Life Cycle Assessment of the Industrial Use of Expanded Polystyrene Packaging in Europe

Case Study: Comparison of Three Fishbox solutions

Reference : 5845

November 2011

POST PEER REVIEW REPORT

Prepared for:

The European Manufacturers of Expanded Polystyrene (EUMEPS) association, Packaging section

by:

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1. Executive Summary

Introduction – Goal and scope of the study

The European Manufacturers of Expanded Polystyrene (EUMEPS) Association – Packaging section commissioned PwC Ecobilan to conduct a comparative Life Cycle Assessment (LCA) of packaging for fresh fish, made of Expanded Polystyrene (EPS) on one hand, and of Corrugated Polypropylene and water-resistant Cardboard on the other hand.

The study aims at obtaining robust comparative LCA results at the European level for several fishbox packaging solutions. In that scope the study is based on two specific fish markets: France and Spain corresponding to three specific packaging markets: France, Spain and Scandinavia.

The study has been conducted according to the requirements of International Standards (ISO 14040 and ISO 14044). An external critical review was carried out by an independent LCA expert, TÜV Rheinland, and representatives from interested parties (the French technical association for Retail industry Perifem, retail company Mousquetaires, Union du Mareyage Français). The critical reviewer concluded that the study was conducted according to the ISO standards.

The follow-up of the LCA study was insured by a EUMEPS Packaging ad-hoc Task Force composed of 3 members from Spain and France, through regular contact with PwC-Ecobilan and through 4 meetings that took place all along the study from September 2010 to June 2011.

Functional unit and system boundaries

Considering the market segmentations described above, three different functional units were considered:

- **“packaging 4 kg of fresh fish fillets (e.g., cod) to transport it from local harbour in France to local professional fish market respecting national regulations on chilled fresh fish”.**
- **“packaging 6 kg of fresh fish (e.g., sardines) to transport it from local harbour in Spain to local professional fish market respecting national regulations on chilled fresh fish”.**
- **“packaging 20 kg of fresh salmon to transport it from Danish fisheries to professional fish market in Rungis Paris, respecting national regulations on chilled fresh fish”.**

Three types of packaging solutions were considered to perform these functions:

- Expanded EPS packaging, with respective weights of 96, 145 and 526 grams per box on these three markets,
- Corrugated Polypropylene (PP) , with respective weights of 230, 310 and 738 grams per box on these three markets,
- Corrugated cardboard, with a Polyethylene film on both sides, respective weights of 815, 1040 and 2650 grams per box on these three markets.

This LCA study corresponds to a "cradle-to-grave" study, i.e. the whole life cycle of the fishbox packaging system was considered. Therefore, the study includes the various transport routes that are taken by the packaging material from the site of production of raw material, through the manufacture of the fishbox packaging, its delivery to the fish customer and its final end of life disposal route.

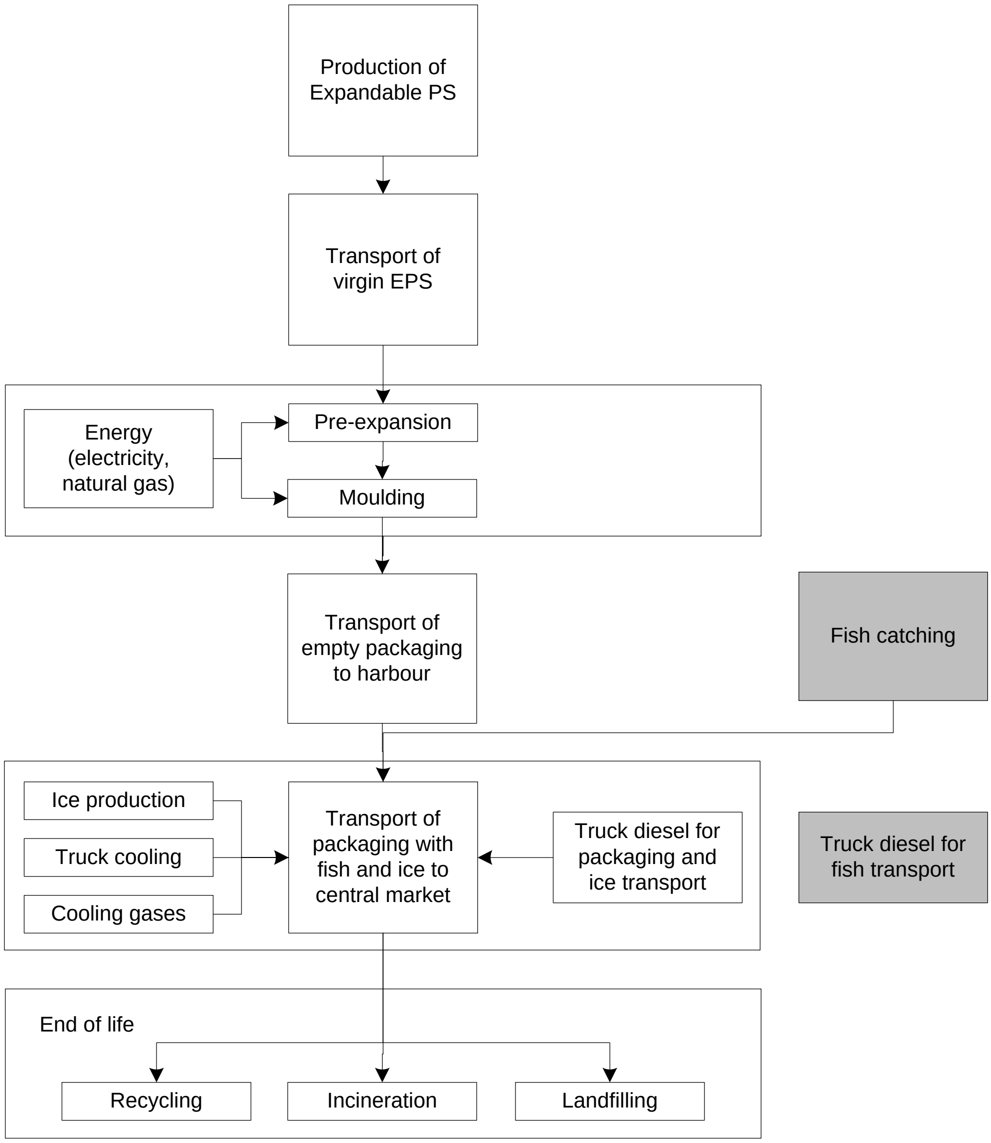

Figure 1: System boundaries of the life cycle of EPS fishbox packaging

The production of fish and consumption of diesel oil directly related to the transport of fish were voluntarily omitted from the system boundaries. The reason for the exclusion of these stages is that they do absolutely not vary from one packaging solution to another. At the production stage, quantities produced are exactly the same and produced in the same conditions. No differences in losses of the product were reported with any of the compared solution. At the transport stage, the quantity of transported fish including the ice is the same and only dimensions and mass of the box to contain it varies depending on the chosen packaging solution.

The main steps that were not accounted for, mostly because of their negligible nature, were production of the means of production (machines and building), the production of the moulds, the production of the chemicals used to soften the water and the lubricants, the supply of the fish and its transport, the production of the glue when used to assemble the boxes, and the production of ink when these ones are printed.

Sources of data and main hypotheses

Dimensions and weight of the EPS boxes were provided by EPS producers. Dimensions and weight of the PP boxes were provided by a corrugated PP box supplier. Weight of the cardboard boxes were calculated from the dimensions of the EPS and PP boxes, folding diagram provided by a cardboard producer and surface weight provided by another cardboard producer.

Data concerning the manufacture of EPS packaging, the distribution steps as well as some recycling steps of the packaging system were specifically collected for the purpose of this study in 2010-2011 by questionnaires distributed to EPS manufacturers. The data were provided by 7 European industrial companies and are relevant for 2010. Data was also collected from a corrugated PP producer and correspond to 2010 manufacturing conditions.

The data used to model the production of expandable PS correspond to the eco-profile published in 2006 by Plastics Europe. Similarly, PlasticsEurope data were used for PP and PE raw materials (2005-2006 data). Corrugated cardboard are made of recycled fibers and literature data published in 2009 by FEFCO (European Federation of Corrugated Board Manufacturers) were used to model the production step.

The European fuel mix for electricity generation represents the European and relevant national situations for 2008.

To model the fate of used packaging system (EPS, PP and cardboard), a ratio between recycling, incineration with energy recovery and landfilling was used. This ratio depends on the country considered and is representative of 2007 data. Concerning recycling of EPS and PP, the reference scenario considers a stock method, whereby no benefit for recycling is allocated to the fishbox. The end-of life steps (incineration and landfilling) were modelled with PwC Ecobilan in-house data derived from the WISARD2 software.

For transportation steps[1], classical models were used based on literature data and on real distances of transport collected for the purpose of the study.

For the recycling of used EPS and PP in an open loop, considered in a sensitivity analysis, it was assumed that 1 kg of used and material replaces 1 kg of virgin material. Thus, the use of shredded waste EPS avoids the use of virgin general purpose PS.

For any energy recovered from the incineration of waste, the approach chosen was to subtract from the inventory the environmental impacts linked to the production of the energy quantity (electricity or steam) that the incineration process allows to save (considering that an average 35% of the energy from the waste is recovered).

LCA results and conclusions [2]

The LCA results consist of main results related to the reference scenario and of a set of sensitivity analyses performed on key parameters such as the electricity grid conditions and waste management conditions [3], assumption regarding modeling of recycling and energy efficiency of EPS transformation.

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Where do the impacts come from?

From the analysis of the reference results it can be ascertained that there are two main stages of the life cycle of the fishbox packaging solutions considered that contribute to the greatest impact upon the environment.

[1] See chapter 5.11.1 Transport model

[2] See chapter 6.2 Presentation of results for the reference scenarios

[3] See Table 12: Description of packaging end of life

- **Production of raw materials**. This step typically represents 40-60% of energy consumption, emissions of greenhouse gases and acidification for EPS; 40-95% of the same indicators for the PP box and 45-80% for the cardboard box.
- **Transformation of main packaging constituent**, especially in the case of EPS packaging. This step typically represents in the case of EPS 20-50% of energy and water consumption, emissions of greenhouse gases and acidification and more than 80% of formation of photochemical oxidants; 6-23% of energy consumption, emissions of greenhouse gases and acidification for the PP box and 15-25% of these indicators for the cardboard box.

Transport requirements (fuel, ice) linked to packaging only play a secondary role, even for long distances. We here remind the reader that it was not possible during the present study to link the thermal insulation parameters of the boxes with the energy needed to refrigerate the trucks, which was assumed constant whatever the packaging solution chosen. Integrating this aspect in the result would probably be in favor of EPS packaging.

Consequently, the **weight of packaging** per quantity of fish transported is a key parameter to assess the environmental impacts of any fish packaging system. Any reduction effort to reduce the weight (without modifying the characteristics of the box) will play a tangible role on the overall result.

What is the relative impact of EPS packaging compared with other packaging systems?

On the French market (4kg fish per box, 300 km transport of fresh fish to fish market), the EPS packaging performs similarly or better than PP and cardboard, except for the formation of photochemical oxidants.

Results are comparable on the Spanish market (6kg fish per box, 300 km transport of fresh fish to fish market), except that PP performs better than EPS for the formation of photochemical oxidants as well as water consumption.

On the Scandinavian market (20 kg fish, 1200 km transport of fresh fish to fish market), results are more balanced:

- EPS and PP perform similarly for 5 indicators (energy consumption, acidification, water consumption and water eutrophication), EPS perfoms better than PP for waste production but worse for greenhouse gas emissions and formation of photochemical oxidants.
- EPS perfoms better than cardboard for waste production, water consumption and water eutrophication but worse for energy consumption, greenhouse gas emissions and formation of photochemical oxidants. EPS and cardboard perform similarly for acidification.

From the analysis of the first sensitivity analysis representing European averages parameters for electricity grid and waste management, these balanced results are confirmed.

Two other sensitivity analyses were performed to address the modeling of recycling waste plastics. When credits are considered for recycling these materials, the relative results of EPS packaging are improved. The EPS packaging performs better than PP and cardboard, except for the formation of photochemical oxidants.

Similar improvement trends for EPS packaging would be observed on the two other markets.

How to improve the environmental results of EPS packaging systems?

In a fourth sensitivity analysis, the EPS packaging solution integrated data from a transformation site with energy reduced by 68% as compared to the reference scenarios. In that case, the EPS packaging solution performs better than PP, except for the formation of photochemical oxidants and water consumption, and better than cardboard except for the formation of photochemical oxidants.

2. Introduction

2.1 Background to Study

The European Manufacturers of Expanded Polystyrene (EUMEPS) Association – Packaging section commissioned PwC Ecobilan to conduct a comparative Life Cycle Assessment (LCA) of packaging for fresh fish, made of Expanded Polystyrene (EPS) on one hand, and of Corrugated Polypropylene and water-resistant Cardboard on the other hand.

The data used in this study has been obtained through a number of different sources and, where data has been unavailable, assumptions have been made. As a result we have taken care to highlight any limitations to the data. The process data on the transformation step of EPS has been obtained from industry through EUMEPS and other national associations.

The methodology, data collection method, main hypotheses and interpretation techniques adopted in the study were agreed with EUMEPS during meetings attended by members of the project team from July 2010 to June 2011 in Paris. A previous study[4] carried out by PwC Ecobilan in 2001 was used as a guideline for this European wide analysis.

It should be noted that should the results of this LCA be used to inform the decision making process, there are many other factors that play an important role in this process that this study does not consider such as economic and social impacts.

The study has been conducted according to the requirements of International Standards (ISO 14040, and ISO 14044).

2.2 Life Cycle Assessment

LCA is an environmental systems analysis and accounting tool for quantifying the inputs and outputs of an option, whether a product, a process or an activity and relating these to environmental impacts. LCA is a systematic approach, where the system of interest comprises the operations that collectively produce the product or constitute the activity under examination.

An LCA offers a clear and comprehensive picture of the flows of energy and materials through a system and gives a holistic and objective basis for comparisons. Results are presented in terms of the system function so that the value of that function can be balanced against the environmental effects with which it is associated.

The results of an LCA quantify the potential environmental impacts of a product system over the life cycle, to help identify opportunities for improvement and to indicate more sustainable options where a comparison is made. The results may also contribute to the design process by targeting more significant environmental impacts and the phase of the life cycle to which they relate.

[4] PwC has already carried a peer-reviewed LCA study of a packaging in 2001 for EUMEPS. The product studied was a packaging for a TV set.

The LCA concept dates from the late 1960s and early studies concentrated simply on the use of energy and materials in the manufacture of products. More recently the focus of researchers has broadened to cover a range of sectors and to include a wide variety of environmental concerns including global warming and acidification. The emphasis on the use of LCA in making improvements in product manufacture is changing too and the approach is becoming widely used by both industry and government as a means of comparing the environmental advantages and disadvantages of design options, alternative strategies and of informing and justifying policy development. Table 1.1 summarises the four phases of LCA as specified by ISO 14040.

Table 1.1 Stages of Life Cycle Assessment (ISO 14040 & 14044)[5]

Phase	Activities
Goal and scope definition	Defines the purpose and scope of the study and sets out the framework in which it will be carried out, including boundary conditions, underlying assumptions, allocation procedures, data quality, etc.
Inventory analysis	Compilation and quantification of inputs and outputs for a given product system throughout its life cycle.
Impact assessment	Assessment of the environmental effects of the inputs and outputs identified in the inventory, comprising: • selection: selection of impact categories, category indicators and characterisation models; • classification: assignment of LCI results to impact categories; and • characterisation: calculation of category indicator results.
Interpretation	Analysis of results, making conclusions, explaining limitations and providing recommendations based on the findings of the preceding phases of the LCA or LCI study and to report the results of the life cycle interpretation in a transparent manner.

[5] ISO 14040: 2006 (E) Environmental management – Life cycle assessment – Principles and framework
ISO 14044: 2006 (E) Environmental management -- Life cycle assessment -- Requirements and guidelines

2.3 Report Structure

The report comprises the following chapters:

Chapter 1	Executive Summary
Chapter 2	Introduction
Chapter 3	LCA Practitioners and Commissioning Body
Chapter 4	Goal and Scope
Chapter 5	Life Cycle Inventory analysis: sources of main data and hypotheses
Chapter 6	Life cycle inventory and life cycle impacts assessment results for the reference scenario
Chapter 7	Life Cycle Sensitivity Analyses and Interpretation
Chapter 8	Conclusions
Chapter 9	External Critical Review

These chapters are supported by a number of appendices providing detailed information regarding items such as system boundaries, end-of-life modelling, impact assessment methods, etc.

3. LCA Practitioners and Commissioning Body

3.1 LCA Practitioners

The LCA was carried out by PwC Ecobilan and involved staff from the Paris office. Contact addresses details for the LCA practitioners are as follows:

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3.2 Commissioning Body

The project was commissioned by the European Manufacturers of Expanded Polystyrene (EUMEPS). Contact address details for EUMEPS are as follows.

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Regular contact was maintained with the EUMEPS "Task Force" via André Barbarit and Clément Spiteri throughout the duration of the project. The EUMEPS Environmental "Task force" attended 4 meetings that took place all along the study, from July 2010 to June 2011. The EUMEPS "Environmental Task Force" members were:

- Clément Spiteri, ECO-PSE[6] (French Association), France
- André Barbarit, Isobox Technologies (Company member of Eco-PSE), France
- Elena Corrales, ANAPE[7] (Spanish association), Spain

[6] French eco-organisation for expanded polystyrene
[7] Spanish Asociación Nacional de Poliestireno Expandido

4. Goal and Scope of the study

4.1 Introduction

This chapter presents the goal and scope of the LCA study. In particular, the product considered in this LCA, the functional unit and system boundaries are described.

The target audience for the project is broad. Primarily, the study is aimed at providing information to EUMEPS to inform them of the environmental implications of transporting fresh fish from harbours to fish markets in Europe with an EPS packaging solution. In addition, the aim is to compare the environmental performance of the EPS packaging solution with those of several alternative materials.

The study will be used to provide information to stakeholders in industry and other external parties.

4.2 Goal of the study

The study aims at obtaining robust comparative LCA results at the European level for several fishbox packaging solutions. In that scope the study is based on two specific fish markets: France and Spain corresponding to three specific packaging markets: France, Spain and Scandinavia.
While France represents an average market among the most important European countries in terms of fish consumption, the Spanish situation is representative of other fish markets in the south of Europe like Italy.

Country	**Fish catches (t/year)**	**National fish consumption (kg/year/ inhabitant)**
France	499 256	35.20
Spain	918 705	40.63
Denmark	690 611	24.66
European Union	**5 131 354**	**20.7**

Table 1: Statistics for fish catches and fish consumption in Europe
Source for catches statistics: Eurostat 2008
Source for national fish consumption: FAO 2005

4.3 Scope of the study

4.3.1 Description of the product studied

Fishbox market trends

Two broad families of boxes are used on the French fish market:

- large EPS boxes (e.g., reference 8422 from Isobox Technologies 795x395x289mm, 55,4 liters of capacity) to carry fresh fish (e.g., 20 kg salmon) from Norway to French harbours (e.g. Boulogne-sur-Mer, North region) where re-packaging may occur.

- smaller boxes to carry fresh fish (e.g., reference 4210 from Isobox Technologies 398x264x137mm, 8,3 liters of capacity, to carry 4 kg cod) from French harbours to municipal markets and in particular the Rungis market near Paris.

There is a tendency in France towards reduction of the size of the packaging boxes. The French fish box market for EPS packaging was 10 200 t/yr in 2009 (source: Eco-PSE)

In Spain, most of the EPS boxes are used to carry 6 kg of fresh fish (e.g., sardines) in 500x300x140 mm boxes from harbours to central markets.

2004	2005	2006	2007	2008	2009
10 760	10 869	11 879	13 086	12 710	13 680

Table 2: ***Quantity of EPS fish boxes produced in Spain in tonnes per year (source ANAPE)***

Market competitors to EPS fishbox packaging solutions

The interviews and market studies we could get with the help of EUMEPS confirmed that **Expanded Polystyrene** remains the widest used solution for fishbox packaging in Europe, with a market share estimated between **80% and 90%**. A solution of box made of wood (crates) has the second presence on the market, but their function is quite different since this type of box is rather limited to the transportation of "blue fish" (like sardine and anchovy) which represent a small share of the total market of fresh fish in terms of volume.

Second emerging identified competitors are the fishboxes made of **polypropylene** and those made of **laminated corrugated cardboard**. They represent respectively an average of **3%** and **2%** of the current European market.

Identified competitors in France include:

- Coolseal by Tri-pack plastics, 100% recyclable PP boxes[8]. Each box has two parts (base, lid). There are around 35 different dimensions, such as:
  - a 785x390x160 mm 738g box to carry 20 kg of salmon and 5 kg of ice;
  - a 460x310x110 mm 310g box to carry 6 kg of fish and 2 kg of ice;
  - a 395x247x120 mm 230g box to carry 4 kg of fish and 2 kg of ice.
- Cardboard and a wax layer, as proposed by D S Smith Packaging (Waterproofed cardboard boxes for seafood transport)[9] or cardboard covered with a polyethylene layer as proposed by Mondi Group or Smurfit Kappa.
- Wood boxes is also an existing solution, but mainly used aboard fishing boats.

Identified competitors in Spain include:

- Afcofish cardboard trays[10], manufactured by the Spanish corrugated board association Afco, and corrugated board producers, amongst them Grupo Lantero (SCA partner), Cartisa (IP) and Saica. This alternative has been for instance used by Carrefour. The Paraten® liner used (LDPE/kraft paper) provides a watertight and high-degree of moisture vapour barrier. Capacity: 6kg fresh fish packed on ice in a 400x400x130mm draining box made of two parts. It claims to be adapted to the following duration of logistics: 24 hr refrigerated truck.

[8] See www.tri-pack.co.uk
[9] See http://www.dssmith-packaging.co.uk/fresh_food/fresh_meat_poultry_and_fish/
[10] See http://www.mondigroup.com/products/desktopdefault.aspx/tabid-1460/

Identified competitors serving the EU market include:

- Plastic boxes developed by PSA Plast[11] (typically 725x485x130mm but there are other dimensions) to transport fish. PSA Plast is a Portuguese company exporting 40% of its products to the rest of Europe.
- Corrugated polypropylene "CoolSeal" boxes developed by Tri-pack plastics, a Britsh company specialised in polypropylene plastic packaging industry. The CoolSeal catalogue offers a wide range of boxes, dedicated to many types of fresh food packaging (for fish, fish filets, salmon, shellfish, meat…).

Solutions chosen for the study:

For purposes of this study, the solutions kept for the comparison are:

For the "French" packaging market, boxes with a 10l useful volume

-The polystyrene box from Isobox Technologies 398x264x137mm;
-The polypropylene box from Coolseal 395x247x120mm;
-A simulated typical PE laminated corrugated cardboard box 398x264x137mm
Note. There is no identified commercial reference for this model. Dimensions here are an assumption based on to the Isobox EPS box. Weight is calculated by Isobox and PwC based on surface weight communicated by Smurfit and pre-folding diagram provided by Sical.

To carry 4 kg of fresh fish + 2 kg of ice, on 300 km to the French Market

And

For the "Spanish" packaging market, boxes with a 15l useful volume

-The polystyrene box from Isobox Technologies 500x300x140mm for the Spanish Market;
-The polypropylene box from Coolseal 460x310x110mm;
- A simulated typical PE laminated corrugated cardboard box 400x400x130mm.
Note. There is no identified commercial reference for this model. Dimensions correspond to the AFCOFISH-Tray by Mondi. Weight is calculated by ISOBOX and PwC based on surface weight communicated by Smurfit and prefolding diagram provided by Sical.

To carry 6 kg of fresh fish + 2 kg of ice, on 300 km to the Spanish Market.

and

For the "Scandinavian" packaging market, boxes with a 42l useful volume

-The polystyrene box from Styropack 796 x 398 x 200 mm;
-The polypropylene box from Coolseal 785x390x160;
--A simulated typical PE laminated corrugated cardboard box 785x390x160 mm
Note. There is no identified commercial reference for this model. Dimensions here are considered equivalent to the CoolSeal solution, weight is calculated by Isobox and PwC based on surface weight communicated by Smurfit and pre-folding diagram provided by Sical.

To carry 20 kg of fresh fish + 5 kg of ice on 1 200 km from Denmark to the Rungis market in France.

[11] See www.psaplast.com/alimpeixefrances.htm

Figure 1: Fishbox packaging markets chosen for the study as representative producers of fresh fish in Europe

In blue are represented the EPS fishboxes production sites where data was collected for the study.

Presentation of the products

Box to transport 4 kg of fish and 2 kg of ice	**Expanded Polystyrene Fish box**	**Polypropylene Fish box**	**Corrugated Cardboard Fish box**
Dimensions (in mm)	398x264x137	395x247x120	398x264x137
Weight (in g)	96	230	815
Composition	Expanded polystyrene	Polypropylene	Corrugated cardboard laminated with LDPE (average of 2x6 g/m^2)
Source	Isobox	CoolSeal	Simulated Box Weight calculated by Isobox based on data from Isobox (dimensions), Smurfit (surface weight) and Sical (pre-folding diagram)

Table 3: Characteristics of small boxes for the French packaging market (useful volume: 10l)

Box to transport 6 kg of fish and 2 kg of ice	**Expanded Polystyrene Fish box**	**Polypropylene Fish box**	**Corrugated Cardboard Fish box**
Dimensions (in mm)	500x300x140	460x310x110	400x400x130
Weight (in g)	145	310	1040
Composition	Expanded polystyrene	Polypropylene	Corrugated cardboard laminated with LDPE (average of 2x6 g/m^2)
Source	ANAPE	CoolSeal	Simulated Box Weight calculated by Isobox based on data from CoolSeal (dimensions) Smurfit (surface weight) and Sical (pre-folding diagram)

Table 4: Characteristics of small boxes for the Spanish market (useful volume: 15l)

Box to transport 20 kg of fish and 5 kg of ice	Expanded Polystyrene Fish box	Polypropylene Fish box	Corrugated Cardboard Fish box
Dimensions (in mm)	796x398x200	785x390x160	785x390x160
Weight (in g)	526	738	2650
Composition	Expanded polystyrene	Polypropylene	Corrugated cardboard laminated with LDPE (average of 2x6 g/m^2)
Source	Styropack	CoolSeal	Simulated Box Weight calculated by Isobox based on data from CoolSeal (dimensions), Smurfit (surface weight) and Sical (pre-folding diagram)

Table 5: Characteristics of large boxes for the Scandinavian market (useful volume: 42l)

4.3.2 Functional unit

Considering the market segmentations described above, three different functional units were considered:

- **"packaging 4 kg of fresh fish fillets (e.g., cod) to transport it from local harbour in France to local professional fish market respecting national regulations on chilled fresh fish".**
- **"packaging 6 kg of fresh fish (e.g., sardines) to transport it from local harbour in Spain to local professional fish market respecting national regulations on chilled fresh fish".**
- **"packaging 20 kg of fresh salmon to transport it from Danish fisheries to professional fish market in Rungis Paris, respecting national regulations on chilled fresh fish".**

In France, national regulations on chilled fresh fish in particular implies that fish is constantly kept at a temperature of less than 4°C (national order 20/07/1998). In Spain, same conditions must be fulfilled (Resolución No:002505, 07/06/2004 Ministerio de Transporte).

NOTE. The ability of the packaging to retain the fish cold as long as possible is an advantage for the EPS packaging, as demonstrated by experimental studies led by CEMAFROID[12]. However, within the scope of the current LCA study, this important insulation characteristic was not

[12] "Essai comparatif d'une caisse en polystyrène expansé et d'une caisse en polypropylène pour le transport du poisson », CEMAFROID, Rapport d'essais N°ECO PSE 160209, March 2009.

integrated in the calculations. From discussions with logistic companies, it seems that there is currently not enough information to estimate the surplus energy consumed by trucks when transporting packaging with low insulating capacity.

4.3.3 System Boundaries

Description of the system under study

In this study, the whole life cycle of the packaging for fresh fish is considered. Therefore, the study includes the various transport routes that are taken by the raw material (EPS, PP or cardboard) from the site of production of virgin raw material, through the manufacture of the packaging, its delivery to the customer, its use (transportation of fresh fish) and the final end of life disposal route.

The whole system was broken down into the following sub-systems (see Figure 2):

1. Production of the raw materials (expandable PS, polypropylene granules, paper, polyethylene)
2. Transport of raw materials to the transformation site,
3. Transformation of
   - expandable PS into EPS packaging on the premises of EUMEPS members (pre-expansion, expansion and moulding steps),
   - polypropylene into corrugated PP boxes,
   - paper into corrugated boards with polyethylene lamination (both sides)
4. Transport of the packaging to the harbour site for packing fresh fish and ice,
5. Transport of the packaging around fresh fish with ice, including :
   - Ice production
   - Extra fuel consumption to cool the truck goods compartment,
   - Maintenance of refrigerating fluids
   - Fuel consumption to carry ice and packaging
6. End of life of the packaging (collection with domestic waste, landfilling, incineration, recycling)

The results presented in this report are broken down into these 6 sub-systems. The detailed system boundaries for each sub-system are illustrated in Appendix A.

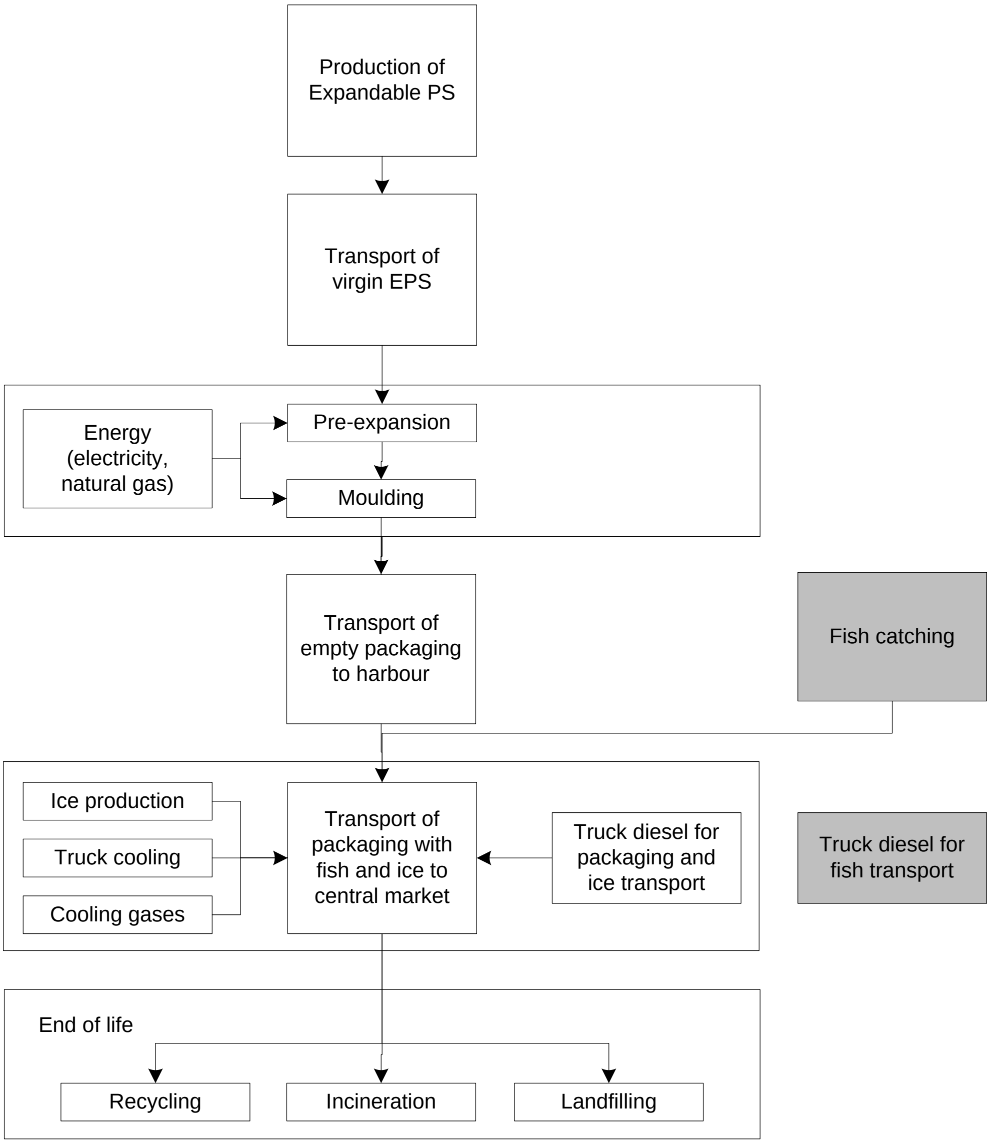


Figure 2: System of the life cycle of a fish box (EPS material)

Stages in grey are not taken into account.

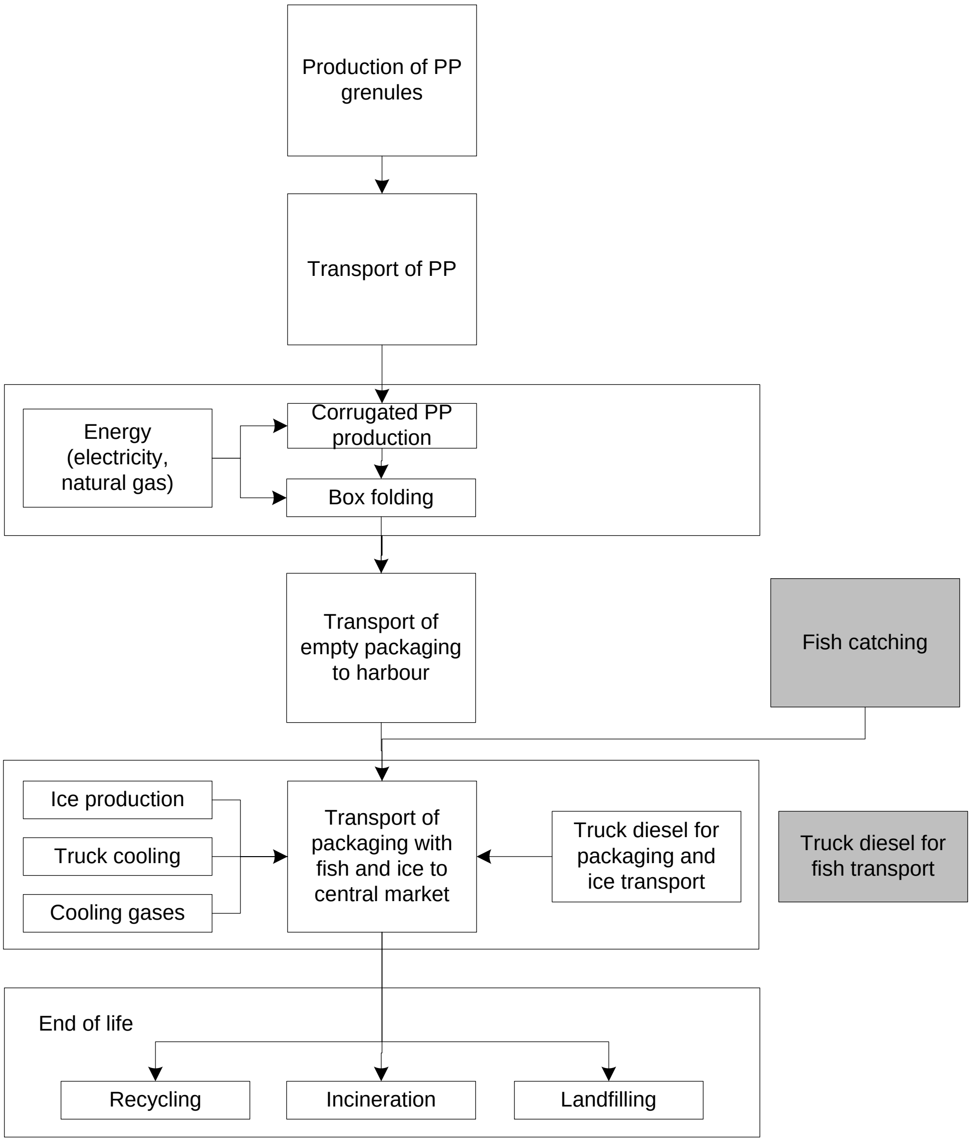


Figure 3: System of the life cycle of a fish box (PP material)

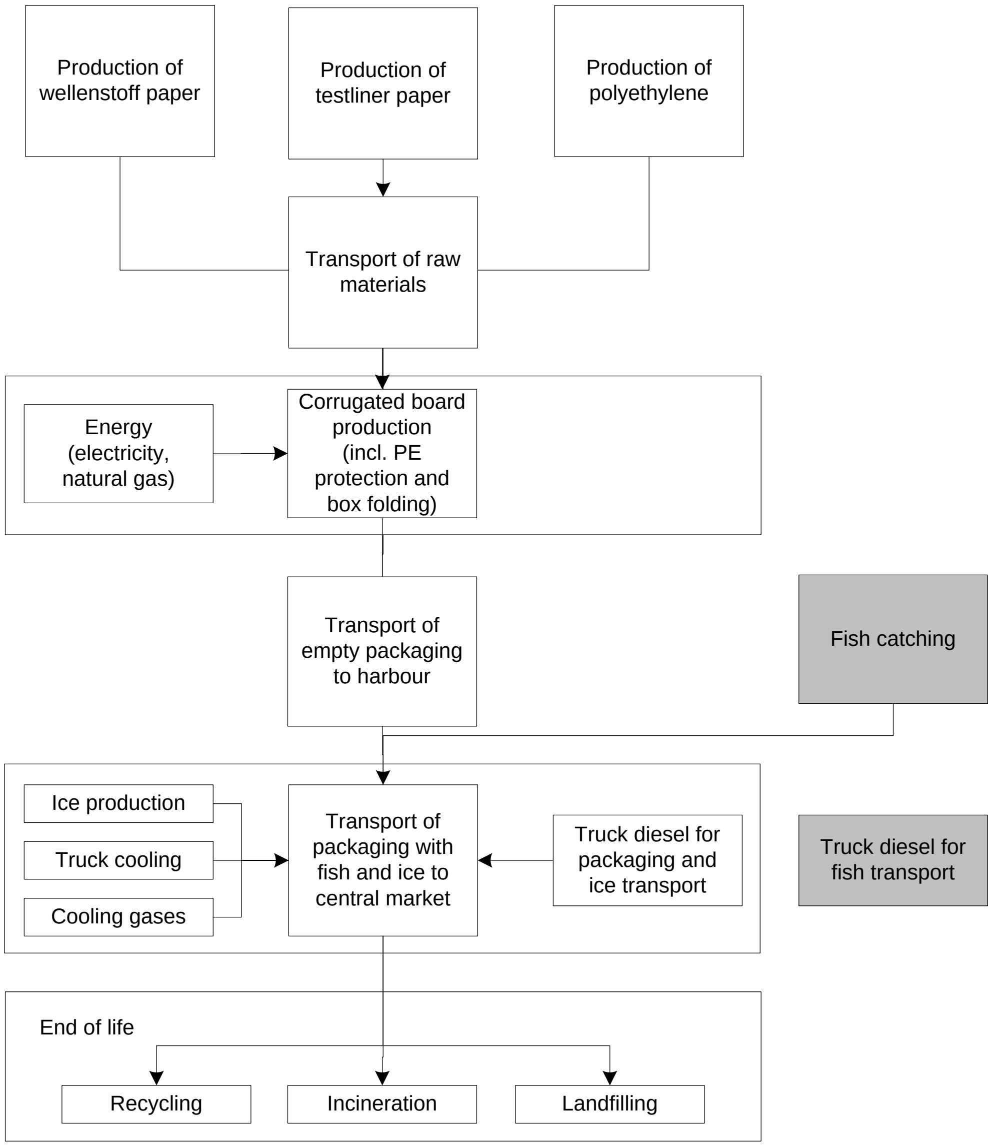


Figure 4: System of the life cycle of a fish box (cardboard material with PE film)

Criteria for the inclusion of inflows and outflows to the system

The upstream and downstream data for the system inflows and outflows were systematically included when:

- they represented more than 1% of the inflows or outflows in terms of mass, or
- they consisted of energy flows, or
- they were considered to have a significant environmental impact (for example: inclusion within the system boundary of a well-known toxic element, even though its mass contribution is not very high).

Life cycle steps omitted

The following section indicates the steps that were not taken into consideration during the life cycle of the packaging.

1. In general, the construction of buildings and machines was not included within the system. In fact, the environmental impacts linked to the construction and disassembly of buildings and equipment (e.g., impacts from the production of steel used in the construction of buildings or equipment) are amortised throughout their lifetime, a period during which an extremely large number of packaging units are produced. Since experience indicates that the environmental impacts from these components are negligible relative to those coming from the function of the plant, this hypothesis is justified in the scope of this project.
2. The production of the mould (made of aluminium) is also amortised throughout their lifespan (around 15 years) and is therefore not included either.
3. The production of the lubricant, the production of the chemical products used to soften the water (sodium hypochlorite, sodium hydroxide, a flocculent, a natural tannic acid, natural detergent made of citrus fruits) the production of the salt (sodium chloride) are excluded from the system, their percentage in mass being respectively of 0.08, 0.53 and 0.59 %. Aside from this fact, their quantity can vary and is mainly related to the quality of the local water where the production site is located. The quantity of these products was not important enough for its production to have any significant impact. The sites told us that a small quantity of waste lubricant and waste chemicals is included in the total waste quantity they reported. Hence, the related water emissions or waste generation from those products are taken into account because they were included in the total data provided by the sites.
4. The production of the printing, since the reference box is supposed not be printed which is the case most of the time. Anyway, the ink, when it is used, only represents an average of 0.02% in mass of the box.
5. The supply of the fish (wild catches or aquaculture) is not included in the system as this step is independent from the type of packaging that is chosen.
   The production of fish and consumption of diesel oil directly related to the transport of fish were voluntarily omitted from the system boundaries. The reason for the exclusion of these stages is that they do absolutely not vary from one packaging solution to another. At the production stage, quantities produced are exactly the same and produced in the same conditions. No differences in losses of the product were reported with any of the compared solution. At the transport stage, the quantity of transported fish including the ice is the same and only dimensions and mass of the box to contain it varies depending on the chosen packaging solution.
6. The consumption of diesel oil directly related to the transport of the fish themselves was not taken into account as the goal of the study was to compare several packaging with the same content. However, energy consumption related to the ice production and transportation has been included. Indeed, even if no evidence has been found to justify a difference in the quantity of ice between one type of fish box and another, it is likely that the quantity of ice required is related to the insulation capacity of the box material.
7. The production of the glue when used in the case of the cardboard and polypropylene boxes as the quantity involved is known to be very limited.

In total, we consider to have included the environmental impacts related to the production of more than **98%** in mass of the inputs in this LCA study.

4.3.4 Material recovery

Recycling of waste EPS packaging is carried out in an open loop, as EPS fish boxes are only made of virgin EPS. There are different ways to take into account this process route within the scope of a LCA study and ISO 14044 (§4.3.4 Allocation) requires to undertake a sensitivity analysis in that case.

Several methods are used in LCA to model mechanical recycling. Description of these methods have recently been summarized in a research paper ("METHOD FOR TAKING INTO ACCOUNT THE END-OF-LIFE WHEN PERFORMING LIFE CYCLE ANALYSIS (LCA) 'PRODUCT' – State of the art.", BIO IS for RECORD, June 2011, available from http://www.record-net.org/record/synthPDF/Synth_record10-1019_1A.pdf. The stock method is currently the method of reference to deal with allocation issues in case of material recycling for the Environmental Product Declaration system in France (NF0 01-010). This approach is presented by CSTB (the French Technical and Scientific Center for the Building sector) at a LCA discussion forum "Règles d'affectations des recyclages dans les FDES françaises pour les produits de construction", November 2007 (http://www.lcaforum.ch/Portals/0/DF_Archive/DF33/Pajani%20-%20CSTB%20-%20LCA%20DF33.pdf). Stock method (or "cut-off" method) is usually considered as a conservative approach to assessing environmental impacts of recycling, as the only benefit of applying this approach is to reduce landfilling and incineration.

The stock method is probably the simplest of the allocation methods that can be used. A stock of recycled material needs first to be defined. When recycled materials are used, all impacts from the stock extraction and downstream are taken into account. Symmetrically, when post-consumer waste is recycled, all impacts are taken into account until the material to be recycled reaches the stock. In the case of EPS, the stock is located at the recycling facility. Compacting-Shredding of post-consumer EPS waste to be recycled is consequently taken into account.

In the reference scenario of the present study, a stock method was used, which means that no credit was allocated to EPS packaging in case of recycling.

In the sensitivity analysis #2, EPS is considered to be recycled in an open-loop into rigid objects, like plastic trays (see "'Recycle your used fish boxes' says EPS Packaging Group", http://www.eps.co.uk/about_eps/packaging/newsletters/2002_4_november/news_2002_4_1_fishbox.htm). Eco-PSE considers that 85% of recycled EPS is used for PS applications (CD casings, disposable cameras, coat hangers, see "Matières premières secondaires 2007 Confirmation de la filière PS", http://www.ecopse.fr/page.asp?IDp=12). The assumption that 1 kg of recycled EPS saves 1 kg of PS resin and that the avoided impacts of the production of this 1 kg of PS are credited to EPS packaging is an optimistic scenario, which counterbalances the conservative approach used in the reference scenario.

Sensitivity analysis #4 attempts to strike a balance between the previous two situations with the assumption that only half of the benefit of open-loop recycling is allocated to EPS packaging.

Similarly to EPS, recycling of waste PP packaging is carried out in an open loop, as PP fish boxes are considered to be only made of virgin PP. Within the scope of the LCA study, in the reference scenario, a stock method was used, no credit was allocated to PP packaging. In two sensitivity analyses (see §7.4 and §7.6), it was considered that 1 kg of used PP replaces 1 kg of virgin polypropylene and the benefits of this saving was allocated totally or in half to PP packaging.

Corrugated boards are part of a closed-loop recycling system. In the framework of the LCA project, if was considered that waste cardboards can be recycled into cardboards, even with the PE surface films that might limit recycling possibilities. The recycling of waste corrugated cardboard is modelled using a stock method, in accordance with the recycling methodology detailed in chapter 2.2 of FEFCO 2009 report. Indeed, the quantity of wastepaper used in the system to produce cardboard is almost the same as the quantity of wastepaper obtained by recycling (around 620 kg per 1000 packaging units in the Spanish case).

Secondary packaging (wood, cardboard and PE film) that are sent after use to recycling are classified as recovered matter; the end of life treatment is not included in the system boundaries.

4.3.5 Energy recovery

Energy is recovered during the incineration of used EPS, PP or Cardboard packaging during the end-of-life phase.
This section shows how to arrive at a system that has only one unique function: to package and carry fresh fish. The method is explained below for the incineration of EPS but has been applied in the same way for the incineration of PP and cardboard.

If it is assumed that the incineration of 1 tonne of EPS packaging leads to the production of Y MJ in the form of electricity and X MJ in the form of steam.

The overall energy demand in Europe is assumed to be constant. This energy thus replaces the Y MJ of electricity and X MJ of steam that would need to be produced by a classic energy source if the incineration of household waste were not in place.

As a result, the system under study that is producing the electricity and steam should be completed by subtracting the environmental impacts from the production of Y MJ of electricity and X MJ of steam by the standard means of electricity generation in Europe. The following diagram illustrates this differential approach:

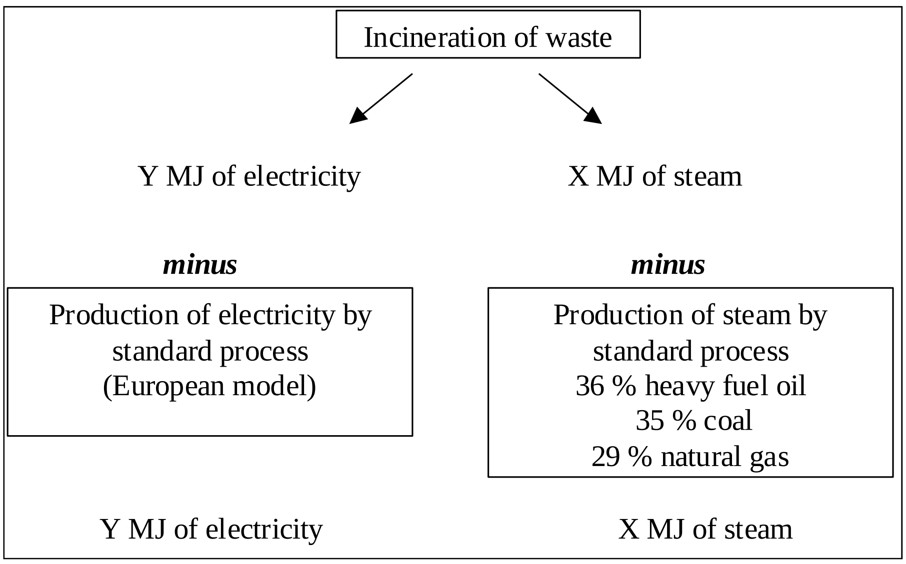


Figure 5 Consideration of energy recovery for incinerated waste

The standard process of production of steam in Europe, i.e. the breakdown between heavy fuel oil, natural gas and coal was assimilated to French data owing to lack of such data at the European level.

4.3.6 Data Categories

Environmental flows

8 data categories were utilised to characterise inputs and outputs of the system:

- raw materials consumption (e.g. raw oil, raw natural gas, bauxite…);
- water used as inputs;
- products as outputs (the functional unit of each unit process);
- air emissions;
- water emissions;
- soil emissions;
- waste as outputs;
- recovered matter as outputs (when their effective reuse or recycling is outside the system boundaries).

Energy indicators

The following energy flows were calculated:

- **« E Total Primary Energy »:** the total primary energy expressed in «MJ» represents all energy drawn from natural resources, burned as combustible at each life cycle step, (corresponding to fuel energy) or present in material which is consumed at each life cycle step (that corresponds to Feedstock Energy or the energy content in the material), including all losses. The total primary energy can be split into either non-renewable energy and renewable energy or fuel energy and feedstock energy. The following equation illustrates this :

Total primary energy = Non-renewable energy + Renewable energy = Fuel energy + Feedstock energy

- **« E Non Renewable Energy »:** part of total primary energy that is non-renewable expressed in MJ (energy content in oil, natural gas....),
- **« E Renewable Energy »:** part of total primary energy which is renewable expressed in MJ (energy contains of wood coming from a renewable forest source, hydraulic energy...),
- **« E Feedstock Energy »:** part of total primary energy expressed in MJ that is contained within used materials such as combustible fuel material. For example, energy contained in oil, natural gas and wood (for linoleum flooring) which are used as raw materials for the production of plastics (including losses).
- **« E Fuel Energy »:** part of total primary energy expressed in MJ which contains in used materials such as combustible, for example, energy contains in oil, natural gas used such as combustible in order to product steam for plastics production.

Environmental impact indicators

Based on the environmental flows calculated, the environmental impact indicators listed in the table below were calculated:

Environmental Indicator	Method used in this study
Depletion of non-renewable resource	CML 2000 method see appendix E for details on the method
Increase of greenhouse effect	IPCC-Greenhouse effect 2008 (direct, 100 years) see appendix E for details on the method
Acidification potential	CML 2000 method see appendix E for details on the method
Photochemical oxidants creation potential	WMO method see appendix E for details on the method
Water eutrophication potential	CML 2000 method see appendix E for details on the method

Table 6: List of environmental impact indicators calculated

Regarding greenhouse effect, also referred to as global warming, the International Panel on Climate Change (IPCC) publishes 3 different quantitative assessment methods relating to 3 time-horizons (20, 100 and 500 years). The 100 years time horizon was selected within this study because this is the most common method used in LCA studies and also because it corresponds to the reference one used for greenhouse gases inventories done at a country level or at an individual company level. Moreover, the 20 year horizon does not cover all the associated impacts linked with climate change and the 500 years horizon can be considered as being fraught with more uncertainties.

Environmental impacts not considered

-**Toxicity impacts** (human toxicity and eco-toxicity) were not assessed in the present study because it was considered that the finished packaging products under study have a low impact on this environmental topic, due to their compliance with the regulation for food contact.

-Although the use of some refrigerating fluids during refrigerated transports are considered to have played a role on **stratospheric ozone depletion**, this impact was not considered as a relevant impact for the following reasons: (a) the Montreal Protocol regulation bans the use of the refrigerating fluids with the highest impact on ozone depletion and (b) the systems considered for the different packaging solutions consume the same quantity of those fluids and hence the three packaging solutions would have the same impacts.

4.3.7 Data Quality

International standards relating to LCA require assessment of data with respect to age, geographical and technical coverage.

This study aims at assessing the environmental impacts of EPS packaging, in Europe and at the present time.

Data Age

Data related to the **production of expandable polystyrene** were published in **June 2006** and data related to the production of **polypropylene** were published in **March 2005**, both by **PlasticsEurope** (*Association of Plastics Manufacturers in Europe- Avenue E. Van Nieuwenhuyse 4, Box 3 Auderghem, B - 1160 Brussels*).
Data concerning the **manufacture of EPS packaging** and the distribution steps of the packaging were collected in late 2010 by questionnaires distributed to EUMEPS members. The data are relevant for 2009. They were obtained from 4 production sites and 3 companies in Spain through the ANAPE, 2 production sites and one company in France, one production site and one company in Denmark, at all 5 companies and 8 production sites.
Data related to the **corrugated cardboard production** were published in **November 2009**, by **FEFCO** *(European associations of corrugated board manufacturers-avenue Louise 250 BE – 1050 Brussels).*
Data related to the **production of the corrugated PP box** were collected in 2011 from DS Smith Kaysersberg *77, route de Lapoutroie 68240 Kaysersberg- France* and relate to 2010.
The European fuel mix for **electricity** generation represents the European, Spanish, Danish or French situation for 2008 using International Energy Agency Statistics 2010.
The **treatment of domestic waste** (landfill, incineration, recycling) that is used to model the end-of-life of the EPS, PP and cardboard packaging material is representative of 2007 data.

Geographical Coverage

All main data are representative of the European situation.

- Data concerning the production of expandable PS and PP correspond to the data published by PlasticsEurope and are thus representative of the European situation.
- Data related to the cardboard production were published by FEFCO (European Federation of Corrugated Board Manufacturers).
- Data concerning the manufacture of EPS packaging were collected within 5 companies belonging to 3 European countries: Denmark, France, and Spain.
- Boxes were considered to be produced at the closest production site from the place where they are used to transport the fish. Transport distances of empty packaging were defined on the basis of this assumption (see table 10).
- The data related to the fate of domestic waste are representative of the national situation where the market is located (see table 12).

Data related to the Electricity production are adapted to the local mix (Spanish, French, Danish or European 27 countries) in 2008.

Technical Coverage

The data on production processes can be considered as representing the current techniques.

4.4 Critical Review Considerations

An external critical review was carried out by two independent LCA experts Daniela Kölsch and Patricia Wolf (TÜVRheinland) and representatives from interested parties (Olivier Gosset, environment coordinator, les Mousquetaires and Perifem, Philippe Violleau, Union du Mareyage de France) and PwC Ecobilan's answers to these remarks are presented in section 9 of this report.

5. Life Cycle Inventory analysis: sources of main data and hypotheses

Industrial data were specifically collected for this project for the following steps:
- transformation of expandable PS into EPS packaging;
- PP corrugated board production;
- cardboard covering with a PE layer;
- cardboard and PP boxes folding;
- transportation of virgin expandable PS to the site of transformation;
- transportation of empty packaging to the wholesale fish merchants;
- production of ice;
- transportation of filled EPS packaging (with fish and ice) from wholesale fish merchants to retailers;
- transportation of used EPS (for recycling, incineration, landfilling);
- shredding of used EPS and its related energy use.

Other data come from bibliographical sources and previous European studies; these are presented in appendix C.

5.1 Production of expandable polystyrene (PS)

Data for the production of expandable PS correspond to the eco-profile of expandable PS published by **PlasticsEurope**, in 2006.

5.2 Transformation of PS into EPS

The data on transformation steps were collected specifically for this LCA study with a questionnaire that was then sent to various industrial companies by representatives from EUMEPS. The questionnaires were filled in directly by sites during the period July 2010 to February 2011.

5.2.1 Data Collection Procedure

The data collection process first involved the design of a specific Excel questionnaire for the data required. An example of a sample questionnaire is shown in appendix B. The following data was sought from the questionnaire:
- the inputs and outputs related to the transformation of PS into EPS packaging;
- the characteristics of the transportation steps located upstream and downstream of the transformation site (average distance of transport, real load of truck, maximum load, type of truck…).

Each data provider was also asked to qualify the quality of data by providing general information on them (initial source, year of data, representation, data gaps…).

5.2.2 Data Treatment

The data were gathered and then processed by PwC Ecobilan. The treatment step of the "raw data" consisted of:

- a mass balance between inputs and outputs in order to check that the difference between inputs and outputs was within +/-2%.
- a comparison of data for the same parameter in order to detect any odd values. For instance, the total energy consumption from each data source was checked to see whether it was within the same order of magnitude from one site to the other.
- direct checking with the site, whenever necessary.
- calculation of an average value for each piece of data provided.

5.2.3 Sources of data

The initial questionnaire was sent to more than 10 companies producing EPS packaging, of which 7 returned completed questionnaires to PwC Ecobilan (in some cases, the questionnaires were only partially filled in). Data for the processing of PS to EPS was provided by the following 7 European organisations/companies:

Denmark (1)	Styropack
France (2)	Isobox Technologies : Douarnenez, Limetz
Spain (4)	Industrias del Noroeste, Forel S.A, Poliespor S.A. Castel, Poliespor S.A. Tarragona

Table 7: Sources of data for the transformation step of EPS

5.2.4 Analysis of data

The analysis of data from the 7 sites from which data was collected is available in the table below.

Input	**Min**	**Max**	**Average (arithmetic for reference case)**
Electricity (GJ/t)	3	6	4.5
Natural gas (GJ/t)	16	51	36
Total Electricity + Natural gas (GJ/t)	20	57	41
Water consumption (m^3/t)	11	18	15

Table 8: Analysis of data collected during project

These results are consistent with the results of a previous LCA study[13] carried out for EUMEPS in 2001 over 15 EPS transformation sites, whereby:

- total energy was between 18 and 54 GJ/t (average : 34 GJ/t).
- water consumption was between 8 and 21 m^3/t (average: 14 m^3/t).

5.3 Production of polypropylene (PP)

Data for the production of PP granules correspond to the eco-profile of Polypropylene published by **PlasticsEurope**, in 2006. Data have been obtained for the production of 5.69 million tonnes of PP. This represents 76.9% of all West European production.

[13] LCA of Expanded Polystyrene (EPS) used in TV-packaging-2001

5.4 Transformation of PP into corrugated PP

The data on PP transformation steps were collected specifically for this LCA study with a questionnaire that was then sent to one production site of corrugated PP: **DS Smith Kaysersberg**, *68240 Kaysersberg, France*, in February 2011. Total energy consumption is around 6 GJ/t.

Data related to box folding were communicated by **Sical**. *69, Rue du Docteur Pontier 62380 Lumbres-France*. The related consumption of natural gas and electricity were provided for the cardboard folding case, and are considered here equivalent for PP as a minimum.

5.5 Production of corrugated cardboard

Data for the production of corrugated cardboard correspond to the European Database for Corrugated Board Life Cycle Studies published by **FEFCO** (European Federation of Corrugated Board Manufacturers), in 2009.
Data represent the weighted averages of the inputs into and outputs from the production sites per ton net saleable product from the paper and corrugated board production sites for the year 2008.

The data for the production of the four major paper grades: Semichemical Fluting, Kraftliner, Testliner and Wellenstoff as well as for the production of corrugated board were collected directly from the producers and checked by technical experts.

- **The data for Semichemical Fluting and Kraftliner** represent more than 70% of the total annual production of corrugated base papers from primary fibres in Europe. The data for Semichemical Fluting and Kraftliner also represent 78% of the total consumption of these grades for corrugated board production in Europe. These paper grades are produced in large mills, located in Austria, Finland, France, Portugal, Slovakia and Sweden. Their total production was 3.706.364 tonnes net saleable paper in 2008. The mills each have an annual production of 88.000 - 669.000 tonnes net saleable paper.
- **The data for the production of Testliner and Wellenstoff** were collected from mills, together producing about 63% (9.700.000 tonnes) of the total annual production of corrugated base papers from recovered paper in Europe. They were provided by paper mills in Austria, Czech Republic, France, Germany, Italy, the Netherlands, Spain and Great Britain. The mills each have an annual production of 36.820 - 1.122.752 tonnes net saleable paper based on 100% recovered paper.
- **The data on corrugated board production** are based on 236 plants in Austria, Belgium, Czech republic, Denmark, Estonia, Finland, France, Germany, Great Britain, Greece, Hungary, Ireland, Italy, Lithuania, The Netherlands, Norway, Poland, Russia, Spain, Sweden Switzerland. Together they produced 9.051.000 tonnes net saleable product, which is 42% of the total annual production of corrugated board in Europe.

5.6 Protection of corrugated cardboard with PE films

The process for corrugated cardboard protection with a polyethylene film solution is a modelling referring to FEFCO 2009 data for corrugated cardboard, and adapted with Sical France data for PE covering and folding.
Energy for lamination of PE is taken from a technical description of a lamination machine produced by **Ruian Fangtai Machinery Co**. Ltd, a Chinese company.

5.7 Transportation steps related to fishbox packaging

For the transportation of packed fresh fish, data were collected by PwC Ecobilan by directly contacting fish markets, logistics companies or by the means of the French and Spanish EPS Associations who asked their members to provide such information.

	EPS	Polypropylene	Cardboard
Type of transport considered	Transport in a truck Consumption of diesel : 38 l/100 km with a payload of 24t Distance : 800 km (France, Denmark), 1500 km (Spain) Empty returns: 30%		
Material transported	Virgin expandable PS	Polypropylene granules	Paper and Polyethylene

Table 9: Transport of raw materials from supplier to transformation stage

Note: the average European distance in the 2001 LCA study for transport of expandable PS was 700 km., real load was 23t with 50% empty return rate.

	EPS	**Polypropylene**	**Cardboard**
Type of transport considered	Transport in a truck Consumption of diesel : 38 l/100 km with a payload of 24t Empty returns: 30%		
Distance	80 km (France), 100 km (Spain), 100 km (Denmark)	400 km (France), 400 km (Spain), 400 km (Denmark)	200 km (France), 100 km (Spain), 100 km (Denmark)
Truck saturated in…	volume	weight	weight
Number of boxes per truck	7 000 (France) 4 750 (Spain) 1 300 (Denmark)	85 000 (France, Spain) 30 000 (Denmark) (boxes are folded)	44 000 (France,Spain) 16 000 (Denmark) (boxes are folded)
Actual Payload (t)	0.672 (France) 0.689 (Spain) 0.684 (Denmark)	19.5	26.5

Table 10: Transport of empty packaging from plant to harbour

	EPS	Polypropylene	Cardboard
Type of transport considered	Transport in a refrigerated truck Consumption of diesel : 38 l/100 km with a payload of 24t Distance : 300 km (France), 300 km (Spain), 1200 km (Denmark-France) Duration of the trip : 3 hrs (France), 3 hrs (Spain), 12 hrs (Denmark-France)		
Refrigeration	Additional diesel consumption for cooling the truck : 4 l/h Quantity of ice per fish box: 2 kg (4kg fish box France, 6 kg fish box Spain), 5 kg (20 kg fish box) Consumption of electricity to produce ice: 80 kWh/t of ice produced. (*Source: GEA Généglace S.A.S)* Refrigerant fluids: leaks (CF_4) represent between 0.9 and 1.35 kg/year and per truck (Source: ADEME)		
Number of boxes per truck	3900 (4 kg fish box) 2700 (6 kg fish box) 800 (25 kg fish box)	3900 (4 kg fish box) 2700 (6 kg fish box) 800 (25 kg fish box)	3900 (4 kg fish box) 2700 (6 kg fish box) 800 (25 kg fish box)
Actual Payload (t)	24 tonnes	24 tonnes	24 tonnes

Table 11: Data and sources of data for the transport of fresh fish from harbour to central market

Only the impacts linked to the transport of ice and packaging are taken into account. The impacts linked to the transport of the fish itself are not included in the scope of the present study.

The production of fish and consumption of diesel oil directly related to the transport of fish were voluntarily omitted from the system boundaries. The reason for the exclusion of these stages is that they do absolutely not vary from one packaging solution to another. At the production stage, quantities produced are exactly the same and produced in the same conditions. No differences in losses of the product were reported with any of the compared solution. We consider this contribution as a fixed impact.

On the contrary, at the transport stage, dimensions and mass of the box to contain it varies depending on the chosen packaging solution. We consider this contribution as a variable impact.

As a summary, impacts during the journey were allocated on a mass basis for variable impacts, whereas fixed impacts were allocated to fish. Impact of empty returns of the trucks was allocated to the fish and not to the fishbox.

Formula for the calculation of diesel consumption

The diesel consumption Q_t of the truck is based on the distance travelled by the goods, the diesel consumption per km of the truck, the actual load of the truck and if there is, or not, an empty return.

$$Q_t = c \times d \times (\frac{1}{3} \times \frac{C_r}{C_u} + \frac{2}{3} + R \times \frac{2}{3})$$

The following parameters are considered:

Q_t: total consumption in litre

c: diesel consumption of the truck in l/km - by default: 0.38 l/km

d: distance in km

C_u: possible load in t (tonne) - by default: 24 tonnes.

C_r: actual load in t (tonne) - by default: 24 tonnes. The load is the sum of the fish weight plus the packaging&ice weight : $C_r = C_{r\ fish} + C_{r\ pack}$

R: value of empty return

(R=1 in the case of empty return, 0 If no empty return - by default 30%)

The diesel consumption of the full truck is divided between the consumption for the fish transport ($Q_{t\ fish}$) and the one for the transport of packaging and ice ($Q_{t\ pack}$).
By definition, $Q_t = Q_{t\ fish} + Q_{t\ pack}$, with :

$$Q_{tfish} = c \times d \times (\frac{1}{3} \times \frac{C_{rfish}}{C_u})$$

$$Q_{tpack} = c \times d \times (\frac{1}{3} \times \frac{C_{rpack}}{C_u} + \frac{2}{3} + R \times \frac{2}{3})$$

Concerning the additional diesel consumption for cooling the truck, the person we met from the ***Syndicat Français des Mareyeurs*** (French syndicate of wholesale sea-fish merchants) was not able to distinguish between the different types of packaging so the same extra diesel consumption was assumed whatever the packaging type.
The additional consumption of fuel has been calculated from a previous study carried out by PwC-Ecobilan. The extra for the diesel is **4 Litres of Diesel oil /hour of use of the truck[14].**

5.8 Ice production

Concerning the production of ice, information was provided by a company producing ice for the logistics sector, **GEA Refrigeration**, part of **GEA Geneglace S.A.S** *9, rue des Orfèvres - ZAC de la Forêt - 44840 Les Sorinières - France*. Usual electricity consumption is **between 65 and 95 kWh/t ice produced**.

[14] Confidential client, LCA of cheese production, 2008.

5.9 End of life

After use, the fish box packaging was considered to be:
- collected with either domestic waste and/or the separate collection system in place for plastic packaging,
- landfilled, recycled or incinerated with energy recovery[15]
- Other waste disposal routes were not studied, as they were not considered to be significantly relevant to the disposal of this particular material.

This end-of life model was applied to:
- the used EPS box
- the used cardboard box
- the used PP box.

	EPS[16]	Polypropylene	Cardboard
Waste collection	Packaging elements are either incinerated, recycled or landfilled depending on national waste management practices. Waste transport by truck before treatment: 50km		
Packaging waste management	**France:** Recycling: 60% Incineration: 16% Landfilling: 24%	**France:** Recycling: 21% Incineration: 32% Landfilling: 47%	**France:** Recycling: 89% Incineration: 8% Landfilling: 3%
	Spain: Recycling: 6% Incineration: 12% Landfilling: 82%	**Spain:** Recycling: 23% Incineration: 14% Landfilling: 63%	**Spain:** Recycling: 70% Incineration: 5% Landfilling: 25%
	Europe: Recycling : 42% Incineration : 24% Landfilling : 34%	**Europe:** Recycling : 28% Incineration : 23% Landfilling : 49%	**Europe:** Recycling : 75% Incineration : 8% Landfilling : 17%

Table 12: Description of packaging end of life

The data related to the split between incineration and landfilling as well as recycling data for PP and cardboard derive from statistics published by Eurostat in 2009 and related to year 2007[17].

[15] The hypothesis that 100 % of incineration is made with energy recovery was chosen in order to match the European Directive 2000/76/CE dated 4 December 2000 and related to the incineration of waste. Article 4 stipulates that the energy produced by the incineration of waste should be done, when feasible.
[16] Source : Study carried out by Consultic (http://www.consultic.de) for EUMEPS in 2010
[17] http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/wastestreams/packaging_waste

The WISARD[18] software was used to model the incineration and landfilling of a given packaging. This tool is a life cycle tool for waste collection and management that allows the modelling of the treatment of a waste fraction based on its characteristics. Appendix D gives a detailed description of the model for incineration and landfilling.
In the reference scenario, the recycling shredding EPS and the transportation to the landfill / incineration / recycling site for all materials. In a sensitivity analysis, the benefit of recycling plastic packaging was also considered.

Distance	50 km	Typical waste collection values
Real load of truck	12 t	
Maximum load	12 t	
Empty return	50%	
Truck Consumption	76l/100 km (includes the diesel consumption during the periods when waste bins are emptied)	Domestic waste collection truck. Source WISARD database

Table 13: Data and sources of data for the transportation steps related to the end of life treatment

5.10 Compaction and shredding of waste EPS packaging

It is assumed that the EPS is sent expanded to the local treatment site, regardless of the end of life scenario. The specific data collection for this study reported that Recycled EPS was shredded and sent then by boat at a distance of 6 240 km to industries in China making CD/DVD boxes, coat hangers, insulation products and IT packaging. Closed loops regarding EPS used for food packaging is impossible since not legal for health and safety reasons. Most of the production losses before use are reinvested in closed loops though.
The data related to this step were collected with the same questionnaire as for the transformation step. The average data and sources of data are presented in the table below.

Consumption of electricity/ton of EPS	270 kWh	Ikos Opale Valo Emballage 13 Rue Pierre Loti 62 200 Boulogne Sur Mer France
Distance to final customer by boat	6 240 km	

Table 14: Data and sources of data for the shredding step of waste EPS packaging

Note on the transport of PP to recycling facility. Though polypropylene might also be sent or partly sent abroad, we did not get any official source for this information and assumed that PP recycling took place in the country of waste production. In any case, results for EPS show that the contribution of used plastic shipment to total results is very low compared to other stages and the exclusion of this sea transport stage does not influence the conclusions of the present study.

[18] Waste – Integrated Systems Assessment for Recovery and Disposal

5.11 Key assumptions

Note. Appendix D was added to compare the value of our "background" datasets listed below with the EcoInvent ones. We conclude that the difference is either minimal or acceptable for modules with less influence over total results (diesel production).

5.11.1 Transport model

Road transport

Module	**Articulated lorry transport; Euro 0, 1, 2, 3, 4 mix; 40 t total weight, 27 t max payload (parameterised with 24 t)**
Source	European Reference Life Cycle Database (ELCD)
Year	2007
Max Payload	24 tons
Converted original data set from: (source data set)	GaBi database 2006
Technology description including background system	Weighted average of articulated lorries with 40t total weight for emission standards from EURO 0 to EURO 4. Payload of lorry is 27t. The following combustion emissions (measured data) of the lorry are taken into account: ammonia, benzene, carbon dioxide, carbon monoxide, methane, nitrogen oxides, nitrous oxide, NMVOC, particulate PM 2.5, sulfur dioxide, toluene, xylene. NMVOC, toluene and xylene emissions of the vehicle result from imperfect combustion and evaporation losses via diffusion through the tank. Lorry fueled by diesel.
Diesel Oil Net Calorific Value	Net calorific value: 42.96 MJ
System Boundary	Gate to gate

Module	**Diesel Oil: Production**
Source	Laboratorium fur Energiesysteme ETH, Zurïch, 1996 Teil 1, Erdöl -Page 173-174
Year	1996
Representativeness	This data sheet is representative of european average in 1994.
Technology description (Primary Data sources)	1) Schmidt K.H, Romey I, "'Kohle, Erdöl, Erdgas; Chemie und Technik"', Würzburg 1981. 2) Concawe (Hrsg.), \'quality of aquous effluents from oil refineries in western europe\', Concawe report n°84/53, Brussels 1984 3) Concawe (Hrsg.), "oil refineries waste survey -disposal methods, quantities and costs", Concawe report n° 5/89, Brussels 1989. 4) Concawe (Hrsg), "'Performance of Oil Industry Pipeline in Western Europe Statistical Summary of Reported Spillages-1994"', Concawe report n° 4/95, Brussels 1995 5) <Raffoil 1991> "Vertrauliche Informationen einer modernen, westeuropaischen Raffinerie", 1991.
Electricity for Production	IEA 2008, European 27 Countries
System Boundary	Cradle to gate

Sea transport

Module	Freighter (various good, in kg.km)
Source	Swiss Federal Office of Environment, Forests and Landscape (FOEFL or BUWAL) Environmental Series No. 32 Bern, February 1991. pages A16, A8 (precombustion) Adaptation covers CO2, methane, N2O emissions (Ecobilan Data).
Year	1991
Size	40,000 gross metric tons
Fuel consumption	One hour: 15 km for 40,000 metric tons of load = 600,000 metric ton.km 0.21 * 40,000 = 8,400 kWh fuel consumption = 8,400 x 0.35 = 2,940 kg for 600,000 metric ton.km = 0.0049 kg/km.metric ton
Average Speed	15 km/h
System Boundary	Cradle to gate

5.11.2 Electricity model

The model used for grid electricity production is representative of the European situation in 1998 (see details in Table 15).

Electricity efficiency, production, supply and combustion of each type of fuel, except for hydroelectricity and nuclear electricity, have been derived from data published in 1996 by the Federal Office for Energy (ETH[19]).

For the hydroelectricity model, an efficiency of 90 % was applied to convert hydropower to primary energy.

For nuclear electricity, the data of the nuclear cycle and efficiency were derived from previous LCA studies performed by Ecobilan for the nuclear sector.

	European Union (27 countries), 2008	**France 2008**	**Spain 2008**	**Denmark 2008**
Coal	16.34 %	4.08%	14.46%	48%
Lignite	10.5 %	-	1.06%	-
Fuel Oil	3.2 %	1%	5.74%	3.3%
Natural Gas	23.32 %	3.81%	38.76%	18.96%
Nuclear	27.79 %	76.45%	18.81%	-
Non thermal (hydro+wind+waves+tide)	14.24 %	12.96%	18.58%	18.96%
Process Gas (coke oven gas + blast furnace gas)	1.04 %	0.67%	0.4%	-
Free electricity (geothermal, solar, biomass and animal products, industrial waste, municipal waste)	3.66 %	1%	2.1%	10.7%
Distribution losses	6.01 %	5.72%	4.78%	6.59%

Table 15: Characteristics of grid electricity in 2008 in Europe, France, Spain and Denmark (source: International Energy Agency, 2010)

[19] ETH, Eidgenössische Technische Hochschule, Federal Office of Energy based in Zürich - "Ökoinventare für Energie Systeme"

5.11.3 Assumptions related to waste composition

In order to model the incineration and landfilling of the packaging items (EPS, PP and cardboard), the composition and parameters of each material presented in the table below were considered.

Parameter	EPS	PP	Cardboard
Net Calorific value (NCV)	40.0 MJ/kg	45.0 MJ/kg	16.1 MJ/kg
Composition	10 % humidity dry content: 92.3 % C 7.7 % H	10 % humidity dry content: 78 % C 13 % H 4 % O 1.4 % Cl 0.1 % N 0.1 % S 3.4 % mineral matter	10 % humidity dry content: 43.71 % C biomass 6.35 % H 44.15 % O 0.54 % Cl 0.45 % N 0.14 % S 0.17 % Fe 1.04 % Al
Quantity of biogas released during the decomposition of waste over 100 years	0 kg/kg	0 kg/kg	0.375 kg/kg[20]

Table 16: Physical characteristics of EPS, PP and cardboard

For cardboard and PP, the waste composition data come directly from PricewaterhouseCoopers – Ecobilan waste management software WISARD[21]. In this modelling, a waste fraction is made of one main material (e.g. PP) contaminated by other elements present in the domestic waste stream, which explains the trace elements in the above table. PE films present in cardboard packaging was not taken into account in the modeling of incineration due to its limited share in the packaging (average of 1% in mass of the box).

5.11.4 Assumptions related to incineration of waste

The incineration model used in the study was obtained from PwC– Ecobilan waste management software WISARD. Energy recovery ratios are taken from average 2008 data of 11 European countries[22]

- 46,95 million t of household waste were incinerated in 2008.
- Energy recovered was as follows:
  - 13920 GWh electricity → 297 kWh/t generic household waste
  - 33320 GWh steam → 2 555 MJ/t generic household waste

Countries considered to obtain those average data are: Belgium; Czech Republic; France; Denmark; Finland; Hungary; Ireland; Netherlands; Norway; Portugal; Germany.
The main parameters of the incineration model are presented in the following Table.

[20] This means that after 100 years, and for 1 kg of cardboard landfilled, there will be 1 kg - 0.375 kg = 0.625 kg remaining in the landfill.
[21] WISARD: Waste Integrated Systems Assessment for Recovery and Disposal
[22] Source: http://www.cewep.eu/information/data/subdir/442._Country_Report_on_Waste_Management.html

Energy recovery parameters (with an average NCV of 9 MJ/kg of waste)	
Electricity consumption	80 kWh/t
Electricity exported	297 kWh/t
Steam exported	2 555 MJ/t
Overall energy recovery efficiency	40 %
Type of flue gas treatment	Gas cleaning consists of a spray absorber (as a rule) where lime slurry is atomised and reacts with acid gases and conditions these for the baghouse filter. In addition activated carbon is dosed before the baghouse filter. Inputs are hydrated or quick lime, activated carbon, water; outputs consist of gas cleaning residuals (incorporating fly ash) and treated flue gas

Table 17: Characteristics of the incinerator model

The application of these parameters to each type of waste gives the results displayed in the following table.

Parameter	EPS	PP	Cardboard
Net Calorific Value (NCV) NCV measures the energy contained in the waste stream	40.0 MJ	45.0 MJ	16.1 MJ
Quantity of electricity recovered from the waste incineration	4.75 MJ	5.34 MJ	1.91 MJ
Quantity of steam recovered from the waste incineration	11.3 MJ	12.7 MJ	4.57 MJ

Table 18: Energy recovered from waste incineration (per 1 kg of product)

Owing to the assumption that the incinerator produces electricity and steam, it is assumed that the production of electricity and steam from classical fuels (natural gas, coal, nuclear fuel…) is avoided. Section 4.3.5 and section 5.11.2 respectively present the mix of fuels used for steam and production electricity.

5.11.5 Assumptions related to landfilling of waste

Information for the landfilling of waste (EPS, cardboard and LDPE) was also obtained from WISARD software. The WISARD model is presented in details in appendix D. The landfill used in the model was a large wet clay line landfill and data on construction of the site is based on UK data. However some operation parameters (listed in Table 19) were derived from average French data, as they were considered to be more representative than one data set from a UK landfill.

Production of biogas	- 30 % direct discharged - 70 % flared (methane is burnt to CO2)
Recovery of energy from biogas treatment	None
Production of leachates	85 l/ produced / t landfilled waste
Treatment of leachates	- 10% is not treated - 90 % is treated with a biological treatment

Table 19: Characteristics of landfilling model

6. Life cycle inventory and life cycle impacts assessment results for the reference scenario

6.1 Presentation of the interpretation of results

Results are first presented for the reference scenarios detailed in §4, corresponding to the three functional units:

- **"packaging 4 kg of fresh fish fillets (e.g., cod) from local harbour in France to local professional fish market respecting national regulations on chilled fresh fish".** This situation is called the "**French Market**" (for packaging) in the tables and graphs below.
- **"packaging 6 kg of fresh fish (e.g., sardines) from local harbour in Spain to local professional fish market respecting national regulations on chilled fresh fish".** This situation is called the "**Spanish Market**" (for packaging) in the tables and graphs below.
- **"packaging 20 kg of fresh salmon from Danish fisheries to professional fish market in Rungis Paris, respecting national regulations on chilled fresh fish"..**This situation is called the "**Scandinavian Market**" (for packaging) in the tables and graphs below.

6.1.1 Characterisation of the different stages for interpretation

Results are calculated for **1 000 packaging units**.

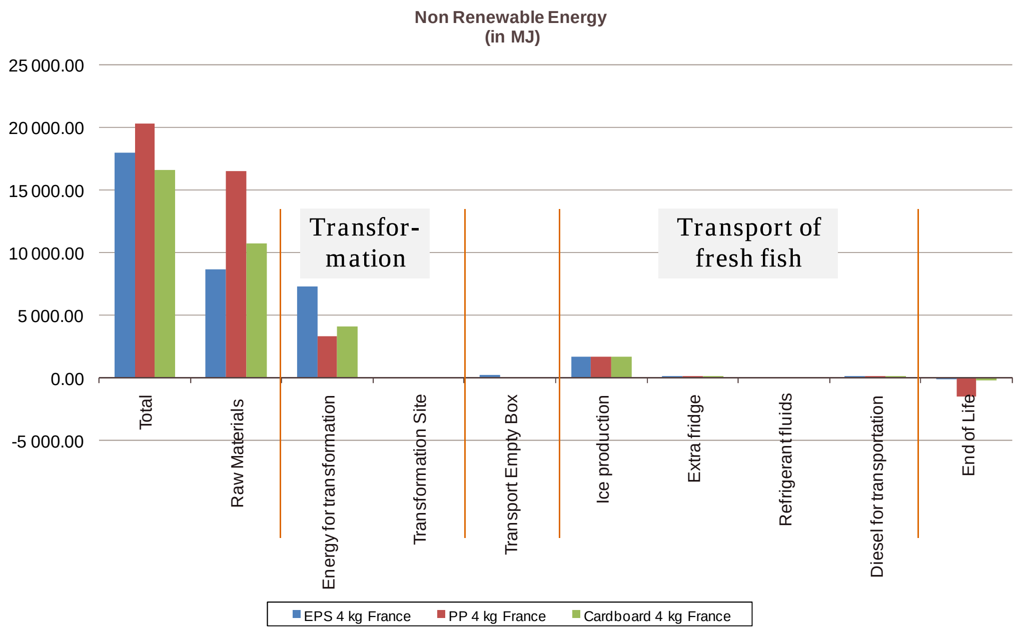


Figure 6: Characterisation of the different stages for the interpretation of results – N-R Energy-small box case

1. “Total” encompasses the total life cycle of the fishbox from cradle to grave.
2. “Raw materials” encompasses all the raw materials production to produce the box including packaging for the box and packaging for raw materials from cradle to gate.
3. Transformation stage gathers:
   a. “Energy for transformation”, i.e. the production and combustion of fuels (mostly natural gas), the production and supply of electricity;
   b. “Transformation Site,” is only relevant in the case of EPS air and water emissions at site level. Air emissions related to the combustion of Energies are separated in this sub-stage only in the case of EPS, but aggregated in the “Energy for transformation” stage for cardboard and polypropylene.

4. “Transport empty box” stage corresponds to the transport of the empty packaging from the production plant to the harbour. The empty packaging is considered folded during this transport stage for cardboard and polypropylene.
5. “Transport of fresh fish” stage gathers:
   a. “Ice production” is the production of the ice to be included into the packaging for transportation of the fresh fish;
   b. “Extra for the fridge” is the energy necessary to fulfil the functional unit requirements during the fish transportation stage, that is to say to keep it at a temperature of less than 4°C. The energy taken into account is an extra of diesel oil consumption;
   c. “refrigerant fluids” are the leaks of carbon tetrafluorides (CF_4) during the transportation stage;
   d. “Diesel for transportation” includes the production as well as the combustion of the diesel into the truck engine. This stage is only allocated to the transportation of the boxes not excluding the share to transport the fish itself.

6. “End of life” includes all the ways of transportation to the end of life treatment site, as well as the end of life scenarios for each material for the part of the product recycled or incinerated. In the reference scenario, as explained in §4.3.4, the share of the product that is recycled is quantified as recovered matter, but, in the reference scenario, neither the impacts of the recycling process nor its benefits are included in the system boundaries (stock method).

6.2 Presentation of results for the reference scenarios

6.2.1.1 *Non renewable energy*

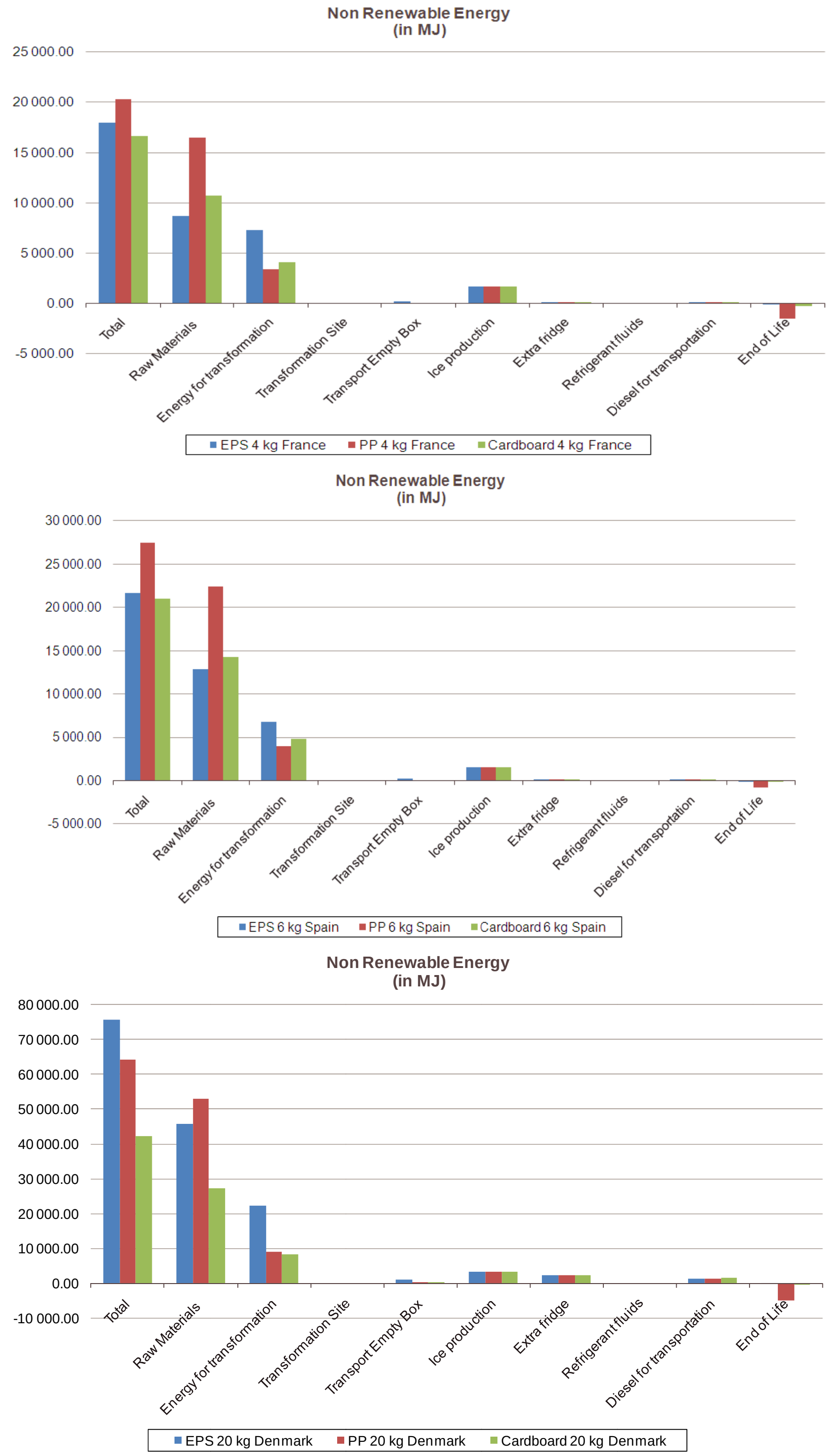


Figure 7: Consumption of Non Renewable Energy (in MJ)

pwc

Consumption of Non Renewable Energy (in MJ)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**18 008**	**20 347**	**16 650**
Raw Materials	8 678	16 493	10 754
Transformation	7 267	3 372	4 091
Transport Empty Box	203	77	89
Ice production	1670	1670	1670
Extra fridge	119	119	119
Refrigerant fluids	0.0	0.0	0.0
Diesel	127	132	152
End of Life	-55	-1515	-225

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**21 629**	**27 438**	**20 971**
Raw Materials	12 869	22 387	14 248
Transformation	6 802	3 955	4 859
Transport Empty Box	265	83	49
Ice production	1 529	1529	1529
Extra fridge	168	168	168
Refrigerant fluids	0.0	0.0	0.0
Diesel	140	148	179
End of Life	-146	-834	-62

Scandinavian Market (42l)

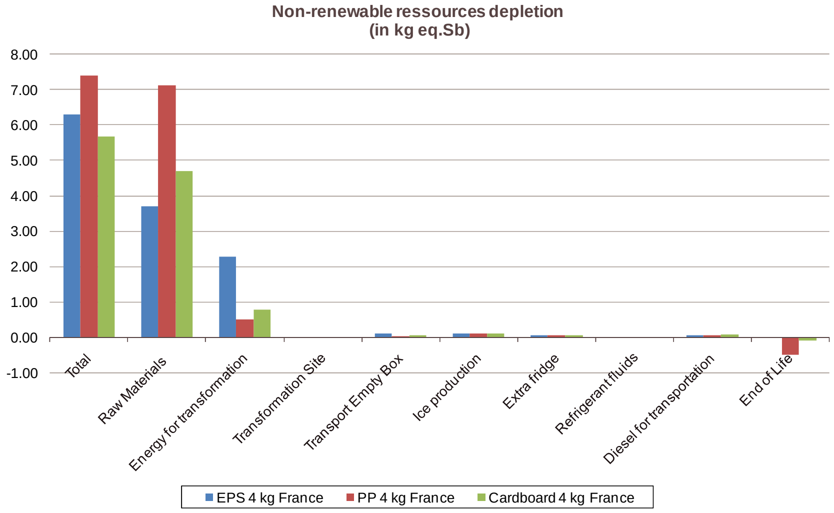
Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20 kg Denmark
Total	**75 647**	**64 180**	**42 220**
Raw Materials	45 737	52 922	27 183
Transformation	22 343	8 957	8 308
Transport Empty Box	969	225	119
Ice production	3325	3325	3325
Extra fridge	2271	2271	2271
Refrigerant fluids	0.0	0.0	0.0
Diesel	1302	1342	1584
End of Life	-300	-4863	-569

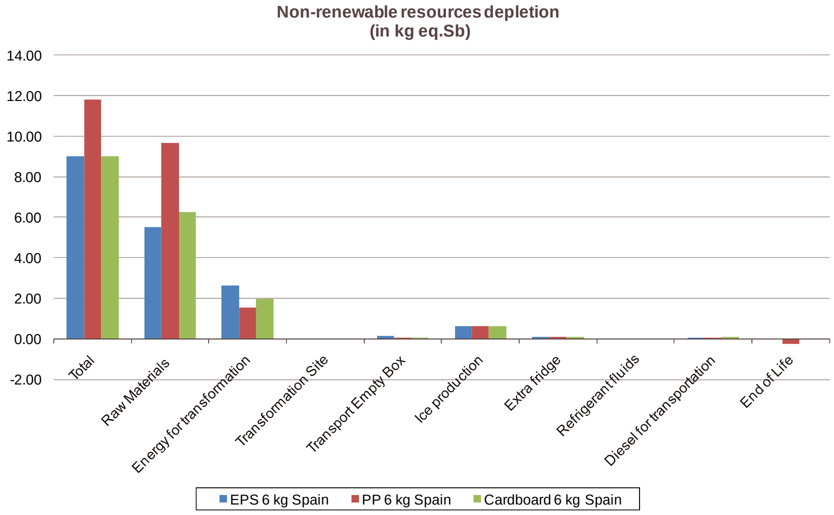
For the EPS box, 89-90% of the non-renewable energy is consumed at the production stage among which 46-60% are consumed at the Expansible Polystyrene production stage, 21-32 % for the natural gas and 6-9% for the electricity used at the transformation stage.
It has to be noted that the transport of the empty box is not significant (1% of the total) and will be therefore even less significant in the case of PP and Cardboard boxes (transported folded at this stage). Transport of box containing the fish represents between 9 and 11 % among which the production of ice is the main contributor (between 4 and 9%, proportionally depending on the distance).

For the PP box the production stage represents 96-98% of the total among which 80-81% are consumed at the Polypropylene raw material production stage. The consumption of electricity for the transformation process participates to 10-12% of the total non-renewable energy consumption.

For the cardboard box, the production stage consumes 89-91% of the non-renewable energy. The production of the raw materials corresponds to 62-63% of the total and the energies for transformation 20-24% of the total.

6.2.1.2 Depletion of Non-renewable resources





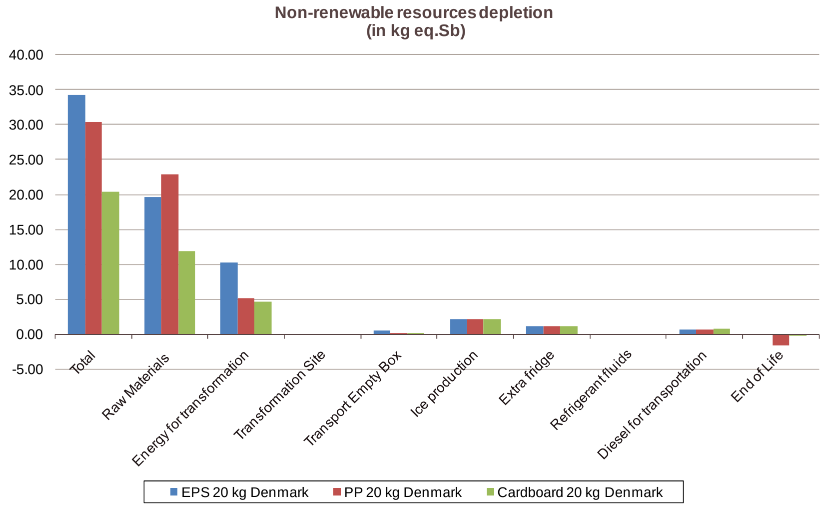


Figure 8: Depletion of Non Renewable Resources (in kg Sb eq.)

Depletion of Non Renewable Resources (in kg Sb eq.)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**6.30**	**7.41**	**5.68**
Raw Materials	3.71	7.13	4.69
Transformation	2.27	0.50	0.79
Transport Empty Box	0.10	0.04	0.04
Ice production	0.11	0.11	0.11
Extra fridge	0.06	0.06	0.06
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.06	0.06	0.07
End of Life	-0.01	-0.49	-0.08

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**8.99**	**11.79**	**8.99**
Raw Materials	5.52	9.68	6.24
Transformation	2.62	1.56	1.96
Transport Empty Box	0.13	0.04	0.02
Ice production	0.61	0.61	0.61
Extra fridge	0.08	0.08	0.08
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.07	0.07	0.09
End of Life	-0.03	-0.26	-0.01

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20kg Denmark
Total	**34.20**	**30.42**	**20.36**
Raw Materials	19.61	22.87	11.86
Transformation	10.26	5.10	4.63
Transport Empty Box	0.47	0.11	0.06
Ice production	2.17	2.17	2.17
Extra fridge	1.10	1.10	1.10
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.63	0.65	0.76
End of Life	-0.03	-1.56	-0.21

For the EPS box, 87-95% of the consumption of non-renewable resources comes from the production stage. 56-59% are due to the production of the raw material for the box, and 18-35% to the use of natural gas for transformation. The contribution share of the electricity for transformation is respectively 2% for France, 6% for Spain, and 12% for Denmark of the total life cycle.

For the PP box, the production of the polypropylene granules is responsible of 74-95% of the total resources depletion. Energies for transformation process (natural gas + electricity) contribute to 7-16% of this impact that is to say almost the rest.

For the cardboard box, 81-97% of the non-renewable resources are consumed at the production stage. 55-79% are consumed for the raw materials production, and 16-23% for the energies used for the cardboard production and transformation (folding and PE covering).

6.2.1.3 Emission of greenhouse gases

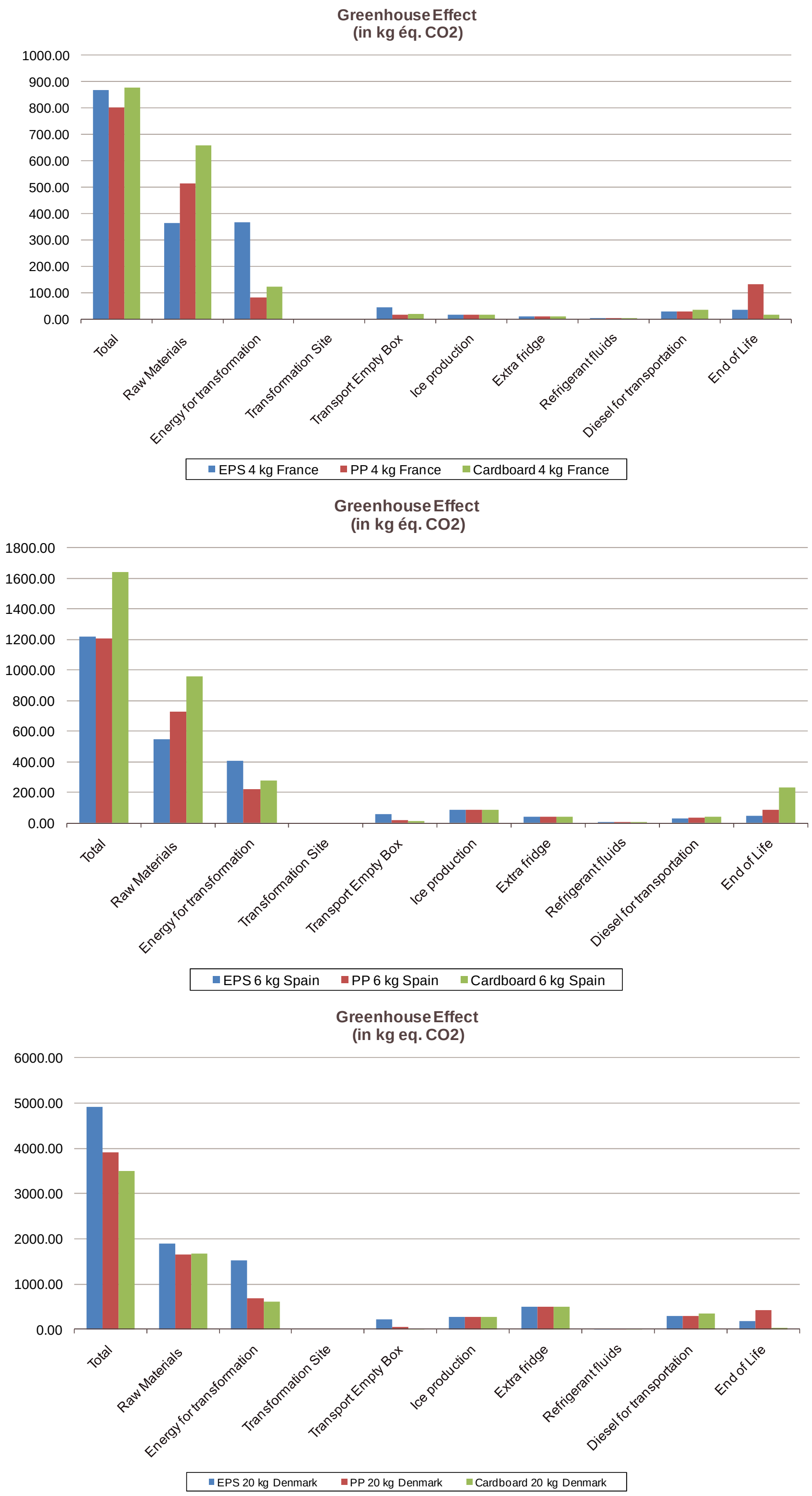


Figure 9: Emission of Greenhouse gases (in kg CO_2 eq., 100 years)

Emission of Greenhouse gases (in kg CO_2 eq., 100 years)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**868**	**802**	**878**
Raw Materials	364.34	515.46	659.50
Transformation	367.62	81.27	121.60
Transport Empty Box	45.56	17.27	20.00
Ice production	17.05	17.05	17.05
Extra fridge	9.53	9.53	9.53
Refrigerant fluids	0.65	0.65	0.65
Diesel	28.42	29.59	34.14
End of Life	34.90	131.04	15.27

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**1 206**	**1209**	**1642**
Raw Materials	550.02	730.03	959.19
Transformation	409.59	221.74	278.88
Transport Empty Box	59.47	18.70	11.01
Ice production	82.83	82.83	82.83
Extra fridge	37.70	37.70	37.70
Refrigerant fluids	0.94	0.94	0.94
Diesel	31.44	33.19	40.15
End of Life	34.30	83.64	230.81

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20kg Denmark
Total	**4914**	**3911**	**3509**
Raw Materials	1897.39	1653.97	1666.95
Transformation	1518.08	687.22	623.28
Transport Empty	217.26	50.47	26.68
Ice production	276.82	276.82	276.82
Extra fridge	509.00	509.00	509.00
Refrigerant fluids	12.65	12.65	12.65
Diesel	291.78	300.88	354.94
End of Life	191.21	420.45	38.60

EPS Box: 70-83% of greenhouse gases are emitted at the production stage. 37-41% are generated during the production of the expansible polystyrene, 20-40% are due to the use of natural gas at the transformation stage, and the share of the electricity for transformation is 2% for the French box, 6% for the Spanish box and 11% for the Danish box. The transport of the empty box is only 4-5% for this impact. The transport of the box including the fish emits 8-22% of the total (300-1200 km) The end of life including shredding and the transport by boat for the part of shredded EPS when recycled is only responsible of 4% of the total.

PP Box: The production stage is responsible of 60-79% of the total emissions of GhG among which the PP raw material production represents 39-58%. The energies for transformation contribute to 10-18% of the total life cycle.

Cardboard Box: 65-87% of the emissions of GhG take place at the production stage. 40-62% of the total life cycle emissions are occurring during the production of raw materials and 14-18% are due to the use of raw material for the transformation process.

6.2.1.4 Acidification

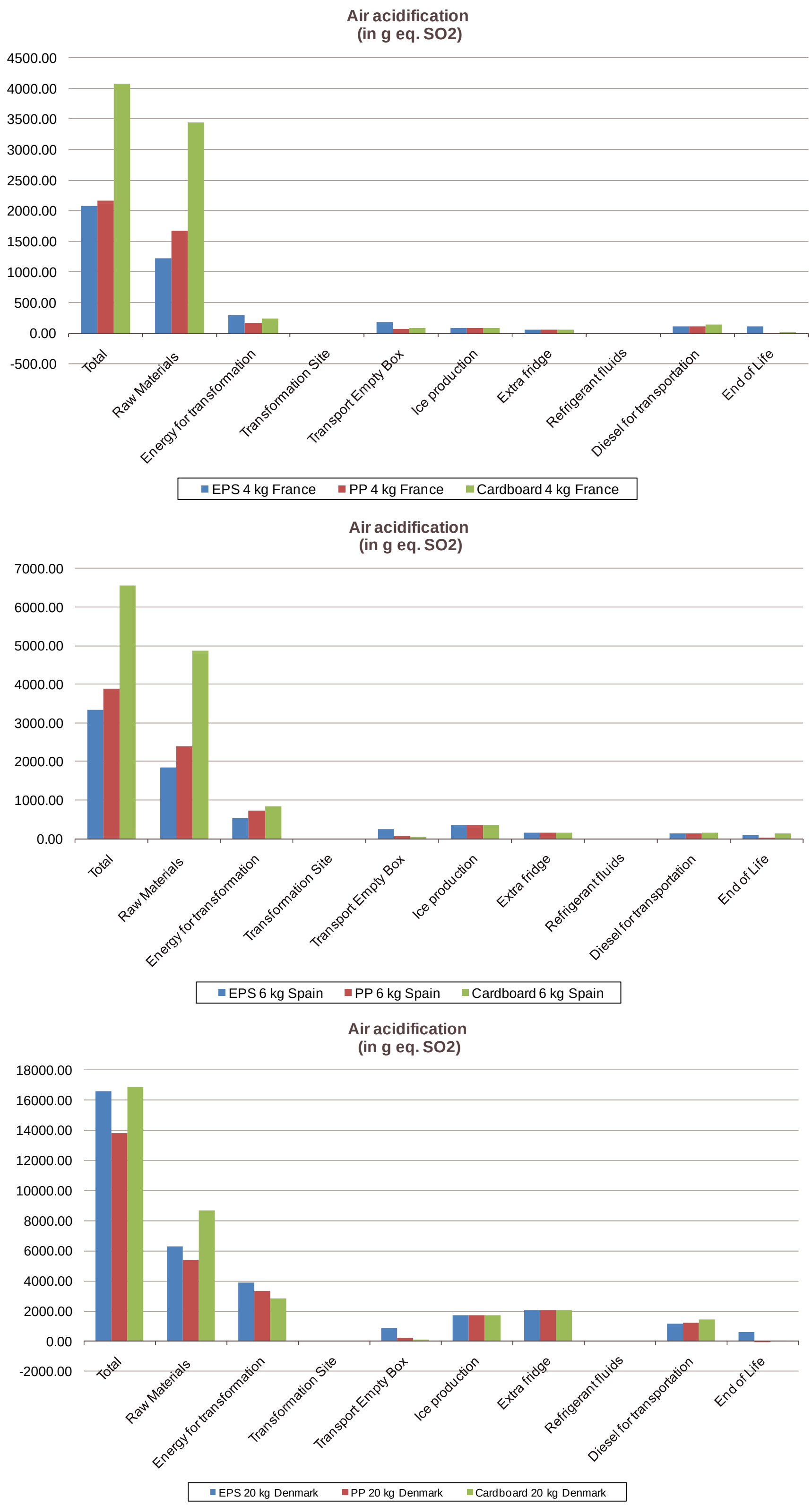


Figure 10: Acidification (in g SO_2 eq.)

Acidification (in g SO_2 eq.)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**2075**	**2169**	**4077**
Raw Materials	1222.65	1677.69	3445.59
Transformation	295.33	168.15	247.27
Transport Empty Box	182.19	69.04	79.96
Ice production	91.32	91.32	91.32
Extra fridge	57.13	57.13	57.13
Refrigerant fluids	0.00	0.00	0.00
Diesel	113.64	118.31	136.52
End of Life	112.45	-12.30	18.74

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**3 277**	**3887**	**6548**
Raw Materials	1 841.35	2402.27	4867.19
Transformation	523.54	734.82	835.24
Transport Empty Box	237.79	74.77	44.01
Ice production	360.44	360.44	360.44
Extra fridge	150.76	150.76	150.76
Refrigerant fluids	0.00	0.00	0.00
Diesel	125.73	132.71	160.55
End of Life	37.30	31.52	130.00

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20kg Denmark
Total	**16594**	**13822**	**16866**
Raw Materials	6279.19	5383.19	8709.11
Transformation	3910.62	3321.19	2831.54
Transport Empty	868.77	201.80	106.70
Ice production	1716.77	1716.77	1716.77
Extra fridge	2035.31	2035.31	2035.31
Refrigerant fluids	0.00	0.00	0.00
Diesel	1166.74	1203.15	1419.30
End of Life	616.14	-39.46	47.37

EPS box: 61%-72% of the acidification is attributable to the production stage. The raw material production is responsible to 36-51% of the total life cycle, and the energy for transformation represents 14-24%. The transport of the empty box generates 5-9% and the transport to convey the fish 15-30% of the total acidification for the life cycle. The end of life stage including the transport by boat is only of 4-5%.

PP box: The production stage represents 63-83% of the life cycle. The PP raw material production represents 39% of the impact for the Danish box and 77% for the French box, which can be explained by the higher impact of energy for transformation in the Danish case because of the electricity grid, the electricity for transformation representing 6% of this impact in the French case versus 23% in the Danish case.

Cardboard Box: The production stage is responsible of 68-90% of the acidification. The production of raw material generates 45-73% of the acidification (mostly through SO_2), but it can be noted that the transport of these raw material reaches up to 6-15% (mostly through NO_x) in the case of cardboard. Transport of empty box does not exceed 2% and the transport of the boxes including the fish is of 8% for the French case and up to 31% for the Scandinavian case (due to a longer transport distance).

6.2.1.5 Formation of photochemical oxidants

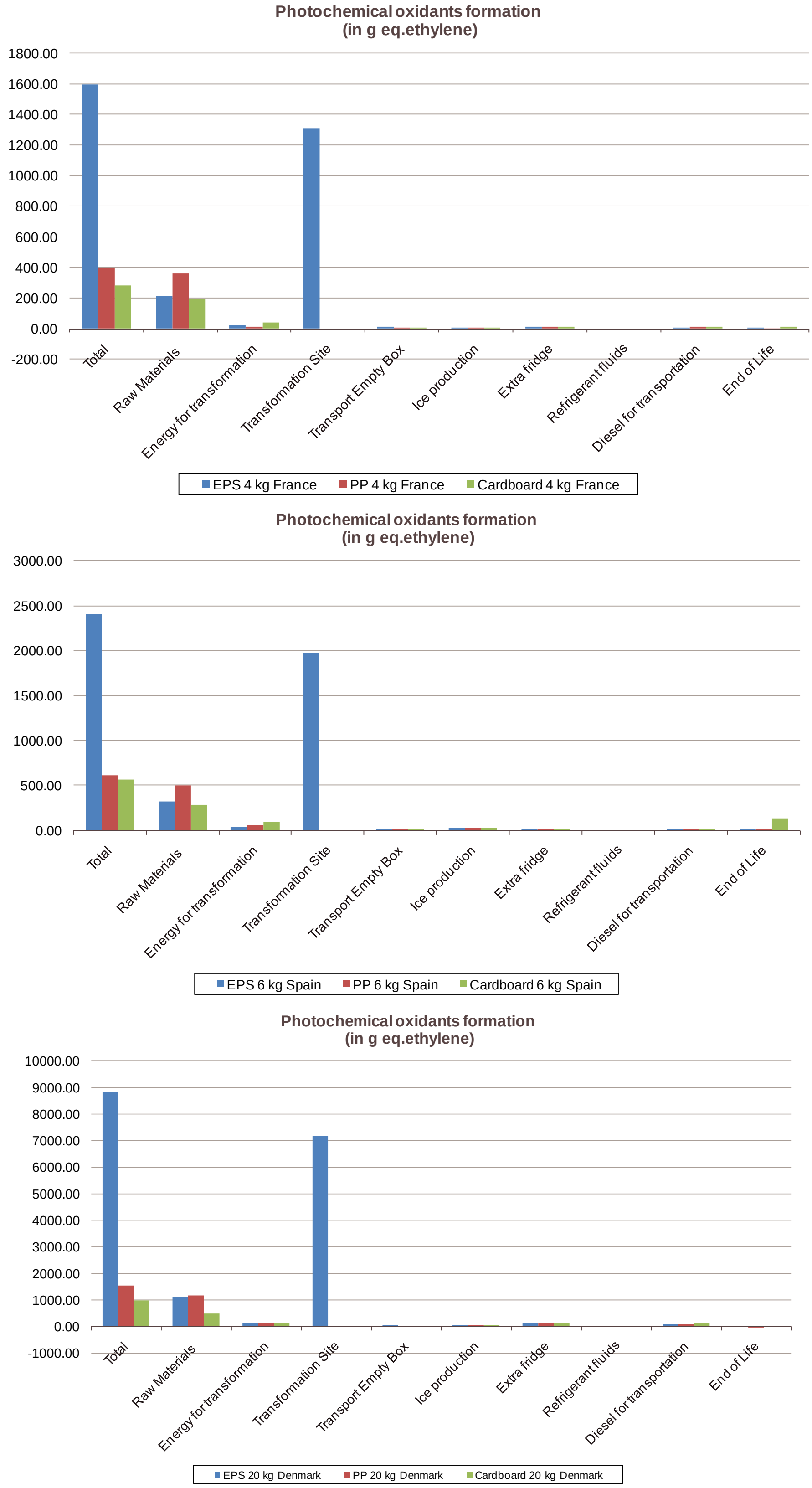


Figure 11: Photochemical Oxidants formation (in g eq. ethylene)

Photochemical Oxidants formation (in g eq. ethylene)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**1595.10**	**399.75**	**280.45**
Raw Materials	214.34	362.49	192.11
Energy for Transformation	24.43	13.53	41.12
Transformation Site	1309.44	0.00	0.00
Transport Empty Box	14.09	5.34	6.19
Ice production	7.27	7.27	7.27
Extra fridge	12.63	12.63	12.63
Refrigerant fluids	0.00	0.00	0.00
Diesel	8.79	9.15	10.56
End of Life	4.10	-10.67	10.57

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**2 408.10**	**612.37**	**565.25**
Raw Materials	317.44	499.49	281.54
Energy for transformat	41.47	**56.32**	**91.49**
Transformation Site	1 977.80	0.00	0.00
Transport Empty Box	18.40	**5.78**	**3.40**
Ice production	27.49	27.49	27.49
Extra fridge	11.66	**11.66**	**11.66**
Refrigerant fluids	0.00	0.00	0.00
Diesel	9.73	**10.27**	**12.42**
End of Life	4.12	1.36	137.24

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20kg Denmark
Total	**8824.95**	**1555.84**	**994.49**
Raw Materials	1108.17	1163.13	485.58
Energy for transformat	151.75	107.82	153.70
Transformation Site	7174.64	0.00	0.00
Transport Empty Box	67.21	15.61	8.25
Ice production	52.99	52.99	52.99
Extra fridge	157.46	157.46	157.46
Refrigerant fluids	0.00	0.00	0.00
Diesel	90.26	93.08	109.80
End of Life	22.48	-34.25	26.71

EPS Box: The generation of photochemical oxidants predominates at the transformation stage with 82%. Those emissions are due to the Pentane rejected into air. The production of the Expansible Polystyrene is responsible of 12% of photochemical oxidants.

PP Box: the main source of emission is the production of polypropylene.

Cardboard Box: the main source of emission is the production of the raw material to make the corrugated cardbord.

6.2.1.6 Water consumption

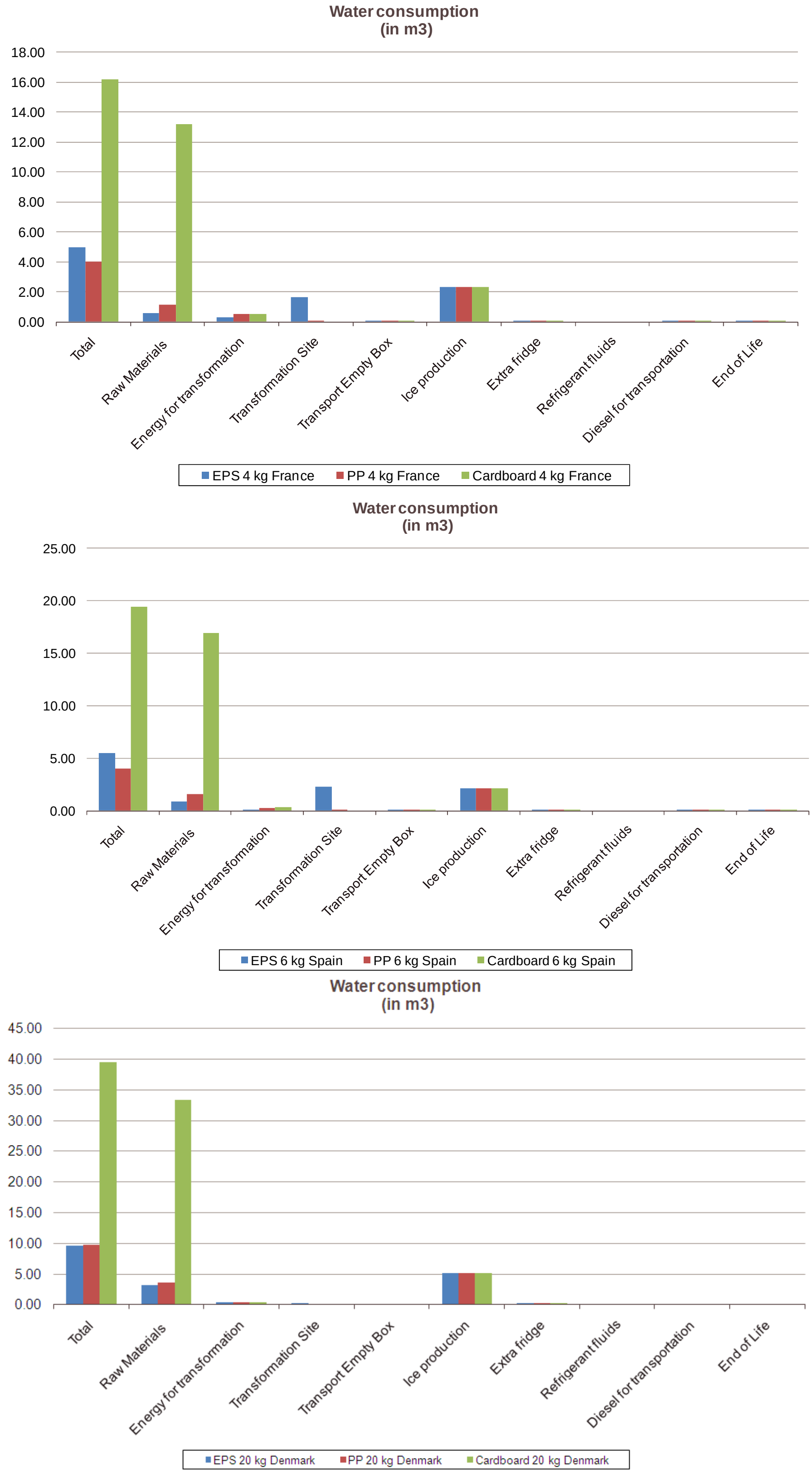


Figure 12: Water consumption (in m^3)

Water consumption (in m^3)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**4.97**	**4.04**	**16.16**
Raw Materials	0.60	1.13	13.21
Energy for transformation	0.32	0.49	0.54
Transformation Site	1.66	0.01	0.00
Transport Empty Box	0.02	0.01	0.01
Ice production	2.33	2.33	2.33
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.01	0.01	0.01
End of Life	0.01	0.03	0.04

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**5.51**	**4.02**	**19.44**
Raw Materials	0.90	1.54	16.91
Energy for transformation	0.12	0.26	0.29
Transformation Site	2.29	0.02	0.00
Transport Empty Box	0.03	0.01	0.00
Ice production	2.13	2.13	2.13
Extra fridge	0.02	0.02	0.02
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.01	0.01	0.02
End of Life	0.02	0.04	0.07

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20 kg Denmark
Total	**9.64**	**9.82**	**39.52**
Raw Materials	3.19	3.64	33.39
Energy for transform	0.46	0.44	0.42
Transformation Site	0.25	0.04	0.00
Transport Empty	0.09	0.02	0.01
Ice production	5.23	5.23	5.23
Extra fridge	0.22	0.22	0.22
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.13	0.13	0.15
End of Life	0.06	0.10	0.09

EPS Box: Most of the water consumption is coming from the ice making (39-50% of total water used). The water used for EPS transformation is also significant (33-42%).

PP Box: Most of the water consumption is coming from the ice making (53-58%). Production of polypropylene is also contributing to the result (28-38%).

Cardboard box: Production of the raw materials for the corrugated cardboard is the largest water consuming stage (81-86%).

6.2.1.7 Water eutrophication

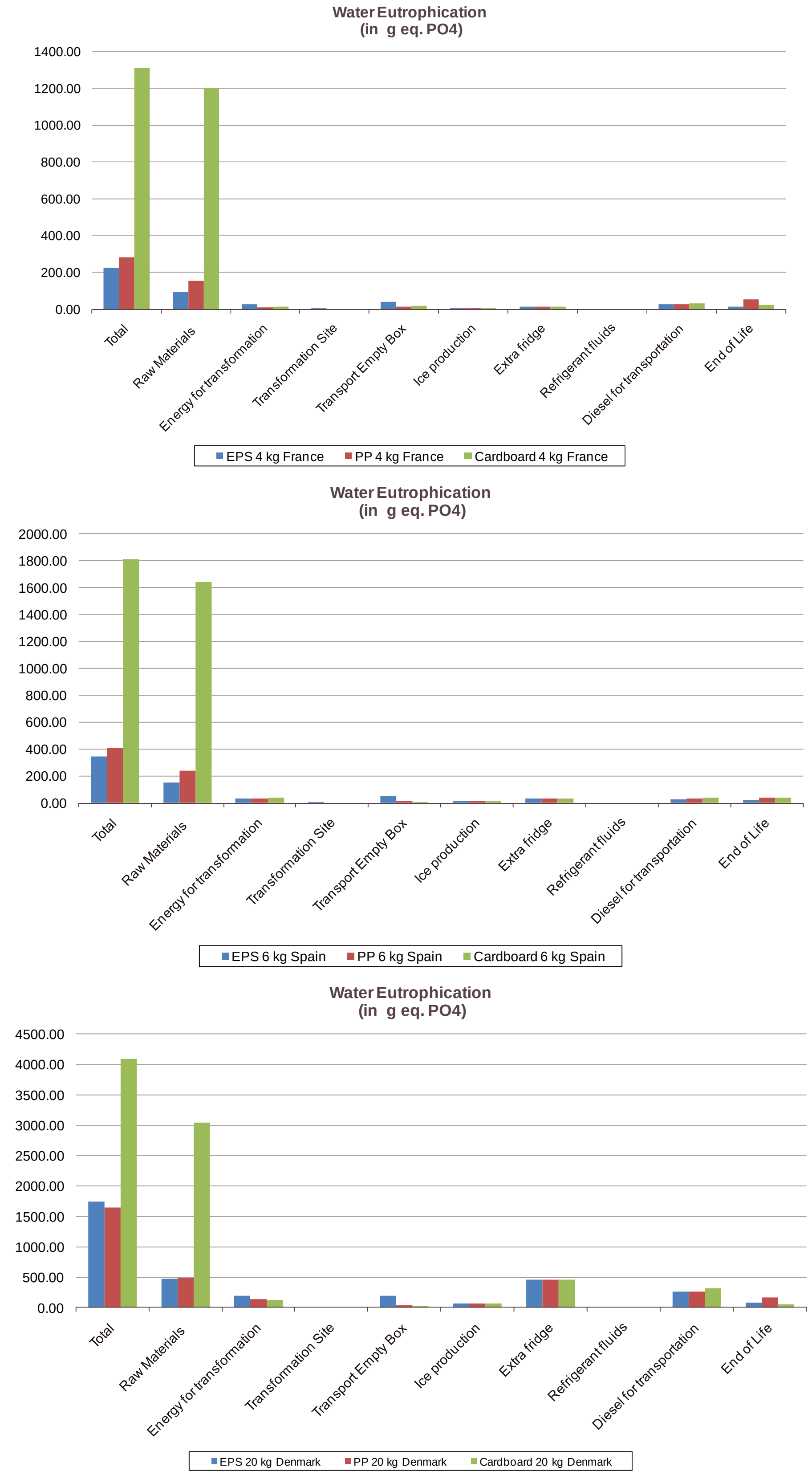


Figure 13: Water Eutrophication (in g eq. PO_4^{3-})

Water Eutrophication (in g eq. PO_4^{3-})

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**222.84**	**280.28**	**1310.60**
Raw Materials	92.00	154.32	1203.52
Energy for transformation	27.42	11.22	15.12
Transformation Site	3.10	0.00	0.00
Transport Empty Box	40.74	15.44	17.88
Ice production	5.17	5.17	5.17
Extra fridge	13.76	13.76	13.76
Refrigerant fluids	0.00	0.00	0.00
Diesel	25.41	26.46	30.53
End of Life	15.24	53.92	24.62

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**343.94**	**410.47**	**1813.58**
Raw Materials	149.26	239.53	1640.97
Energy for transformation	35.49	34.08	39.18
Transformation Site	7.05	0.00	0.00
Transport Empty Box	53.18	16.72	9.84
Ice production	15.56	15.56	15.56
Extra fridge	33.71	33.71	33.71
Refrigerant fluids	0.00	0.00	0.00
Diesel	28.12	29.68	35.90
End of Life	21.57	41.18	38.41

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20 kg Denmark
Total	**1740**	**1651**	**4093**
Raw Materials	476	495	3042
Energy for transformation	199	143	122
Transport Empty Box	194	45	24
Ice production	70	70	70
Extra fridge	455	455	455
Refrigerant fluids	0	0	0
Diesel	261	269	317
End of Life	83	173	62

EPS Box: The largest contributor to the eutrophication is the expansible polystyrene production (18-33%) and the transports (46-60% for all the transport stages –raw material, empty box and box containing fish) among which the main transport is the most significant.

PP Box: The largest contributor to the eutrophication is polypropylene production (24-43%). Transport stages contribute to almost all the rest of this impact through the life cycle.

Cardboard box: The largest contributor to the eutrophication is the corrugated cardboard production (78-84%). Rest of the impact are due to the transport stages.

6.2.1.8 Solid waste production

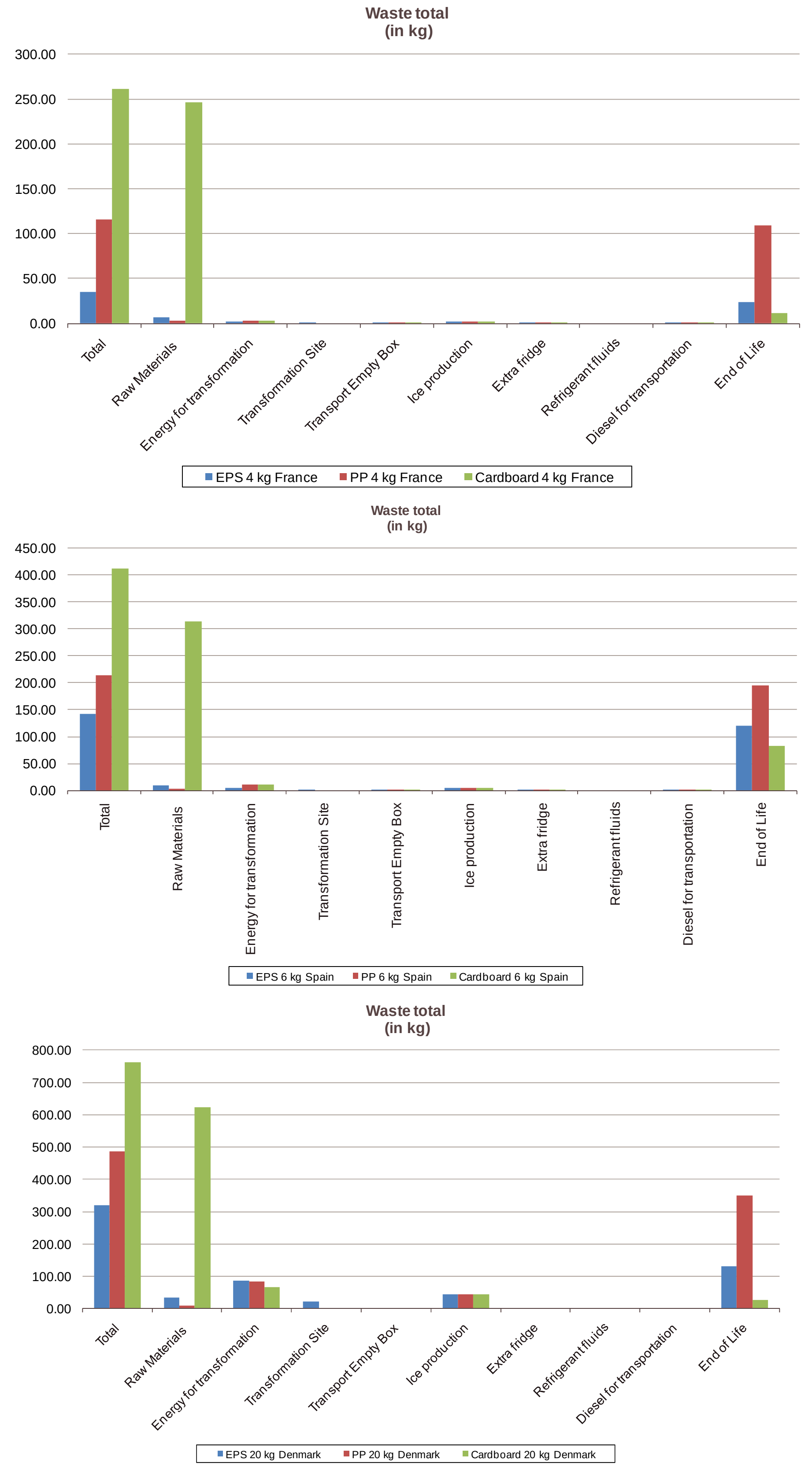


Figure 14: Total waste production (in kg)

Waste total (in kg)

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**34.56**	**115.85**	**261.55**
Raw Materials	6.74	2.75	246.09
Energy for transformation	1.77	2.56	2.68
Transformation Site	0.45	0.00	0.00
Transport Empty Box	0.03	0.01	0.01
Ice production	1.72	1.72	1.72
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.02	0.02	0.02
End of Life	23.83	108.77	11.01

Spanish Market (15l)

Stage	EPS 6 kg Spain	PP 6 kg Spain	Cardboard 6 kg Spain
Total	**142.14**	**214.40**	**412.56**
Raw Materials	9.96	3.73	314.10
Energy for transformat	4.93	10.34	10.40
Transformation Site	2.09	0.00	0.00
Transport Empty Box	0.03	0.01	0.01
Ice production	5.33	5.33	5.33
Extra fridge	0.02	0.02	0.02
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.02	0.02	0.02
End of Life	119.75	194.95	82.68

Scandinavian Market (42l)

Stage	EPS 20 kg Denmark	PP 20 kg Denmark	Cardboard 20 kg Denmark
Total	**320.89**	**486.27**	**761.73**
Raw Materials	35.62	8.84	622.03
Energy for transformation	86.54	83.48	66.91
Transformation Site	23.14	0.00	0.00
Transport Empty Box	0.12	0.03	0.02
Ice production	44.45	44.45	44.45
Extra fridge	0.29	0.29	0.29
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.17	0.17	0.20
End of Life	130.57	349.01	27.84

EPS Box: The largest contributor to waste production is the landfilling of the packaging after use (41-78%).

PP Box: The largest contributor to waste production is the landfilling of the packaging after use (72-94%).

Cardboard box: The largest contributors to waste production are the raw materials used for the corrugated cardboard production (76-94%).

6.3 Comparison of the environmental performance of the packaging solutions under the reference scenarios

The following table compares the relative performance of the three packaging scenarios for the three markets studied. On each market, the results of the EPS packaging are taken as the reference.

When the performance of another packaging is within 20% of the EPS packaging value, the two are considered equivalent, due to uncertainties in LCA calculations.
When the performance of another packaging solution is lower by more than 20% than the one of the EPS packaging, the value is highlighted in green.
When the performance of another packaging solution is higher by more than 20% than the one of the EPS packaging, the value is highlighted in orange.

Indicator		EPS	PP	Cardboard	EPS	PP	Cardboard	EPS	PP	Cardboard
		4 kg	4 kg	4 kg	6 kg	6 kg	6 kg	20 kg	20 kg	20 kg
		France	France	France	Spanish	Spanish	Spanish	Scandinavian	Scandinavian	Scandinavian
Non renewable primary energy	MJ	1	1.1	0.9	1	1.3	1.0	1	0.8	0.6
Depletion of Non Renewable Resources	kg eq. Sb	1	1.2	0.9	1	1.3	1.0	1	0.9	0.6
Emission of Greenhouse gases	kg CO2 eq., 100 years	1	0.9	1.0	1	1.0	1.4	1	0.8	0.7
Air acidification	g SO2 eq.	1	1.0	2.0	1	1.2	2.0	1	0.8	1.0
Photochemical Oxidants formation	g eq. ethylene	1	0.3	0.2	1	0.3	0.2	1	0.2	0.1
Water consumption	m3	1	0.8	3.3	1	0.7	3.5	1	1.0	4.1
Water Eutrophication	in g eq. PO43-	1	1.3	5.9	1	1.2	5.3	1	0.9	2.4
Total waste production	kg	1	3.4	7.6	1	2.1	4.1	1	1.5	2.4

Table 20: Comparative results of the three packaging solutions on the three markets

On the French market (4kg fish per box, 300 km), the EPS packaging performs similarly or better than PP and cardboard, except for the formation of photochemical oxidants.

Results are comparable on the Spanish market (6kg fish per box, 300 km), except that PP performs better than EPS for the formation of photochemical oxidants as well as water consumption.

On the Scandinavian market (20 kg fish, 1200 km), results are more balanced:

- EPS and PP perform similarly for 5 indicators (energy consumption, acidification, water consumption and water eutrophication), EPS performs better than PP for waste production but worse for greenhouse gas emissions and formation of photochemical oxidants.
- EPS performs better than cardboard for waste production, water consumption and water eutrophication but worse for energy consumption, greenhouse gas emissions and formation of photochemical oxidants. EPS and cardboard perform similarly for acidification.

The reason for the different relative results on the Scandinavian market is the difference in relative weights of packaging.

- EPS packaging weighs 2 (resp. 8) times less than PP (resp. cardboard) on the French and Spanish markets.
- EPS packaging weighs only 1.4 (resp 5) times less than PP (resp. cardboard) on the Scandinavian market. We need to note here that cardboard weight for large boxes used on the Scandinavian market were calculated (see table 3), which may introduce uncertainties in the weight considered for cardboard boxes.

7. Life Cycle Sensitivity Analyses and Interpretation

7.1 Introduction on sensitivity analysis

Sensitivity analysis is essential to fully interpret the LCIs and LCIAs and to test the significance of the assumptions and parameters. In this chapter, we describe the approach to sensitivity analyses followed by presentation and interpretation of the sensitivity analyses that have been carried out.

Sensitivity analyses were performed for a variety of parameters to establish the magnitude of influence on the LCIs and impact assessments. The approach to selecting sensitivity analyses was to apply analyses where:

- assumptions have been made which, in our opinion, might significantly influence the results of the inventories and impact assessments (e.g. taking into account of the avoided impacts for recycled polystyrene and polypropylene); and
- where data have been applied concerning a particular energy mix (e.g. specific local electricity mix for transformation process).

7.2 List of sensitivity analyses carried out

Table below presents the sensitivity analyses performed within this LCA study.

Number	Description of sensitivity analyses	Section
1	Use of European average parameters (Electricity grid, Waste management)	7.3
2	Use of the avoided impact approach to represent recycling of plastics	7.4
3	Improvement of EPS transformation site	7.5
4	Use of the avoided impact approach to represent recycling of plastics with and allocation limited to 50% of the benefits (as asked by critical review panel)	7.5

Table 21: List of sensitivity analyses carried out

7.3 Sensitivity analysis #1: Use of European average parameters

This sensitivity analysis was performed to test the sensitivity of the results to the choice of the country where packaging is produced. In the reference scenario, three markets were considered: France, Spain, Scandinavia.

In this sensitivity analysis, results are calculated for 1000 packaging units with parameters representing an average European situation:

- the European electricity production LCA model (27 countries, 2008)
- Distance for main transport is 300 km
- Average European parameters for packaging end of life are described in §5.9.

Chosen case for this sensitivity analysis is the Spanish Box (15l capacity).

Applied method for end of life is the stock method (i.e. no avoided impact from recycling), as in the reference case.

7.3.1 Detailed results

7.3.1.1 Non renewable energy

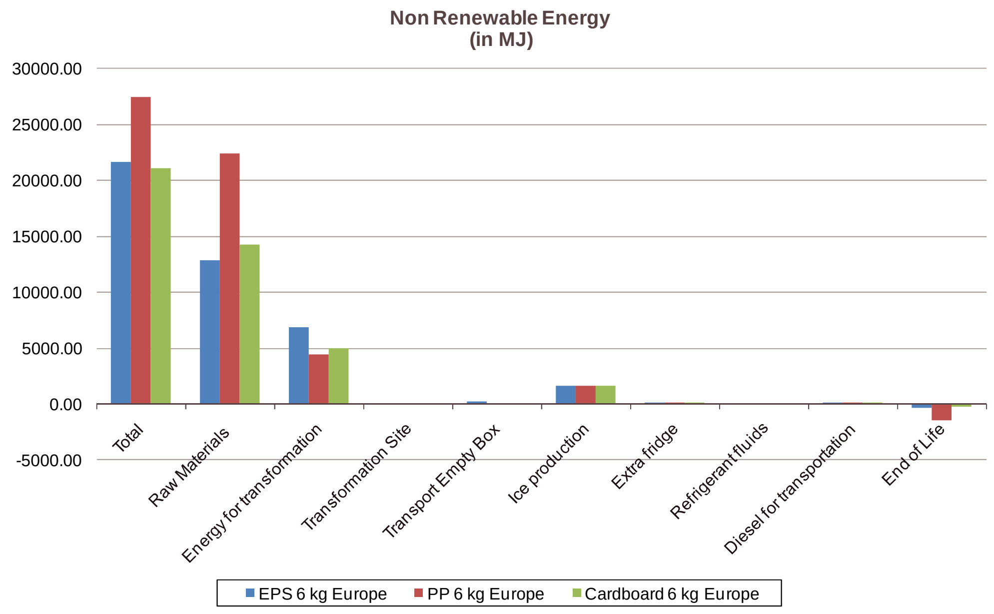


Figure 15: Consumption of Non Renewable Energy (in MJ) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**21679**	**27422**	**21098**
Raw Materials	12869.66	22387.38	14248.41
Transformation	6891.48	4436.67	5051.12
Transport Empty	265.32	83.43	49.11
Ice production	1628.13	1628.13	1628.13
Extra fridge	168.22	168.22	168.22
Refrigerant fluids	0.00	0.00	0.00
Diesel	140.29	148.08	179.14
End of Life	-283.76	-1429.63	-226.19

7.3.1.2 Depletion of Non renewable resources

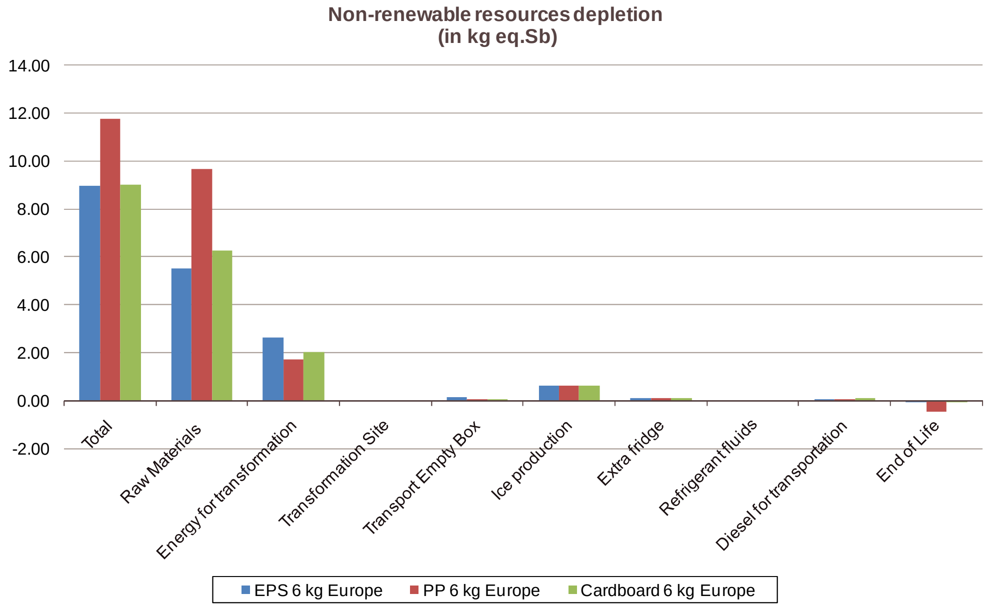


Figure 16: Depletion of Non renewable resources (in kg eq. Sb) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**8.99**	**11.78**	**9.00**
Raw Materials	5.52	9.68	6.24
Transformation	2.64	1.72	2.02
Transport Empty Box	0.13	0.04	0.02
Ice production	0.64	0.64	0.64
Extra fridge	0.08	0.08	0.08
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.07	0.07	0.09
End of Life	-0.08	-0.46	-0.08

7.3.1.3 Emission of greenhouse gases

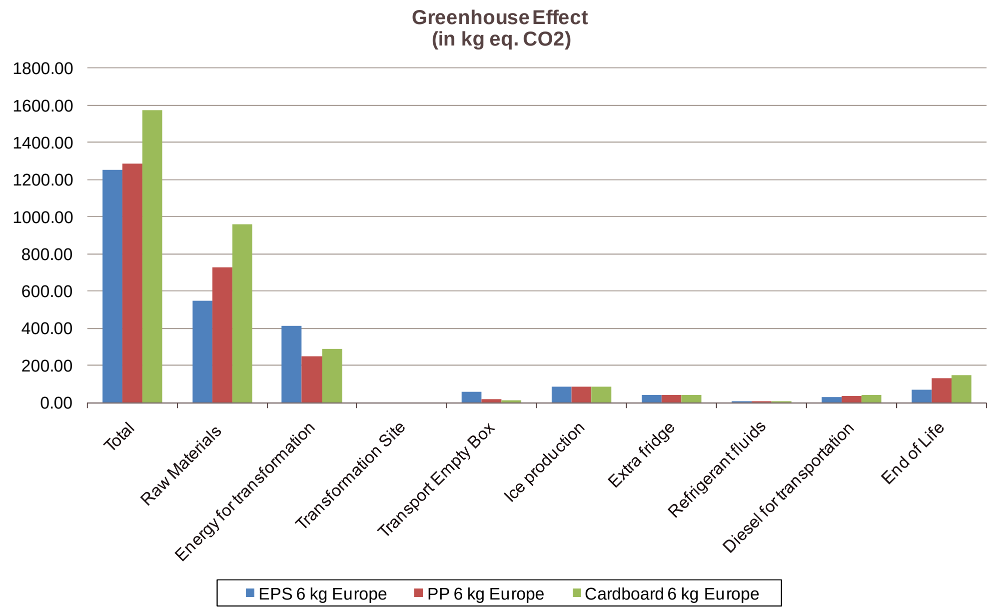


Figure 17: Greenhouse gases (in kg eq. $CO_{2,}$ 100 years) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**1245**	**1287**	**1576**
Raw Materials	550.02	730.03	959.19
Transformation	414.47	249.58	289.43
Transport Empty Box	59.47	18.70	11.01
Ice production	88.26	88.26	88.26
Extra fridge	37.70	37.70	37.70
Refrigerant fluids	0.94	0.94	0.94
Diesel	31.44	33.19	40.15
End of Life	67.49	128.18	149.55

7.3.1.4 Acidification

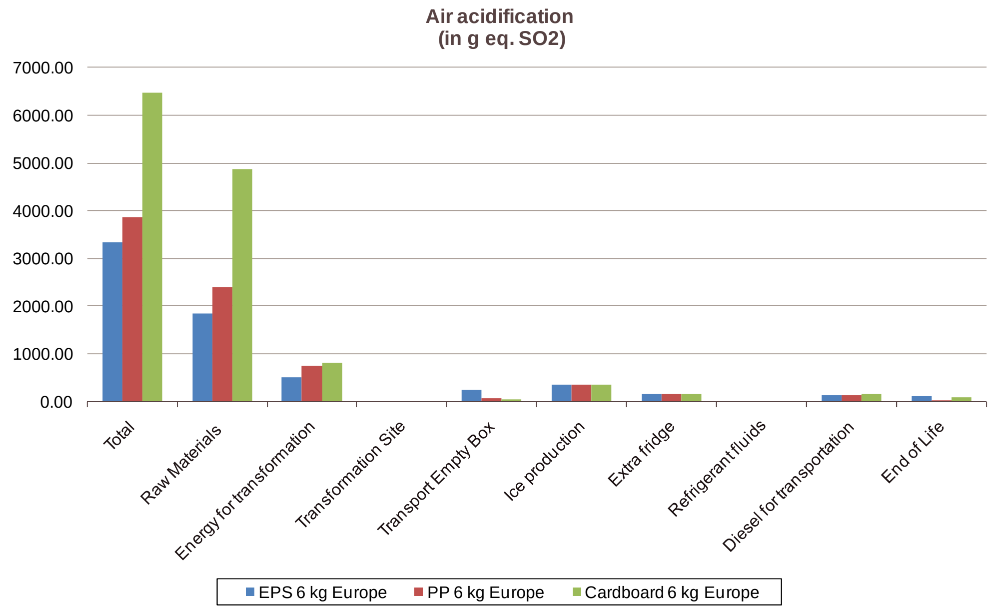


Figure 18: Acidification (in g eq. SO_2) – average European scenario

European situation (15l)

	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**3331**	**3855**	**6476**
Raw Materials	1841.35	2402.27	4867.19
Transformation	514.59	739.86	815.89
Transport Empty Box	237.79	74.77	44.01
Ice production	350.49	350.49	350.49
Extra fridge	150.76	150.76	150.76
Refrigerant fluids	0.00	0.00	0.00
Diesel	125.73	132.71	160.55
End of Life	110.06	3.45	86.80

7.3.1.5 Formation of photochemical oxidants

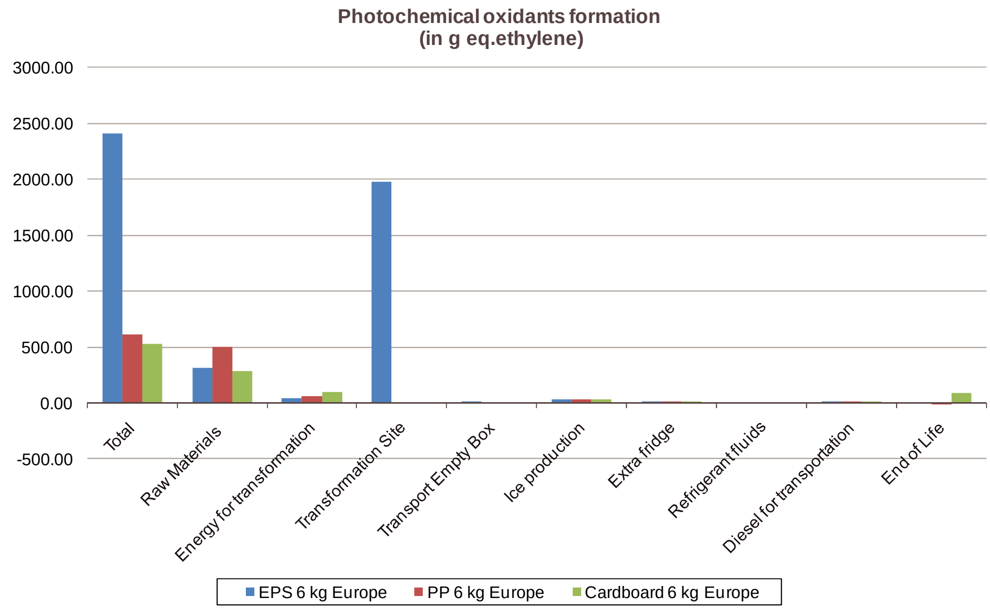


Figure 19: Photochemical oxidants formation (in g eq. ethylene) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**2411.45**	**614.54**	**527.36**
Raw Materials	317.44	499.49	281.54
Energy for transform	44.14	64.18	97.28
Transformation Site	1977.80	0.00	0.00
Transport Empty Box	18.40	5.78	3.40
Ice production	30.46	30.46	30.46
Extra fridge	11.66	11.66	11.66
Refrigerant fluids	0.00	0.00	0.00
Diesel	9.73	10.27	12.42
End of Life	1.82	-7.30	90.59

7.3.1.6 Water consumption

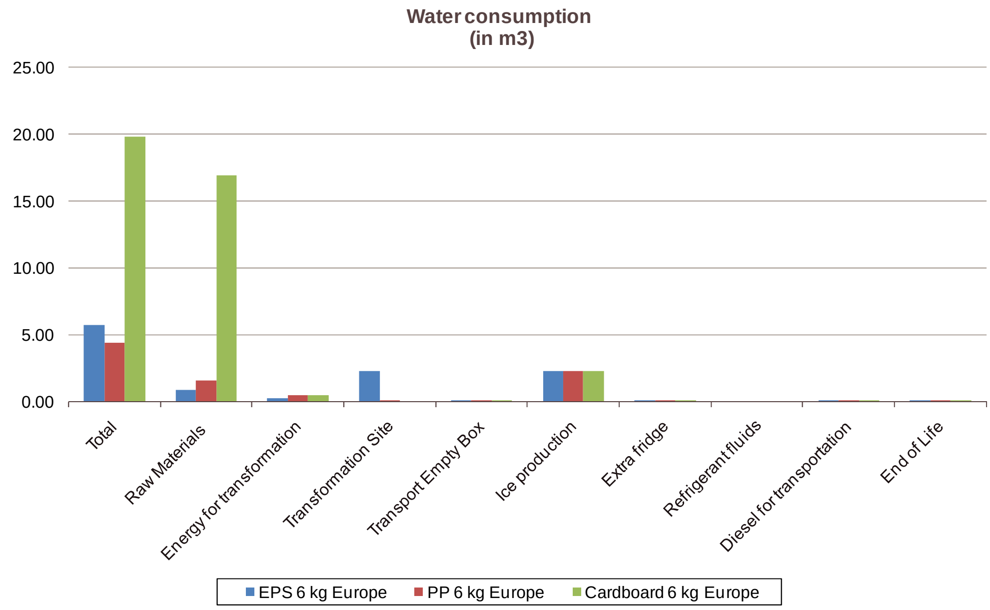


Figure 20: Water consumption (in m^3) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**5.73**	**4.37**	**19.78**
Raw Materials	0.90	1.54	16.91
Energy for transform	0.23	0.49	0.52
Transformation Site	2.29	0.02	0.00
Transport Empty Box	0.03	0.01	0.00
Ice production	2.25	2.25	2.25
Extra fridge	0.02	0.02	0.02
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.01	0.01	0.02
End of Life	0.02	0.04	0.07

7.3.1.7 Water eutrophication

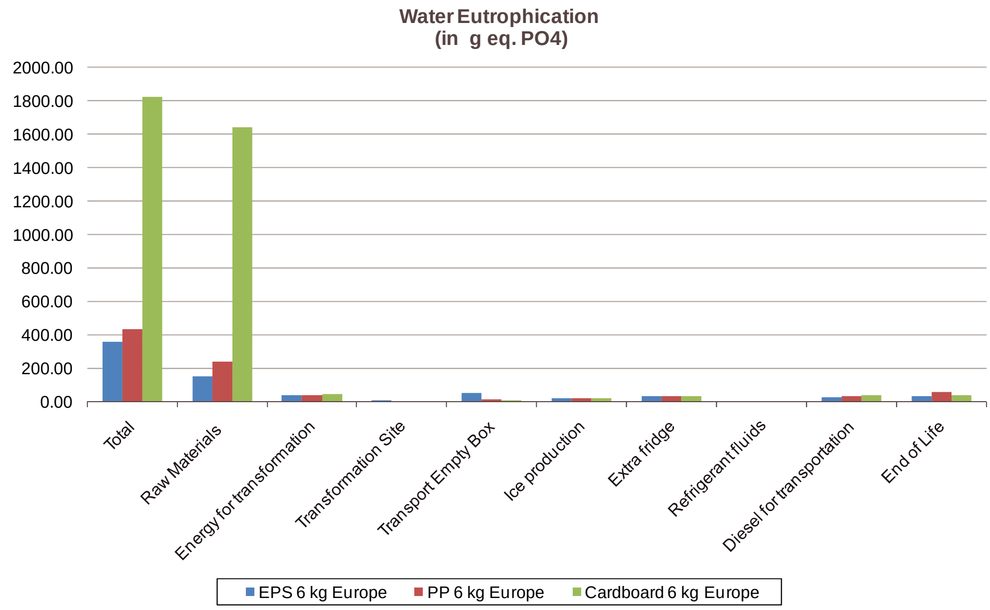


Figure 21: Water eutrophication (in g eq. PO_4^{3-}) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**357.09**	**430.90**	**1821.28**
Raw Materials	149.26	239.53	1640.97
Energy for transform	36.90	38.76	42.22
Transformation Site	7.05	0.00	0.00
Transport Empty Box	53.18	16.72	9.84
Ice production	17.12	17.12	17.12
Extra fridge	33.71	33.71	33.71
Refrigerant fluids	0.00	0.00	0.00
Diesel	28.12	29.68	35.90
End of Life	31.75	55.37	41.50

7.3.1.8 Solid waste production

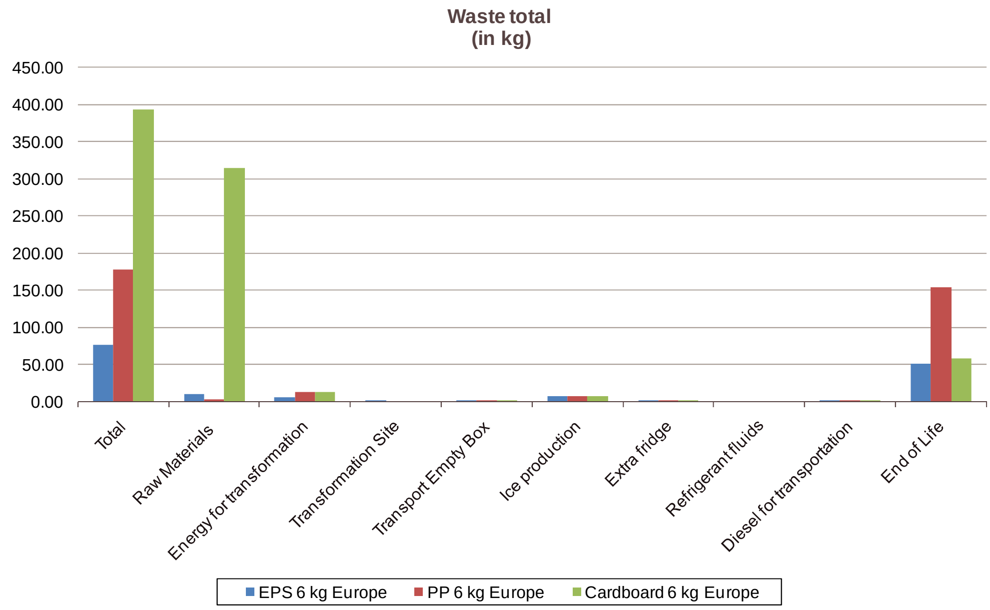


Figure 22: Waste total (in kg) – average European scenario

European situation (15l)

Stage	EPS 6 kg Europe	PP 6 kg Europe	Cardboard 6 kg Europe
Total	**76.02**	**177.67**	**392.88**
Raw Materials	9.96	3.73	314.10
Energy for transform	6.27	13.55	13.30
Transformation Site	2.09	0.00	0.00
Transport Empty Box	0.03	0.01	0.01
Ice production	6.81	6.81	6.81
Extra fridge	0.02	0.02	0.02
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.02	0.02	0.02
End of Life	50.81	153.52	58.62

7.3.2 Summary of results (sensitivity analysis #1)

Similarly to the reference scenario, the following table compares the relative performance of the three packaging scenarios in an average European situation. The results of the EPS packaging are taken as the reference.

Indicator		EPS	PP	Cardboard
		6 kg	6 kg	6 kg
		Europe	Europe	Europe
Non renewable primary energy	MJ	1	1.3	1
Depletion of Non Renewable Resources	kg eq. Sb	1	1.3	1.0
Emission of Greenhouse gases	kg CO2 eq., 100 years	1	1	1.3
Air acidification	g SO2 eq.	1	1.2	1.9
Photochemical Oxidants formation	g eq. ethylene	1	0.3	0.2
Water consumption	m3	1	0.8	3.5
Water Eutrophication	in g eq. PO43-	1	1.2	5.1
Total waste production	kg	1	2.3	5.2

Table 22: Comparative results of the three packaging solutions in an average European situation

Results are very close to those of the Spanish market in the reference situation.

7.4 Sensitivity analysis #2: Use of the avoided impacts approach to represent plastics recycling

This sensitivity analysis was performed to test the sensitivity of the results to the allocation rule used in the reference scenarios for packaging end of life (stock method, see §4.3.4).

The reference scenario applies the stocks method for the recovered products. In the present sensitivity analysis, we performed a sensitivity analysis on the French market, applying the avoided impacts for the part of the plastic products which is recycled.

The extension of the system boundaries introduced in this sensitivity analysis is described in §4.3.4 for both materials:

- In the case of EPS, shredded EPS is replaced by the general purposes polystyrene cradle to gate production (Polystyrene general purpose, PlasticsEurope, 2005). Waste EPS that was in food contact is never reused to make new expansible PS but recycled in other products like CD boxes or coat-hangers.
- Waste polypropylene is recycled and avoids virgin PP (LCI model: Polypropylene Production, Plastics Europe 2005).

It has to be noted that in the case of cardboard recycling the avoided impact method has not been applied in the simulation, since the benefits of using recycled cardboard is already taken into account in the FEFCO cradle to gate balance.

Results are calculated for 1000 packaging units.

7.4.1 Detailed results

7.4.1.1 Non renewable energy

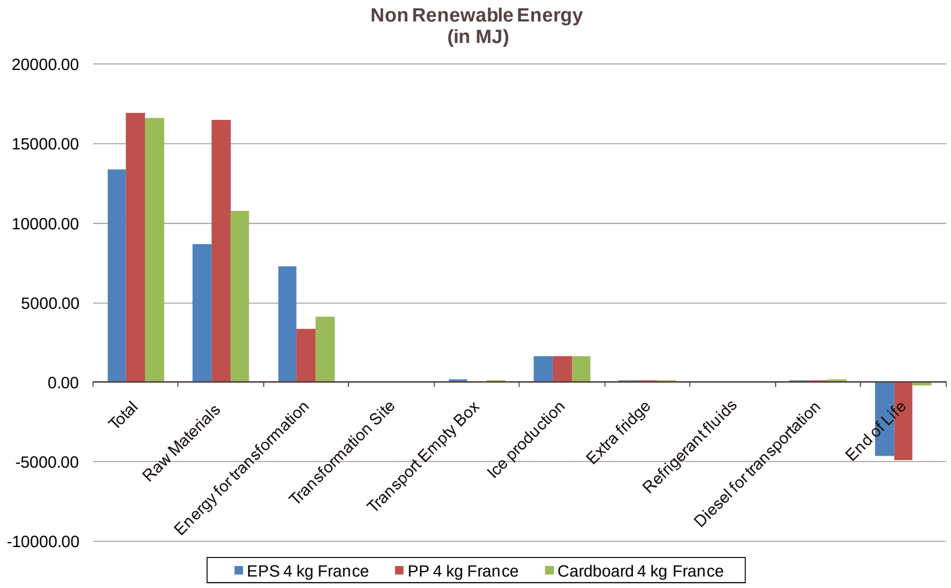


Figure 23: Consumption of Non Renewable Energy (in MJ) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**13 393**	**16 947**	**16 647**
Raw Materials	8678.27	16493.19	10754.49
Transformation	7266.77	3372.32	4090.68
Transport Empty	203.28	77.04	89.22
Ice production	1669.62	1669.62	1669.62
Extra fridge	116.46	116.46	116.46
Refrigerant fluids	0.00	0.00	0.00
Diesel	126.80	132.01	152.33
End of Life	-4668.07	-4912.89	-225.21

7.4.1.2 Depletion of Non renewable resources

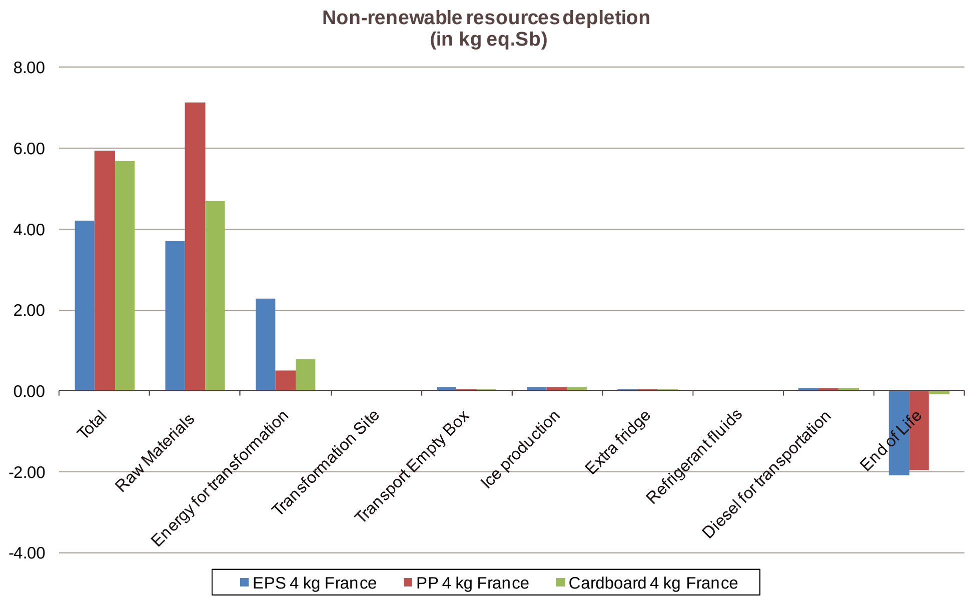


Figure 24: Depletion of Non renewable resources (in kg eq. Sb) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**4.22**	**5.94**	**5.68**
Raw Materials	3.71	7.13	4.69
Transformation	2.27	0.50	0.79
Transport Empty Box	0.10	0.04	0.04
Ice production	0.11	0.11	0.11
Extra fridge	0.06	0.06	0.06
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.06	0.06	0.07
End of Life	-2.08	-1.95	-0.08

7.4.1.3 Emission of greenhouse gases

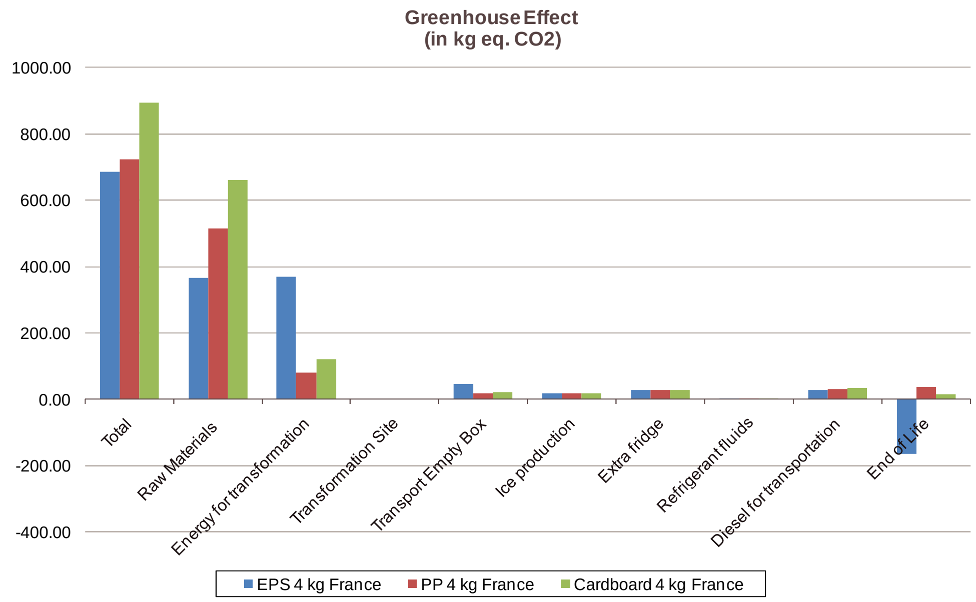


Figure 25: Greenhouse gases (in kg eq. CO_2, 100 years) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**684**	**723**	**894**
Raw Materials	364.34	515.46	659.50
Transformation	367.62	81.27	121.60
Transport Empty Box	45.56	17.27	20.00
Ice production	17.05	17.05	17.05
Extra fridge	26.10	26.10	26.10
Refrigerant fluids	0.65	0.65	0.65
Diesel	28.42	29.59	34.14
End of Life	-165.14	35.63	15.27

7.4.1.4 Acidification

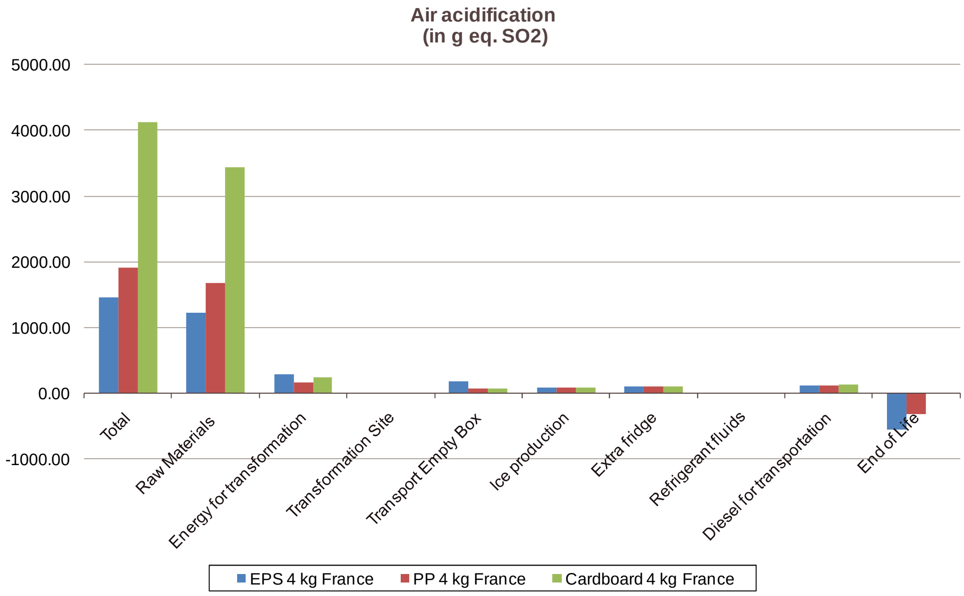


Figure 26: Acidification (in g eq. SO_2) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**1463**	**1916**	**4124**
Raw Materials	1222.65	1677.69	3445.59
Transformation	295.33	168.15	247.27
Transport Empty Box	182.19	69.04	79.96
Ice production	91.32	91.32	91.32
Extra fridge	104.38	104.38	104.38
Refrigerant fluids	0.00	0.00	0.00
Diesel	113.64	118.31	136.52
End of Life	-546.70	-312.44	18.74

7.4.1.5 Formation of photochemical oxidants

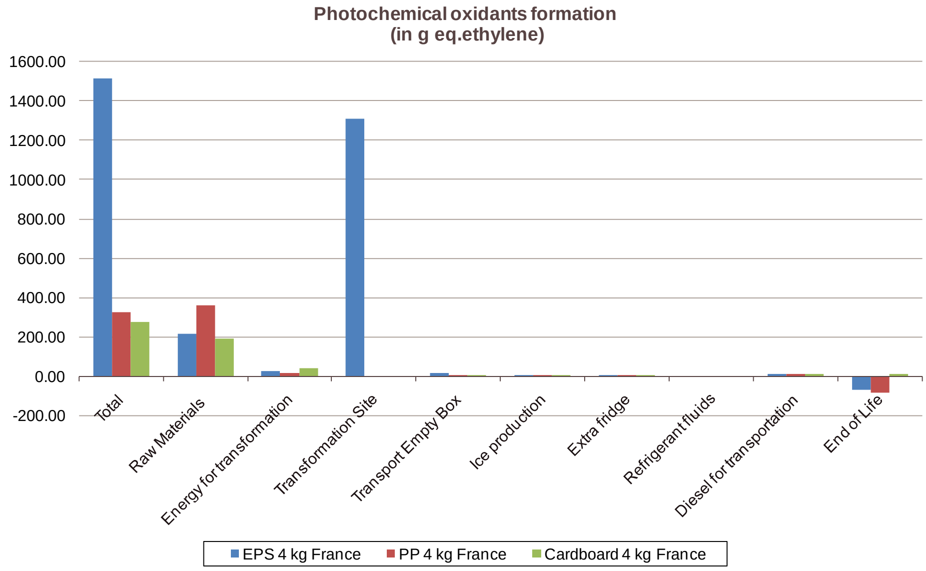


Figure 27: Photochemical oxidants formation (in g eq. ethylene) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**1515**	**323**	**276**
Raw Materials	214.34	362.49	192.11
Energy for transform	24.43	13.53	41.12
Transformation Site	1309.44	0.00	0.00
Transport Empty Box	14.09	5.34	6.19
Ice production	7.27	7.27	7.27
Extra fridge	8.07	8.07	8.07
Refrigerant fluids	0.00	0.00	0.00
Diesel	8.79	9.15	10.56
End of Life	-71.18	-82.44	10.57

7.4.1.6 Water consumption

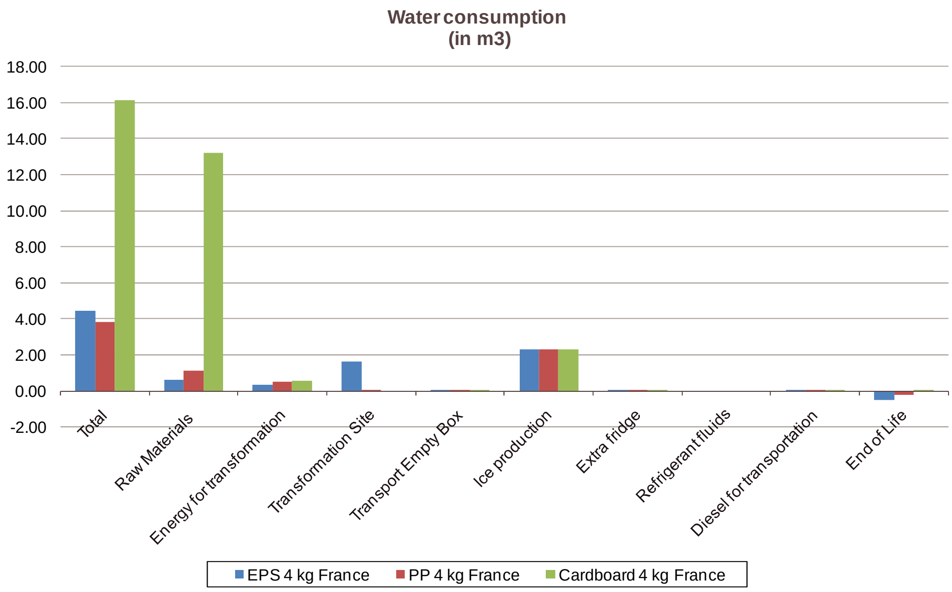


Figure 28: Water consumption (in m^3) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**4.44**	**3.80**	**16.16**
Raw Materials	0.60	1.13	13.21
Energy for transform	0.32	0.49	0.54
Transformation Site	1.66	0.01	0.00
Transport Empty Box	0.02	0.01	0.01
Ice production	2.33	2.33	2.33
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.01	0.01	0.01
End of Life	-0.52	-0.20	0.04

7.4.1.7 Water eutrophication

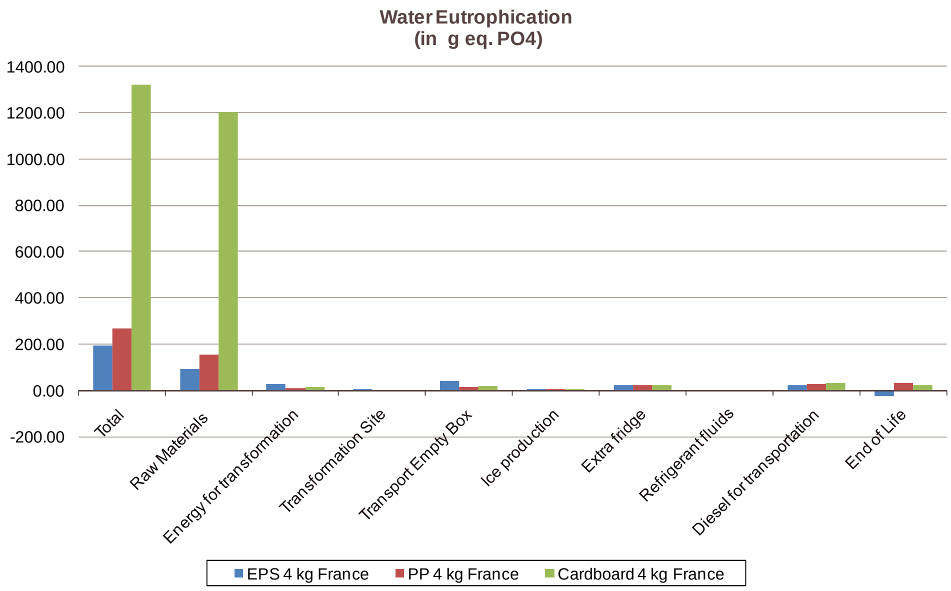


Figure 29: Water eutrophication (in g eq. PO_4^{3-}) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**192**	**268**	**1320**
Raw Materials	92.00	154.32	1203.52
Energy for transform	27.42	11.22	15.12
Transformation Site	3.10	0.00	0.00
Transport Empty Box	40.74	15.44	17.88
Ice production	5.17	5.17	5.17
Extra fridge	23.34	23.34	23.34
Refrigerant fluids	0.00	0.00	0.00
Diesel	25.41	26.46	30.53
End of Life	-25.33	32.30	24.62

7.4.1.8 Solid waste production

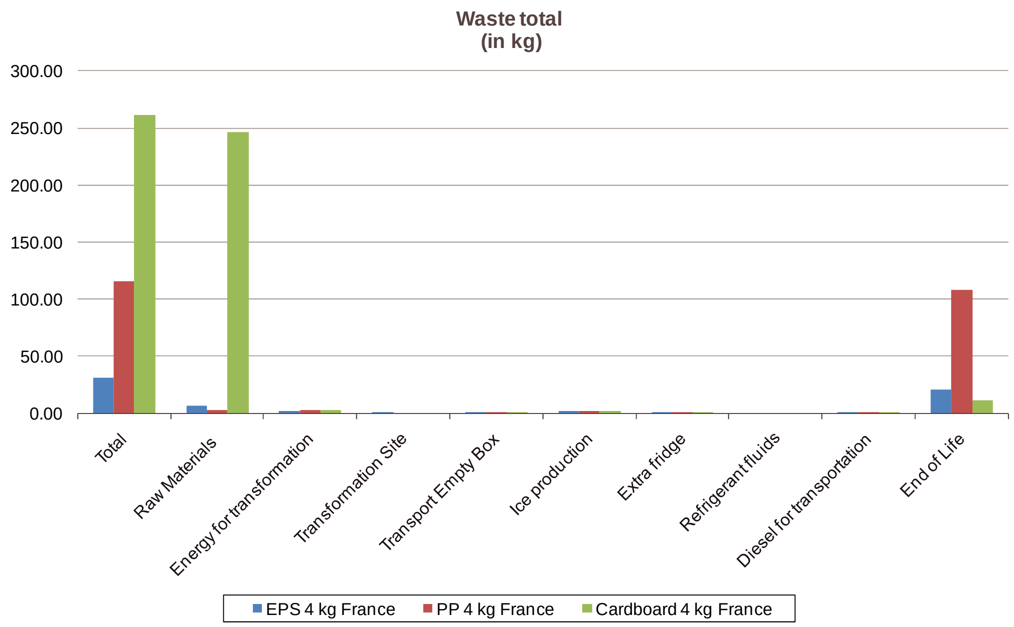


Figure 30: Waste total (in kg) – avoided impacts

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**31**	**115**	**262**
Raw Materials	6.74	2.75	246
Energy for transform	1.77	2.56	2.68
Transformation Site	0.45	0.00	0.00
Transport Empty Box	0.03	0.01	0.01
Ice production	1.72	1.72	1.72
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.02	0.02	0.02
End of Life	20.61	108.22	11.01

7.4.2 Summary of results (sensitivity analysis #2)

Similarly to the reference scenario, the following table compares the relative performance of the three packaging scenarios when avoided impacts are considered for EPS and PP packaging. The results of the EPS packaging are taken as the reference.

Indicator		EPS	PP	Cardboard
		4 kg	4 kg	4 kg
		France	France	France
Non renewable primary energy	MJ	1	1.3	1.2
Depletion of Non Renewable Resources	kg eq. Sb	1	1.4	1.3
Emission of Greenhouse gases	kg CO2 eq., 100 years	1	1.1	1.3
Air acidification	g SO2 eq.	1	1.3	2.8
Photochemical Oxidants formation	g eq. ethylene	1	0.2	0.2
Water consumption	m3	1	0.9	3.6
Water Eutrophication	in g eq. PO43-	1	1.4	6.9
Total waste production	kg	1	3.7	8.5

Table 23: Comparative results of the three packaging solutions on the French market with avoided impacts considered for recycling

When credits are considered for recycling, the relative results of EPS packaging are improved. The EPS packaging performs better than PP and cardboard, except for the formation of photochemical oxidants.

Similar improvement trends for EPS packaging would be observed on the two other markets.

7.5 Sensitivity analysis #3: Improvement of the EPS transformation site

This sensitivity analysis was performed to quantify the possible improvement of the environmental impact for EPS packaging due to a performance improvement of the EPS transformation site. Data for optimized production site come from Synbra production site in the Netherlands –year of production 2009 and are an average of all EPS products manufactured on site (not exclusively fishbox packaging).
Chosen case for this sensitivity analysis is an average between the Spanish Box and the French Box. (12,5 litres capacity).
Results are calculated for 1000 packaging units with the European electricity model (27 countries - 2008). Distance for main transport is 300 km.

7.5.1 Detailed results

7.5.1.1 Non renewable energy

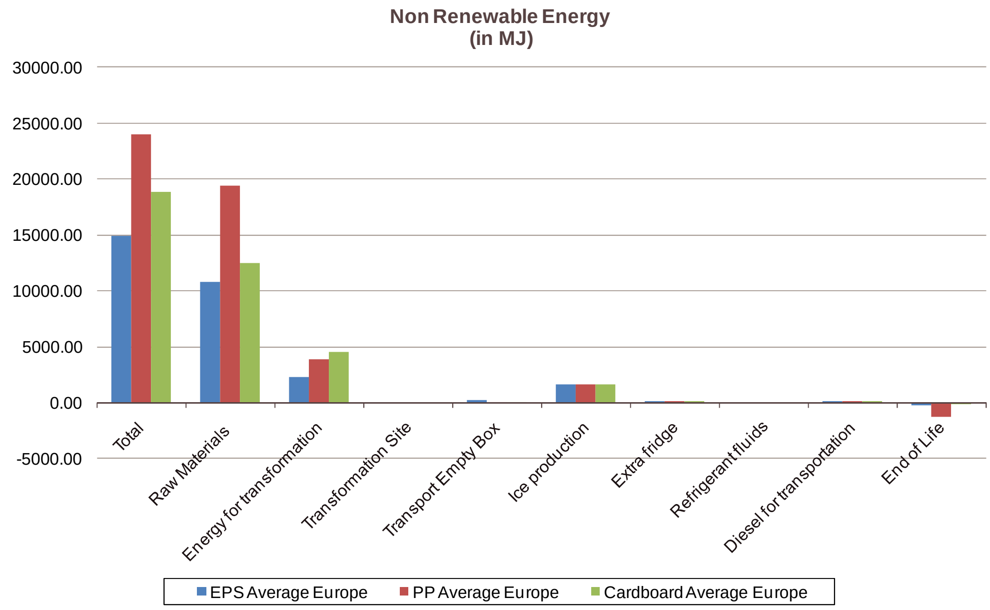


Figure 31: Consumption of Non Renewable Energy (in MJ) – EPS transformation improved

European average (12,5l)

Stage	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**14 921**	**24 035**	**18 858**
Raw Materials	10794.69	19430.18	12473.02
Transformation	2248.30	3875.57	4543.80
Transport Empty	218.51	80.23	70.29
Ice production	1628.13	1628.13	1628.13
Extra fridge	137.64	137.64	137.64
Refrigerant fluids	0.00	0.00	0.00
Diesel	129.80	136.09	160.95
End of Life	-235.81	-1252.66	-155.81

7.5.1.1 Depletion of Non renewable resources

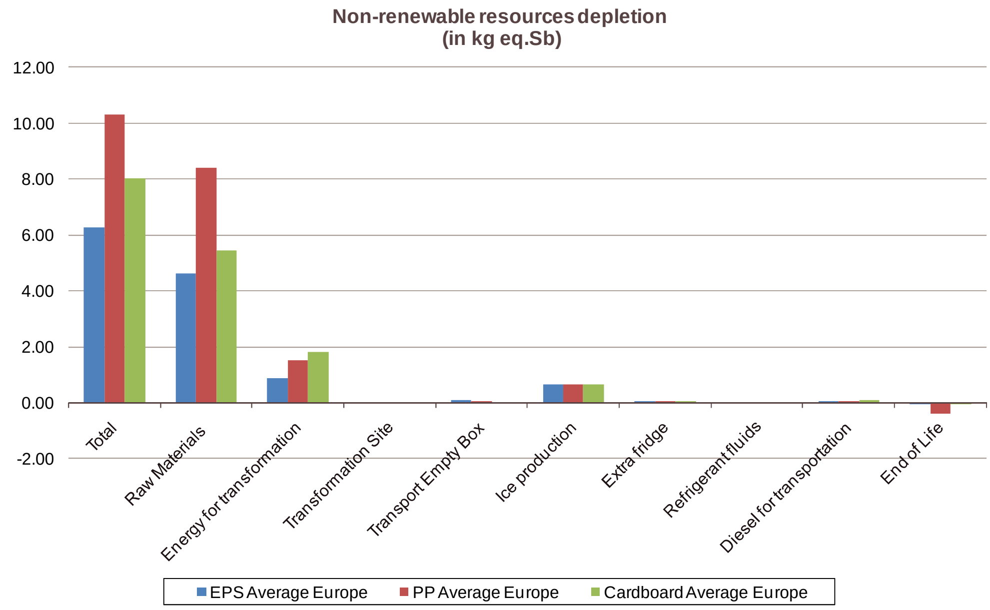


Figure 32: Depletion of Non renewable resources (in kg eq. Sb) – EPS transformation improved

European average (12,5l)

Stage	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**6.29**	**10.31**	**8.03**
Raw Materials	4.62	8.40	5.45
Transformation	0.86	1.51	1.81
Transport Empty	0.11	0.04	0.03
Ice production	0.64	0.64	0.64
Extra fridge	0.07	0.07	0.07
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.06	0.07	0.08
End of Life	-0.07	-0.40	-0.05

7.5.1.1 Emission of greenhouse gases

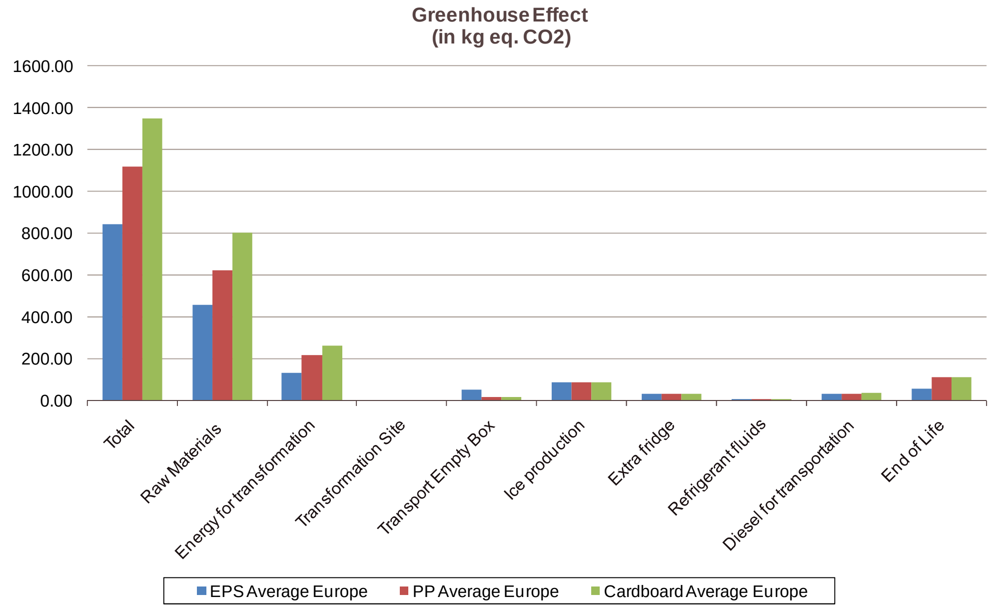


Figure 33: Greenhouse gases (in kg eq. CO_2, 100 years) – EPS transformation improved

European average (12,5l)

	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**845**	**1 120**	**1 347**
Raw Materials	457.28	620.47	802.98
Transformation	133.26	218.06	260.46
Transport Empty	48.97	17.98	15.75
Ice production	88.26	88.26	88.26
Extra fridge	30.85	30.85	30.85
Refrigerant fluids	0.77	0.77	0.77
Diesel	29.09	30.50	36.07
End of Life	56.09	113.34	111.61

7.5.1.1 Acidification

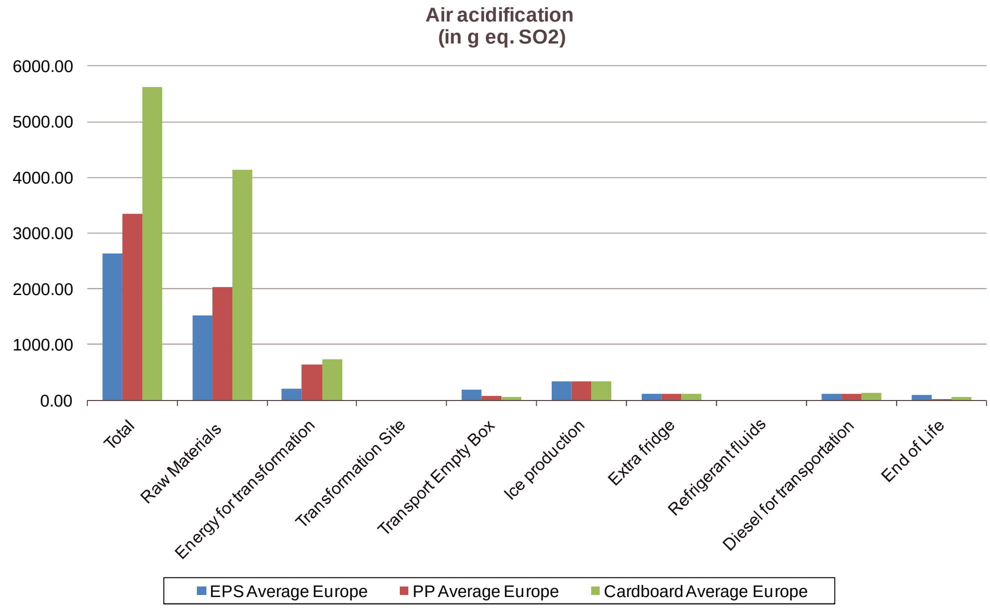


Figure 34: Acidification (in g eq. SO_2) – EPS transformation improved

European average (12,5l)

	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**2 625**	**3 350**	**5 612**
Raw Materials	1532.77	2030.89	4130.95
Transformation	214.28	645.35	730.92
Transport Empty	195.83	71.91	62.99
Ice production	350.49	350.49	350.49
Extra fridge	123.35	123.35	123.35
Refrigerant fluids	0.00	0.00	0.00
Diesel	116.33	121.97	144.25
End of Life	91.46	6.51	68.63

7.5.1.1 Formation of photochemical oxidants

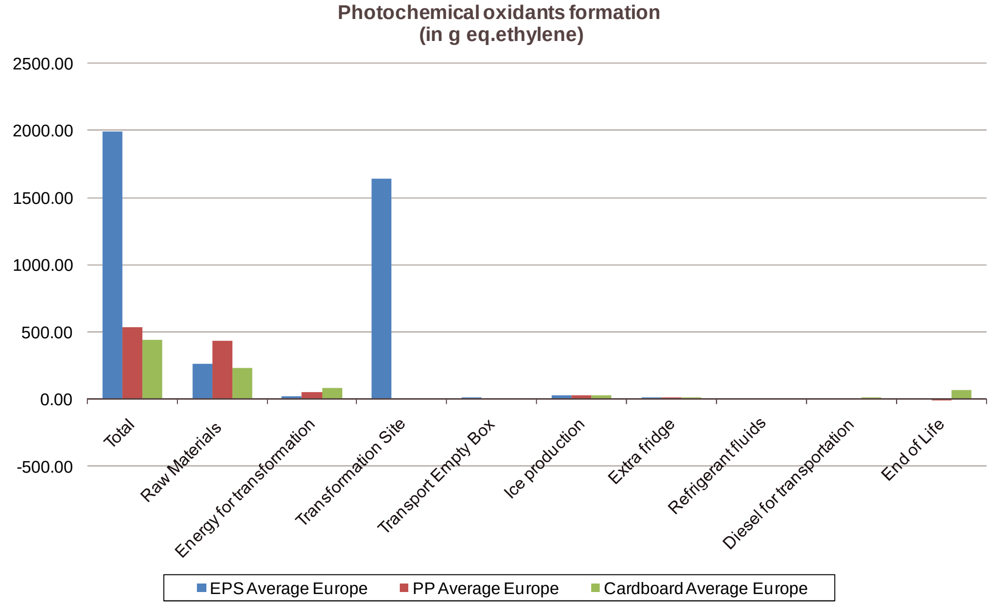


Figure 35: Photochemical oxidants formation (in g eq. ethylene) – EPS transformation improved

European average (12,5l)

	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**1994.20**	**535.60**	**445.15**
Raw Materials	266.45	430.29	234.86
Energy for transfor	18.46	55.98	87.04
Transformation Site	1643.62	0.00	0.00
Transport Empty	15.15	5.56	4.87
Ice production	30.46	30.46	30.46
Extra fridge	9.54	9.54	9.54
Refrigerant fluids	0.00	0.00	0.00
Diesel	9.00	9.44	11.16
End of Life	1.51	-5.67	67.21

7.5.1.1 Water consumption

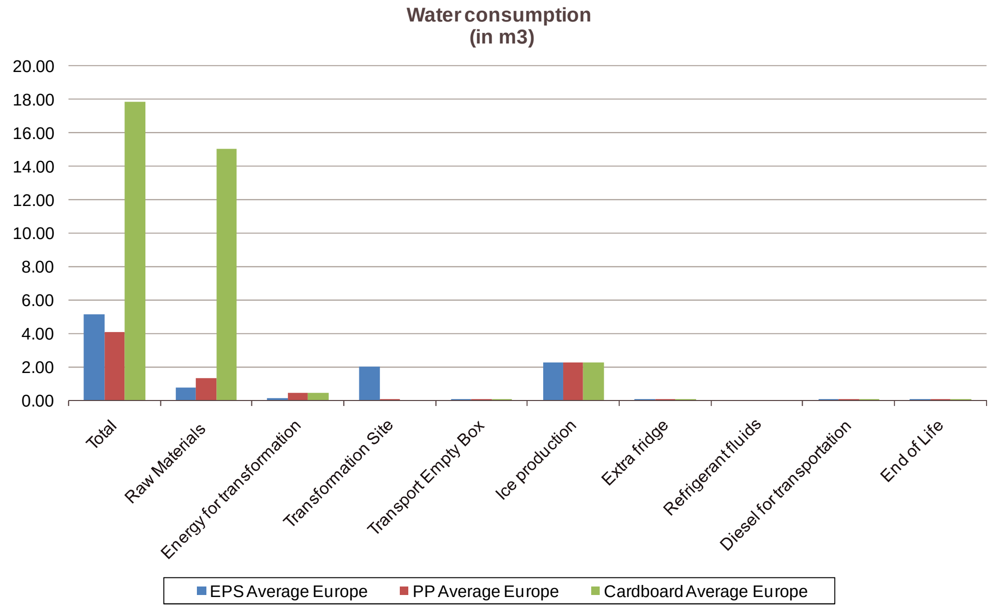


Figure 36: Water consumption (in m^3) – EPS transformation improved

European average (12,5l)

	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**5.16**	**4.10**	**17.85**
Raw Materials	0.75	1.34	15.06
Energy for transfor	0.11	0.43	0.46
Transformation Site	1.99	0.01	0.00
Transport Empty	0.02	0.01	0.01
Ice production	2.25	2.25	2.25
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.01	0.01	0.02
End of Life	0.01	0.04	0.05

7.5.1.1 Water eutrophication

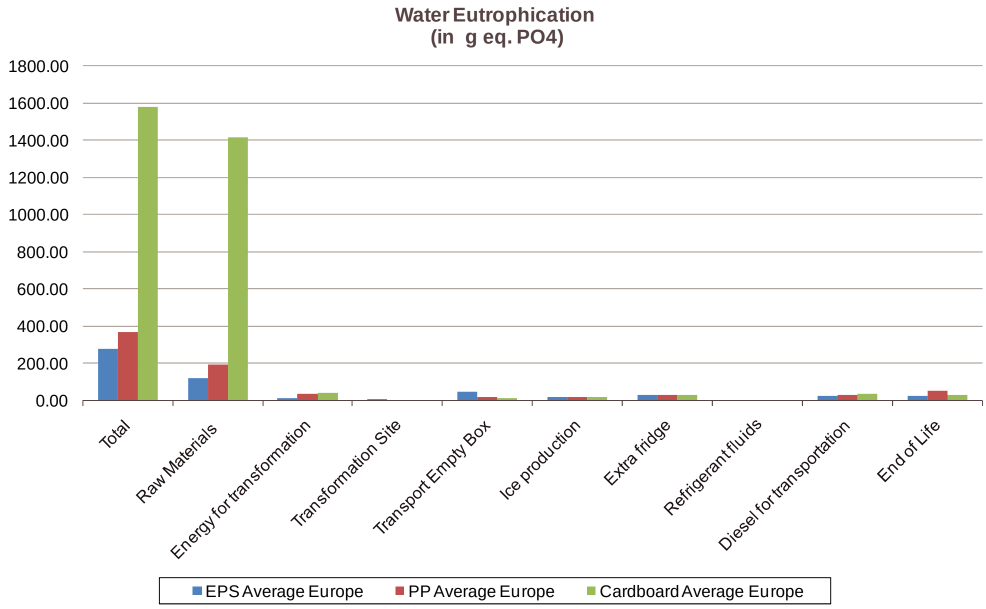


Figure 37: Water eutrophication (in g eq. PO_4^{3-}) – EPS transformation improved

European average (12,5l)

	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**279.75**	**366.36**	**1576.62**
Raw Materials	119.82	194.89	1416.56
Energy for transfor	13.74	33.82	37.88
Transformation Site	5.29	0.00	0.00
Transport Empty	43.79	16.08	14.09
Ice production	17.12	17.12	17.12
Extra fridge	27.58	27.58	27.58
Refrigerant fluids	0.00	0.00	0.00
Diesel	26.01	27.27	32.26
End of Life	26.39	49.58	31.13

7.5.1.1 Solid waste production

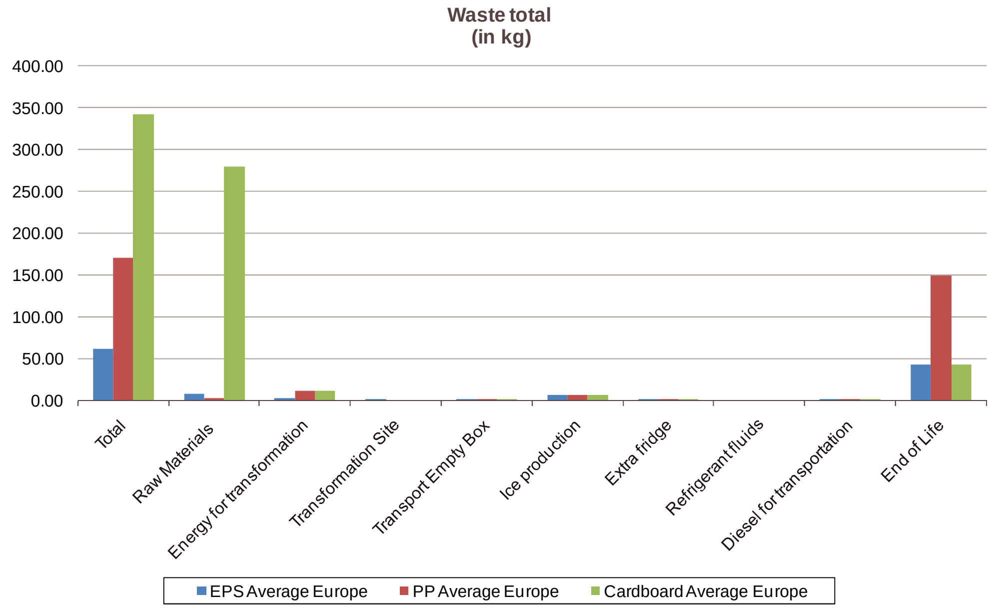


Figure 38: Waste total (in kg) – EPS transformation improved

European average (12,5l)

	EPS Average Europe	PP Average Europe	Cardboard Average Europe
Total	**61.75**	**170.66**	**341.99**
Raw Materials	8.37	3.24	280.09
Energy for transfor	3.13	11.82	11.90
Transformation Site	1.15	0.00	0.00
Transport Empty	0.03	0.01	0.01
Ice production	6.81	6.81	6.81
Extra fridge	0.02	0.02	0.02
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.02	0.02	0.02
End of Life	42.22	148.74	43.13

7.5.2 Summary of results (sensitivity analysis #3)

Similarly to the reference scenario, the following table compares the relative performance of the three packaging scenarios for the three markets studied. On each market, the results of the EPS packaging are taken as the reference.

Indicator		EPS	PP	Cardboard
		Average	Average	Average
		Europe	Europe	Europe
Non renewable primary energy	MJ	1	1.6	1.3
Depletion of Non Renewable Resources	kg eq. Sb	1	1.6	1.3
Emission of Greenhouse gases	kg CO2 eq., 100 years	1	1	1.6
Air acidification	g SO2 eq.	1	1.3	2.1
Photochemical Oxidants formation	g eq. ethylene	1	0.3	0.2
Water consumption	m3	1	0.8	3.5
Water Eutrophication	in g eq. PO43-	1	1.3	5.6
Total waste production	kg	1	2.8	5.5

Table 24: Comparative results of the three packaging solutions on the French market with improved performance for EPS transformation

In this sensitivity analysis, the EPS packaging solution integrates data from a transformation site with energy consumption reduced by 68% as compared to the reference scenarios. In that case, the EPS packaging solution performs better than PP, except for the formation of photochemical oxidants and water consumption, and better than cardboard except for the formation of photochemical oxidants

7.6 Sensitivity analysis #4: Use of the avoided impacts approach to represent plastics recycling with 50% of the benefits

Following a suggestion of the critical review panel, this sensitivity analysis was performed to test the sensitivity of the results to the allocation rule used in the reference scenarios for packaging end of life (stock method, see §4.3.4) and hence to complete the approach taken in sensitivity analysis #2.

We performed a sensitivity analysis on the French market, applying the avoided impact approach and allocating 50% of the calculated benefits to the part of the plastic products (EPS, PP) which is recycled.

This approach is currently proposed to calculate the impacts due to plastic recycling in France[23] and was also proposed for LCA of packaging in Germany in 2002 (note: in this study, alternative method was the stock method)[24].

Results are calculated for 1000 packaging units.

[23] ADEME/AFNOR BPX 30-323-0, best practices for environmental labelling, 2011.

[24] "Ökobilanz für Getränkeverpackungen II / Phase 2", Prognos AB and IFEU for German Environmt Agency (UBA), 2002, p.14. See http://www.umweltdaten.de/publikationen/fpdf-l/2180.pdf

7.6.1 Detailed results

7.6.1.1 Non renewable energy

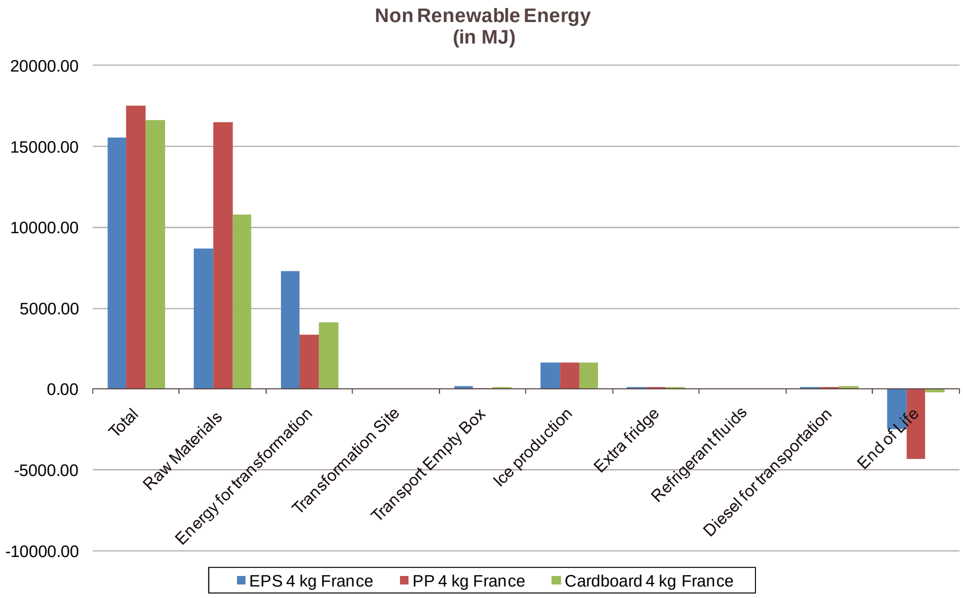


Figure 39: Consumption of Non Renewable Energy (in MJ) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**15 560**	**17 531**	**16 647**
Raw Materials	8678.27	16493.19	10754.49
Transformation	7266.77	3372.32	4090.68
Transport Empty	203.28	77.04	89.22
Ice production	1669.62	1669.62	1669.62
Extra fridge	116.46	116.46	116.46
Refrigerant fluids	0.00	0.00	0.00
Diesel	126.80	132.01	152.33
End of Life	-2501.60	-4329.98	-225.58

7.6.1.2 Depletion of Non renewable resources

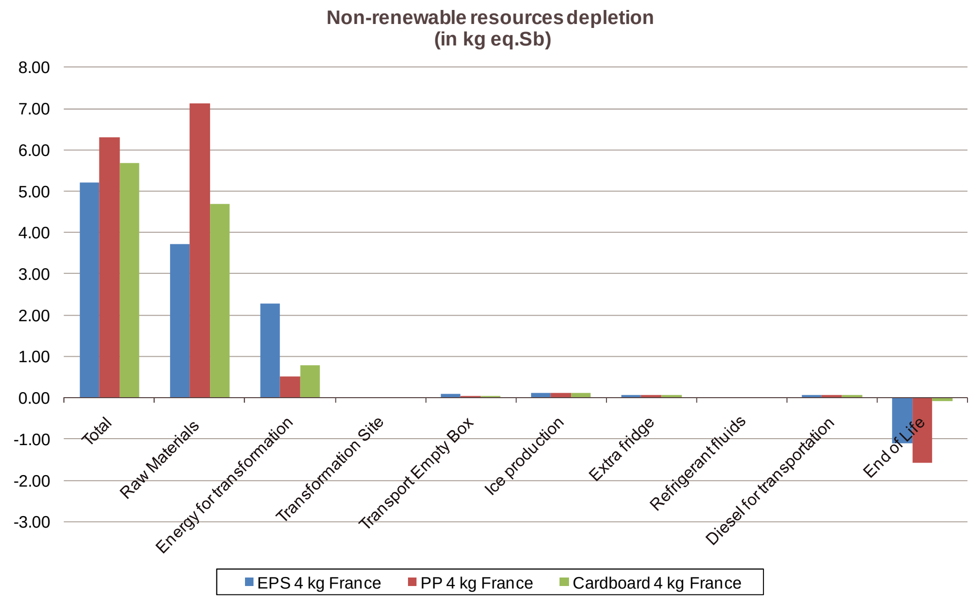


Figure 40: Depletion of Non renewable resources (in kg eq. Sb) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**5.21**	**6.31**	**5.68**
Raw Materials	3.71	7.13	4.69
Transformation	2.27	0.50	0.79
Transport Empty Box	0.10	0.04	0.04
Ice production	0.11	0.11	0.11
Extra fridge	0.06	0.06	0.06
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.06	0.06	0.07
End of Life	-1.09	-1.58	-0.08

7.6.1.3 Emission of greenhouse gases

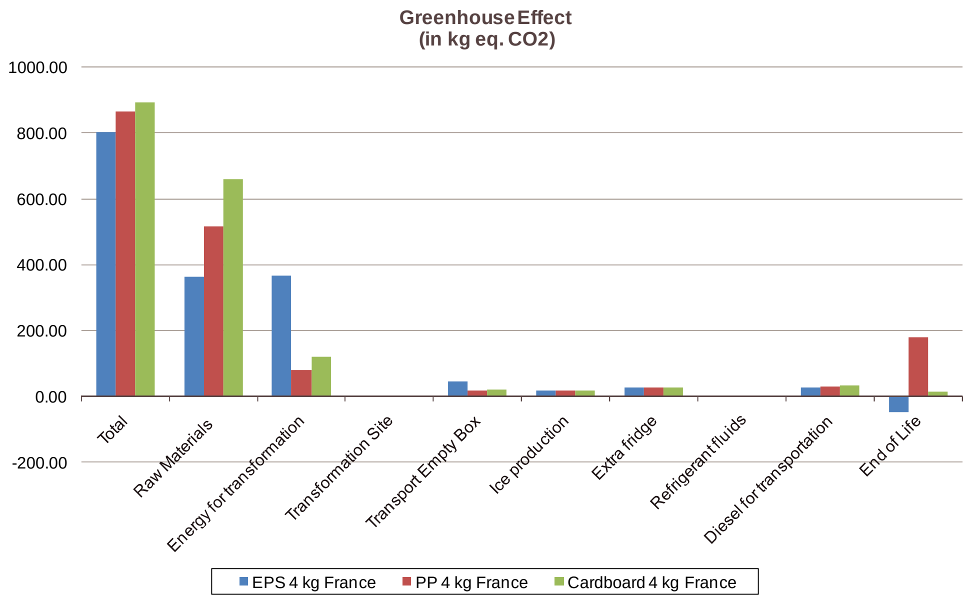


Figure 41: Greenhouse gases (in kg eq. CO_2, 100 years) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**803**	**866**	**894**
Raw Materials	364	515	659
Transformation	368	81	122
Transport Empty Box	45.56	17.27	20.00
Ice production	17.05	17.05	17.05
Extra fridge	26.10	26.10	26.10
Refrigerant fluids	0.65	0.65	0.65
Diesel	28.42	29.59	34.14
End of Life	-46.25	178.45	14.54

7.6.1.4 Acidification

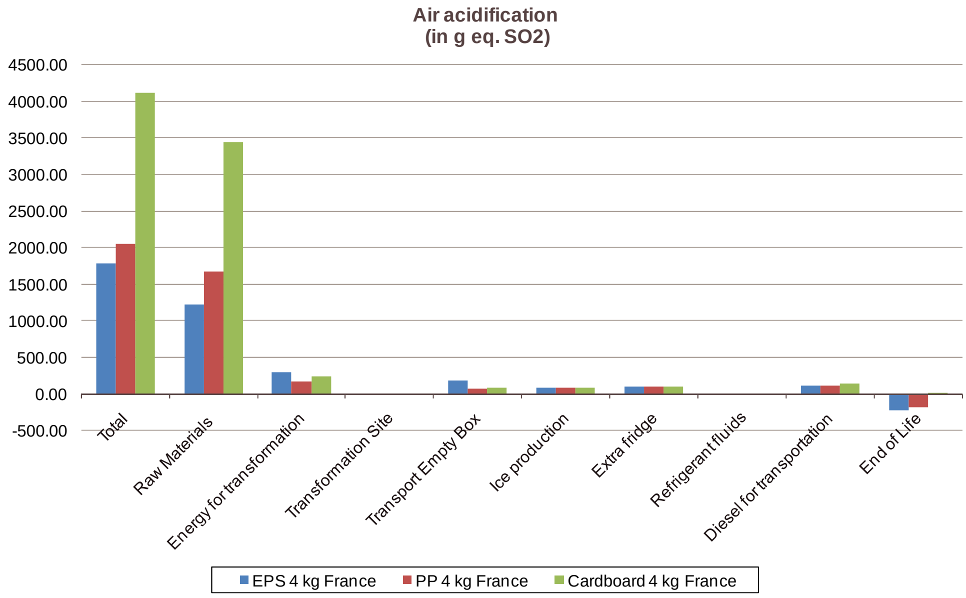


Figure 42: Acidification (in g eq. SO_2) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**1787**	**2054**	**4123**
Raw Materials	1222.65	1677.69	3445.59
Transformation	295.33	168.15	247.27
Transport Empty Box	182.19	69.04	79.96
Ice production	91.32	91.32	91.32
Extra fridge	104.38	104.38	104.38
Refrigerant fluids	0.00	0.00	0.00
Diesel	113.64	118.31	136.52
End of Life	-222.86	-175.20	18.39

7.6.1.5 Formation of photochemical oxidants

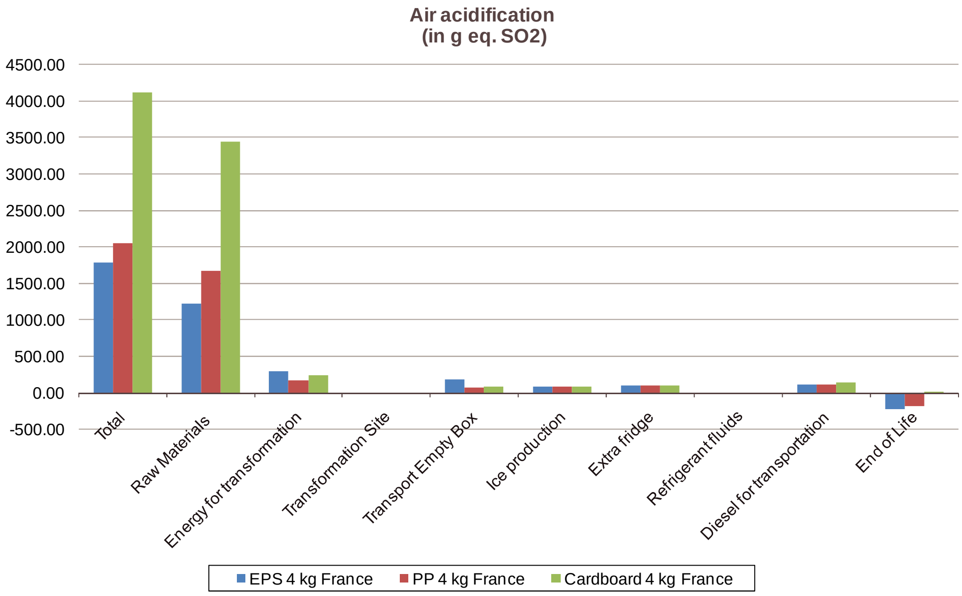


Figure 43: Photochemical oxidants formation (in g eq. ethylene) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**1551.38**	**351.28**	**275.46**
Raw Materials	214.34	362.49	192.11
Energy for transfor	24.43	13.53	41.12
Transformation Site	1309.44	0.00	0.00
Transport Empty Box	14.09	5.34	6.19
Ice production	7.27	7.27	7.27
Extra fridge	8.07	8.07	8.07
Refrigerant fluids	0.00	0.00	0.00
Diesel	8.79	9.15	10.56
End of Life	-35.06	-54.58	10.13

7.6.1.6 Water consumption

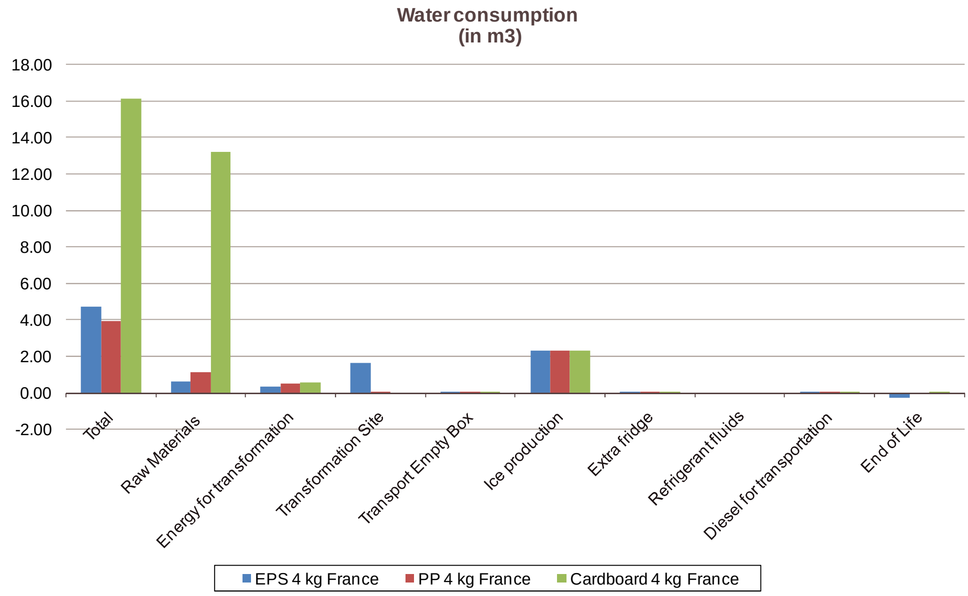


Figure 44: Water consumption (in m^3) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**4.71**	**3.94**	**16.16**
Raw Materials	0.60	1.13	13.21
Energy for transfor	0.32	0.49	0.54
Transformation Site	1.66	0.01	0.00
Transport Empty Box	0.02	0.01	0.01
Ice production	2.33	2.33	2.33
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.01	0.01	0.01
End of Life	-0.25	-0.06	0.04

7.6.1.7 Water eutrophication

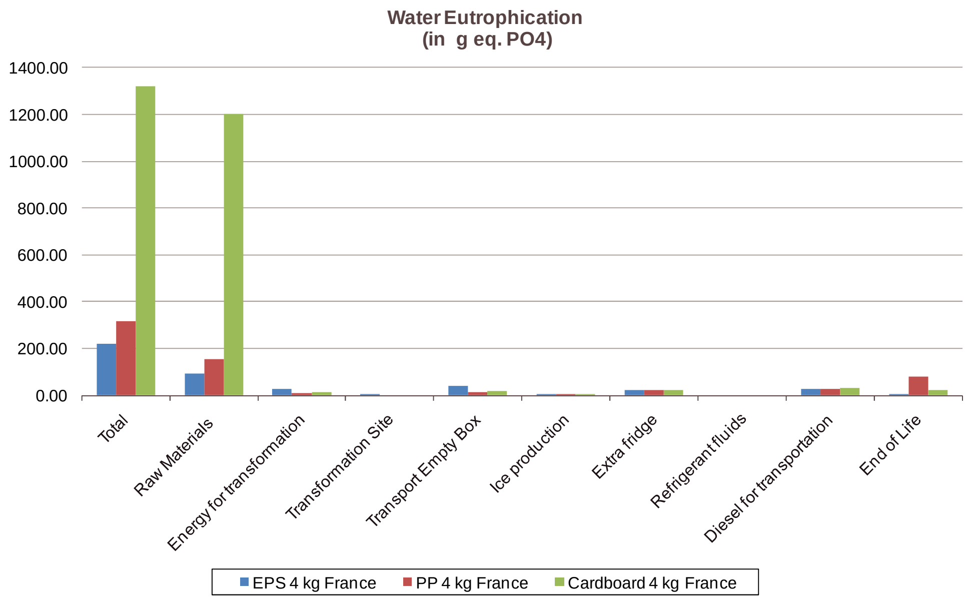


Figure 45: Water eutrophication (in g eq. PO_4^{3-}) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**221.80**	**317.77**	**1320.13**
Raw Materials	92.00	154.32	1203.52
Energy for transfor	27.42	11.22	15.12
Transformation Site	3.10	0.00	0.00
Transport Empty Box	40.74	15.44	17.88
Ice production	5.17	5.17	5.17
Extra fridge	23.34	23.34	23.34
Refrigerant fluids	0.00	0.00	0.00
Diesel	25.41	26.46	30.53
End of Life	4.61	81.83	24.57

7.6.1.8 Solid waste production

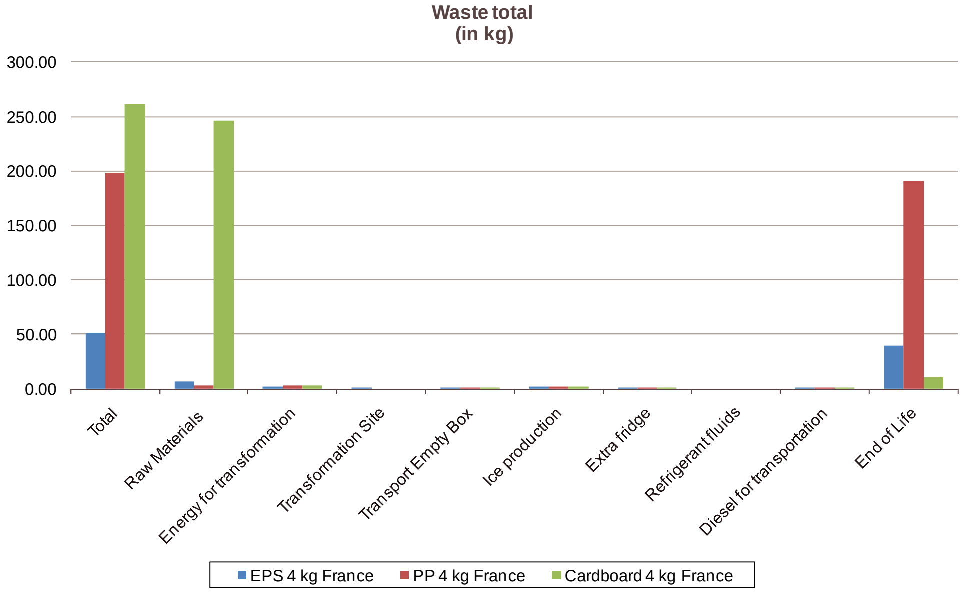


Figure 46: Waste total (in kg) – avoided impacts 50%

French Market (10l)

Stage	EPS 4 kg France	PP 4 kg France	Cardboard 4 kg France
Total	**50.65**	**198.16**	**261.30**
Raw Materials	6.74	2.75	246.09
Energy for transfor	1.77	2.56	2.68
Transformation Site	0.45	0.00	0.00
Transport Empty Box	0.03	0.01	0.01
Ice production	1.72	1.72	1.72
Extra fridge	0.01	0.01	0.01
Refrigerant fluids	0.00	0.00	0.00
Diesel	0.02	0.02	0.02
End of Life	39.92	191.09	10.76

7.6.2 Summary of results (sensitivity analysis #4)

Similarly to the reference scenario, the following table compares the relative performance of the three packaging scenarios when avoided impacts are considered for EPS and PP packaging. The results of the EPS packaging are taken as the reference.

Indicator		EPS	PP	Cardboard
		4 kg	4 kg	4 kg
		France	France	France
Non renewable primary energy	MJ	1	1.1	1.1
Depletion of Non Renewable Resources	kg eq. Sb	1	1.2	1.1
Emission of Greenhouse gases	kg CO2 eq., 100 years	1	1.1	1.1
Air acidification	g SO2 eq.	1	1.1	2.3
Photochemical Oxidants formation	g eq. ethylene	1	0.2	0.2
Water consumption	m3	1	0.8	3.4
Water Eutrophication	in g eq. PO43-	1	1.4	6.0
Total waste production	kg	1	3.9	5.2

Table 25: Comparative results of the three packaging solutions on the French market with 50% avoided impacts considered for recycling

When credits are considered for recycling, and half of them are allocated to EPS packaging, the relative results of EPS packaging are improved. The EPS packaging performs equally or better than PP and cardboard, except for the formation of photochemical oxidants.

Similar improvement trends for EPS packaging would be observed on the two other markets.

8. Conclusions

1. **Production is the most important stage and packaging weight the key parameter**

From the analysis of the reference results it can be ascertained that there are two main stages of the life cycle of the fishbox packaging solutions considered that contribute to the greatest impact upon the environment.

- **Production of raw materials**. This step typically represents 40-60% of energy consumption, emissions of greenhouse gases and acidification for EPS; 40-95% of the same indicators for the PP box and 45-80% for the cardboard box.
- **Transformation of main packaging constituent**, especially in the case of EPS packaging. This step typically represents in the case of EPS 20-50% of energy and water consumption, emissions of greenhouse gases and acidification and more than 80% of formation of photochemical oxidants; 6-23% of energy consumption, emissions of greenhouse gases and acidification for the PP box and 15-25% of these indicators for the cardboard box.

Transport requirements (fuel, ice) linked to packaging only play a secondary role, even for long distances. We here remind the reader that it was not possible during the present study to link the thermal insulation parameters of the boxes with the energy needed to refrigerate the trucks, which was assumed constant whatever the packaging solution chosen. Integrating this aspect in the result would probably be in favor of EPS packaging.

Consequently, the **weight of packaging** per quantity of fish transported is a key parameter to assess the environmental impacts of any fish packaging system. Any reduction effort to reduce the weight (without modifying the characteristics of the box) will play a tangible role on the overall result.

2. **There is no packaging solution preferable for all environmental impacts analysed**

On the French market (4kg fish per box, 300 km transport of fresh fish to fish market), the EPS packaging performs similarly or better than PP and cardboard, except for the formation of photochemical oxidants.

Results are comparable on the Spanish market (6kg fish per box, 300 km transport of fresh fish to fish market), except that PP performs better than EPS for the formation of photochemical oxidants as well as water consumption.

On the Scandinavian market (20 kg fish, 1200 km transport of fresh fish to fish market), results are more balanced:

- EPS and PP perform similarly for 5 indicators (energy consumption, acidification, water consumption and water eutrophication), EPS perfoms better than PP for waste production but worse for greenhouse gas emissions and formation of photochemical oxidants.
- EPS perfoms better than cardboard for waste production, water consumption and water eutrophication but worse for energy consumption, greenhouse gas emissions and formation of photochemical oxidants. EPS and cardboard perform similarly for acidification.

From the analysis of the first sensitivity analysis representing European averages parameters for electricity grid and waste management, these balanced results are confirmed.

Another sensitivity analysis was performed to address the modeling of recycling waste plastics. When credits are considered for recycling these materials, the relative results of EPS packaging are improved. The EPS packaging performs better than PP and cardboard, except for the formation of photochemical oxidants.
Similar improvement trends for EPS packaging would be observed on the two other markets.

3. **Improvement options identified for EPS transformation influence the overall results**

In a third sensitivity analysis, the EPS packaging solution integrated data from a transformation site with energy consumption reduced by 68% as compared to the reference scenarios. In that case, the EPS packaging solution performs better than PP, except for the formation of photochemical oxidants and water consumption, and better than cardboard except for the formation of photochemical oxidants.

9. External Critical Review

9.1 Reviewers

The external critical review was carried out by two independent LCA experts Daniela Kölsch and Patricia Wolf (TÜVRheinland) and representatives from interested parties (Olivier Gosset, environment coordinator, les Mousquetaires and Perifem, Philippe Violleau, Union du Mareyage de France).

9.2 Comments of the critical review

See next pages

9.3 PwC Ecobilan answers to the comments

To the comment about the age of the data for transport and oil production we made a comparison between the data we used and the data available in the last version (2.2) of Ecoinvent. This comparison and its conclusions are available in Appendix D: Comparison between used energy data and other available data

TÜVRheinland®

Prüfbericht-Nr.: *Test Report No.:*	**21176923 001**	**Seite 1 von 9** *Page 1 of 9*
Auftraggeber: *Client:*	The European Manufacturers of Expanded Polystyrene (EUMEPS) association, Packaging section	
Gegenstand der Prüfung: *Test item:*	Life Cycle Assessment of the Industrial Use of Expanded Polystyrene Packaging in Europe – Case Study: Comparison of Three Fishbox solutions	
Prüfgrundlage: *Test specification:*	ISO 14040:2006 ISO 14044:2006	
Prüfergebnis: *Test Result:*	**Der Prüfgegenstand entspricht oben genannter Prüfgrundlage(n).** *The test item passed the test specification(s).*	

geprüft/ *reviewed by:*

Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*
22.11.2011	Dr. Daniela Kölsch Sachverständige/Expert	

geprüft/ *reviewed by:*

Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*
22.11.2011	Patricia Wolf Sachverständige/Expert	

Sonstiges:
Other Aspects:

- Final Report in PDF format, prepared by Olivier Muller (PwC), Jean-Michel Hébert (PwC) and Aude Chappert (PwC): "Life Cycle Assessment of Industrial Use of Expanded Polystyrene Packaging in Europe – Case Study: Comparison of Three Fishbox solutions", September 2011 on behalf of EUMEPS
- Report in PDF format, prepared by Olivier Muller (PwC), Jean-Michel Hébert (PwC) and Aude Chappert (PwC): "Life Cycle Assessment of Industrial Use of Expanded Polystyrene Packaging in Europe – Case Study: Comparison of Three Fishbox solutions", November 2011 on behalf of EUMEPS

On behalf of

The European Manufactures of Expanded Polystyrene (EUMEPS) association, Packaging section

Critical Review for „Life Cycle Assessment of Industrial Use of Expanded Polystyrene Packaging in Europe – Case Study: Comparison of Three Fishbox solutions"

was performed by

TÜV Rheinland LGA Products GmbH

Patricia Wolf

Dr. Daniela Kölsch

Cologne, 22 November 2011

Content:

1. General information and background of the study

The European Manufacturers of Expanded Polystyrene (EUMEPS) Association – Packaging section commissioned PwC Ecobilan to conduct a comparative Life Cycle Assessment (LCA) of packaging for fresh fish made of Expanded Polystyrene (EPS) on the one hand and of Corrugated Polypropylene and water-resistant Cardboard on the other hand.

The goal of the study is to provide information to EUMEPS regarding environmental consequences of transporting fish within Europe. In addition, a comparison of the EPS packaging with alternative materials should provide information of the environmental performance of EPS within the framework of these packaging solutions.

Therefore, the study aims at obtaining comparative LCA results at European level and it will be used to provide information to stakeholders in industry and to other external parties.

The study is based on two specific fish markets (France and Spain) respectively three different packaging markets (France, Spain and Scandinavia).

The following steps are considered in the life cycle of the packaging for fresh fish:

1. Production of the raw materials,
2. Transport of raw materials to the transformation site,
3. Transformation of materials into the packaging,
4. Transport of the packaging to the harbour site for packing fresh fish and ice,
5. Transport of the packaging around fresh fish with ice (including ice production, extra fuel consumption to cool the truck goods compartment, maintenance of refrigerating fluids and fuel consumption to carry ice and packaging),
6. End of life of the packaging (collection with domestic waste, landfilling, incineration, recycling).

The analysis uses a life cycle approach including all relevant life cycle steps, according to the international standards ISO 14040:2006 and ISO 14044:2006.

TÜV Rheinland LGA Products GmbH (TRLP, reviewer – Daniela Kölsch and Patricia Wolf) was commissioned by EUMEPS to carry out the critical review of the study. Since the present study has the aim to be in line with the international standards ISO 14040:2006 and ISO 14044:2006, a critical review by independent experts is necessary. As the international standard does not specify whether the critical review has to be carried out concomitantly or a posteriori, both approaches are in accordance to the named standards.

A preliminary report was delivered by EUMEPS to TRLP on 24th of September 2011. Recommendations from TRLP concerning the presentation of the results and open questions were discussed at a meeting on 10th of October 2011 in Paris. One of the outcomes of this meeting was that EUMEPS wish to have a critical review by a panel of interested parties. EUMEPS, PwC and TRLP decided to conduct the TRLP review independently from the other reviewers due to the given short deadlines. TRLP summarized a list of open points and sent it to PwC Ecobilan on 14th of October. Afterwards, the originator of the study (PwC Ecobilan) implemented the proposed changes and comments and provided the revised report on 14th of November 2011 to TRLP. The reviewers were informed that the comments of the following interested party representatives were also integrated in the new report:

- Philippe Violleau for UMF (Union du Mareyage Français)
- Olivier Gosset environment coordinator, les Mousquetaires and Perifem.

The aim of the critical review prepared by TRLP is to prove the reliability, transparency, relevance and representativeness of the used methods and data in this comparative life cycle assessment.

2. Standards and criteria

The critical review is carried out according to the international standards ISO 14040:2006 and 14044:2006. The critical review shall ensure that (see ISO 14044:2006):

- „the methods used to carry out the LCA are consistent with this International Standard,
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent."

3. Results of the critical review

3.1 Objective and use of the study

In a first step, EUMEPS want to gain information about the environmental performance of the EPS packaging ensuring the transport of fresh fish in general and compared to alternative materials in particular.

In addition, EUMEPS plan to use the results of the LCA study in order to inform stakeholders from industry and other external parties.

Therefore, the study aims at providing comparative LCA results for several fishbox packaging solutions for two European fish markets (France and Spain) corresponding to three packaging markets (France, Spain and Scandinavia). In this study, France represents an average market among the most important European countries in terms of fish consumption. Spain represents the other fish markets in the south of Europe.

3.2 Used methods in this analysis

Definition of the system boundaries

The study is based on the life cycle approach including all relevant life cycle steps. Some of the life cycle steps are omitted due to the fact that these steps seem to be of minor relevance or similar for the three packaging options. These omitted steps are well and reasonable documented in the report.

Choice of environmental categories

The international standards do not dictate impacts which should be examined. There are not even effects which should be studied as a minimum. Following impact categories are considered in this study:

- Energy indicators (total primary energy, non-renewable energy, renewable energy, feedstock energy and fuel energy),
- Depletion of non-renewable resources,
- Increase of greenhouse effect,
- Acidification potential,
- Photochemical oxidants creation potential,
- Water eutrophication potential.

The different impact categories are described in detail in the report and refer to scientific publications, as well as documents distributed by the Ministry of Environment in France. In general, the selected environmental impact categories follow the requirements of international standards ISO 14040:2006 and ISO 14044:2006, the choice seems to be sufficient and is in accordance with the state of the art. The report also refers to some environmental impacts which are not considered, like toxicity and stratospheric ozone depletion. The reason for the exclusion of toxicity is the assumption of the originators that the impact is low due to regulations of food packaging. The reviewers recommend including toxicity in a subsequent revised study (if applicable) due to the fact that the pre-chains of the materials might have an impact on toxicity. Therefore, the consideration of toxicity might support the results in a meaningful way.

However, the selected environmental impact categories are in line with the defined goal and the context of the LCA study.

Sensitivity and scenarios

Four different scenarios are performed to determine the effect of changes in data and choice of the methodological approach which is an accepted procedure within the LCA application. Two scenarios justify the assumptions made in the reference scenario regarding recycling and the used stock or "cut-off" method. Another scenario is performed on the key parameters electricity grid and waste management conditions. The fourth scenario is based on real case improvements for the transformation of EPS.

According to the results, the originator of the study shows with the help of the scenarios that the reference scenario is based on conservative assumptions regarding the end of life treatment. Therefore the scenario can be seen as a worst case for the EPS packaging.

The analysis steps are generally justified on scientific basis and reflect the state of the art.

3.3 Used data

The present study is based on primary data from EUMEPS members (five companies and eight production sites in Spain, France, and Denmark) concerning data for manufacturing and distribution of EPS packaging. These data are representative for the year 2009. The collection was done by questionnaires; some examples are available in the report.

Secondary data are taken from accepted databases, like the PlasticsEurope (2005 and 2006) and FEFCO (2009). These databases are well known and scientifically reviewed, therefore, the data quality is estimated to be high; the LCIs are up to date and sufficient for this study.

Other secondary data are taken from literature and are documented in the final report.

It can be assumed that the data in general are appropriate. Nonetheless a verification or quality check of data was not performed by the reviewers. To ensure the traceability of data, calculations and documentation were explained to the reviewers during the meeting in detail. Thus, the data collection was examined by the reviewers. Altogether the data seem to be sufficient and conclusive in itself in relation to the objective of the study.

3.4 Transparency and consistency of the calculation and report

It was noted by the reviewers that the report has to follow the requirements of ISO 14040:2006 and ISO 14044:2006 since these standards provide a framework for presenting an LCA study in a clear and understandable way; results should be presented consistently and transparently.

Background information, assumptions, used data and their quality are well described in the report. Both, the graphical and tabular representation of the results are comprehensible. Nevertheless, the reviewers recommend presenting the "energy for transformation" and the "transformation site" as one life cycle step, because the "transformation site" is for PP and cardboard included in the "energy for transformation".

The reviewers recommend reflecting the results in more detail, although the description of the analysed impact categories is explicit. The explanations concerning assumptions and results are sufficient.

The final executive report itself is coherent, legible, and clear.

4. Summary of critical review

In accordance with the standards ISO 14040:2006 and ISO 14044:2006, a critical review was carried out for the LCA study "Life Cycle Assessment of the Industrial Use of Expanded Polystyrene Packaging in Europe – Case Study: Comparison of Three Fishbox solutions".

All steps in this LCA are performed according to the LCA method described in the ISO standards. All assumptions in relation to the results are documented comprehensibly to the reviewer. They are scientifically based and reflect the state of the art. The results are basically consistent. The used data are appropriate for the goal and scope of the study. Necessary recommendations for the report were discussed during the review. The presentation of results is generally understandable. The study supplied is coherent and transparent.

The reviewers recommend publishing the results of the study not without the used assumptions documented in the report and a sufficient description and reflection of the results.

Literature

International Organisation for Standardisation (ISO), Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006).

International Organisation for Standardisation (ISO), Life cycle assessment – Requirements and guidelines (ISO 14044:2006).

Cologne, November 22, 2011

Dr. Daniela Kölsch
Expert

Patricia Wolf
Expert

10. Glossary of Terms and Abbreviations

Allocation:	Partitioning the input or output flows of a unit process to the product system under study.
Cut off criteria	Limits which define the degree of detail to which the system boundaries are taken, in respect of modelling unit processes back to the 'cradle' in a 'cradle to gate' study.
Data quality:	Nature or characteristic of collected or integrated data.
Ecobalance:	Life cycle inventory
Environmental impact:	Representation of possible change to the environment resulting from a product system (as defined in the LCA)
Eutrophication	Enrichment in mineral salts of marine or lake waters when it refers to the natural process or, as the enrichment in nutritive elements of waters when referring to human intervention
Feedstock energy:	Combustion heat of raw material inputs, which are not used as an energy source, to a product system, expressed in terms of higher heating value or lower heating value.
Fossil fuels (fuel energy):	Potential energy inherent in the fossil fuel feedstock measured by calorific value, which can be realised by combustion.
Functional unit:	Quantified performance of a product system for use as a reference unit in a life cycle assessment.
Input:	Material or energy which enters a unit process (materials may include raw materials, products, and energy may be in the form of feedstock energy, fuel energy, electricity and from renewable/non-renewable sources).
Life cycle:	Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal.
Life cycle impact: assessment:	Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system.

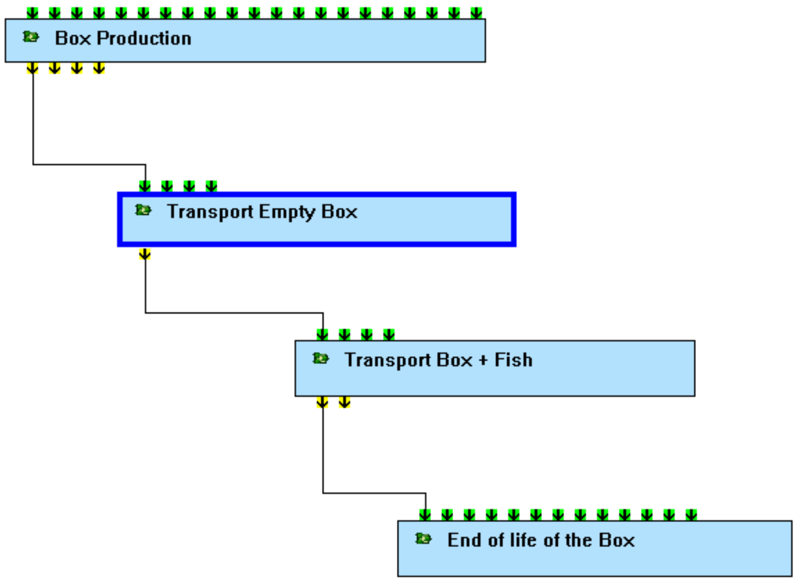
Life cycle inventory analysis:	Phase of life cycle assessment involving the compilation and quantification of inputs and output, for a given product system throughout its life cycle.
Medium oriented	Life cycle impact assessment method that addresses measures of environmental concern in a particular medium, e.g. air, water
Output:	Material or energy which leaves a unit process (materials may include raw materials, products, emissions and waste).
Primary material:	Material derived from a virgin source, eg. extraction and processing of mineral resources.
Problem orientated	Life cycle impact assessment methodology which addresses specific environmental concerns, e.g. global warming and acidification
Product system:	Collection of materially and energetically connected unit processes which performs one or more defined functions.
Raw material:	Primary or secondary material that is used to produce a product.
Recycling	Reprocessing in a production process of the waste materials for the original purpose or for other purposes including organic recycling but excluding energy recovery
Reference flow:	Relates to the functional unit and is used for the calculation and propagation of life cycle inventory data.
Secondary material:	Material derived from a product at its end of life which can be used in another application after further processing (open loop recycling).
Sensitivity analysis:	Systematic procedure for estimating the effects on the outcome of a study of the chosen methods and data.
System boundary:	Interface between a product system and the environment or other product systems.
Transparency:	Open, comprehensive and understandable presentation of information.
Uncertainty analysis:	A systematic procedure to ascertain and quantify the uncertainty introduced in the results of a life cycle inventory due to the cumulative effects of input uncertainty and data variability. It uses either ranges or probability distributions to determine uncertainty in the results.

Unit process:	Smallest portion of a product system for which data care collected when performing a life cycle assessment.
Waste:	Any output from the system which is disposed.
Waste (fuel energy):	Potential energy inherent in the waste feedstock measured by calorific value, which can be realised by combustion.

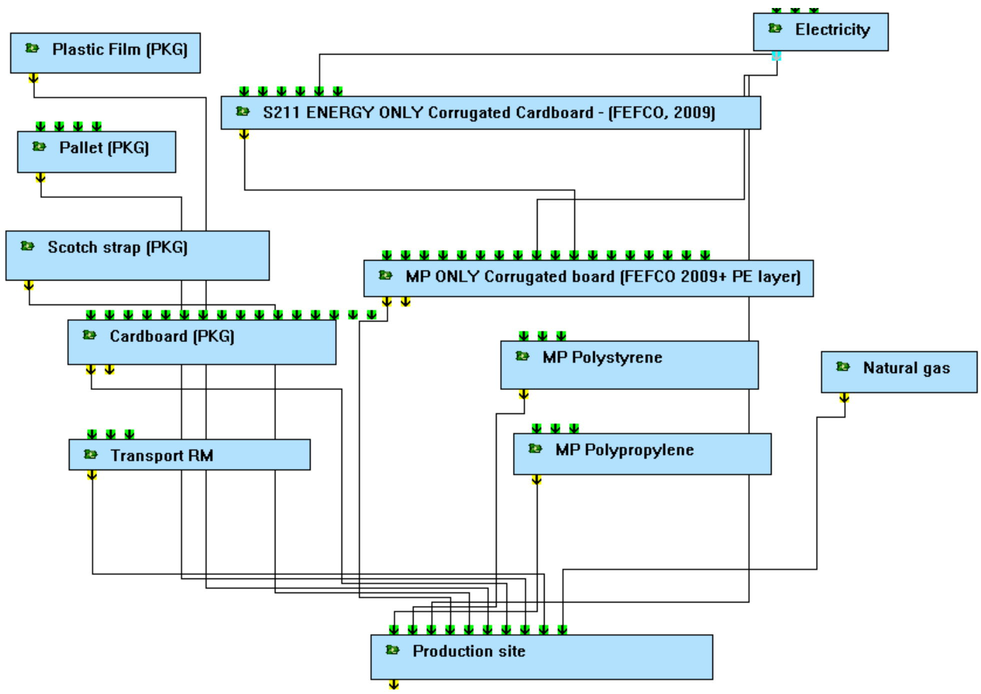
ALARP	As low as reasonably possible
APME	Association of Plastic Manufacturers in Europe
Allocation	Partitioning the input or output flows of a unit process to the product system under study.
BPEO	Best practicable environmental option
CFC	Chlorofluorocarbons
CH_4	Methane
Cl_2	Chlorine
CML	University of Leiden, Centre for Environmental Studies
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
Data quality	Nature or characteristic of collected or integrated data
DEAM	Data for Environmental Analysis and Management
EDC	Ethylene dichloride
EPS	Expandable polystyrene
EU	European Union
EUMEPS	The European Manufactures of Expanded Polystyrene
g eq.	Gram equivalent
GWP	Global warming potential
H^+	Hydrogen ion
IPPC	Integrated Pollution Prevention Control
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organisation
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
MSW	Municipal Solid Waste
NH_4^+, NH_3 as N	Ammonium ions and ammonia, expressed as equivalent nitrogen
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
N_2O	Nitrous oxide
ODP	Ozone Depletion Potential
PE	Polyethylene
PET	Polyethylene terephthalate
PO_4^{3-}, HPO_{4-},	Phosphate ions
PP	Polypropylene

PS	Polystyrene
SO_2	Sulphur dioxide
SO_x	Oxides of sulphur
TEAM™	Tools for Environmental Analysis and Management. TEAM™ is the proprietary tool of the Ecobilan Group for Life Cycle Assessment
VOCs	Volatile Organic Compounds
WISARD	Waste Integrated Systems Assessment for Recovery and Disposal
% w/w	Percent weight/weight

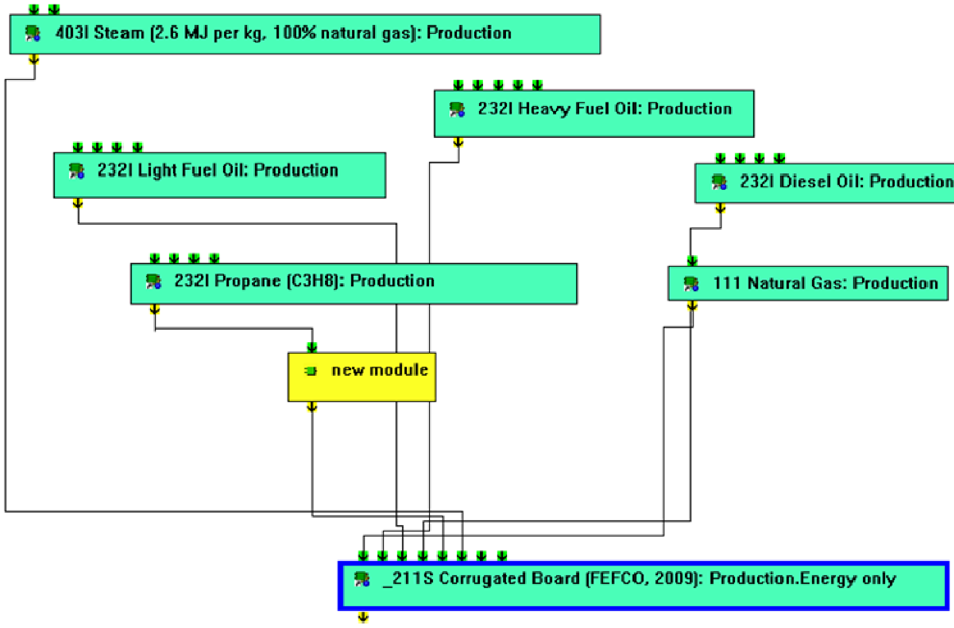
Appendix A: Detailed description of sub systems



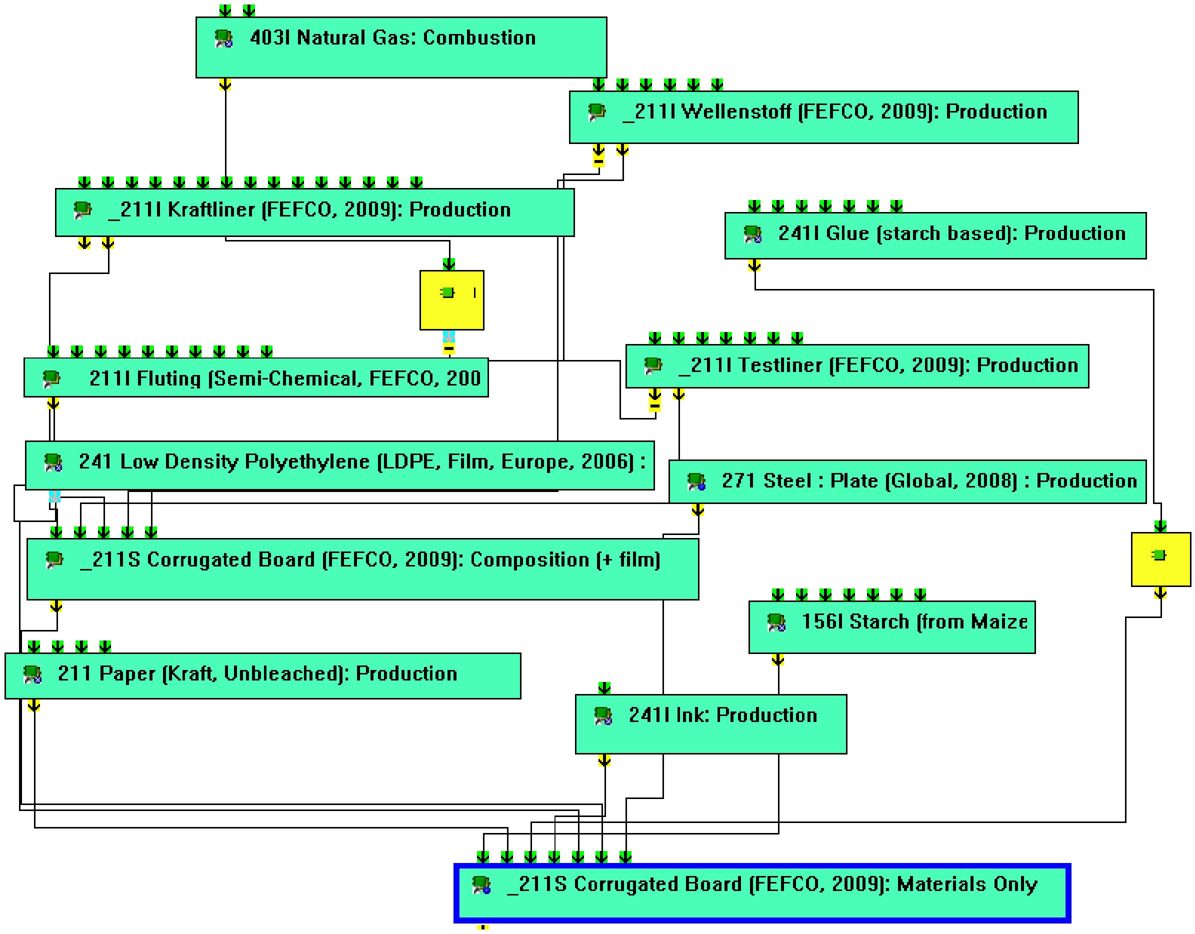
Modelling in TEAM 1: Main system



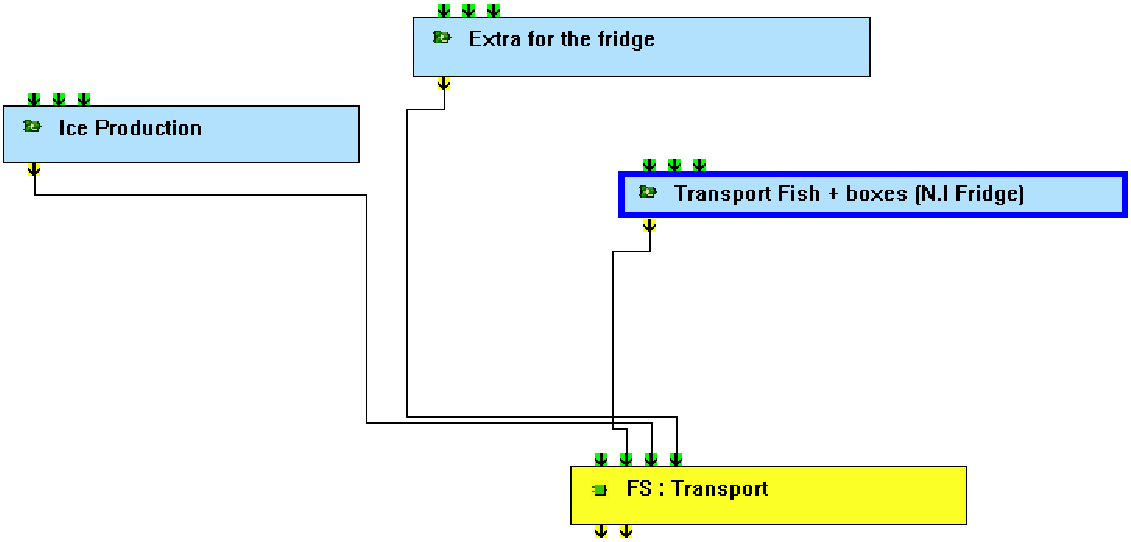
Modelling in TEAM 2: Production



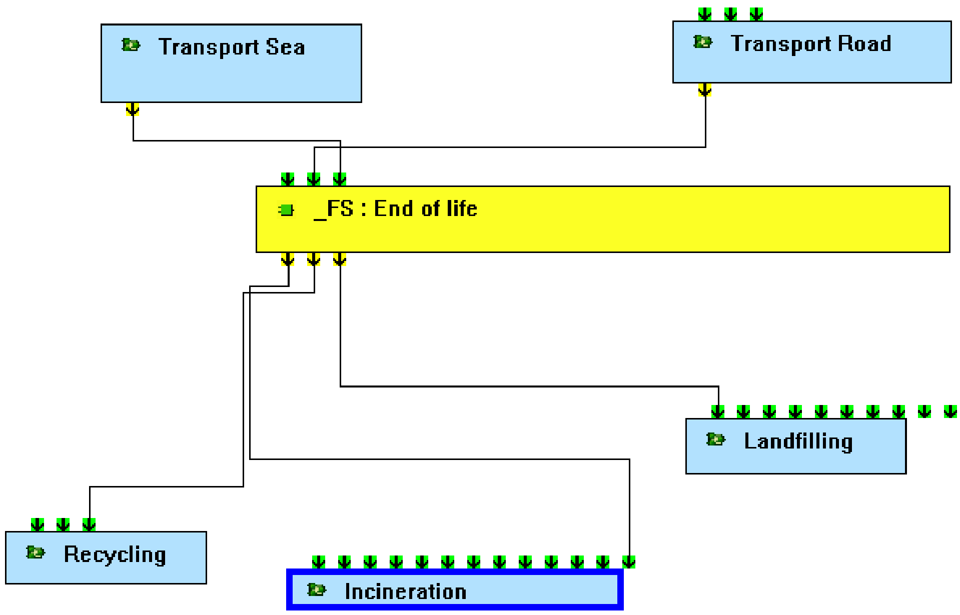
Modelling in TEAM 3: Energies for cardboard production



Modelling in TEAM 4: Raw materials for cardboard production



Modelling in TEAM 5: Transport of fish with fishbaxes



Modelling in TEAM 6: End of life

Appendix B: Sample questionnaire for data collection of main data

10.1 Questionnaire for collecting manufacturing values

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LCI questionnaire related to the EPS box production for fresh fish

1. Information related to the company		**Contact**	
Company		Name	
Address		Position	
		Phone	
		Email	
Data related to year	**2009**		

2 A. Caracteristics of the product (reference box)

Product name							
Reference quantity	Units		**or**	Tonnes			
Dimmensions	mm		**x**		**x**		
Mass of one unit of one box of the reference model	Grammes						

2 B. : Calculation of the allocations rules

Total quantity of packaging boxes (all formats)	Tonnes	
Total quantity of other products (if relevant)	Tonnes	

Comments:

3. Consumptions

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 59

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products

3.1. Energy ressources

Natural gas	MJ (PCI)		Propane	MJ (PCI)	
Electricity France	MJ elec		Heavy fuel oil	MJ (PCI)	
Diesel oil	MJ (PCI)		Other fuel Indicate which one	MJ (PCI)	
Liquefied petroleum gas (LPG)	MJ (PCI)		Other fuel Indicate which one	MJ (PCI)	

3.2. Water consumption

Water consumption from the public network	L		Others	L	
Water consumption from underground (well)	L		Others Please indicate	L	
Cooling water	L		Others Please indicate	L	

3.3.Consumption of raw materials

Raw materials

Expansible polystyrene	t	
Other.. Please indicate	t	
.... Please indicate	t	
... Please indicate	t	
... Please indicate	t	

Comments:

3.4. Packaging

Packaging

Pallet	t	
Plastic film	t	
Others Please indicate	t	
.... Please indicate	t	

4. Emissions and waste

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 68

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products

4.1. Emissions into air (excepted emissions due to the combustion)

Pentane	g	
...	g	
...	g	
...	g	

Comments:

4.2. Releases into water

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 69

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products

Discharged water		L	
COD (Chemical Oxygen Demand)		g/L	
BOD5 (5 Day biological Oxygen Demand)		g/L	
Nitrogen (N)		g/L	
Suspended Matter		g/L	
Others	Préciser	g/L	
...	Préciser	g/L	

Comments:

4.3. Recovered matter

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 70

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products

Recovered matter from packaging (please indicated material)	t	
...	t	
...	t	

Comments:

4.4. Waste

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 74

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products

Hazardous waste	Precise nature and destination	t	
Industrial non hazardous waste	Precise nature and destination	t	
Others	Precise	Unité	
Others	Precise	Unité	

Comments:

5. Transportation of raw materials (supplying)

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 75

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products

	Road transport					By train	By boat	
	Distance	Actual load	Empty return percentage rate	Consumption of the truck	Possible load	Distance	Distance	Place of origin (provider)
	km	kg	%	L diesel /km	kg	km	km	
Default values		Maximum load	30%	0.38	24 000			
Transportation of raw materials								
Expansible polystyrene								Please indicate
....								Please indicate
...								Please indicate
								Please indicate
Transportation of packaging material								
Plastic film								Please indicate
Others (precise the nature)								Please indicate
Others (precise the nature)								Please indicate

10.2 Questionnaires related to logistics

ECOBILAN
PRICEWATERHOUSECOOPERS

Facultative LCI questionnaire related to the transportation of EPS boxes to the packaging place

(by default, the reference quantity indicated in the cell L25 is selected)

Zone de groupe 10

Thank you to indicate to which production the declared quantities refer to by selecting the appropriate checkbox	Reference box	Production all formats included	Production of boxes and other products
	⦿	○	○

Transportation of the EPS boxes to the fish packaging place (optional)

	By road					By train	By boat
	Distance	Actual load	Percentage of empty return	Consumption of the truck	Possible load	Distance	Distance
	km	kg	%	L diesel /km	kg	km	km
Default values		Possible load	30%	0.38	24 000		
Packaging place							
Please indicate							
Please indicate							
Please indicate							
Please indicate							

ECOBILAN
PRICEWATERHOUSECOOPERS

Cuestionario ICV de transporte de las cajas de EPS hasta el lugar de envase del pescado

Dimensiones en mm	mm	500.00 x 300.00 x 140.00
Peso individual de una caja de referencia	grammos	145.00
Cantidad de cajas por pale	Unidades	
Cantidad de pale en un camion	Unidades	

Transporte de las cajas de EPS hasta el lugar de envase del pescado

	Por carretera					Por ferrocarril	Por Barco
	Distancia	Peso Real	Porcentaje de regreso vacio	Consumo del camion	Peso Maximo	Distancia	Distancia
	km	kg	%	L diesel /km	kg	km	km
Valores por defecto		Peso Maximo	30%	0.38	24 000		
Lugar de envase							
Indicar							
Indicar							
Indicar							
Indicar							

Page 1

Appendix C: Sources of secondary data

Data	***Data Characterization***	***Process Description***	***Sources***
111 Natural Gas (Europe, 2005): Production	Please visit www.plasticseurope.org for further information.	Production of Natural gas in Western Europe including its transportation	Eco-profiles of the European Plastics Industry-I.Boustead-PlasticsEurope, Brussels, March 2005-available on web site: http://www.PlasticsEurope.org
156I Starch (from Maize): Production	NCV of starch: 16.1 MJ/kg-Source Fire Protection Handbook	Drying of Starch	BUWAL (LCI of Packagings) n°250-Volume II-page 453-primary source:-Ökobilanz von Kunstoff aus Maisstarke, Projektarbeit an der Liechensteinischen Ingieurschule, 1993
211 Paper (Kraft, Unbleached): Production	data derived from one plant in Switzerland.-all transport included (150 km rail)	Production of 1000 kg kraft (unbleached) from pulp unbleached with sulphate	BUWAL (Bundesamt für Umwelt, Wald und Landschaft) n°250-Band II: Ökoinventare für Verpackungen-Bern, 1996-Page 212-213
211I Fluting (Semi-Chemical, FEFCO, 2009): Production	The data are based on weighted average data for 2008 of the production per ton net saleable paper and corrugated board sheets and boxes.	Production of fluting	European database for Corrugated Cardboard Life Cycle Studies 2009
211I Kraftliner (FEFCO, 2009): Production	The data are based on weighted average data for 2008 of the production per ton net saleable paper and corrugated board sheets and boxes.	Production of Kraftliner	European database for Corrugated Cardboard Life Cycle Studies 2009
211I Testliner (FEFCO, 2009): Production	The data are based on weighted average data for 2008 of the production per ton net saleable paper and corrugated board sheets and boxes.	Production of testliner	European database for Corrugated Cardboard Life Cycle Studies 2009
211I Wellenstoff (FEFCO, 2009): Production	The data are based on weighted average data for 2008 of the production per ton net saleable paper and corrugated board sheets and boxes.	Production of Wellenstoff	European database for Corrugated Cardboard Life Cycle Studies 2009
232I Diesel Oil: Production	This data sheet is representative of european average in 1994.	Data on Diesel Production using extracted oil	Laboratorium fur Energiesysteme -ETH, Zurïch, 1996-Teil 1, Erdol-Page 173-174--
232I Heavy Fuel Oil: Production		Data on primary mining (excludes water, steam or CO2 injection into the oil reservoir).-Average transportation (included):-- river barge: 1000 km - - pipeline: 125 km- - tanker: 4500 km	Buwal 132 (1991) A9 adapted by Ecobilan.-Adaptation covers CO2 emissions added for what Buwal calls precombustion for fuels production models; cross loop treatment for fuels production models; recalculation from process data when provided in the Buwal, in order to check, calculation updated using recent European electricity model.
232I Light Fuel Oil: Production	This data sheet is representative of european average in 1994.	Data on Light Fuel Oil Production using extracted oil---	Laboratorium fur Energiesysteme -ETH, Zurïch, 1996-Teil 1, Erdol-Page 173-174-.
232I Propane (C3H8): Production	This data sheet is representative of european average in 1994.	Production of Propane (C3H8)--	Laboratorium fur Energiesysteme -ETH, Zurich, 1996-Teil 1, Erdol-Page 171-172
241 Hydrochloric Acid (HCl, 100%): Production	Elf Atochem expertise.	Direct synthesis:-H2 + Cl2 -> 2 HCl--This reaction is very exothermic and it is necessary to cool the reactor	ELF ATOCHEM expertise, Mr. Lecouls' letter of 25 July 1997

241 Low Density Polyethylene (LDPE): Production	Data have been obtained from the production of some 4.48 million tonnes of LDPE. The data derived from 27 polymerisation plants.-Data on the production relate to practices in 1999--It represents 93,5% of all West European production in 1999.	Production of 1 kg polyethylene (LDPE) --Produced by a high pressure process only : when monomer is held at high pressures and temperatures, monomer/polymer mixture acts as a polymerisation medium. Initiators and catalysts can be added to this medium. It employs pressures up to 300 MPa and temperatures up to 300°C.--In order to handle materials under such high pressures and to control temperatures, two types of reactor are used :-- The stirred autoclave -- The tubular reactor	Eco-profiles of the European Plastics Industry-I.Boustead-PlasticsEurope, Brussels, March 2005-available on web site: http://www.PlasticsEurope.org
241 Low Density Polyethylene (LDPE, Film, Europe, 2006) : Production	Please visit www.plasticseurope.org for further information.	Production of Polyethylene (LDPE) Film	Eco-profiles of the European Plastics Industry-I.Boustead-PlasticsEurope, Brussels, March 2005-available on web site: http://www.PlasticsEurope.org
241 Polyethylene Terephthalate (PET, Film, Europe, 2005): Production	Please visit www.plasticseurope.org for further information.	Data on the production of PET film has been obtained from six separate operations and the average reported here is weighted by the production from each of these facilities. Final packaging has been excluded	Eco-profiles of the European Plastics Industry-I.Boustead-PlasticsEurope, Brussels, March 2005-available on web site: http://www.PlasticsEurope.org
241 Polystyrene (PS, General Purpose, Europe, 2005): Production	Please visit www.plasticseurope.org for further information.	Production of 1 kg polystyrene (general purpose , GPPS)	Eco-profiles of the European Plastics Industry-I.Boustead-PlasticsEurope, Brussels, March 2005-available on web site: http://www.PlasticsEurope.org
241I Glue (starch based): Production	site data 1991-confidential	Production of starch based glue used for corrugated board	Former Ecobilan study performed in 1993 for FEFCO-primary source: Saint-Gobain Papier Bois (SGPB) Mortagne (1991)
241I Ink: Production		production of ink	site data (1993)
271 Steel : Plate (Global, 2008) : Production	The reference year for the data is for 2005 to 2007, depending on each company providing data. Some upstream data is based on 2008 data.--Region : Global	Production of 1kg of steel plate, global average. recycling rate 95%---A flat steel sheet rolled on a hot rolling mill. It can be found on the market in sheets and is further processed into finished products by the manufacturers.-Heavy plate is used in a large number of sectors: structural steels. shipbuilding. pipes. pressure vessels. boilers. heavy metal structures. offshore structures etc.-Typical thickness between 2 to 20 mm. The maximum width is 1860 mm.-	Worldsteel 2010
401 Electricity (Denmark, 2008): Production	Representative of average production in Denmark (2008) for breakdown and 2008 for transport losses-	Production of electricity in Denmark-2008 data for breakdown of sources-production of fuels and	1) For combustion of coal, lignite, heavy fuel oil, natural gas, process gas:-Laboratorium für Energiesysteme ETH, Zurich, 1996 --2) For breakdown efficiencies:-International Energy

		combustion in power plants	Agency -Electricity information 2010-
401 Electricity (European Union, 27 Countries, 2008): Production	Representative of average production in The European Union 27 countries (2008) for breakdown and 2008 for transport losses-	Production of electricity in the European Union-2008 data for breakdown of sources-production of fuels and combustion in power plants	1) For combustion of coal, lignite, heavy fuel oil, natural gas, process gas:-Laboratorium für Energiesysteme ETH, Zurich, 1996 --2) For breakdown efficiencies:-International Energy Agency -Electricity information 2010-
401 Electricity (France, 2008): Production	Representative of average production in France (2008) for breakdown and 2008 for transport losses-	Production of electricity in France-2008 data for breakdown of sources-production of fuels and combustion in power plants	1) For combustion of coal, lignite, heavy fuel oil, natural gas, process gas:-Laboratorium für Energiesysteme ETH, Zurich, 1996 --2) For breakdown efficiencies:-International Energy Agency -Electricity information 2010-
401 Electricity (Spain, 2008): Production	Representative of average production in Spain (2008) for breakdown and 2008 for transport losses	Production of electricity in Spain-2008 data for breakdown of sources-production of fuels and combustion in power plants	1) For combustion of coal, lignite, heavy fuel oil, natural gas, process gas:-Laboratorium für Energiesysteme ETH, Zurich, 1996 --2) For breakdown efficiencies:-International energy agency publication \'Electricity Information 2010\'-Web site : www.iea.org--3) For transport losses-International energy agency publication \'Electricity Information 2010\'-Web site : www.iea.org-
403I Natural Gas: Combustion		Combustion of Natural Gas in Boiler	Laboratorium fur Energiesysteme -ETH, Zurich, 1996-Teil 1, Erdgas-Page 66-67
403I Steam (2.6 MJ per kg, 100% natural gas): Production		production of steam with 100% natural gas	Steam production model developed by Ecobilan.
403S Natural Gas: Combustion (Low NOx)		Combustion of Natural Gas in Boiler (Low-NOx <100 kW)	Laboratorium fur Energiesysteme -ETH, Zurich, 1996-Teil 1, Erdgas-Page 66-67
602S Articulated lorry transport; Euro 0, 1, 2, 3, 4 mix; 40 t total weight, 24 t max payload		Assumptions-Real load = 24 tonnes-Actual load = 24 tonnes -Combustion of 1 litre of Diesel Oil in a truck. Aggregated from a parametrized module.	ELCD 2007 (Gabi Model) http://lca.jrc.ec.europa.eu/lcainfohub/datasets/elcd/processes/b444f4d0-3393-11dd-bd11-0800200c9a66_02.01.000.xml
611 Sea Transport (Freighter, kg.km)		Freighter (various goods)-Size: > 40,000 gross metric tons-Spec. power: 0.21 kW / metric ton-Fuel consumption: 0.35 kg / kWh-Includes combustion and precombustion.	Swiss Federal Office of Environment, Forests and Landscape-(FOEFL or BUWAL)-Environmental Series No. 32-Bern, February 1991. -pages A16, A8 (precombustion)-Adaptation covers CO2, methane, N2O emissions (Ecobilan Data).
900 Cardboard: Incineration	WISARD module 2007		Ecobilan Wisard Module 2007
900 Cardboard: Landfilling	WISARD module 2007		Ecobilan Wisard Module 2007
900 Polystyrene : Inscineration	WISARD module 2007		Ecobilan Wisard Module 2007
900 PP Incineration	WISARD module 2007		Ecobilan Wisard Module 2007
900 PP Lanfilling	WISARD module 2007		Ecobilan Wisard Module 2007
900 PS: Landfilling	WISARD module 2007		Ecobilan Wisard Module 2007
EUR-flat pallet (RER, 2000-2002)			firstAuthor: Kellenberger D. additional Authors: Althaus H.-J., Jungbluth N., Könniger T. year: 2007 title: Life Cycle Inventories of Building Products title Of Anthology: Final report ecoinvent data v2.0

Appendix D: Comparison between used energy data and other available data

Production and combustion of natural gas	DEAM™	Ecoinvent
Module	111 Natural Gas (Europe, 2005): Production + 403S Natural Gas: Combustion	Natural gas, burned in industrial furnace >100kW (RER, 2000)
Source	PlasticsEurope 2005 for producion + ETH 1996 for combustion	ETH-Zentrum HAD
Year	2005 for production and 1996 for combustion	2000
Natural Gas in ground in kg/MJ	0.023	0.024
CO_2 fossil in g/MJ	66.6	64.1
SOX in g/MJ	0.027	0.025
NOX in g/MJ	0.00012	0.00023
Total Primary Energy in MJ/MJ	1.2	1.1

Conclusion for natural gas: The DEAM™ modeling system and the Ecoinvent cradle to gate data for the combustion of natural gas in an industrial boiler are very similar in terms of value for the main contributing flows, especially the ones resulting from the combustion.

Production of diesel oil	DEAM™	Ecoinvent
Module	232I Diesel Oil: Production	diesel, at regional storage (CH, 1989-2000)
Source	ETH 1996	ETH-Zentrum HAD
Year	1996	2000
Oil in ground in kg/kg	1.06	1.1
CO_2 fossil in g/kg	295	504
SOX in g/kg	1.48	3.03
NOX in g/kg	0.71	2.26
Total Primary Energy in MJ/kg	45.1	50.6

Conclusion for the production of diesel oil: a difference of 71% for CO2 emissions, between Ecoinvent and DEAM™. Values for Emmisions of SOx and NOx are also much more important in Ecoinvent. However, the production of diesel oil used as fuel for transportation contributes to only an average of 10% of the impacts of the whole transportation stage. In the case of CO2 emissions for instance, this represents a difference of 5% at the whole transportation stage.

Combustion of light fuel oil (including production)	DEAM™	Ecoinvent
Module	403I Light Fuel Oil: Combustion	light fuel oil, burned in industrial furnace 1MW, non-modulating (RER, 1991-2000)
Source	ETH 1996	ETH-Zentrum HAD
Year	1996	2000
Oil in ground in kg/kg	0.0256	0.0258
CO_2 fossil in g/kg	84.06	85.25
SOX in g/kg	0.108	0.150
NOX in g/kg	0.00070	0.00082
Total Primary Energy in MJ/kg	1.173	1.183

Conclusion for light fuel oil: The DEAM™ and the Ecoinvent cradle to gate data for the combustion of dieseil in an industrial boiler are very similar in terms of value for the main contributing flows, especially the ones resulting from the combustion. A difference of 38% for sulphur oxide can be noted though.

Combustion of heavy fuel oil (including production)	DEAM™	Ecoinvent
Module	403I Heavy Fuel Oil: Combustion	heavy fuel oil, burned in industrial furnace 1MW, non-modulating (RER, 1991-2000)
Source	ETH 1996	ETH-Zentrum HAD
Year	1996	2000
Oil in ground in kg/kg	0.0273	0.0271
CO_2 fossil in g/kg	91.2	88.5
SOX in g/kg	1.26	0.50
NOX in g/kg	0.0017	0.0018
Total Primary Energy in MJ/kg	1.17	1.18

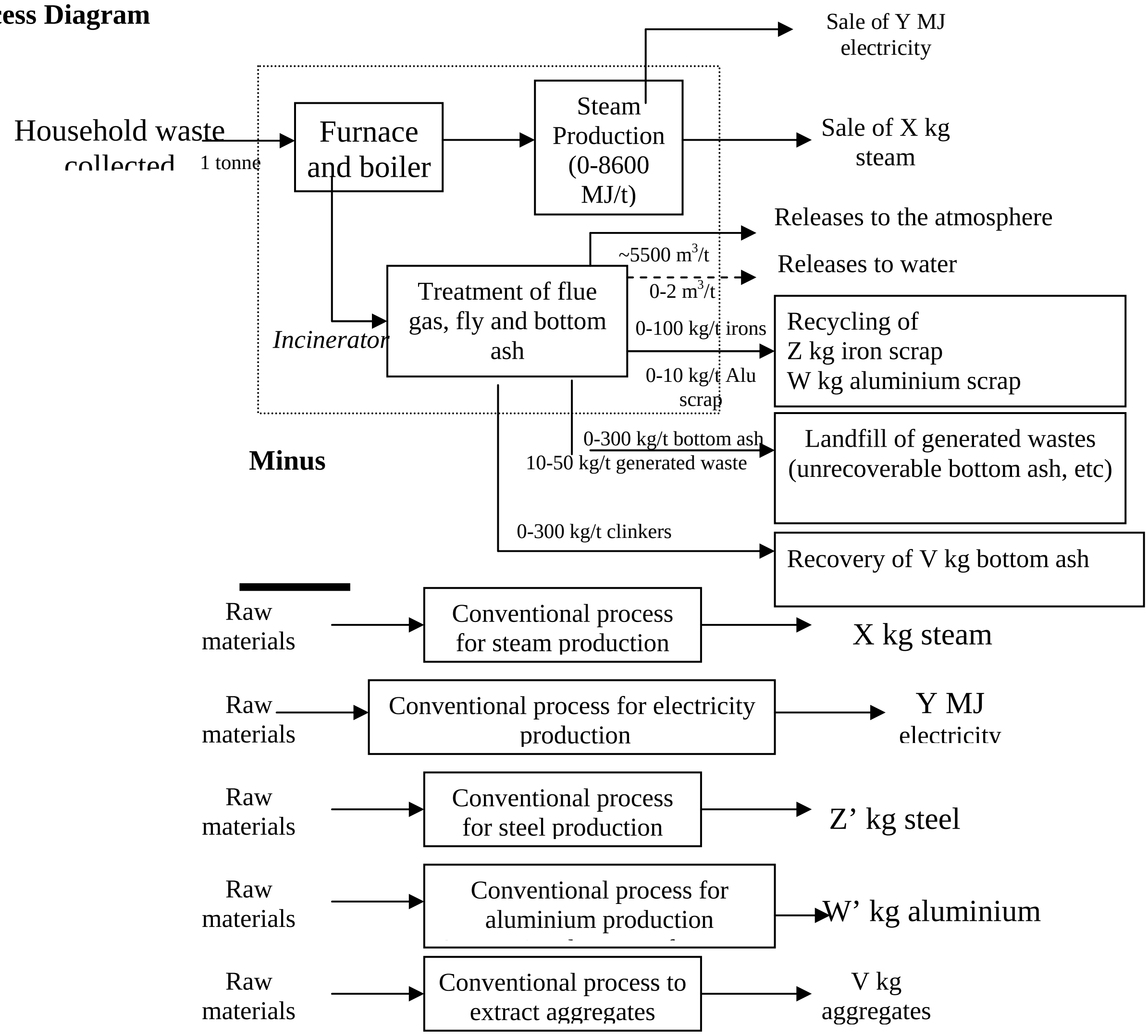
Conclusion for Heavyt fuel oil: The DEAM™ and the Ecoinvent cradle to gate data for the combustion of diesel in an industrial boiler are very similar in terms of value for the main contributing flows, especially the ones resulting from the combustion. A difference of 60% for sulphur oxide can be noted though.

Appendix D: Modelling of incineration and landfilling with WISARD™

10.3 Incineration of household wastes with recovery of steam and/or electricity

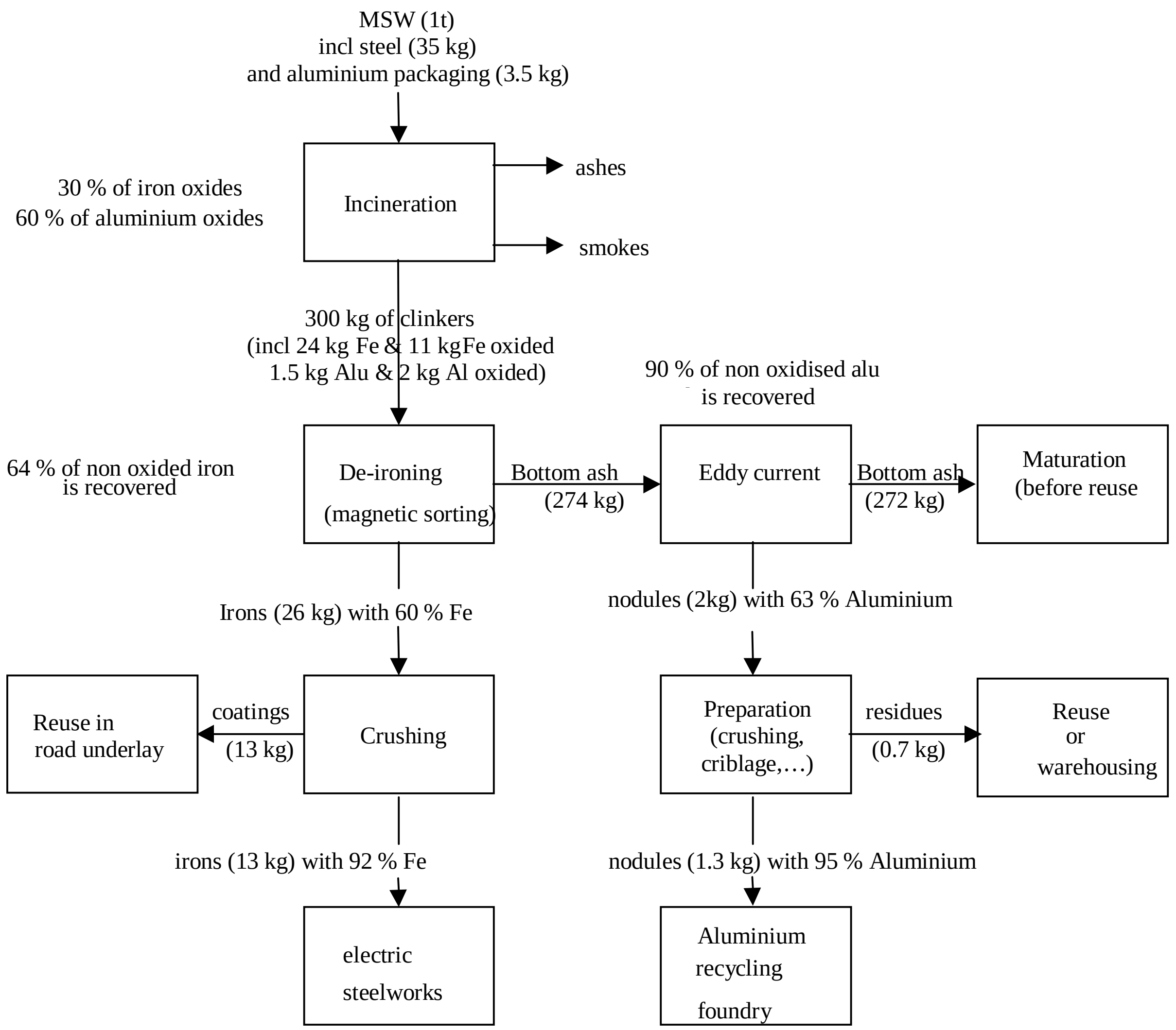
A- Process Description
Modelling the incineration of household wastes with steam and/or electricity recovery. The following processes are taken into account : - Unloading waste in the refuse pit, loading grab. - Incineration in a grate furnace, rotating furnace or fluidised-bed incinerator. - Heat recovery in a boiler. Steam can be sold and/or used to produce electricity. - Scrubbing (dry, semi-dry, wet) and fly-ash removal (electrostatic precipitator, fabric filter). - Processing of scrubbing effluents in a water treatment plant prior to release to sewer. - Removal of ferrous and non-ferrous fractions from bottom ash using magnetic and eddy current equipment.
Comments – The Functional Unit is 'to incinerate household wastes whose quantity and composition are defined in other parts of the tool'.

Process Diagram



Note : Figures are indicative only. For more information on reuse routes, please refer to corresponding data sheets

The following diagram shows the various recycling routes for recovered metals after incineration (indicated numbers)



B- System Definition

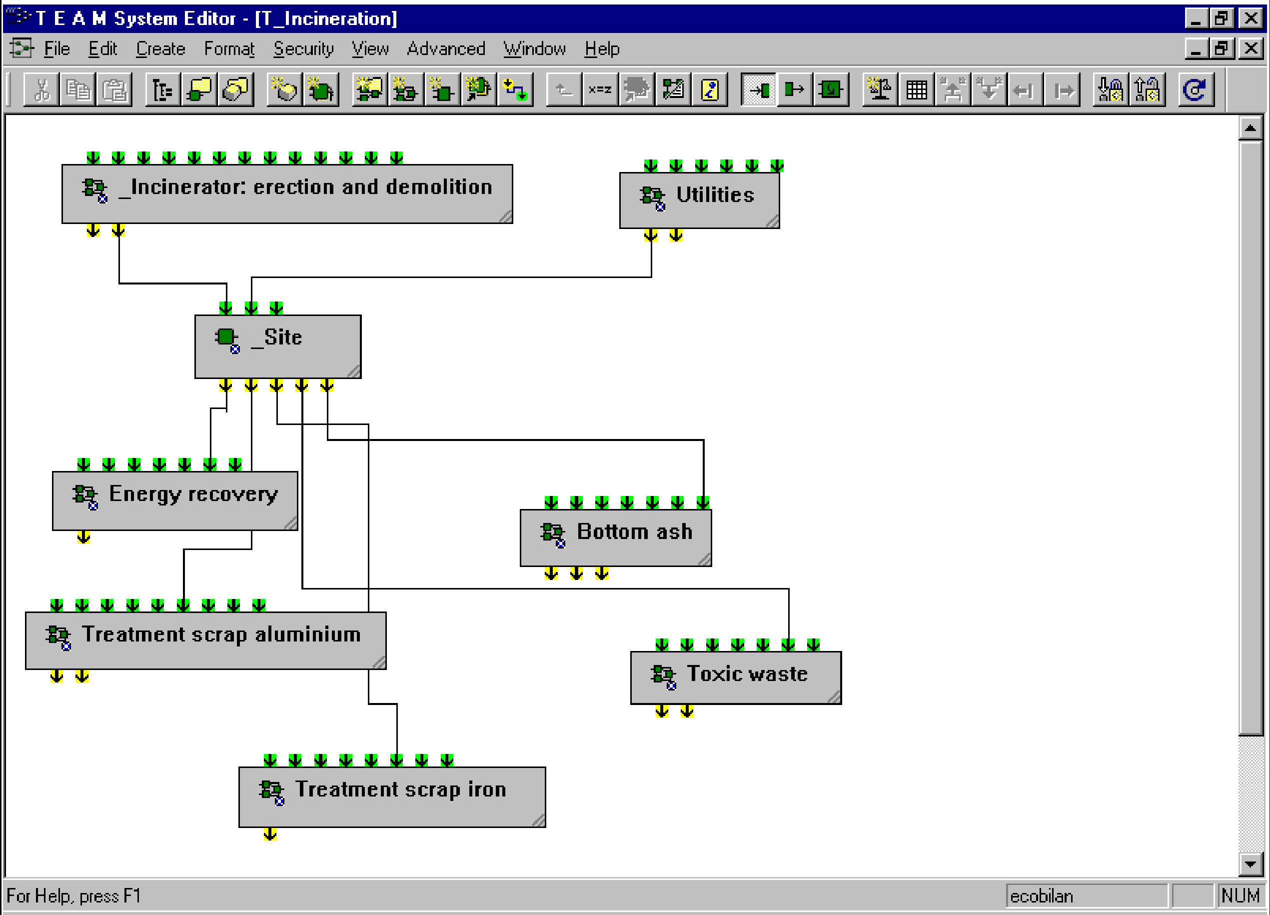
Included :

- Construction and demolition of the incineration site.
- Processes linked to the site operation (consumption of site vehicles, machinery …).
- Utility usage.
- Flue gas scrubbing.
- Processing of scrubbing liquid after flue gas treatment
- Processing of bottom ash (metal scrap recovery).
- Transport and recycling of iron and aluminium scrap (see corresponding sheets).
- Transport and landfill of unrecoverable bottom ash and fly ash (see corresponding sheets).
- Transport and recovery of bottom ash for use in road underlay (see corresponding sheet).

Excluded :

- Collection and transport of household wastes to the incineration site (taken into account elsewhere in the tool).

TEAM[TM]



C- Main Data Characteristics

Date type :

Parameters relating to site management-: Sources [1], [2], [3].

Data processing :

- **Nature :** mass balance
- **Allocations rules used** :

Flow Type	Allocation rule
Consumption on site, construction and demolition	Allocation by mass
Use	Allocation by mass
Solid outgoings	Bottom ash : mineral content of incoming wastes Ferrous waste : ferrous materials content of incoming wastes Aluminium wastes : aluminium content of incoming wastes
Operations material consumption for energy production	Allocation according to energy content of wastes
Operations energy production	Allocation according to energy content of wastes
Operations material consumption for the treatment of flue gas	Allocation according to the content in sulphur and chlorine of wastes
Operations (flue gas treatment) – outflows	
Volume of flue gas ($V_{flue\ gas}$)	$V_{flue\ gas} = V_{flue\ gas}(0)$[25] $* LHV_{wet}/LHV_{wet}(0)$
CO_2	$CO_2 = CO_2\ (0) * C/C(0)$
CO	$CO = [CO]\ (0) * V_{flue\ gas}$
SO_x	$SO_x = [SO_x]\ (0) * V_{flue\ gas}$ if there is sulphur in wastes, otherwise 0
NO_x	$NO_x = [NO_x]\ (0) * V_{flue\ gas}$
N_2O	$N_2O = [N_2O]\ (0) * V_{flue\ gas}$
NH_3	$NH_3 = [NH_3]\ (0) * V_{flue\ gas}$
HCl	$HCl = [HCl]\ (0) * V_{flue\ gas}$ if there is chlorine in wastes, otherwise 0 .
HF	$HF = [HF]\ (0) * V_{flue\ gas}$ if there is fluoride in wastes, otherwise 0 .
HBr	$HBr = [HBr]\ (0) * V_{flue\ gas}$ if there is bromine in wastes, otherwise 0.
Dusts	Dusts = [Dusts] (0) * $V_{flue\ gas}$
Heavy metals	Heavy metals = [heavy metals] (0) * $V_{flue\ gas}$ if there are heavy metals in wastes, otherwise 0.
Zn	$Zn = [Zn]\ (0) * V_{flue\ gas}$ if there is zinc in wastes, otherwise 0.
Hg	$Hg = [Hg]\ (0) * V_{flue\ gas}$ if there is mercury in wastes, otherwise 0.
Cd	$Cd = [Cd]\ (0) * V_{flue\ gas}$ if there is cadmium in wastes, otherwise 0.
Fly ashes	½ Content in mineral materials + ½ (content Chlorine + Sulphur) of wastes
Operations material consumption for the treatment of waste water	Allocation according to the content in sulphur and chlorine of wastes
Operations (treatment of scrubbing water)– outflows	
Suspended matter	1/3 Content in mineral materials + 2/3 (content Chlorine + Sulphur) of wastes
COD	1/3 energy content + 2/3 (content Chlorine + Sulphur) of wastes
BOD_5	1/3 energy content + 2/3 (content Chlorine + Sulphur) of wastes
N (total)	1/3 energy content + 2/3 (content Chlorine + Sulphur) of wastes
P (total)	1/3 energy content + 2/3 (content Chlorine + Sulphur) of wastes
Chlorides	1/3 energy content + 2/3 (content Chlorine + Sulphur) of wastes
Phenols	1/3 energy content + 2/3 (content Chlorine + Sulphur) of wastes
Heavy metals	Content in heavy metals of wastes
Solid Residues (sludge cake)	½ Content in mineral materials + ½ (content Chlorine + Sulphur) of wastes

Representativity :

[25] suffix (0) is used in reference to the typical composition of wastes. Brackets [ ] refer to concentrations in mg/Nm^3.

- **Year :** techniques used in the 1990s
- **Geographical area :** Europe
- **Site Capacity** : Variable
- **Market share** in the UK: refer to Environment Agency data

Module characteristics :

- **Reliability** : Modelling from the operations of more than 15 sites in Europe.
- **Completeness** : High

D- Data sources

- **Identification :**

Source [1] : 'Life Cycle Assessment on the management and treatment of household waste by incineration, landfill, composting and anaerobic digestion', A study performed by the Ecobilan Group for ADEME, 1994 - 1997.

Source [2] : « Life Cycle Inventory of the Incineration of Municipal Solid Waste », Tebodin UK Ltd, 1996, report for the Environment Agency of England and Wales.

Source [3] : « Life Cycle Inventory development for Incineration construction and dismantling », Chem 1997, Systems, report for the Environment Agency of England and Wales.

Contact :

Date of transmission for main data :

Main Sources detailed by category :

- **Raw materials** : parameters according to data from [1], [2] & [3]
- **Energies** : parameters according to data from [1], [2] &[3]
- **Air emissions** : parameters according to data from [1] & [2]
- **Releases to water** : parameters according to data from [1] & [2]
- **Wastes and co-products** : parameters according to data from [1] & [2]

E- Confidentiality Aspect

Data under agreement : Process data
Confidentiality agreement : No

F- Ecobilan

Module creation : Estelle Vial, Christèle Wojewodka
Module Validation : Olivier Muller

10.4 Landfill of household waste with leachates and landfill gas treatment

A- Process Description

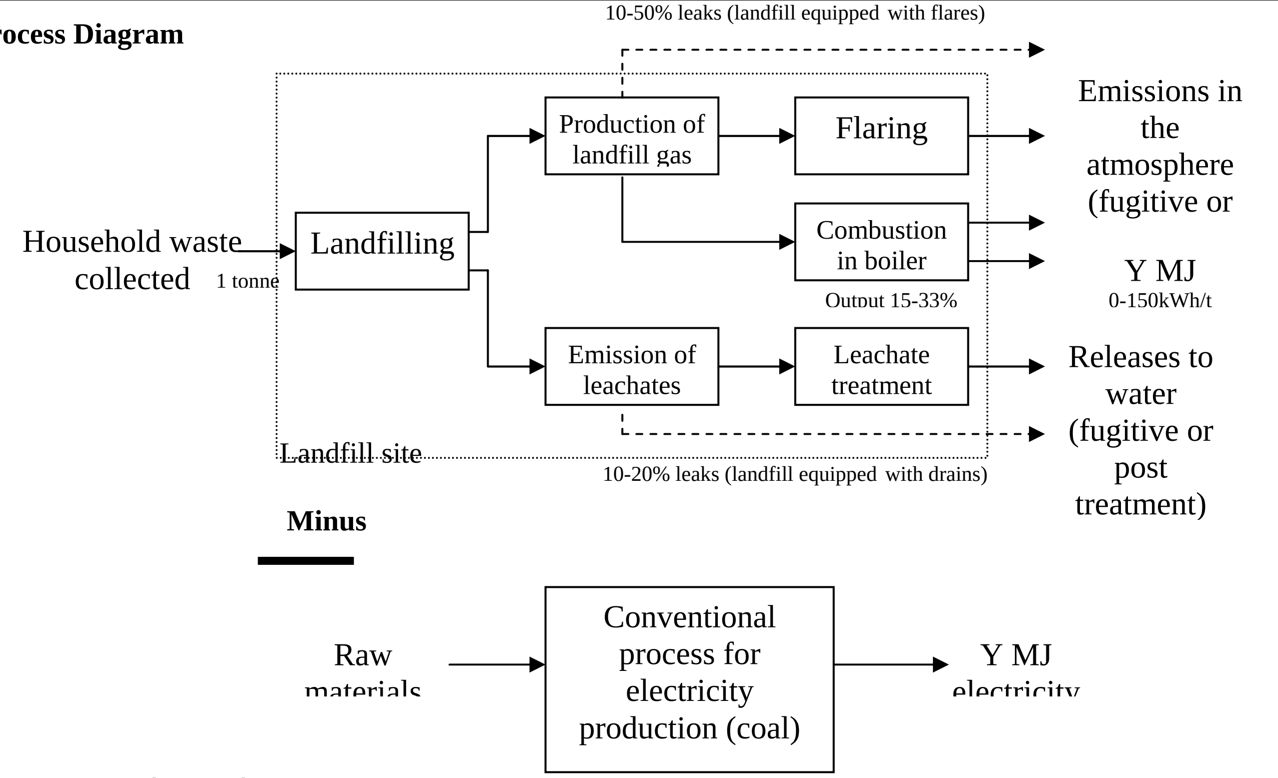
Modelling the landfill of household waste. The following operations are taken into account:

- Construction of landfill cells
- Deposit of waste into the cells.
- Periodic covering with clay and/or sand.
- Collection and combustion of landfill gas in flares and/or in a boiler used for electricity production.
- Collection and processing of leachates (by physio-chemical means or evaporation by incineration).

Comments

The functional unit is « to landfill MSW whose quantity and composition have been defined in another part of the tool ». Data concerning the production of landfill gas and leachates relate to a period of around 100 years. This makes the collection of data difficult.

Process Diagram



Note : Figures are indicative only.

B-System Definition

Included :

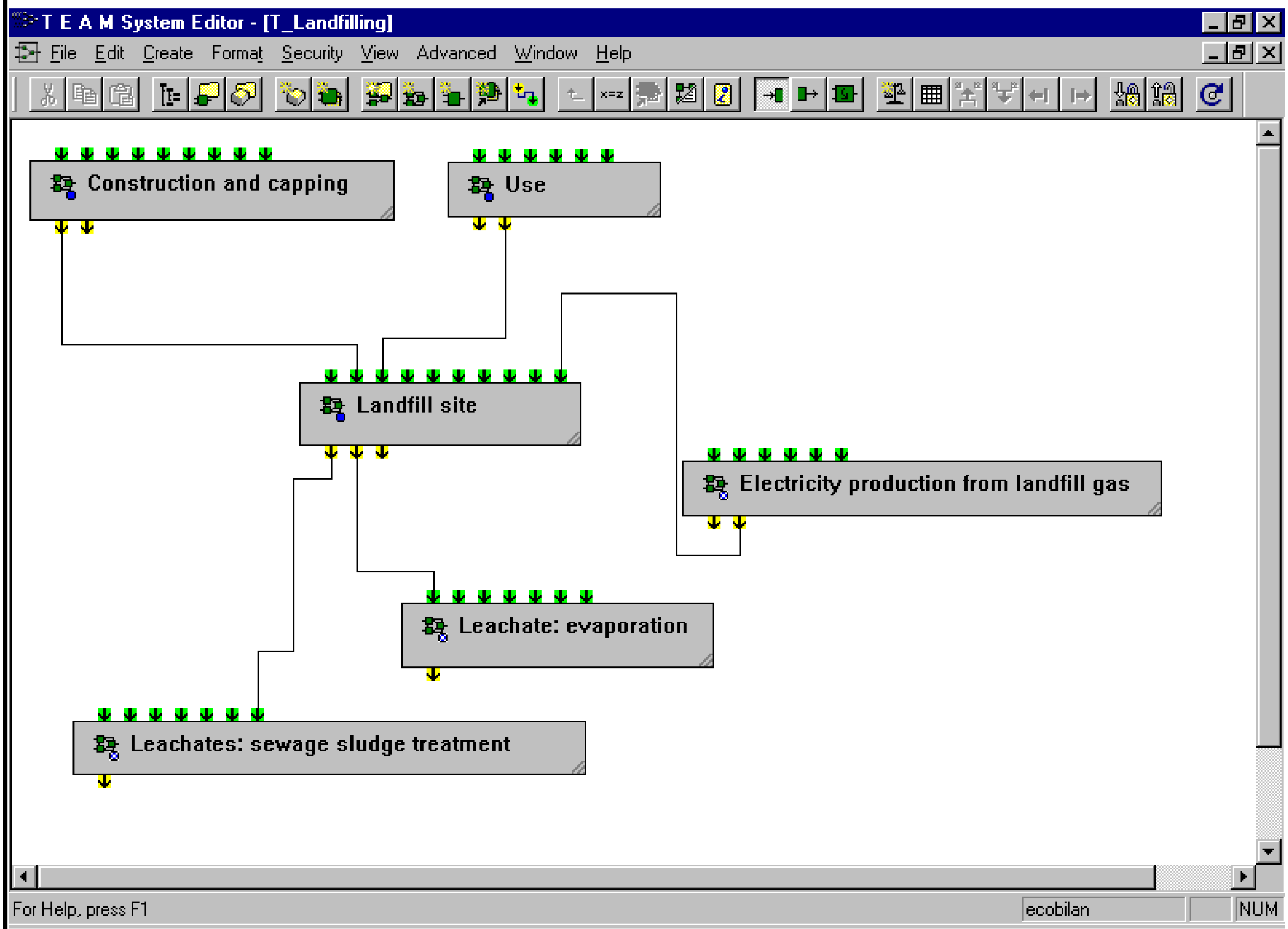
- Construction and cover of the site at end of use.
- Operation for landfilling (consumption of fuel and lubricants for machinery,…).
- Leachate produced from water passing through household waste in landfill.
- Decomposition of putrescible waste with production of landfill gas.
- Treatment of leachates in water treatment plant.
- Combustion of captured landfill gas.
- Fugitive emissions of landfill gas
- Fugitive emissions of leachates.

Excluded :

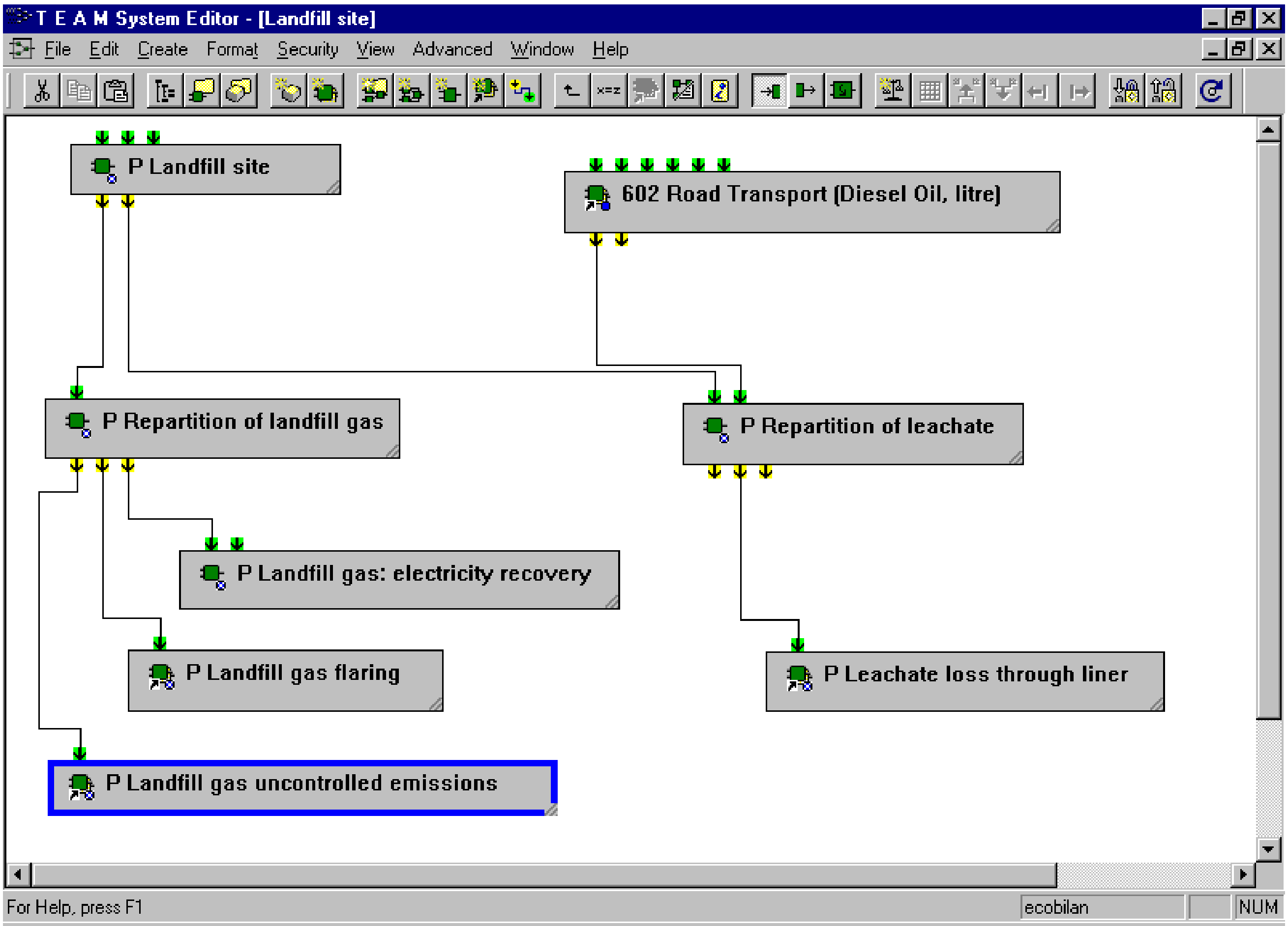
- Collection and transport of household waste to the landfill site (taken into account elsewhere in the tool)
- Transport of raw materials to the site.
- Leachates processing by other means : physical (inverted osmosis, ultra-filtration), thermal (incineration).
- The outcome for water treatment plant sludge (they represent less than 0.6% of the entire weight of incoming municipal waste).

TEAM™

Main system for landfilling



Sub-system for the landfill site



C- Main Data Characteristics

Data Type :

- Parameters relative to site management: Sources [1] & [2].

Data processing :

- **Nature :** mass balance
- **Allocation rules** :

Flow Type	Allocation rule
On-site consumption, construction & decommissioning	Allocation by mass : Consumption (kg/kg waste)=total cons. (kg)/site capacity/site life span
Use	Allocation by mass
Operations material consumption related to energy production	**Allocation according to the potential formation of landfill gas from the wastes.** The parameter appears in the 'wastes' database (q_i in kg/kg for a fraction i). The quantity of landfill gas Q_{tot} produced is therefore for a waste with a composition of n mass m_i fractions each : $Q_{tot} = \Sigma\ m_i\ (kg) * q_i$, for i={l, .. n}
Production of leachates	Allocation by mass

Representativity :

- **Year :** 1997 - 1999
- **Geographical area:** United Kingdom
- **Site Capacity** : Variable
- **Market Share** : Inexcess of 90% goes to landfill (1999)

Module Characteristics :

- **Reliability** : Modelling made from the operation of more than 9 sites in the United Kingdom
- **Completeness** : High

D- Data Sources

- **Identification :**

Source

[1]: « Inventory Development for Waste Management Operations: Landfill », WS Atkins Environment, 1997, report prepared for the Environment Agency of England and Wales.

[2]: WISARD Landfill Inventory: Extension of inventory to include landfill design/size options, Dr Bob Gregory, Land Quality Management Ltd, SChEME, University of Nottingham, January 2000

Contact :

Date of transmission for main data : 1999

Main Sources, detailed by category :

- **Raw materials** : parameters according to data from [1]& [2]
- **Energy** : parameters according to data from [1] & [2]
- **Air emissions** : parameters according to data from [2]. Refer also to module tables at the end of the DIQS section.
- **Releases to water** : parameters according to data from [2]. See also module tables at the end of the DIQS section.
- **Wastes and co-products** : parameters according to data from [2]

E- Confidentiality

Data under agreement : Process data
Confidentiality agreement: No

F- Ecobilan

Module Creation :, Ashley Tolliday
Module Validation : Olivier Muller

Appendix E: General methodology for life cycle assessment studies

The evaluation of industrial systems is not a recent subject. The first attempts -limited to energetic aspects- to evaluate the environmental impacts of a product life cycle took place in the seventies.

Life Cycle Analysis results may provide useful information for a variety of decision-making processes. A general conceptual framework for Life Cycle Assessment or Analysis (LCA) has been elaborated by the International Organisation for Standardisation (ISO). International Standard ISO 14040[26] was prepared by Technical Committee ISO/TC 207, Environmental management, Subcommittee SC 5, Life cycle assessment. Four steps have been distinguished:

– goal and scope definition,
– inventory analysis,
– impact assessment,
– interpretation.
–

The first step, *Goal and Scope definition*, consists of defining the intended application, the reasons for carrying out the study and the intended audience. The scope definition includes the type of system to be studied, the type of impact and methodology of impact assessment, and subsequent interpretation to be used, the data requirements, the assumptions and limitations of the study.

The second step, *Life Cycle Inventory (LCI) or ecobalance*, involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land associated with the system.

The third step, *Impact assessment*, is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. This phase consists in three sub-steps:

– *classification*: a mapping of items in the inventory with known environmental effects or impacts (e.g. global warming, acidification, resource depletion, etc...).
– *characterisation*: a calculation of scientifically-based indices; each index is an estimation of the potential impact of the inventory items contributing to a given environmental effect (e.g. global warming potential, acidification potential, resource depletion index, etc....).
– *evaluation*: the process of ranking or weighting various indices representing environmental impacts, in order to further 'aggregate' the parameters and aid decision making. Evaluation is a value based process, not a scientific one.

26 ISO 14040 : Environmental management - Life cycle assessment - Principles and framework, 2006.

The fourth step, *Life Cycle Interpretation*, is the phase in which the findings from the inventory analysis and the impact assessment are combined, consistent with the defined goal and scope in order to reach conclusions and recommendations.

The methodology for inventory analysis is well established (although some details are still debated). It is described in the following Chapter 10.5.

Impact assessment is still an open research domain, and the existing techniques are therefore subject to controversies. Few of them match the general framework for impact assessment as it was described above. They are described in the following Chapter 10.6.

Life Cycle Interpretation has not yet been formalised, but can be carried out in practice directly after the inventory analysis, and or after impact assessment.

10.5 Life Cycle Inventory

An inventory, or ecobalance, is a quantitative list of material and energy inputs and outputs for a given system. This list must be as complete and detailed as possible, subject to data availability.

10.5.1 The functional unit

The flows listed in the Life Cycle Inventories (LCI) are not calculated for physical quantities of the products, but on the basis of the performance characteristics (functions) of an equivalent service. The functional unit defines the quantification of these identified functions.
LCI is intended to evaluate the environmental impacts of a product which serves a given purpose. The choice of the unit relies on this purpose, and cannot merely be a unit of production (for instance mass or volume). It has instead to be a unit of use, which is called the functional unit. The unit is the basis for the calculation of any LCI.

10.5.2 System delimitation

The system is an abstraction of some set of real world activities or industrial processes. Processes and activities are represented as modules; each module has its own inputs, which are provided by other modules or directly by the environment of the system, and its own outputs, which are directed to other modules or directly to the environment of the system.

The system boundaries define which unit processes shall be included within the LCA. Several factors determine the system boundaries including the intended application of the study, the assumptions made, cut-off criteria, data and cost constraints and the intended audience.
When judiciously delimited, the system may encompass all processes that are directly or indirectly linked to the consumption of a product or a service, and that may have significant environmental impacts. In such a case, the environment of the system is very close to what is usually called the 'environment'. Ultimate flows entering the system consists of natural organic or mineral resources as well as natural energy sources, whereas those flowing out of the system consist of emissions towards environmental 'sinks' such as air, water, soil, etc.... In practice, some industrial activities are not included within the system; the practitioner should nonetheless justify that the contribution of such activities to environmental inputs and outputs of the system are relatively insignificant.

This justification usually relies on two kinds of criteria:

– quantitative ones: for instance the weight or energy content of the product whose production route has been neglected is small compared to other raw materials from the same stage.

– qualitative ones: toxicity (inclusion within the system boundary of a well-known toxic element, even though its mass contribution is not very high).

Such a system encompasses all activities from the 'cradle' (the sources of natural resources necessary for the product) to the 'grave' (the end of the life of the product, often corresponding to final releases to environmental sinks).
Transport steps and energy sources production are included in the system. The Figure 47 shows a general representation of a system for LCI.

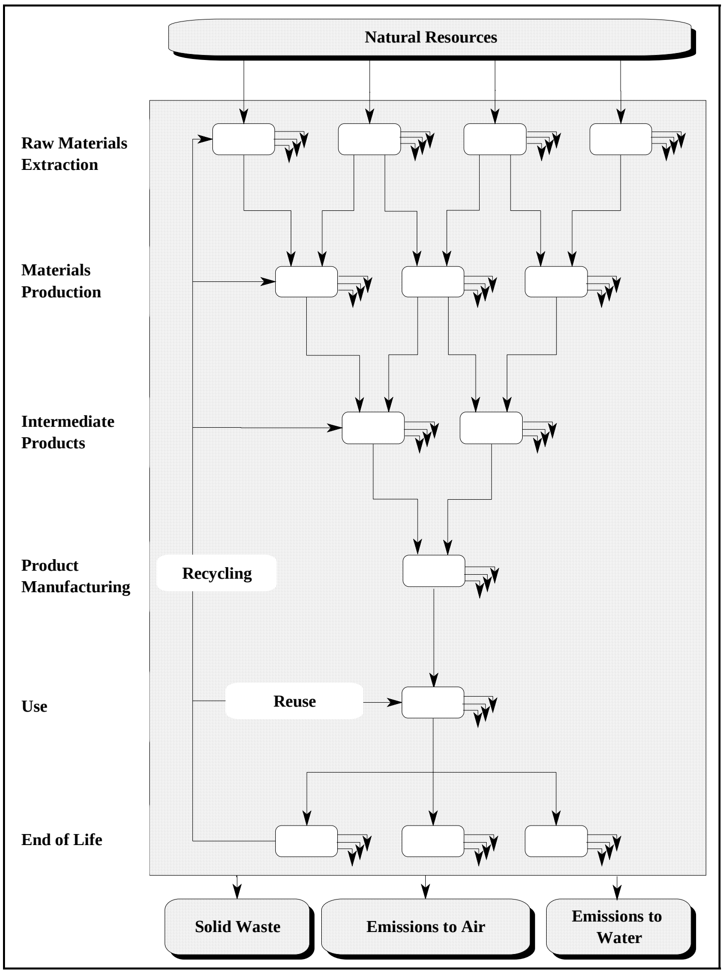


Figure 47: Simplified representation of a system for Life Cycle Inventory

10.5.3 Data collection

Data are collected, either from industrial operators (this should be the preferred source of data, at least for the main processes in the system), or from public databases and the literature, for every module in the system. Data can also be estimated through models and engineering calculations. In practice, all data categories may include a mixture of measured, calculated and estimated data. The individual data categories should be further detailed to satisfy the goal of the study. The data include:

– material inflows and outflows to and from the module (primary resources, intermediate materials and products for inputs; products, emissions released to air, water and soil and waste directed to a waste management operation for outputs);

– energy inflows and outflows.

The following figure shows the information that must be collected for each module.

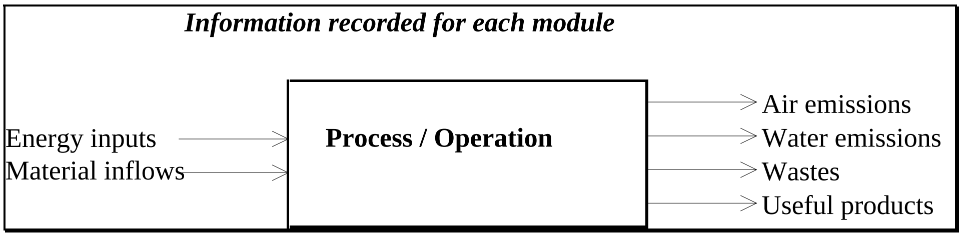


Figure 48: Information recorded for each module

10.5.4 Calculation procedures

Following the data collection process, calculation procedures are needed to generate the results of the inventory of the defined system for each unit process and for the defined functional unit of the product system that is to be modelled. Several operation steps are needed for data calculation :

– validation of data,
– relating data to functional unit and data aggregation,
– refining the system boundaries.

Ecobilan uses its LCI software TEAM™ to perform the calculations.

10.5.5 Allocation procedures

Allocation procedures are needed when dealing with systems involving multiple products.
Industrial process may generate co-products or valorised materials. Rules have to be chosen to allocate inputs and outputs between these co-products or between the studied product and recovered materials according to clearly stated procedures, which shall be documented and justified. Different rules exist, related for instance to mass, volume, calorific value.

10.6 Impact Assessment and Interpretation of Life Cycle Inventory

This phase of environmental assessment relies on the inventory and develops two types of analysis:

– analysis of the origins of impact flows or factors in the life cycle,

– analysis of flows regarding their effects or impacts.

10.6.1 Identification of impact factors origins in the life cycle

It brings to the forefront the steps or materials which are the main contribution to the system flows. This mode of analysis highlights, once the life cycle flows have been translated into impacts, the most efficient domains of action in order to reduce environmental impacts.
Moreover, in the absence of environmental impact quantification for some flows, this mode of analysis allows a global management to reduce them.

10.6.2 Analysis of the flows regarding their effects on the environment

The purpose of this approach is to propose tools to analyse the ecobalance in terms of known environmental problems so that the analysis is based on indices which tend to evaluate the contribution of substances to a given environmental effect.

The main difficulty with this second mode of analysis comes from the fact that these indices are closely linked to the present state of scientific knowledge. They are elaborated by experts and represent a consensus but have to be updated as knowledge improves. Therefore, transparency is critical to impact assessment to ensure that assumptions are clearly described and reported.

ECOBILAN uses indices produced or compiled by IPCC[27], WMO[28], RIVM[29], VROM[30] and CML[31], as well as documents distributed by the Ministry of the Environment in France. Four environmental effects, to which substances and materials used during the studied products life cycle, are frequently estimated :

- the depletion of non renewable resources,
- the global warming effect,
- the acidification (of rains, soils, waters, ...),
- the water eutrophication.

10.6.3 Non renewable resource depletion

The purpose is to evaluate the contribution of the studied systems to non renewable resources depletion. Non renewable resources are hydrocarbons or ores. Three indices (Table 1) are available. They are calculated as the sum of consumed quantities weighted by the inverse of the amount of estimated known resources (R) and/or the number of available years of reserve (Y), equal to the ratio between present-day annual world consumption.and estimated known resources.

27 Intergovernmental Panel on Climate Change (United Nation Organisation)
28 World Meteorological Organisation
29 National Institute of Public Health and Environmental Protection (The Netherlands)
30 One department of the National Institute of Public Health and Environmental Protection (The Netherlands)
31 Centre for Environmental Science Leiden University (The Netherlands)

Resources	Reserve (R) ($10^{e}6$ t)	1/RY ($10^{e}15$*yr-1)	1/Y (yr-1)
(r) Antimony (Sb, ore)	3.2	13671.8	23
(r) Arsenic (As, ore)	1.26	26455.0	30
(r) Barium Sulphate (BaSO4, in	480	26.91	77
(r) Bauxite (Al2O3.2 H2O, ore)	34000	0.108	272
(r) Bismuth (Bi, ore)	0.26	67455.6	57
(r) Cadmium (Cd, ore)	1.2	13820	60
(r) Chromium (Cr, ore)	5200	0.319	603
(r) Coal (in ground)	2980000	0.00050	666
(r) Cobalt (Co, ore)	9.5	335.734	314
(r) Copper (Cu, ore)	650	28.16	55
(r) Fluorspar (CaF2, ore)	370	33.163	81
(r) Gold (Au, ore)	0.072	463000	30
(r) Ilmenite (FeO.TiO2, ore)	1220	5.74	143
(r) Iron (Fe, ore)	160000	0.04	157
(r) Lead (Pb, ore)	140	157	45
(r) Lignite (in ground)	2980000	0.00050	666
(r) Lithium (Li, ore)	9.4	181.077	588
(r) Manganese (Mn, ore)	5000	0.296	676
(r) Mercury (Hg, ore)	0.24	45139	92
(r) Molybdenum (Mo, ore)	12	944.444	88
(r) Natural Gas (in ground)	130000	0.117	66
(r) Nickel (Ni, ore)	140	59.7	120
(r) Oil (in ground)	239000	0.0557	75
(r) Palladium (Pd, ore)	0.078	20545.6	624
(r) Perlite (SiO2, ore)	2000	0.468	1070
(r) Phosphate Rock (in ground)	35000	0.115	248
(r) Platinium (Pt, ore)	0.078	25476.6	503
(r) Potasium (K, as K2O, in	17000	0.086	683
(r) Potassium Chloride (KCl, in	17000	0.086	683
(r) Rutile (TiO2, Ore)	630	11.121	143
(r) Silver (Ag, ore)	0.42	92837	26
(r) Strontium Sulphate (SrSO4, in	12	2361.11	35
(r) Sulphur (S, in ground)	3500	4.408	65
(r) Tin (Sn, ore)	12	1500	56
(r) Titanium (Ti, ore)	378	18.535	143
(r) Tungsten (W, ore)	3.2	3271.48	96
(r) Uranium (U, ore)	13.41	181	412
(r) Vanadium (V, ore)	27	48.011	771
(r) Zinc (Zn, ore)	440	40.29	56
(r) Zirconium (Zr, ore)	65	214.675	72

Table 1 : Non renewable resources depletion coefficients (sources : US Bureau of Mines 1998, World Energy Council 1998)

10.6.4 Global Warming Effect

Global warming effect corresponds to the atmospheric average temperature increase, induced by the increase of the average atmospheric concentration of various substances of anthropogenic origin.

Direct contribution

The solar radiation is re-emitted by the earth surface in the form of infrared radiation, which can be partially absorbed by different atmospheric chemical species. The radiate balance determines the average temperature on earth. Thus, the environmental imbalance does not rise from the existence of this effect, which is necessary to the survival of species, but from its increase.

The unit used to measure a substance contribution to the greenhouse effect is **the CO_2 mass equivalent.** The Global Warming Potential (GWP) of a gaseous substance is the greenhouse effect potential of a gram emission of that substance, compared to one gram of CO_2. The typical uncertainty of the figures contained in the table below is more or less 35% relative to the CO_2 reference.

Indirect contribution

The « greenhouse effect potential » takes into account not only the direct contribution of a gas, as described above, but also its indirect contribution, through the production or destruction of other greenhouse gases or its interaction with gases of the atmosphere. CFCs for instance, are greenhouse gases and thus have a direct impact. On the other hand, they contribute to the destruction of the stratospheric ozone which is another greenhouse gas. The result of the action of the CFC on global warming thus has a positive and a negative component.

According to IPCC, the indirect action of nitrogen oxides (NO_x), would also be twofold: increase of the atmospheric content of ozone (O_3) by photochemical reactions and thus increase of the concentration of a greenhouse gas on one hand (indirect positive contribution), and on the other hand (indirect negative contribution) increase of OH concentration, a very reactive free radical which decreases the lifetime and thus, CH_4, HCFC and HFC concentration, all of them greenhouse gases.

According to the IPCC, methane, which has a direct global warming effect, also has an indirect effect on earth warming. Only a part of methane indirect effect is taken into account.

Greenhouse gases	Unit	100 years
(a) Carbon Dioxide (CO2, fossil)	g eq. CO_2	1
(a) Carbon Tetrachloride (CCl4)	g eq. CO_2	1400
(a) Carbon Tetrafluoride (CF4)	g eq. CO_2	7390
(a) CFC 11 (CFCl3)	g eq. CO_2	4750
(a) CFC 113 (CF2ClCFCl2)	g eq. CO_2	6130
(a) CFC 114 (CF2ClCF2Cl)	g eq. CO_2	10000
(a) CFC 115 (CF3CF2Cl)	g eq. CO_2	7370
(a) CFC 12 (CCl2F2)	g eq. CO_2	10900
(a) CFC 13 (CF3Cl)	g eq. CO_2	14400
(a) Chloroform (CHCl3, HC-20)	g eq. CO_2	5
(a) Dimethyl Ether (CH3OCH3)	g eq. CO_2	1
(a) Halon 1201 (CHF2Br)	g eq. CO_2	470

Greenhouse gases	Unit	100 years
(a) Halon 1211 (CF2ClBr)	g eq. CO_2	1890
(a) Halon 1301 (CF3Br)	g eq. CO_2	7140
(a) HCFC 123 (CHCl2CF3)	g eq. CO_2	77
(a) HCFC 124 (CHClFCF3)	g eq. CO_2	609
(a) HCFC 141b (CFCl2CH3)	g eq. CO_2	725
(a) HCFC 142b (CF2ClCH3)	g eq. CO_2	2310
(a) HCFC 21 (CHCl2F)	g eq. CO_2	210
(a) HCFC 22 (CHF2Cl)	g eq. CO_2	1810
(a) HCFC 225ca (C3HF5Cl2)	g eq. CO_2	122
(a) HCFC 225cb (C3HF5Cl2)	g eq. CO_2	595
(a) HCFE 235da2 (C3H2ClF5O)	g eq. CO_2	350
(a) Hexafluoroethane (C2F6, FC116)	g eq. CO_2	12200
(a) HFC 125 (CF3CHF2)	g eq. CO_2	3500
(a) HFC 134 (C2H2F4)	g eq. CO_2	1100
(a) HFC 134a (CF3CH2F)	g eq. CO_2	1430
(a) HFC 143 (C2H3F3)	g eq. CO_2	330
(a) HFC 143a (CF3CH3)	g eq. CO_2	4470
(a) HFC 152 (CH2FCH2F)	g eq. CO_2	43
(a) HFC 152a (CHF2CH3)	g eq. CO_2	124
(a) HFC 161 (CH3CH2F)	g eq. CO_2	12
(a) HFC 227ea (CF3CF2CHF2)	g eq. CO_2	3220
(a) HFC 23 (CHF3)	g eq. CO_2	14800
(a) HFC 236cb (CH2FCF2CF3)	g eq. CO_2	1300
(a) HFC 236ea (CHF2CHFCF3)	g eq. CO_2	1200
(a) HFC 236fa (CF3CF2CH2F)	g eq. CO_2	9810
(a) HFC 245ca (CF3CF2CH3)	g eq. CO_2	640
(a) HFC 32 (CH2F2)	g eq. CO_2	675
(a) HFC 365mfc (C4H5F5)	g eq. CO_2	794
(a) HFC 41 (CH3F)	g eq. CO_2	97
(a) HFC 43-10 mee	g eq. CO_2	1640
(a) HFE 125 (CF3OCHF2)	g eq. CO_2	14900
(a) HFE 134 (CHF2OCHF2)	g eq. CO_2	6320
(a) HFE 143a (CH3OCF3)	g eq. CO_2	756
(a) HFE 245fa2 (C3H3F5O)	g eq. CO_2	659
(a) HFE 254cb (C3H4F4O)	g eq. CO_2	30
(a) HFE 7100 (C4F9OCH3)	g eq. CO_2	390
(a) HFE 7200 (C4F9OC2H5)	g eq. CO_2	55
(a) Methane (CH4)	g eq. CO_2	25
(a) Methyl Bromide (CH3Br)	g eq. CO_2	5
(a) Methyl Chloride (CH3Cl)	g eq. CO_2	13
(a) Methyl Chloroform (CH3CCl3, HC-140a)	g eq. CO_2	146
(a) Methylene Bromide (CH2Br2)	g eq. CO_2	1
(a)Methylene Chloride (CH2Cl2, HC-130)	g eq. CO_2	8.7
(a) Nitrous Oxide (N2O)	g eq. CO_2	298
(a) Perfluorobutane (C4F10)	g eq. CO_2	8860

Greenhouse gases	Unit	100 years
(a) Perfluorocyclobutane (c-C4F8)	g eq. CO_2	10300
(a) Perfluorohexane (C6F14)	g eq. CO_2	9300
(a) Perfluoropentane (C5F12)	g eq. CO_2	9160
(a) Perfluoropropane (C3F8)	g eq. CO_2	8830
(a) Sulphur Hexafluoride (SF6)	g eq. CO_2	22800

Table 26: Greenhouse gases coefficients (sources: IPCC 2008)

10.6.5 Acidification

Acidification is defined as the acid substances content increase in low atmosphere, generating « acid rains » and the decline of some forests. The unit taken for the contribution measurement of a substance to the acidification is **the acidification potential (H^+).** As this effect has a regional dimension, the spatial distribution of the concerned gases emissions can modulate the global calculation result of a life cycle impact, in terms of acidification.

Emissions contributing to acidification	1/Coefficient
(a) Ammonia (NH3)	17
(a) Chromic Acid (H2CrO4)	29.5
(a) Hydrogen Bromide (HBr)	81
(a) Hydrogen Chloride (HCl)	36.5
(a) Hydrogen Cyanide (HCN)	27
(a) Hydrogen Fluoride (HF)	20
(a) Hydrogen Sulphide (H2S)	17
(a) Nitrogen Oxides (NOx as NO2)	46
(a) Sulphur Oxides (SOx as SO2)	32
(a) Sulphuric Acid (H2SO4)	49

Table 27: Acidification coefficients (source: Leiden university, Netherlands)

10.6.6 Eutrophication

Eutrophication stems from the introduction into water of an aqueous medium of nutrients, especially nitrogen and phosphorus containing compounds. Excess of these nutrients causes an overgrowth of algal biomass (algal blooms). During the day, algal photosynthesis consumes CO_2 and gives rise to a pH increase. Transparency of waters is reduced. After few weeks, algal biomass begins to decay and is metabolised by protozoa and bacteria. This results in dissolved O_2 decrease, CO_2 release and acidification, which can lead to the destruction of the fauna and flora of the aquatic medium.
The contribution of releases to eutrophication is deduced:

- from the average elementary composition of algae (considering that each release contributes to algae development and that the other atomic elements necessary to this development are available in the natural medium),

- from the biological demand in oxygen of other substances, which induce through their decomposition a decrease of the dissolved oxygen level (BOD being not systematically measured, the COD, for which the relation with BOD is known for certain substances, is then used).

The unit considered for the contribution of a substance to eutrophication is **the phosphate equivalent.**

However, it should be noted that it is less relevant to apprehend eutrophication in terms of global effect than for previously described effects. Such an effect will in fact depend on local conditions, such as the rate of flow of the river into which the substance is being discharged, the vicinity of other discharge sources, etc....

Emissions contributing to eutrophication	Coefficient
(w) Ammonia (NH4+)	0.42
(w) COD (Chemical Oxygen	0.022
(w) Nitrates (NO3-)	0.095
(w) Nitrites (NO2-)	0.13
(w) Nitrogen (N, total)	0.42
(w) Nitrogen Dioxide (NO2)	0.13
(w) Nitrogen Oxide (NO)	0.2
(w) Nitrogenous Matter (Kjeldhal,	0.42
(w) Nitrogenous Matter	0.42
(w) Phosphates (PO4 3-)	3.06
(w) Phosphorous Matter	3.06
(w) Phosphorus (P)	3.06
(w) Phosphorus Pentoxide (P2O5)	1.336

Table 28: Eutrophication coefficients (source: Leiden University, Netherlands)

10.6.7 Toxicity of emissions towards humans and ecosystems

Several methods exist to evaluate the toxicity of emissions towards humans and ecosystems:

- **Indicator based on Mackay model,** developed in 1992 by the *Center of Environmental Science* (CML, Leiden University, Netherlands) in the framework of *Netherlands National Reuse of Waste Research Program* (NOH).
- **Indicator based on USES 1.0 model**, developed in 1995 by the *Center of Environmental Science* (CML, Leiden University, Netherlands) and by the *National Institute of Public Health and Environmental Protection* (RIVM, Bilthoven, Netherlands). Coefficients are derived from PEC/PNEC ratio (Predicted Environmental Concentration / Predicted No Effect Concentration) based on USES (Uniform System for the Evaluation of Substances) model. More sophisticated than the Mackay model, USES takes into account transfer of pollutants between compartments.
- **Indicator based on the USES 2.0 model**, developed in 1999 by Mark Huijbregts (Amsterdam University) and based on the second version of USES (developed by RIVM).
- **Indicator based on an empirical approach**, developed in 1995 by Olivier Jolliet and Pierre Crettaz, from the Université Polytechnique Fédérale de Lausanne. Dilution factors are defined empirically from national emissions and pollutant concentration in the atmosphere.