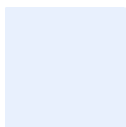




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Comparative sustainability assessment of fish boxes in Europe



eumeps

The voice of the
European EPS industry

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Executive summary

Context

The Packaging and Packaging Waste Regulation (PPWR) entered into force on 11 February 2025, setting targets to the implementation of reusable packaging in the EU. The boxes used to transport fish in the EU are concerned by the reuse targets:

- At least 40% of packaging must be reusable packaging within a reuse system by 2030
- At least 70% of packaging must be reusable packaging within a reuse system by 2040

EUMEPS and the EU fishing, fish farming and fish industry associations are concerned by the consequences that might arise from this regulation and believe that the environmental, economic, and social implications of such obligations should be assessed before the implementation.

This study, commissioned by EUMEPS, aims at evaluating and comparing the environmental, economic, and social impacts of the single use EPS boxes and alternative solutions for the transport of fresh fish.

Goal and scope of the study

This study evaluates the environmental, economic, and social impacts of the standard EPS fish boxes and compares them to alternative boxes that may fit the criteria of the PPWR. The pursued goal of this study is to identify whether there is an environmental, economic, or social advantage of using EPS boxes compared to alternative boxes.

To complement this quantitative assessment of the situation in the long run, a qualitative analysis of the short and medium transition costs associated to a shift in the packaging type is presented.

The environmental LCA section of the study has been reviewed, by an external expert panel, against ISO 14040 and 14044 standards, ensuring robust methodology and result reliability.

The LCA assesses the 16 impact categories recommended by the European Commission (EC) as section of the Product Environmental Footprint (PEF) guidelines. Out of these 16 categories, ultimately five have been selected as relevant for this study following the EC's recommendation for categories selection: Climate change; Resource use, fossils; Photochemical ozone formation; Particulate matter; and Resource use, minerals, and metals.

The functional unit is defined as *“the transport and protection of fresh fish in direct contact with ice during one step of the fish distribution (packing with ice and fish, storage at emitter, transport, storage at receiver, and unpacking of the box) in the European Union to obtain 1kg of fish fit for human consumption at selling place.”*

Five types of boxes are analysed:

- Single-use EPS boxes: the current industry standard for fish transport
- Reusable EPS boxes: reuse system for the single use EPS boxes (not existing)
- Single-use cardboard boxes (currently used for some short distance transport)
- Insulated reusable hard plastic (PP) boxes with double wall technology (existing in smaller sizes than what is modelled)

- Non insulated reusable hard plastic (HDPE) boxes (currently used for some same day deliveries)

The system boundaries are cradle-to-grave, encompassing the entire lifecycle of the box, from raw material production to end-of-life. It includes all processes affected by the choice of a packaging system, i.e. all logistical operations such as transport of the empty box to the fish market, fish farm or fish factory, ice production, use of the box during fish distribution, collection for reuse, cleaning, and sanitising. The system boundaries are the same for the environmental, economic, and social evaluations.

Model and data

Primary data for the single use EPS boxes were provided by EUMEPS. Data for alternative boxes was sourced from box manufacturers and actors from the reusable boxes industry.

Fish industry representatives provided detailed information on fish distribution logistics.

Secondary data was mainly sourced from Ecoinvent 3.10, but also COPERT V (for precise transport modeling). For the economic and social aspects, data coming from EUROSTAT and grey literature are used to complement primary data.

The analysis was performed using RangelCA (cf. Annexe 3), an advanced LCA software developed by RDC Environment and Excel.

A key modelling assumption is that the amount of ice is adapted to the specific needs linked to the distance.

However, in practice, industrials optimize their system by standardizing the boxes and their content. This means the amount of ice is determined by the most demanding case, i.e. the longest distance. This means the lower amount of fish per box would be applicable also for shorter distances. Modelling this practical case would further improve the better positioning of the single use and reusable EPS boxes which have better insulating properties than other box type.

Results – three pillars of sustainability

This study allows for a comparison of the aggregated societal impacts, i.e. the addition of monetised environmental impacts, economic costs, and social value of job creation.

When combining the results for the three pillars, the single use EPS box outperforms the reusable boxes (the insulated and non-insulated hard plastic reusable boxes, with 60 uses, and the reusable EPS box, with 5 uses) and cardboard box for all distribution distances above 200 km.

Switching to reusable boxes would reduce impacts and costs related to production and end-of-life, but the increase of the impact of the transport logistics is larger. The number of uses of the reusable boxes was found to have a limited impact on the results. The end-of-life of the single use boxes was also found to have limited influence on the results.

Switching to cardboard boxes would increase the impacts of transport for long distribution distances: because the cardboard boxes have lower insulating properties, more ice is needed, and this leaves less space for fish. This means the amount of fish transported in one box is lower, hence increasing the transport cost per unit. For the base case (2800 km with one driver), 127 lorries filled with cardboard boxes are needed to transport the same amount of fish as 100 lorries filled with single use or reusable EPS boxes.

For distribution distances below 200 km, the burden of return logistics is lighter and the relative impacts of all five studied boxes do not significantly differ, considering uncertainty and variety of existing situations.

Note: If one box were to involve more fish loss than the others, this box would in practice be disqualified from an economic and environmental viewpoint. Indeed, the value of the fish loss itself (typically about 6€/kg lost) and the environmental impacts associated to fish production and fishing both outweigh in practice the possible advantages related to the box.

Results – focus on the environmental impacts

Considering the climate change impact category, alternative boxes do not show any environmental benefit compared to single-use EPS boxes when the distribution distance exceeds 1250 km.

The **cardboard box** generates lower impacts to climate change than the single use EPS box for distances below 800 km with a standard diesel lorry with one driver (and below 1250 km with two drivers). In contrast, the cardboard box shows a higher impact for distances above 2900 km with a standard diesel vehicle.

For an equal distribution distance, the impact of the fish distribution phase for the cardboard box is higher than the impact of this phase for the single use EPS box.

Because the production of the cardboard box has lower impacts on climate change than the production of the single-use EPS box, the total impact of the cardboard box is lower than the impact of the single use EPS box for shorter distances. For longer distances, the single use EPS box has a lower impact on climate change.

The **reusable EPS box** has similar impacts on climate change to the single use EPS box for distribution distances between 150 km and 2 650 km with a standard diesel lorry. For shorter distances, the reusable EPS box has a lower impact on climate change than the single use EPS box.

The **insulated reusable PP box** has similar impacts on climate change to the single use EPS box for distances up to 2200 km with one driver and up to 2600 km with two drivers, for a standard diesel lorry.

The **non-insulated HDPE reusable box** can only be used for short distribution distances (<720 km) but has similar impact to the single use EPS box for those distances.

Any increase in the fuel efficiency of the lorries or the use of electric vehicle would have a positive influence on the impacts of the boxes on climate change. This positive influence would be greater for alternative boxes than for the single-use EPS box because the impact of transport is higher for alternative boxes. As a result, an increase of the range of distribution distance for which the alternative boxes have an impact lower or equivalent to the single use EPS box is expected.

The alternative boxes significantly outperform the single use EPS box for only one of the indicators studied: photo-chemical ozone formation – human health (the other indicators studied are Particulate Matter; Resource use, fossils; and Resource use, minerals and metals).

This is due to the emission of pentane during EPS expansion. Because the impact of the production of EPS is high, the impact of the single use EPS box remains higher than the impact of the alternatives no matter the distribution distance, especially if an electric vehicle is used.

In any case, if one box were to involve more fish loss than the others, this box would be disqualified from an environmental viewpoint, as the increased impact of fish production linked to a higher fish loss would outweigh any possible benefit related to the use of the box.

Results – focus on the economic impacts

In the base case (2 800 km), using a single use EPS box is less costly than the compared alternatives, the cost advantage varying between 0.09 and 0.17 €/kg fish depending on the competing box type.

The single use EPS box display lower economic costs than all the compared alternative solutions, for transport distances above 1000 km with one driver. When two drivers are riding, the threshold distance is 1 200 km.

The good performance of the EPS box is explained by its better insulation properties, allowing to convey a smaller amount of ice in the box, hence leaving more room to transport fish. As a result, more fish is transported per lorry than with competing boxes and the economic cost associated with transport is smaller.

The main discriminating factor for reusable solutions is the economic cost of return transport.

The cardboard is discriminated mainly by its relatively poor insulation properties, and also by its production cost and the need for ice bags to prevent water to weaken the box. Lastly, the higher weight of cardboard boxes reduces the maximum number of boxes per lorry.

Note: If one box were to involve more fish loss than the others, this box would be disqualified from an economic viewpoint, as the value of the fish loss itself (typically about 6€/kg loss) outweighs in practice any possible advantage in costs related to the box.

Results – focus on the social impacts

Considering social impacts alone, the single use EPS box involves less job creation than the compared alternative solutions, which is a corollary to its cost-efficiency. For the base case (2 800 km with one driver), the difference in the value of the jobs created varying between 0.01 and 0.02 €/kg fish depending on the box type.

The extra jobs created by the reusable solutions are linked to the return transport of the boxes which is labour intensive.

The extra jobs created by the cardboard boxes are linked to the increased number of lorries and drivers needed for transport.

Even though the switch from single use EPS boxes to alternative solutions would result in job losses in the EPS industry, the number of new jobs created would be higher than the number of lost jobs.

A limit of this conclusion is that the additional jobs are mainly for drivers and drivers are difficult to find. The “job creation” could then become a “vacancies” creation.

Qualitative assessment of the transition costs in the short and medium run

A regulation driven change in the box material to transport fish in the EU would lead to transition costs in the short-medium run.

The main sources of negative economic impact on the industry of switching from EPS to reuse or cardboard boxes are:

- Sunk costs of premature decommission of non-amortised capital (machines and facilities);
- Reduced economy of scale due to co-existence of standards;
- Expected demand variation for solid plastic boxes may result in building new production lines and close them shortly later, because of the need to rapidly accumulate the stock of reusable packaging creates a peak in demand.

1 Introduction

1.1 Context

EUMEPS (Association of the European Manufacturers of Expanded Polystyrene) is the representative of the manufacturers of EPS fish boxes in Europe.

The Packaging and Packaging Waste Regulation (PPWR) entered into force on 11 February 2025. This regulation mandates reuse targets, including:

- At least 40% of packaging must be reusable packaging within a reuse system by 2030
- At least 70% of packaging must be reusable packaging within a reuse system by 2040

The application of Article 29 of the PPWR would require a shift to alternatives to single use EPS fish boxes, such as single use cardboard fish boxes or reusable plastic boxes.

EUMEPS and the EU fishing, fish farming and fish industry associations are concerned by the consequences that might arise from those targets and believe the environmental, economic, and social implications of such obligations should be assessed.

This study aims to evaluate and compare the environmental, economic, and social impacts of the single use EPS boxes and alternative reusable or cardboard based solutions: single use cardboard boxes, reusable hard plastic boxes, reusable EPS boxes.

1.2 Goal of the study

The objective is to support public comparative assertions, highlighting the potential environmental, economic, and social impacts of single use EPS boxes used for fish transport in Europe, compared to the alternative systems.

To achieve this goal, the study combines an environmental (Life Cycle Assessment - LCA), economic and social assessment, focusing on the same scope.

The Life Cycle Assessment (LCA) study analyses the environmental impacts of boxes used for fish transport in Europe in compliance with ISO 14040 and ISO 14044.

The study compares the single use EPS boxes to four alternative solutions:

- Cardboard boxes;
- Insulated hard plastic PP reusable boxes;
- Non-insulated hard plastic HDPE reusable boxes;
- Reusable EPS boxes.

1.3 General approach: quantify environmental, economic, and social differences in the long run, describe short-medium run transition burden

1.3.1 Three studies combined forming a 3 pillars cost-benefit analysis

This study combines the 3 pillars of sustainability:

- An environmental Life Cycle Assessment (LCA) in compliance with ISO 14040 and ISO 14044. The results of the life cycle assessment have been monetised, valuing all environmental impacts in terms of costs and benefits for the society, in euros. While the monetised environmental impacts are used for the three-pillar “cost-benefit analysis”, they cannot be used, alone, to compare the environmental impacts of the studied systems and to claim one has lower impacts than the others;
- An economic assessment of economic costs along the value chain, following the same scope as the LCA;
- A social assessment of the value of job creation for the society (in euros), following the same scope as the LCA.

The sum of the three pillars forms a “cost-benefit analysis” taking economic costs as well as environmental and social externalities into account.

1.3.2 Long-term impact quantification and a qualitative description of short-run transition burden

In the case of an industrial shift driven by the regulation, one can distinguish two sets of impacts:

- **Transition period impacts (assessed qualitatively)**, i.e., the transition costs, which can be significant. The industry must develop new solutions, adapt or replace production lines before amortisation, deal with the potential co-existence of different technical standards and adopt solutions having not yet reached their economies of scale.
- **Long run impacts (assessed quantitatively)**: In the long run, we assume that the compared packaging solutions are mature, established, and optimised. This means that value chains are optimised, and investments can be amortised on their full lifespan.

In this study, we quantify the impacts of different packaging solutions focusing on their technical characteristics, i.e. in a long run technical scenario. In addition to this quantitative assessment, we describe the main burdens and challenges associated with the transition period.

1.4 Target audience

The results from this study are expected to be communicated to the European Commission and EU Fisheries and Aquaculture Advisory Councils to negotiate in the framework of a delegated act exempting EPS fish boxes from reuse targets mandated by Article 29 of Packaging and Packaging Waste Regulation (PPWR) for the fishing industry.

1.5 Peer review of the environmental LCA study

The environmental LCA section of this report was reviewed by an independent panel of experts. Such a review is necessary for the conformance to ISO standards 14040 and 14044. This way, results of the environmental LCA can be communicated externally, and comparative claims can be released.

The panel comprises of the following members:

- Frank Wellenreuther (Institut für Energie und Umweltforschung), LCA expert with a focus on packaging
- Chris Foster (EuGeos), LCA expert with experience with the fish industry
- Roland Fehringer (c7-consult e.U.), independent consultant for LCA and sustainability reporting; waste, packaging, and plastic expert

The critical review report will be presented at the end of this report.

This peer review only analyses the environmental LCA section. Monetised environmental impacts, socio-economical assessment and the cost-benefit analysis are not covered by this review.

2 Scope of the study

2.1 Functional unit

To make a fair comparison among the different systems, it is necessary to precisely and quantitatively define the 'functional unit', i.e. the (various) function(s) fulfilled by the systems. This allows an objective comparison of performances corresponding to the different routes used to fulfil the same function.

In accordance with the general goal of this study, the functional unit is defined as:

Transport and protect fresh fish on ice in direct contact with the packaging during one step of the fish distribution (packing the box with ice and fish, storage at emitter, transport, storage at receiver, and unpacking of the box) in the European Union to obtain 1kg of fish fit for human consumption at the selling place.

The reference flow associated with this functional unit is one use of one box to transport fresh fish and obtain 1kg of fish fit for human consumption.

In this study, the transit of the fish through wholesalers is not considered to be an additional step in the fish distribution because wholesalers do not open the boxes and repack the fish before sending it the customer: in fact, the boxes are sealed to prevent any contamination. In this study, one step of the fish distribution leads to one use of the box.

2.2 Systems studied

In this report, five different boxes are assessed. They all have the capacity to carry a maximum load of 25 kg of fish and ice.

2.2.1 Single-use EPS box

The modelled single use EPS box is the most used box to transport fish in the European Union. It has a carrying load capacity of 25kg and drainage holes. During transport, the meltwater is allowed to drain from the boxes into the lorries, and then, off the lorries to the road through drainage holes.



Figure 2-1. EPS box¹

¹ Source : (1) The Norwegian EPD Foundation. (2019). *Environmental Product Declaration, EPS fish box, 20kg standard*. Retrieved from https://vartdalplast.no/wp-content/uploads/2023/09/0_NEPD-1924-793_EPS-fiskekasse-20kg-standard-EPS-f.pdf

2.2.2 Reusable EPS box

All EPS boxes used by the fishing industry are currently single use. As a result, there is no available data on the specifications of reusable EPS boxes and on the reuse system they would require. The LCA modeling is thus prospective.

Two hypotheses were formulated to model the reusable EPS box:

- 1) The EPS reusable box shares the same specifications as the single use box.
- 2) In an optimised technological scenario, the reuse system (logistics and cleaning process) for EPS reusable boxes is the same as for the other reusable boxes (cf. Figure 2-4).
- 3) The reusable EPS boxes are used up to 5 times (cf. Return rates section 3.2.6.1).

2.2.3 Cardboard box



The modelled cardboard box is a corrugated box comprising inner and outer paperboard liners, paperboard fluting in the middle and coated with PET for water resistance. It has a carrying load capacity of 25kg.

The cardboard box is produced in Europe and transported flat to the fish farm, fish market or fish factory and is constructed into a box and glued on site.

Figure 2-2. Cardboard box²

The box is watertight and prevents the evacuation of melted water. To prevent contact of water with the fish, the ice must be packed in single use watertight plastic bags.

The box is flattened at the end of its life to optimise its transport.

2.2.4 Insulated reusable PP box

The insulated reusable box is modelled based on a polypropylene insulated box used for fish and sea-food transport with a carrying load capacity of 6kg. This box was scaled up in order to model the use of a box with a carrying load capacity of 25kg.

The dimensions of the boxes were increased so that the interior volume of the box is large enough to fit the product and the thickness of the box walls was increased so that the box is strong enough to carry the load.

² Source : (2) StoraEnso and LCA Consulting Oy. (2018). *Ecofish box LCA*. Retrieved from <https://info.storaenso.com/fr/ps/ecofishbox-lca-study>



Figure 2-3. Insulated reusable PP box³

This insulated reusable PP box is a box with double wall technology for better insulation (one layer of air between two layers of polypropylene).

The insulated reusable PP box is produced in Europe and the empty containers and lids are stackable for an optimised transport to the fish farm, fish market or fish factory. The box includes holes for water drainage and allows for the evacuation of melted ice. During transport, the meltwater is allowed to drain from the boxes into the lorries, and then, off the lorries to the road through drainage holes.

The reuse system modelled is described below:

The boxes used for fish transport are pre-cleaned and collected after one use and sent to the nearest collection centre where they are inspected. Based on interviews with actors of the reusable box industry, the average distance between box users and the collection centre is 100-200 km in Europe.

If the box is not damaged, it is cleaned and sanitised, then dispatched to the client.

Because fish production is very concentrated and far from consumption places in Europe, the possibility of local reuse of the boxes is limited. As a result, the boxes will eventually have to be returned to their original geographical location. Based on the geographical distribution of fish production and fish consumption in Europe, the proportion of local reuse (transport distance of 100-200 km) has been assumed to be 25%.

Based on interviews with actors of the reusable box industry, the hard plastic boxes (the insulated PP reusable box and the non-insulated HDPE reusable box) are used up to 60 times. The boxes that are collected and then scrapped are sent for recycling.

According to the reusable box industry, if the collected box is no longer reusable and is scrapped, it is recycled.

More details are available in section 3.2.6.

³ Source : (3) IFCO. (2024). *MARINA IFCO reusable fish crate data sheet*. Retrieved from <https://www.ifco.com/food-solutions/fish-seafood-reusable-packaging-solution/marina-ifco-reusable-fish-crate/>

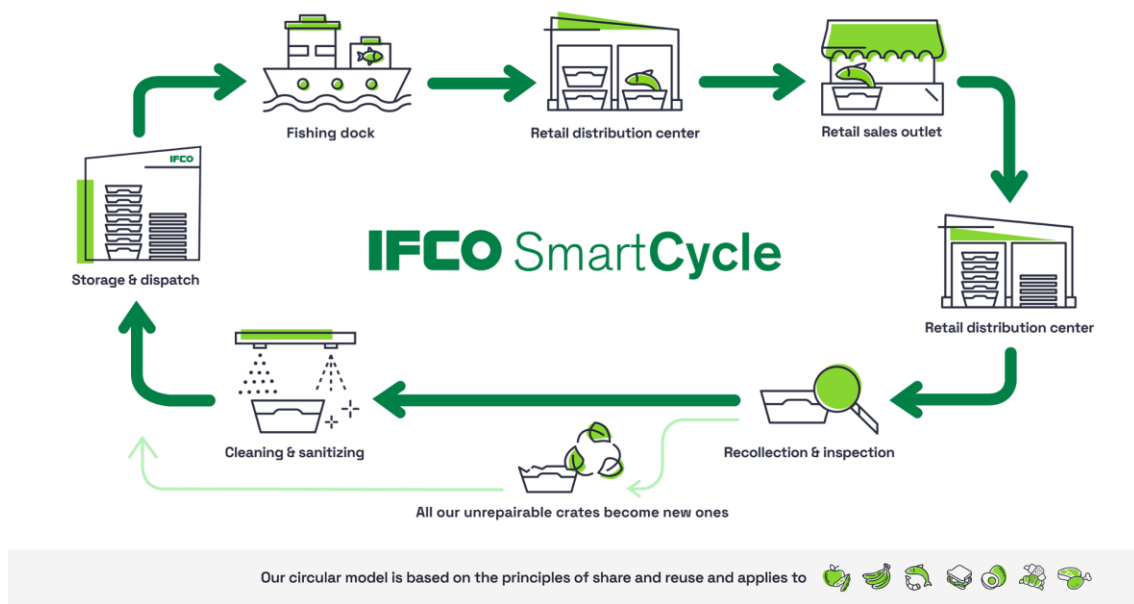


Figure 2-4: IFCO SmartCycle⁴

2.2.5 Non-insulated reusable HDPE box

The non insulated reusable box modelled is a HDPE box with a lid produced in Europe. It has a carrying load capacity of 25kg. The empty containers are nestable for an optimized transport to the fish farm, fish market or fish factory.

The box includes holes for water drainage and allows for the evacuation of melt water. During transport, the meltwater is allowed to drain from the boxes into the lorries, and then, off the lorries to the road through drainage holes.

The logistics of reuse are the same as for the insulated reusable box. Based on interviews with actors of the reusable box industry, the hard plastic boxes (the insulated PP reusable box and the non-insulated HDPE reusable box) are used up to 60 times.

⁴ <https://www.ifco.com/fr/the-ifco-way/smartcycle/>



Figure 2-5. Non-insulated reusable HDPE box with lid⁵

2.3 System boundaries

2.3.1 General system boundaries for the environmental assessment

The life cycle considered extends from raw material extraction to the end-of-life of the box. The main life cycle stages are production, logistic transport, fish distribution (storage and transport), reuse for the relevant boxes, and end-of-life of boxes.

The life cycle steps included in the study are:

- Production and transport of raw materials for boxes
 - For EPS boxes (single use and reusable):
 - ❖ Polystyrene
 - For Cardboard boxes:
 - ❖ Corrugated board
 - ❖ Plastic lining: PET
 - For non-insulated reusable HDPE boxes:
 - ❖ Hard plastic: HDPE
 - For insulated reusable PP boxes:
 - ❖ Hard plastic: PP
- Boxes manufacturing
- Ice production (because the ice is section of the proper packaging to transport fresh fish, it was included as section of the scope)
 - Including the production and EoL⁶ of leak tight bags to pack ice for cardboard boxes
- Transport of the empty boxes to the fish farm, market, or factory
 - Including the production and EoL of tertiary packaging

⁵ Source : (4) BEWI. (2021) *Sustainable packaging product catalog*. Retrieved from https://bewi.com/wp-content/uploads/2021/03/Sustainable_packaging_EN.pdf

⁶ End-of-life.

- Storage of the empty boxes
 - Energy consumption for ambient storage
- Packing of the empty boxes with fish and ice
 - Production and use of glue for the Cardboard boxes
 - Production and EoL of tertiary packaging
- Storage of boxed fish at the emitter (energy consumption for refrigerated storage)
- Fish transport, from the emitter to the receiver (Refrigerated transport)
- Storage of boxed fish at the receiver (energy consumption for refrigerated storage)
- Preparation for the end-of-life
 - For single use and reusable EPS boxes: compaction of the waste boxes
- Reuse of boxes: pre-cleaning, collection, cleaning and sanitizing, and dispatch
 - Including the production and EoL of tertiary packaging
- End-of-life of boxes: transport and treatment

The life cycle steps not included in the LCA are:

- Fish production
 - The production of fish is not section of the impact of the boxes, as such it is not section of the base case.
 - The fish loss and its environmental impacts were studied as section of the sensitivity analysis. The loss rate was considered identical for all boxes in the base case as the boxes are designed so that all hygiene standards are respected.

If the fish loss was to increase, the amount of fresh fish needed to deliver 1 kg to the receiver would increase. For this reason, the influence of fish loss on the impacts of fish production was studied during the sensitivity analysis.
- End-of-life of fish waste (see Fish production)
- Transport of glue since it falls under the cut-off criteria (section 2.6).
- Infrastructure of the manufacturing plants, collection centres and fish farm/market/factory (depreciation of the buildings), since it falls under the cut-off criteria (section 2.6).
- The construction and EoL of the production machines for ice, cardboard box construction and EPS compaction (but their use is included).

2.3.2 Specificities of the economic and social assessment

2.3.2.1 Principles

By default, the system boundaries and the technical assumptions are the same as in the environmental LCA.

The modeling approach to consider the different stages, however, can differ amongst pillars:

- The economic cost assessment often uses product and services prices to account for the production cost of a product or service, that naturally includes the whole upstream supply chain. This simplification relies on the assumption that the difference between the price and the production cost is low.
- The social assessment focusses on the quantification of hours of labour for workers directly involved in the value chain, i.e. in direct contact with the box.

This simplification is justified by the fact that differences in labour intensity across scenarios for indirect activities (electricity production, lorry manufacturing, building construction, etc.) are negligible.

2.3.2.2 Specification of stages and items

The following table specifies the sub-steps modelled in the economic and social assessment and the steps defined by convention used to present the results of the study.

Table 2-1. Steps and sub-steps taken into account for the socio-economic assessment

Step (by convention)	Substep	Economic cost	Social assessment
Box production/re-use/empty box transport	Box production and delivery for single use options	New box cost delivered at gate	Box production labour intensity
	Box production, return logistics and cleaning for re-usable solutions	Modelled cost per use (see Data used section)	Modelled labour intensity
	Empty boxes lorry unloading	Forklift +operator	Operator time
	Empty boxes storage inside	Occupied surface	/
Ice production	Ice production	Ice production cost	Ice production labour intensity
Packing the box with fish and ice	Cardboard box folding machine (only for cardboard)	Machine production, electricity, space, maintenance	Machine production
	Manipulation of the box to pack fish in the box	Labour cost per box	Labour intensity per box
	Cold storage of filled box before transport	Space and energy	/
Fish distribution	Lorry loading	Forklift +operator	Operator time
	Transport	Transport cost	Labour intensity of driver
	Lorry unloading	Forklift +operator	Operator time

	Storage of filled box at destination	Space and energy	/
	Box handling	Labour cost per box	Labour intensity per box
	Waste or reusable box storage	Space outside	/
End of life	Waste box compression (when relevant)	Machine production, electricity, space, maintenance	Machine production
	Waste transport	Transport cost	Labour intensity of driver
	Waste recycling	Material value (positive or negative)	Sorting and pre-treatment labour intensity
	Waste treatment	Incineration cost	Labour intensity

2.4 Spatial validity

The geographical scope for the delivery place is Europe (EU-27). Specific data collection is carried out for Europe.

The spatial representativeness of the data used is further assessed in section 3.4.2.1.

2.5 Time representativeness

Primary data for boxes characteristics have been provided by box manufacturers in 2025.

The time representativeness of the data is further assessed in section 3.4.2.1.

2.6 Cut-off criteria

In practice, completeness is not possible to achieve for all life cycle steps of the modeling. For this reason, ISO 14044:2006 defines the following inclusion criteria, in order to assess whether a component or material production should be considered:

- Contribution to indicators studied
- Contribution to the functional unit mass
- Contribution to the functional unit energy consumption

The exclusion threshold that has been established is 5%. This means that the sum of all elementary flows from non-considered processes must be less than 5% of the contribution to the indicators studied. This threshold is a compromise between precision and feasibility (especially data availability).

Each elementary flow from non-considered processes must be, individually, less than 1% of the contribution to the indicators studied.

In this report, we have collected data using an iterative approach as suggested by ILCD handbook: “In order to achieve the required precision with the minimum necessary effort, it is recommended to collect data and select external data sources in an iterative manner”:

- The first iteration aims at defining important parameters. It is carried out by using rough estimates given by stakeholders that see the “big picture”.
- The second iteration aims at specifying data or parameters that have an important impact. This step is achieved by direct contact with specialists. Gaps identified during the first iteration are filled.
- The third iteration is a final validation of data.

This procedure optimises the time spent on data collection. Indeed, more time is spent on key issues, making the results more reliable and less time is spent on parameters with little influence on results.

As mentioned in ILCD handbook: “The apparent paradox is that one must know the final result of the LCA (so one can show that the omission of a certain process is insignificant for the overall result) to be

able to know which processes, elementary flows, etc. can be left out. This paradox is solved through the procedure described above.

2.7 Impact categories

2.7.1 Environmental LCA

Environmental impacts are grouped into environmental impact categories (see table below) using characterisation factors for the different elementary flows contributing to the same environmental problem. The results of the study are presented using environmental indicators.

Table 2-2 describes the 16 environmental impact categories recommended by the JRC in the PEF guidelines (version EF v3.1 – source (5)). A selection of the relevant impact categories has been carried out, based on the PEF recommendations (normalisation and weighting), in the section 4.1.

Table 2-2. Considered impact categories and reference units

Impact category	Indicator	Unit	Life cycle impact assessment model	Robustness
Climate change – without biogenic CO ₂	Radiative forcing as Global Warming Potential (GWP100)	kg CO ₂ eq	Baseline model of 100 years of the IPCC (based on IPCC 2021)	I
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11 eq	Steady-state ODPs as in (WMO 1999)	I
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model (Rosenbaum et al, 2008)	III/interim
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model (Rosenbaum et al, 2008)	III/interim
Particulate matter	Impact on human health	disease incidence	PM method recommended by UNEP (UNEP 2016)	I
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U235 eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	II
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008	II
Acidification	Accumulated Exceedance (AE)	mol H ⁺ eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	II

Impact category	Indicator	Unit	Life cycle impact assessment model	Robustness
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe	II
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe	II
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model, (Rosenbaum et al, 2008)	III/interim
Land use	Aggregated Soil quality index	Points (dimensionless)	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)	III
Water scarcity	User deprivation potential	m3 water eq of deprived water	Available Water Remaining (AWARE) as recommended by UNEP, 2016	III
Resource use, minerals, and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.	III
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil) ²⁴	MJ	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002	III

Classification of robustness as determined by the JRC is as follows:

I	Recommended and satisfactory
II	Recommended but in need of improvements
III	Recommended, but to be applied with caution
Interim	In development

2.7.2 Economic cost assessment

The result of the economic cost assessment is expressed in **euro exclusive VAT**. The cost modelling must reflect the average situation in the EU. The reference year for the value of one Euro is 2025.

Hence, all cost parameters are expressed in average European price levels for 2025, using Eurostat's purchasing power parities data where relevant, as well as European inflation data to adjust across countries where relevant.

2.7.3 Social job creation assessment

The social job creation result is expressed in social value of job creation, valued in euros.

The rationale is as follows:

- When the unemployment rate lies above the frictional (minimal) level, a more labour-intensive system is generally considered preferable to a less labour-intensive system, *ceteris paribus*, because the more labour intensive system is likely to create jobs.
- Job creation is positively valued for several reasons including the decrease in societal costs to pay for unemployment benefits and social security.

In practice, we follow the prescriptions of EU's Guide to Cost-Benefit Analysis of Investment projects⁷, proposing a set of coefficients corresponding to four typical job market situations existing in the EU to use to compute the social value of job creation, i.e. the difference between labour cost and shadow wage. Using an average of the proposed coefficient, we value one Full Time equivalent at 15 153 EUR/FTE.

⁷ Source : (7) EU. (2015). Guide to Cost-Benefit Analysis of Investment projects - Economic appraisal tool for Cohesion Policy 2014-2020.

2.8 Data sources

2.8.1 LCA study

Firstly, two types of data can be distinguished in LCA studies:

- **Primary data (activity data)** expressing the relationships between processes (e.g.: litre of fuel per km is required for lorry refrigeration)
- **Secondary data (life cycle inventories)** corresponding to the resource use and emissions associated with each unit process and expressed as elementary flows (e.g.: diesel, burned in building machine, GLO, Ecoinvent 3.10)

Furthermore, in each case, two types of sources exist:

- Primary sources: collected directly from EUMPES, box manufacturer, and fish industry representatives
- Secondary sources: collected from LCA reference databases.

The primary data collected for this study cover:

- The technical characteristics of the boxes;
- The fish distribution distance and the amount of fuel linked to refrigeration during transport;
- The energy and water consumption for the box cleaning process.

Concerning primary data collection, RDC Environment organized interviews with EUMEPS, box manufacturers and fish industry representatives. RDC Environment also visited a fish production plant, an EPS recycling plant, a fish market, and a box cleaning facility. Answers have been thoroughly discussed to ensure that figures fit with LCA practitioner's expectations and are used properly.

The secondary sources used are:

- COPERT V for emissions arising from lorry transport
- Ecoinvent 3.10 for all other datasets

The COPERT V database has been chosen as it allows a more specific modeling for lorry transport (see section 3.1.2).

The ecoinvent v3.10 database was selected as it was the latest version available at the start of the study. Additionally, since ecoinvent sometimes issues corrections after releasing a new version, RDC generally waits a few months before adopting the latest release to ensure it is free of significant errors.

2.8.2 Monetisation of the environmental impacts

2.8.2.1 Convert physical impacts in euros for improved interpretation

The monetisation transforms environmental impacts expressed in physical units (e.g. CO₂ eq./ product) into the associated damage cost, expressed in monetary terms (EUR / product).

The monetised environmental impact is calculated to measure global current and future burden caused by the associated environmental impact, valued in euros. The notion of “cost of inaction”, i.e. the cost of not abating pollution, or “environmental externalities” are other ways of putting it.

One key advantage of monetisation is that all impact categories are expressed in a same comparable unit, which is also comparable with other known values, such as the price, turnover and GDP. While the monetised environmental impacts are used for the three-pillar “cost-benefit analysis”, they cannot be used, alone, to compare the environmental impacts of the studied systems and to claim one has lower impacts than the others.

Note that only the share of the environmental cost that is not already taken into account into the economic cost and prices (e.g. via taxation or EU-ETS) is considered. This prevents double counting.

2.8.2.2 Data sources used to monetise

Monetising all environmental categories requires the application of a number of separated specific assessments and methods.

RDC developed a set of monetising factors, using the best available method. A table presenting the sources is presented in appendix.

RDC’s set of indicators follow the principles of reference textbooks such as OECD (2018)⁸, EU (2015)⁹ and the ISO14008:2019 monetary valuation of environmental impacts and related environmental aspects¹⁰.

2.8.3 Economic and social impacts

Information sources fuelling the economic and social modeling include

- The same primary data as for the LCA study: data collection via questionnaires, interviews and visits were conducted to collect information.
- General data coming from institutional data and statistics providers, such as
 - Eurostat
 - EU
- Literature, RDC own models and web search for specific data such as labour intensity of production, transport cost, recycling costs, etc.

⁸ Source : (6) OECD. (2018). *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*, OECD Publishing, Paris, <https://doi.org/10.1787/9789264085169-en>.

⁹ Source : (7) EU. (2015). *Guide to Cost-Benefit Analysis of Investment projects - Economic appraisal tool for Cohesion Policy 2014-2020*.

¹⁰ Source : (8) ISO. (2019). *ISO 14008:2019, Monetary valuation of environmental impacts and related environmental aspects*. Retrieved from <https://www.iso.org/standard/43243.html>

2.9 Biogenic carbon

Biogenic carbon is analysed as any other elementary flow, considering emissions and removals.

In practice, wood growth captures biogenic carbon and cardboard incineration, or degradation emits biogenic carbon. Theoretically the sum of both processes should be neutral, and the inclusion of biogenic carbon should not influence LCA results. There are 3 reasons why the balance may not be neutral:

- a. Some carbon is emitted as methane, with a higher GWP than carbon dioxide.
- b. Some carbon is not emitted and stays for a long period in the Technosphere in products or in waste (concept of delayed emissions)
- c. Tree cut-off is not followed by (same) tree growth¹¹, i.e.
 - either another type of tree/plant grows
 - or the land is used for another biological purpose (agriculture, farming)
 - or the land becomes arid (no plant)

Case a is applicable to the study for the landfill disposal of the cardboard box: 70% of the carbon content of the kraftliner is emitted as CO₂ and 30% as methane.

Case b has not been considered in this study as the box is single use and cardboard degrades quickly.

Case c can be applicable if the forest is not renewed. To be “carbon neutral” a wood consumption needs thus 100% reforestation. If reforestation rate is less than 100%, the biogenic carbon cycle is not neutral anymore and emissions due to end of life may be higher than carbon capture by tree growth. As it is assumed that the wood fibres used to produce the box are sustainably sourced, case c is not applicable.

2.10 Circular Footprint formula

The environmental assessment of recycled products and products containing recycled materials must tackle two types of questions:

- What is the benefit of recycling?
- To which product is this benefit allocated, the product that will be recycled at the end-of-life or the product that uses the recycled material?

The calculation method applied is based on the circular footprint formula (CFF) recommended by the PEF methodology. This calculation method was chosen for the base case as the results from this study are expected to be communicated to the European Commission and EU Fisheries and Aquaculture Advisory Councils.

The “cut-off” method was considered as a sensitivity analysis (cf. section 4.6.4) in order to compare the systems using another method. This method states that the primary user carries the environmental

¹¹ In fact, the carbon of the cut tree has been captured anyway, independently from the use of the cut tree. What counts is the future carbon capture, by the new plant (tree) that takes the place left by the cut tree.

impacts of the production process (this follows the “polluter pays” principle). For this reason, the impact of producing the recycled product from the waste is cut-off from the impacts of the EoL.

The parameters of the CFF are the following:

A	Allocation factor of burdens and credits between supplier and user of recycled materials. <i>A is the percentage of the recycling burdens and credits allocated to the user of the recycled materials.</i>
E_v	Specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material
E_v'	Specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
E_{recycled}	Specific emissions and resources consumed (per unit of analysis) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
E_{recyclingEoL}	Specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process
E_D	Specific emissions and resources consumed (per unit of analysis) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
E_{ER}	Specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, ...).
E_{SE,heat} and E_{SE,elec}	Specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source, heat and electricity respectively.
Q_p	Quality of the primary material, i.e. quality of the virgin material.
Q_{sin}	Quality of the secondary material, i.e. the quality of the recycled material at the point of substitution.
Q_{sout}	Quality of the secondary material, i.e. the quality of the recyclable material at the point of substitution.
R1	It is the proportion of material in the input to the production that has been recycled from a previous system.
R2	It is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.
R3	It is the proportion of the material in the product that is used for energy recovery at EoL.
X_{ER,heat} and X_{ER,elec}	The efficiency of the energy recovery process for both heat and electricity.

LHV Lower Heating Value of the material in the product that is used for energy recovery.

Impact of the recycling content on the impacts of the production of raw materials:

$$(1 - R1) \times Ev + R1 \times (E_{recycled} \times A + (1 - A) \times Ev \times \frac{Q_{sin}}{Q_p})$$

Impact of recycling rate on the impacts of the EoL:

$$(1 - A) \times R2 \times (E_{recycling\ EoL} - Ev' \times \frac{Q_{sout}}{Q_p})$$

Impact of incineration with energy recovery on the impacts of the EoL:

$$R3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

Impact of landfilling on the impact of the EoL:

$$(1 - R2 - R3) \times E_D$$

Table 2-3. Default data for A, Qs/Qp, provided by the PEF method, Annex C

Material	A	Qsin/Qp = Qsout/Qp
EPS	0.5	1
Corrugated board	0.2	1
PET	0.5	1
PP	0.5	0.9
HDPE	0.5	0.9

2.11 Limitations of the study

The outcomes of this study remain applicable to the defined goal and scope, as well as the detailed data provided in the chapter 2.8.1. Nonetheless, it is crucial to acknowledge that the results are influenced by several limitations at various levels.

This section aims to transparently outline the limitations encountered during the assessment process, contributing to a clearer understanding of the reliability and scope of the LCA findings.

■ Limitations related to the lack of primary data regarding the alternative boxes

The alternative boxes are not commonly used by the fish industry today. Therefore, assumptions had to be made.

As there is no alternative insulated reusable PP box currently on market with a 25 kg load carrying capacity, the modelling of the insulated reusable PP box was based on a smaller box (load carrying capacity of 6kg) scaled up.

Because they are not currently used for very long distance transport, the real insulating properties of the alternative boxes are also unknown.

■ Limitations related to the distribution distances

In the Marine Fish PEFCR, the average fish distribution distance in Europe is 2 800 km, it is used as the base case in this study because the results are expected to be communicated to the European Commission and EU Fisheries and Aquaculture Advisory Councils.

However, this distance does not reflect the real average distribution distance in Europe, which is expected to be smaller.

Indeed, using trade data from the three main chilled fish exporters in the EU and EEA (Norway, Sweden and Denmark), **a European average fish distribution distance (for fish traded internationally in the EU) of 2 350 km was calculated**

This distance is below the average cited by the PEFCR and might still be an overestimation of the average transport distance :

- In this assessment, the sample size is limited to three countries while the EU and EEA count 30 members

Most of the countries that were not taken into account in this calculation are found in central Europe. As a result, the export of the fish they produce would require less transport than exports from Norway or Sweden.

- Only international fish transport was taken into account

Due to lack of data regarding the transport of fresh fish produced and consumed in the same country, only the transport of exported fish was taken into account.

The average fish transport distance within each EU and EEA member would be much smaller than the average transport distance related to international trade.

To mitigate the limitations related to the uncertainties regarding distribution distance, **the impact of fish distribution over a distance comprised between 5 and 5 000 km (the longest fish distribution distance in Europe) has been assessed during sensitivity analysis to determine which boxes are the most sustainable depending on distance.**

■ Limitations related to real amount of ice packed in the boxes

In the base case, the amount of ice packed in the boxes is optimised: it is considered to be equal to the amount needed to ensure the fish is in direct contact with the ice throughout distribution (enough ice so that it has not completely melted at the end of distribution) with a 10% excess.

In order to keep a conservative approach and compare the single use EPS box to the best possible alternative solutions, the amount of ice packed in the box was modelled as if the optimal amount of ice was packed in the box for each transport.

In reality, it is difficult to adjust the amount of ice in each box based on the duration of distribution. Indeed, the fish often go through wholesalers and the producer that packs the boxes does not always know their final destination. It is also impossible to add more ice throughout the distribution process as fish boxes must be sealed to guarantee the fish has not been tempered with. The wholesalers are not repackaging the fish contained in one box to send it to different customers.

Currently, all single use EPS boxes (of the studied size) are packed with 5kg of ice no matter the duration of distribution. This amount of ice is enough to guarantee the fish freshness for the maximum temperature in the refrigerated lorries (4°C) for over 6 days (over the maximum distribution duration in Europe).

Other box types (cardboard boxes, non-insulated reusable HDPE boxes) are only used for short distribution distances (same day delivery) and are also packed with 5 kg of ice.

Modelling this practical case would further improve the better positioning of the single use and reusable EPS boxes which have better insulating properties than the alternatives boxes.

Because the amount of ice modelled is the minimum needed for each distance, the impact of the boxes may be underestimated, especially for shorter distances and for boxes with lower insulating properties (e.g. cardboard boxes).

■ Limitations related to the lack of data regarding the reusable EPS boxes

As they do not exist (yet), the reusable EPS boxes were modelled using the specifications of the single use EPS boxes. This means they cannot be stacked when transported empty. However, it is probable that stackable EPS boxes would be developed if the boxes were meant to be reused. So, the impact of the return transport is probably overestimated. During sensitivity analysis, a stackable reusable EPS box was modelled (cf. section 4.6.9).

The box cleaning was modelled as identical to the other reusable box cleaning. However, EPS is porous so the cleaning technology (applied to the current reusable boxes) might not be applicable. If the boxes were to be reused, a different cleaning method could be needed.

■ Limitations related to the calculations of the environmental impact “resource use, mineral and metal” used in the LCA – (does not affect monetised assessment)

This indicator has a low level of robustness according to the PEF guidelines.

In particular, it considers the "ultimate reserve" (content of the Earth's crust in each chemical element) as the maximum amount that could be used.

There is currently no evidence that the ultimate reserve and the ultimately extractable reserve have the same value and, more importantly, are proportional by resource. Consequently, this method fails to address the issue of scarcity. As an example, at the current production rate, there would still be 84 million years of copper production ahead of us based on this ultimate reserve.

This causes difficulties in interpreting the results obtained with this method, as some metals can generate high contributions due to a high characterization factor, although they may not be significantly affected by the scarcity issue.

Note that this limitation does not affect the environmental results when presented in euros. Indeed, to monetise, we use the method recommended by UNEP SETAC (the GLAM methodology), which does not suffer from this limitation.

3 Data used

Some of the data is presented as a fixed value (e.g., the weight of the EPS box is 600 g) while other data is presented as a range (e.g. electricity consumption for ice production is between 0.1255 and 0.2022 kWh/kg).

When data is presented as a range, the base case scenario considers the average value (e.g., 0.16385 kWh/kg for previous example) in the calculation. However, in the sensitivity analysis, multiple iterations are done, and parameters can vary from the bottom bound to the higher bound of each range.

More information on the sensitivity analysis is available in the appendix Annexe 3. R

3.1 Data common to multiple life cycle stages – Environmental LCA

3.1.1 Use of electricity and heat

Electricity and heating mixes considered are average region consumption mixes.

Region-specific dataset is provided by Ecoinvent 3.10, based on IEA data for the reference 2015 (market group for electricity, low voltage – RER, Ecoinvent 3.10). The GHG emissions per kWh used in Europe is 328 g eq CO₂ eq/kWh.

Use of heat or avoided heat production is modelled using the average European mix provided by Ecoinvent 3.10 (heat production, natural gas, at industrial furnace low-NOx >100kW - Europe without Switzerland, Ecoinvent 3.10). The GHG emissions per MJ used in Europe is 82.2 g eq CO₂ eq/MJ.

Avoided heat and electricity are both considered when it comes to energy recovery during the end-of-life incineration.

3.1.2 Lorry transport

Fuel consumptions and airborne emissions from lorries are obtained from the COPERT V methodology (version 5.0). This methodology considers several parameters which influence fuel consumption and related emissions:

- Type of lorry used (lorry capacity, European norm...).
- Average speed throughout the trip.
- Average slope of the route.
- Payload.

Via COPERT V, it is possible to calculate the fuel consumption of a fully loaded lorry.

The payload and empty return rate are taken into account as follows¹²:

¹² Source : (9) ADEME. (2022). CADRE DE REFERENCE - ACV COMPARATIVES ENTRE DIFFERENTES SOLUTIONS D'EMBALLAGES.

$$\text{Consumption(liters)} = \text{distance(km)} * \frac{x}{100} * \left(\frac{2}{3} + \frac{1}{3} * \frac{\text{payload}}{\text{payload max}} + \text{empty return rate} * \frac{2}{3} \right)$$

Where x is the fuel consumption of the fully loaded lorry (maximum payload) expressed in litres/100 km. I.e., two-thirds of the fuel consumption of the fully loaded lorry is associated with the lorry weight and one third with the load.

The empty return rate (section of the trip that the lorry must achieve empty before being reloaded) is assumed to be 29% (European average published by Eurostat, 2008).

The lorries considered in this study:

- Have a maximum payload of 24 tons;
- Are “Articulated 40 Tons” (framework);
- Have an impact when they are empty that represents around 70% of those when lorries are fully loaded (the factor 70% is a coarse average value derived from the COPERT 5 methodology)

Lorries are modelled with 5.3% of EURO 4, 9.4% of EURO 5 and 84.7% of EURO 6 in the Europe¹³.

Diesel supply is modelled with the Ecoinvent 3.10 dataset “market for diesel, low sulphur,” which corresponds to a diesel with a calorific value of 42.8 MJ/kg and sulphur content of 500 ppm.

3.1.3 Train transport

Train transport is modelled based on the tonnage transported and on the transport distance using the Ecoinvent 3.10 dataset “transport, freight train, RER”.

3.1.4 Barge transport

Barge transport is modelled based on the tonnage transported and on the transport distance using the Ecoinvent 3.10 dataset “transport, freight, inland waterways, barge, RER”.

Barge transport is modelled with:

- 45% of large barges with a maximum load over 1500 tons (Source: Ecoinvent Report 14, Table 8.10 Dry bulk Barges). The fuel consumption of those barges is 6.8 g / ton.km (Source: CO₂ emissions in CE Delft 2011, Table 46, “Rhine CEMT VI”).

¹³ Based on the age of the vehicles in Europe in 2023 – EURO6 is considered for lorries constructed from year 2013, EURO V for 2008-21012, EURO IV for before.

Source : (10) EUROSTAT. (2024). *Road freight transport by age of vehicle, EU, 2019, 2022 and 2023 (% share in tonne-kilometres)*. Retrieved from [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Road freight transport by age of vehicle, EU, 2019, 2022 and 2023 \(%25 share in tonne-kilometres\).png](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Road_freight_transport_by_age_of_vehicle,_EU,_2019,_2022_and_2023_(%25_share_in_tonne-kilometres).png)

- 55% of small barges (maximum load <1500 tons). The fuel consumption of those barges is 10.4g / ton.km (Source: CO₂ emissions in CE Delft 2011, Table 46, "Rhine Herne Canal CEMT IV").

The fuel consumption of empty barges is considered as 60% of a fully loaded barge (Source: (11) Eco-transit 2010, IFEU 2010, p 65-66: "It was further assumed that on the empty voyages vessels would require 40 % less power")

The empty return rate (section of the trip that the barge must achieve empty before being reloaded) is assumed to be 50% (Source: (11) Eco-transit 2010, IFEU 2010, p 21: "empty return trips of around 50 % of the time can be assumed").

This means that if the fully loaded trip is 1000km, there is an additional trip of 500 km (50% of 1000 km) to go to the next filling place, consuming 60% (per km) of a fully loaded barge. The equivalent full load trip is thus 1300 km ($1000 + 500 \cdot 60\%$).

3.2 Environmental LCA - Data per life cycle stage

3.2.1 Box production

3.2.1.1 Box specifications

Table 3-1. Single use and reusable EPS box's specifications¹⁴

Specifications		Values
Dimensions	External dimensions (L x W x H)	80 x 40 x 22.5 cm
	Internal dimensions (L x W x H)	74.5 x 34.5 x 17 cm
	Stacking heights (full / empty container)	22.5 cm / 22.5 cm
Material	EPS	
Weight	600 g	
Logistics	Maximum load capacity	25 kg
	Max. number of empty boxes per European pallet (Pallet height of 2m)	27
	Max. number of empty boxes per lorry (33 European pallets)	891
	Max. number of full boxes per European pallet (Pallet height of 2m)	27
	Max. number of full boxes per lorry - based on volume limitations (33 European pallets)	891

The box volume is thus 72l (80*40*22.5 cm³). The volume of the box content is 43.7l (74.5 x 34.5 x 17 cm³). The ratio content/total volume is thus 60.7%.

¹⁴ Source : (1) The Norwegian EPD Foundation. (2019). *Environmental Product Declaration, EPS fish box*.

Table 3-2. Cardboard box's specifications¹⁵

Specifications		Values
Dimensions	External dimensions (L x W x H)	798 x 397 x 177 mm
	Internal dimensions ¹ (L x W x H)	760 x 359 x 158 mm
	Stacking heights (full/empty ¹ container)	177 / 15 mm
Material	Cardboard double-lined with PET	
Weight	1 197.43 g (Corrugated board) + 63.02 g (PET) + 10.55g (glue) = 1271 g	
Logistics	Maximum load capacity	25 kg
	Max. number of empty flat boxes per European pallet ² (Pallet height of 2m)	105
	Max. number of empty flat boxes per lorry (33 European pallets) ²	3 465
	Max. number of full boxes per European pallet ³ (Pallet height of 1.6m ⁴)	27
	Max. number of full boxes per lorry based on volume limitations (33 European pallets) ³	891

The box volume is thus 56.1l (798 x 397 x 177 mm³). The volume of the box content is 43.1l (760 x 359 x 158 mm³). The ratio content/total volume is thus 76.9%.

¹⁵ Source : (2) StoraEnso and LCA Consulting Oy. (2018). *Ecofish box LCA*. Retrieved from <https://info.storaenso.com/fr/ps/ecofishbox-lca-study>

¹ Note: Estimated by RDC Environment

The **internal dimensions** were estimated using the external dimensions of the box, its weight and the density of corrugated board¹⁶: $d = 89.52 \text{ kg. m}^3$.

$$\text{Wall thickness (m)} = \frac{\text{Weight without glue (kg)}}{\text{Density (kg. m}^{-3}\text{) x Wall area (m}^2\text{)}}$$

The wall area considered includes 8 vertical walls (the 4 vertical walls of the box and the 4 vertical walls of the lid) and 2 horizontal walls (the bottom of the box and the top of the lid).

$$\text{Wall thickness (m)} = 0.0095 \text{ m} = 0.95 \text{ cm}$$

² Note: Estimated by RDC Environment



The **maximum number of flat empty boxes per European pallet** was estimated based on the estimated dimensions of a flat box: 1 flat boxes ($L = 115.2 \text{ cm} \times W = 75.1 \text{ cm}$) can fit on a standard $80 \times 120 \text{ cm}$ European pallet and up to 105 stacks / flat box + lid layers (For one stack, $H = 1.9 \text{ cm}$) are possible for a maximum height of 2m.

Figure 3-1. Flat cardboard box without lid¹⁷

³ Note: Estimated by RDC Environment

The **maximum number of full boxes per European pallet** was estimated based on the boxes' external dimensions: 3 full boxes ($L = 80 \text{ cm} \times W = 40 \text{ cm}$) can fit on a standard $80 \times 120 \text{ cm}$ European pallet and up to 9 stacks (For one stack, $H = 17.7 \text{ cm}$) are possible for a maximum height of 1.6m. Thus 27 boxes (3×9) can be put on a pallet.

⁴ The maximum height of 1.60m is used by the fish industry to preserve the structural integrity of the cardboard boxes, which can be weakened by humidity.

¹⁶ Source : (12) M. Cekon, K. Struhala and R. Slávik. (2017). *Cardboard-Based Packaging Materials as Renewable Thermal Insulation of Buildings: Thermal and Life-Cycle Performance*, JOURNAL OF RENEWABLE MATERIALS, <http://dx.doi.org/10.7569/JRM.2017.634135>

¹⁷ Source : (2) StoraEnso and LCA Consulting Oy. (2018). *Ecofish box LCA*. Retrieved from <https://info.storaenso.com/fr/ps/ecofishbox-lca-study>

Table 3-3. Insulated reusable PP box's specifications¹⁸

Specifications		Values
Dimensions ⁴	External dimensions (L x W x H)	800 x 400 x 199 mm
	Internal dimensions (L x W x H)	765 x 365 x 155 mm
	Stacking heights (full/empty container)	200 mm / 100 mm
Material	Polypropylene	
Weight ⁴	2 812 g (crate) + 1 600 g (lid) = 4 412 g	
Logistics*	Maximum load capacity	25 kg
	Max. number of empty stacked boxes per European pallet ⁵ (Pallet height of 2m)	60
	Max. number of empty stacked boxes per lorry ⁵ (33 European pallets)	1980
	Max. number of full boxes per European pallet ⁶ (Pallet height of 2m)	30
	Max. number of full boxes per lorry ⁶ based on volume limitations (33 European pallets)	990

The box volume is thus 63.7l (800 x 400 x 199 mm³). The volume of the box content is 43.3l (765 x 365 x 155 mm³). The ratio content/total volume is thus 68.0%.

⁴Note: Estimated by RDC Environment

The **dimensions of the box** were calculated based on the volume necessary to transport 25 kg of fish and ice and on the wall thickness necessary to carry the load. Based on RDC measurements regarding

the thickness of polypropylene boxes with large carrying load, the thickness of the polypropylene walls has been increased by 1.25 compared to the original box which has a capacity of 6kg.

*The **weight of the box** was calculated based on the weight of the original box and the dimensions of the modelled box.*

⁵*Note: Estimated by RDC Environment*

*The **maximum number of empty boxes per European pallet** was estimated based on the boxes' external dimensions and stacking height: 3 boxes (L = 80 cm x W = 40 cm) can fit on a standard 80x120 cm European pallet and up to 20 stacks (For one stack, H = 10 cm) are possible for a maximum height of 2m.*

⁶*Note: Estimated by RDC Environment*

*The **maximum number of full boxes per European pallet** was estimated based on the boxes' external dimensions: 3 full boxes (L = 80 cm x W = 40 cm) can fit on a standard 80x120 cm European pallet and up to 10 stacks (H = 20 cm) are possible for a maximum height of 2m.*

¹⁸ Source : (3) IFCO. (2024). *MARINA IFCO reusable fish crate data sheet*. Retrieved from <https://www.ifco.com/food-solutions/fish-seafood-reusable-packaging-solution/marina-ifco-reusable-fish-crate/>

Table 3-4. Non-insulated reusable HDPE box's specifications ¹⁹

Specifications		Values
Dimensions	External dimensions (L x W x H)	800 x 400 x 200 mm
	Internal dimensions (L x W x H)	760 x 330 x 160 mm
	Stacking heights (full/empty container)	200/60 mm
Material	HDPE	
Weight	2 050 g box + 910 g lid = 2 960 g	
Logistics	Maximum load capacity	25 kg
	Max. number of empty stacked boxes per European pallet (Pallet height of 2m)	80
	Max. number of empty stacked boxes per lorry (33 European pallets)	2 640
	Max. number of full boxes per European pallet (Pallet height of 2m)	30
	Max. number of full boxes per lorry based on volume limitations (33 European pallets)	990

The box volume is thus 64.0l (800 x 400 x 200 mm³). The volume of the box content is 40.1l (760 x 330 x 160 mm³). The ratio content/total volume is thus 62.7%.

¹⁹ Source : (4) BEWI. (2021) *Sustainable packaging product catalog*. Retrieved from https://bewi.com/wp-content/uploads/2021/03/Sustainable_packaging_EN.pdf

The large difference between external and internal dimensions is due to the shape of the box. The real thickness of the box (0.36 cm) was estimated based off its weight and internal dimensions.

The thickness of the lid is 1.4625 cm.

3.2.1.2 Raw materials production

Table 3-5. Composition of the different boxes

Box	Raw materials	Weight of raw materials (kg)	Recycled content
EPS box (single use and reusable)	Expandable PS (pentane included)	0.636	0% Source: Manufacturer data sheet ²⁰
Cardboard box ²¹	Corrugated board	1.198	88 % Source: Default data provided by the PEF Method, Annex C
	PET	0.0646	0 % Source: Default data provided by the PEF Method, Annex C
Insulated reusable PP box	PP	4.439	0% Source : industry interview
Non insulated reusable HDPE box	HDPE	2.978	0% Source : industry interview

The weight of raw materials needed to produce one box includes the raw materials which will be lost during the production of the boxes: EPS expansion, moulding injection, extrusion ...

All the raw materials were assumed to be produced in Europe.

²⁰ Source : (1) The Norwegian EPD Foundation. (2019). *Environmental Product Declaration, EPS fish box*.

²¹ The glue is not included in the box production stage as it is only added when the box is constructed at the fish farm / market / factory. It is included in the « box packing with fish and ice » stage (Cf. section 3.2.4).

Table 3-6. Datasets used to model raw materials production

Box	Material	Dataset	Dataset source
EPS box (single use and reusable)	Expandable polystyrene (virgin)	polystyrene, expandable, RER	Ecoinvent 3.10
Cardboard box	PET (virgin)	polyethylene terephthalate, granulate, bottle grade, RER	Ecoinvent 3.10
	Container board (virgin)	containerboard production, linerboard, kraftliner, RER *	Ecoinvent 3.10
	Cardboard (recycled)	containerboard production, linerboard, testliner, RER	Ecoinvent 3.10
Insulated reusable PP box	Polypropylene (virgin)	polypropylene, granulate, RER	Ecoinvent 3.10
Non insulated reusable HDPE box	HDPE (virgin)	Polyethylene, HDPE, granulate, RER	Ecoinvent 3.10

***Note:** the dataset “containerboard production, linerboard, kraftliner, RER” models the production of container board whose recycled material content is 27.2%. The data has been corrected so that there is no recycled material included.

The biogenic carbon content of kraftliner is 0.426 kg of carbon / kg (Source: Ecoinvent) which represents 1.56 kg of CO₂ stored in one kg of kraftliner. The biogenic carbon was removed from the Ecoinvent inventory and an elementary flow of CO₂ taken from the air has been added manually to prevent result distortions linked to the Ecoinvent allocations.

3.2.1.3 Transport of raw materials

The transport of raw materials was modelled using the default data provided by the PEF Method²² for the transport distance of raw materials from supplier located inside Europe to the factory in Europe.

The loading rate of lorries for raw materials transport is considered to be 60%: load of 14.4 tons.

²² Source : (13) European Commission. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method*, JRC Technical Reports. Retrieved from https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf

Table 3-7. Mode of transport and distance for the transport of raw materials from supplier to the factory

Mode of transport	Distance (km)
Transport by lorry (cf. Lorry transport)	130
Transport by train (cf. Train transport)	240
Transport by barge (cf. Barge transport)	270

3.2.1.4 Box manufacturing

Table 3-8. Datasets used to model box manufacturing

Box	Material	Dataset	Dataset source
EPS box (single use and reusable)	EPS	polymer foaming, RER*	Ecoinvent 3.10
Cardboard box	PET	extrusion, plastic film, RER	Ecoinvent 3.10
	Corrugated board	N/A	
Insulated reusable PP box	Polypropylene	Injection moulding, RER	Ecoinvent 3.10
Non insulated reusable HDPE box	HDPE	Injection moulding, RER	Ecoinvent 3.10

***Note:** The emissions of pentane linked to polymer foaming in the Ecoinvent dataset is smaller than the primary data received by EPS box manufacturer. Therefore, the elementary flow of pentane emitted to air was modified. It is assumed that all the pentane found in expandable EPS is emitted during EPS expansion.

3.2.2 Distribution of empty boxes to the fish farm / fish market / fish factory

3.2.2.1 Tertiary packaging

The tertiary packaging during the distribution of empty boxes to the fish farm / fish market / fish factory includes, for each pallet:

- One pallet (25 kg for the European pallets) modelled using the Ecoinvent 3.10 dataset “market for EUR-flat pallet, RER”. The pallet is reused 30 times.
- One LDPE plastic film (0.2 kg) modelled using the Ecoinvent 3.10 datasets “polyethylene production, low density, granulate, RoW” and “extrusion, plastic film, RoW”.

The EoL of the tertiary packaging is incineration.

The model is kept simple as this stage has little impact compared to others.

3.2.2.2 Transport of empty boxes

The transport of the boxes was modelled using the default data provided by the PEF Method²³ for the transport distance of packaging material from supplier located inside Europe to the factory in Europe.

Table 3-9. Mode of transport and distance for the transport of packaging material from supplier to the factory

Mode of transport	Distance (km)
Transport by lorry (cf. Lorry transport)	230
Transport by train (cf. Train transport)	280
Transport by barge (cf. Barge transport)	360

Currently, most single use EPS boxes are manufactured in very close proximity to the fish farms or factories where they are used to shorten the transport distance.

The default values may be inadequate for the very specific case of Norway, the transport distance would either be:

- Much shorter than the default PEF distances because the box production line is in proximity of the factory (what is currently the case for single use EPS boxes) ;
- Much longer than the default PEF distances if the boxes were produced in central Europe.

The load of the lorries was calculated for each box type.

²³ Source : (13) European Commission. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method*, JRC Technical Reports. Retrieved from https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf

Table 3-10. weight of empty box and lorryload transported

	Weight of one box (kg)	Number of boxes per pallet	Weight of tertiary packaging for one pallet (kg)	Weight of one filled pallet (kg)	Load for one lorry (kg)
EPS box (single use and reusable)	0.600	27	25.2 (European pallet)	41.4	1 366 (33 European pallets)
Cardboard box	1.260 ²⁴	105	25.2 (European pallet)	157.5	5 199 (33 European pallets)
Insulated PP reusable box	4.412	60	25.2 (European pallet)	289.9	9 568 (33 European pallets)
Non insulated reusable HDPE box	2.960	80	25.2 (European pallet)	262	8 846 (33 European pallets)

3.2.2.3 Ambient storage

The energy consumption linked to ambient storage was modelled based on the recommendations of the PEF Method²⁵.

The default PEF data used is the following:

- In a distribution centre, the storage energy consumption is 30 kWh/m²·year and 360 MJ/m²·year of bought gas (= burnt in boiler)

²⁴ The glue is not included in the transport of the empty box as it is only added when the box is constructed at the fish farm / market / factory. It is included in the « box packing with fish and ice » stage (Cf. section 3.2.4).

²⁵ Source : (13) European Commission. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method*, JRC Technical Reports. Retrieved from https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf

The energy consumption related to the storage of the empty packaging may be overestimated. Indeed, packaging is often stored in warehouse without heating and minimum electricity consumption. Using the default PEF values is a conservative choice. Because the duration of storage in m³.day is the same for each box, no box type is advantaged by this uncertainty.

Assuming a 2m storage height for the box pallets, it results in an electricity consumption of 15kWh/m³/year and 180MJ/m³/year.

- The storage volume needed is 4 times the volume of the product.

The stock of EPS boxes (single use and reusable) is limited to one day supply due to the size of the boxes and the possibility of quick supply.

The duration of the storage of the empty boxes is assumed to be inversely proportional to the storage volume: the smaller the storage volume needed, the longer the box can be stored in the facility.

The storage volume of one empty box was calculated using the volume of one pallet (1.92m³ = 1.2*0.8*2) divided by the number of empty boxes that can be stored on one pallet.

Table 3-11. Storage volume for the empty boxes

Box	Volume occupied by one box (m ³)	Storage volume (m ³)	
		According to PEF, 4 time the volume occupied by one box	Duration of storage (days)
EPS box (single use and reusable)	0.0711	0.284	1
Cardboard box (flat)	0.0183	0.0731	3.9
Insulated reusable PP box (stacked)	0.032	0.128	2.25
Non insulated reusable HDPE box (stacked)	0.024	0.096	6.75

3.2.3 Ice production

3.2.3.1 Amount of ice needed

It is required that fish remains on ice during distribution. The volume of fish that can be transported in a box is the box internal volume minus the volume of ice needed.

There must be enough ice in a box to compensate ice melting and ice melting compensates heat transferred through the box. In a well-insulated box, the amount of ice needed to compensate melting is smaller, allowing to transport more fish per unit of internal volume.

The amount of ice needed during distribution is calculated based on **the amount of heat entering the boxes (Q) through conduction during distribution using Fourier law.**

The amount of heat entering the box depends on:

- The box's insulation properties: thickness of the box's walls (e) and material conductivity (k) and the box's surface exchanging heat with the outside (S) (cf. box dimensions in section 3.2.1.1)

For stacked boxes, the boxes that are at the top corner or the bottom corner of the stack are the ones with the greatest heat exchanging surface: half the box surface is exposed to the outside of the stack, half the box surface is in contact with other boxes and will not exchange heat. To ensure there is enough ice in the boxes, the greatest heat exchanging surfaces have been used during calculation.

- The duration (t) and temperature of distribution (T)

$$\text{Fourier law: } Q = S \times t \times (T - 0^{\circ}\text{C}) \times \frac{1}{\frac{e1}{k1} + \frac{e2}{k2}}$$

As the boxes are closed and not in direct contact with sunlight, the heat exchange linked to convection or radiation is considered negligible.

The amount of ice needed during distribution is:

$$\text{Weight ice (kg)} = \frac{Q}{\text{Heat of fusion of water} = 0.09278 \text{ kWh/kg}}$$

The amount of ice needed is calculated so that an **excess of ice of 10%** remains at the end of distribution if there are no delays. This ensures the freshness of the fish throughout transportation even if there are delays (traffic jams, administrative delays when traveling through borders ...).

Using more than 18 kg of ice per box is not possible. Indeed, with 18 kg of shaved ice (density of 0.445 g/cm³), there would be no more room left in the boxes for fish: the box would be completely filled with ice.

■ Box's insulating properties

Table 3-12. Insulating properties of the different boxes

	Material 1	Thickness 1 (m)	Material 2	Thickness 2 (m)
EPS box (reusable and single use)	EPS $k = 0.037 \text{ W/(m.K)}$ ²⁶	$e = 0.0275 \text{ m}$		
Cardboard box*	Corrugated card-board $k = 0.0486 \text{ W/(m.K)}$ ²⁷	$e = 0.0133 \text{ m}$		
Insulated reusable PP box	Polypropylene $k = 0.11 \text{ W/(m.K)}$ ²⁸	$e = 0.00523 \text{ m}$	Air $k = 0.024 \text{ W/(m.K)}$ ²⁹	$e = 0.0148 \text{ m}$
Non-insulated reusable HDPE box	HDPE $k = 0.35 \text{ W/(m.K)}$ ³⁰	$e = 0.0243 \text{ m}$		

*Note: the impact of the PET coating on the insulating properties of the Cardboard box was considered negligible

The thickness of the box's walls was calculated based on the box's external and internal dimensions, their weight and the density of the material they are made of.

The thermal conductivity of the EPS boxes (single use and reusable) was chosen amongst a range of value based on EUMEPS data. The thermal conductivity chosen for the analysis is the highest, as it is the most conservative option.

²⁶EUMEPS

²⁷ Source : (12) M. Cekon, K. Struhala and R. Slávik. (2017). *Cardboard-Based Packaging Materials as Renewable Thermal Insulation of Buildings: Thermal and Life-Cycle Performance*, JOURNAL OF RENEWABLE MATERIALS, <http://dx.doi.org/10.7569/JRM.2017.634135>

²⁸ <https://www.professionalplastics.com/professionalplastics/ThermalPropertiesofPlasticMaterials.pdf?srsId=AfmBOoq6vSxRTs6EOPYI5aUCQXOONRQN9hmbVgjHQYvX9UrAZCDWvyn>

²⁹ https://www.engineeringtoolbox.com/air-properties-viscosity-conductivity-heat-capacity-d_1509.html

³⁰Source : (14) Chaudhry. (2020). *Thermally enhanced pristine polyolefins: fundamentals, progress and prospective*, Journal of Materials Research and Technology, <http://dx.doi.org/10.1016/j.jmrt.2020.07.101>

The thermal conductivity of the alternative boxes (excluding the reusable EPS box) was chosen to model the best insulating properties possible (best case). Because alternative boxes are not currently used to transport fish over long distances, it is unknown whether the real insulating properties of the boxes will be the same in practice as in theory.

For example, the thermal conductivity coefficient of the corrugated board may vary depending on the humidity of the cardboard and on its structure.

The surface exposed to the air of the lorry is, at worst, half the surface of the box: the boxes at the top and bottom corner of the pallets will be the most exposed, the others are mostly in contact with boxes that are at the same temperature as them (temperature of melting ice).

For this reason, the heat exchanged through the walls of the box and the amount of ice needed were calculated using half the surface area of the boxes.

■ Temperature of transport

Even though the temperature inside distribution lorries varies between 0°C and 4°C, the amount of ice needed is calculated using the maximum temperature of 4°C.

Indeed, the fish producers would not want to risk not having enough ice in their box and losing their fish, as an increase in fish loss is not acceptable from an environmental and economic point of view. The impacts of fish production being much higher than the impacts of the boxes (cf. section 4.6.10), an increase in fish loss would result in larger impacts than what could be gained from using one box rather than another.

■ Duration of transport

The duration of transport was modelled with one driver manning the lorry in the base case and two drivers manning the lorry in the sensitivity analysis.

The duration of transport based on distance was calculated taking account the **EU rules for working in road transport**³¹ :

- A driver can drive up to 9 hours a day (24 hours),
- A driver must take a break of at least 45 minutes for every 4 hours and 30 minutes of driving time,
- A driver must take at least 11 hours of rest for every 24 hours of service,
- If there are **two or more drivers (known as multi-manning)** :
 - Drivers can take their daily 11 hours rest within a period of 30 hours (instead of 24 hours),

³¹ Source : (15) EU. (2025). *EU rules for working in road transport*. Retrieved from https://europa.eu/youreurope/citizens/work/work-abroad/rules-working-road-transport/index_en.htm

- Drivers can take their 45-minute breaks (every 4 hours and 30 minutes) in the vehicle.
- Therefore, two drivers can relay to drive up to 9×2 hours without stopping the vehicle

For a lorry manned by one driver, the driver will rest twice a day: 45 minutes after 4 hours and 30 minutes of driving and again for 45 minutes + 13 hours 30 minutes after another 4 hours and 30 minutes of driving.

For a lorry manned by two drivers, the driver will relay each other every 4 hours and 30 minutes: one driver rests in the lorry 4 hours and 30 minutes while the other drive. For 18 hours, there are no break during which the lorry stops (except a short break for the driver change).

Once the drivers have each driven 9 hours, they cannot drive anymore until the 24-hour period is up: they will stop and rest for 11 hours before driving again.

The results of the calculation regarding the duration of transport depending on the distance with one or two drivers are available in the Figure 3-2.

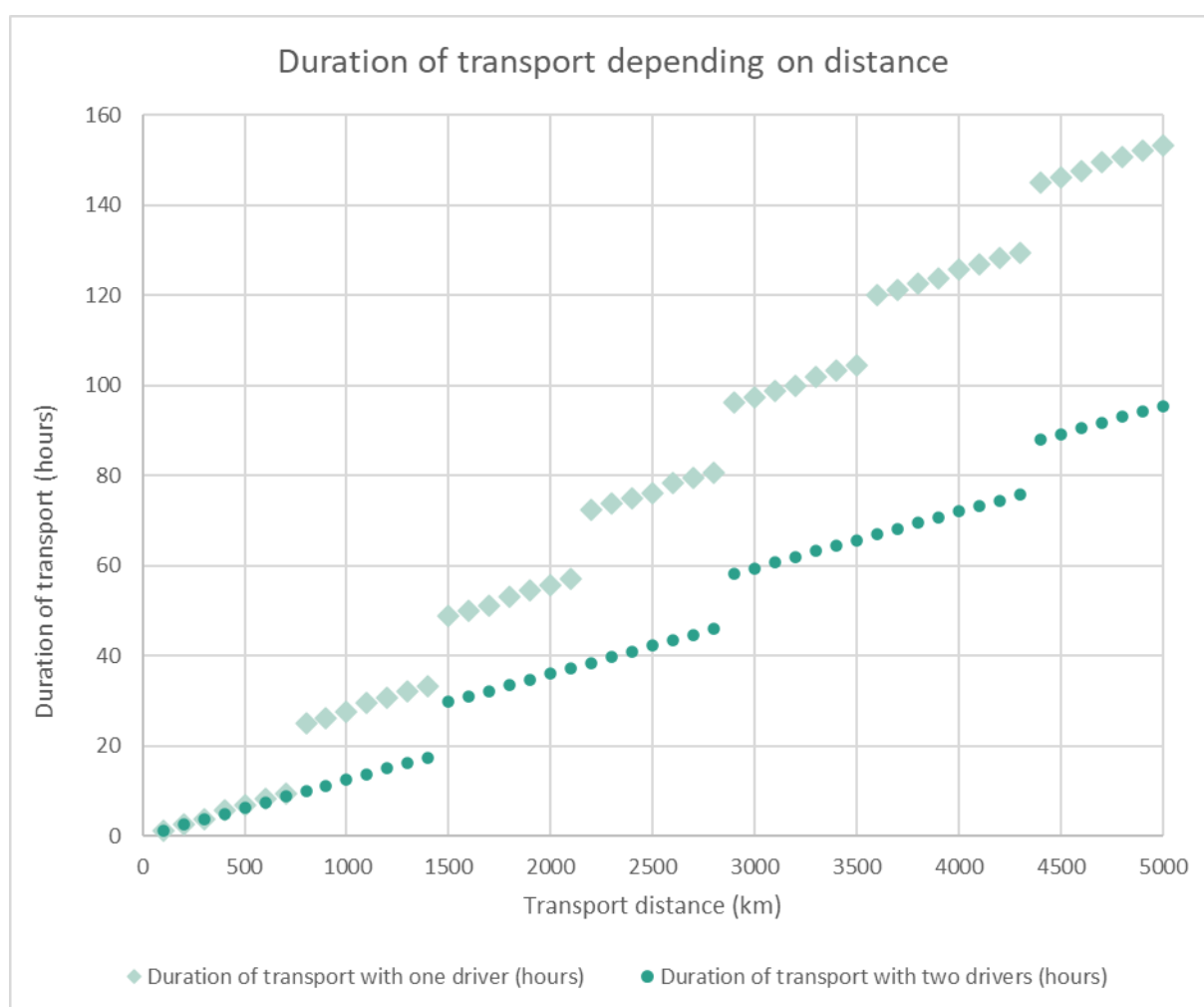


Figure 3-2 : Duration of transport depending on distance for one and two drivers manning the lorry.

The average speed of the lorry, when driving, is assumed to be 80km/hour, which corresponds to the lower bound of the maximum speed limit for trucks in Europe (e.g. Belgium or Germany).

■ Amount of ice packed in the boxes

In the base case, the amount of ice packed in the boxes is optimised: it is considered to be equal to the amount needed to ensure the fish is in contact with ice throughout distribution including a 10% excess.

The amount of ice needed in the box depending on distance was modelled for each box type using Fourier laws. The results are available in the Figure 3-3 and Figure 3-4.

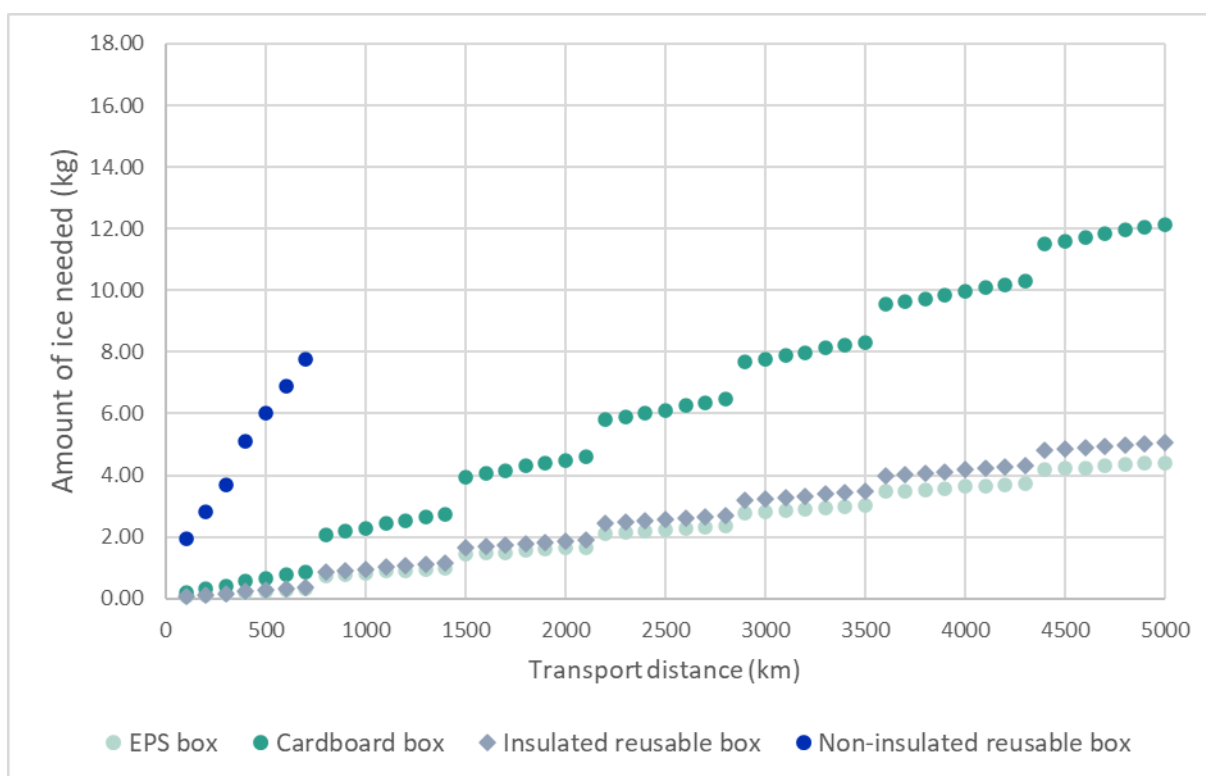


Figure 3-3. Amount of ice needed in each box with one driver

With only one driver, the non-insulated HDPE box cannot be used for transport distances longer than 720 km.

Indeed, after travelling 720 km (9 hours), the lorry driver must stop for the night. During this time, the ice keeps melting. As a result, more than 18 kg of ice would be needed for an overnight trip with the non-insulated HDPE reusable box. Using more than 18 kg of ice per box is not possible. With 18 kg of shaved ice (density of 0.445 g/cm³), there would be no more room left in the boxes for fish: the box would be completely filled with ice.

As a result, the non-insulated HDPE box cannot be used for a transport distance of 2 800 km and is not assessed in the base case.

There are no significant differences between the insulating properties of the insulated reusable PP box and the EPS boxes (single use and reusable) – the difference in the amount of ice needed is less than 10% and those boxes all need less than 5 kg of ice for the longest distances.

The graph below shows the amount of ice needed when two drivers are riding the lorry.

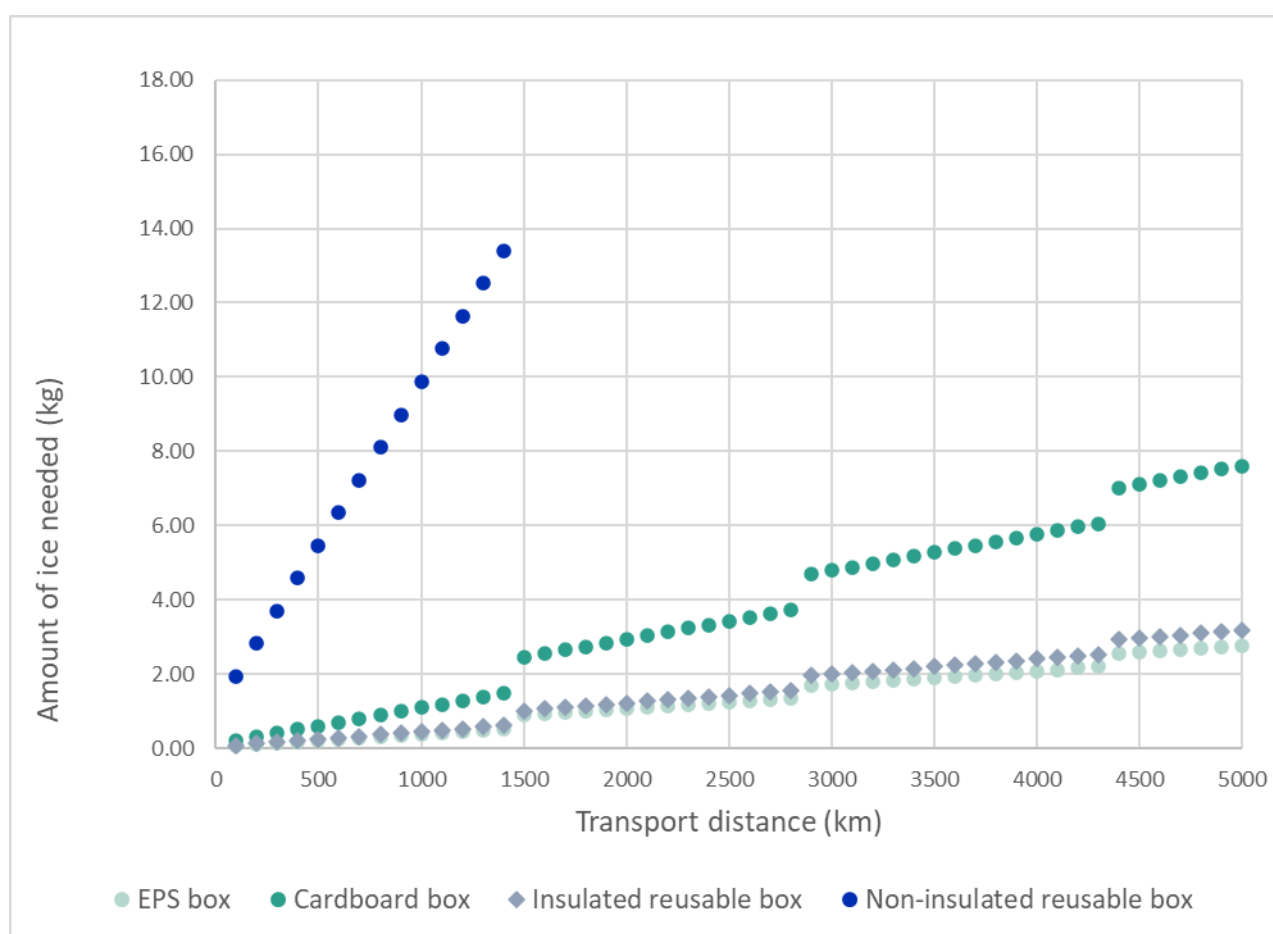


Figure 3-4. Amount of ice needed in each box with two drivers

With two drivers, the non-insulated HDPE box cannot be used for transport distances longer than 1 400 km. Currently, the non-insulated HDPE reusable boxes are only used by the fish industry for shorter transports (same day delivery).

It is difficult to adjust the amount of ice in each box based on the duration of distribution. Indeed, the fishes often go through wholesalers and the producer that packs the boxes does not always know their final destination. It is also impossible to add more ice throughout the distribution process as fish boxes must be sealed to guarantee the fish has not been tempered with.

Currently, all single use EPS boxes (of the studied size) are packed with 5 kg of ice no matter the duration of distribution. This amount of ice is enough to guarantee the fish freshness for the maximum temperature in the refrigerated lorries (4°C) for over 6 days (over the maximum distribution duration in Europe).

For this reason, our model might underestimate the amount of ice that would really be packed in the boxes, especially for shorter distances.

3.2.3.2 Water and electricity use

The production of ice requires:

- **Water** modelled using the Ecoinvent 3.10 dataset “market group for tap water, RER”.

The water used to produce the ice does not go through a specific treatment. If the ice is produced on a fishing boat, sea water is used (this case was not modelled).

- **Electricity to produce the ice**

According to the FAO³² (Food and Agriculture Organization of the United Nations), the energy consumption necessary to produce ice is comprised between **0.2022 kWh/kg of ice** (for a machine with a production capacity of 550 kg/24h and a water temperature of 10°C) and **0.1255 kWh/kg of ice** (for a machine with a production capacity of 10 000 kg/24h and a water temperature of 21°C). The **average** of those two values was used to model ice production.

- **Electricity to store the ice**

The daily electricity consumption for Frozen storage is 0.0044 kWh/day/kg (source: RDC expertise from previous study). Ice storage is assumed to last 5 hours before the ice is used. This means a consumption of 0.001 kWh/kg, i.e. less than 1% of the energy for ice production.

3.2.3.3 Production of leak tight bag for the cardboard box

For cardboard boxes, the ice is packed into watertight LDPE bags.

For the base case, four flat plastic bags are used to pack the ice, each capable of holding up to 1.5kg of ice (3L). The dimensions of one bag are 40cmx20cm with a thickness of 120µm and a weight of 20.5 g. The bags together weigh 82g.

They are modelled using the Ecoinvent 3.10 datasets “polyethylene production, low density, granulate, RoW” and “extrusion, plastic film, RoW”.

The EoL of the plastic bag is incineration.

They are transported to the fish farm/market/factory by lorry (cf. section 3.2.1.3).

3.2.4 Packing the box with fish and ice

As the cardboard box is transport flat to the fish farm/market/factory, a machine and glue are needed to construct the box.

This machine consumes 0.01 kWh of electricity per box (Source: StoraEnso³³).

³² Source : (16) FAO. (2005). *L'utilisation de la glace sur les bateaux de pêche artisanale*, FAO DOCUMENT TECHNIQUE SUR LES PÊCHES 436. Retrieved from <https://www.fao.org/4/y5013f/y5013f05.htm>

³³ Source : (2) StoraEnso and LCA Consulting Oy. (2018). *Ecofish box LCA*. Retrieved from <https://info.storaenso.com/fr/ps/ecofishbox-lca-study>

10.55 g of glue are used for one box. The glue is modelled using the Ecoinvent 3.10 dataset “ethylene vinyl acetate copolymer production, RER”.

3.2.5 Distribution of fish boxes

3.2.5.1 Tertiary packaging

The tertiary packaging during the fish distribution includes, for each pallet:

- One pallet (25 kg) modelled using the Ecoinvent 3.10 dataset “market for EUR-flat pallet, RER”. The pallet is considered to be reused 30 times.
- One LDPE plastic film (0.2 kg) modelled using the Ecoinvent 3.10 datasets “polyethylene production, low density, granulate, RoW” and “extrusion, plastic film, RoW”.

The EoL of the tertiary packaging is modelled with the assumption that the packaging is not recycled. It is incinerated.

3.2.5.2 Refrigerated storage

The energy consumption and refrigerants gases use linked to refrigerated storage were modelled based on the recommendations of the PEF Method.

The default PEF data used is the following:

- In a distribution centre, the storage energy consumption is 30 kWh/m²·year and 360 MJ/m²·year of gas bought (= burnt in boiler)

Assuming a 2m storage height for filled pallets, it results in an electricity consumption of 15kWh/m³/year and 180MJ/m³/year.

- For centres that contain cooling systems, the additional energy use for the chilled or frozen storage is 40 kWh/m³·year (with an assumption of 2m high for the fridges and freezers).
- The storage volume needed is 3 times the volume of the product.

According to the PEF method, the gas content in fridges and freezers is 0.29 kg R404A per m² (retail OEFSR38). A 10% annual leakage is considered (Palandre 2003). The R404A is composed of R143a (52 %), R125 (44%) and R134a (4%).

Because the use of fluorinated refrigerant is limited by European regulation, other refrigerants will be used in the near future. A common replacement is liquid CO₂.

For this reason, the gas chosen to model refrigerant leakage is liquid CO₂. The production of refrigerant gas was modelled using only the Ecoinvent 3.10 dataset “market for carbon dioxide liquid, RER”.

The refrigerant gas leakage to air was modelled using elementary flows.

The volume occupied by one box was calculated using the volume occupied by one pallet (1.92m³ = 1.2*0.8*2) divided by the number of full boxes that can be stored on one pallet.

Table 3-13. Storage volume for the full boxes

Box	Volume occupied by one box (m ³)	Storage volume (m ³)
		According to PEF, 3 times the volume occupied by one box
EPS box (single use and reusable)	0.0711	0.213
Cardboard box	0.0711	0.213
Insulated reusable PP box	0.064	0.192
Non insulated reusable HDPE box	0.064	0.192

The duration of the storage of box is assumed to be 3 hours before transport at the emitter and 3 hours after transport at the receiver before the boxes are unpacked³⁴.

According to fish industry representatives, the temperature of storage averages is comprised between 0 and 2°C. As the temperature of storage is above 0°C, the duration of storage will have an impact on the amount of ice required to fulfil hygiene requirements (Cf. section 3.2.3).

3.2.5.3 Transport

In this study, the transport of the fish is considered to be done exclusively by lorry.

1. Loading rate of lorries

The number of pallets that can be transported is limited by the maximum load of the lorry (24 tons); not by the volume (with the exception of the EPS boxes, single use and reusable). It was calculated for each box.

Table 3-14. Number of boxes per pallet, number of pallets per lorry and lorry load

	Weight of one filled box (kg)	Number of boxes per pallet	Weight of tertiary packaging for one pallet (kg)	Weight of one filled pallet (kg)	Number of European pallets per lorry	Lorry load (tonnes)
EPS box	25.6	27	25.2	716	33	23.6

³⁴ Source: Industry interview

(single use and reusable)						
Cardboard box	26.34	27	25.2	736.4	32	23.6
Insulated reusable PP box	29.412	30	25.2	908	26	23.6
Non insulated reusable HDPE box	27.91	30	25.2	862.5	27	23.3

2. Average fish distribution distance

In the Marine Fish PEFCR, the average fish distribution distance in Europe is 2 800 km. It is used as the base case in this study because the results are expected to be communicated to the European Commission and EU Fisheries and Aquaculture Advisory Councils.

This average fish distribution distance might be overestimated.

Indeed, another average fish distribution distance was estimated using trade data from 2022 sourced from the World Integrated Trade Solution³⁵.

The trade data was first used to determine which countries in the EU and EEA are the main exporters of fresh chilled fish to other EU and EEA countries. Three countries were countries selected for further analysis: Norway, Sweden and Denmark. Together those countries export more than 90% of the fresh fish exported by the EU and EEA.

For each of these countries, the average fish distribution distance during export was calculated using the amount of fish (in kg) exported to each EU and EEA countries and the average distance separating them from those countries.

Table 3-15. Average chilled fish distribution distance during export for Norway, Sweden and Denmark

Country	Average distribution distance during export (km)
Norway	2 370

³⁵ World Integrated Trade Solution, <https://wits.worldbank.org/>

Sweden	2 380
Denmark	1 580

Using data from those three countries, a European average fish distribution distance of 2 350 km was calculated. This distance is below the average cited by the PEFCR and might still be an overestimation of the average transport distance:

- In this assessment, the sample size is limited to three countries while the EU and EEA count 30 members
Most of the countries that were not taken into account in this calculation are found in central Europe. As a result, the export of the fish they produce would require less transport than exports from Norway or Sweden.
- Only international fish transport was taken into account
Due to lack of data regarding the transport of fresh fish produced and consumed in the same country, only the transport of exported fish was taken into account.
The average fish transport distance within each EU and EEA member would be much smaller than the average transport distance related to international trade.

As fish can be transported over distances as small as a few kilometres (e.g., from the fishing boat to the fish market) and over very large distances (e.g., from the north of Norway to the south of Europe) and because of the uncertainty regarding the average fish distribution distance in Europe, **the impact of fish distribution over a distance comprised between 5 and 5 000 km (the longest distribution distance in Europe) has been assessed during sensitivity analysis to determine which boxes are the most sustainable depending on distance.**

3. Lorry refrigeration

Fuel consumption linked to refrigeration is obtained from primary sources in the fish industry (Lisner). For a refrigerated lorry capable of transporting 33 standard European pallets, whose temperature is kept between 0°C to + 4°C, the fuel consumption linked to refrigeration is 0.027 litres of diesel per km for an average speed of 80 km/hour, which is equivalent to 2.16 litres of diesel / hour of transport.

A sensitivity analysis regarding energy consumption for refrigeration during distribution was performed in order to assess the impact of the weather on distribution: the energy consumption for refrigeration would be higher if the outside temperature is very high and lower if it is very low.

A range of energy consumption +/- 50% of the average was used during the sensitivity analysis.

Diesel supply and fuel combustion is modelled with the Ecoinvent 3.10 dataset “diesel, burned in diesel-electric generating set, 18.5kW” with 1 MJ equal to the consumption of 0.0234 kg of diesel.

Because the use of fluorinated refrigerant is limited by European regulation, other refrigerants will be used in the near future. A common replacement is liquid CO₂.

For this reason, the gas chosen to model refrigerant leakage is liquid CO₂. The production of refrigerant gas was modelled using only the Ecoinvent 3.10 dataset “market for carbon dioxide liquid, RER”.

The refrigerant gas leakage to air was modelled using elementary flows.

For a 40-foot, high cube reefer, 7.69x10⁻⁸ kg of refrigerant leaks per kg of merchandise stored for one day.

3.2.6 Reuse system

3.2.6.1 Return rates

- For the reusable hard plastic boxes, the number of uses is comprised between 10 and 60.³⁶
- For the reusable EPS boxes, the number of uses is comprised between 2 and 5.

Currently, EPS boxes are not reused in the fishing industry.

As EPS boxes for electronics are used between 3 and 5 times on average because they are fragile, it is assumed that boxes that similar boxes that will also need to be cleaned cannot be reused a larger amount of time (Source : EUMEPS).

The highest number of uses was used as base case to make a conservative comparison between the single use EPS box and alternatives: the single use EPS boxes are compared to the best possible alternatives.

The reuse-system is modelled using three parameters:

- **The return rate:** percentage of boxes returned after one use
- **The scrap rate:** percentage of boxes that are no longer functional after each return
- **The collection rate:** percentage of boxes that have been collected across all uses

$$\text{Collection rate} = (\text{return rate})^{\text{number of uses}}$$

Table 3-16. Return rate, scrap rate and collection rate for reusable boxes

	Number of uses	Return rate	Scrap rate	Collection rate
Reusable EPS box	2	85%	35%	72.3%
	5 (base case)	85%	5%	44.4%

³⁶ Industry interview

Insulated reusable PP box	10	95%	5%	59.9%
	60 (base case)	99%	0.675%	54.7%
Non insulated reusable HDPE box	10	95%	5%	59.9%
	60 (base case)	99%	0.675%	54.7%

For the hard plastic reusable boxes, the return rate and scrap rate used come are assumptions coming from previous RDC studies where the reusable packaging was also used between 10 and 60 times.

The return rate for the reusable EPS boxes are also assumptions. They are lower than the return rate for the other reusable box as the reusable EPS box are not stackable (more difficult to store and transport) and more fragile. As a result, they are more likely to be discarded before collection.

The scrap rate for the reusable EPS boxes is higher than the scrap rate for the hard plastic boxes as EPS is more fragile and more likely to be damaged.

3.2.6.2 Collection

The tertiary packaging during the collection of reusable boxes includes, for each pallet:

- One pallet (25 kg for the European pallets) modelled using the Ecoinvent 3.10 dataset “market for EUR-flat pallet, RER”. The pallet is considered to be reused 30 times.
- One LDPE plastic film (0.2 kg) modelled using the Ecoinvent 3.10 datasets “polyethylene production, low density, granulate, RoW” and “extrusion, plastic film, RoW”.

The EoL of the tertiary packaging is modelled with the assumption that the packaging is not recycled. It is incinerated.

The reusable boxes are collected and sent to the collection centres by lorry. According to industry interviews the average collection distance is between 100 and 200 km.

The number of boxes that can be transported at once and the loading rate of lorries are the same as for the empty box transport (Cf. Transport of empty boxes).

3.2.6.3 Cleaning and sanitizing

The reusable boxes need to go through a rigorous cleaning, sanitizing and drying process in order to maintain hygiene.

Before collection, they are pre-cleaned with water (1L of cold water / box). Cold water is modelled with the Ecoinvent 3.10 dataset “tap water, market group – RER”

The boxes are then cleaned three times: at the collection center, after arrival at the fish farm/fish market/fish factory and right before use.

The automated cleaning³⁷ process was included:

- Cold water: between 3.65 L and 4.87 L per box
- Hot water: between 3.65 L and 4.87 L per box
Hot water is modelled using cold water and heat. The amount of heat (in MJ) necessary to heat the water is calculated using the temperature of hot water (60°C) and the specific heat of water (4190 J/(kg.°C))
- Cleaning agent, sodium hydroxide: between 12g and 16g per box.
It is modelled using the Ecoinvent 3.10 dataset “sodium hydroxide to generic market for neutralising agent – RoW”.
- Electricity use: 0.49 kWh per box.

3.2.6.4 Dispatch

The tertiary packaging during the dispatch of reusable boxes includes, for each pallet:

- One pallet (25 kg for the European pallets) modelled using the Ecoinvent 3.10 dataset “market for EUR-flat pallet, RER”. The pallet is considered to be reused 30 times.
- One LDPE plastic film (0.2 kg) modelled using the Ecoinvent 3.10 datasets “polyethylene production, low density, granulate, RoW” and “extrusion, plastic film, RoW”.

The EoL of the tertiary packaging is modelled with the assumption that the packaging is not recycled. It is incinerated.

The boxes are dispatched to the end-user by lorry. **As fish production and fish consumption are not evenly distributed geographically, the local reuse of the boxes (100 km – 200km) is not always possible:**

- In 2022, four EU countries were responsible for about two-thirds (67.0 %) of the EU's total output in tonnes live weight of farmed aquatic organisms ; Spain produced a little over one-quarter (an estimated 25.2 %) of the total, followed by France (17.0 %), Greece (13.0 %) and Italy (12.0 %).³⁸
- At the same time Germany and Poland, which together produce only 7.5% of the fish tonnage, consume 23% of all processed chilled seafood.³⁹
- Norway, Sweden and Denmark are responsible for 5% of the fish consumption by EU and EEA countries but are responsible for 90% of chilled fish exports within the Eu and EEA.

³⁷ Data from an automated reusable box cleaning plant in Boulogne-sur-Mer fish market

³⁸ Source : (17) EUROSTAT. (2025). *Aquaculture statistics*. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture_statistics

³⁹ Source : (18) EUMOFA. (2024). *THE EU FISH MARKET*. Retrieved from https://eumofa.eu/documents/20124/145239/EFM2024_EN.pdf

The base case model includes, out of 4 reuse, 1 local reuse (dispatch distance = 100 km - 200 km) and 3 return to the first user (the dispatch distance is the same as the fish distribution distance). This proportion of local reuse is an assumption because of the lack of exhaustive data regarding the domestic fish market in each EU and EEA country and regarding intra EU and intra EEA trade.

Because 90% of the chilled fish traded between EU and EEA countries comes from Norway, Sweden and Denmark, less than 10% of the chilled fish would be traded between central European countries. As a result, the 25% local reuse may be an overestimation. Because this overestimation would be in favour of the reusable alternatives to the single use EPS box, it is a conservative assumption.

The impact of the number of local reuse (proportion of local reuse from 25% to 75%) has been assessed during sensitivity analysis.

The number of boxes that can be transported at once and the loading rate of lorries are the same as for the empty box transport (Cf. section 3.2.2.2).

3.2.6.5 Storage

The reuse phase also includes storage:

- Before collection, the boxes that are to be returned are stored
- At the distribution centre
- At the fish market / fish farm

The energy consumption linked to ambient storage was modelled based on the recommendations of the PEF Method (Cf. 3.2.2.3. Ambient storage).

The duration of storage is assumed to be 7 days at each step of the reuse chain.

3.2.7 End-of-life of boxes

3.2.7.1 End-of-Life pre-treatment

The EPS boxes (single use and reusable) that are to be recycled are first compacted using a compaction machine that consumes between 0.279 kWh / kg of EPS and 0.391 kWh / kg of EPS⁴⁰.

For the single use EPS boxes, the proportion of EPS that will be compacted is equal to the recycling rate of EPS.

For the reusable EPS boxes, the proportion of EPS that will be compacted is equal to:

Collection rate x recycling rate of collected EPS boxes + (1-collection rate) x recycling rate of mixed plastic packaging

⁴⁰ Barton tech, *Compactor EPS C200*, <https://bartontech.eu/products/eps-compactors/compactor-eps-c200/>

The cardboard boxes are manually flattened before transport.

3.2.7.2 End-of-life transport

The boxes are transported to the treatment facility by lorry. The amount of waste boxes that can be transported is equal to the amount of empty boxes that can be transported at once (Cf. section 3.2.2).

The distance to the treatment facility is detailed in the Table 3-17. Distance to treatment facility.

Table 3-17. Distance to treatment facility

Treatment	Distance	Source
Plastic recycling	424 km	ADEME, 2022
Complex cardboard recycling	449 km	ADEME, 2022
Incineration	100 km	RDC Assumption
Sanitary landfill	100 km	RDC Assumption

3.2.7.3 End-of-life treatment

The end-of-Life of single use boxes is described in the [Table 3-18](#).

Table 3-18. End-of-life – single use boxes

	EoL treatment	%	Source
EPS box (single use)	EPS box – to recycling ⁴¹	77.5%	Global tracker
	EPS box – to incineration (with energy recovery)	22.5%	European landfill directive (2004)
	EPS box – to landfill	0%	European landfill directive (2004)
Cardboard box	Cardboard box – to recycling	61%	ADEME, 2023 ⁴²
	Cardboard box – to incineration (with energy recovery)	39%	European landfill directive (2004)
	Cardboard box – to landfill	0%	European landfill directive (2004)

The current recycling rate for EPS in Europe is 55%, this rate is expected to rise and may reach 100%. For this reason, an average value between 100% and 55% was chosen as the base case. The uncertainty regarding the recycling rate was studied during sensitivity analysis.

Recycling cardboard coated with plastic is currently a challenge for recyclers and the current recycling rate is considered to be very low. Nevertheless, it is assumed the same recycling rate as other complex cardboard could be achieved : this recycling rate is currently 61% in France according to the ADEME. The uncertainty regarding the recycling rate was studied during sensitivity analysis. According to recyclers, only the cardboard of the complex cardboard boxes can be recycled. In our case, which means the PET coating is never recycled, it is always incinerated.

Based on the European landfill directive (2004), it is not allowed to landfill waste with more than 5 % TOC (total organic carbon). Therefore, plastic packaging waste or cardboard packaging waste that has not been sent to recycling should not be landfilled but incinerated instead.

The end-of-life of reusable boxes is described in the [Table 3-19](#).

Scrapped boxes (boxes too damaged that are disposed of after inspection at the service centre) are considered to be all sent to recycling.

The end-life of lost boxes (boxes that go missing after a rotation) is more difficult to assess because the boxes are not in a well-defined cycle anymore. These boxes are considered to be incinerated.

Table 3-19. End-of-life – Lost and scrapped reusable boxes

EoL treatment			Source
Boxes scrapped <i>Disposed after inspection at the service center</i>	Insulated PP reusable box – to recycling	100 %	IFCO, 2025
	Non-insulated HDPE reusable box – to recycling	100 %	IFCO, 2025
	EPS box (reusable) – to recycling	100 %	Assumption
Lost boxes* <i>Boxes lost during the rotation</i>	Insulated reusable box PP – to incineration (with energy recovery)	100 %	Assumption
	Non-insulated reusable box HDPE – to incineration (with energy recovery)	100 %	Assumption
	Reusable EPS box – to incineration (with energy recovery)	100 %	Assumption

*Note: the EoL of lost boxes is assumed to be 100 % incineration. Indeed, a lost box is not likely to properly sorted and thus sent to recycling. Based on the European landfill directive (2004), it is not allowed to landfill waste with more than 5 % TOC. Therefore, plastic packaging waste should not be landfilled but incinerated instead.

⁴¹ The current recycling rate of EPS is 55% in Europe (EUMEPS) but is expected to reach 100% in an optimized scenario.

⁴²Source : (19) ADEME, Direction de la Supervision des filières REP. (2023). *Note de calcul*. Retrieved from <https://www.ecologie.gouv.fr/sites/default/files/documents/Note%20ADEME%20%20co%C3%BBt%20%20r%C3%A9f%C3%A9rence%20SPGD%202024%20ao%C3%BBt%202023.pdf>

Table 3-20: End-of-life – Datasets used to model the EoL treatments

Boxes	Data sets used					
	$E_{v'}$	$E_{\text{recyclingEoL}}$	E_D	E_{ER}	$E_{SE,heat}$	$E_{SE,elec}$
EPS box (single use and reusable)	Polystyrene production, general purpose, RER	Polyethylene production, high density, granulate, recycled, Europe without Switzerland	Treatment of waste polystyrene, sanitary landfill, RoW	Treatment of waste polystyrene, municipal incineration, GLO	Heat production, natural gas, at industrial furnace low-NOx >100kW, Europe without Switzerland	Market group for electricity, low voltage, RER
Insulated reusable PP box	Polypropylene, PP, granulate, at plant, RER		Treatment of waste polypropylene, sanitary landfill, RoW	Treatment of waste polypropylene, municipal incineration, GLO		
Non insulated reusable HDPE box	Polyethylene, HDPE, granulate, at plant, RER		Treatment of waste polyethylene, sanitary landfill, RoW	Treatment of waste polyethylene, municipal incineration, GLO		
Cardboard box	Container-board production, liner-board, kraft-liner, RER	Container-board production, liner-board, testliner, RER	Treatment of waste polyethylene terephthalate, sanitary landfill, RoW Treatment of waste paperboard, sanitary landfill, RoW	Treatment of waste polyethylene terephthalate, municipal incineration, GLO Treatment of waste paperboard, municipal incineration, GLO		

E_v'	Specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
$E_{\text{recyclingEoL}}$	Specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process
E_D	Specific emissions and resources consumed (per unit of analysis) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
E_{ER}	Specific emissions and resources consumed (per unit of analysis) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, ...).
$E_{SE,heat}$ and $E_{SE,elec}$	Specific emissions and resources consumed (per unit of analysis) that would have arisen from the specific substituted energy source, heat and electricity, respectively.

3.2.7.4 Focus on cardboard boxes

The carton of complex cardboard can be recycled. It is assumed that the other components of the complex cardboard (PET coating) are not recycled⁴³. For cardboard boxes that are selectively collected, the transport of selective collection is taken into account, and it is considered that, along this route, all materials other than carton are incinerated.

For cardboard boxes that are not selectively collected, the impact of the degradation of biogenic cardboard found in the box need to be taken into account as methane, which is emitted during sanitary landfill, has a higher impact on climate change than CO₂.

Figure 3-5 and Table 3-21 describe the modeling of emissions in landfill due to cardboard decomposition in landfill.

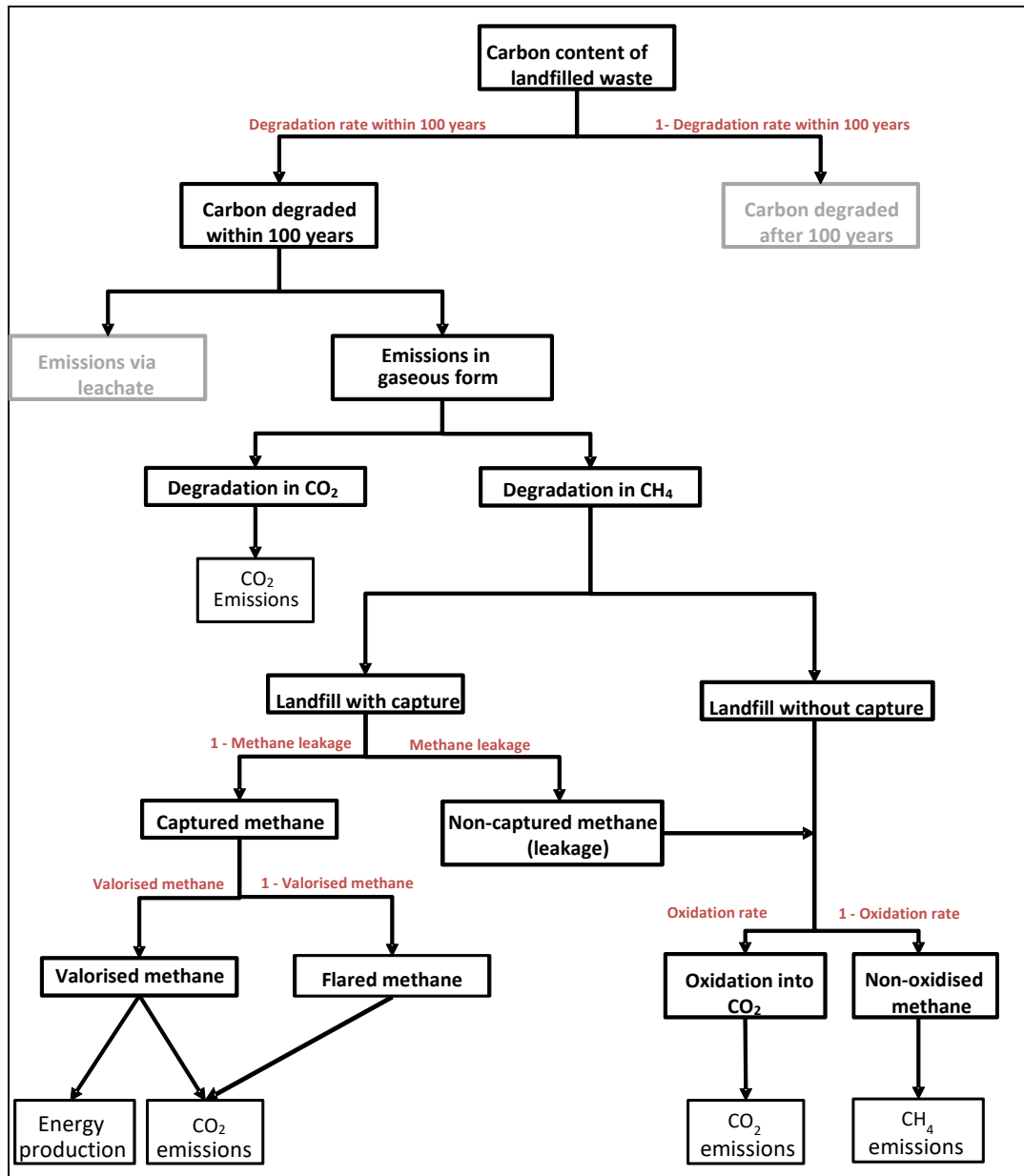
Table 3-21. End-of-life – Parameters of modeling of carbon emissions due to material degradation in landfill

	Value / default values if editable	Source
Degradation rate (within 100 years)		
Cardboard	44%	

⁴³ Source : (20) CITEO. (2025). *Les défis du matériau papier-carton*. Retrieved from <https://www.citeo.com/le-mag/les-defis-du-materiau-papier-carton>

	Value / default values if editable	Source
Share of emissions		
Section of degraded carbon emitted in gaseous form	97.1%	Ecoinvent
Fraction gaseous emissions as CO ₂ versus CH ₄	50%	IPCC recommendation 2006
Fraction of methane in leakage that oxidizes into CO ₂	10%	IPCC recommendation 2006
Characteristics of landfill sites		
Share of methane captured in landfills	70%	RDC Assumption
Share of captured methane valorised as electricity (the remaining section is flared)	75%	RDC Assumption
LHV of methane	13.9 kWh/kg	French study: « RECORD, Application de la méthode Bilan Carbone® aux activités de gestion des déchets, 2009, 133 p, n°07-1017/1A » p79 - p 83 – p103
Efficiency of electricity production	30%	Assumption based on the range of values available in different studies: • 33% in the study “Record” p103 • 28% in ecoinvent report “Life Cycle Inventories of Waste treatment Services – Section II”, 2009
No thermal valorisation		Assumption

Figure 3-5. Scheme of the modeling of carbon emissions in landfill



3.3 Key economic and social data

All technical parameters are common to the three pillars and presented in sections related to the environmental LCA.

This section presents the key economic and social data determining the difference in cost and labour intensity (cf. Annexe 5).

3.3.1 Box production

3.3.1.1 Economic cost assessment

The following values are considered.

Table 3-22. Data used for economic cost assessment – box production

Box	Box cost, delivered at gate (new box)	Source
EPS, single use	2.37 €/box	Industry data, based on an optimised scenario
Cardboard, single use, including ice bags	2.61 €/box	Modelled cost based on ■ The cardboard box cost is based on observed prices for similar boxes sold in pallet loads (Extrapolated based on weight) ■ A 20% reduction is considered as a result of optimisation due to scaling ■ A PET layer corresponding to 5% of the weight is considered ■ LDPE bags (82g, empty) to hold the ice are considered (0.164€/box) ■ The cost related to the machine to fill the bags with ice is considered. Ice is considered separately for all boxes.
Insulated reusable PP box	20 €/box	RDC assumption based on interviews and web search
Non-insulated reusable HDPE box	10 €/box	
EPS, reusable	2.37 €/box	Same box as EPS single use.

3.3.1.2 Social assessment

The following values are considered.

Table 3-23. Data used for social assessment – box production

Box	Labour intensity	Source
-----	------------------	--------

EPS, single use	4.65116E-05 ETP/kg EPS	RDC assessment based on EUMEPS data in EUMEPS, 2021, <i>The EPS-industry's journey towards circularity</i> .
Cardboard, single use	1.29856E-06/kg cardboard	RDC assumption based on FEFCO 2023 activity report
Insulated reusable PP box	See reuse system data.	
Non-insulated reusable HDPE box		
EPS, reusable	4.65116E-05 ETP/kg EPS	Same box as EPS single use.

3.3.2 Ice production

3.3.2.1 Economic and social assessments

Table 3-24. Data used for economic and social assessments – ice production

Item	Value	Source
Economic cost	0.08 €/kg	Assumptions based on industry interviews, based on an industrial ice production facility (optimised production).
Labour intensity	4.54545E-07 ETP/kg	

3.3.3 Distribution of fish (filled boxes)

Table 3-25. Data used for economic cost assessment – fish distribution

Item	Average value	Source
Refrigerated lorry, 26 T, one driver	1.59 €/km	RDC model based on a combination of: ■ Data from French “Comité national routier” publications ■ Data from interviews with fish transporters ■ Cross check with fuel consumptions considered in the LCA model. The model separates the costs proportional to the distance, the costs proportional to the working hours of the driver and the costs proportional to the duration of unavailability of the lorry due to its use.
Refrigerated lorry, 26 T, two drivers	1.49 €/km	

		■ The models considers time spent resting as explained in section 3.2.3.1 Amount of ice needed in the title <i>Duration of transport.</i> ■ The second driver is assumed to receive a prime corresponding to 25% of the salary when not driving while the lorry is riding.
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The labour intensity of transport corresponds to the duration of driving + 45 min pause every 9 hours, including a waiting time during loading and unloading.

Inside storage space cost is valued at 80€/m² (RDC assumption based on Cushman and Wakefield 2023).

Energy used is valued using the consumption data considered in the environmental model.

3.3.4 Reuse system

3.3.4.1 Modeling principles

A custom economic and social model was built to assess the cost and labour intensity of the return and cleaning logistics per use. The model considers optimised and largely automatised box sorting and cleaning facilities.

The parametrisation of the model relies on the following principles

- Consistency with assumptions used in the environmental model, i.e. number of rotations, dispatch transport distances, lorry loading optimization, water and energy consumption.
- Coherence with a set of different independent sources:
 - Industry interviews relating i.e. the price per use of different reusable box and crate types;
 - Cleaning facilities site visits;
 - Literature review.

3.3.4.2 Results of the reuse cost and labour intensity model

Table 3-26. Data used for economic and social assessments – reuse

Box type	Cost per use	FTE per use
EPS reusable	5.91 €/use	3.32734E-05
Non-insulated reusable HDPE box	1.35 €/use	7.3765E-06
Insulated reusable PP box	3.12 €/use	0.000018

As an example, the graph below shows the estimated cost per use for a non-insulated reusable HDPE box, in the base case.

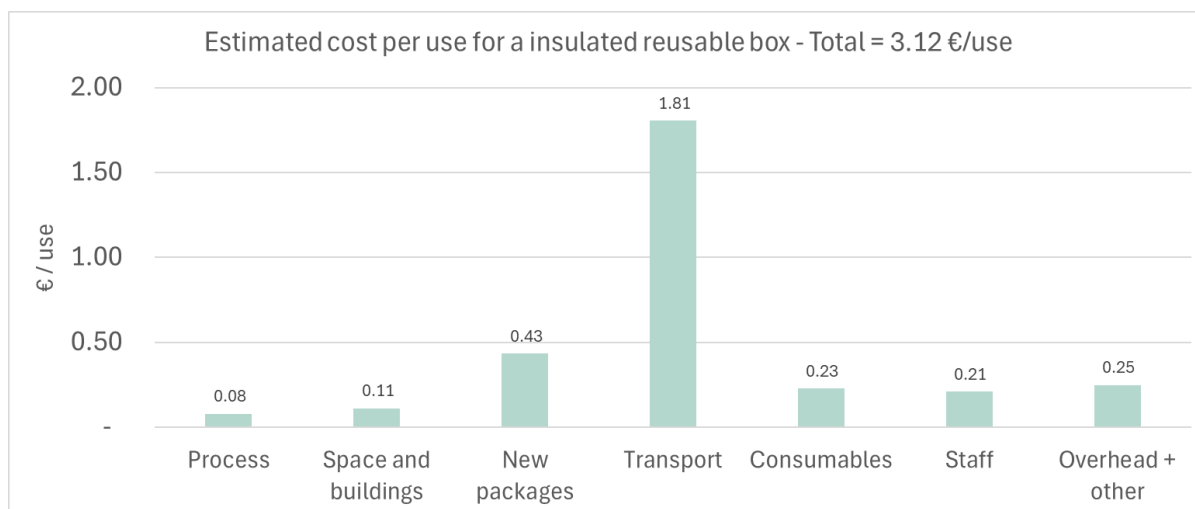


Figure 3-6. Cost per use for a non-insulated reusable HDPE box (€/use)

3.4 Data quality

3.4.1 Methodology

Choices are made when modeling processes for an LCA: both primary data and secondary data are used. Primary data is specific to the process while secondary data is a generic data developed by data-base providers. Primary and secondary data are selected in accordance with the goals, the scope, and the methodological choices of the study.

The data quality review supports the conclusions of the study. According to ISO 14044, this analysis has the purpose of "*better understanding the reliability of the collection of indicator results, the LCIA profile*" and it helps "*to understand better the significance, uncertainty and sensitivity of the LCIA results*".

A semi-quantitative assessment is carried out using the following procedure:

1. Ranking the life cycle inventories in descending order of contributions for all studied impact categories
2. Identifying the inventories contributing to at least 80% of the impacts for each relevant impact category
3. Assessing the quality of the data by a semi-quantitative judgement based on different criteria related to the data, as defined in the ISO 14044 reference⁴⁴:

⁴⁴ Note that this standard is complementary to ISO 14 044 – thus the quality assessment is also compliant with the ISO 14 044 standard.

- **Representativeness:** assessment of the degree to which the data set reflects the true population of interest, based on the technological representativeness [TeR], temporal representativeness [TiR] and geographical representativeness [GR]
- **Completeness:** percentage of total flow that is measured or estimated
- **Consistency:** qualitative assessment of whether or not the study methodology is applied uniformly to the various components of the sensitivity analysis
- **Reproducibility:** qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;

3.4.2 Data quality assessment

3.4.2.1 Representativeness

The **representativeness** (R) is an expert judgement of whether the chosen data set is relevant to the process requirement that is being modelled. It is based on three sub criteria: technological, temporal, and geographical coverage of the process or product being modelled.

Five quality levels are defined for these criteria:

- very good (1)
- good (2)
- fair (3)
- poor (4)
- very poor (5)

The quality of each lifecycle inventory used in the study is assessed according to the score system shown in Table 3-27. The total score for the representativeness is the average value of these three sub ratings.

Table 3-27. Score system for data quality assessment [Source: RDC based on European Commission recommendations⁴⁵]

Score	Temporal representativeness (TiR)	Technological representativeness (TeR)	Geographical representativeness (GR)
1	Less than 2 years from the reference year of the study	The technology involved in the study is exactly the same as in the LCI	The process modelled in the study takes place in the geographical area included in the LCI.
2	Less than 5 years from the reference year of the study	The technology involved in the study is covered by the mix of technologies included in the LCI.	The process modelled in the study takes place in one of the geographical areas covered by the LCI.
3	Less than 10 years from the reference year of the study	The technology involved in the study is partially covered by the mix of technologies included in the LCI.	The process modelled in the study takes place in one of the geographical areas extrapolated by the LCI
4	Less than 15 years from the reference year of the study	The technology involved in the study is similar to the technologies included in the LCI.	The process modelled in the study takes place in a geographical area that is not covered by the data set but there are sufficient similarities between the areas.
5	More than 15 years from the reference year of the study	The technology involved in the study is different from the technologies included in the LCI.	The process modelled in the study takes place in a different geographical area than area included in the LCI.

The temporal representativeness⁴⁶ criterion is based on a consideration on several sub-criteria:

- The difference between the reference year (2025) of the study and the date of publication of secondary data sets⁴⁷ (TiR dataset validity)
- The difference between the reference year (2025) of the study and the reference year of the secondary datasets (TiR reference year)

The final rate for TiR considered is the average between TiR dataset validity and TiR reference year.

⁴⁵ Source : (21) European Commission (JRC). (2020). Guide for EF compliant data sets (section 5.2.17 – Data quality criteria and rating)

⁴⁶ The reference year for this study is 2025

⁴⁷ ecoinvent v3.10 database was published in November 2023.

A data quality rating can be defined to estimate the quality level of each lifecycle inventory used in the study based on the three requirements described in this section. The level is defined as follows.

Table 3-28. Quality level regarding their quality requirements [Source: RDC based on ILCD 2010]

Data quality ratio (DQR)	Data quality level
≤ 1.6	Excellent quality
>1.6 and ≤ 2.0	Very good quality
>2.0 and ≤ 3.0	Good quality
>3 and ≤ 4.0	Fair quality
>4	Poor quality

Most of the primary data regarding box composition, weight and dimensions comes directly from the box manufacturers and is considered to be of excellent quality because they are measurements conducted by the manufacturer on their own boxes.

Regarding the insulated reusable PP box, the data used was calculated and extrapolated from the weight and the dimensions of a smaller box.

The data regarding the average fish distribution distance in Europe and the diesel consumption linked to refrigeration during transport comes from the fish industry and is considered excellent quality.

Table 3-29 below shows the scores for the inventories (secondary data) with high influence on the results of this study, following the methodology described in section 3.4.1.

Table 3-29. Assessment of the coverage, representativeness of the main inventories

Life cycle step	Inventory	TiR	TeR	GR	DQR
Raw materials production	Polyethylene, HDPE, granulate, RER, EI 3.10	3	2	1	2
	Polystyrene production, expandable, RER, EI 3.10	2.5	2	1	1.8

	Polypropylene production, granulate, RER, EI 3.10	2	2	1	1.7
	Polyethylene terephthalate, granulate, bottle grade, RER, EI 3.10	2	3	1	2.3
	Container-board production, linerboard, kraftliner, RER, EI 3.10	1.5	2	1	1.5
	Container-board production, linerboard, testliner, RER, EI 3.10	1.5	2	1	1.5
Box manufacturing	Injection moulding, RER, EI 3.10	3	2	1	2
	Extrusion, plastic film, RER, EI 3.10	3	2	1	2
	Polymer foaming, RER, EI 3.10	3	2	1	2
Ice production	Market group for electricity, low voltage, RER, EI 3.10	2	2	1	1.7
	Market group for tap water, RER, EI 3.10	2	2	1	2.3
Logistics: transport	Articulated lorry, 24 t payload, emission	2	2	1	1.7

	model from COPERT V				
	Diesel, burned in diesel-electric generating set, 18.5kW, GLO, EI 3.10	2.5	3	4	3.2
Logistics: Storage	Heat production, natural gas, at boiler condensing modulating <100kW, Europe without Switzerland, EI 3.10	3	3	1	2.7
	Heat production, natural gas, at boiler modulating <100kW, Europe without Switzerland, EI 3.10	3	3	1	2.3
	Market group for electricity, low voltage, RER, EI 3.10	2	2	1	1.7
Reuse cleaning	Heat production, natural gas, at boiler condensing modulating <100kW, Europe without Switzerland, EI 3.10	3	3	1	2.3
	Heat production, natural gas, at boiler modulating <100kW,	3	3	1	2.3

	Europe without Switzerland, EI 3.10				
	market group for tap water, RER, EI 3.10	2	2	1	1.7
	Market group for electricity, low voltage, RER, EI 3.10	2	2	1	1.7
	Sodium hydroxide to generic market for neutralising agent, RoW, EI 3.10	3	4	4	3.7
EoL	Market group for electricity, low voltage, RER, EI 3.10	2	2	1	1.7
	Heat production, natural gas, at industrial furnace low-NOx >100kW, Europe without Switzerland, EI 3.10	3	2	1	2
	Treatment of waste, municipal incineration, RoW, EI 3.10	3	2	4	3.3
	Treatment of waste sanitary landfill, RoW, EI 3.10	3	2	4	3.3
	Polyethylene production,	2	2	1	1.7

	high density, granulate, recycled, Europe without Switzerland, EI 3.10				
	Polyethylene production, high density, granulate, recycled, Europe without Switzerland, EI 3.10 – Proxy for recycled PP	2	4	1	2.3
	polyethylene, high density, granulate, recycled, Europe without Switzerland, EI 3.10	3	2	1	2

Overall, the quality of the secondary used in this study ranges between excellent and fair quality, with most secondary data being very good quality.

3.4.2.2 Completeness

The data collection and LCA modeling approach carried out in this study aim to cover 100% of the studied flows. As mentioned previously concerning the cut-off criteria (*section 2.6*), an exclusion threshold of 5% has been established in the study.

3.4.2.3 Reproducibility

The reproducibility of the results is ensured in this study as the report details the methodology, the primary data, the main hypothesis and all LCIs used for the LCA model. As well, a professional LCA software (RangeLCA) was used to model the system. The model remains available to the authors in case verification or changes are needed. It is clearly commented, and parameters are used to be able to reproduce the results.

4 Environmental impacts

4.1 Selection of the indicators

In order to make this report more readable, the results are analysed in detail for the impact categories considered as the most relevant.

The selection has been carried out based on the recommendation from the PEF guidelines⁴⁸. The impact categories selected through this process (detail available in Annexe 4) are listed below:

- Climate change
- Resource use, fossils
- Photochemical ozone formation
- Particulate matter
- Resource use, minerals and metals

These selected indicators allow us to cover more than 80% (80% to 83% depending on the box) of the environmental footprint (single score) according to the PEF guidelines.

4.2 Phase description

The impact of each box has been divided into 6 phases:

- Box production
 - It includes the production of raw materials, their transport and the production of the boxes
- Empty box transport
 - It includes the production of the tertiary packaging used to transport the empty boxes, their transport to the fish market/fish farm/ fish factory and their storage before use.
- Ice production
 - It includes the use of electricity and water to produce ice. For the cardboard box, it also includes the production of leak tight bags in which the ice will be packed.
- Packing the box with fish and ice
 - For the cardboard box, it includes the electricity consumption for the machine which transforms the boxes from flat to usable.
- Fish distribution
 - It includes the production of the tertiary packaging used to transport the full boxes, the cold storage of full boxes and the transport of the full boxes.

⁴⁸ Source : (13) European Commission. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method*, JRC Technical Reports. Retrieved from https://eplca.jrc.ec.europa.eu/permalink/PEF_method.pdf

- EoL
 - It includes the pre-treatment of the boxes (EPS compaction) the transport of the boxes to the treatment facility and their treatment.
- Reuse
 - It includes the transport of the boxes to the collection/cleaning facility, the cleaning and sanitizing of the boxes and their dispatch to their new user.

4.3 Significance of the results: minimum 5% difference

The environmental impacts of each box were analysed to determine whether the differences between the single use EPS box and the alternative boxes are significant.

Whenever this study concludes that one box has different impacts than another, the difference between the results is above 5%. It means that no matter the recycling rate or number of uses of those boxes or other possible parameter variations and uncertainties (except those varying together), the difference between the impacts the boxes are at least 5%.

The main differentiating parameters are the recycling rate (cf. section 4.6.3) and the number of uses (cf. section 4.6.2). The distribution distance is a key parameter, varying identically for all compared boxes : the boxes are always compared for an identical distribution distance.

A significance threshold of 5 % is appropriate in the case of the study and was chosen given that the main uncertainties are already taken into account through the use of ranges of parameter values in the software RangelCA (cf. *Annexe 3*).

4.4 Absolute values – base case

This section presents the environmental impacts for the base case for each box for the selected impact categories and for the total life cycle associated with the studied functional unit (cf. *Annexe 1*).

These impacts refer to one use of one box to transport fresh fish and obtain 1kg of fish fit for human consumption.

The non-insulated reusable HDPE box is not section of the assessment for the base case as it cannot be used the same way the single use EPS box is used today for long distance transport (cf. section 3.2.3.1).

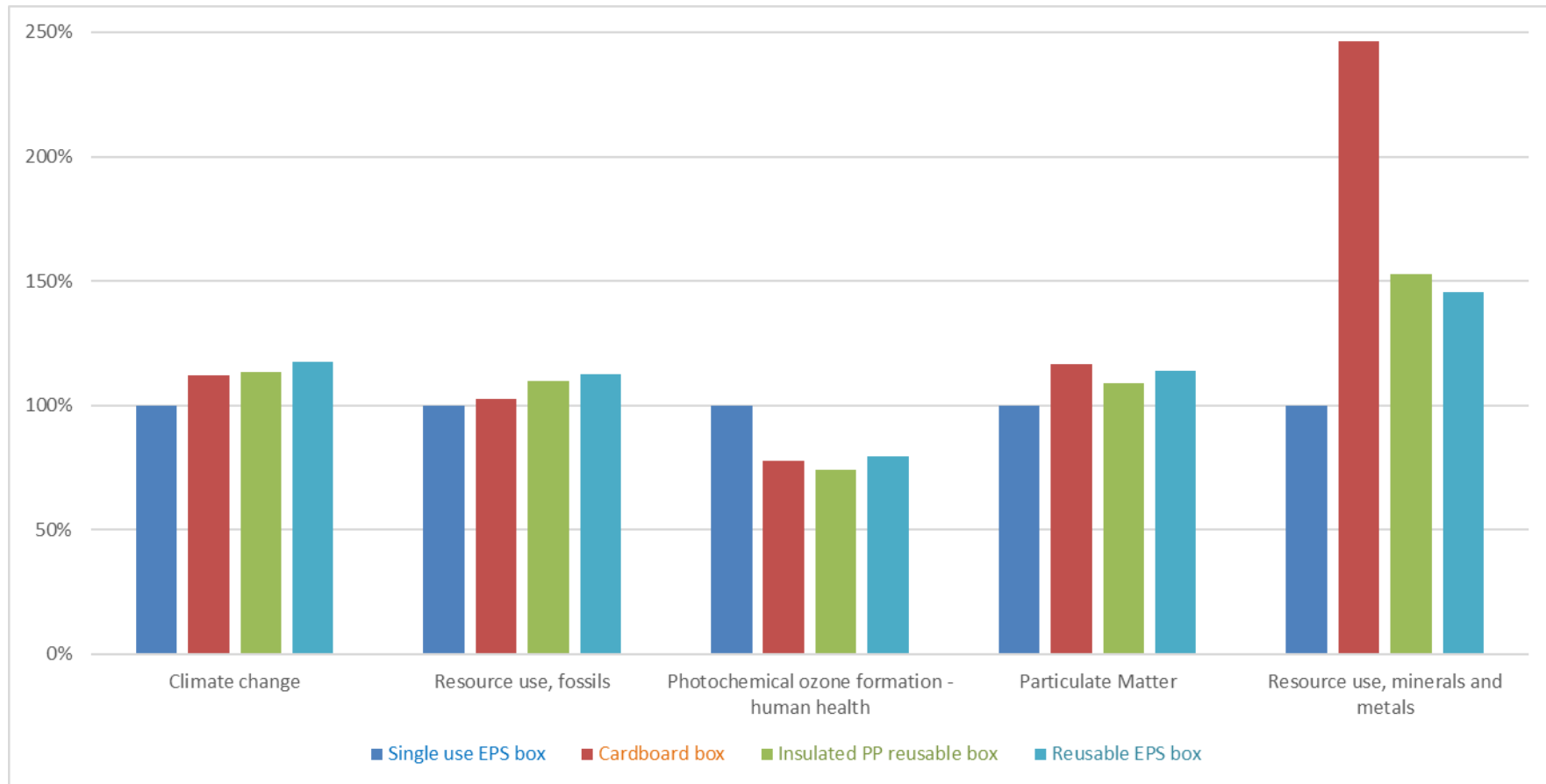


Figure 4-1. Environmental impacts of the studied boxes. Reference scenario (100%) is the single use EPS box

- None of the studied boxes outperforms the other across all indicators.

4.5 Details per indicator – base case

This chapter aims at identifying the key issues for the main indicators and at giving an overview of the different contributions to the total life cycle.

4.5.1 Climate change

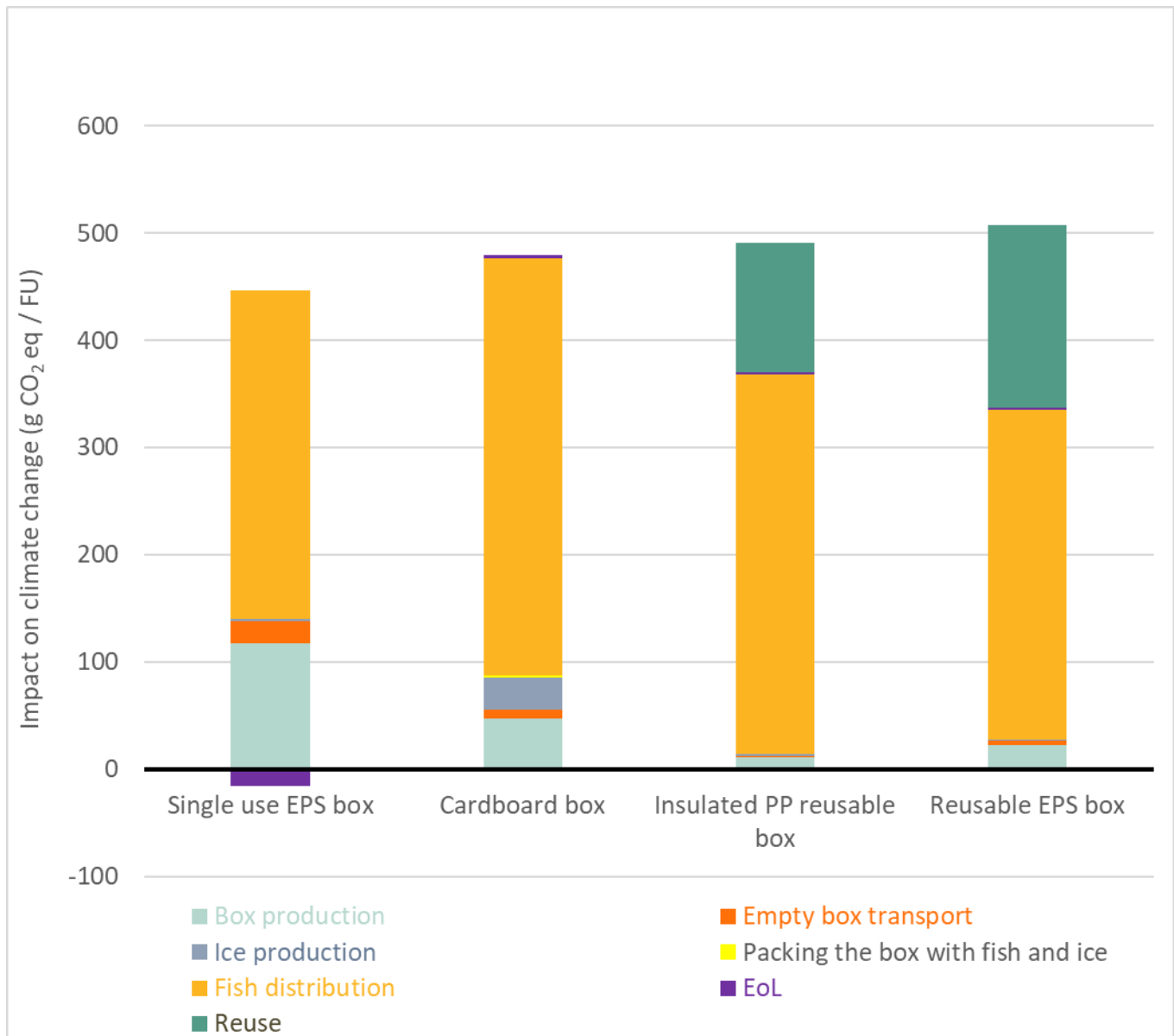


Figure 4-2. Environmental impacts of the studied boxes. Impact on climate change – base case
(g CO₂ eq / FU)

■ Hotspot analysis

- For each box, the most contributing life cycle stage is the **fish distribution phase**. This is due to the CO₂ emissions from the lorries fuel combustion over a relatively long distance: the fish distribution distance in the base case is 2 800 km.
- For the reusable boxes (insulated reusable PP box and EPS reusable box), the second most contributing life cycle stage is the **reuse phase**. This is once again due to the CO₂ emissions from the lorries: the return distance is 2 138 km.
- For the single use EPS box, the impact of **box production** is the second most contributing life cycle stage and represents a large part of the impact (27%).
- For the reusable boxes (insulated reusable PP box and EPS reusable box), the impact of the **box production** and **end-of-life** phases is attenuated by the number of uses.

■ System comparison

- The reusable boxes (insulated reusable PP box and EPS reusable box) have a higher overall impact than the single use EPS box.
 - The impact of the **fish distribution** phase is higher for the insulated reusable PP box mostly due to its high weight that limits the number of boxes that can be transported in one lorry: 1.1 lorries filled with insulated reusable PP boxes are needed to transport the same amount of fish than 1 lorry filled with EPS boxes (single use or reusable).
 - The impact of **reuse** is relatively high because of the large return distance of 2 138 km.
- The cardboard box has a higher overall impact than the single use EPS box. This is due to its insulating properties:
 - Because the cardboard box requires a larger amount of ice to transport fresh fish, the number of fish that can be transported is greatly reduced, **increasing the impacts of each phase**.
For the base case, 1.27 lorries filled with cardboard boxes are needed to transport the same number of fish as 1 lorry filled with EPS boxes (single use or reusable).

■ Conclusion

- For the base case, the single use EPS box has the smallest impact on climate change
- The reusable EPS box has the greatest impact (18.8% more than single use EPS box), followed by the insulated reusable PP box (14.14% more than single use EPS box) and the cardboard box (11.5% more than single use EPS box).

- **The difference between the cardboard box and the single use EPS box is not significant for a distribution distance of 2800 km with one driver.** Indeed, there is an uncertainty regarding the recycling rate of the single use EPS box and the cardboard box. Considering the variation of the recycling rate of EPS from 55% to 100% and the variation of the recycling rate of cardboard from 0% to 100%, the sensitivity analysis shows that there is an overlap between the impact on climate change of those two boxes for that distance. **When considering the uncertainties regarding the recycling rate of the boxes, there are no significant differences between the single use EPS box and the cardboard box (overlap of the results).**

- **The difference between the single use EPS box and the reusables boxes (insulated reusable PP box and EPS reusable box) is significant for a distribution distance of 2800 km with one driver.** Indeed, the sensitivity analysis shows that there is no overlap between the impact on climate change of the single use EPS box and insulated reusable PP box and between the impact of the single use EPS box and reusable EPS box for that distance. **When considering the uncertainties, the differences between the single use EPS box and the reusable boxes are above the 5% significance threshold.**

4.5.2 Fossil resources

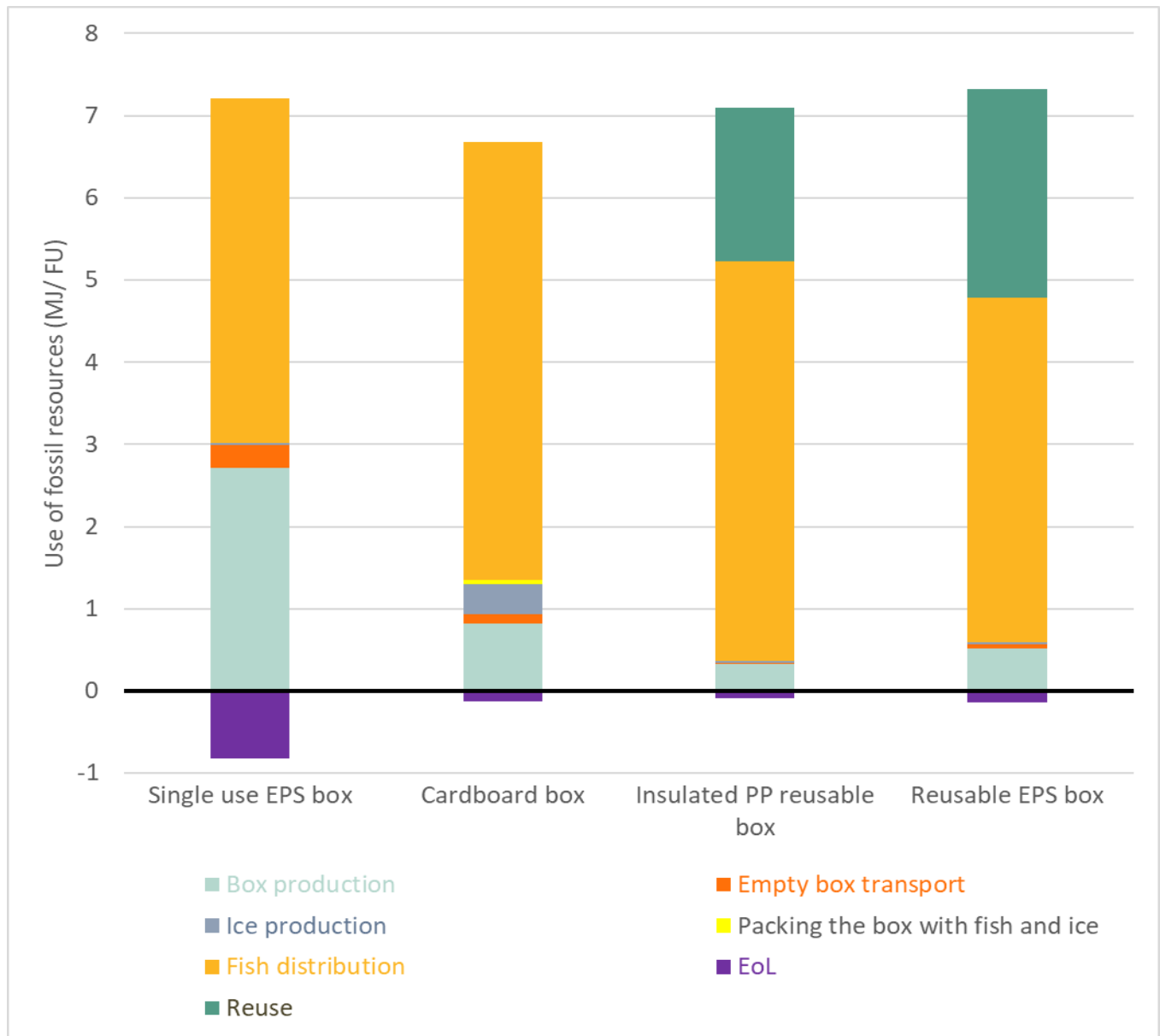


Figure 4-3 Environmental impacts of the studied boxes. Impact on the use of fossil resources – base case (MJ / FU)

■ Hotspot analysis

- The use of fossil resources shows similar repartition of contributions to the climate change category. Indeed, fossil resource use and fossil GHG emissions are closely related (fossil CO₂ emissions often also mean use of fossil resources).

- For each box, the most contributing life cycle stage is the **fish distribution phase**. This is due to the fuel consumption from the lorries over relative long distance: the fish distribution distance is 2 800 km.
- For the reusable boxes (Insulated PP reusable box and EPS reusable box), the second most contributing life cycle stage is the **reuse phase**. This is once again due to the fuel consumption from the lorries: the return distance is 2 138 km.
- For the single use EPS box, the impact of **box production** is the second most contributing life cycle stage and represents a large part of the impact (42%). This is because EPS is directly made from fossil resources.
- For the reusable boxes (PP and EPS, also directly made from fossil resources), the impact of the **box production** and **end-of-life** phases is attenuated by the number of uses.

■ System comparison

- The reusable boxes (insulated reusable PP box and EPS reusable box) have a higher impact than the single use EPS box (6.4 MJ/ FU).
 - The impact of transport during the **reuse phase** is higher than the benefits from multiple use on the **production** phase.
 - The impact of transport during the **reuse phase** is high because of the large distance.
 - The impact of the **fish distribution** phase is higher for the insulated reusable PP box due to its high weight that limits the number of boxes that can be transported in one lorry.
- There are no significant differences between the single use EPS box and the cardboard box
 - The cardboard box requires a larger amount of ice to transport fresh fish across 2 800 km, **increasing the impacts of each phase**.
 - The **production** of the cardboard box which contains 5% plastic requires little fossil resources compared to the EPS box which is entirely made of fossil resources.
 - The two factors mitigate each other.

■ Conclusion

- For the base case, the single use EPS box has the smallest impact (3% less than the cardboard box) – **the difference between the single use EPS box and the cardboard box is not significant.**

Indeed, there is an uncertainty regarding the recycling rate of the single use EPS box and the cardboard box. Considering the variation of the recycling rate of EPS from 55% to 100% and the variation of the recycling rate of cardboard from 0% to 100%, the impacts of the two boxes overlap.

When considering the uncertainties, there are no significant differences between the single use EPS box and the cardboard box (overlap of the results).

- The reusable EPS box has the greatest impact (12.4% more than single use EPS), followed by the insulated PP reusable box (9.67% more than single use EPS) – **the difference between the single use EPS box and the reusable boxes (PP and EPS) are not significant.**

For a 2 800 km distribution distance, there is no overlap between the impacts of each box when considering the main uncertainties (recycling rate and number of uses). **But when considering the uncertainties, the differences between the single use EPS box and the reusable boxes are not above the 5% significance threshold.**

4.5.3 Photochemical ozone formation – human health

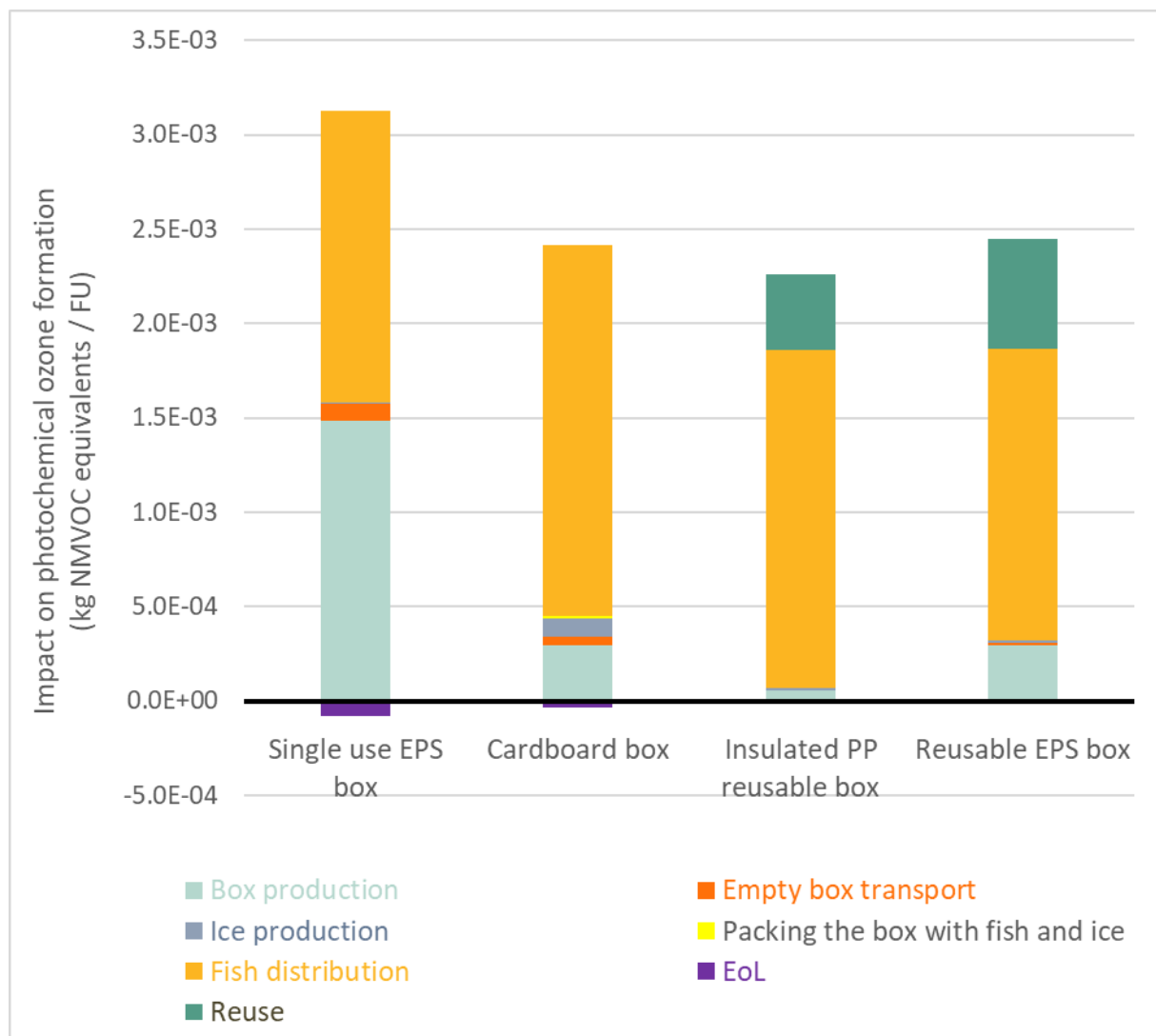


Figure 4-4 Environmental impacts of the studied boxes. Impact on the photochemical ozone formation – human health – base case (kg NMVOC equivalents / FU)

■ Hotspot analysis

- For the single use EPS box, the impact of **box production** is the most contributing life cycle stage and represents a large part of the impact (49%). This is because of the emissions of pentane (a VOC, volatile organic compound) during EPS expansion. It is assumed that all the pentane is emitted during EPS expansion.
- The **recycling of EPS** has little impact on photochemical ozone formation. Indeed, recycling EPS does not prevent pentane emissions: the pentane is emitted when the box is formed not when the polystyrene beads are produced.
- For the reusable boxes and the cardboard box, the most contributing life cycle stage is the **fish distribution phase**. This is due to the NOx emissions from the lorries fuel combustion over relative long distance: the fish distribution distance is 2 800 km.

■ System comparison

- The reusables boxes (insulated reusable PP box and EPS reusable box) have a lower impact on the photochemical formation of ozone than the single use EPS box:
 - The production of EPS and the associated pentane emissions has a large impact on the formation of photochemical ozone.
 - For the EPS reusable box, the high impact of EPS **production** is mitigated by the number of uses.
 - The impact of transport during reuse is smaller than the impact prevented by the reuse of the box.
- The cardboard box has a lower impact than the single use EPS box.
 - Indeed, the impact of the **production** of EPS is much higher than the impact of cardboard **production**.

■ Conclusion

- For the base case, the reusable boxes have the smallest impact (26% less than the single use EPS box for the insulated PP box, 20 % less for the EPS reusable box). The cardboard box has a smaller impact than the single use EPS box (22% less).

The differences between the single use EPS box and the alternative boxes are significant.

There is no uncertainty behind the emissions of pentane from the production of the single use EPS box which is the main driver of these differences.

The uncertainties regarding the number of uses of the reusable boxes (EPS and insulated PP) have little influence on the difference.

Finally, the EoL of the boxes has little impact on photochemical ozone formation. As a result, the uncertainties linked to the recycling rates are not large and there is large difference in impact between the boxes when considering them.

When considering the uncertainties, the differences between the single use EPS box and the alternatives are above the 5% significance threshold.

4.5.4 Particulate Matter

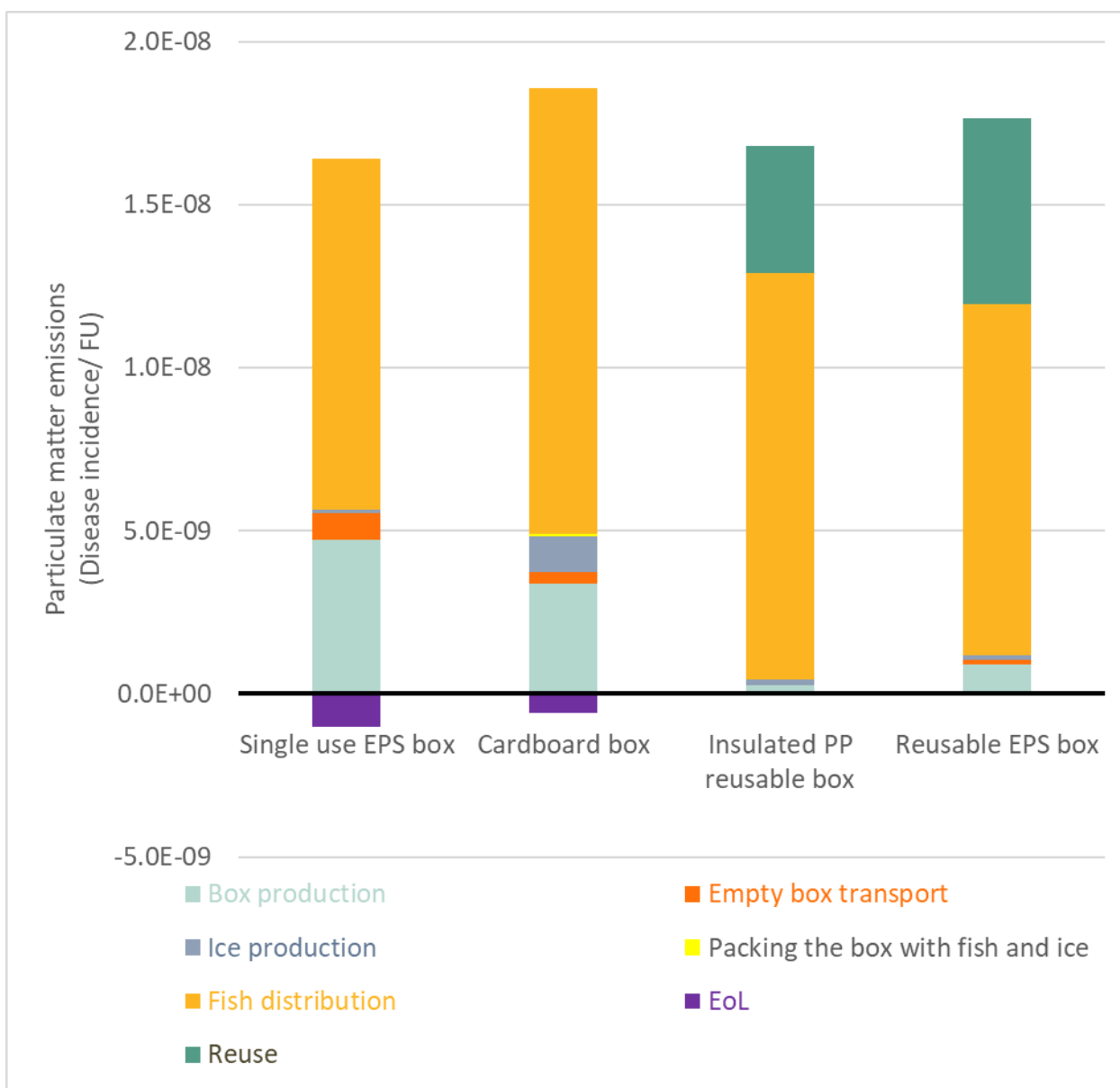


Figure 4-5 Environmental impacts of the studied boxes. Impact on particulate matter emissions - base case (Disease incidence / FU)

Hotspot analysis

- For each box, the most contributing life cycle stage is the **fish distribution phase**. This is due to the particulate matter emissions from the lorries fuel combustion over relative long distance: the fish distribution distance is 2 800 km.
- For the reusable boxes (insulated reusable PP box and EPS reusable box), the second most contributing life cycle stage is the **reuse phase**. This is once again due to the particulate matter emissions from the lorries.

- For the single use EPS box, the impact of **box production** is the second most contributing life cycle stage and represents a large part of the impact.
- For the reusable boxes, the impact of the **box production** and **end-of-life** phases is attenuated by the number of uses.

■ System comparison

- The single use EPS box has the lowest impacts:
 - The insulated reusable PP box is heavier than the EPS boxes (single use and reusable) and limits the amount of filled boxes that can be transported at once. As a result, the impact of **fish distribution** is higher.
 - The resulting particulate matter emissions of transport during the **reuse phase** are large, especially for the reusable EPS box whose logistics are not optimized: the box is not stackable which limits the number of empty boxes that can be transported at once.
 - The cardboard box has a higher overall impact than both the single use EPS box and reusable boxes. This is due to the higher amount of ice transported in the box which reduces the amount of fish transported and increases the impacts of **each phase** as a result.

■ Conclusion

For the base case, the cardboard box has the greatest impact (16.7% more than single use EPS)

At 2800 km, the difference between the single use EPS box and the cardboard box is significant. Indeed, the difference is mostly linked to the impact of distribution. As a result, **when considering the uncertainties regarding the recycling rate of the boxes, the differences between the single use EPS box and the cardboard box are above the 5% significance threshold.**

- The reusable EPS box has an impact 9% higher than the single use EPS box and the insulated reusable PP box has an impact 14% higher than the single use EPS box.

When considering the uncertainties regarding the recycling rate of the boxes, the differences between the single use EPS box and the reusable boxes are above the 5% significance threshold. The uncertainty regarding the return distance (proportion of local reuse) is considered to be in favour of the reusable boxes – which means that the impact of the reusable boxes may be higher and the difference, when considering this uncertainty, would be even larger.

4.5.5 Mineral and metal resources

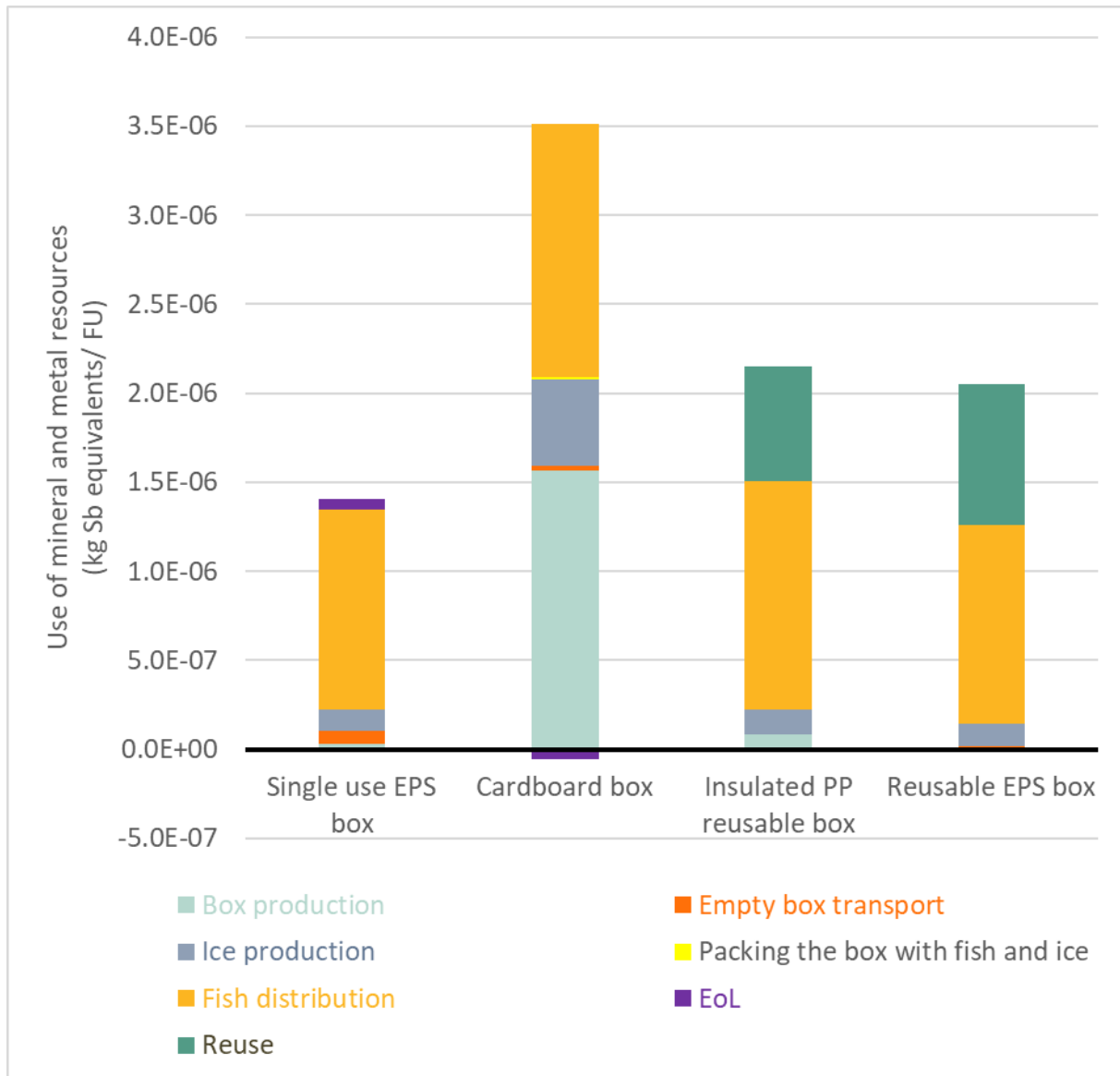


Figure 4-6 Environmental impacts of the studied boxes. Impact on the use of mineral and metal resources - base case (kg Sb equivalents / FU)

- For the cardboard box, the impact of **box production** is the most contributing life cycle stage. The production of PET to line the cardboard box represents 45% of the impact of the cardboard box on metal and mineral resource use. Indeed, an antimony-based catalyst is used for PET production.
- For the other boxes, the most contributing life cycle stage is the **fish distribution phase**. This contribution is related to the production of the lorry, which requires large amounts of metals.

- For the reusable boxes (Insulated PP reusable box and EPS reusable box), the second most contributing life cycle stage is the **reuse phase**. This is once again due to transport and lorry production
- **System comparison**
 - The cardboard box has the highest impact on the use of minerals and metals.
 - This is due to the high impact of PET **production**.
 - The reusable boxes (insulated PP reusable box and reusable EPS box) have a higher overall impact than the single use EPS box. This is due to multiple factors:
 - During the **reuse phase**, the use of lorries is necessary for transport, requiring a large amount of metals for their production. This is especially true for the reusable EPS box whose logistics are not optimized: the box is not stackable which limits the number of empty boxes that can be transported in one lorry at once.
 - The impact of the **fish distribution** phase is higher for the insulated reusable PP box due to its high weight that limits the number of boxes that can be transported in one lorry.
- **Conclusion**
 - For the base case, the single use EPS box has the smallest impact.
 - The cardboard box (146% more than the single use EPS box) has the greatest impact, followed by the insulated reusable PP box (53% more than single use EPS) and the EPS reusable box (45% more than single use EPS)

However, the results on this indicator shall be discussed with high precautions. This indicator is related to a low level of robustness according to the PEF guidelines.

In particular, it considers the "ultimate reserve" (content of the Earth's crust in each chemical element) as the reserve that would be depleted. There is currently no evidence that the ultimate reserve and the ultimately extractable reserve have the same value and, more importantly, are proportional by resource. Consequently, this method fails to address the issue of scarcity. As an example, at the current production rate, there would still be 84 million years of copper production ahead of us based on this ultimate reserve.

This causes difficulties in interpreting the results obtained with this method, as some metals can generate high contributions due to a high characterization factor, although they may not be significantly affected by the scarcity issue.

These limitations regarding this indicator are further discussed in the Annexe 2.

Because of the limitations of the indicator "resource use, minerals and metals" – the difference between the single use EPS box and the alternative boxes are not considered significant.

4.6 Sensitivity analysis

In a sensitivity analysis, the model calculates 1000 iterations producing each time a specific result via a Monte Carlo simulation. The result of a single iteration is the impact for a specific scenario considering a possible value in the statistical distribution encoded for every sensitive parameter. The 1000 results are then plotted in a chart; this allows to evaluate the entire range of possible impacts for all the studied systems. The sensitivity analysis is focused on the climate change indicator (in particular, without biogenic carbon) The variables studied are: Fish distribution distance; Number of uses for reusable boxes; End-of-life treatments; End-of-life model: cut-off method ; Fuel consumption for lorry refrigeration; Number of drivers; Use of electric vehicles ; Proportion of local reuse; Use of a stackable EPS box; Fish loss and the impact of cleaning vs the impact of using a single use plastic liner.

4.6.1 Fish distribution distance

The influence of the fish distribution distance on the impact of the different boxes on climate change is shown in Figure 4-7, Figure 4-8, Figure 4-9,

Figure 4-10 and Figure 4-11.

The other varying parameters that have an impact on the results shown in these figures are:

- The number of uses of the reusable boxes (cf. Number of uses of reusable boxes)
- The EoL of the boxes (cf. End-of-life treatments)

The recycling rate of EPS varies between 55% and 100% ; the recycling rate of the cardboard box varies between 0% and 100% ; the number of uses of the insulated (PP) and non-insulated (HDPE) hard plastic reusable boxes varies between 10 and 60; and the number of uses of the reusable EPS box varies between 2 and 5.

The impact of those parameters is further assessed in section 4.6.2 and 4.6.3 of the report.

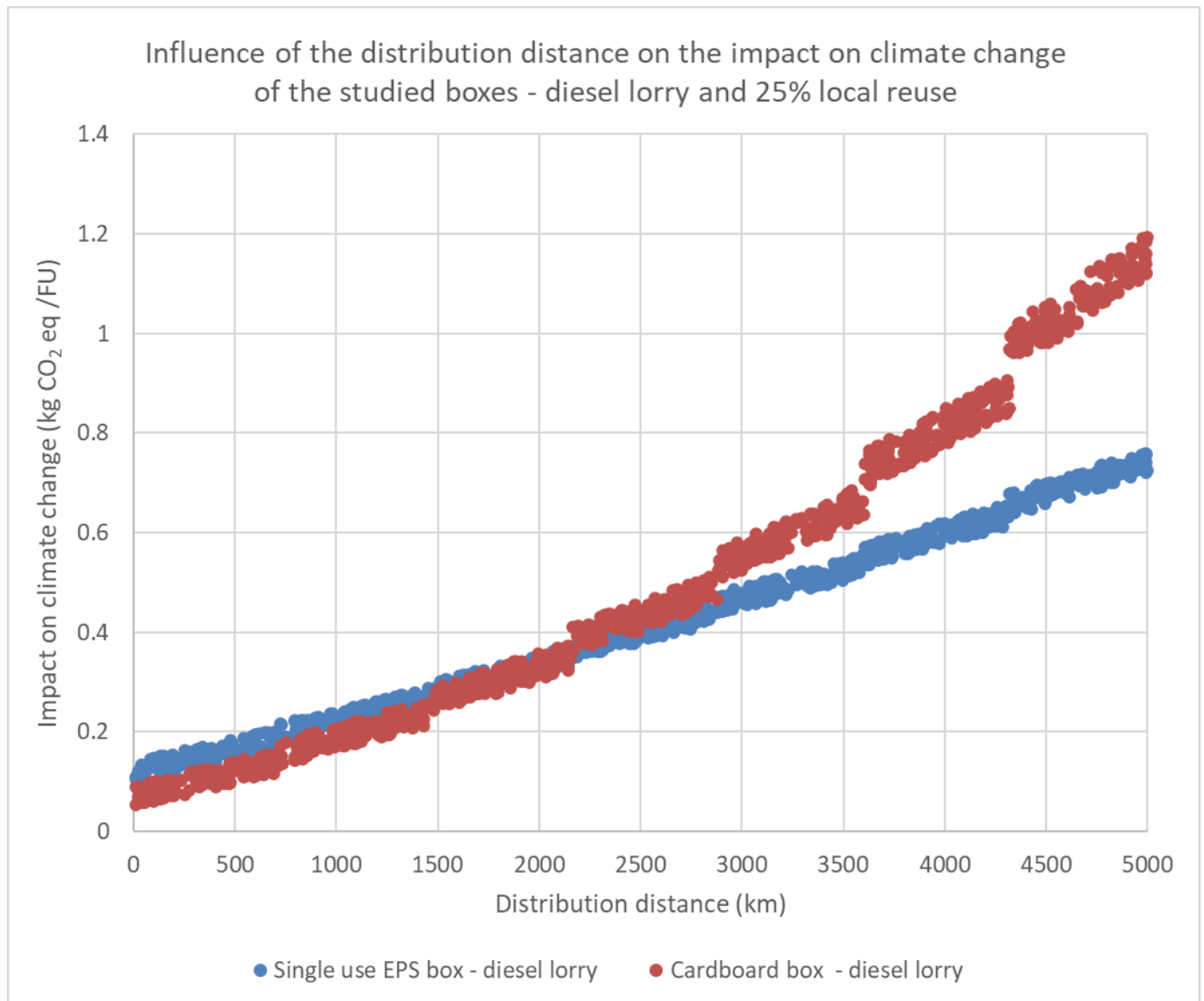


Figure 4-7. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs. cardboard box, diesel lorry and 25% local reuse

Even though the impact of the boxes on climate change varies a lot depending on fish distribution distances, there are no significant differences between the single use EPS box and the cardboard box for a fish distribution distance between 800 km and 2 900 km (difference below the 5% threshold when considering uncertainties). For longer distances, the single use EPS box has a lower impact. For shorter distances, the cardboard box has a lower impact.

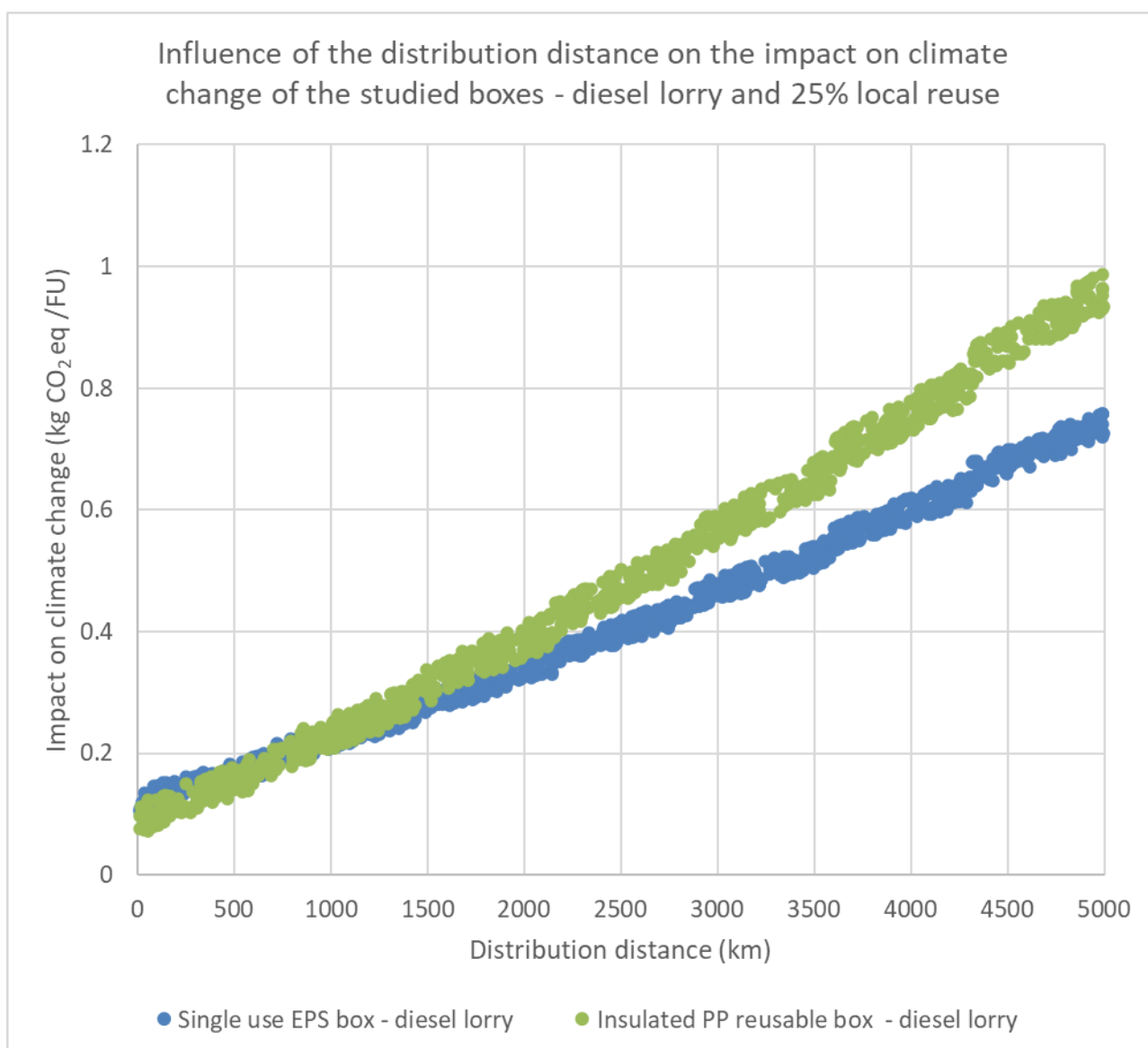


Figure 4-8. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs insulated PP reusable box, diesel lorry and 25% local reuse

Even though the impact of the boxes on climate change varies a lot depending on fish distribution distances, there are no significant differences between the single use EPS box and insulated reusable PP box for a fish distribution distance below 2 200 km (difference below the 5% threshold when considering uncertainties). For longer distances, the single use EPS box has a lower impact.

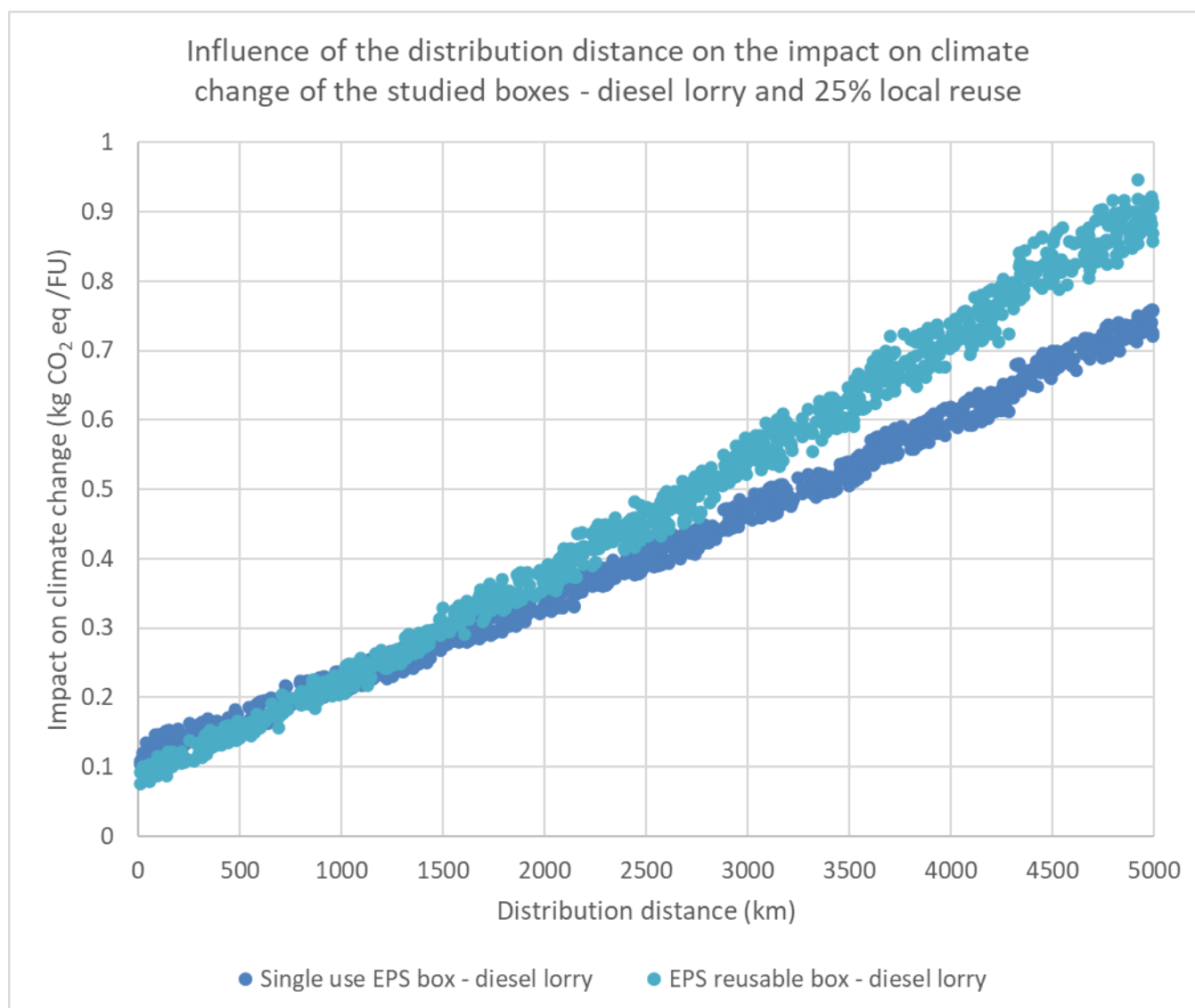


Figure 4-9. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs reusable EPS box, diesel lorry and 25% local reuse

Even though the impact of the boxes on climate change varies a lot depending on fish distribution distances, there are no significant differences between the single use EPS box and the reusable EPS box for distances between 125 km and 2 650 km (difference below the 5% threshold when considering uncertainties). For larger distances, the single use EPS box has a smaller impact on climate change. For smaller distances, the reusable EPS box has a smaller impact on climate change.

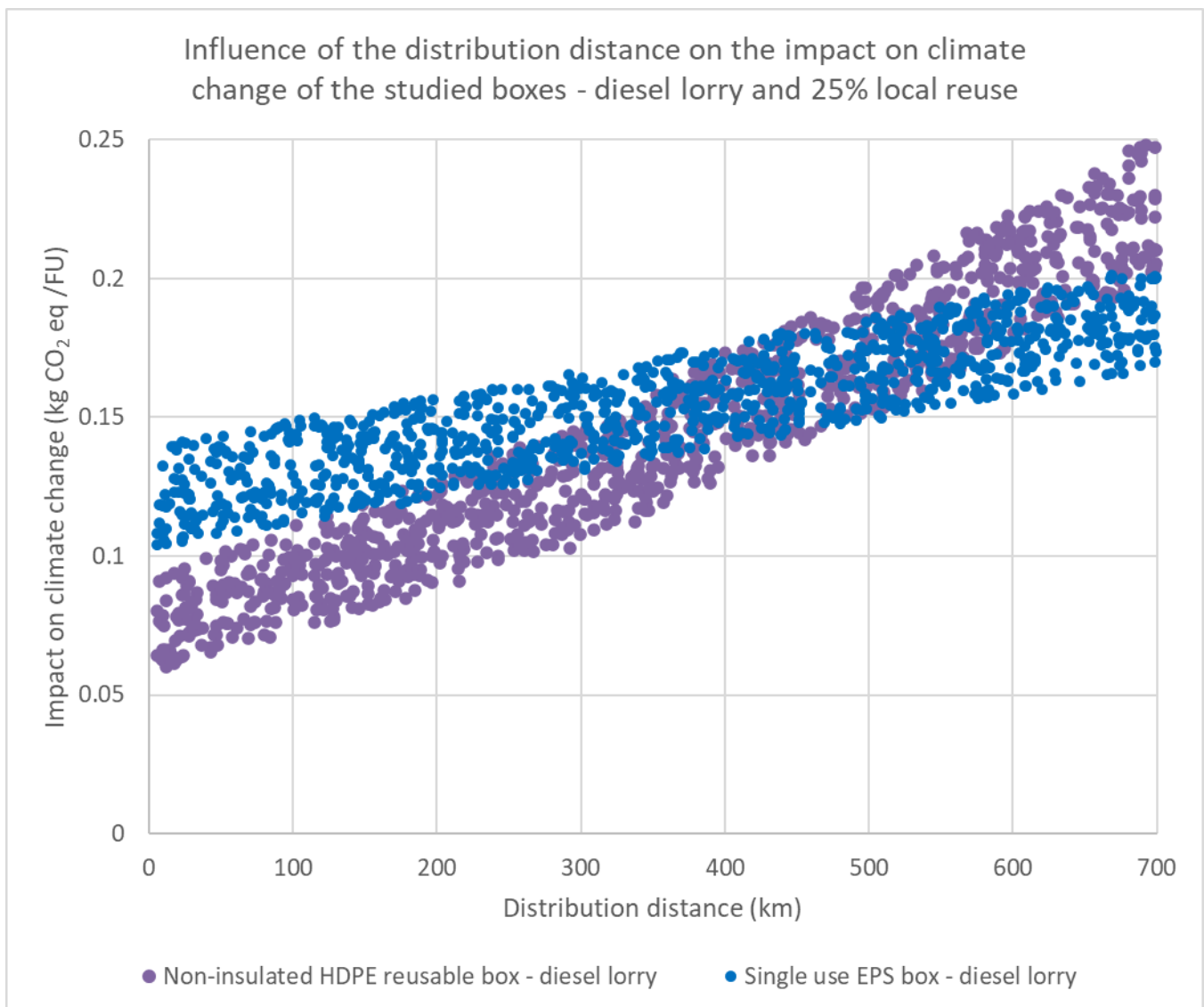


Figure 4-10. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs non insulated HDPE reusable box, diesel lorry and 25% local reuse

For distances below 700 km, fish distribution distance has a smaller influence on the impact of the boxes. For distances below 100 km, the non-insulated reusable HDPE box has a lower impact on climate change than the single use EPS box. For longer distances, there are no significant differences (difference below the 5% threshold when considering uncertainties).

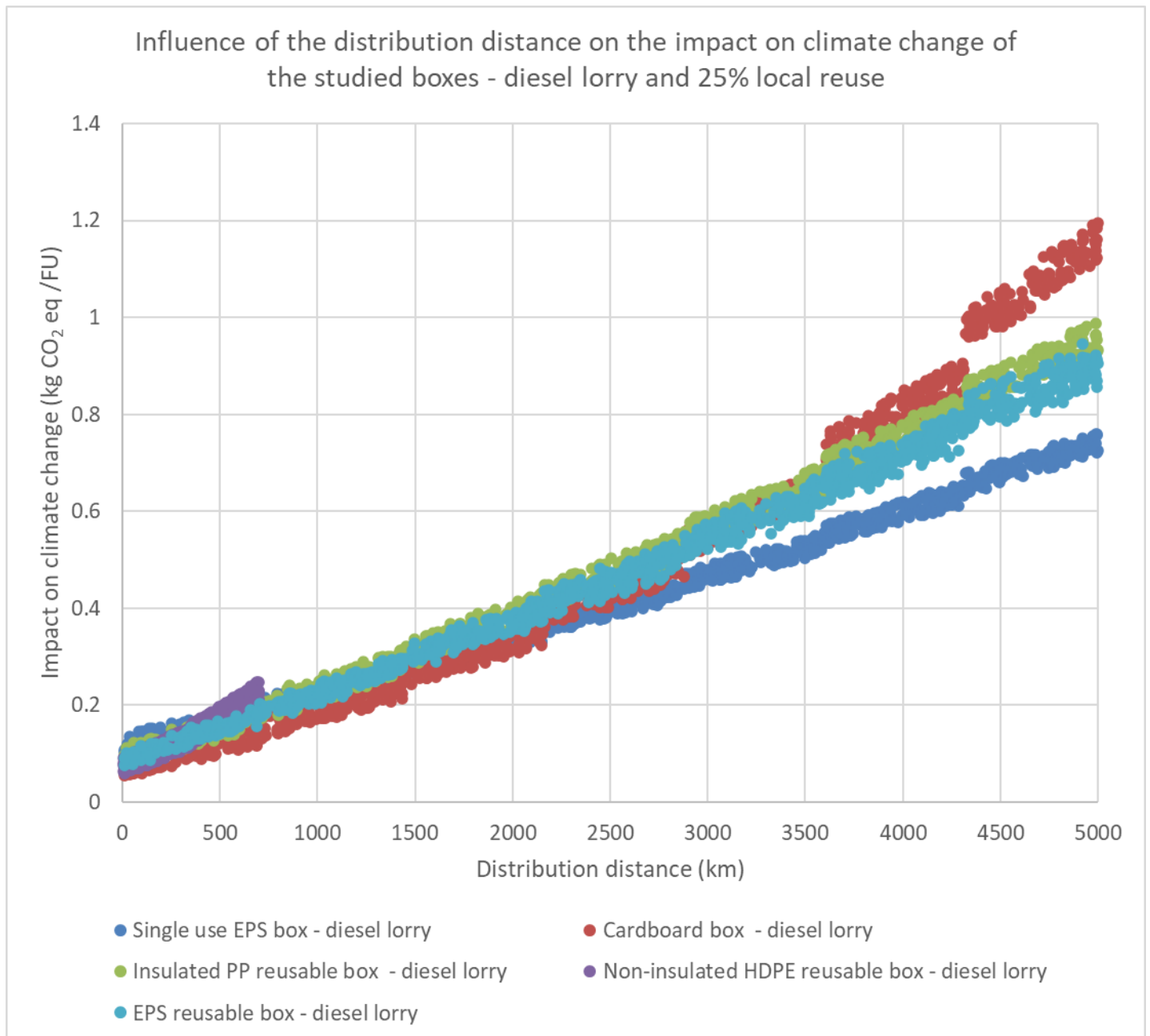


Figure 4-11. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – all boxes

For distribution distances longer than 2 900 km, the single use EPS box has the smallest impact on climate change. For shorter distances, there are no significant differences between the EPS box and the alternatives, or the alternatives have a lower impact.

The impact of the insulated reusable PP box and the reusable EPS box are similar across all distribution distances.

The non-insulated reusable HDPE box can only be used for distribution distances below 720 km, but it has a similar or lower impact to the other boxes across those distances.

Because the non-insulated HDPE box has low insulation properties, the amount of ice needed to maintain hygienic conditions increases quickly with the transport distance. As a result, no fish can be transported for distances above 720 km (one day). Indeed, the duration of the nightly rest before distribution could resume would result in a large amount of ice melting (cf. section 3.2.3.1).

For the EPS boxes (single use and reusable) and the insulated reusable PP box, the amount of ice needed for transport increases more slowly with distance thanks to better insulation properties. As a result, the amount of fish that can be transported does not vary much between those three boxes.

The insulating properties of the cardboard box are lower: this box requires twice as much ice as the single use and reusable EPS boxes for the same distribution duration. As a result, the impact of the cardboard box increases faster than the impact of the single use EPS box with distance.

The difference between the single use EPS box and the insulated reusable PP box and the difference between the single use EPS box and the reusable EPS box are mostly linked to the impact of reuse: the longer the fish distribution distance, the longer the dispatch of the box will be to return to its original location.

Any increase in the **fuel efficiency** of the lorries would have a positive influence on the impacts of the boxes. This positive influence would be greater for alternative boxes than for the single use EPS box because the relative contribution of transport is higher for alternative boxes, especially over long distances. As a result, an increase of the range of distribution distance for which the alternative boxes have an impact lower or equivalent to the single use EPS box is expected.

4.6.2 Number of uses of reusable boxes

The collection rate is calculated as $(\text{return rate})^{\text{number of uses}}$. All collected boxes that are scrapped are recycled, all lost boxes are incinerated. Because the number of uses of each reusable box is directly linked to a return rate, the number of uses of the boxes has a direct impact on their EoL.

For the reusable EPS box, the number of uses vary between 2 and 5. The return rate remains the same, but the scrap rate varies: the greatest incertitude is the strength of the box and its ability to withstand reuse and cleaning.

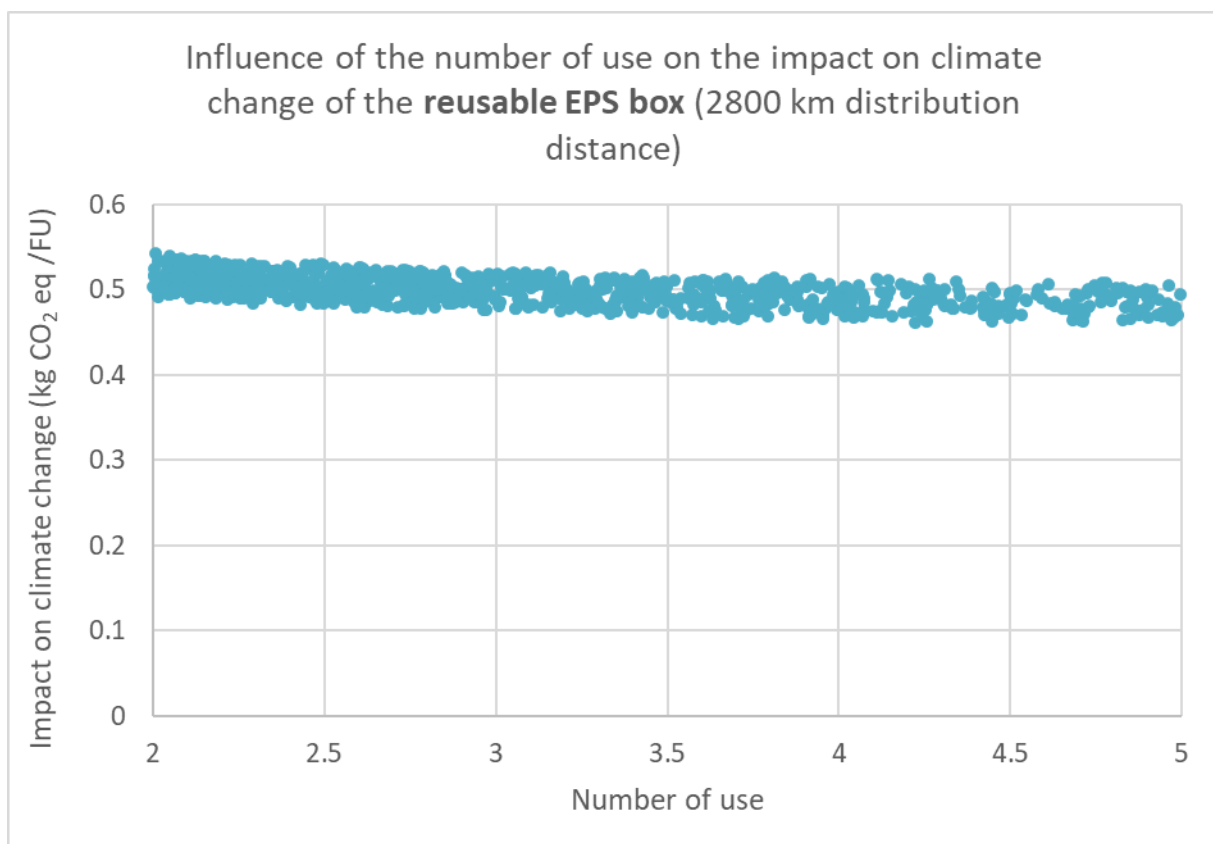


Figure 4-1. Influence of the number of uses on the impact of the EPS reusable box on climate change (kg CO₂ eq/ FU) – base case

The number of uses has little to no influence on the impact of the boxes on climate change for a distribution distance of 2 800km. The smaller the distribution distance, the bigger the impact of the number of uses will be (in %), as the total impact of the box will be lower..

For the insulated (PP) and non-insulated (HDPE) hard plastic reusable boxes, the number of uses varies between 10 and 60.

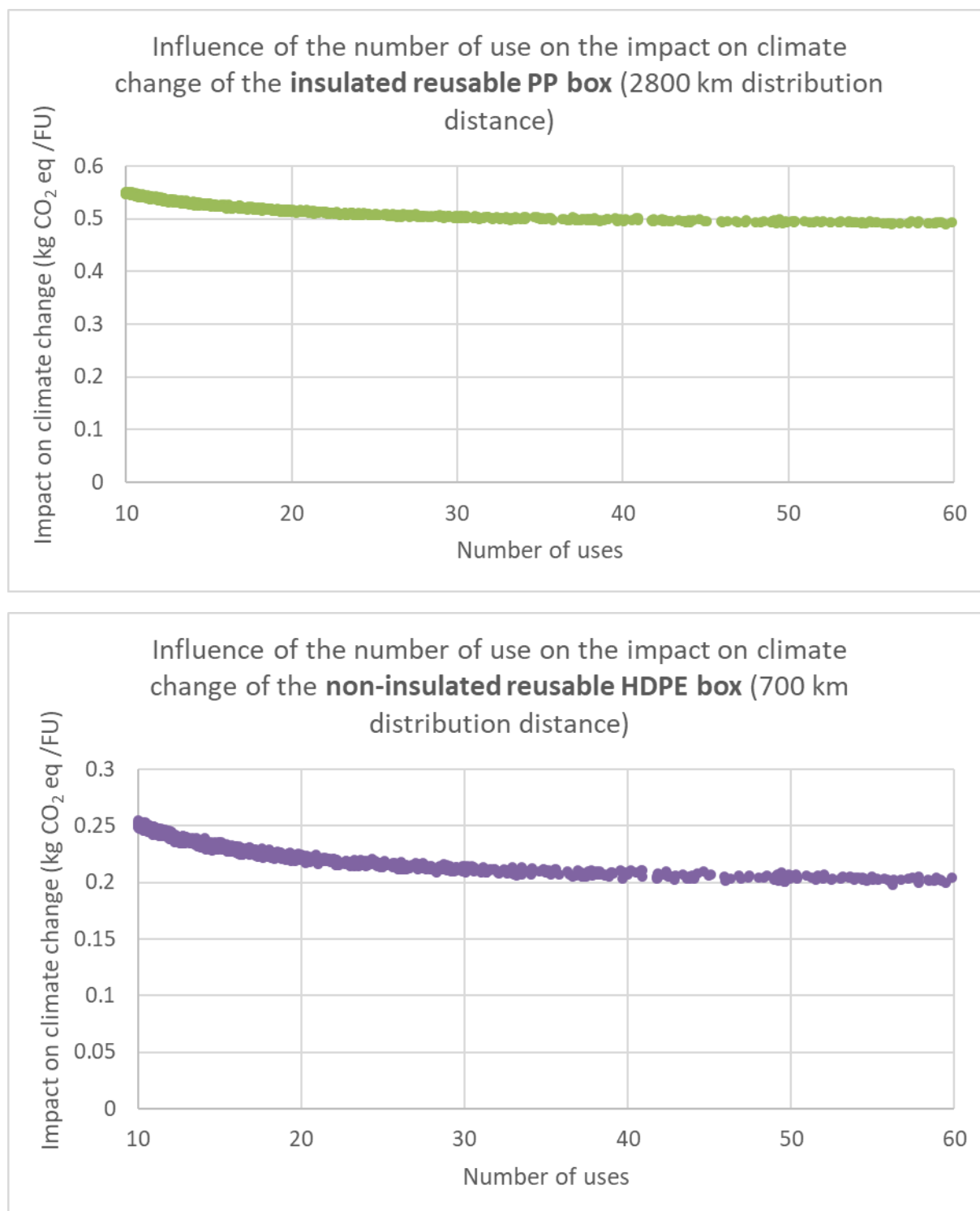


Figure 4-2. Influence of the number of uses on the impact of the hard plastic reusable boxes on climate change (kg CO₂ eq/ FU) – base case

The number of uses has an impact on the results for the base case distance (2800km): by going from 10 to 30 uses, the impact is reduced by 9% for the insulated reusable PP box and by 12% for the non-insulated reusable HDPE box.

Any increase of the number of uses above 30, has little to no influence over the results. The smaller the distribution distance, the bigger the impact of the number of uses will be (in %), as the total impact of the box will be lower..

4.6.3 End-of-life treatments

The sensitivity analysis of the EoL focuses on the single use EPS box and cardboard box as the variation in the EoL linked to the number of uses has already been assessed in the previous section.

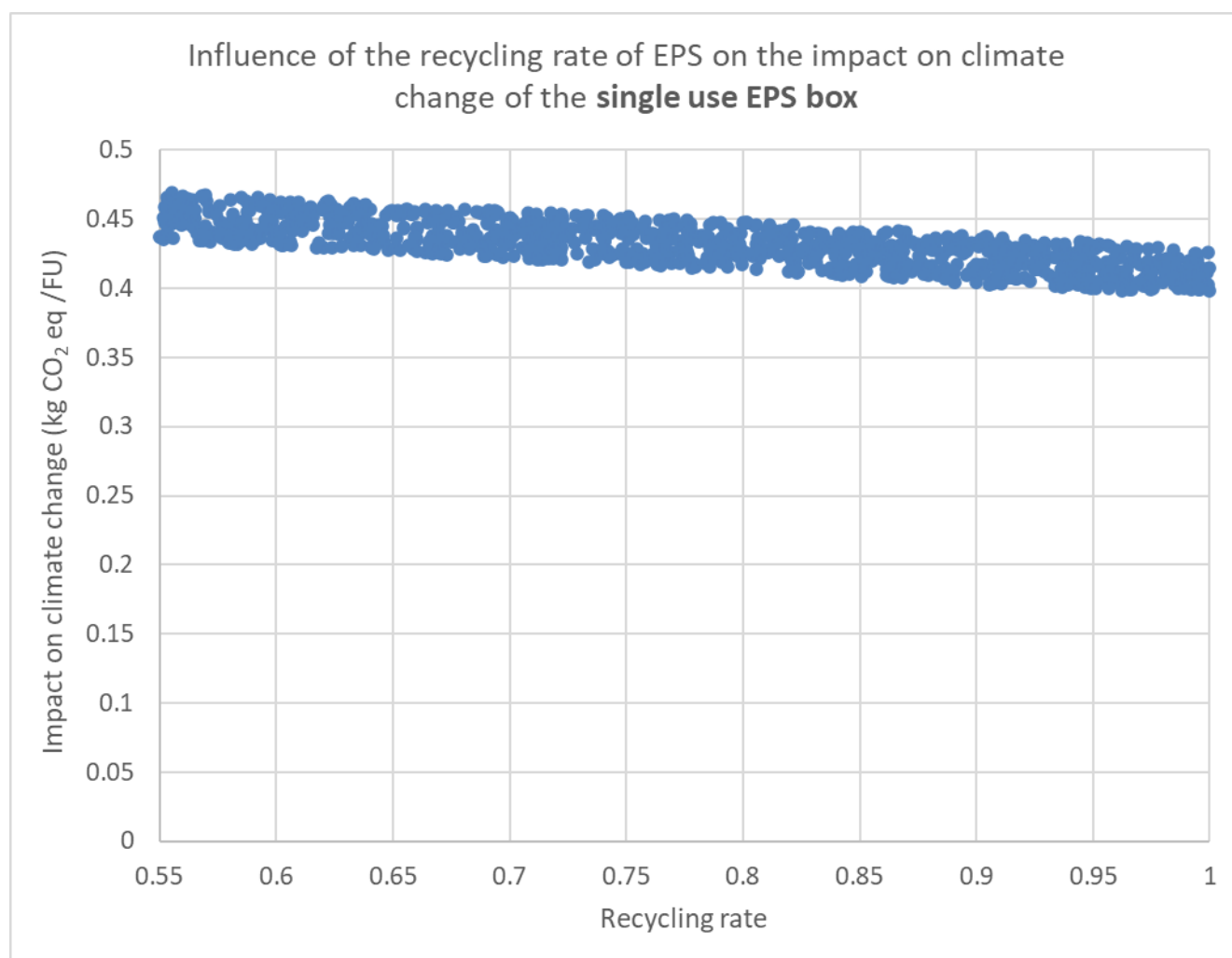


Figure 4-12 Impact of the recycling rate of EPS on the impact on climate change for the single use EPS box (kg CO₂ eq/FU) – base case

For the base case, the recycling rate of EPS has a small impact on the results (-11% when going from 55% recycling to 100% recycling). The smaller the distribution distance, the bigger the impact of the recycling rate (in %) will be, as the total impact of the box will be lower.

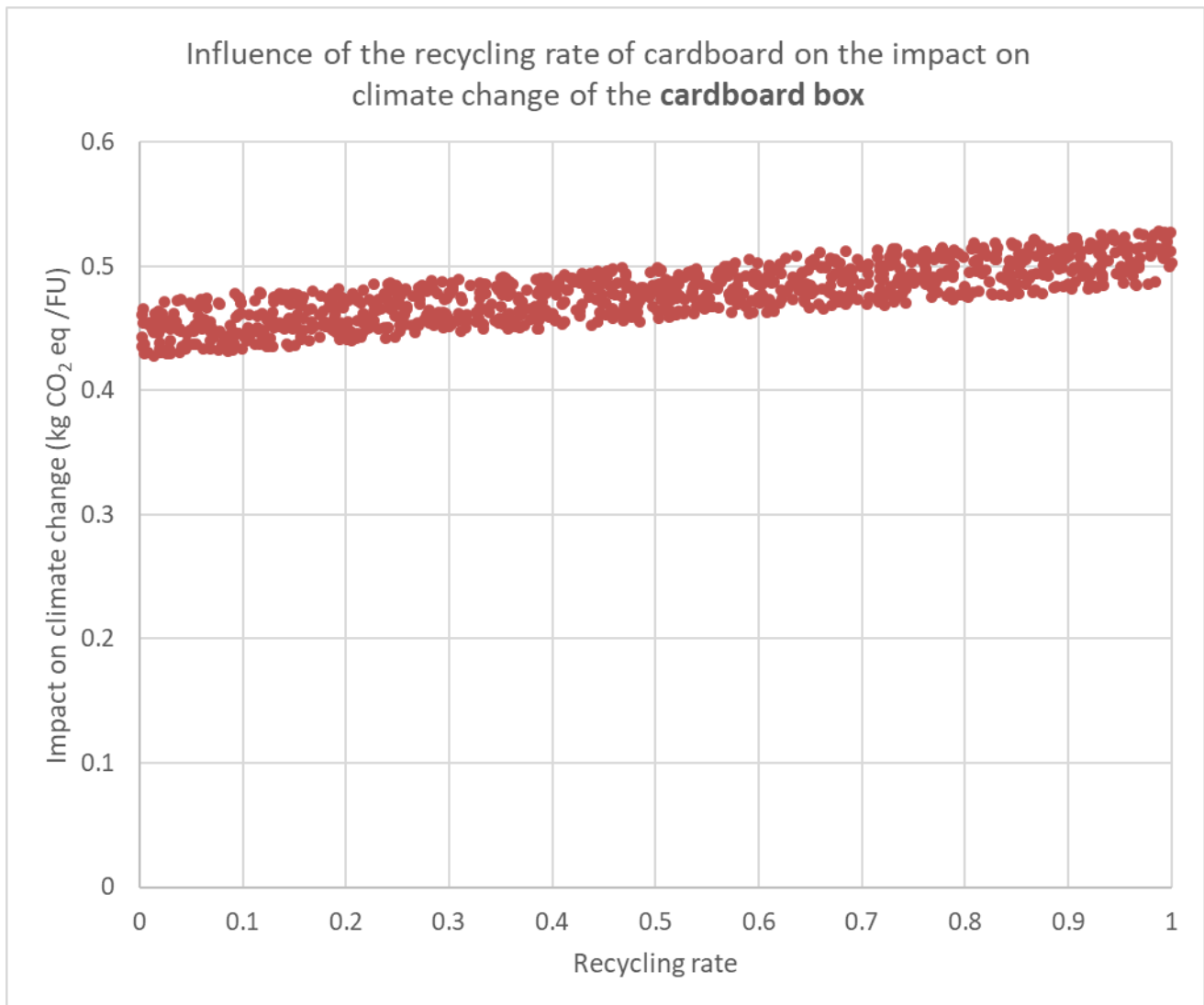


Figure 4-13 Impact of the recycling rate of cardboard on the impact on climate change for the cardboard box (kg CO₂ eq/FU) – base case

For the base case, the recycling rate of cardboard has a small impact on the results (+ 16 % when going from 0% recycling to 100% recycling). The smaller the distribution distance, the bigger the impact of the recycling rate will be (in %), as the total impact of the box will be lower..

4.6.4 End-of-Life methodology: cut-off methodology vs CFF methodology

The CFF methodology was used as the base-case for this assessment as this is the methodology recommended by the European Commission.

A sensitivity analysis was performed to analyse the impact of the EoL methodology used. The results using the CFF methodology were compared with results using the cut-off methodology.

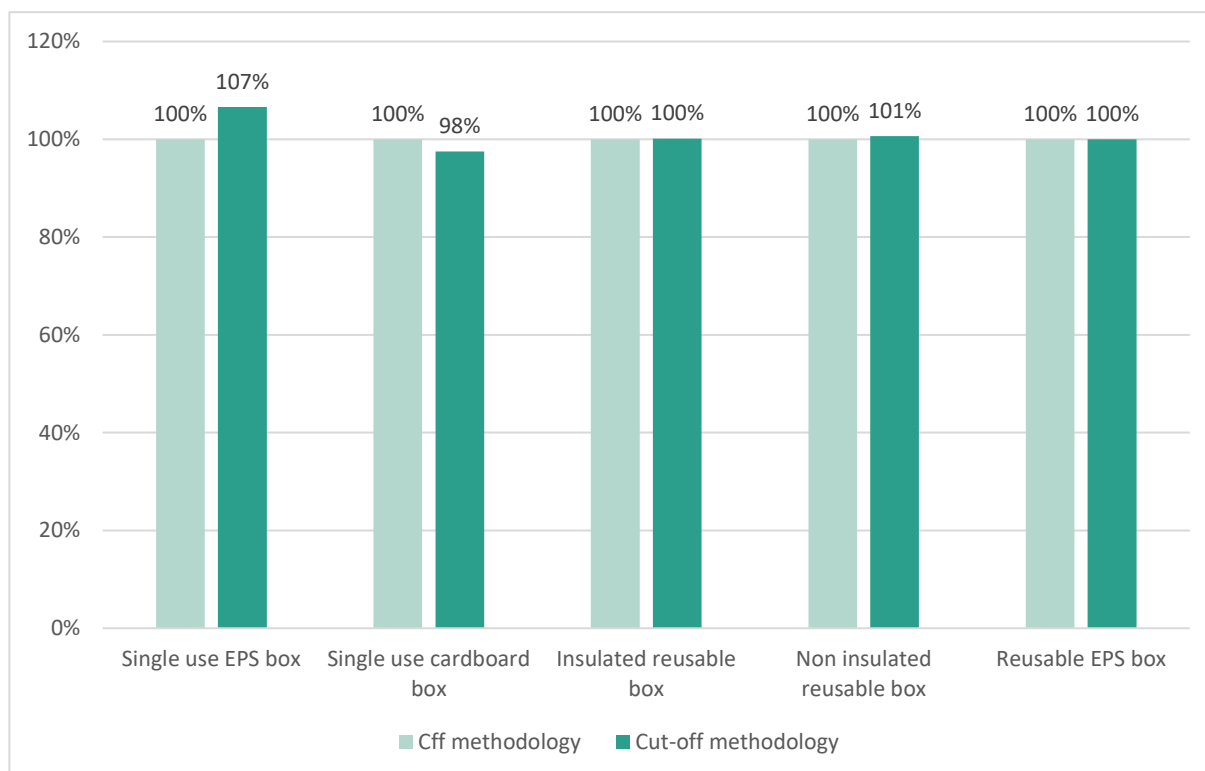


Figure 4-14. Impacts of the studied boxes on climate change. Reference scenario (100%) are the results for the CFF Methodology with a distribution distance of 2800 km.

The use of the CFF methodology benefits the single use EPS box as the calculated impacts of this box are higher when using the cut-off methodology. Indeed, recycling EPS has a positive influence on the impacts on climate change. For this reason, using the cut-off method, which does not include the benefits or impacts of EoL recycling as part of the impacts of the product, leads to a higher impact.

Regarding the cardboard box, the impact of recycling the cardboard is higher than the impact of producing virgin cardboard. For this reason, using the cut-off method, which does not include the benefits or impacts of EoL recycling as part of the impacts of the product, leads to a lower impact.

As the impacts of the EoL are very low for the reusable boxes, using the CFF method instead of the cut-off method has little to no impacts on the results for those boxes.

As the impact of the single use EPS box is higher with the cut-off method, using this methodology would result in an increase of the range of distribution distances for which the alternative boxes have a lower or equivalent impact on climate change than the single use EPS box.

Despite those differences, we have made the choice to use the CFF methodology as base case because the results from this study are expected to be communicated to the European Commission and EU Fisheries and Aquaculture Advisory Councils.

4.6.5 Fuel consumption for lorry refrigeration

In this sensitivity analysis, the influence of a variation in fuel consumption for refrigeration on the impact of the single use EPS box and the cardboard box for a distribution distance of 2800 km. Those boxes have been chosen because they are, for a distribution distance of 2800 km, the boxes that allow to transport the most and the less fish in one lorry, respectively.

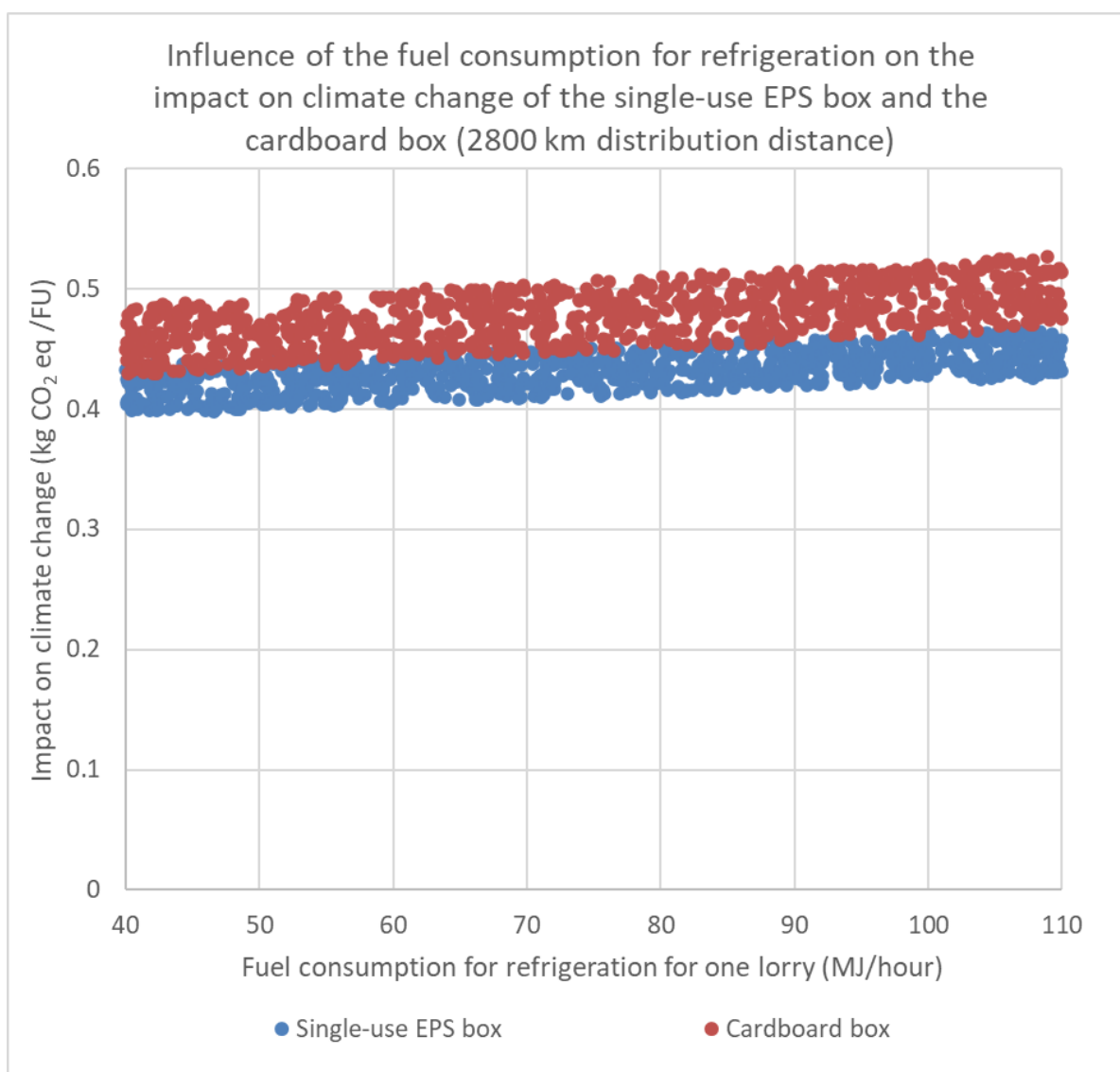


Figure 4-15. Impact of fuel consumption for refrigeration on the impact on climate change for the different boxes (kg CO₂ eq/FU) – base case

Because the fuel consumption for refrigeration is much smaller than the fuel consumption by the lorry engine, an increase of fuel consumption because of higher external temperatures or a decrease in the lorry internal temperature would have little impact on climate change.

4.6.6 Number of drivers

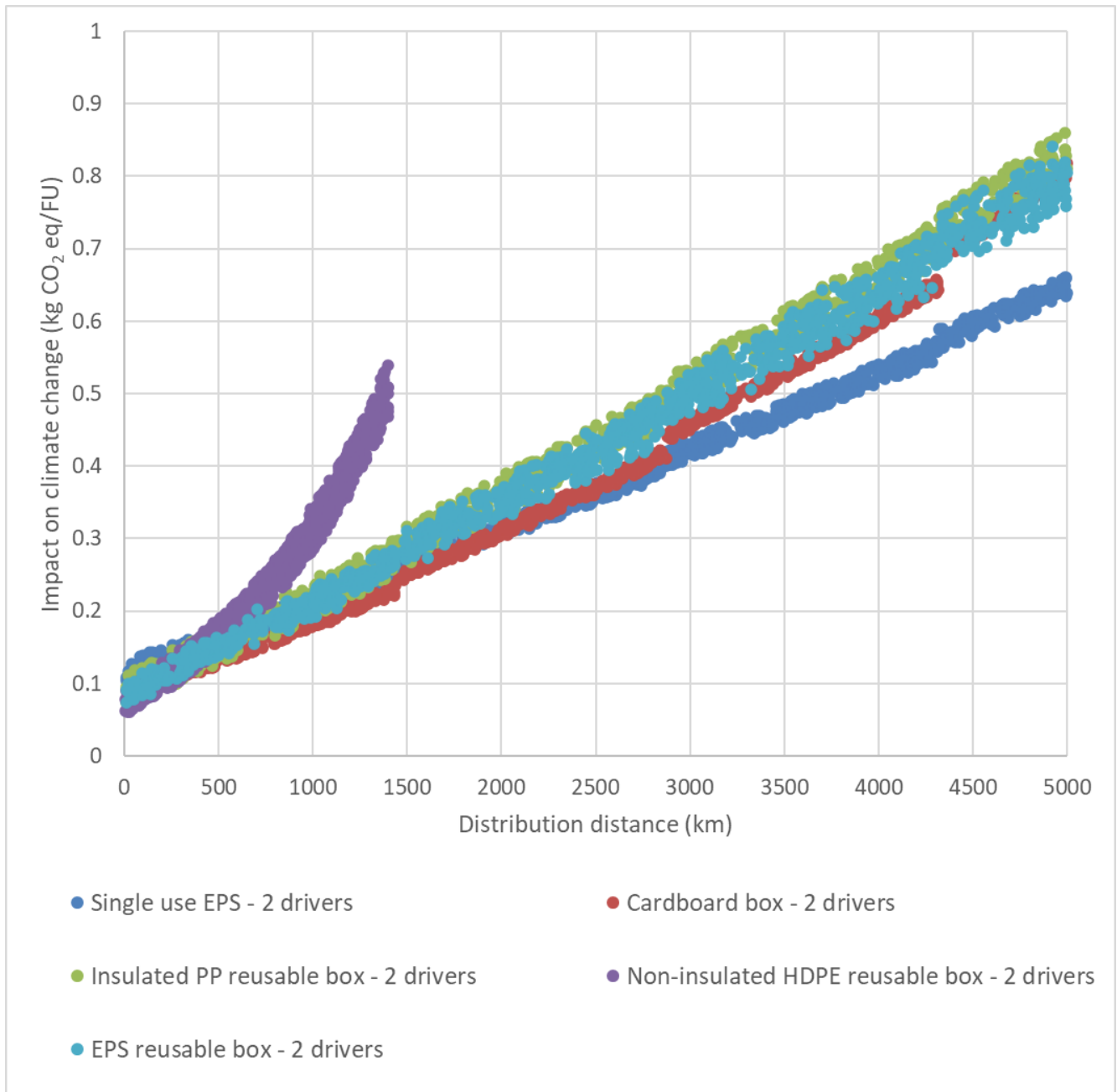


Figure 4-16. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – all boxes with two drivers

There are no differences between the impacts with two drivers and one driver for distribution distances shorter than 720 km (one day) because the duration of distribution is almost the same.

For distribution distances longer than 2 900 km, the single use EPS box has the smallest impact on climate change. For distribution distances shorter than 1250 km, the cardboard box has a lower impact on climate change than the single use EPS box.

For distances lower than 2650 km, there are no significant differences between the impact of EPS reusable box, single use EPS box and insulated reusable PP box (difference below the 5% threshold when considering uncertainties).

The impact of the insulated reusable PP box and the reusable EPS box are similar across all distribution distances because of the impact of the return transport.

The non-insulated reusable HDPE box can be used for distribution distances up to 1400 km, but it has a higher impact than the other boxes for distances above 700 km.

The use of two drivers has a positive impact on climate change compared to one driver. This is especially true for the cardboard box for longer distances, because the insulating properties of this box are lower than the insulating properties of the single use EPS box, reusable EPS box and insulated reusable PP box.

Indeed, if the duration of transport is shorter a smaller amount of ice needs to be packed. As a result, more fish can be transported at once which reduces the amount of lorries needed.

A shorter journey also results in a decrease in fuel consumption for refrigeration.

4.6.7 Use of electric vehicles

In the future, electric vehicle may be used to transport merchandise. For this reason, a sensitivity analysis was performed to analyse the impact of each box if electric vehicles are used.

The amount of electricity consumption is assumed to be 1.1 kWh⁴⁹ per km per lorry for transport and 4-12.5 kWh per hour per lorry for refrigeration (the amount of energy needed for refrigeration is considered to be the same as with diesel refrigeration – it was adjusted to take into account the better efficiency of electric motors : the yield for electric motors is 90% while the yield for diesel motors is 35.1%⁵⁰).

⁴⁹ <https://www.volvolorries.com/en-en/news-stories/press-releases/2022/jan/volvos-heavy-duty-electric-lorry-is-put-to-the-test-excels-in-both-range-and-energy-efficiency.html>

⁵⁰ Ecoinvent data

For a full day of driving (720km), 913 kWh of electricity are necessary (taking into account the maximum amount of electricity for refrigeration). During the 45 minutes break, the lorry can be recharged, allowing to charge 227 kWh⁵¹.

Amongst the electric vehicle batteries available on the market, only a 728 kWh – 4,160 kg⁵¹ battery has enough capacity for the long-distance transport of fish.

During fish transport, the number of pallets that can be transported is limited by the maximum load of the lorry (24 tons); not by the volume. For an electric vehicle, the added weight of the battery must be considered.

In our model, the weight of the battery is 4 160 kg (modelled using the EI dataset “market for battery, Li-ion, NMC811, rechargeable, prismatic, GLO”). As a result, the maximum weight of the transported merchandise cannot exceed 19 840 kg.

The maximum number of full boxes that can be transported by an electric lorry was calculated for each box type.

Table 4-3. Number of boxes per pallet, number of pallets per lorry and lorry load

	Weight of one filled box (kg)	Number of boxes per pallet	Weight of tertiary packaging for one pallet (kg)	Weight of one filled pallet (kg)	Number of European pallets per lorry	Lorry load (tonnes)
EPS box (single use and reusable)	25.6	27	25.2	716	27	19.3
Cardboard box	26.34	27	25.2	736	26	19.15
Insulated reusable PP box	29.41	30	25.2	908	21	19.1
Non insulated reusable HDPE box	27.96	30	25.2	864	22	19.0

⁵¹ <https://www.scania.com/group/en/home/electrification/e-mobility-hub/all-you-need-to-know-about-range-and-payload-for-electric-lorries.html>

The maximum number of empty boxes that can be transported by an electric lorry does not change as the weight of those boxes is below 19.8 tons (cf. Table 3-10).

The maximum number of waste boxes that can be transported does not change as the weight of those boxes is below 19.8 tons (cf. Table 3-10 and section 3.2.7.2).

The emissions linked to tyre and brake wear were modelled using the EI datasets “tyre wear emissions, lorry, RER” and “brake wear emissions, lorry, RER”.

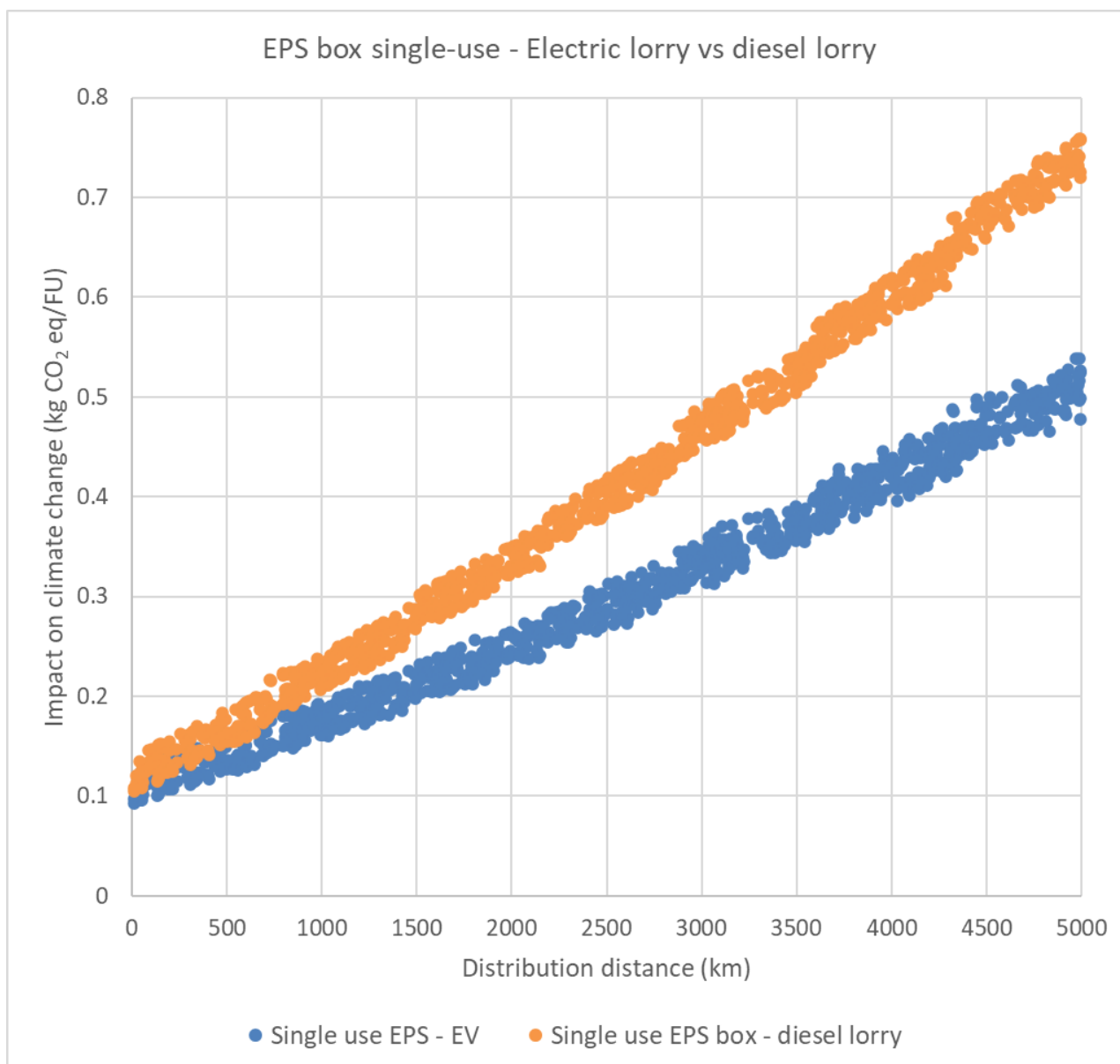


Figure 4-17. Influence of the type of lorry used for transport on the single use EPS box impact on climate change (kg CO₂ equivalents / FU) – electric lorry vs diesel lorry

The use of electric lorries has a positive impact on climate change compared to diesel lorries. This is especially true for the reusable boxes for longer distances because the impact of the transport during reuse is also reduced.

Any decrease in the carbon intensity of electricity would result in an increase of the advantages of the electric lorry.

The use of electric lorries instead of standard diesel lorries leads to a decrease of the impact of transport on climate change larger than what could be achieved by switching from one box to another.

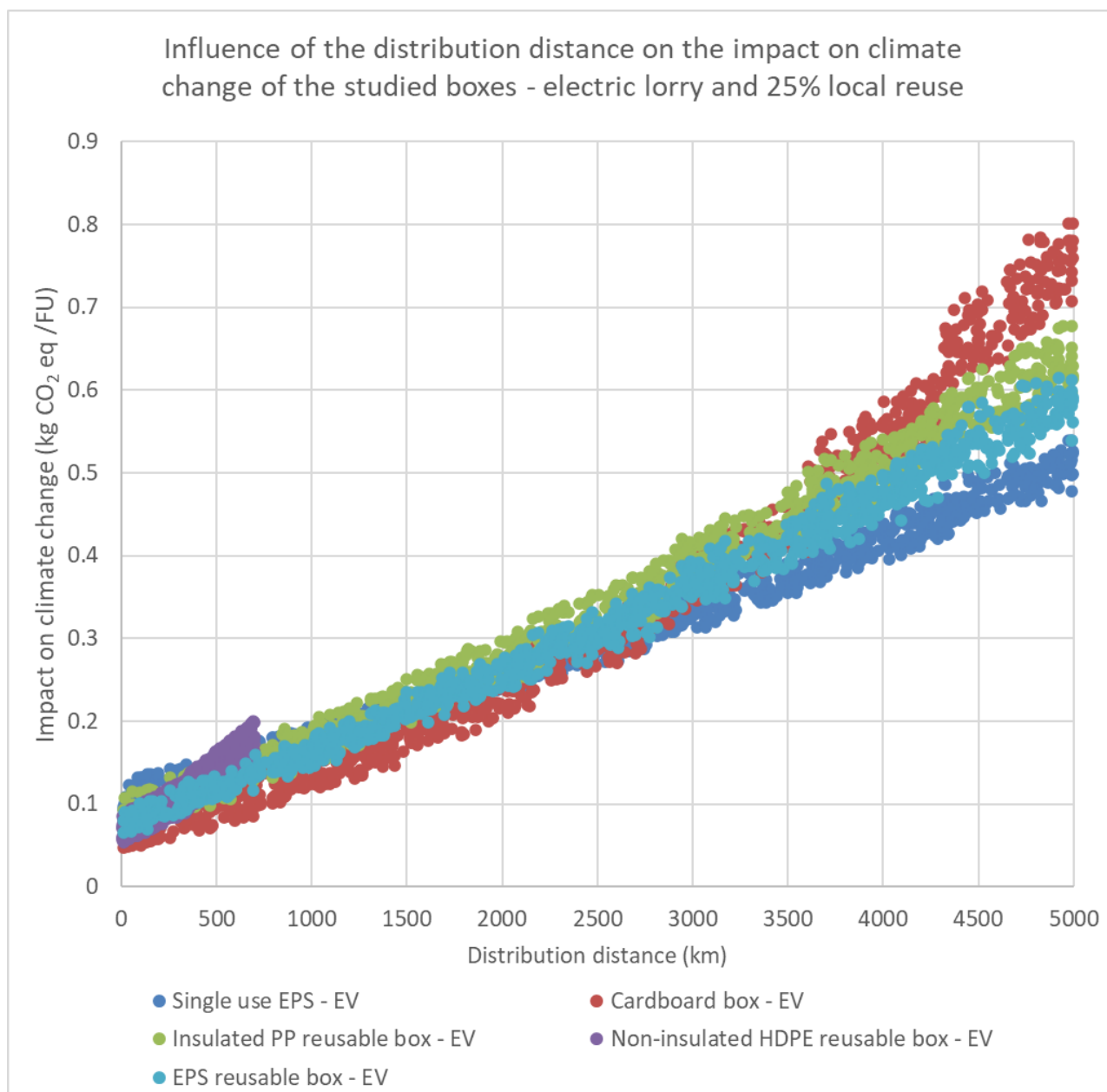


Figure 4-18. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs alternative boxes, transported by electric vehicle (1 driver)

The impacts on climate change of the different studied boxes overlap across all distribution distances (no difference when considering uncertainties).

The impact of the cardboard box is lower than the impact of the single use EPS box for distances below 850 km. The impact of the single use EPS box is lower than the impact of the cardboard box for distances above 3600 km.

The insulating properties of the cardboard box are lower: this box requires twice as much ice as the single-use and reusable EPS boxes for the same distribution duration. As a result, the impact of the cardboard box increases faster than the impact of the single use EPS box with distance.

The impact of the single use EPS box is higher than the impact of the insulated reusable PP box for distances above 4000 km. Below this threshold, the impacts are similar (the difference between the impacts is below the 5% significance threshold when considering uncertainties).

The difference between the single use EPS box and the insulated reusable PP box is mostly linked to the impact of reuse: the longer the fish distribution distance, the longer the dispatch of the box will be to return to its original location.

Across all distances the impact of the single use EPS box and the reusable EPS box overlap (no difference when considering uncertainties).

The non-insulated reusable HDPE box can only be used for distribution distances below 720 km, but it has a similar or lower impact to the other boxes across those distances.

Because the non-insulated HDPE box has low insulation properties, the amount of ice needed to maintain hygienic conditions increases quickly with the transport distance. As a result, no fish can be transported for distances above 720 km (one day). Indeed, the duration of the nightly rest before distribution would result in a large amount of ice melting (cf. section 3.2.3.1).

4.6.8 Proportion of local reuse (dispatch distance of reusable boxes)

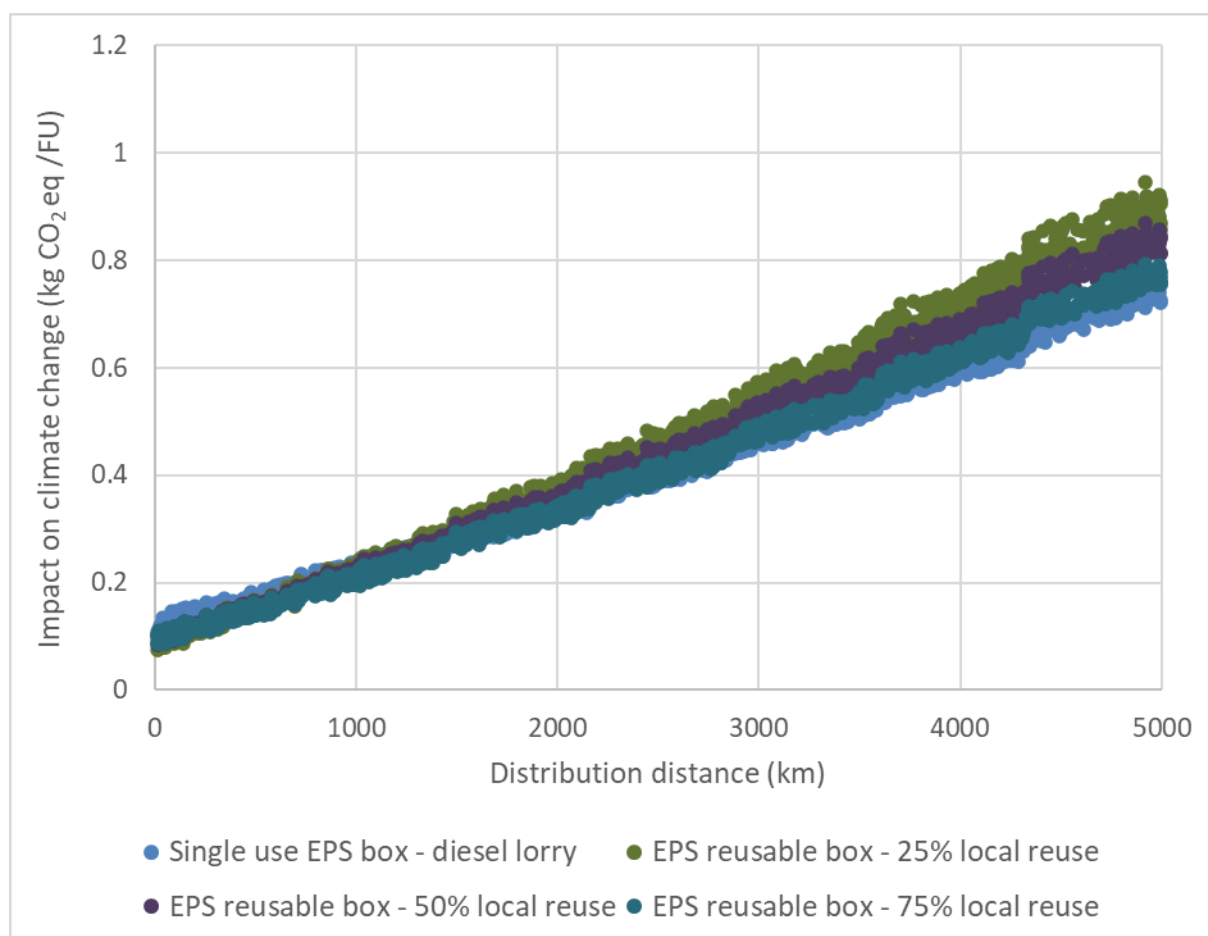


Figure 4-19. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs reusable EPS box for different number of local reuses

- For 50% of local reuse:
 - The impact of the reusable EPS box does not significantly differ from the impact of the single use EPS box for distribution distances lower than 3 000 km (difference below the 5% threshold when considering uncertainties).
- For 75% of local reuse:
 - The impact of the reusable EPS box does not significantly differ from the impact of the single use EPS box across all distribution distances (difference below the 5% threshold when considering uncertainties).

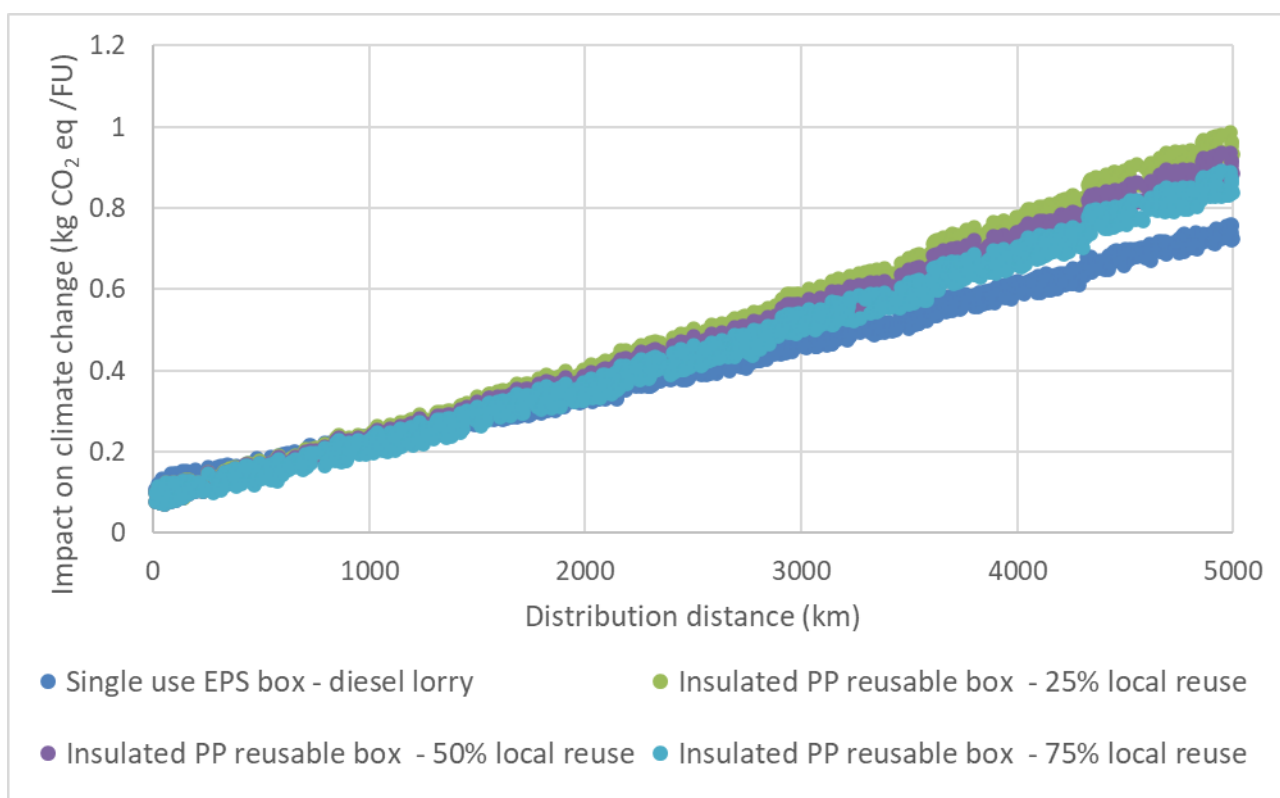


Figure 4-20. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs insulated reusable PP box for different number of local reuses

- For 50% of local reuse:
 - The impact of the insulated reusable PP box does not significantly differ from the impact of the single use boxes for distribution distances lower than 2 500 km (difference below the 5% significance threshold when considering uncertainties).
- For 75% of local reuse:
 - The impact of the reusable box does not significantly differ from the impact of the single use boxes for distribution distances lower than 3 500km (difference below the 5% significance threshold when considering uncertainties).

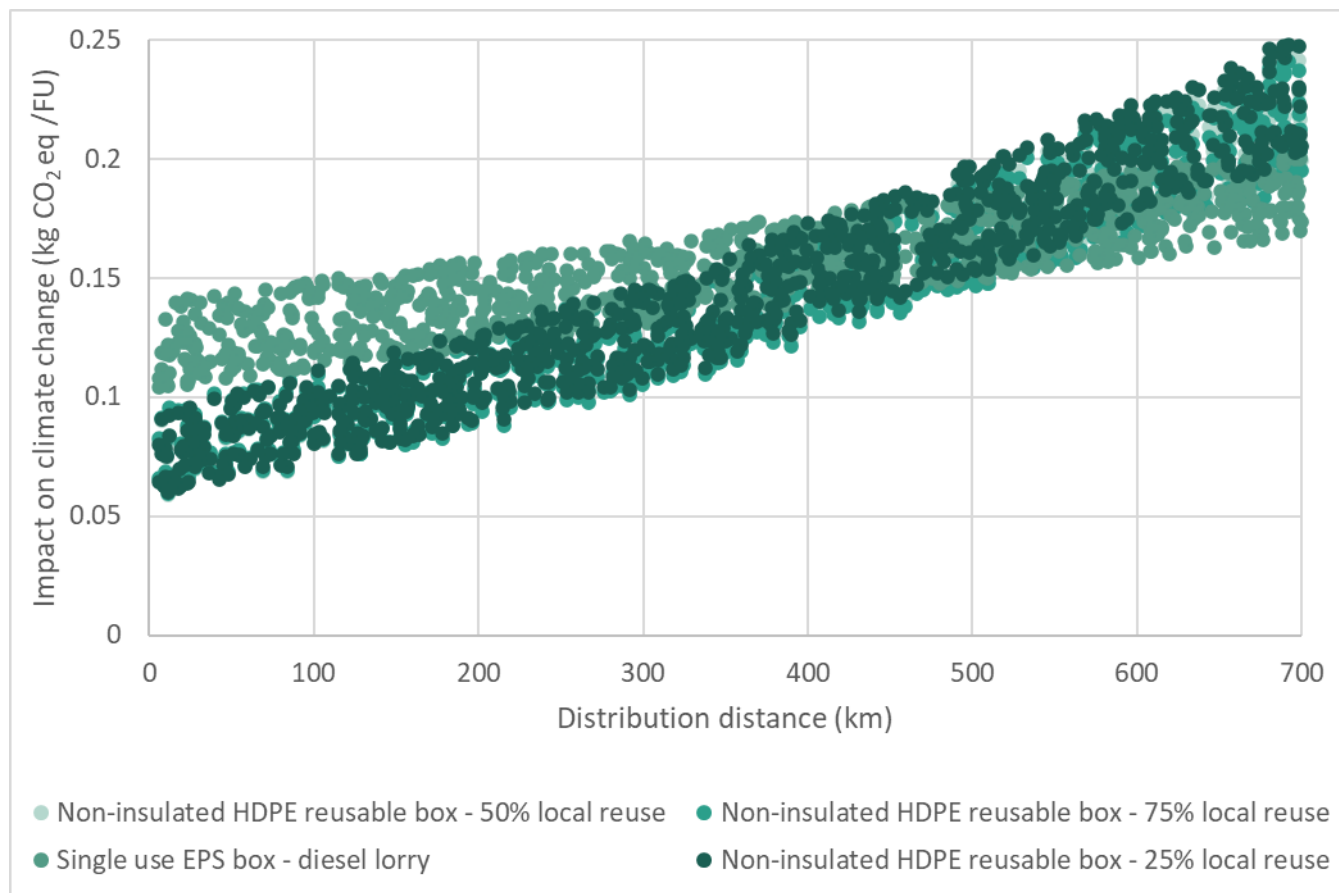


Figure 4-21. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs non-insulated HDPE reusable box for different number of local reuses

For the different proportion of local reuse, the impacts of the non-insulated HDPE box are similar. Because the distribution distances are already short, an increase in local reuse has little impact.

As a whole, the impact of the reusable boxes on climate change is reduced when the proportion of local reuse increase.

4.6.9 Stackable reusable EPS box

The impact of having optimized return logistics for the reusable EPS box was further analysed by modeling the impacts of a stackable EPS box.

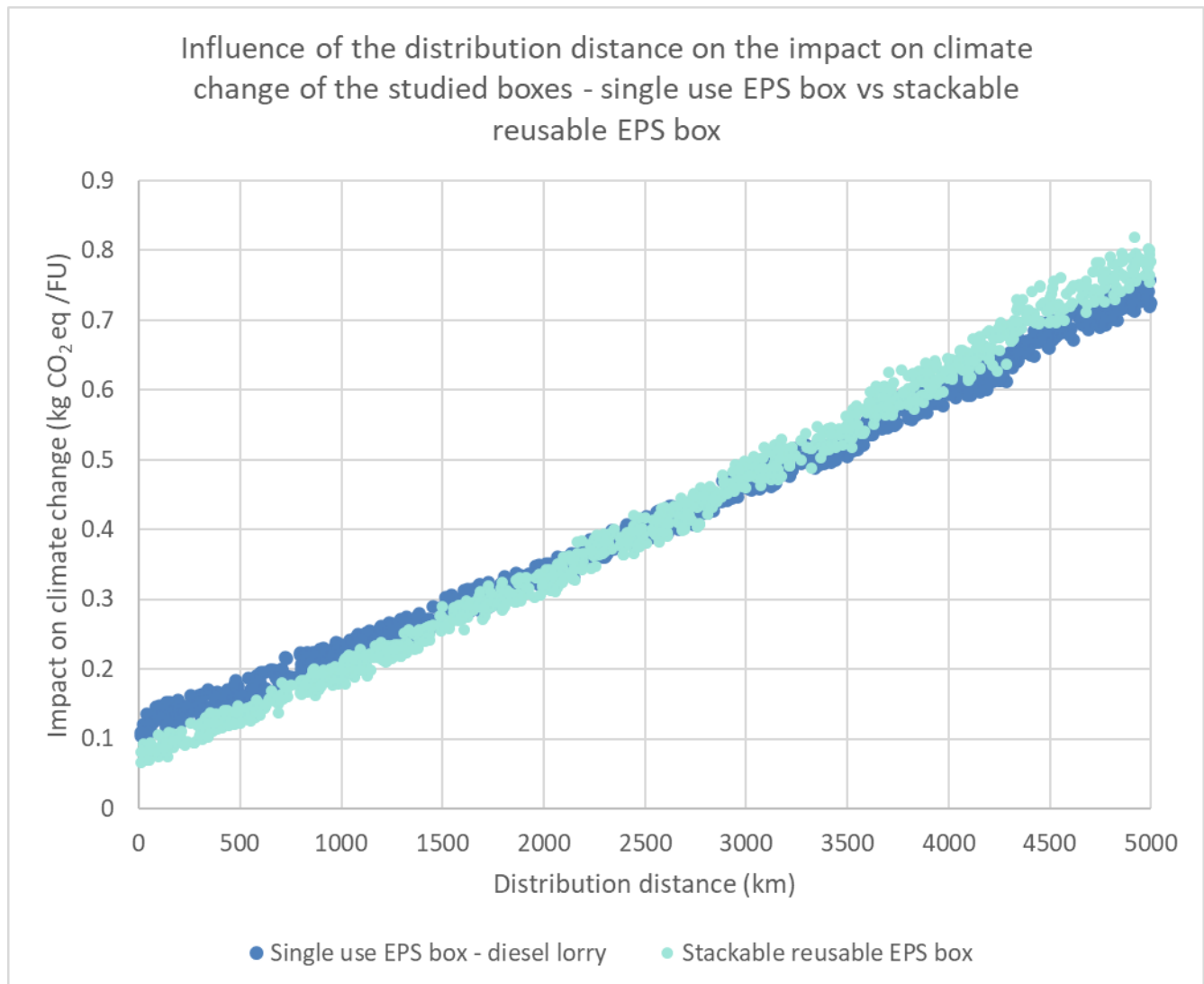


Figure 4-22. Influence of fish distribution distance on the studied boxes' impact on climate change (kg CO₂ equivalents / FU) – single use EPS box vs stackable reusable EPS box.

Using a stackable reusable EPS box would significantly improve the impact of the box over long distances: there are no significant differences between the impacts of the stackable reusable EPS box and the single use EPS box on climate change for long distances (no differences when considering uncertainties)..

For distances below 250 km, the stackable reusable EPS box has a lower impact on climate change.

This type of box does not currently exist.

4.6.10 Fish loss

The percentage of fish loss during transport has an influence on the environmental impacts of the boxes because these impacts are calculated based on the amount of fish fit for human consumption the boxes transport:

$$\text{Amount of fish for human consumption} = \text{Amount of fish transported} \times (1 - \text{fish loss})$$

The percentage of fish loss also has an influence on the impacts on the previous steps of the fish value chain which are not included in this study: fishing or fish farming.

Using the results of the Marine Fish PEFCR, the environmental impacts of fishing and fish farming have been compared with the impacts of the boxes calculated in this story.

Because the impacts of fish production are much higher than the impacts of the boxes for multiple indicators, the impact of fish production and of the EoL of fish losses was taken into account during this sensitivity analysis.

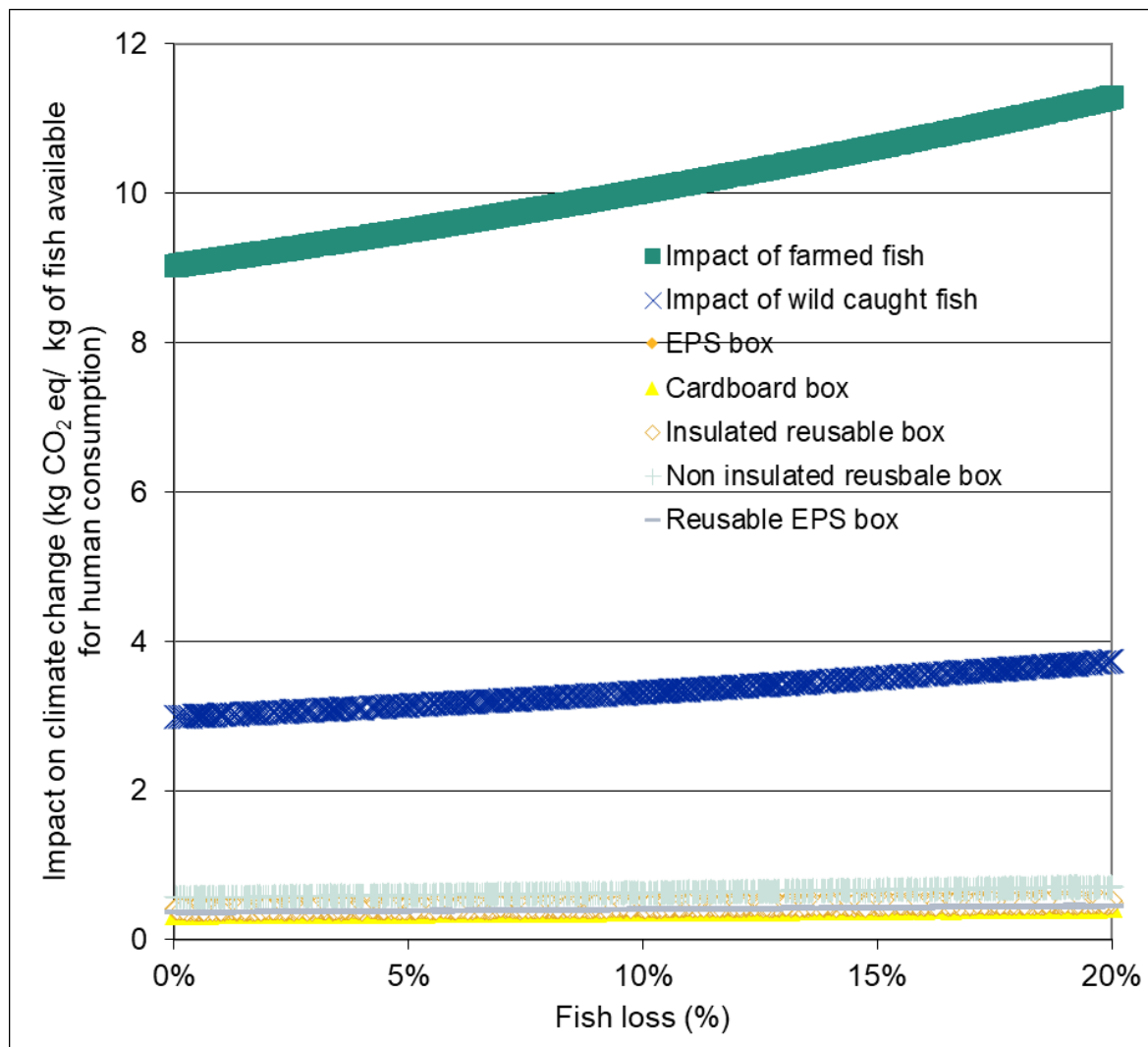


Figure 4-23. Influence of fish loss on the impact on climate change (kg CO₂ equivalents / kg of farmed fish available for human consumption) – base case

For a distribution distance of 2 800 km, the increase in impacts linked to the loss of fish is greater than the differences of impact between each box. This is especially true for farmed fish which has a larger environmental impact than wild caught fish.

In the base case, the loss rate associated with each box is identical (4%), as the boxes have been modelled in a way that should ensure no increase in fish loss. If the use of one box were to cause an increase in fish loss, the resulting impact would be greater than the possible benefits that might arise from using one box rather than the other.

A fish loss increase of 1% results in an increase of 0.11 kg CO₂ eq of the impact of the farmed fish. For a distribution distance of 2 800 km, the difference of impact between the single use EPS box (smallest impact) and reusable EPS box (largest impact) is 0.08 kg CO₂ eq. As a result, if the single use EPS box had a loss rate 1% higher (4% of fish loss to 5% of fish loss) than the loss rate of the reusable EPS box, the total impact of the single use EPS box over the fish value chain would be higher than the total impact of the reusable EPS box. This example is not realistic; it serves only as a way to show the potential impact of fish loss.

4.6.11 Cleaning vs single use plastic liner

This additional analysis aims to answer the question: “What would be the impact of using a single use plastic cover instead of cleaning the reusable boxes?”.

The following table shows the resulting impacts of the two options for the selected indicators:

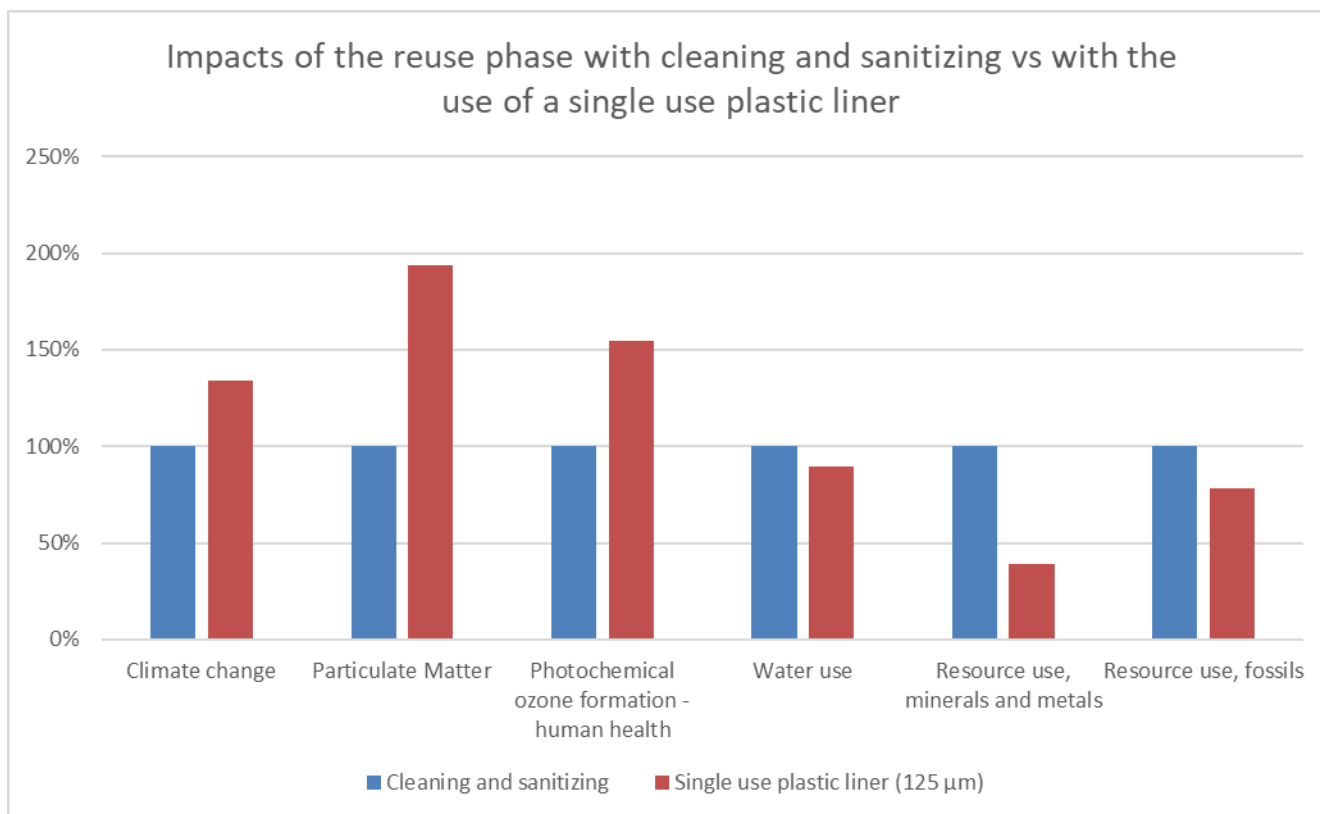


Figure 4-24. Comparison of the impacts of cleaning and sanitizing reusable boxes vs the use of a single use plastic liner

Cleaning and sanitizing the box would result in a lower impact on Climate Change, on Particulate Matter and on Photochemical Ozone Formation.

On the other hand, using a single use plastic liner would allow to reduce water use, the use of fossil resources and the use of mineral and metal resources. Indeed, cleaning and sanitizing require using hot water which consumes water and fossil resources (gas for heating) and a detergent (Sodium Hydroxide). The process to produce sodium hydroxide requires chlor-alkali electrolysis which consumes barium carbonate (mineral resources).

In this assessment, the impact of the use of a plastic liner on the distribution phase (increased weight of the box because of the liner) was not modelled.

Other possible challenges linked to the use of a liner have not been taken into account.

5 Economic costs

5.1.1 Base case

The following graph presents the estimated economic cost associated with the modelled stages, for each of the packaging options. The following lessons can be drawn:

- The costs of the value chain using single use EPS box are the lowest of the compared options for the transport distance of 2 800 km.
- The main reason for the good performance of the EPS box is the good isolation properties of the box, allowing to carry less ice per box, hence leaving more room to carry fish.
- The reusable EPS box shows the same isolation properties, but the cost of the return logistics disadvantages this solution when compared to single use EPS.
- The fish distribution phase (i.e. transport) is the most contributing phase, followed by the cost of the packaging itself, including the return logistics and cleaning for the concerned options.
 - The cost of distribution phase is a function of the quantity of fish transported in the lorry, which mainly depends on the quantity of ice needed in the box together with the fish. The quantities of fish and ice are a function of the isolation properties of the box.
 - The better the isolation, the lower the ice quantity needed, the more fish in the box, the lower the transport cost per unit of fish.
- The cost of the box itself corresponds to
 - The cost of the new boxes for EPS and cardboard box. The cost of the cardboard box includes ice bags. Uncertainty remains on the cost of the cardboard box, as no public data exist on the large-scale production cost of such boxes.
 - For the reusable systems, the cost is a function of
 - the number of empty boxes that fit in a lorry, which is subject to evolution
 - the number of effective rotations, i.e. the robustness of the box combined with the ability of the pooler to localise and collect all boxes spread on the EU territory.

The reusable EPS box assumed in the model performs relatively poorly on both parameters.

Note that the non-insulated reusable box is not considered for the transport distance of 2 800 km, as it is considered non-realistic as the trip duration is too long and the ice would melt. The results are shown on the graph for a transport distance of 700 km.

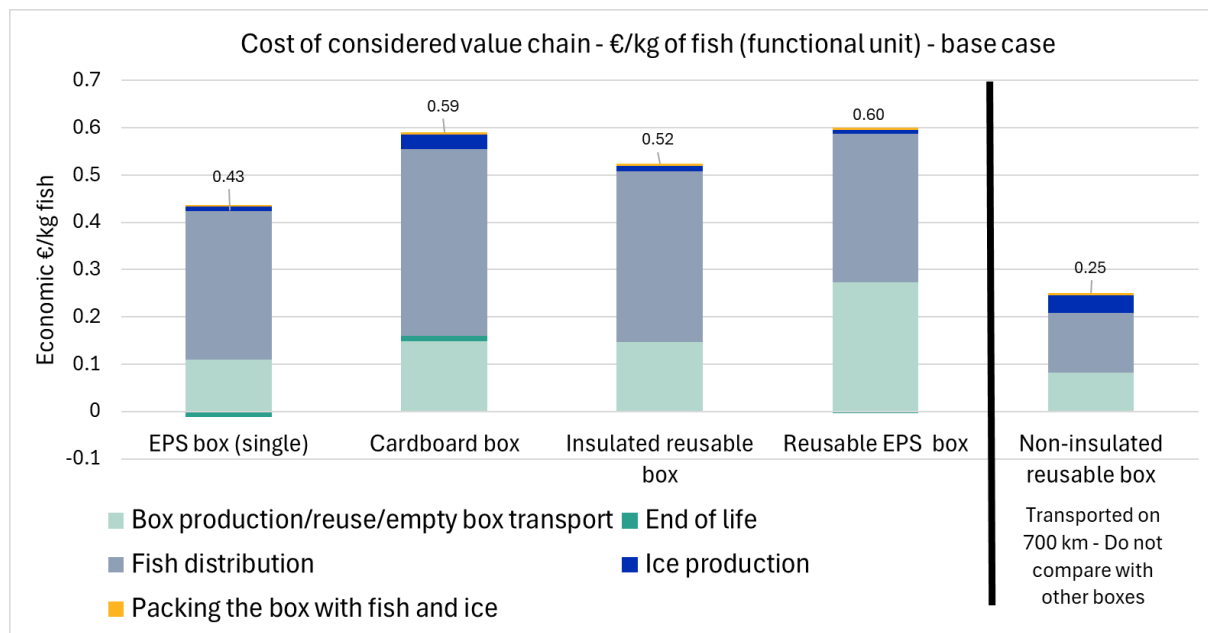


Figure 5-1. Cost of considered value chain (euros / FU) – base case

5.1.2 Sensitivity analysis

The sensitivity analysis covers the following parameters :

- Fish distribution distance, with 1 or 2 drivers;
- Fish loss.

5.1.2.1 Fish distribution distance

The influence of the fish distribution distance on the cost of the value chain of the different boxes is shown in the figures below. The first figure shows the results when one driver is driving the lorry. The second figure shows the costs when two drivers are driving, allowing to ride a longer distance before stopping to rest.

The other varying parameters that have an impact on the results shown in these figures are:

- The number of uses of the reusable boxes (cf. Number of uses of reusable boxes)
- The number of uses of the insulated and non-insulated reusable boxes vary between 10 and 60; and the number of uses of the reusable EPS box vary between 2 and 5.

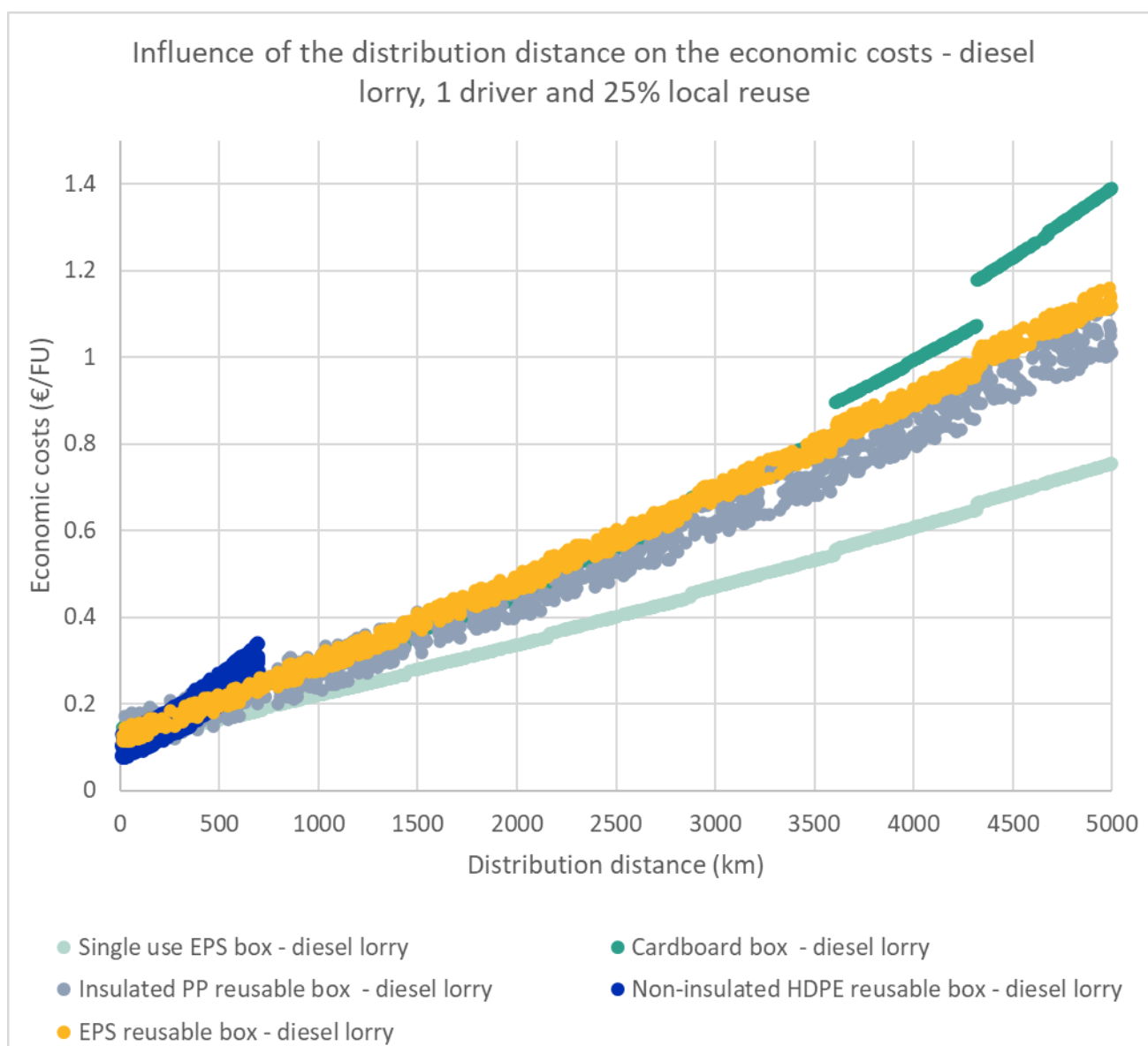


Figure 5-2. Influence of fish distribution distance on the studied boxes' economic cost (euros / FU) – 1 driver and 25% local reuse

With one driver,

- From 1000 km of transport distance onwards, the single use EPS boxes display lower costs;
- Below 1000 km, there is no significant difference between the costs of the insulated reusable boxes and the single use EPS boxes (the difference does not exceed the 5% threshold when considering uncertainties). For shorter distances under 200 km and 400 km respectively, the costs associated to the non-insulated reusable box and reusable EPS box are also non-significantly different from the single use EPS and the insulated box solutions (the difference does not exceed the 5% threshold when considering uncertainties).

With two drivers (see figure below),

- From 1 200 of transport distance onwards, the single use EPS boxes display lower costs;
- Below 1 200 km, situations can exist where the reusable insulated box (and the non-insulated reusable box and the reusable EPS box, below 200 km and 300 km respectively) cost less than the single use EPS solution.

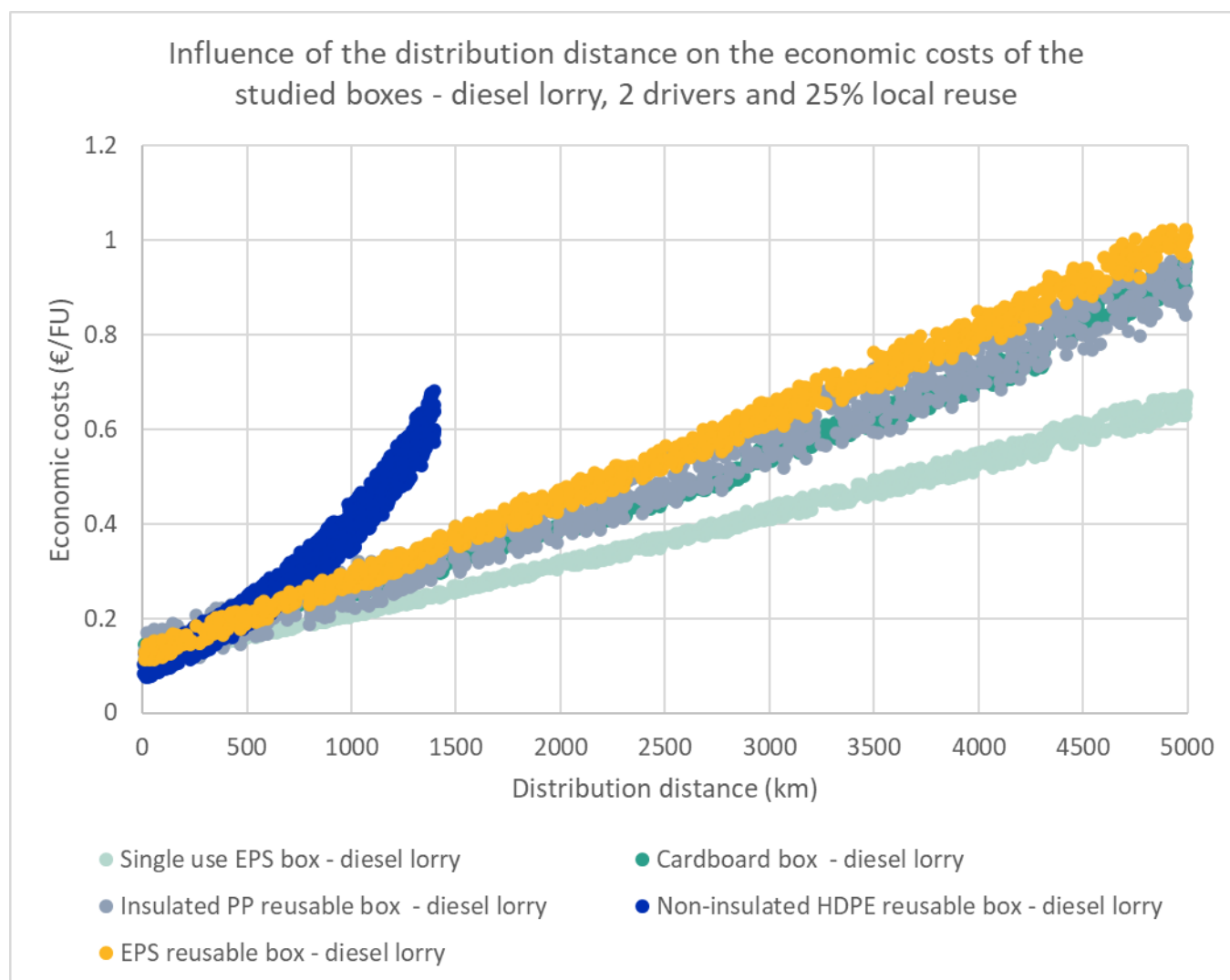


Figure 5-3. Influence of fish distribution distance on the studied boxes' economic cost (euros / FU) – 2 drivers and 25% local reuse

The cost of the cardboard box is always higher than the cost of the single use EPS box.

5.1.2.2 Economic impact of fish loss

The percentage of fish loss during transport has an influence on the transport and logistic costs per unit of fish for human consumption (functional unit) : the bigger the losses, the bigger the amount of fish one need to produce and transport to deliver one unit of fish for human consumption:

$$\text{Amount of fish for human consumption} = \text{Amount of fish transported} \times (1 - \text{fish loss})$$

The percentage of fish loss also has an influence on the cost of the previous steps of the fish value chain which are not included in this study: fishing or fish farming.

In the base case (4% loss and average distribution distance), the typical cost of the fish is 6.25€/kg of fish after transport (6€ before transport, before the losses). The cost of producing fish is much higher than the cost of its transport + the cost of the use of the boxes.

An increase of the loss rate by 1% would result in an increase of the cost of the fish by 0.06€/kg whereas the maximal economic impact of the choice of the box is about 0.17€/kg at 2 800km (difference of cost between the less expensive and the most expensive boxes). This means that even a small difference in average loss associated to one type of box would, in practice, outweigh the differences in logistical costs as computed in the model.

If one box was less expensive but caused a greater amount of fish loss, its use might not make sense from an economic point of view as the costs linked to the losses would outweigh the benefits of cheaper logistics.

6 Social value of job creation

6.1.1 Meaning of the social value of job creation

The social value of job creation attributed to the modelled value chain corresponds to the benefit for society of a decrease in unemployment, such as a decreased cost for social security.

The social value of creating jobs depends on the type of jobs and the job market situation per type of job: the higher the unemployment rate, the higher the benefit of creating jobs.

6.1.2 Results analysis

The following graph presents the modelled value of job creation associated with the stages, for each of the packaging options. Note that the positive values shown on the graph correspond to a positive impact for the society (which is the opposite convention compared to the graphs showing environmental and economic impacts).

The non-insulated reusable box is not considered for the transport distance of 2 800 km: it is considered non-realistic as the trip duration is too long too much ice would be needed. The results are shown on the graph for a transport distance of 700 km.

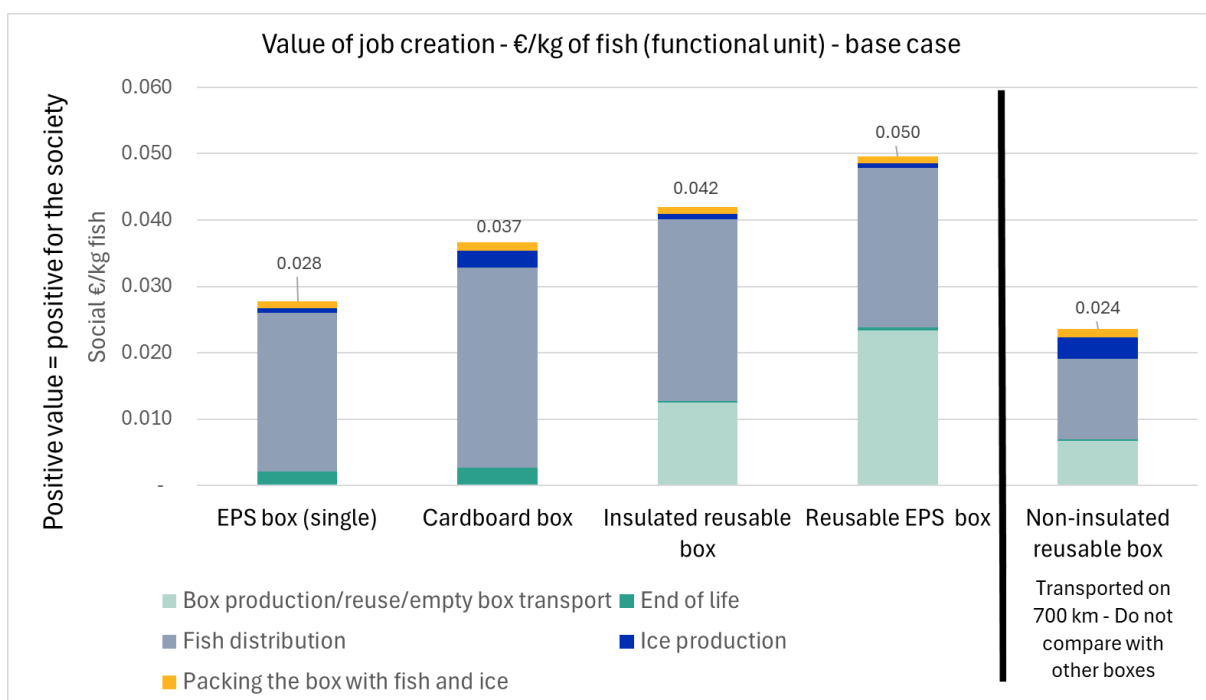


Figure 6-1. Value of job creation (euros / FU) – base case

The following lessons can be drawn:

- The single use EPS box solution presents the lowest contribution to job creation of the compared options, which is a corollary to its cost-efficiency. The other solutions are more labour intensive. The difference in the social value of the jobs created vary between 0.01 and 0.02 €/kg fish depending on the box type.

- The main contributors to labour intensity are:
 - the distribution and the transport in particular, varying as explained above for the economic cost;
 - the return logistics (reuse, empty box transport, cleaning) for the reusable boxes require labour time, mainly for transport.

6.1.3 Sensitivity analysis

The influence of the fish distribution distance on the value of job creation of the different boxes is shown in the figure below. The further the fish is transported, the more labour is needed to drive the lorry.

The results are shown on two graphs : the first for one driver and the second for two drivers.

Analysing the effect of transport distance, we see that:

- Across all distances, the value of the jobs created by the single use EPS box is smaller than the value for the reusable and cardboard box.
- Across all distances, the value of the jobs created by the insulated reusable PP box is smaller than the value for the EPS reusable box.

The impact of the number of drivers is limited, because the worked hours considered are the driving hours only.

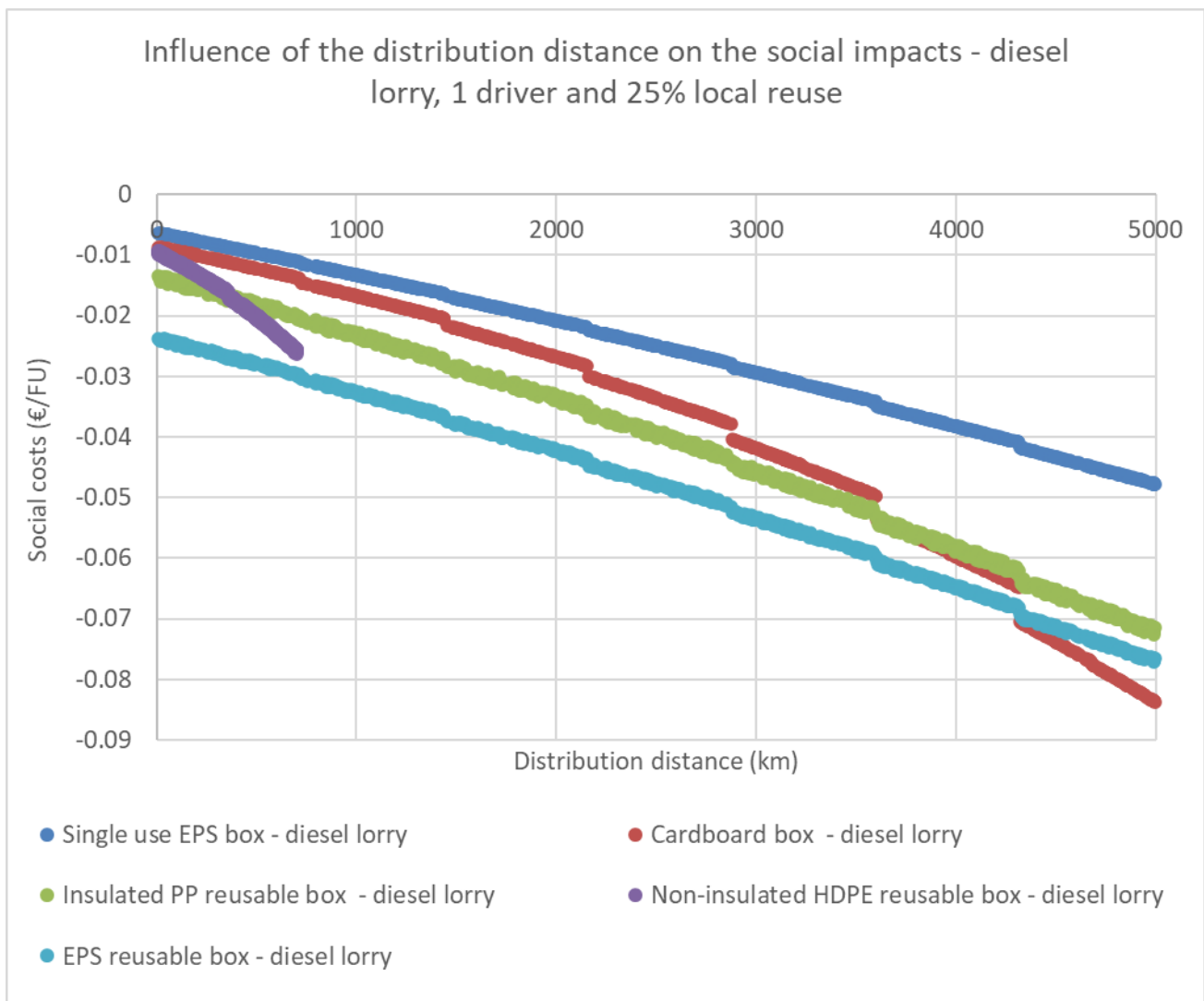


Figure 6-2. Influence of fish distribution distance on the studied boxes' social impacts (euros / FU) – 1 driver and 25% local reuse

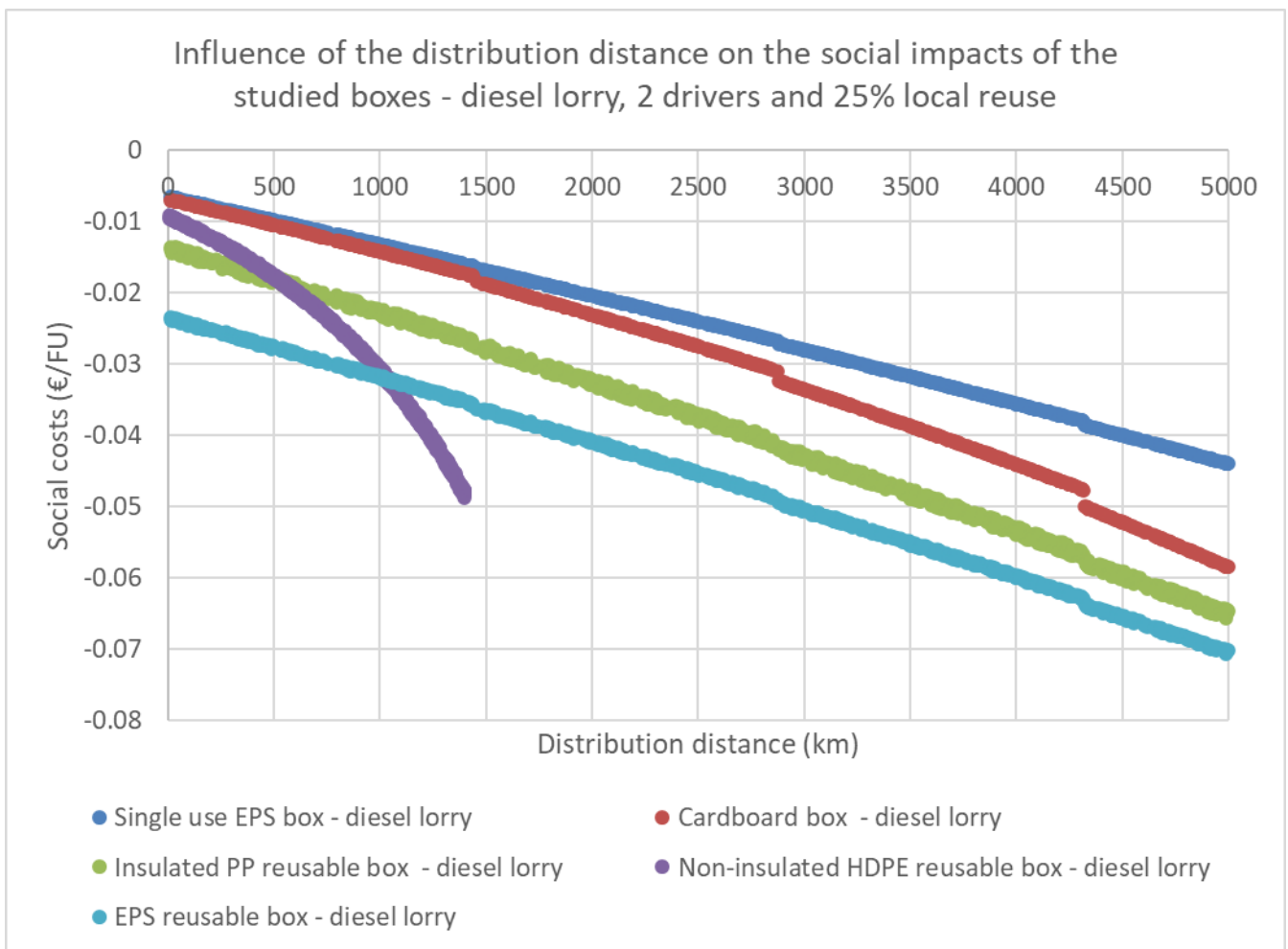


Figure 6-3. Influence of fish distribution distance on the studied boxes' social impacts (euros / FU) – 2 drivers and 25% local reuse

7 Aggregated impacts

The economic costs, monetised environmental impacts and monetised social value of job creation have been aggregated to perform a three pillars “cost-benefit analysis” taking economic costs as well as environmental and social externalities into account.

7.1 Monetised environmental impacts

The environmental impacts and social have been monetised.

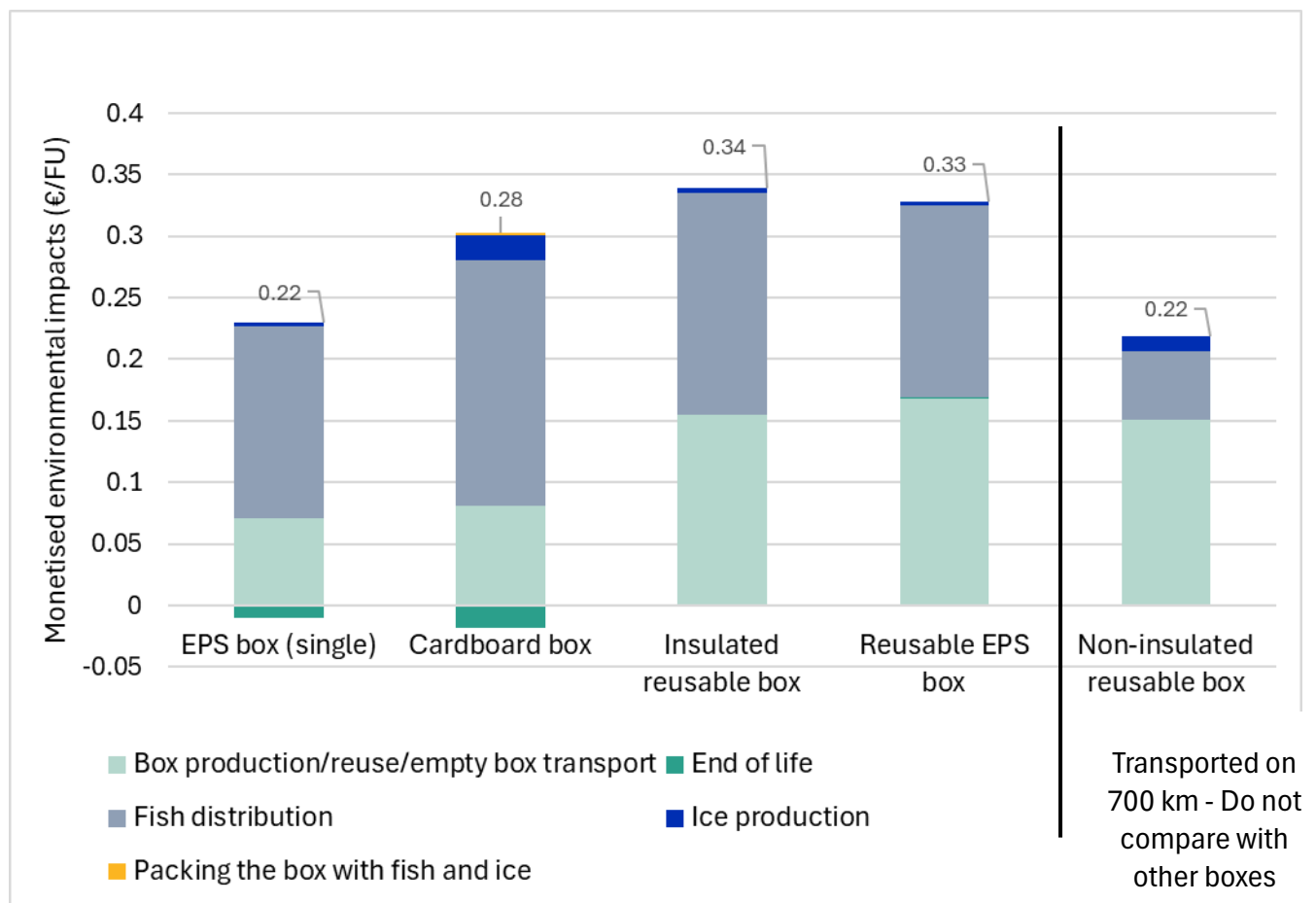


Figure 7-1. Monetised environmental impacts by life cycle phase for the base case (euros / FU)

For the base case:

- The impact of the cardboard box is 27 % higher than the impact of the EPS box.
- The reusable boxes have a higher impact than the single use boxes.

The influence of the fish distribution distance on the monetised environmental impacts of the different boxes is shown in the figure below.

The other varying parameters that have an impact on the results shown in these figures are:

- The number of uses of the reusable boxes (cf. Number of uses of reusable boxes)
 - the number of uses of the insulated and non-insulated reusable boxes varies between 10 and 60;
 - the number of uses of the reusable EPS box varies between 2 and 5.
- The EoL of the boxes (cf. End-of-life treatments):
 - the recycling rate of EPS varies between 55% and 100% ;
 - the recycling rate of the cardboard box varies between 0% and 100%.

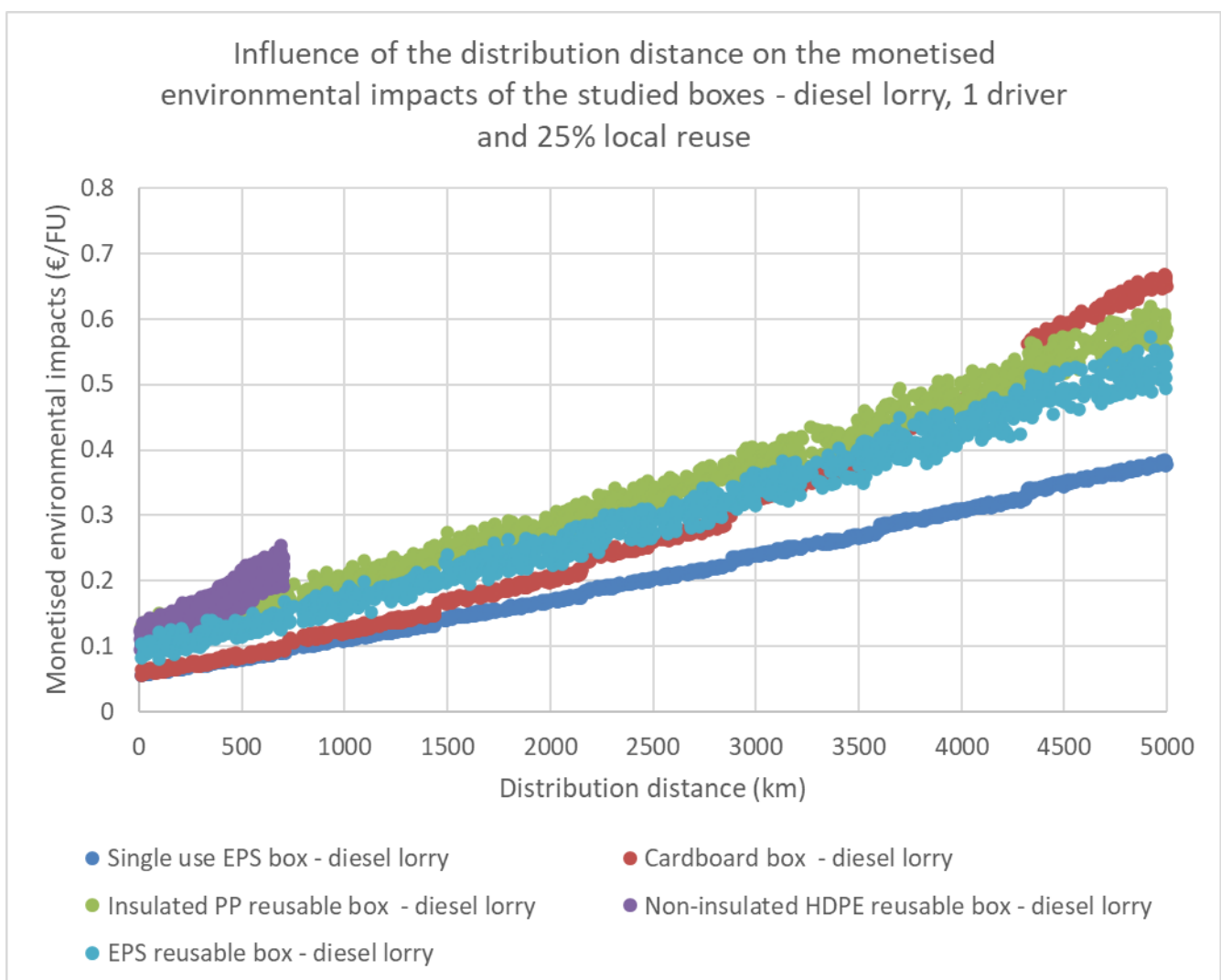


Figure 7-2. Influence of fish distribution distance on the studied boxes' impact on monetised environmental impacts (euros / FU) – 25% local reuse and 1 driver

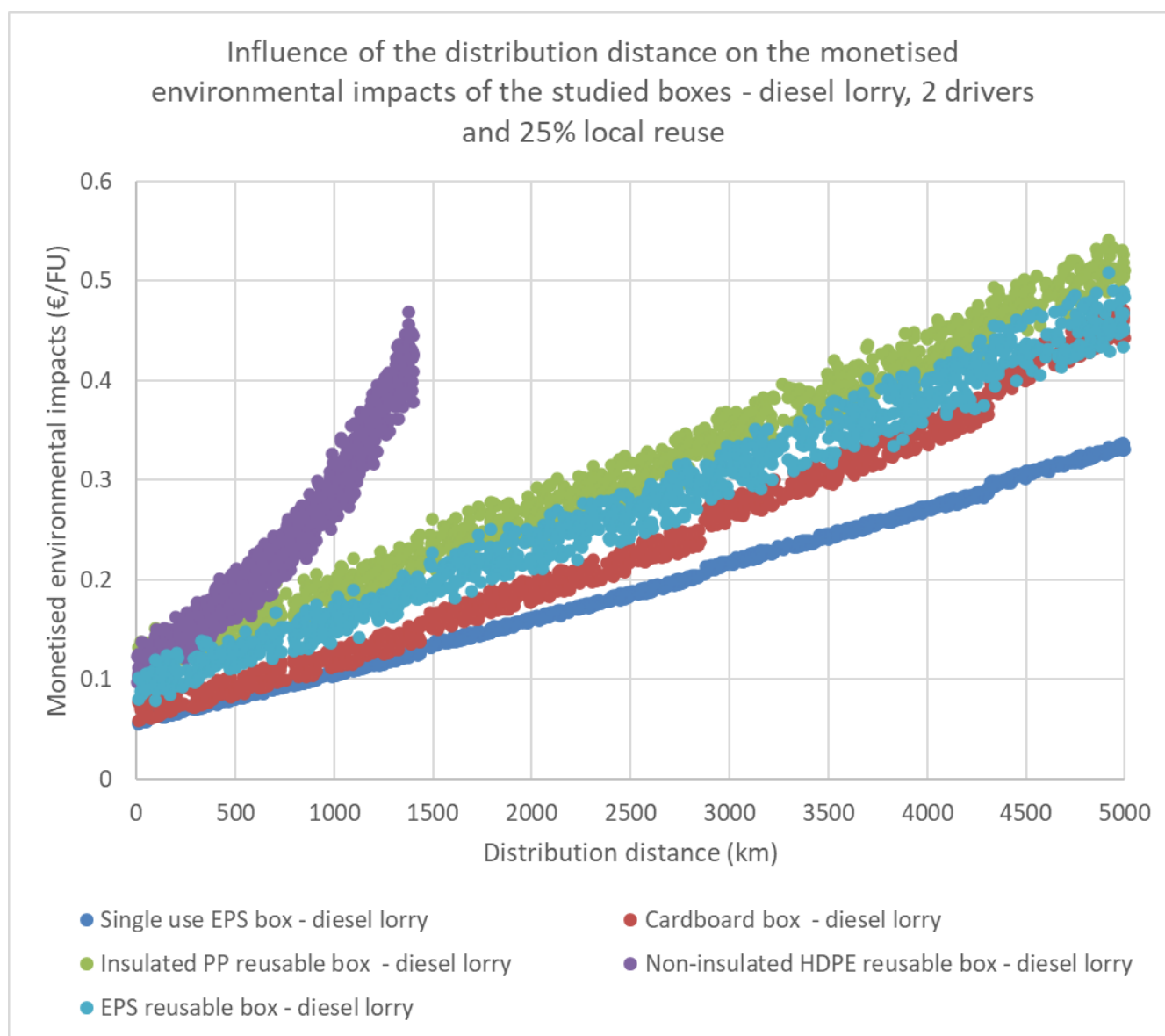


Figure 7-3. Influence of fish distribution distance on the studied boxes' impact on monetised environmental impacts (euros / FU) – 25% local reuse and 2 drivers

With one or two drivers, across all distances, the aggregated environmental impacts of the single use EPS box are smaller or similar to the impacts of the alternative boxes. For distances shorter than 1500 km, there are no significant differences between the impacts for of the cardboard boxes and single use EPS boxes (difference below the 5% significance threshold when considering uncertainties).

7.2 Aggregated social, economic, and environmental impacts for the average fish distribution distance

Note that the non-insulated reusable box is not considered for the transport distance of 2 800 km, as it is considered non-realistic as the trip duration is too long and the amount of ice needed would be too high. The results are shown on the graphs for a transport distance of 700 km.

The graph below shows the aggregated impacts distributed per stage of the value chain. Positive values correspond to negative impacts for the society, and vice versa.

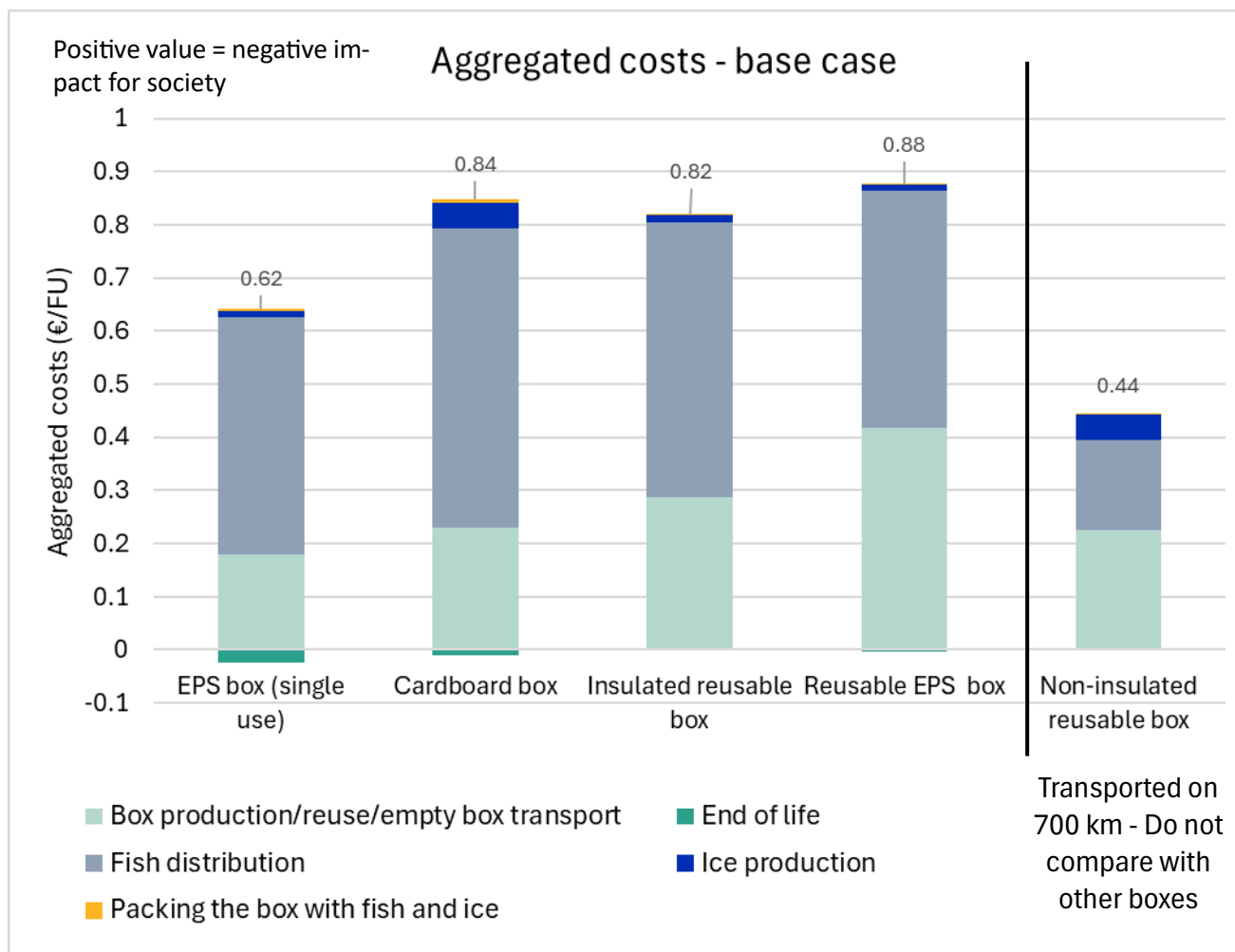


Figure 7-4. Aggregated environmental and socioeconomic impacts by life cycle phase for the base case (euros / FU)

The graph below shows the same aggregated impacts as above; this time distributed per pillar of the sustainability assessment. Positive values correspond to negative impacts for the society, and vice versa.

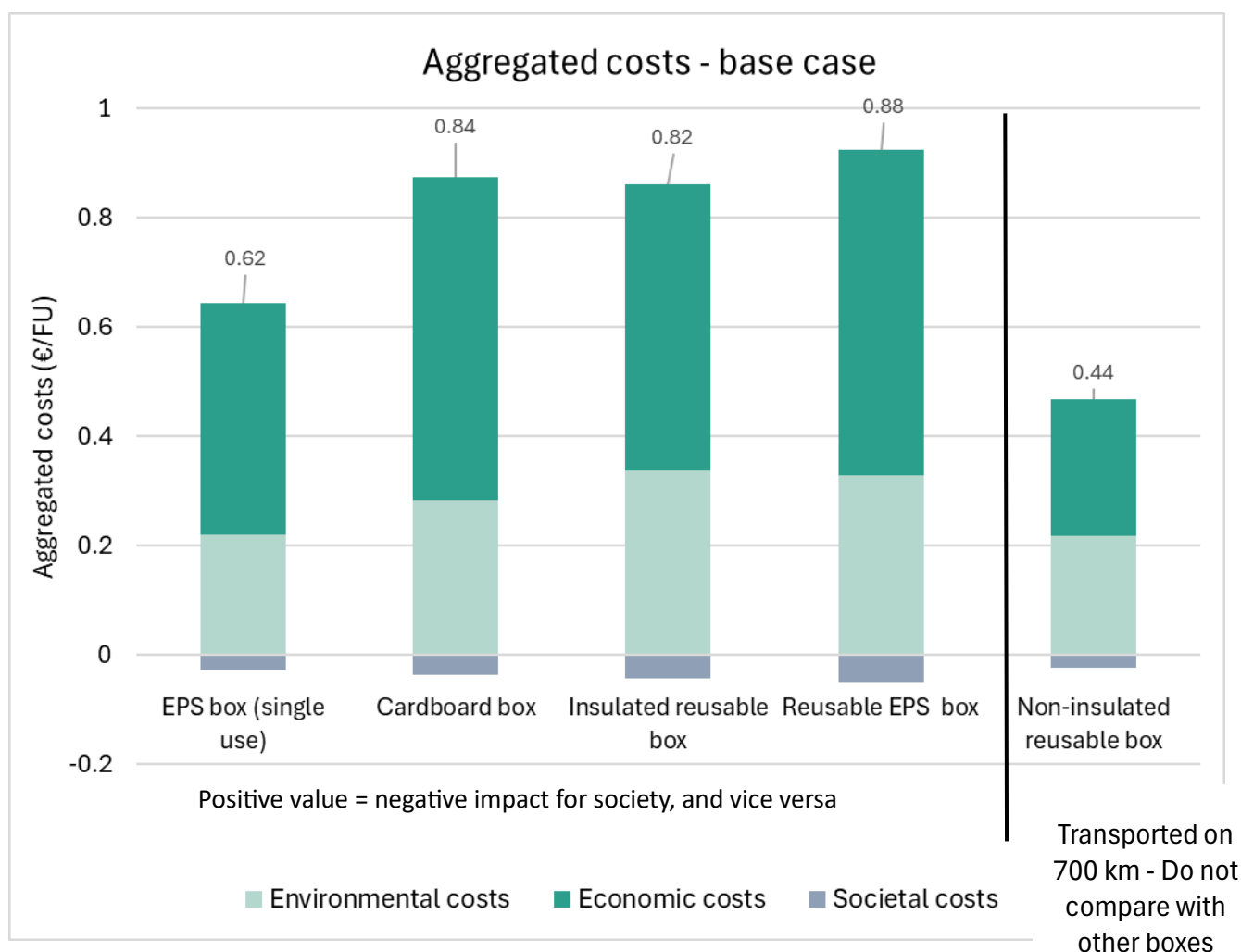


Figure 7-5. Aggregated environmental, economic, and social impacts by pillar of the sustainability assessment for the base case (euros / FU)

In the base case, the single use EPS box performs better than the competing boxes and displays a lower aggregated impact per unit of fish delivered. The impacts associated to the cardboard box and the reusable boxes are of a similar order of magnitude. The non insulated box is not comparable as its use for the 2 800 km distance is considered non-realistic (too much ice needed, no room left for the fish).

7.3 Aggregated impacts : Sensitivity analysis

The influence of the fish distribution distance on the aggregated environmental, economic, and social impacts of the different boxes is shown in the figure below, for one driver.

The other varying parameters that have an impact on the results shown in these figures are:

- The number of uses of the reusable boxes (cf. Number of uses of reusable boxes)
- The EoL of the boxes (cf. End-of-life treatments)

The recycling rate of EPS varies between 55% and 100% ; the recycling rate of the cardboard box varies between 0% and 100% ; the number of uses of the insulated and non-insulated reusable boxes varies between 10 and 60; and the number of uses of the reusable EPS box varies between 2 and 5.

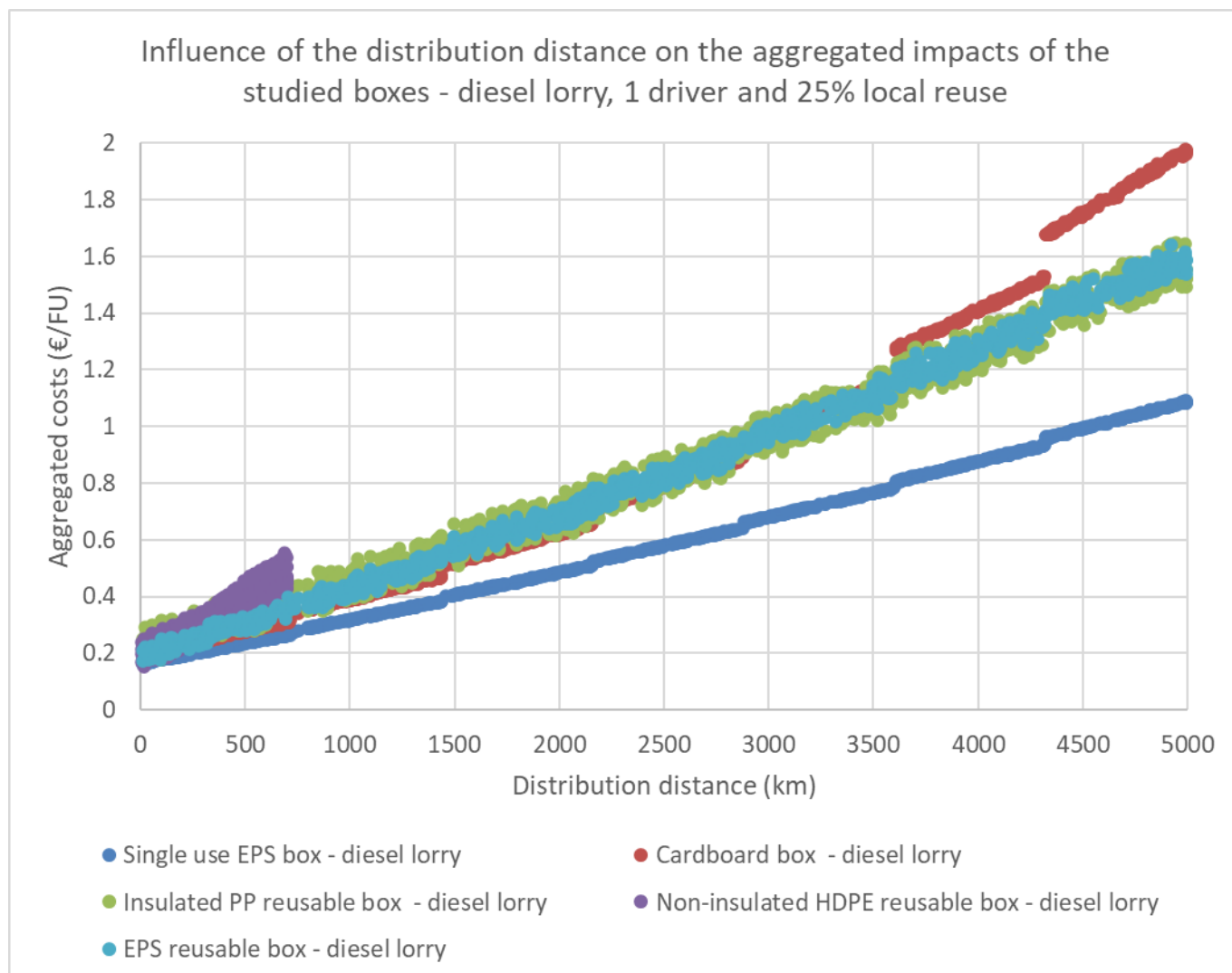


Figure 7-6. Influence of the fish distribution distance on the aggregated environmental, societal, and economic impacts (euros / FU) – 25% local reuse and one driver.

The single use EPS box performs better than the other boxes as soon as the transport distance exceeds 200 km when one driver is driving.

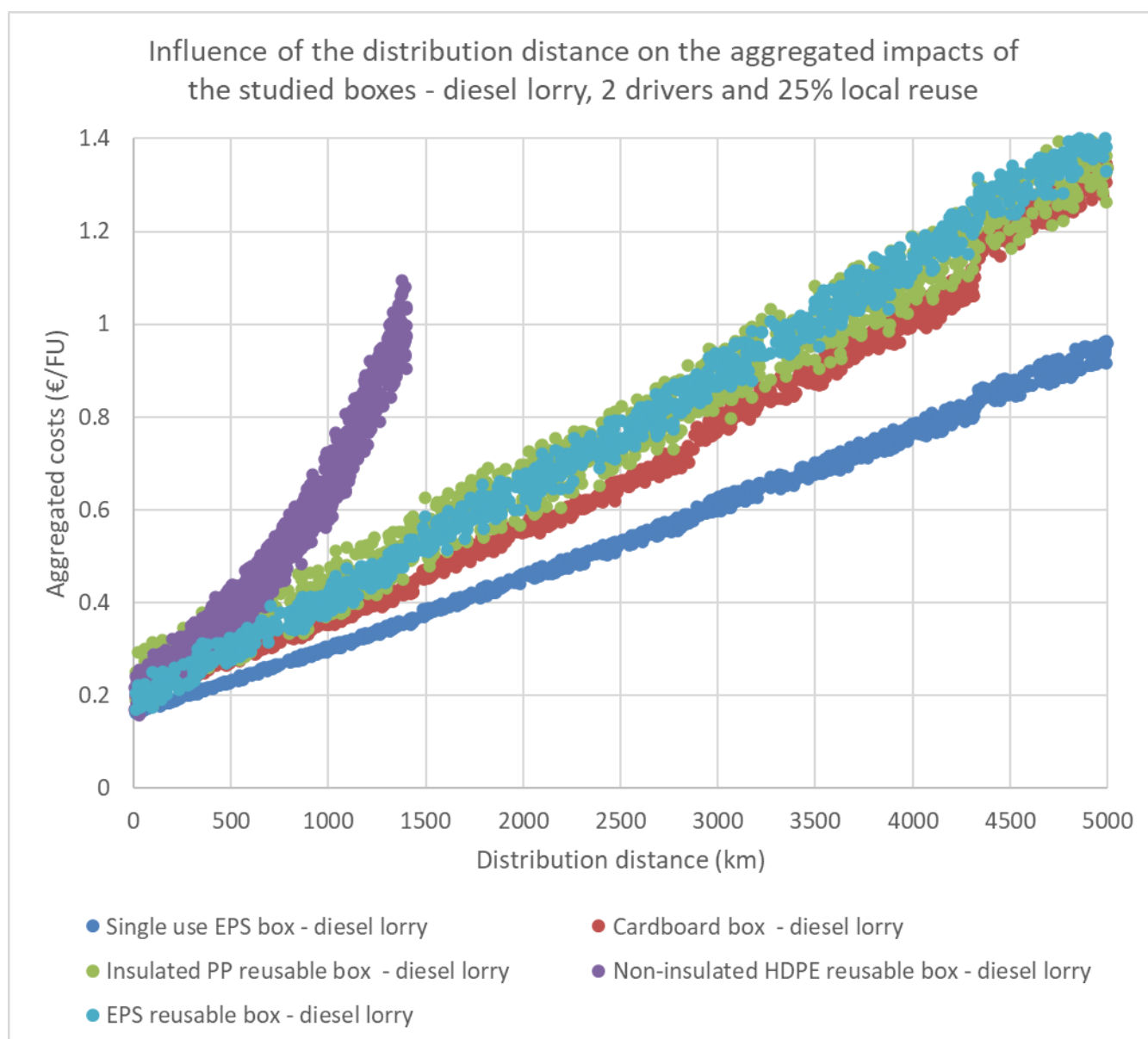


Figure 7-7. Influence of the fish distribution distance on the aggregated environmental, societal, and economic impacts (euros / FU) – 25% local reuse and two drivers.

The use of two drivers is decreasing the economic, societal and environmental costs of all boxes, and particularly for the cardboard box which has lower insulating properties. For the maximum distance (5000 km), the impacts of the cardboard box are 34% lower with two drivers than with a single driver.

We can conclude that, no matter the number of drivers, the use of alternative boxes over distribution distances longer than 200 km would have negative impacts for society compared to the use of single use EPS boxes.

8 Qualitative analysis: Transition costs and challenges

The modelling above looks at the long-term equilibrium industrial solutions, notably making assumptions about the possibility to develop a cost-efficient continentwide return system for food contact insulated boxes and to design a recyclable and resistant enough large size cardboard box. This does not consider the short-term impact of a regulation-induced shift, which is discussed qualitatively here.

The EPS box is currently used by the market because it is the most cost effective. The main sources of (negative) economic impact on the industry of switching from EPS to reuse or cardboard boxed are:

- **Sunk costs of premature decommission of non-amortised capital** (machines and facilities);
- **Reduced economy of scale** due to co-existence of standards;
- **Expected demand variation** for boxes may result in building new production lines and closing them shortly later.

8.1 Sunk cost of premature decommission of not-amortised capital (machines and facilities)

The existing EPS box production, EPS compression and EPS recycling facilities vary in age and level of amortisation.

- The machines in the facilities are used between 10-30 years, with amortisation over 10-15 years in most cases.
- Decommissioning these machines before the end of their lifespan represents a sunk cost for the industry (which will vary based on how old the current machines are). The loss on the cost of the machine itself is unlikely to be compensated by the re-sale on the second-hand market.

In some cases, this change in box system will have a broader impact on plant infrastructure and costs. As an example, the conveyors used to feed the fish packing chain with boxes may have to be adapted or replaced, which can involve more premature replacement of non-amortised capital.

8.2 Reduced economies of scale due to co-existence of standards

The shift towards the use of an alternative packaging is likely to involve a period where the infrastructure cost cannot be distributed on as many products as in business as usual.

In particular, the following sub-optimal situations are expected:

- The new standard packaging has not emerged yet: different standards co-exist, leading to increased storage space needs, incompatibility of conveyors and machines, underused transport volume, etc.
- Co-existence of single use and reuse systems leading to the need to duplicate storage space, palletisation techniques, conveyor sizes. Note that this situation is likely to last in the long run if the new packaging solution used for inside EU trade differ from the one used for extra-EU trade.

- the poolers have not yet reached their optimal market size: their cleaning and sorting facilities are underused and are too few, leading to high treatment and transport costs.

8.3 Expected demand variation for boxes may result in building new production lines and close them shortly later

The application of the PPWR is likely to create a significant increase in demand for crates, boxes, and other solid plastic packaging items to be used as a reusable substitute to single use packaging.

This demand shock is all the more significant that the full reusable packaging stocks are to be built in a few years, before the demand decreases to reach a level high enough to replace old stocks and feed normal growth.

Given the limited production capacity, the plastic convertors could have to open new lines and facilities to meet this variation in demand and shut them down a few years later⁵².

⁵² Analysis pointed out by EUPC.

Source : (22) European Commission . (2008). *Study to analyse the derogation request on the use of heavy metals in plastic crates and plastic pallets*.

Conclusions

Conclusion 1. The single use EPS boxes are preferred to the alternative solutions from a societal perspective for transport distances above 200 km.

This study allows for a comparison of the aggregated societal impacts, i.e. the addition of monetised environmental impacts, economic costs, and social value of job creation. When combining the results for the three pillars, the single use EPS boxes outperform the alternative solutions for all distances above 200 km.

The good performance of the single use EPS box is explained by its isolation properties, allowing to convey a smaller amount of ice in the box, hence leaving more room to transport fish. As a result, more fish is transported per lorry than with competing boxes and the economic and environmental costs associated with transport are limited.

Reusable boxes (EPS, insulated PP and non-insulated HDPE reusable boxes) are outperformed due to the economic and environmental cost of the return transport of the empty box.

In addition to its poorer isolation properties, the cardboard boxes are disadvantaged by their weight : their weight limits the amount of filled boxes that can be transported at once. This lead to a higher impact of transport compared to the other impacts when the transport distance increases.

Consequently, for an equal distance, the impact of transporting one kg of fish in the cardboard box is higher. For long distances, this effect has a larger impact. For the base case (2800 km with one driver), 127 lorries filled with cardboard boxes are needed to transport the same amount of fish as 100 lorries filled with EPS boxes.

For distances shorter than 200 km, the burden of return logistics is lighter and the difference in the amount of ice needed per box is smaller. As a result, relative performances of boxes do not significantly differ, considering uncertainty and variety of existing situations.

Conclusion 2. Considering the climate change impact category, alternative boxes do not show any environmental benefit compared to single-use EPS boxes when the distribution distance exceeds 1250 km.

The **cardboard box** has lower impacts on climate change than the single use EPS box for distribution distances below 800 km (1250 km with two drivers) with a standard diesel truck and 850 km with an EV with one driver. The cardboard box shows a higher impact for distances above 2900 km with a standard diesel vehicle.

The **reusable EPS box** has similar impacts on climate change to the single use EPS box for distribution distances between 150 km and 2 650 km with a standard diesel lorry (one or two drivers). For shorter distances, the reusable EPS box has a lower impact on climate change than the single use EPS box. With an electric lorry, there are no significant differences between the single use EPS box and the reusable EPS box for long distances.

If a stackable reusable EPS box was developed and used, its impact on climate change would be similar to the single use box across all distances above 250 km with a standard diesel lorry and one driver. For

shorter distances, the stackable reusable EPS box has a lower impact on climate change than the single use EPS box.

The **insulated reusable PP box** has similar impacts to the single use EPS box for distances up to 2200 km with one driver and up to 2600 km with two drivers, for a standard diesel lorry.

For an electric lorry, the insulated reusable PP box has similar impacts to the single use EPS box for distances up to 4 000 km.

The non-insulated HDPE reusable box has similar impacts to the single use EPS box for distances between 100km and 700 km, no matter the number of drivers. For shorter distances, the reusable box has lower impacts.

Any increase in the fuel efficiency of the lorries would have a positive influence on the impacts of the boxes. This positive influence would be greater for alternative boxes than for the single-use EPS box because the impact of transport is higher for alternative boxes. As a result, an increase of the range of distribution distance for which the alternative boxes have an impact lower or equivalent to the single use EPS box is expected.

Conclusion 3. The alternative boxes significantly outperform the EPS boxes for only one of the indicators studied: photo-chemical ozone formation – human health.

This is due to the emission of pentane during EPS expansion. Because the impact of the production of EPS is relatively high on this impact category, the impact of the single use EPS box remains higher than the impact of the alternatives no matter the distribution distance, especially is an electric vehicle is used.

Conclusion 4. The use of electric lorries for transport is the best option to reduce the impact of fish boxes on climate change

The use of electric lorries instead of standard diesel lorries leads to a decrease of the impact of transport on climate change larger than what could be achieved by switching from one box to another.

Conclusion 5. The single use EPS boxes display lower economic costs than the compared alternative solutions, for transport distances over 1000 km with one driver (base case). When two drivers are riding, the threshold distance is 1 200 km.

The good performance of the single use EPS box is explained by its isolation properties, allowing to convey a smaller amount of ice in the box, hence leaving more room to transport fish. As a result, more fish is transported per lorry than with competing boxes and the economic costs associated with transport are limited.

The main discriminating factor for reusable solutions is the economic costs of return transport.

The cardboard is discriminated mainly by its relatively poor isolation properties, and also by its production cost and the need for ice bags to prevent water to weaken the box. Lastly, the weight of cardboard the box limits the number of boxes per lorry.

For the base case (2 800 km with one driver), the difference between the cost of the single use EPS box and the alternatives varies between 0.09 and 0.17 €/kg fish depending on the box type.

Conclusion 6. The single use EPS box involves less job creation than the compared alternative solutions.

Considering social impacts alone, the single use EPS box involves less job creation than the compared alternative solutions, which is a corollary to its cost-efficiency. For the base case (2 800 km with one driver), the difference in the value of the jobs created varying between 0.01 and 0.02 €/kg fish depending on the box type.

The extra jobs created by the reusable solutions are linked to the return transport of the boxes which is labour intensive.

The extra jobs created by the cardboard boxes are linked to the increased number of lorries and drivers needed for transport.

Even though the switch from single use EPS boxes to alternative solutions would result in job losses in the EPS industry, the number of new jobs created would be higher than the number of jobs lost.

Conclusion 7. The use of two drivers leads to lower costs and environmental impacts

The use of two drivers for long distances leads to a decrease in environmental impacts and costs. This is because less ice needs to be packed, and more fish can be transported instead. This is especially true for the cardboard box over long distances: the insulating properties of the cardboard boxes are lower than those of single use EPS boxes and insulated reusable boxes, requiring more ice.

Conclusion 8. A regulation driven change in the box material to transport fish in the EU leads to transition costs in the short-medium run

The main sources of negative economic impact on the industry of switching from EPS to reuse or cardboard boxed are:

- Sunk costs of premature decommission of non-amortised capital (machines and facilities);
- Reduced economy of scale due to co-existence of standards;
- Expected demand variation for solid plastic boxes may result in building new production lines and close them shortly later, because of the need to rapidly accumulate the stock of reusable packaging creates a peak in demand.

Conclusion 9. If one of the boxes were to involve more fish loss than the others, this box could be disqualified both environmentally and economically. Indeed, the large environmental and economic impact of fish production before it is transported makes the fish loss one of the most important factors.

In the base case, the loss rate associated with each box is identical as the alternative boxes were modelled in a way that should ensure there is no increase in loss rate. If the use of one box causes an increase in fish loss, the resulting impact could be greater than the possible benefits that might arise from using this box rather than another.

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Appendices

Annexe 1. Results on the 16 PEF impact categories

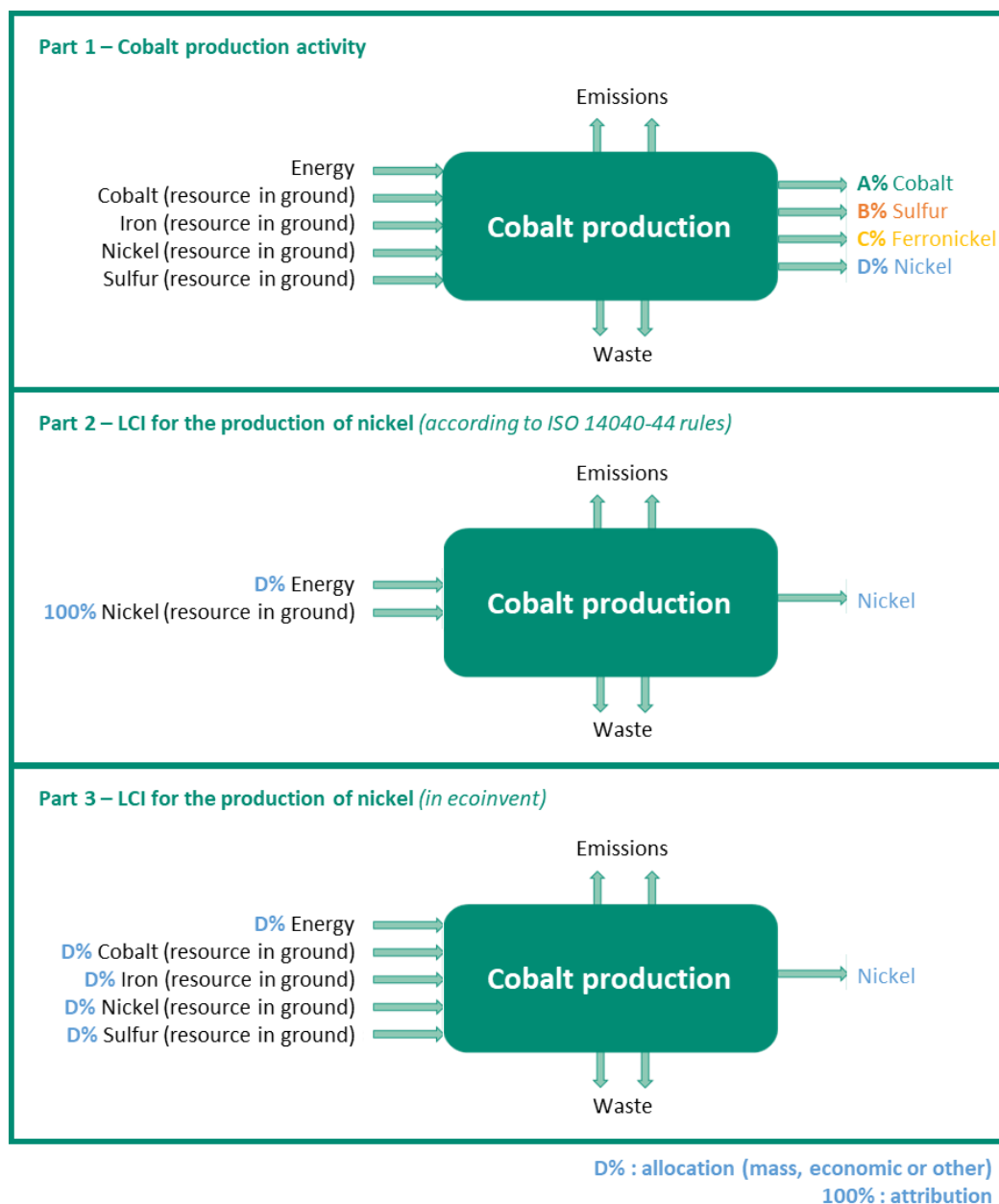
Indicators	Unit	Results for the base case			
		Single use EPS box	Cardboard box	Insulated re-usable box	Reusable EPS box
Climate change	kg CO2 Equivalents	4.27E-01	4.79E-01	4.87E-01	1.96E-01
Ozone depletion	kg CFC11 equivalents	7.50E-09	6.36E-08	1.00E-08	4.74E-09
Human toxicity, non-cancer	CTUh	6.43E-11	9.12E-11	9.70E-11	6.22E-11
Human toxicity, cancer	CTUh	1.99E-09	3.33E-09	2.78E-09	1.67E-09
Particulate Matter	Disease incidence	1.54E-08	1.80E-08	1.68E-08	6.53E-09
Ionising radiation, human health	kBq U235 equivalents	9.59E-03	9.57E-03	2.02E-02	1.91E-02
Photochemical ozone formation - human health	kg NMVO C equivalents	3.05E-03	2.38E-03	2.26E-03	7.41E-04
Acidification	mol H+ equivalents	1.46E-03	1.72E-03	1.60E-03	6.31E-04
Eutrophication, terrestrial	mol N equivalents	4.59E-03	5.99E-03	5.27E-03	1.61E-03
Eutrophication, freshwater	kg P equivalents	3.55E-05	6.28E-05	5.31E-05	4.07E-05

Eutrophication marine	kg N equivalents	4.26E-04	5.80E-04	4.88E-04	1.53E-04
Ecotoxicity, freshwater	CTUe	7.63E-01	1.43E+00	1.02E+00	5.21E-01
Land use	dimensionless (pt)	3.08E+00	7.84E+00	4.29E+00	2.12E+00
Water use	m ³ -world equivalents	9.38E-02	8.14E-02	5.20E-02	4.39E-02
Resource use, minerals, and metals	kg Sb equivalents	1.40E-06	3.46E-06	2.15E-06	1.50E-06
Resource use, fossils	MJ	6.39E+00	6.55E+00	7.01E+00	3.00E+00

Annexe 2. Limitation with the Resource use (minerals and metals) results

Firstly, there is a limit related to the construction of the LCIs in Ecoinvent. Mining activities aim to extract ores that often contain several minerals and metals. Consequently, for any mining activities, there are often more than one product (co-product). In order to distinguish the life cycle inventory of each of these co-products, there should not be any allocation but rather an attribution of all the relevant flows to each of the relevant co-products. As an example, if we consider the extraction of cobalt, other metals such as nickel will also be extracted (Figure 8-1, section 1).

Figure 8-1: Allocation for metal extraction in ecoinvent



According to the ISO 14040-44, the extraction of the nickel from the earth crust should be entirely attributed to the nickel LCI and allocation should be avoided. When it is not possible, for example for all the energy consumptions, emissions, and waste that cannot be distinguished by co-products, an allocation (mass, economic or other) must be applied. Taking the same example, the energy required to extract the cobalt and the nickel cannot be directly attributed to a specific metal (both are extracted at the same time), therefore should be allocated with an mass or economic allocation (Figure 8-1, section 2).

However, the ecoinvent database applies these allocations indiscriminately to the entire mining activity (input resources, energy, emissions, waste) and no direct attributions are done. Thus, each of the co-product LCI contains resources that are neither found in the metal produced nor in the waste generated by the activity. When considering the example of the cobalt production activity, the flow for the extraction of the cobalt is found in the nickel ecoinvent LCI (Figure 8-1, section 3).

This indiscriminately allocation causes imprecision when looking at the results for this indicator as some metals or mineral can generate a large contribution even though it shouldn't be allocated to the studied system.

Secondly, there is also a limit related to the characterization method itself: the abiotic resource depletion (ADP ultimate reserves). This method aims to take into account the scarcity of mineral resources, and therefore the limits in the availability of these resources for current and future generations. Extraction of mineral resources from the ground is considered as contributing to the depletion of the "reserve" of these mineral resources. The ADP Ultimate Reserve approach more specifically considers the "ultimate reserve" as the reserve that would be depleted. This reserve is based on the content of the Earth's crust in each chemical element. Therefore, the characterization factors are based, as a proxy, on the total amount of mineral resources (including metals) in the Earth's crust (the "ultimate reserve").

While the "ultimate reserve" is often used to represent the total amount of mineral resources in the Earth's crust, it does not precisely reflect the "ultimately extractable reserve". There is currently no evidence that the ultimate reserve and the ultimately extractable reserve have the same value and, more importantly, are proportional by resource. Consequently, this method fails to address the issue of scarcity. As an example, at the current production rate, there would still be 84 million years of copper production ahead of us based on this ultimate reserve.

This causes difficulties in interpreting the results obtained with this method, as some metals can generate high contributions due to a high characterization factor, although they may not be significantly affected by the scarcity issue.

Annexe 3. RangeLCA presentation

The software used to calculate the results in this report is RangeLCA, a tool developed by RDC Environment.

The software automatically calculates:

- The average impact results, which represent the average of the results obtained for all random combinations of parameters.

- The results obtained for each parameter combination (for example, 1000 combinations). These results can be plotted on a graph based on the value of one of the variable parameters of the model. These graphs, known as "Range" graphs, allow to evaluate the sensitivity of the results with respect to the parameter plotted on the x-axis.
- The ranking of all parameters in descending order of sensitivity. This allows the software to determine the sensitivity of different results to each variable parameter of the model, while keeping all other parameters variable (instead of having all other parameters fixed, as is typically done).

This type of results ensures a precise and comprehensive analysis of the studied system. The software enables the study of a large number of possible scenarios. In practice, it allows for:

- Creating Range graphs to:
 - Identify the possible results (minimum and maximum values).
 - Evaluate the probability of the studied scenarios.
 - Graphically represent the sensitivity of the results to a specific parameter (slope of the linear regression line).
- Determining all the causal links between the variables of the model.
- Identifying the critical point (or critical zone) where the conclusions may change.
- Identifying the list of the most sensitive parameters (automatically calculated by the software).

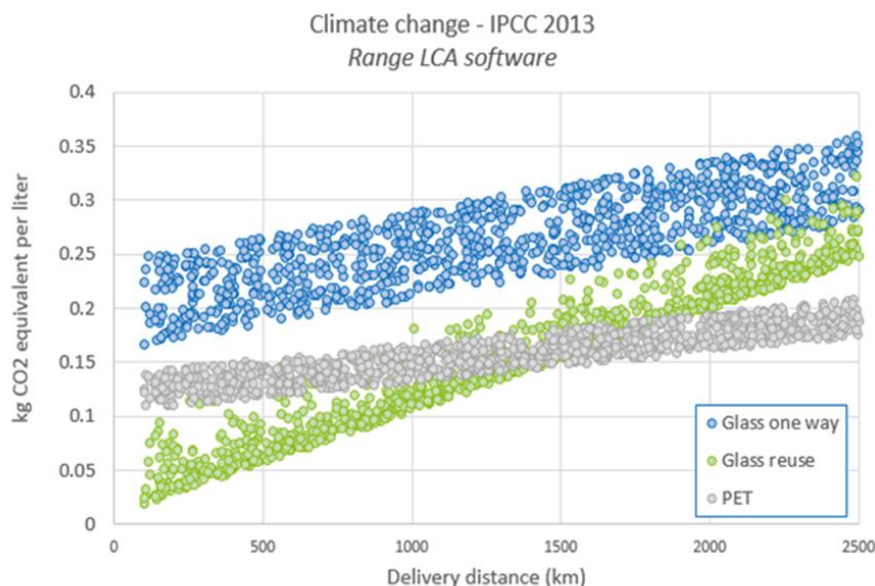


Figure 8-2. Example of a "Range" graph calculated on RangeLCA

Note that the results shown above are examples and don't correspond to the present study.

The interpretation keys for the results are as follows:

- Each point corresponds to a result for a specific set of fixed parameters. Thus, all results corresponding to all potential parameter combinations of the model's variables are represented on this figure.
- The steeper the trend line, the more sensitive the results are to the parameter presented on the x-coordinate axis.
- The vertical dispersion (width of the point band) directly corresponds to the relative importance of residual variability.

Annexe 4. Selection of the most relevant impact categories

The PEF has developed normalization and weighing factors for all impact category results to obtain a single environmental score. These are as follows:

Table 8-1: Normalization and weighing factors for the impact categories

Impact category	Unit	Normalization factor [1]	Weighing factor [2]
Climate Change	kg CO ₂ eq.	7.55E+03	21.06%
Ozone depletion	kg CFC11 eq.	5.23E-02	6.31%
Cancer human health effects	CTUh	1.73E-05	2.13%
Non-cancer human health effects	CTUh	1.29E-04	1.84%
Particulate Matter	DALY	5.95E-04	8.96%
Ionising radiation - human health	kBq Uranium 235 eq.	4.22E+03	5.01%
Photochemical ozone formation	kg NMVOC eq.	4.09E+01	4.78%
Acidification	Moles H eq.	5.56E+01	6.20%
Eutrophication terrestrial	Moles N eq.	1.77E+02	3.71%
Eutrophication freshwater	kg P eq.	1.61E+00	2.80%
Eutrophication marine	kg N eq.	1.95E+01	2.96%
Ecotoxicity freshwater	CTUe	5.67E+04	1.92%
Land Use	pt	8.19E+05	7.94%
Water use	m ³	1.15E+04	8.51%
Resource use, minerals, and metals	kg Sb eq.	6.36E-02	7.55%
Resource use, fossils	MJ	6.50E+04	8.32%

Source : (23) Sala S, Cerutti AK, Pant R. (2018). Development of a weighting approach for Environmental Footprint. European Commission, Joint Research Centre, Publication Office of the European Union, Luxembourg. ISBN 978-92-79-68041-0.

Source : (5) European commission. (2020). *PEF Guidelines*. <https://eplca.jrc.ec.europa.eu/LCDN/developerEF.html>

Table 8-2: Relative contribution to the single score per indicator for each scenario for the base case

	Single use EPS box (2800 km)	Cardboard box (2800 km)	Insulated PP reusable box (2800 km)	Non insulated HDPE reusable box (700 km)	Reusable EPS box (2800 km)
Climate change	35.85%	34.17%	36.96%	33.85%	37.45%
Ozone depletion	0.03%	0.20%	0.03%	0.04%	0.03%
Human toxicity, cancer	0.24%	0.29%	0.33%	0.47%	0.31%
Human toxicity, non-cancer	0.85%	1.22%	1.08%	1.47%	1.03%
Particulate Matter	6.97%	6.92%	6.87%	6.07%	7.04%
Ionising radiation, human health	0.34%	0.29%	0.65%	1.40%	0.54%
Photochemical ozone formation - human health	10.74%	7.11%	7.19%	5.36%	7.58%
Acidification	4.91%	4.90%	4.85%	4.35%	4.69%
Eutrophication, terrestrial	2.90%	3.22%	3.01%	2.09%	2.83%
Eutrophication, freshwater	1.86%	2.80%	2.52%	4.38%	2.26%
Eutrophication marine	1.94%	2.25%	2.01%	1.43%	1.89%

Ecotoxicity, freshwater	0.78%	1.24%	0.94%	1.09%	0.91%
Land use	0.90%	1.94%	1.13%	1.27%	1.10%
Water use	2.09%	1.55%	1.05%	2.01%	1.26%
Resource use, minerals and metals	5.01%	10.49%	6.93%	10.98%	6.42%
Resource use, fossils	24.60%	21.44%	24.43%	23.73%	24.67%

The relevant impact categories are highlighted in blue. They have been identified as all impact categories that cumulatively contribute to at least 80% to the total environmental impact for each of the scenarios, starting from the largest to the smallest contributions.

Annexe 5. Data sources for monetisation

Table 8-3: Monetary valuation methodology RDC Environment – 2023- for ongoing studies

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model		Data source for reference monetised value
Global Warming Potential	Strong world climate politics	The monetary values correspond to the avoidance costs associated with an emissions trajectory (or carbon budget) making it possible to achieve zero net emissions in 2050.	Avoidance cost 2020	Extrapolation from CO ₂ to other GHG using GWP from IPCC 2021	Quinet, 2019 Source : (24)
Global Warming Potential	Weak world climate politics	The monetary values represent the marginal cost of CO ₂ emissions. The models are based on version 3 of the FUND (Climate Framework for Uncertainty, Negotiation and Distribution) integrated assessment model (IAM).	Damage cost 2020	Choice of model without preference for present, representing intergenerational equity Extrapolation from CO ₂ to other GHG using GWP from IPCC 2021	Anthoff, 2007 from NEEDS project Source : (25)
Acidification	Lakes	This monetary value is based on the repairing cost corresponding to liming of lakes in Sweden and Norway.	Repair cost	Quantification of damage by kg SO ₂ via literature Extrapolation to other elementary flows using the LCIA method recommended by EF3.0 (Accumulated exceedance model, Seppälä, 2006 et Posch, 2008)	RDC-Pira 2003 Source : (26)
	Crops	This monetary value is based on the cost of repairing, i.e. applying lime or limestone for neutralizing soil acidity.	Repair cost		IVM 2000 Source : (27)
	Forests	This monetary value is based on the damage cost estimated as timber loss due to incremental emissions of SO ₂ .	Damage cost (loss of productivity)		IVM 2000 Source : (27)

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model		Data source for reference monetised value
	Materials and structure	This monetary value is based on the cost of repairing, i.e. the cost replacing materials used in buildings because of their corrosion by acidifying pollutants.	Repair cost		Watkiss 2001 Source : (28)
Stratospheric Ozone Depletion	-	This monetary value is based on the damage cost of UV rays on health.	Damage cost	Extrapolation using LCIA method recommended by EF3.0 (WMO 2014)	American study, 1998
Eutrophication	Freshwater	This monetary value is based on the cost of repairing eutrophication-related damage in the Flemish Region (Belgium).	Repair cost (ecosystem restoration cost)	Cost per kg P Extrapolation to other elementary flows using the LCIA method recommended by EF3.0 (EUTREND model, Struijs et al., 2009 as applied in ReCiPe 2008)	OVAM 2017 Source : (29)
	Marine	This monetary value is based on the cost of repairing eutrophication-related damage in the Flemish Region (Belgium).	Repair cost (ecosystem restoration cost)	Cost per kg N Extrapolation to other elementary flows using the LCIA method recommended by EF3.0 (EUTREND model, Struijs et al., 2009 as applied in ReCiPe 2008)	OVAM 2017 Source : (29)

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model		Data source for reference monetised value
	Terrestrial	-	No default method	No default method	No default method
Natural Resource Consumption	Fossil	The monetary value is based on resource market prices that are corrected to take future generations into account.	Corrected market price of resources	The method covers all the resources.	Huppertz et al., 2019 Source : (30)
	Mineral	The monetary value is based on resource market prices that are corrected to take future generations into account.	Corrected market price of resources	The method covers all the resources.	Huppertz et al., 2019 Source : (30)
Water Use	-	The monetary value corresponds to the desalination of seawater and its transport. It includes the economic cost of desalination and transport, as well as the cost of environmental damage associated with these activities.	Avoidance cost	Cost of desalination and transport of water + Environmental cost of desalination Extrapolation to geographical areas using the LCIA method recommended by EF3.0 (AWARE model, Boulay et al., 2018; UNEP 2016)	Tol et al. 2005 Source : (31) Ecoinvent 3.7.1 for tap water production by desalination
Land Use	-	-	No default method	No default method	No default method

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model		Data source for reference monetised value
Ecotoxicity	freshwater	The monetary value corresponds to the value attached to protection of terrestrial biodiversity and is based on the costs citizens say are willing to pay to protect biodiversity. The underlying assumption is that all terrestrial species are valued equally and therefore that freshwater species are valued identical to terrestrial species.	Damage cost	Damage value by CTUe based on restoration cost Extrapolation to all elementary flows using the LCIA method recommended by EF3.0 (Usetox 2.1 model, (Fantke et al. 2017), adapted as in Saouter et al., 2018)	OVAM 2017 Source : (29)
Photochemical ozone formation	Vegetation	This monetary value is based on the damage cost due to reduced crop yields as well as forest and grassland production.	Damage cost (loss of productivity for crops, forests, and grasslands)	Marginal damage cost per kg NOx and per kg NMVOC for crops and forests (and extrapolated for grasslands) Extrapolation of value per kg NOx to all nitrates and NOx using the LCIA method "Ozone formation, Terrestrial ecosystems - Recipe 2016 – Mid-point" Extrapolation of value per kg NMVOC to all VOCs using the LCIA method "Photochemical ozone formation - human health" recommended by EF 3.0 (LOTOS-EUROS model, Van	ETC/ATNI 2020 Source : (32) ADEME 2019 (for extrapolation to grasslands) Source : (33)

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model		Data source for reference monetised value
			Zelm et al., 2008, as applied in ReCiPe 2008)		
Toxicity	Carcinogens	The highest value between two methods was chosen to be conservative: one method is based on the damage cost obtained through the impact pathway approach for one reference substance for the category and the other one is based on an end-point method where the impact is expressed in DALY.	Cost of damage to human health	Maximum between: - Cost associated with 1kg Cr^{VI} extrapolated to all elementary flows using LCIA method recommended by EF3.0 (Usetox 2.1 model, Fantke et al. 2017, adapted as in Saouter et al., 2018) - Recipe 2016 to assess human health damage in DALY x Maximum value of DALY by WHO- The Commission on Macroeconomics and Health	EcoSenseWeb Tool 2007 Source : (34) Commission on Macroeconomics and Health. 2001 Source : (36)

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model		Data source for reference monetised value
	Non-carcinogens	The highest value between two methods was chosen to be conservative: one method is based on the damage cost obtained through the impact pathway approach for one reference substance for the category and the other one is based on an end-point method where the impact is expressed in DALY.	Cost of damage to human health	Maximum between: - Cost associated with 1kg Pb extrapolated to all elementary flows using LCIA method recommended by EF3.0 (Usetox 2.1 model, Fantke et al. 2017, adapted as in Saouter et al., 2018) - Recipe 2016 to assess human health damage in DALY x Maximum value of DALY by WHO- The Commission on Macroeconomics and Health	EcoSenseWeb Tool 2007 Source : (34) Commission on Macroeconomics and Health. 2001 Source : (36)
	Particulate matter	The highest value between two methods was chosen to be conservative: one method is based on the damage cost obtained through the impact pathway approach for one reference substance for the category and the	Cost of damage to human health	Maximum between: - Cost associated with 1kg PM2.5 extrapo-	IHME (Study "Global Burden of Disease", 2019) Source : (36)

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model	Data source for reference monetised value
		other one is based on an end-point method where the impact is expressed in DALY.	lated to all elementary flows using LCIA method recommended by EF3.0 (PM model, Fantke et al. 2016 in UNEP 2016) - Recipe 2016 to assess human health damage in DALY x Maximum value of DALY by WHO- The Commission on Macroeconomics and Health	Commission on Macroeconomics and Health. 2001 Source : (36)
	Tropospheric Ozone	The highest value between two methods was chosen to be conservative: one method is based on the damage cost obtained through the impact pathway approach for one reference substance for the category and the other one is based on an end-point method where the impact is expressed in DALY.	Cost of damage to human health Maximum between: - Cost associated with 1kg NMVOC extrapolated to all elementary flows using the LCIA method recommended by EF3.0 (LO-TOS-EUROS model, Van Zelm et al., 2008,	EcoSenseWeb Tool 2007 Source : (34) Commission on Macroeconomics and Health. 2001 Source : (36)

Impact category	Sub-category	Short explanation of the monetary valuation principle	Main characteristics of the model	Data source for reference monetised value
			as applied in ReCiPe 2008) - Recipe 2016 to assess human health damage in DALY x Maximum value of DALY by WHO- The Commission on Macroeconomics and Health	
Ionising Radiation	-	The damage is quantified in DALY. The health impacts from exposure to Ionising radiation relate to cancers (fatal and non-fatal) and severe hereditary effects.	Cost of damage to human health Cost by based on OVAM Extrapolation to other elementary flows using the LCIA method recommended by EF3.0 (Human health effect model, Frischknecht et al, 2000, as developed by Dreicer et al. 1995)	OVAM 2017 Source : (29)

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