of food loss and waste varies over time, which affects the results.

As with every LCA, the outcomes of a specific study and especially a comparative study also depend on the choices made in the scope definition. Therefore, the results need to be interpreted in the specific context defined. Any generalization beyond the context of the defined scope, is not covered by the study as such.

Conclusion

The study has been carried out in conformity with ISO 14040 and ISO 14044 following the critical review procedures of ISO TS 14071.

22nd February 2022

Matthias Finkbeiner | Greg Thoma | Kai Robertson

(the review statement was approved by email)

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