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Re-Engineering Business for Sustainability (REBUS)

Life Cycle Assessment: Conventional versus Product Service System approach to the provision of a child car seat (infant carrier)

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Glossary

Acronym / term	Description
A	Acidification
ABS	Acrylonitrile butadiene styrene
CC	Climate change
CF	Characterisation Factor
EF	Eutrophication freshwater
ELCD	European Life Cycle Database
EM	Eutrophication marine
EoL	End of Life
EPS	Expanded Polystyrene
ET	Eutrophication terrestrial
ETF	Ecotoxicity freshwater
HTC	Human toxicity, cancer effects
HTNC	Human toxicity, non-cancer effects
IR	Ionizing radiation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LU	Land use
NI	Normalised impact: Characterised environmental impact expressed as a percentage of the impact of an average EU person per annum
OD	Ozone depletion
PA6	Polyamide 6
PC	Polycarbonate
PE	Polyethylene
PM	Particulate matter
POF	Photochemical ozone formation
POM	Polyoxymethylene
PP	Polypropylene
PSS	Product Service System
RDM	Resource depletion, mineral, fossils and renewables
RDW	Resource depletion water
REBUS	Re-Engineering Business for Sustainability
USLCI	U.S. Life Cycle Inventory Database

Executive summary

This study has undertaken a Life Cycle Assessment (LCA) for Dorel's Maxi-Cosi Pebble car seat (infant carrier). The purpose of the LCA is to compare the environmental impact performance of a 'conventional' versus a 'product service system' (PSS) approach to the purchase of a car seat. The PSS approach involves the return and refurbishment of the car seat prior to reuse, whereas the conventional approach is the sale of a completely new car seat for each customer. Consequently there should be savings in terms of the resources used and associated emissions and impacts. The LCA aims to quantify these for the conventional system and the PSS.

The approach followed LCA stages and processes as defined by ISO 14040 & 14044 as far as was possible given the data available. The functional unit in this instance relates to the number of times a car seat can be refurbished and reused in the PSS. As a minimum this is two uses, but it could be more. Consequently the results are either expressed per 2 uses or as the difference per use. The performance of the PSS is expressed as an incremental increase per use, i.e. for the conventional car seat, the incremental increase is always 100% (as a new car seat is used each time), thus any incremental increases below 100% are an improvement.

The LCA focuses on the resources, energy and emissions associated with the manufacture of the materials used in the car seat and the transport of the car seat. Assembly and refurbishment processes for the car seat; retail; use and end of life phases were not included. Dorel provided primary data on the quantity of different materials used to make the car seat and its replacement parts. For transport, typical/average distances were used. The remaining life cycle inventory data was all secondary data and the majority was derived from the European Life Cycle Database (ELCD), apart from data for Carbon black; Polyoxymethylene (POM) and Viscose, which are not in the ELCD so were derived from alternative sources. All data were scored (out of 25) to assess their quality, with data from the ELCD scoring 17-22 and other sources 7 to 13.

The impact categories used in the LCA are those used in the ELCD. Two of these: Ionizing radiation and Land use, resulted in zero impacts, so were excluded from the results. All the impacts were normalised by expressing the values as a percentage of the impact of the average person in the European Union. In so doing this provided a basis to judge the relative significance of each impact.

The car seat plus its packaging amounts of 4.7 kg of materials. The PSS replaces 1.87 kg of materials per use, thus 2.84 kg of materials directly avoid disposal per use and do not need to be replaced with new materials. This is in itself a valuable outcome of the PSS, however, there is also all the materials, energy, emissions and impacts associated with the manufacturing and transporting of those materials.

In terms of material resource use, each conventional car seat requires 50.8, 11.6 and 3.5 kg of resources from the air, ground and water respectively. Each time the conventional car seat is used these all increase by 100%, but each time a PSS car seat is used the incremental increase is 28.9, 37 and 96.7% respectively. The last of these, resources from water, does not change much as the majority of water resources used go into the manufacture of paper and card, the use of which remains the same in both the conventional and PSS car seats. In terms of energy resource use, each conventional car seat requires 1.1, 290.8, 3.6 and 0.09 MJ from the air, ground, water and the biosphere respectively. Each time a PSS car seat is used the incremental increase is 40.8, 18.3, 44 and 70.9% respectively. The last of these, energy resources from the biosphere, the incremental increase appears to be relatively high as the majority of this goes into the manufacture of GF-Fibre, Paper and Polyethylene (PE), which are replaced in the PSS. However, in comparison to energy resources from the air, ground and water, this only represents a small fraction (0.03% of the total).

With respect to emissions, each conventional car seat results in 65, 0.001 and 0.3 kg emissions to the air, soil and water respectively. Each time a PSS car seat is used the incremental increase is 29.9, 22.5 and 20.5% respectively. This is a significant saving, but it is important to determine what these emission reductions mean in terms of end impacts.

Figure E1 shows the incremental increase in impact for the PSS alongside the normalised impact (NI) for a single use of the conventional car seat. The higher the blue bars the greater the impact significance and the lower the red bars the greater the PSS performance. These can be combined to express the performance in relation to impact significance, resulting in Figure E2. This performance index has been calculated by multiplying the inverse incremental impact of the PSS by the normalised impact of the conventional car seat. This immediately highlights that the performance of the PSS is greatest for reducing the particulate matter impact, followed by acidification, photochemical ozone formation, climate change and eutrophication (terrestrial and marine).

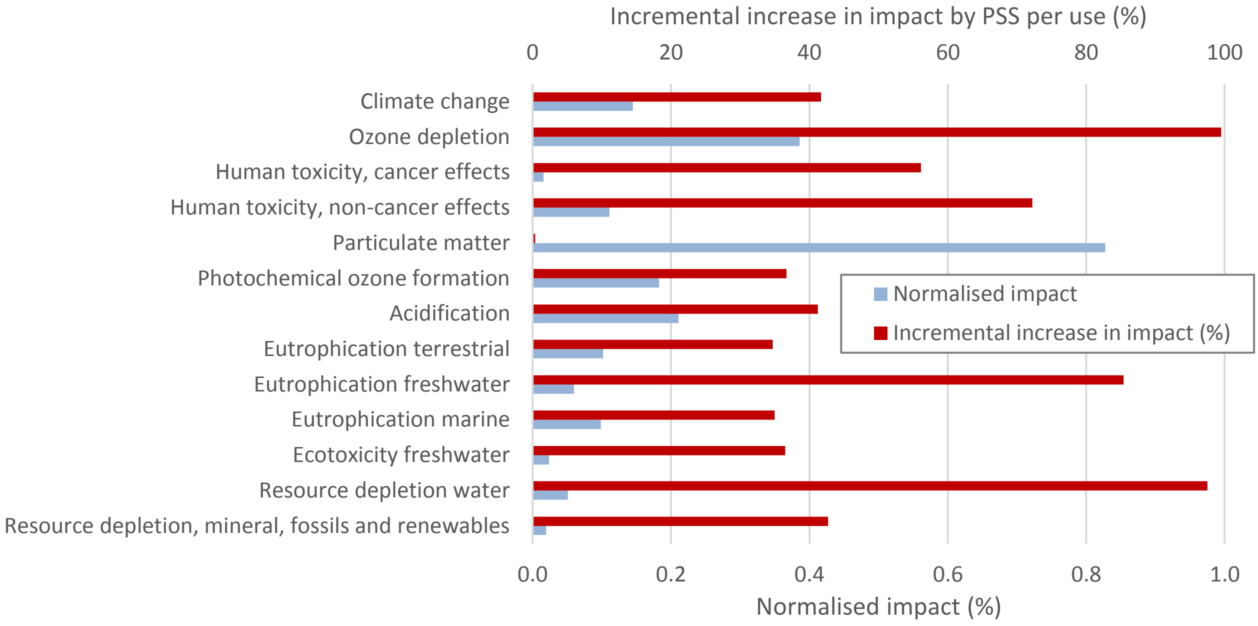

Figure E1: NI for Conventional car seat and Incremental increase in impact by the PSS

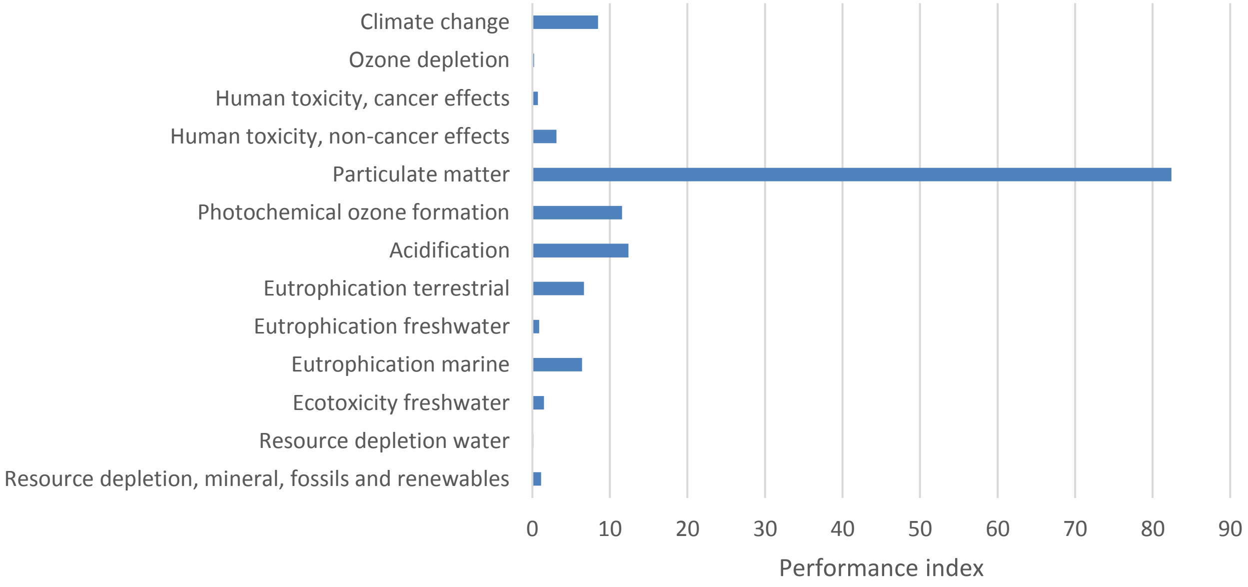

Figure E2: Impact reduction performance of the PSS

If we examine the difference in impact between the conventional and PSS car seats (for 2 uses) and sum the normalised impact for each of the materials we can see the biggest change is in the impact of plastics (on particulate matter, climate change & human toxicity, non-cancer effects) and transport (for photochemical ozone formation, acidification & eutrophication (terrestrial and marine)) (Figure E3). Figure E4 reveals that the reuse of Polypropylene (PP) creates the largest difference in impact, followed by the reduction in ocean transport; then to a lesser degree the reuse of Polycarbonate (PC); Expanded Polystyrene (EPS); Acrylonitrile butadiene styrene (ABS); and Polyamide 6 (PA6).

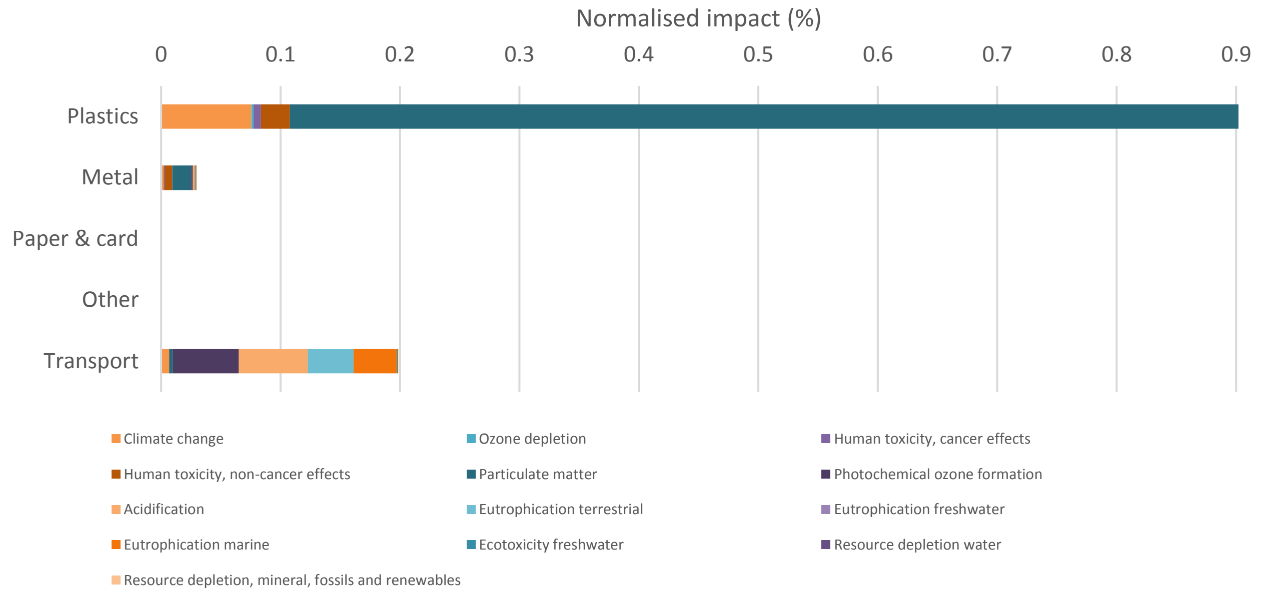

Figure E3: NI difference: Conventional & PSS (2 uses): partial breakdown

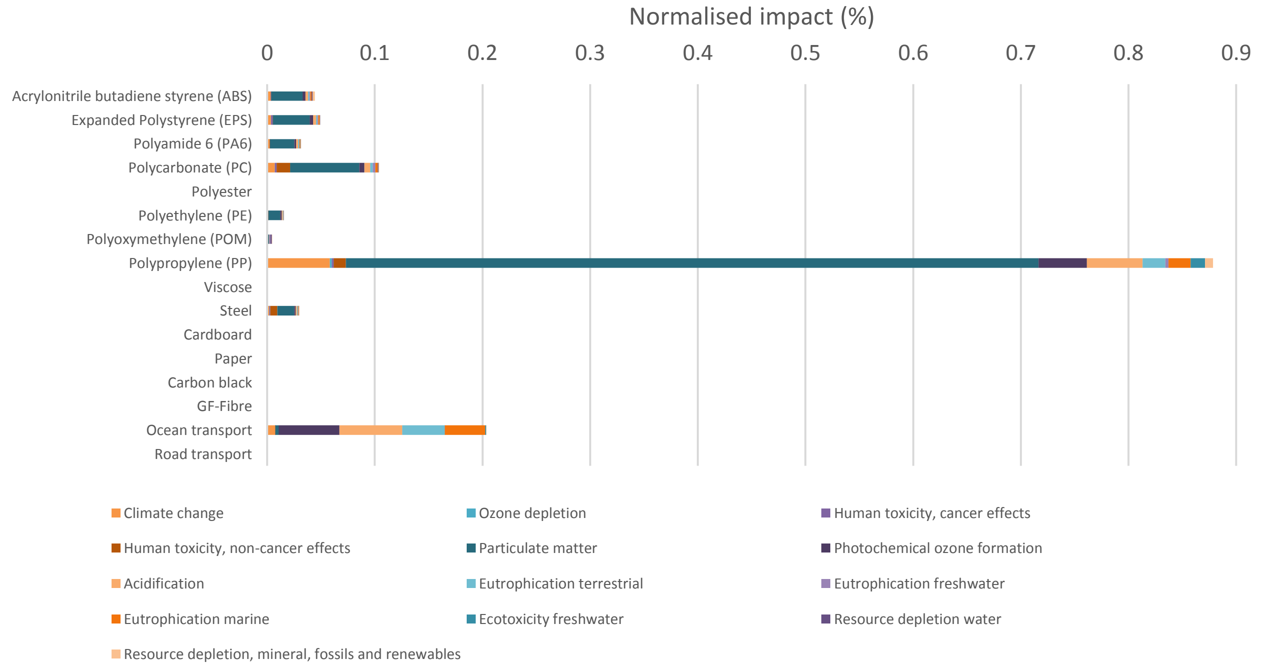

Figure E4: NI difference: Conventional & PSS (2 uses): full breakdown

There are some weaknesses in the data, particularly for Carbon black, Polyoxymethylene (POM) and Viscose, but these do not appear to significantly impact on the key findings of the LCA with respect to the difference between conventional and PSS car seats. However, they do potentially impact on the results of the impact of the car seat. For example, the 0.39% normalised impact for ozone depletion (see Figure E1) arises almost entirely from Viscose. This is not affected by the PSS, but it is the second most significant impact of the car seat, thus given the low data quality score for Viscose (10/25), this impact should be questioned.

This LCA excludes any resources, energy, emissions and impacts associated with the assembly and refurbishment of the car seat and some road transport journeys. However, given the results, it is anticipated that these are likely to be very small compared to the other impacts and would also increase the performance of the PSS, thus there is no scope for them to contradict the findings.

This LCA should be regarded as worst case scenario with respect to the impacts associated with transport. At the outset of the LCA it was assumed that all materials for the car seat are manufactured in China. It has now been highlighted that the bulk of Dorel's car seats are manufactured (assembled) in Holland, Portugal and France. This would reduce the transport impacts, especially ocean transport, due to the decrease in distance, thus the benefits of the PSS would be reduced accordingly. However, some of the materials used in the car seats manufactured in Europe, such as the fabrics and some metals, are manufactured in China, thus there would still be transport impacts associated with these similar to those presented herein, depending on the quantities involved (which are unknown).

The omission of the end of life phase does have the potential to impact upon the performance of the PSS. The diversion of waste from landfill (by reusing materials) in the PSS not only saves the resources, emissions and impacts that go into those materials, but also emissions and impacts from landfilling. This is particularly the case for plastics and their impact on Eutrophication freshwater, which have been estimated to be 44% of the total impact of a conventional car seat. However, if a significant number of conventional car seats are reused and/or their materials are recycled, then this could potentially impact upon the relative performance of the PSS. The impact of different end of life options would need to be calculated to determine this. However, any potential reduction in performance may be offset by the fact that the PSS also has the advantage that the car seat is returned to the company after each use, thus it is more within the control of the company to minimise the end of life impacts.

1.0. Introduction

1.1. Background

This study is part of a wider project funded by Department for Environment, Food and Rural Affairs (Defra) (Project EV0534) in which a Product Service System (PSS) was piloted for nursery equipment. This project explored a number of different aspects including the (i) business model; (ii) behaviour change strategies; and (iii) environmental performance of the PSS compared to a traditional/conventional business model. This document reports on the third aspect, the environmental performance of the PSS, using a child car seat (infant carrier) as a case study.

1.2. Methodology

1.2.1. Introduction

The study undertook a Life Cycle Assessment (LCA) for Dorel's Maxi-Cosi Pebble car seat (infant carrier) (Dorel, 2016). The approach followed LCA stages and processes as defined by ISO 14040 & 14044 (ISO, 2006a&b) as far as was possible given the data available. This section describes the methods employed to obtain the primary data; the Life Cycle Inventory (LCI); and Life Cycle Impact Assessment (LCIA).

1.2.2. Primary data collection

The primary data were obtained directly from Dorel. This data consisted of the following:

- A breakdown of the materials that were used within each car seat and its packaging.
- The amounts of each material replaced during the refurbishment process (for the PSS).
- The average distance each car seat was transported for delivery to the customer.

Details of any energy or materials used in the processes to assemble/refurbish the car seat were not provided. Details on the End of Life (EoL) phase were not provided.

1.2.3. Life Cycle Inventory (LCI)

1.2.3.1. Data sources

Given the lack of data on assembly processes for the car seat, efforts have been made to source LCI data on the resources, energy and emissions associated with the manufacture of the materials used in the car seat and its packaging; the transport of car seat; and the production of the fuel used in the transport.

LCI data for these materials and processes (flows) was sourced from the European Platform on Life Cycle Assessment: European reference Life Cycle Database (ELCD) (JRC, 2016a). Similar data was also examined in the U.S. Life Cycle Inventory Database (USLCI, 2012), but it was considered that although the USLCI had data for some more specific materials the data were not as comprehensive as the ELCD; in some instances had different units; and were probably not as relevant to the European or Asian context. Therefore, it was decided to use the ELCD as the key source for generating LCI data.

For three materials, LCI data could not be sourced from the ELCD or any other similar databases. For these materials emissions data were sourced from other studies and literature.

1.2.3.2. Data management and bespoke software

The amount of data that is stored for each material and process in the ELCD is considerable. For this study the data consists of:

- 938 inputs
- 4320 outputs
- 3809 different substances
- 42,822 characterisation factors (this is for all substances in the ELCD)

This amount of data is not something that can be easily handled within an MS Excel spreadsheet (not without serious risk of errors), so it was decided to construct a MS Access database to store the data and build an MS Visual Basic.NET application to interrogate the database and perform the necessary LCI and LCIA calculations.

LCI data management involved the following processes:

- Import of ELCD characterisation factors into the MS Access database
- Import of ELCD inputs and outputs for each material/process into the MS Access database
- Interrogation of the MS Access database for each material to retrieve the inputs and outputs
- Using the inputs data to determine material and energy resources used from the air, ground, water and the biosphere per kg of material
- Using the outputs data to determine emissions per kg of material

These LCI processes are conceptually illustrated in Figure 1.1, which also encompasses the processes for the LCIA.

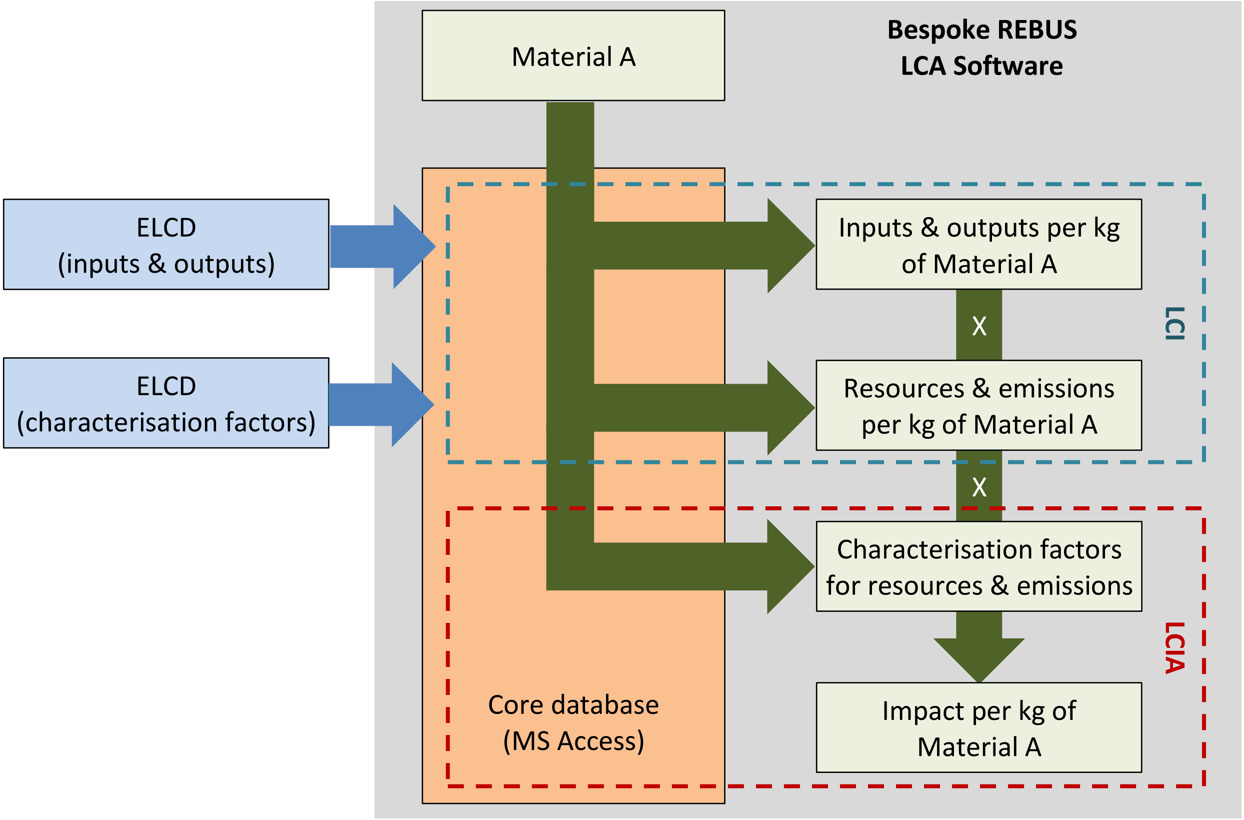

Figure 1.1: Data management processes

The LCI data output from the process shown in Figure 1.1 is expressed in terms of the resources and emissions per kg of each material and per kg per km for transport.

1.2.4. Life Cycle Impact Assessment (LCIA)

1.2.4.1. Data sources

As described in Section 1.2.3.1 the data for most of the materials and processes was obtained from the ELCD (JRC, 2016a), and this includes the characterisation factors to convert the LCI data on resources and emissions into impacts. For some materials, LCI data did not exist in the ELCD. To fill this gap in data, impact data were sought from other studies and literature. In some instances this required conversion of some impact factors – these are described in the notes and assumptions section of the LCA (see Section 2.6).

1.2.3.2. Data management

LCIA data management involved the following processes:

- Calculating the resource depletion impacts of resources used per kg of material (using the appropriate impact characterisation factors)
- Calculating the impact of emissions used per kg of material (using the appropriate impact characterisation factors)

This data was exported to an MS Excel spreadsheet where it was then combined with the primary data gathered for the car seat, for the conventional and PSS approaches, to generate the LCA data.

1.2.5. Data quality assessment

An assessment of the quality of the data used in the study has been made using the data pedigree matrix approach. Table 1.1 shows a pedigree matrix that has been adapted from Weidema and Wesnæs (1996), which is used to derive quality scores for each dataset used in the LCA. Each dataset is awarded a score for each criterion, thus a maximum score of 25 is possible. The criteria are fairly self-explanatory, however the following approach was used to derive each score:

- **Reliability and Completeness:** The description of the data source was used to score these two criteria. For example, data in the ELCD tended to score highly as the ELCD describes the source of the data in detail and is often based on a large number of representative measurements.
- **Temporal:** The reference year and year valid (or the year of the study for non-ELCD data sources) was the main basis for deriving the score for this criterion. Those closest to the year of this study scored the highest
- **Geographical:** The location from where the data was collected and/or the region it represents was used to score this criterion in relation to the known locations relevant for the car seat. For example, much of the data in ELCD is for Europe, but in this study it has been assumed that the manufacture of materials took place in China, consequently many of the ELCD data sources scored low for this criterion, whereas the location of data used for transport was more relevant, thus achieved a higher score.
- **Technological:** The source and description of the data was used to score this criterion. Clearly the primary data scored well for this criterion, as it was company specific, whereas data from the ELCD was more generic, so this achieved a lower score.

The scores for each criterion were summed for each dataset, and thus provided a basis for assessing the quality of each dataset, which was then used to inform the interpretation stage of the LCA.

Table 1.1: Data pedigree matrix

Criterion	Score				
	1	2	3	4	5
Reliability	Unqualified estimate	Qualified estimate	Unverified data based partly on assumptions	Verified data based partly on assumptions or non-verified data based on measurements	Verified data based on measurements
Completeness	Unknown or incomplete data from a small number of sites	Representative data from a small number of sites over a shorter period or inadequate data from adequate number of sites	Representative data from an adequate number of sites but over a shorter period	Representative data from a smaller number of sites over an adequate period	Representative data from an adequate sample of sites over an adequate period
Temporal	Unknown or > 15 years	<15 years difference	<10 years difference	<6 years difference	< 3 years difference
Geographical	Unknown or different area	Data from an area with a slightly similar production structure	Data from an area with a similar production structure	Average data from a larger area	Data from an adequate area
Technological	Unknown or data from related processes and materials, different technology	Data from related processes and materials, same technology	Data from processes under study with different technologies	Data from processes under study for different companies	Data from processes under study and company-specific

Adapted from: Weidema and Wesnæs (1996)

2.0. Goal definition and scope

2.1. Goal/purpose

The purpose of the LCA is to compare the environmental impact/performance of a 'conventional' versus a 'product service system' (PSS) approach to the purchase of a child car seat (Dorel's Maxi-Cosi Pebble). The PSS approach involves the return and refurbishment of the car seat for each use (in addition to production and transport of original car seat), whereas the conventional approach is the sale of a completely new car seat for each use. Consequently there should be a saving in terms of resources used and associated emissions and impacts. Thus the LCA aims to quantify these for the conventional system and the PSS.

2.2. Functional unit

The functional unit in this instance relates to the number of times a car seat can be refurbished and reused in the PSS. As a minimum this is two uses (as below this it would be a single use and thus identical to the conventional system), but it could be more. Three uses was reported in the Dorel study, but this could have been more given a longer period of time for the study. However, in the analysis presented in herein two uses has been used as the basis to derive the data for the comparison. Consequently the results are either expressed per 2 uses or as the difference per use. A key indicator for the performance of the PSS (for resource use, emissions and impacts) is the incremental increase per use, i.e. for the conventional car seat, the incremental increase is always 100% (as a new car seat is used each time), thus any incremental increases per use below 100% are an improvement.

Note: The inverse of the incremental increase per use would be a reduction in impact per use. It was decided not to use this as the performance indicator as it has the potential to be misinterpreted as an overall reduction in impact by the PSS, i.e. the per use element is critical. Hence although the incremental increase in impact per use indicator is a little unorthodox it was determined to be less vulnerable to misinterpretation.

2.3. System boundaries

Figure 2.1 shows the boundaries of the system studied. The system covers both the conventional and the PSS approaches, as many of the processes are common to both. The PSS specific elements of the system are highlighted with the dotted box on the left. These elements apply after the first use of the car seat, as up till that point it follows the same processes as the conventional approach. Then after the use phase the PSS car seat goes into the refurbishment 'loop', whereas the conventional car seat goes into the disposal/EoL phase.

Those shaded green have been included within the study, and those shaded red excluded. Notably, the following processes have been excluded:

- Assembly of the car seat and its refurbishment (for the PSS): This data was not available and was also considered relatively negligible compared to the manufacture of the constituent materials of the car seat.
- Retail of the car seat: It is likely to be the same for the PSS and conventional car seats and was also considered that the impacts are likely to be relatively negligible compared to the other processes.
- The use phase of the car seat: It is considered to be the same in both the conventional and PSS systems, and it is difficult to determine.
- The disposal/EoL phase: Excluded due to lack of data, although a basic estimation of the impact of landfill has been undertaken for comparative purposes and this is included in the discussion (see Section 6.2).

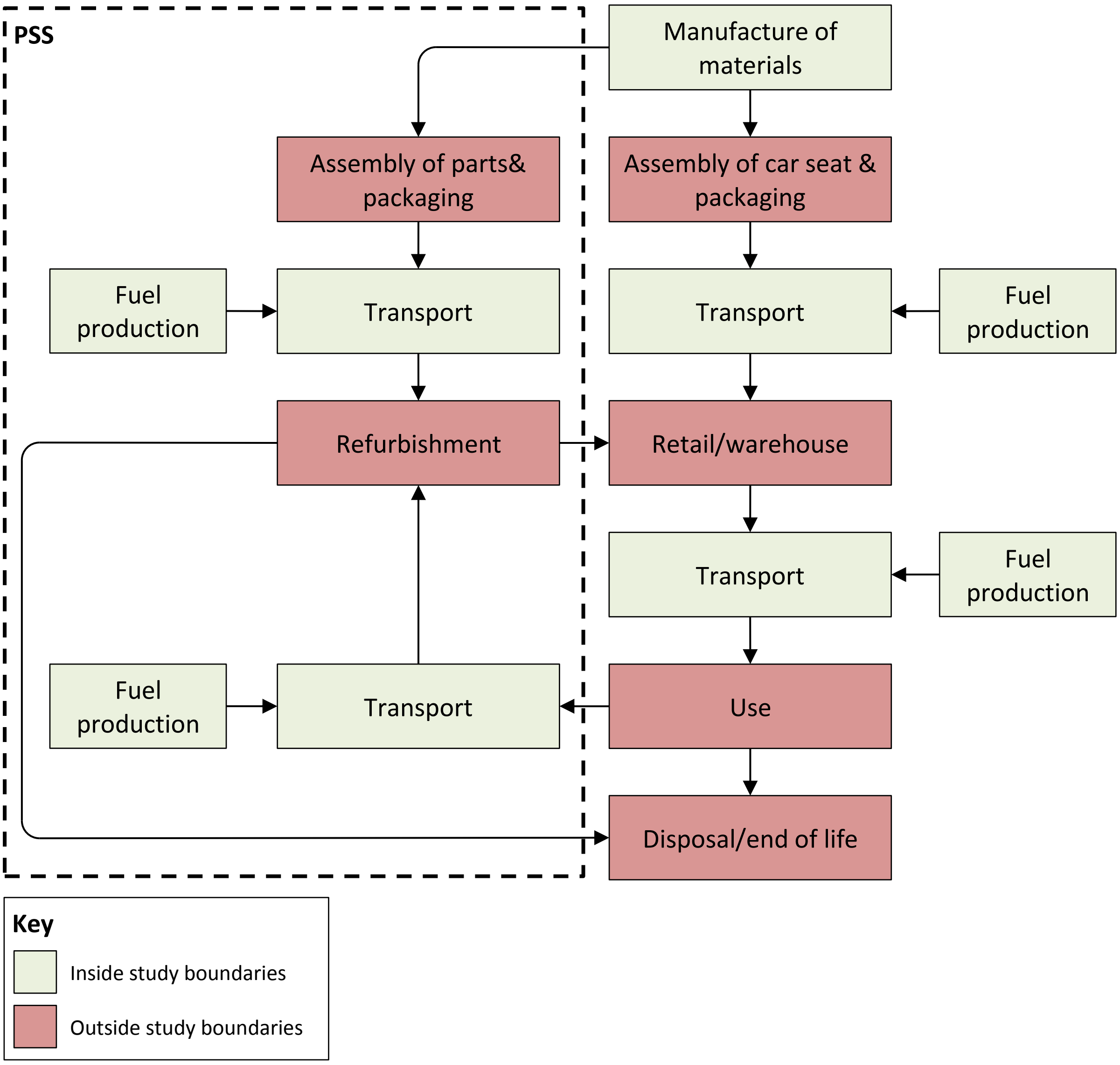

Figure 2.1: System boundaries

2.4. Data sources

2.4.1. Primary data

All primary data were provided directly by Dorel and consisted of data on the quantity of different materials used to make the car seat and its replacement parts and the typical/average distances for transport.

2.4.2. Secondary data

The majority of the life cycle inventory data was derived from the ELCD (JRC, 2016a). The remainder were sourced from relevant literature. Table 2.1 lists the sources of the data used for the materials included in the LCA and the transport and associated fuel.

Table 2.1: LCI data sources

Material / process / flow	Source (plus location and reference-valid year)
Acrylonitrile butadiene styrene (ABS)	ELCD: Acrylonitrile-Butadiene-Styrene granulate (ABS);production mix, at plant (European, 1994-2006)
Carbon black	Emissions data only from Tables 3.23 and 3.24, Volume 3, Chapter 3 in IPCC (2006); Table 6.1.2 in Chapter 6 of US EPA (1995)
Cardboard	ELCD: cartonboard sheets; mixed technology; production mix, at plant; 46% primary fibre, 54% recovered fibre (en) (European, 2009-2016)
Expanded Polystyrene (EPS)	ELCD: Polystyrene expandable granulate (EPS);production mix, at plant (European, 2003-2013)
GF-Fibre*	ELCD: Continuous filament glass fibre (dry chopped strands);at plant (European, 2010-2017)
Paper	ELCD: Graphic Paper; technology mix; production mix, at plant; 79% primary fibre, 21% recycled fibre (European, 2006-2015)
Polyamide 6 (PA6)	ELCD: Polyamide 6.6 fibres (PA 6.6);from adipic acid and hexamethylene diamine (HMDA);production mix, at plant; PA 6.6 granulate without additives (European, 1996-2006)
Polycarbonate (PC)	ELCD: Polycarbonate granulate (PC);production mix, at plant (European, 2005-2012)
Polyester	ELCD: Polyethylene terephthalate fibres (PET);via dimethyl terephthalate (DMT);production mix, at plant; PET granulate without additives (European, 2005-2012)
Polyethylene (PE)*	ELCD: Polyethylene low density granulate (PE-LD);production mix, at plant (European, 1999-2009)
Polyoxymethylene (POM)	Impact data only from PlasticsEurope (2014a) (European, 2010-2016)
Polypropylene (PP)	ELCD: Polypropylene fibres (PP);crude oil based; production mix, at plant; PP granulate without additives (European, 2005-2012)
Steel*	ELCD: Steel hot rolled coil, including recycling; blast furnace route; production mix, at plant;1kg, typical thickness between 2 - 7 mm. typical width between 600 - 2100 mm (Global, 2007-2015)
Viscose	Impact data only from Beton *et al*. (2014); Dibdiakova & Timmermann (2014); Shen & Patel (2008); Shen *et al*. (2010); Turley *et al*. (2009)
Ocean transport	Container ship ocean; technology mix; 27.500 dwt pay load capacity (Global, 2005-2010)
Heavy fuel oil	Heavy fuel oil; from crude oil; consumption mix, at refinery (European, 2003-2012)
Road transport	Articulated lorry transport; Euro 0, 1, 2, 3, 4 mix;40 t total weight, 27 t max payload (European, 2007-2010)
Diesel	Diesel; from crude oil; consumption mix, at refinery;200 ppm sulphur (European, 2003-2012)

* Alternative datasets were available in the ELCD, see notes and assumptions (Section 2.6)

2.4.2. Data quality assessment

The primary and secondary datasets described in Sections 2.4.1 and 2.4.2 have been assessed using the data pedigree matrix (see Section 1.2.5). The results of this assessment are shown in Table 2.2.

Table 2.2: Data quality assessment

Material / process / flow	Reliability	Completeness	Temporal	Geographical	Technological	Total
Primary data						
Materials	4	3	5	5	5	22
Road transport	4	3	5	4	5	21
Ocean transport	2	1	1	2	2	8
Secondary data						
Acrylonitrile butadiene styrene (ABS)	5	5	2	1	4	17
Carbon black	3	1	1	1	1	7
Cardboard	5	5	4	1	3	18
Expanded Polystyrene (EPS)	5	5	4	1	4	19
GF-Fibre*	5	5	5	1	4	20
Paper	5	5	5	1	3	19
Polyamide 6 (PA6)	5	5	4	1	4	19
Polycarbonate (PC)	5	5	2	1	4	17
Polyester	5	5	2	1	4	17
Polyethylene (PE)*	5	5	3	1	4	18
Polyoxymethylene (POM)	3	3	5	1	1	13
Polypropylene (PP)	5	5	4	1	4	19
Steel*	5	5	4	4	3	21
Viscose	2	1	3	3	1	10
Ocean transport	5	5	3	4	4	21
Heavy fuel oil	5	5	4	1	4	19
Road transport	5	5	3	5	4	22
Diesel	5	5	4	1	4	19

2.5. Impact assessment methods

Table 2.3 lists the impact categories that have been included in the study and their units:

Table 2.3: Impact categories

ILCD Impact Category	Unit
Climate change	kg CO_2 eq.
Ozone depletion	kg CFC-11 eq.
Human toxicity, cancer effects	CTUh
Human toxicity, non-cancer effects	CTUh
Particulate matter/Respiratory inorganics	kg PM2.5 eq.
Ionizing radiation, human health	kBq U^{235} eq. (to air)
Photochemical ozone formation, human health	kg NMVOC eq.
Acidification	mol H^+ eq.

ILCD Impact Category	Unit
Eutrophication terrestrial	mol N eq.
Eutrophication freshwater	kg P eq.
Eutrophication marine	kg N eq.
Land use	kg C deficit
Ecotoxicity freshwater	CTUe
Resource depletion water	m^3 water eq.
Resource depletion, mineral, fossils and renewables	kg Sb eq.

These are used in European Platform on Life Cycle Assessment: European reference Life Cycle Database (ELCD) (JRC, 2016a) and the characterisation factors of May 2016 (version 1.0.9) and associated normalisation factors (version 0.1.1 - 15/12/2015) (JRC, 2016b) were used.

The normalised impacts (NIs) have been calculated for the EU only using those provided by Benini *et al*. (2014) and Sala *et al*. (2015). Global normalisation factors do exist (Benini *et al*., 2015), but it was decided to use those for Europe as these were the most relevant.

2.6. Notes and assumptions

2.6.1. System boundaries

Figure 2.1 illustrates the system boundaries of the study. Notable exclusions include the processes associated with the assembly and refurbishment of the car seat; and the retail, use and EoL phases. From the perspective of an LCA of single car seat these are significant omissions, but these are less significant for the purposes of this LCA, i.e. a comparison of the conventional and PSS approaches. The omission of the EoL phase does have the potential to impact upon the performance of the PSS. It is assumed that all conventional car seats are disposed of to landfill. However, if a significant number of car seats are reused (e.g. sold on as second hand) and/or their materials are recycled, then this could potentially impact upon the performance of the PSS, as a key aspect of the PSS is the reuse of materials. Any potential reduction in performance may be offset by the fact that the PSS also has the advantage that the car seat is returned to the company after each use, thus it is within the control of the company to minimise the EoL impact. However, data on the EoL phase has not been provided in this instance, so this cannot be determined in this study.

2.6.2. Car seat materials

The primary data provided was inconsistent, from a variety sources and in a variety of formats. It could not be described as 100% complete and/or fully documented. Consequently a number of assumptions have been made in order to facilitate the LCA. These are:

- All data on replacement parts are considered additional and not subtracted from the total values provided, e.g. the total amount of plastics provided in the questionnaire. For example, there are several different amounts of steel: 205.7g for car seat, 21.9g for steel used in harness. It is unclear if the 21.9g in harness is included in the 205.7g for car seat, so it has been assumed to be additional.
- 590g of fabric consisting of polyester and viscose, has been assumed to be 50% each.
- Small quantities listed as 'confidential substances', 'additives' or 'further additives, not to declare' have been excluded. The sum of these is 0.83g.
- As no data could be found for Acrylamide and amounts are very small 0.009849g per car seat, it has been excluded from the LCA.

- No data were provided on the weight of the plastic bag used in the packaging, but 45g of PE is stated for the car seat (as a whole). In the absence of data an additional 45g of PE has been added to account for the plastic bag used in the packaging.

2.6.3. Transport

2.6.3.1. Ocean transport

As with the primary data for materials, data on transport was inconsistent and more limited than the data on materials. Consequently a number of assumptions were made:

- That all materials are manufactured in China.
- That all car seats are shipped from China to the UK.
- The port from which the goods are shipped is unknown, so has been assumed to be Amoy.
- The port to which are goods are shipped is unknown, so has been assumed to be Harwich.

The ELCD was used to derive inventory data for ocean transport. However, there are four sets of data for ocean transport in the ELCD:

- Bulk carrier ocean; technology mix; 100.000-200.000 dwt (RER)
- Bulk carrier ocean; technology mix; 100.000-200.000 dwt (GLO)
- Container ship ocean; technology mix; 27.500 dwt pay load capacity (RER)
- Container ship ocean; technology mix; 27.500 dwt pay load capacity (GLO)

One of these needed to be selected for use in the LCA. "Container ship ocean; technology mix; 27.500 dwt pay load capacity (GLO)" was selected as it was considered that container ship was the likely means of transport for the car seat, and GLO (global) data were selected over the European (RER) data as the car seats are being shipped from China. Heavy fuel oil is the fuel source in this data for ocean transport, thus data for the production of this fuel was also included in the LCA.

2.6.3.2. Road transport

As with ocean transport, a number of assumptions have been made for road transport:

- The manufacturing location within China is unknown, so it has been excluded/assumed that there is no road transport within China.
- Road transport from the UK port to retail/distribution warehouse is unknown, so has been excluded/assumed that there is no road transport.
- Road transport of the goods from the retail/distribution warehouse to the customer has been assumed to be an average of 153.5km (and the same for the return journey for the PSS).

The ELCD was used to derive inventory data for road transport. However, there are two sets of data for road transport in the ELCD:

- Articulated lorry transport; Euro 0, 1, 2, 3, 4 mix; 40 t total weight, 27 t max payload (RER) (2005-2010)
- Articulated lorry transport; Euro 0, 1, 2, 3, 4 mix; 40 t total weight, 27 t max payload (RER) (2007-2010)

One of these needed to be selected for use in the LCA. The slightly newer data (2007-2010) was selected to be used in this LCA. Diesel is the fuel source in this data for road transport, thus data for the production of this fuel was also included in the LCA.

2.6.4. LCA data for materials

2.6.4.1. GF-Fibre

There are four sets of the data in the ELCD for glass fibre manufacture:

- Continuous filament glass fibre (assembled rovings)
- Continuous filament glass fibre (direct rovings)
- Continuous filament glass fibre (dry chopped strands)
- Continuous filament glass fibre (wet chopped strands)

"Continuous filament glass fibre (dry chopped strands)" has been selected based on the description of the use of this material provided by 3B (2016).

2.6.4.2. Polyethylene (PE)

There are three different sets of data in the ELCD of Polyethylene (PE) (AKA Polythene):

- Polyethylene high density granulate (PE-HD); production mix, at plant
- Polyethylene low density granulate (PE-LD); production mix, at plant
- Polyethylene low linear density granulate (PE-LLD); production mix, at plant

"Polyethylene low density granulate (PE-LD); production mix, at plant" has been selected, as it is this form that is commonly used for plastic bags.

2.6.4.3. Polyoxymethylene (POM)

No LCA/LCI data could be obtained for Polyoxymethylene (POM) in terms of quantifying resource use, manufacturing processes and emissions. Only data on impacts was available in the eco-profile for POM (PlasticsEurope, 2014a). Some of the impact characterisation factors used different units to those used in this LCA, consequently they had to be converted as follows:

- **Acidification:** measured in g SO_2 eq. by PlasticsEurope (2014a), but measured in mol H^+ eq. in this LCA. Converted by applying the mol H^+ eq. acidification characterisation factor for SO_2 to the figures provided by PlasticsEurope (2014a).
- **Photochemical ozone formation:** measured in g Ethene eq. by PlasticsEurope (2014a), but measured in kg NMVOC eq. in this LCA. Converted by applying the kg NMVOC eq. photochemical ozone formation characterisation factor for Ethene to the figures provided by PlasticsEurope (2014a).
- **Water use:** measured in kg by PlasticsEurope (2014a). This figure was converted m^3 water eq. using the characterisation factor for 'ground water, OECD average scarcity', to obtain a value in the appropriate units for the impact category used in this LCA.

2.6.4.4. Steel

There are ten different sets of data for steel in the ELCD:

- Steel hot dip galvanized (ILCD); blast furnace route; production mix, at plant; 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm.
- Steel hot dip galvanized, including recycling; blast furnace route; production mix, at plant; 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm.
- Steel hot rolled coil (ILCD); blast furnace route; production mix, at plant; 1kg, typical thickness between 2 - 7 mm. typical width between 600 - 2100 mm.

- Steel hot rolled coil, including recycling; blast furnace route; production mix, at plant; 1kg, typical thickness between 2 - 7 mm. typical width between 600 - 2100 mm
- Steel hot rolled coil; blast furnace route; production mix, at plant; thickness 2 to 7 mm, width 600 to 2100 mm.
- Steel hot rolled section; blast furnace and electric arc furnace route; production mix, at plant.
- Steel rebar; blast furnace and electric arc furnace route; production mix, at plant.
- Steel sections (ILCD); blast furnace route / electric arc furnace route; production mix, at plant; 1 kg
- Steel sections, including recycling; blast furnace route / electric arc furnace route; production mix, at plant; 1kg.
- Steel tinplate without EoL recycling (collection year 2012/2013); blast furnace route; European, production mix, at plant; 1kg, typical thickness between 0.13 - 0.49 mm. typical width between 600 - 1100 mm.

"Steel hot rolled coil, including recycling; blast furnace route; production mix, at plant; 1kg, typical thickness between 2 - 7 mm. typical width between 600 - 2100 mm" has been selected as it was the most suitable generic data for steel production.

There are several different types of steel used in the production of the car seat: carbon steel, low alloyed steel, stainless steel and steel. Specific data for stainless steel was found in the USLCI (2012), but this was substantially different to the ELCD data (not as comprehensive; different units; and less relevant to the European or Asian context). Thus it was decided to use the generic ELCD steel data for all the types of steel used in the car seat (see Section 2.6.4.6).

2.6.4.5. Viscose

For viscose, there is no data freely available in either the ELCD (JRC, 2016a) or the USA equivalent (USLCI, 2012). However, other LCAs have been undertaken which included viscose and these have been drawn upon to derive impact data per kg of viscose. Table 2.4 shows where the data for each impact category have been derived from:

Table 2.4: Sources of impact data for viscose

Impact category	Source
Climate change	Dibdiakova & Timmermann (2014)
Ozone depletion	Shen & Patel (2008b)
Human toxicity, cancer effects	NA
Human toxicity, non-cancer effects	Derived from Dibdiakova & Timmermann (2014) – see note 1 below
Particulate matter	NA
Ionizing radiation	NA
Photochemical ozone formation	Derived from Shen & Patel (2008b) – see note 2 below
Acidification	Derived from Shen & Patel (2008b) – see note 3 below
Eutrophication terrestrial	NA
Eutrophication freshwater	Shen & Patel (2008b)
Eutrophication marine	NA
Land use	Shen & Patel (2008b) (Viscose (Asia))
Ecotoxicity freshwater	NA
Resource depletion water	Derived from Shen & Patel (2008b) – see note 4 below
Resource depletion, mineral, fossils and renewables	Derived from Shen and Patel (2008b) and Shen *et al*. (2010) – see note 5 below.

Note 1: Human toxicity, non-cancer effects. The LCA undertaken by Dibdiakova and Timmermann (2014) does not provide the manufacturing data, but does provide impact results. However, some of these impact results do not use the same characterisation factors used by JRC and there is no way to directly convert them. To overcome this problem, the data have been reverse calculated, i.e. converting the characterisation equivalents back to their original material amounts and then the original amounts are then re-characterised using the JRC characterisation factors. This has been done using the characterisation factors (CF) provided by the ReCiPe project (ReCiPe, 2012; Wegener Sleeswijk, 2008) to derive the amounts (by dividing the impact value by the CF) for each substance as shown in Table 2.5. These amounts have then been treated an inventory items and then subject to the characterisation factors used in this LCA.

Table 2.5: Conversion of human toxicity impact characterisation factors for viscose

Substance	Impact (kg 1,4-DB eq. per t)	ReCiPe (2012) CF*	Amount (kg) per t
Mercury	371.6475	1224407.857	0.000304
Cadmium	1.532567	125457.4038	0.0000122
Phosphorus	128.7356	18769.96683	0.006859
Phosphorus	114.9425	18769.96683	0.006124
Arsenic	65.90038	552955.2542	0.000119
Lead	56.70498	23114.56276	0.002453
Arsenic, ion	58.23755	356439.4689	0.000163
Vanadium	19.15709	20300.95275	0.000944
Zinc	51.341	1883.145216	0.027263

* Characterisation factor (CF) using the Egalitarian scenario in ReCiPe (2012)

Note 2: Photochemical ozone formation: The data provided by Shen & Patel (2008b) are provided in C_2H_4 (Ethene) equivalents, but measured in kg NMVOC eq. in this LCA. The data were converted by applying the kg NMVOC eq. photochemical ozone formation characterisation factor for Ethene to the figures provided by Shen & Patel (2008b).

Note 3: Acidification: The data provided by Shen & Patel (2008b) are provided in SO_2 eq., but measured in mol H^+ eq. in this LCA. The data were converted by applying the mol H^+ eq. acidification characterisation factor for SO_2 to the figures provided by Shen & Patel (2008b).

Note 4: Resource depletion water: Shen & Patel (2008b) provide a value for water use in cubic metres (m^3). This has been treated as an inventory item for an amount of water resources used.

Note 5: Resource depletion, mineral, fossils and renewables: Shen *et al*. (2010) and Shen and Patel (2008) both quote a figure of 40 kg Sb eq. per tonne of viscose. However, if this data is used, the amount of viscose used in the car seat equates to 6% of the average person in the EU for Resource depletion, which seems very high. Additionally, Shen *et al*. (2010) state a figure of 42 kg Sb eq. per tonne for Polypropylene (PP), yet in the LCA this has been calculated as 0.00327 kg Sb eq. per tonne and 0.00014 kg Sb eq. per tonne by PlasticsEurope (2014b). An explanation for the difference in the impact value has not been determined, so to bring the value more into line with the normalisation data the following has been undertaken to calculate an alternative value for 'Resource depletion, mineral, fossils and renewables' for viscose. According to Shen *et al*. (2010), the Abiotic depletion for viscose is 40 and for PP is 42, so they are roughly similar. Therefore we can base the value for viscose on that derived for PP from our LCA data. Thus, the 0.00327 value for PP, divided by 42 (value in Shen *et al*. (2010) for PP) = 0.0000779. This value is then multiplied by 40, to give a value of 0.00312 kg Sb eq. per tonne viscose. This then equates to 0.01% for the average person in the EU for Resource depletion.

2.6.4.6. Equivalent materials

For a number of materials exact data could not be sourced and/or they were variants of other materials. Therefore the amounts of these materials were combined as shown in Table 2.6.

Table 2.6: Equivalent materials

Actual material	LCA Material
Carbon steel	Steel
Low alloyed steel	Steel
PA66+PA6I/6T-I	Polyamide 6 (PA6)
Polyacetale-copolymer	Polyoxymethylene (POM)
Polyoxymethylene diacetate	Polyoxymethylene (POM)
Polyphthalamide (PPA)	Polyamide 6 (PA6)
Stainless Steel	Steel

3.0. Inventory

3.1. Car seat materials

Table 3.1 lists all the materials that are used to construct a single car seat, plus those used in the associated packaging, as provided by Dorel. The total amounts to 4.724 kg.

Table 3.1: Materials used for one car seat plus packaging

Material	kg
Acrylamide	0.000009849
Acrylonitrile butadiene styrene (ABS)	0.0766
Additives	0.000098
Carbon black	0.00025831
Carbon steel	0.0015
Cardboard	1.05
Confidential substances	0.00011
Expanded Polystyrene (EPS)	0.098
Further Additives, not to declare	0.000717203
GF-Fibre	0.0116522
Low alloyed steel	0.0191
PA66+PA6I/6T-I	0.013136673
Paper	0.0626
Polyacetale-copolymer	0.0003216
Polyamide 6 (PA6)	0.017862
Polycarbonate (PC)	0.083
Polyester	0.347
Polyethylene (PE)	0.090088
Polyoxymethylene (POM)	0.0319
Polyoxymethylene diacetate	0.01910706
Polyphthalamide (PPA)	0.0028
Polypropylene (PP)	2.2964
Stainless steel	0.001271
Steel	0.2057
Viscose	0.29515

LCI and LCIA data do not exist for all the specific materials listed in Table 3.1, therefore they have been rationalised into similar/equivalent materials for which data do exist (see Section 2.6.4.6). The rationalised LCA materials are listed in Table 3.2. The total of this amounts to 4.723 kg, thus only 0.001 kg is unaccounted for in the LCA (consisting of additives and confidential substances). Figure 3.1 shows this data in the form of a pie chart, thus illustrating that Polypropylene (PP) makes up almost half the mass of the car seat and Cardboard almost a quarter. The materials that are replaced in the PSS are listed in Table 3.3.

Table 3.2: Materials used for one car seat plus packaging, rationalised for LCA

LCA Material	kg
Acrylonitrile butadiene styrene (ABS)	0.0766
Carbon black	0.000258
Cardboard	1.05
Expanded Polystyrene (EPS)	0.098
GF-Fibre	0.011652
Paper	0.0626
Polyamide 6 (PA6)	0.033799
Polycarbonate (PC)	0.083
Polyester	0.347
Polyethylene (PE)	0.090088
Polyoxymethylene (POM)	0.031929
Polypropylene (PP)	2.2964
Steel	0.227571
Viscose	0.29515

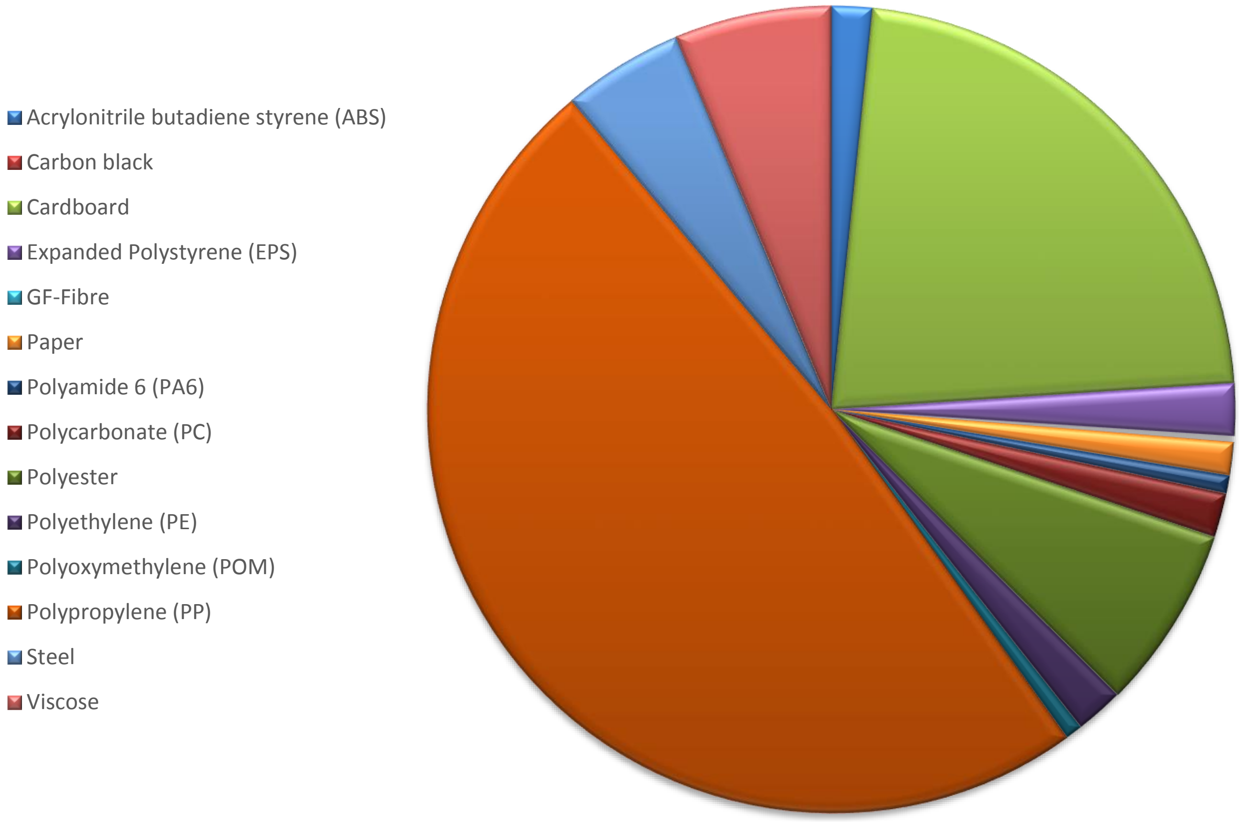

Figure 3.1: Car seat materials pie chart

Table 3.3: Materials replaced during PSS refurbishment

Part	Component	Material	LCA Materia	kg
Car seat	Fabric	Polyester	Polyester	0.29515
		Viscose	Viscose	0.29515
Harness	Buckle	PA66+PA6I/6T-I	Polyamide 6 (PA6)	0.0034398
		GF-Fibre	GF-Fibre	0.0018522
	Axel	Carbon steel	Steel	0.0015
	Latch Spring	Stainless steel	Steel	0.001271
	Cover GR.0+M2, Black	Polyamide 6 (PA6)	Polyamide 6 (PA6)	0.001862
	Housing GR.0 M2, Black	Polyacetale-copolymer	Polyoxymethylene (POM)	0.0003216
		Carbon black	Carbon black	0.00006231
		Polyoxymethylene diacetate	Polyoxymethylene (POM)	0.01910706
	Black, lower tongue	PA66+PA6I/6T-I	Polyamide 6 (PA6)	0.00484843632
		GF-Fibre	GF-Fibre	0.0049
		Carbon black	Carbon black	0.000098
		Polyethylene (PE)	Polyethylene (PE)	0.000044
	Black, upper tongue	PA66+PA6I/6T-I	Polyamide 6 (PA6)	0.00484843632
		GF-Fibre	GF-Fibre	0.0049
		Carbon black	Carbon black	0.000098
		Polyethylene (PE)	Polyethylene (PE)	0.000044
	End Bracket	Low alloyed steel	Steel	0.0191
	Webbing	Polyester	Polyester	0.05185
Packaging	Polythene plastic bag	Polyethylene (PE)	Polyethylene (PE)	0.045
	Recycled cardboard box	Paper	Paper	0.0626
		Cardboard	Cardboard	1.05

3.2. Transport

3.2.1. Ocean transport

The distance from Amoy (China) to Harwich (UK) has been calculated as 18,286 km (Sea-distances.org, 2016). This uses 0.0000037 kg of heavy fuel oil per kg of goods per km (JRC, 2016a). Thus delivery of a whole car seat plus packaging from China to the UK would require 0.318 kg of heavy fuel oil.

3.2.2. Road transport

The average distance a car seat is transported from the warehouse to the customer is 153.5 km (provided by Dorel). This uses 0.0000139 kg of diesel per kg of goods per km (JRC, 2016a). Thus delivery of a whole car seat plus packaging from the warehouse to the customer would require 0.01 kg of diesel.

3.3. Resource use

Table 3.4 compares the resources used for 2 uses of conventional and PSS car seat and also shows the incremental increase in resource per use. The reduction in use of water resources is a lot lower because, as shown in Figure A9, the bulk of water resources are used in the manufacture of paper and cardboard (particularly the cardboard – see Figure A10), which remains unchanged in the PSS compared to the conventional system. The incremental increase in resource use (per use) for the PSS ranges from 28.9 to 96.7% for use of material resources, and 18.2 to 70.9% for energy resources.

Table 3.4: Resources used from the air, ground, water and the biosphere: conventional and PSS (2 uses)

Resource	Conventional	PSS	PSS incremental increase per use (%)
Resources from the air (kg)	101.6	65.5	28.9
Resources from the air (MJ)	2.2	1.6	40.8
Resources from the ground (kg)	23.1	15.8	37
Resources from the ground (MJ)	581.5	344.0	18.2
Resources from water (kg)	2935.9	2887.0	96.7
Resources from water (MJ)	7.1	5.1	44
Resources from the biosphere (kg)	0.0	0.0	0
Resources from the biosphere (MJ)	0.2	0.2	70.9

3.4. Emissions

Table 3.5 compares the emissions for 2 uses of conventional and PSS car seat, and shows that incremental increase in emissions (per use) for the PSS range from 20.5 to 29.9%.

Table 3.5: Emissions to the air, soil and water: conventional and PSS (2 uses)

	Conventional	PSS	PSS incremental increase per use (%)
Emissions to the air (kg)	130.1	84.5	29.9
Emissions to the soil (kg)	0.00188	0.00115	22.5
Emissions to water (kg)	0.6461	0.3895	20.5

Notes: No data on emissions for POM; Emissions to the air data only for carbon black; Emissions to the air and water for viscose has been from derived from Dibdiakova and Timmermann (2014)

4.0. Impact assessment

4.1. Introduction

The compulsory elements of ISO 14040 (ISO, 2006a) include impact classification and characterisation and the optional elements include grouping/damage characterisation (human health, ecosystem quality, etc.); weighting (distance to target, panel procedure); and normalisation. The approach presented here consists of (i) Impact classification and characterisation; and (ii) Impact significance (normalisation).

The impact classification process involves sorting substances into classes according to the effect they have on the environment (e.g. substances that contribute to the greenhouse effect or that contribute to ozone layer depletion). The characterisation process then aggregates substances within each class to produce an impact score. Resources and emissions are converted using characterisation factors into equivalency units (see Table 2.3). The results of this process are presented in Section 4.2.

The amount of each impact, e.g. 26.73 kg CO_2 eq. or 0.116 kg NMVOC eq., are useful with respect to comparing the conventional and PSS car seats. However, they are not very meaningful with respect to how important those quantities are with respect to the significance of the impact. To place the impacts in context and assess their relative importance/significance, they can be normalised by expressing them as a percentage of the average impact per person in the EU. These factors are determined by calculating the total impact of a region and dividing it by the population. In this instance the normalisation percentages have been calculated for the EU (Benini *et al*., 2014; Sala *et al*., 2015) and are presented in Section 4.3.

4.2. Impact classification and characterisation

Table 4.1 provides an overview of the impacts for 2 uses of a conventional and a PSS car seat.

Table 4.1: Overview of the impact of conventional and PSS car seats (2 uses)

Impact category	Unit	Conventional	PSS
Climate change (CC)	kg CO_2 eq.	26.73	18.95
Ozone depletion (OD)	kg CFC-11 eq.	0.000167	0.000166
Human toxicity, cancer effects (HTC)	CTUh	0.0000000118	0.00000000923
Human toxicity, non-cancer effects (HTNC)	CTUh	0.00000119	0.00000102
Particulate matter (PM)	kg PM2.5 eq.	0.0629	0.0316
Ionizing radiation (IR)	kBq U^{235} eq. (to air)	0	0
Photochemical ozone formation (POF)	kg NMVOC eq.	0.116	0.0794
Acidification (A)	mol H+ eq.	0.1995	0.141
Eutrophication terrestrial (ET)	mol N eq.	0.359	0.242
Eutrophication freshwater (EF)	kg P eq.	0.00176	0.00163
Eutrophication marine (EM)	kg N eq.	0.0333	0.0225
Land use (LU)	kg C deficit	0.000195	0.000195
Ecotoxicity freshwater (ETF)	CTUe	4.14	2.83
Resource depletion water (RDW)	m^3 water eq.	0.0827	0.0817
Resource depletion, mineral, fossils and renewables (RDM)	kg Sb eq.	0.0000395	0.0000282

There are no impacts in the Ionizing radiation category and there is no difference in land use between the conventional and the PSS approaches, so these are excluded from further analysis.

The data presented above are for two uses of the conventional and PSS car seats (as this is the minimum required for a PSS). However, a PSS may have more than two uses, thus it is important to determine the reduction in impact per use. This data has the potential to be misleading due to the multiple use nature of this study. For example, if a component is always reused in the PSS, its impacts will always be 100% lower than the conventional car seat, but this does not mean it has the capacity to reduce the impacts presented by 100%. For the minimum of 2 uses it would be 50%, 3 uses 66.6%, 4 uses 75%, etc. To overcome this issue, the two sets of data are presented (Table 4.2): (i) the percent reduction in impact per use compared to a single use the conventional car seat; (ii) the inverse of the percent reduction in impact. The latter represents the incremental increase in impact of the PSS per use (with the conventional car seat being 100% per use, as a new one is used each time), thus the lower the value the better.

Table 4.2: Reduction in impact/incremental increase in impact by the PSS seat per use

Impact category	PSS reduction per use (%)	Incremental increase per use (%)
Climate change (CC)	58.2	41.7
Ozone depletion (OD)	0.49	99.5
Human toxicity, cancer effects (HTC)	43.7	56.1
Human toxicity, non-cancer effects (HTNC)	27.8	72.2
Particulate matter (PM)	99.6	0.4
Photochemical ozone formation (POF)	63.1	36.7
Acidification (A)	58.7	41.2
Eutrophication terrestrial (ET)	65	34.7
Eutrophication freshwater (EF)	14.6	85.4
Eutrophication marine (EM)	64.7	35.0
Ecotoxicity freshwater (ETF)	63.4	36.5
Resource depletion water (RDW)	2.5	97.5
Resource depletion, mineral, fossils and renewables (RDM)	57.3	42.7

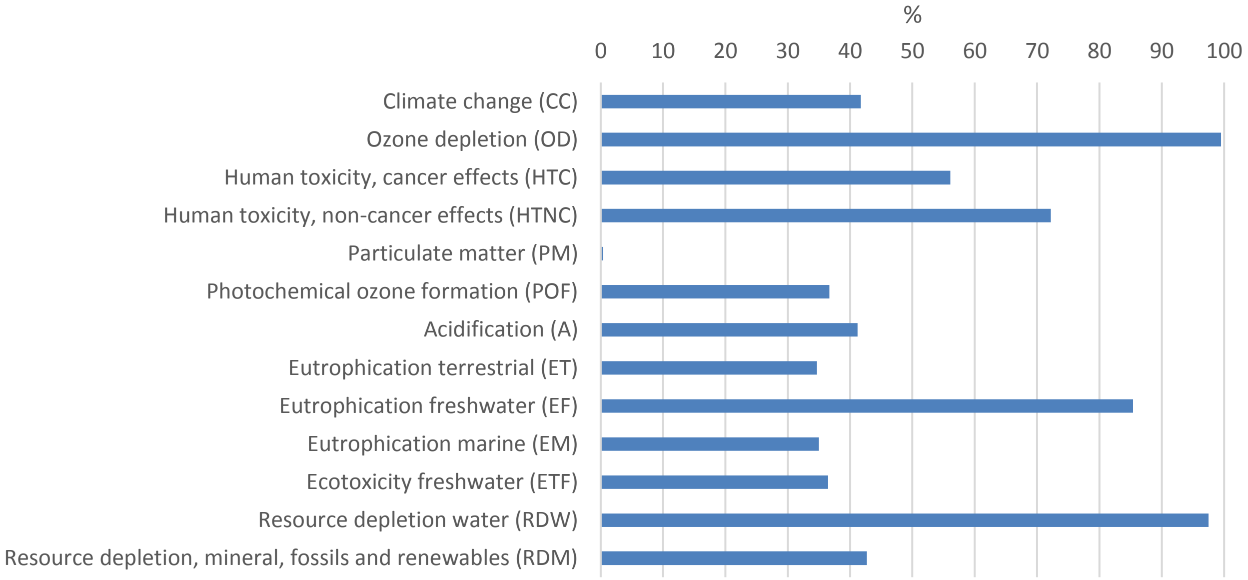

Figure 4.1: Incremental increase in impact by the PSS compared to conventional car seat per use

Figure 4.1 shows that the greatest reduction provided by the PSS is for Particulate matter (PM) (with a 0.4% incremental increase per use, compared to 100% for the conventional seat). There are also significant reductions (over 50%) for seven other impacts. The lowest reduction potential is for Ozone depletion (OD) and Resource depletion water (RDW).

4.3. Impact significance (normalisation)

Table 4.3 shows the impacts normalised by expressing them as a percentage of the average impact per person in the EU. The numbers are relatively low as clearly two child car seats should represent a relatively small proportion of the impact of an average person. These normalised impacts are also presented graphically in Figure 4.2 and the difference between the conventional and PSS car seat is shown in Figure 4.3.

Table 4.3: Normalised impacts for conventional and PSS car seats (2 uses)

Impact category	Conventional	PSS
Climate change (CC)	0.29	0.21
Ozone depletion (OD)	0.77	0.77
Human toxicity, cancer effects (HTC)	0.03	0.025
Human toxicity, non-cancer effects (HTNC)	0.22	0.192
Particulate matter (PM)	1.65	0.83
Photochemical ozone formation (POF)	0.37	0.25
Acidification (A)	0.42	0.298
Eutrophication terrestrial (ET)	0.20	0.138
Eutrophication freshwater (EF)	0.12	0.11
Eutrophication marine (EM)	0.20	0.133
Ecotoxicity freshwater (ETF)	0.05	0.0323
Resource depletion water (RDW)	0.10	0.1003
Resource depletion, mineral, fossils and renewables (RDM)	0.04	0.0279

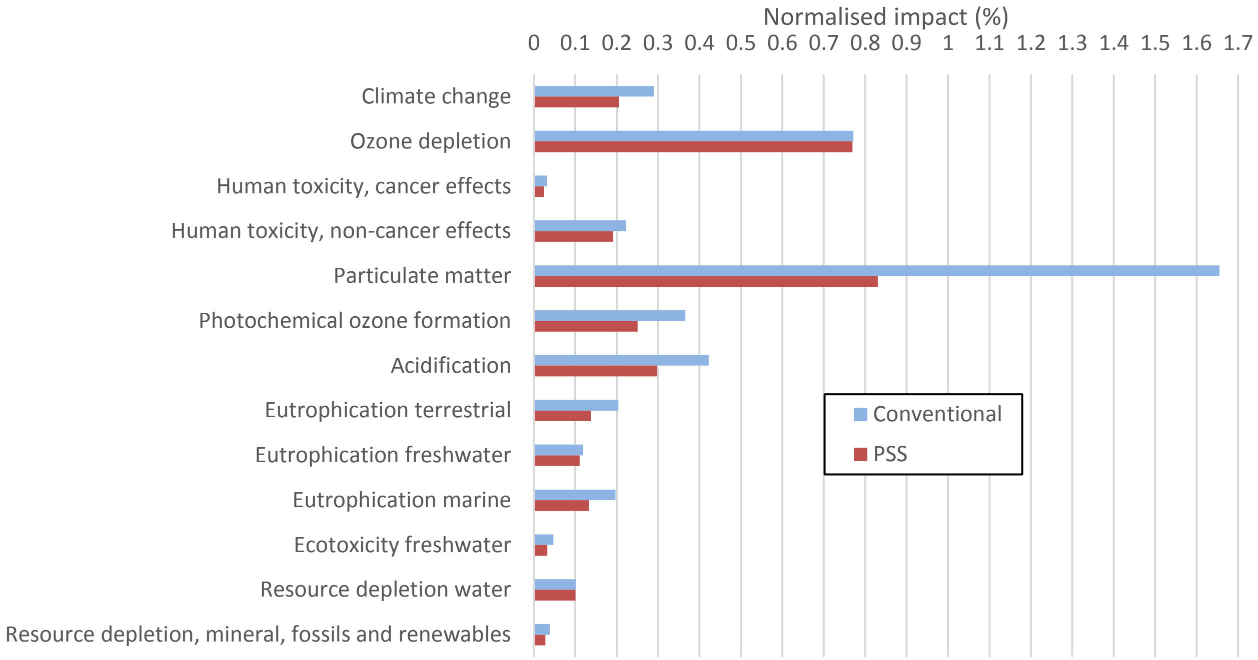

Figure 4.2: NI: Conventional and PSS car seats (2 uses)

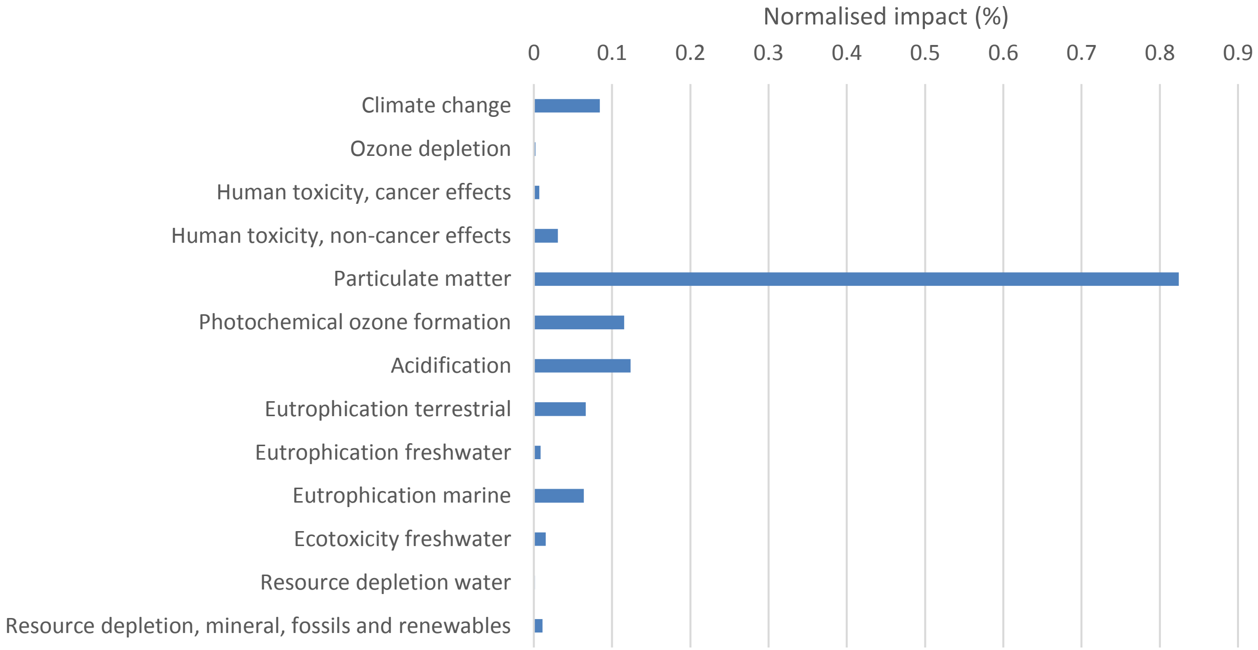

Figure 4.3: Difference in NI between conventional and PSS car seats (2 uses)

Figure 4.4 combines the data on the incremental increase in impact by the PSS compared to conventional car seat per use (Table 4.2) with the normalised impacts for the conventional car seat. In so doing this shows us where PSS has the scope to reduce impacts with respect to their significance. For example, the conventional car seat has a normalised impact of 0.77% for ozone depletion, but the scope to reduce this via the PSS is minimal (99.5% incremental impact), whereas the normalised impact for particulate matter, which is the highest at 1.65%, has an incremental impact of 0.4% with the PSS.

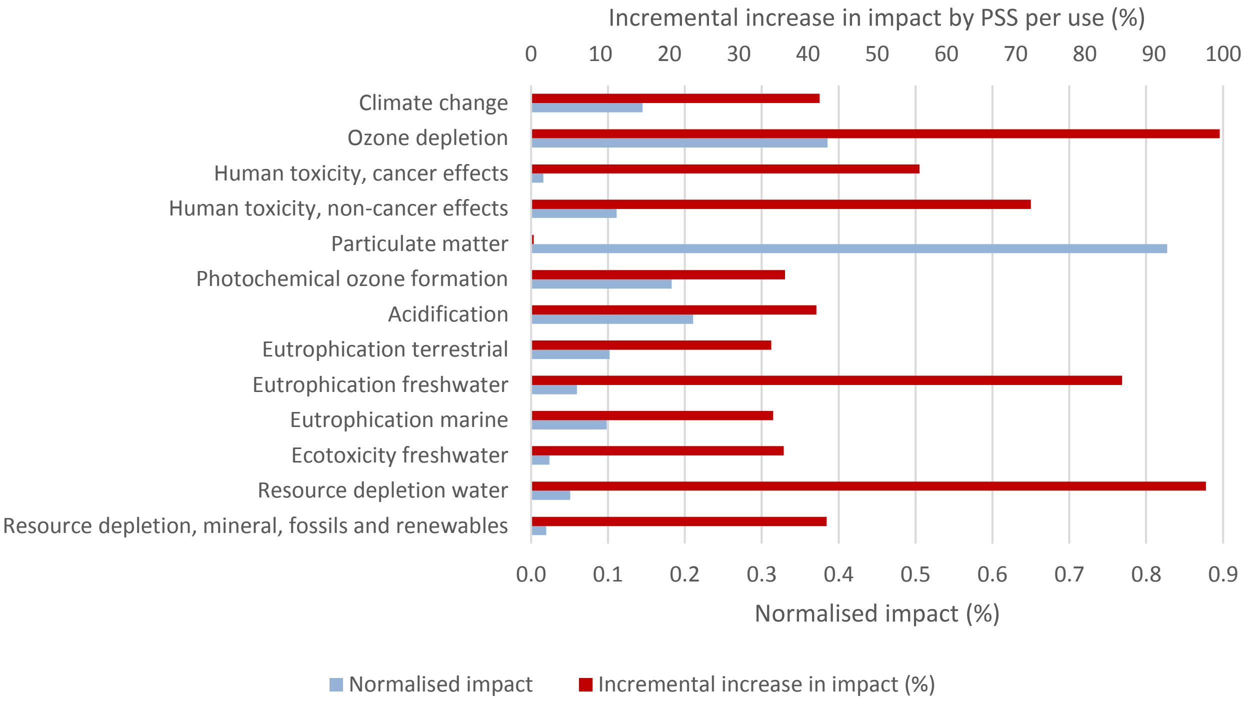

Figure 4.4: NI: Conventional car seat and Incremental increase in impact by the PSS

5.0. Interpretation

5.1. Introduction

The purpose of this LCA is to compare the environmental impact/performance of a 'conventional' versus a PSS approach to the purchase of a child car seat (Dorel's Maxi-Cosi Pebble). On the assumption that a conventionally purchased car seat is disposed of after each use, there is a clear benefit from the PSS with respect to reusing the bulk of the car seat, thus avoiding the disposal of materials. A car seat plus it packaging amounts of 4.7 kg of materials. The PSS replaces 1.87 kg of materials per use, thus 2.84 kg of materials avoid disposal per use (Table 5.1).

Table 5.1: Materials replaced and avoiding disposal in PSS (per use)

Material	Replaced (kg)	Avoiding disposal (kg)	Total (kg)
Acrylonitrile butadiene styrene (ABS)	0	0.0766	0.0766
Carbon black	0.000258	0	0.000258
Cardboard	1.05	0	1.05
Expanded Polystyrene (EPS)	0	0.098	0.098
GF-Fibre	0.011652	0	0.011652
Paper	0.0626	0	0.0626
Polyamide 6 (PA6)	0.0150	0.018799	0.033799
Polycarbonate (PC)	0	0.083	0.083
Polyester	0.347	0	0.347
Polyethylene (PE)	0.0451	0.044988	0.090088
Polyoxymethylene (POM)	0.0194	0.012529	0.031929
Polypropylene (PP)	0	2.2964	2.2964
Steel	0.0219	0.205671	0.227571
Viscose	0.29515	0	0.29515
Total	**1.87**	**2.84**	**4.7**

The 2.84 kg of materials avoiding disposal is in itself a valuable outcome of the PSS. However, there is also all the materials, energy, emissions and impacts associated with the manufacturing and transporting those materials. This LCA attempts to account for these broader benefits. The following sections draw out the key findings from the results presented in LCI and LCIA (Sections 3 and 4) and identify the key materials and processes contributing to the resources used, emissions and impacts.

All the charts can be found in the appendices. These charts provide two breakdowns (partial and full) of the materials and processes that contribute to resource consumption, emissions and impacts. There are also charts that illustrate the resource consumption, emissions and impact intensities (i.e. per kg of each material). For ocean and road transport, the intensity figures have been based on the value per kg for the single ocean journey (18286 km) and the single road journey (153.5 km) and includes the impacts associated with the heavy fuel oil and diesel used for these journeys respectively.

5.2. Resources

5.2.1. Resources from the air

In terms of materials, plastics is the major use of resources from the air, followed by paper and card (see Figure A1.1). The breakdown (Figure A1.2) shows that largest contributors, in descending order are: Polypropylene (PP); Polyester and Polyamide 6 (PA6), with cardboard being the main contributor for paper and card.

Figure A1.5 shows the consumption intensity of resources from the air used per kg of material. This reveals that although Polypropylene (PP) is largest consumer of resources from the air, this is due to the large amount used in the car seat (2.3 kg), as Polyester and Polyamide 6 (PA6) have a far greater consumption intensity of resources from the air per kg.

A similar situation exists with respect to energy resources from the air (see Figures A1.3, 1.4 and 1.6).

5.2.2. Resources from the ground

In terms of materials, plastics is the major use of resources from the ground, followed by paper and card and then metals (see Figure A2.1). The breakdown (Figure A2.2) shows that largest contributors, in descending order are: Polypropylene (PP); Polyester; Cardboard; Steel and Polyamide 6 (PA6). However, as with air, Polyester and Polyamide 6 (PA6) have a far greater consumption intensity of resources from the ground per kg (Figure A2.5).

With respect to energy resources from the ground, the situation is a bit different. The bulk goes into plastics and transport (see Figure A2.3). The breakdown (Figure A2.4) reveals that the bulk of the energy goes into Polypropylene (PP), followed by Polyester and then Ocean transport. There are small, roughly equal, amounts for Polyethylene (PE); Polycarbonate (PC); Polyamide 6 (PA6); Expanded Polystyrene (EPS); and Acrylonitrile butadiene styrene (ABS). Figure A2.6 shows that although only small amounts of these materials are used, the consumption intensity of energy resources from the ground is relatively high per kg, thus this is being reflected in the results for the car seat.

5.2.3. Resources from water

In terms of materials, paper and card is by far the major use of resources from water, followed by a much smaller proportion by plastics (see Figure A3.1) and the bulk of this is used by cardboard (Figure A3.2). The reason for this is illustrated in Figure A3.5 which shows that the production of cardboard has the highest consumption intensity of water per kg with 1,344 kg per kg, compared to the next highest 171 kg per kg for Expanded Polystyrene (EPS).

With respect to energy resources from water, the situation is a bit different, with plastics and paper and card being the highest consumer (see Figure A3.3), albeit with substantially lower amounts than energy resources from the ground. The bulk of this consumption comes from Polypropylene (PP); Polyester; and Cardboard (See Figure A3.4). The consumption intensity (Figure A3.6) reveals that Polyamide 6 (PA6) and Polyester have the greatest intensity.

5.2.2. Resources from the biosphere

In terms of materials, no resources from the biosphere are used. However, with respect to energy resources from the biosphere, plastics, paper and card and other materials are the highest consumer (see Figure A4.1), albeit with substantially lower amounts than energy resources from the air, ground and water. The bulk of this consumption comes from Paper, GF-Fibre, Polyethylene (PE) and Expanded Polystyrene (EPS). The first three of these are all replaced to some extent in the PSS, thus the reduction potential of the PSS is not high for resources from the biosphere. The consumption intensity (Figure A4.3) reveals that GF-Fibre (PA6) and Paper have the greatest intensity, which is reflected in the results.

5.3. Emissions

5.3.1. Emissions to the air

Figure B1.1 shows that plastics have the greatest emissions to the air, followed by, to a much lesser extent, paper and card and then transport. Figure B1.2 reveals that Polypropylene (PP); Polyester; Cardboard and Polyamide 6 (PA6) are the biggest contributors.

Figure B1.3 shows that Polyamide 6 (PA6) has the greatest emissions to the air intensity, followed by Polyester and Polypropylene (PP), and thus this is reflected in the results given the amounts of these materials used.

5.3.2. Emissions to the soil

Figure B2.1 shows that plastics also have the greatest emissions to the soil, followed by (to a much lesser extent) paper and card and transport. The breakdown (Figure B2.2) reveals that Polypropylene (PP); Polyester; Cardboard and Ocean transport are the biggest contributors.

Figure B2.3 shows that Polyamide 6 (PA6); Polyester and Polypropylene (PP) have the greatest emissions intensity to the soil, and thus this is reflected in the results given the amounts of these materials used.

5.3.3. Emissions to water

Figure B3.1 shows that plastics also have the greatest emissions to water, followed by (to a much lesser extent) paper and card and transport. The breakdown (Figure B3.2) reveals that Polypropylene (PP); Polycarbonate (PC); Polyester; Cardboard and Ocean transport are the biggest contributors.

Although only a small amount of the Polycarbonate (PC) is used in the car seat (0.083 kg ~1.8% of the total), it emissions to water intensity (Figure B3.3) means that it is the second largest contributor to emissions to water (27% of the total).

5.4. Impacts

5.4.1. Overview

Table 5.2 lists the impacts in decreasing in order of significance (derived from Figure C1.1). The first two (particulate matter and ozone depletion) are by far the greatest compared to the others. This data can be broken down by the individual materials and processes in the LCA to highlight where the impacts are arising, as shown in Figures C1.2 and C1.3.

Table 5.2: Impacts listed by significance

Band	Normalised impact value	Impact category
High	>0.5%	• Particulate matter • Ozone depletion
Moderate	0.2-0.5%	• Acidification • Photochemical ozone formation • Climate change • Human toxicity, non-cancer effects • Eutrophication terrestrial
Low	<0.2%	• Eutrophication marine • Eutrophication freshwater • Resource depletion water • Ecotoxicity freshwater • Resource depletion, mineral, fossils and renewables • Human toxicity, cancer effects

5.4.2. Climate change

Figure C2.1 shows that the bulk of climate change impacts are coming from plastics, followed by paper and card and transport. Figure C2.2 reveals that Polypropylene (PP); Polyester; Viscose; Cardboard and Ocean transport are the biggest contributors.

Those materials with the greatest impact intensity (Figures C1.8-1.11) include: Polyamide 6 (PA6); Polycarbonate (PC); Viscose and Carbon black. Thus, other than Viscose, the largest contributors to climate change are due to the amounts used and not the intensity of emissions. With regard to transport, as shown in Figures C1.8-1.11, the climate change impact intensity per kg is low compared the manufacture of the materials, thus the contribution from ocean transport is largely due to the distance of the journey.

5.4.3. Ozone depletion

Figure C3.1 shows that just about all the ozone depletion impacts are coming from plastics, and Figure C3.2 shows that this is all from Viscose. This is further illustrated in Figures C1.8-1.11, which show that Viscose has the greatest impact intensity.

It should be noted that the source of the data for Viscose is different to the majority of the other materials (see Table 2.1 and Section 2.6.4.5) and consequently has a lower data quality score (See Section 2.4.2 and Table 2.2) – Viscose has the third lowest data quality score. This should be taken into consideration when interpreting the ozone depletion impact. The data could be correct, but it is also possible that the data provided on ozone depletion may have been calculated differently. However, no other sources of this data could be found, thus no comparisons can be made to confirm the validity of the data.

5.4.4. Human toxicity, cancer effects

Figure C4.1 shows that the bulk of human toxicity, cancer effects impacts are coming from paper and card followed by plastics, and a small amount from metals. Figure C4.2 shows that Paper is the largest contributor, which is quite surprising given the small amount used. This is followed by Polypropylene (PP); Polycarbonate (PC) and Expanded Polystyrene (EPS).

This is reflected in the impact intensity (Figures C1.8-1.11), except for Polypropylene (PP) which has a relatively low impact intensity, thus it is down to the amount being used that is contributing towards the impact.

5.4.5. Human toxicity, non-cancer effects

Figure C5.1 shows that the bulk of human toxicity, non-cancer effects impacts are coming from paper and card followed by plastics, and a small amount from metals. Figure C5.2 shows that Viscose is the largest contributor, followed by Paper; Polycarbonate (PC) and Polypropylene (PP).

Figures C1.8-1.11 show that the impact intensity is highest for paper, which explains the high contribution to this impact given the small amount used. Viscose and Polycarbonate (PC) have the next highest intensity, thus explaining their contribution. Polypropylene (PP) has a relatively low impact intensity, thus it is down to the amount being used that is contributing towards the impact.

5.4.6. Particulate matter

Figure C6.1 shows that the bulk of particulate matter impacts are coming from plastics, and Figure C6.2 shows that this is largely from Polypropylene (PP), followed by, to a much less extent, Polycarbonate (PC); Expanded Polystyrene (EPS); Polyamide 6 (PA6) and Acrylonitrile butadiene styrene (ABS).

Figures C1.8-1.11 show Polyoxymethylene (POM) has the highest impact intensity, but this is not reflected in the impact of the car seat (due to the small amounts used) (noting that POM has a low data quality score – see Table 2.2). Polyamide 6 (PA6) and Polycarbonate (PC) also have a moderate impact intensity, which explains their contribution to the impact given the small amounts used.

5.4.7. Photochemical ozone formation

Figure C7.1 shows that the bulk of photochemical ozone formation impacts are split between plastics and transport, and Figure C7.2 shows that the largest is Ocean transport, followed by Polypropylene (PP) and Polyester.

Figures C1.8-1.11 show that in terms of materials, Polyamide 6 (PA6); Polycarbonate (PC) and Polyester have the highest impact intensity, which is partly reflected in the results with respect to Polyester.

With regard to transport, as shown in Figures C1.8-1.11, the photochemical ozone formation impact intensity per kg is moderate compared the manufacture of the materials, thus the contribution from ocean transport is a combination of the impact intensity and the distance of the journey.

5.4.8. Acidification

Figure C8.1 shows that the bulk of acidification impacts are split between plastics and transport, and Figure C8.2 shows that the largest is Ocean transport, followed by Polypropylene (PP); Viscose and Polyester.

Figures C1.8-1.11 show that in terms of materials, Polyamide 6 (PA6); Viscose; Polycarbonate (PC) and Polyester have the highest impact intensity, which is partly reflected in the results with respect to Viscose and Polyester.

With regard to transport, as shown in Figures C1.8-1.11, the acidification impact intensity per kg is moderate compared the manufacture of the materials, thus the contribution from ocean transport is a combination of the impact intensity and the distance of the journey.

5.4.9. Eutrophication terrestrial

Figure C9.1 shows that the bulk of eutrophication terrestrial impacts are split between plastics and transport, and Figure C9.2 shows that the largest is Ocean transport, followed by Polypropylene (PP) and Polyester.

Figures C1.8-1.11 show that in terms of materials, Polyamide 6 (PA6); Polycarbonate (PC) and Polyester have the highest impact intensity, which is partly reflected in the results with respect to Polyester.

With regard to transport, as shown in Figures C1.8-1.11, the eutrophication terrestrial impact intensity per kg is moderate compared the manufacture of the materials, thus the contribution from ocean transport is a combination of the impact intensity and the distance of the journey.

5.4.10. Eutrophication freshwater

Figure C10.1 shows that the bulk of eutrophication freshwater impacts are coming from plastics, with a small amount from paper and card. Figure C10.2 shows that the bulk of the impact is coming from Viscose, with some much smaller contributions from Polypropylene (PP); Polycarbonate (PC); Polyoxymethylene (POM); Cardboard; and Paper.

Figures C1.8-1.11 show that Viscose has the highest impact intensity, which is reflected in the results, followed by Polyoxymethylene (POM); Polycarbonate (PC) and Paper, which are also partly apparent in the results.

Again it should be noted that the data quality score for Viscose is lower than the other materials (see Table 2.2), so this should be taken into account in the interpretation of these results, given the significance of Viscose for this impact.

5.4.11. Eutrophication marine

Figure C11.1 shows that the bulk of eutrophication marine impacts are split between plastics and transport, and Figure C11.2 shows that the largest is Ocean transport, followed by Polypropylene (PP) and Polyester.

Figures C1.8-1.11 show that in terms of materials, Polyamide 6 (PA6); Polycarbonate (PC) and Polyester have the highest impact intensity, which is partly reflected in the results with respect to Polyester.

With regard to transport, as shown in Figures C1.8-1.11, the eutrophication marine impact intensity per kg is moderate compared the manufacture of the materials, thus the contribution from ocean transport is a combination of the impact intensity and the distance of the journey.

5.4.12. Ecotoxicity freshwater

Figure C12.1 shows that the bulk of ecotoxicity freshwater impacts come from plastics, followed by paper and card and then transport. Figure C12.2 shows that Polypropylene (PP) has the largest impact, followed by Paper; Polyester; Cardboard and Ocean transport.

Figures C1.8-1.11 show that in terms of materials, Paper has by far the greatest impact intensity, and this is reflected in the results. This is followed by Polyamide 6 (PA6); GF-Fibre; and Polyester, the latter of which is also reflected in the results.

5.4.13. Resource depletion water

Figure C13.1 shows that the bulk of resource depletion water impacts come from plastics, and Figure C13.2 shows that this is largely coming from Viscose, followed by a small amount from Polyoxymethylene (POM).

Figures C1.8-1.11 show that Viscose and Polyoxymethylene (POM) have the highest impact intensity, which is reflected in the results.

It should be noted that the data quality score for Viscose and Polyoxymethylene (POM) are lower than the other materials (see Table 2.2), so this should be taken into account in the interpretation of these results, given the significance of Viscose and Polyoxymethylene (POM) for this impact.

5.4.14. Resource depletion, mineral, fossils and renewables

Figure C14.1 shows that the bulk of resource depletion, mineral, fossils and renewables impacts come from plastics and paper and card. Figure C14.2 shows that the greatest impacts are coming from Polypropylene (PP); Paper; Polyester and Acrylonitrile butadiene styrene (ABS).

Figures C1.8-1.11 show that Paper and Acrylonitrile butadiene styrene (ABS) have the highest impact intensities, and this is reflected in the results. This is followed by Polyamide 6 (PA6) and GF-Fibre.

6.0. Summary, discussion and conclusion

6.1 Summary of the findings

The incremental increase in resource use (per use) for the PSS ranges from 28.9 to 96.7% for use of material resources, and 18.2 to 70.9% for energy resources; and the incremental increase in emissions (per use) for the PSS range from 20.5 to 29.9%.

The impacts of the car seat can be classified, in terms of significance, as:

- **High:**
  - **Particulate matter:** the PSS can significantly reduce this, with an incremental impact of 0.4% per use (note: the incremental impact per use of a conventional car seat is 100% for all impacts). This is because the bulk of this impact comes from the materials that are reused for each PSS, especially Polypropylene (PP).
  - **Ozone depletion:** The PSS provides little scope to reduce this impact, with an increase in impact of 99.5% for each use. This is because this impact is almost entirely due to the manufacture of Viscose, which is completely replaced for each PSS, thus is virtually the same as the conventional car seat, i.e. there is no difference. However, it should be noted that the data for Viscose comes from a source with a low data quality score, thus some questions can be asked about the validity and robustness of this data and consequently the findings presented here.
- **Moderate:**
  - **Acidification:** the PSS can moderately reduce this, with an incremental impact of 41.2% per use. The reuse of the Polypropylene (PP) and reduction in ocean transport are the two key factors for this reduction. The replacement of Polyester and Viscose in the refurbishment process for the PSS does negate this benefit slightly as these two materials have higher impact intensities, thus retaining a moderate contribution to the acidification impacts.
  - **Photochemical ozone formation:** the PSS can moderately reduce this, with an incremental impact of 46.7% per use. The reuse of the Polypropylene (PP) and reduction in ocean transport are the two key factors for this reduction. The replacement of Polyester in the refurbishment process for the PSS does negate this benefit slightly as this material has a higher impact intensity, thus retaining a moderate contribution to the photochemical ozone formation impacts.
  - **Climate change:** the PSS can moderately reduce this, with an incremental impact of 41.7% per use. The reuse of the Polypropylene (PP) and reduction in ocean transport are the two key factors for this reduction. The replacement of Polyester; Viscose; Cardboard in the refurbishment process for the PSS does negate this benefit slightly, especially Viscose which has a higher impact intensity.
  - **Human toxicity, non-cancer effects:** the PSS can slightly reduce this, with an incremental impact of 72.2% per use. The reuse of the Polypropylene (PP) provides the greatest benefit, but the replacement of Paper and Viscose (which both have high impact intensities) in the refurbishment process for the PSS, means that the reduction in impact is limited.
  - **Eutrophication terrestrial:** the PSS can moderately reduce this, with an incremental impact of 34.7% per use. The reuse of the Polypropylene (PP) and reduction in ocean transport are the two key factors for this reduction. The replacement of Polyester in the refurbishment process for the PSS does negate this benefit slightly as this material has a higher impact intensity.
- **Low:**
  - **Eutrophication marine:** the PSS can moderately reduce this, with an incremental impact of 35% per use. The reuse of the Polypropylene (PP) and reduction in ocean transport are two key factors for this reduction. The replacement of Polyester in the refurbishment process for the PSS does negate this benefit slightly as this material has a higher impact intensity.

- **Eutrophication freshwater:** the PSS has a minimal effect, with an incremental impact of 85.4% per use. This is because the manufacture of Viscose is the largest contributor to this impact, which is completely replaced for each PSS, thus is virtually the same as the conventional car seat, i.e. there is no difference. However, it should be noted that the data for Viscose comes from a source with a low data quality score, thus some questions can be asked about the validity and robustness of this data and consequently the findings presented here.
- **Resource depletion water:** the PSS provides little scope to reduce this impact, with an incremental impact of 97.5% for each use. This is because this impact is almost entirely due to the manufacture of Viscose, which is completely replaced for each PSS, thus is virtually the same as the conventional car seat, i.e. there is no difference. However, it should be noted that the data for Viscose comes from a source with a low data quality score, thus some questions can be asked about the validity and robustness of this data and consequently the findings presented here.
- **Ecotoxicity freshwater:** the PSS can moderately reduce this, with an incremental impact of 36.5% per use. The reuse of the Polypropylene (PP) and reduction in ocean transport and two key factors for this reduction. The replacement of Paper; Polyester; Cardboard in the refurbishment process for the PSS does negate this benefit slightly, especially for Paper as this material has a high impact intensity.
- **Resource depletion, mineral, fossils and renewables:** the PSS can moderately reduce this, with an incremental impact of 42.7% per use. The reuse of the Polypropylene (PP) and Acrylonitrile butadiene styrene (ABS) are key factors for this reduction. The replacement of Paper and Polyester in the refurbishment process for the PSS does negate this benefit slightly, especially for Paper as this material has a high impact intensity.
- **Human toxicity, cancer effects:** the PSS can moderately reduce this, with an incremental impact of 56.1% per use. The reuse of the Polypropylene (PP); Polycarbonate (PC) and Expanded Polystyrene (EPS) are key factors for this reduction. The replacement of Paper in the refurbishment process for the PSS does negate this benefit slightly as this material has a high impact intensity.

The performance of the PSS in relation to impact reduction, can be summarised by multiplying the normalised impact by the inverse incremental increase in impact (i.e. (100 – incremental increase) x normalised impact). This results in Figure 6.1, which shows that the PSS performs very well for particulate matter, and also well for climate change, photochemical ozone formation, acidification and eutrophication (terrestrial and marine), with minor or negligible benefits for the other impact categories.

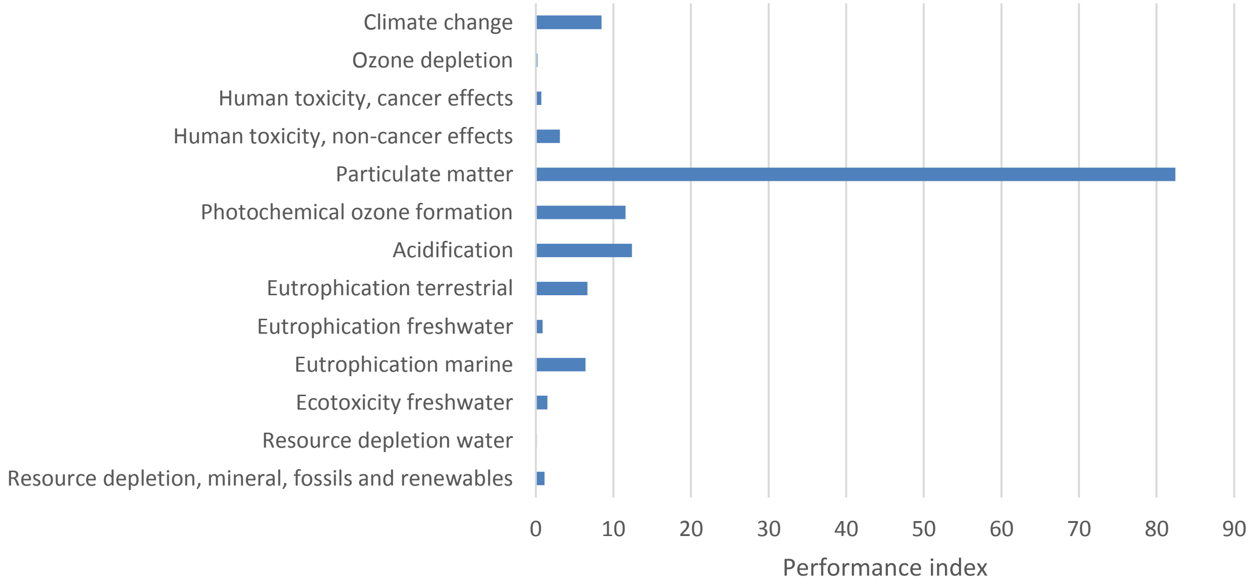

Figure 6.1: Impact reduction performance of the PSS

If we examine the difference in impact between the conventional and PSS car seats (for 2 uses) and sum the normalised impact for each of the materials we can see the biggest change is in the impact of plastics and transport (Figure 6.2). Figure 6.3 reveals that the reuse of Polypropylene (PP) creates the largest difference in impact, followed by the reduction in ocean transport; then to a lesser degree the reuse of Polycarbonate (PC); Expanded Polystyrene (EPS); Acrylonitrile butadiene styrene (ABS); and Polyamide 6 (PA6).

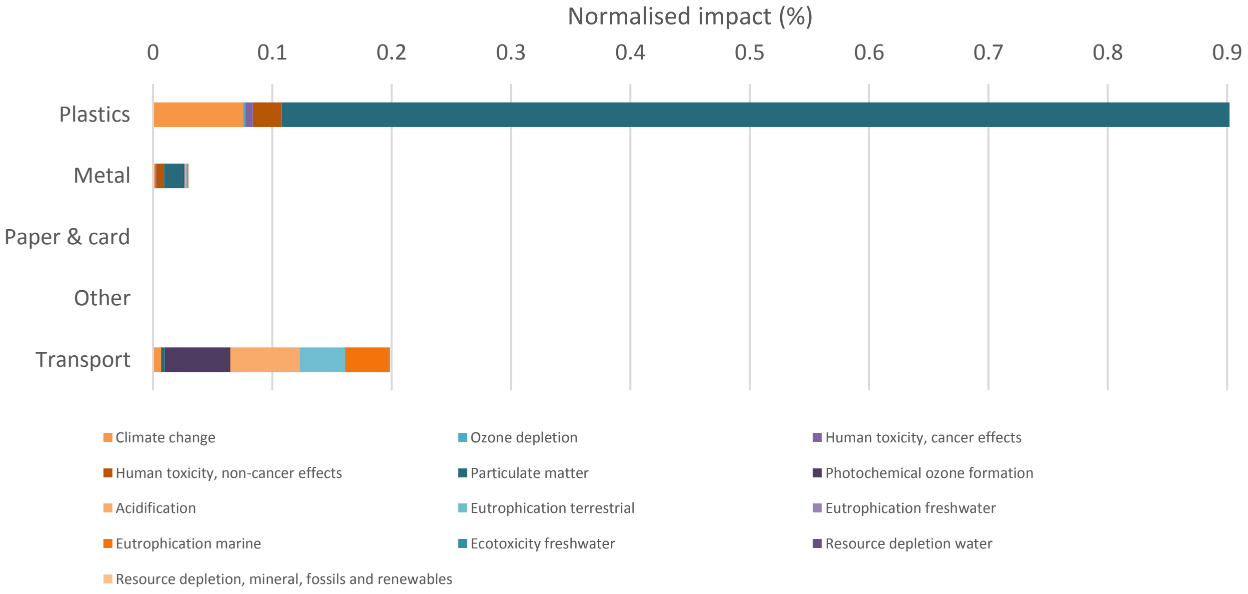

Figure 6.2: NI difference: Conventional & PSS (2 uses): partial breakdown

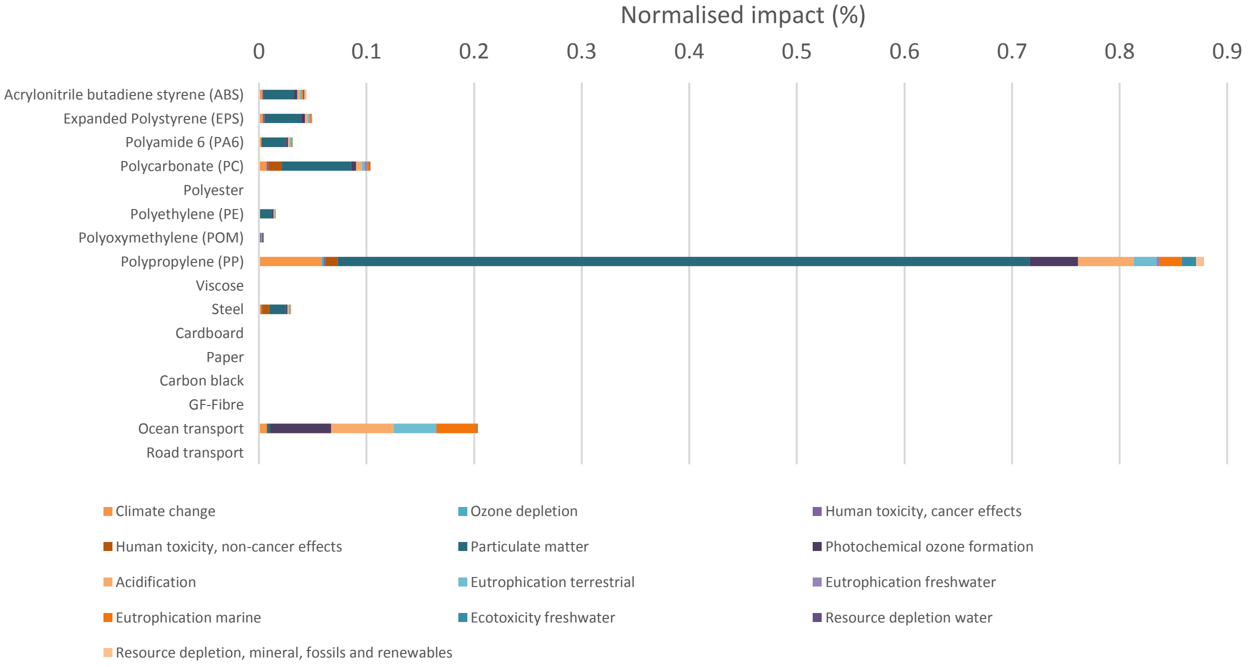

Figure 6.3: NI difference: Conventional & PSS (2 uses): full breakdown

6.2. Discussion

When there are two or more products or systems which may differ in their environmental impact/performance, it is important not to just assume that one performs better than another, even when there are obvious benefits. It is important to characterise and quantify (where possible) the differences in resource consumption, emissions, effects and impacts. When the perspective is extended to cover the broad life cycle of the materials and energy used, this assessment can be complex. In this relatively simple study of a child car seat (infant carrier), there were 938 inputs, 4,320 outputs and 3,809 substances to account for when considering all the materials and processes that go into the manufacture of materials required to build the car seat. LCA provides a framework to objectively account, characterise and assess the resources, emissions, effects and impacts of the conventional and PSS car seats. It embraces the complexity and endeavours to provide transparency. However, to do this inevitably some assumptions need to be made (as outlined in Section 2.6), which should not be forgotten about when interpreting and using the results of this study. These are discussed below along with some other reflections on the study and its outputs.

Firstly, the findings of the study need to be understood in relation to the boundaries of the study (see Figure 2.1). This LCA excludes any resources, energy, emissions and impacts associated with the assembly and refurbishment of the car seat and some road transport journeys have been excluded. However, given the results, it is anticipated that these are likely to be small compared to the other impacts and are also likely to increase the performance of the PSS, thus there is no scope for them to contradict the findings. The retail, use and EoL phases are also excluded from the assessment. The omission of the retail and use phases is less significant for the purposes of this LCA (i.e. a comparison of the conventional and PSS approaches), and thus is unlikely to affect the findings of this study. They would be more significant if this were simply an LCA of the car seat, in which case their quantification would be more important. The omission of the EoL phase does have the potential to impact upon the performance of the PSS. It is assumed that all conventional car seats are disposed of to landfill. Table 6.1 shows the impact of landfilling the steel and plastics that are reused in the PSS (i.e. avoiding landfill) as a proportion of the normalised impact of one use of a conventional car seat - based on data for landfilling ferro metals and plastics in the ELCD (JRC, 2016a).

Table 6.1: Estimate of EoL impacts as a percentage of one conventional car seat

Impact category	Metal (%)	Plastics (%)	Total (%)
Climate change (CC)	0.0223	1.3820	1.4043
Ozone depletion (OD)	0.0001	0.0094	0.0094
Human toxicity, cancer effects (HTC)	0.0021	0.2493	0.2514
Human toxicity, non-cancer effects (HTNC)	0.0017	0.1978	0.1995
Particulate matter (PM)	0.0003	0.0093	0.0095
Photochemical ozone formation (POF)	0.0251	0.8923	0.9174
Acidification (A)	0.0133	0.7498	0.7631
Eutrophication terrestrial (ET)	0.0293	0.9597	0.9889
Eutrophication freshwater (EF)	0.0010	43.6801	43.6811
Eutrophication marine (EM)	0.0540	0.9479	1.0019
Ecotoxicity freshwater (ETF)	0	0	0
Resource depletion water (RDW)	0	0	0
Resource depletion, mineral, fossils and renewables (RDM)	0	0	0

Table 6.1 shows that for metals, the EoL impact is relatively negligible compared to the impact of the other phases for of the conventional car seat. However, for plastics the impacts are more significant, especially for Eutrophication freshwater, where the EoL impact is 43.7% of the total impact of the other phases of the car

seat. Therefore, it would seem there are additional benefits for the PSS for reusing these materials and avoiding landfill. However, if a significant number of car seats are reused (e.g. sold on as second hand) and/or their materials are recycled, then this could potentially impact upon the performance of the PSS, as a key aspect of the PSS is the reuse of materials. Any potential reduction in performance may be offset by the fact that the PSS also has the advantage that the car seat is returned to the company after each use, thus it is within the control of the company to minimise the EoL impact. The impact of different EoL options, e.g. landfill, recycling, incineration, etc., would need to be assessed in order to determine the benefit the PSS provides in relation to these EoL options.

There are also some weaknesses in the data to take into consideration. Firstly, with regard to the primary data supplied by Dorel a number of assumptions had to be made (see Section 2.6.2) in order to overcome issues with regard to completeness and documentation of the data. In terms of quantities of materials the biggest assumptions relate to quantity of viscose and polyester used in the fabrics (as these are replaced in the PSS) which amount of 590g (12.5% of the total mass); and the amount of Polyethylene (PE) used in the packaging which amounts to 45g. Changes to these values could impact on the results, especially with respect to the viscose and polyester used in the fabrics. Secondly, with regard to the secondary data, inventory data was not available for all the materials listed in the primary data. For the majority data for equivalent materials was used (see Section 2.6.4.6), but for Carbon black, Polyoxymethylene (POM) and Viscose no equivalent materials with inventory data could be identified. Consequently data from a variety of (lower quality) sources had to be utilised for these materials. These do not appear to significantly impact on the key findings of the LCA with respect to the difference between conventional and PSS car seats. However, they do potentially impact on the results of the impact of the car seat. For example, the 0.39% normalised impact for ozone depletion (see Figure E1) arises almost entirely from Viscose. This is not affected by the PSS, but it is the second most significant impact of the car seat, thus given the low data quality score for Viscose (10/25), this impact should be questioned.

It should also be noted that at the outset of the LCA it was assumed that all materials for the car seat are manufactured in China. It has now been highlighted that the bulk of Dorel's car seats are manufactured (assembled) in Holland, Portugal and France. However, the fabrics and some metal components are still manufactured in China. Consequently the transport impacts (e.g. see Figure 6.2) are likely to be lower, especially for ocean transport. The quantities manufactured in China and Europe are still unclear, due to the complexity of supply chain. Therefore, the results presented in this LCA should be viewed as a worst case situation with regard to the transport impacts, and consequently the benefits provided by the PSS in relation to transport impacts may be lower for car seats manufactured in Europe.

Finally, the outputs from LCAs can be used to help identify areas where environmental impacts could be reduced and performance improved. One obvious area is the minimisation or elimination of packaging (cardboard, paper and polyethylene) for both the conventional and PSS car seats. Although larger amounts of cardboard are used compared to paper, the latter has a higher impact intensity and consequently small reductions could have a larger impact. Reducing the amount of Polyamide 6 and Polycarbonate would also be beneficial due to their relatively high impact intensity, but only very small amounts of these materials are currently used, so the scope for improvement is minimal. Viscose also appears to have a relatively high impact intensity and significant quantities used, so reducing the use of this material could have benefits, albeit some caveats need to be placed on this due to the data quality issues outlined above.

6.3. Conclusions

The PSS has clear benefits in terms of reducing the consumption of resources, emissions of pollutants and associated impacts compared to the conventional car seat. This LCA had endeavoured to characterise and quantify these reductions and thus provide an estimate of the relative environmental performance of the PSS.

The PSS replaces 1.87 kg of materials per use, thus 2.84 kg of materials directly avoid disposal per use and do not need to be replaced with new materials. This is in itself a valuable outcome of the PSS, however, there is also all the materials, energy, emissions and impacts associated with the manufacturing and transporting those materials. With regard to resource use, each conventional car seat requires 50.8, 11.6 and 3.5 kg of resources from the air, ground and water respectively. Each time the conventional car seat is used these all increase by 100%, but each time a PSS car seat is used the incremental increase is 28.9, 37 and 96.7% respectively, so there are clear benefits in terms of reducing the consumption of resources from the air and ground. Resources from water largely go into paper and cardboard production, which is not changed by the PSS.

With regard to emissions, effects and impacts, each conventional car seat results in 65, 0.001 and 0.3 kg emissions to the air, soil and water respectively. Each time a PSS car seat is used the incremental increase is 29.9, 22.5 and 20.5% respectively. With respect to the impact of these emissions, taking account of the significance of the impact and the incremental increase in impact, the performance of the PSS is greatest for reducing particulate matter, followed by acidification, photochemical ozone formation, climate change and eutrophication. The biggest change is in the impact of plastics (for particulate matter, climate change & human toxicity, non-cancer effects) and transport (for photochemical ozone formation, acidification & eutrophication (terrestrial and marine)). The reuse of Polypropylene (PP) creates the largest difference in impact, followed by the reduction in ocean transport; then to a lesser degree the reuse of Polycarbonate (PC); Expanded Polystyrene (EPS); Acrylonitrile butadiene styrene (ABS); and Polyamide 6 (PA6).

Appendix A. Resources charts

A1. Resources from the air

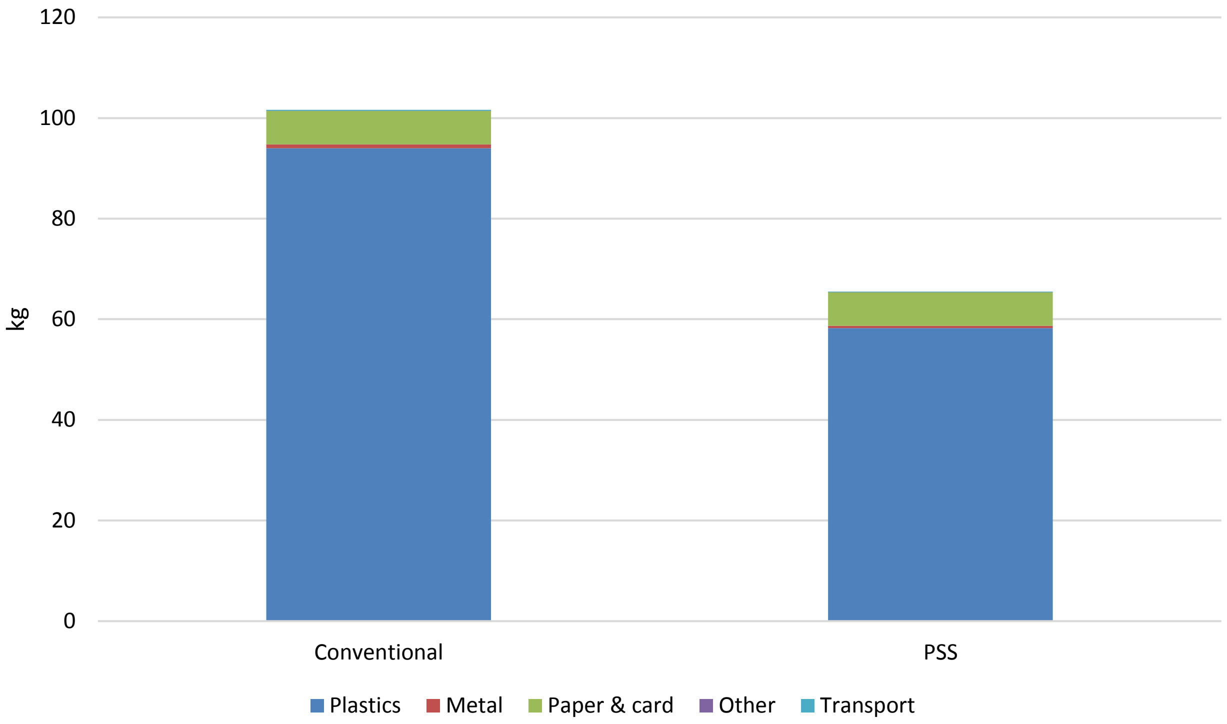

Figure A1.1: Use of material resources from the air for conventional and PSS: partial breakdown

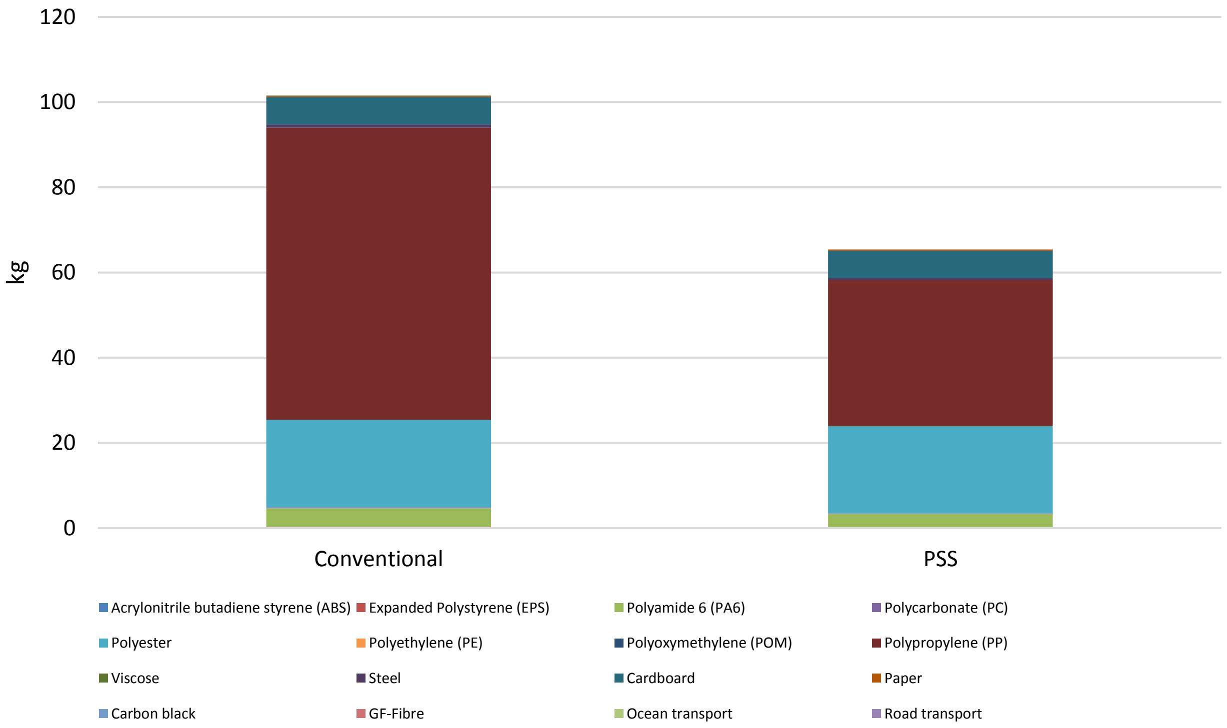

Figure A1.2: Use of material resources from the air for conventional and PSS: full breakdown

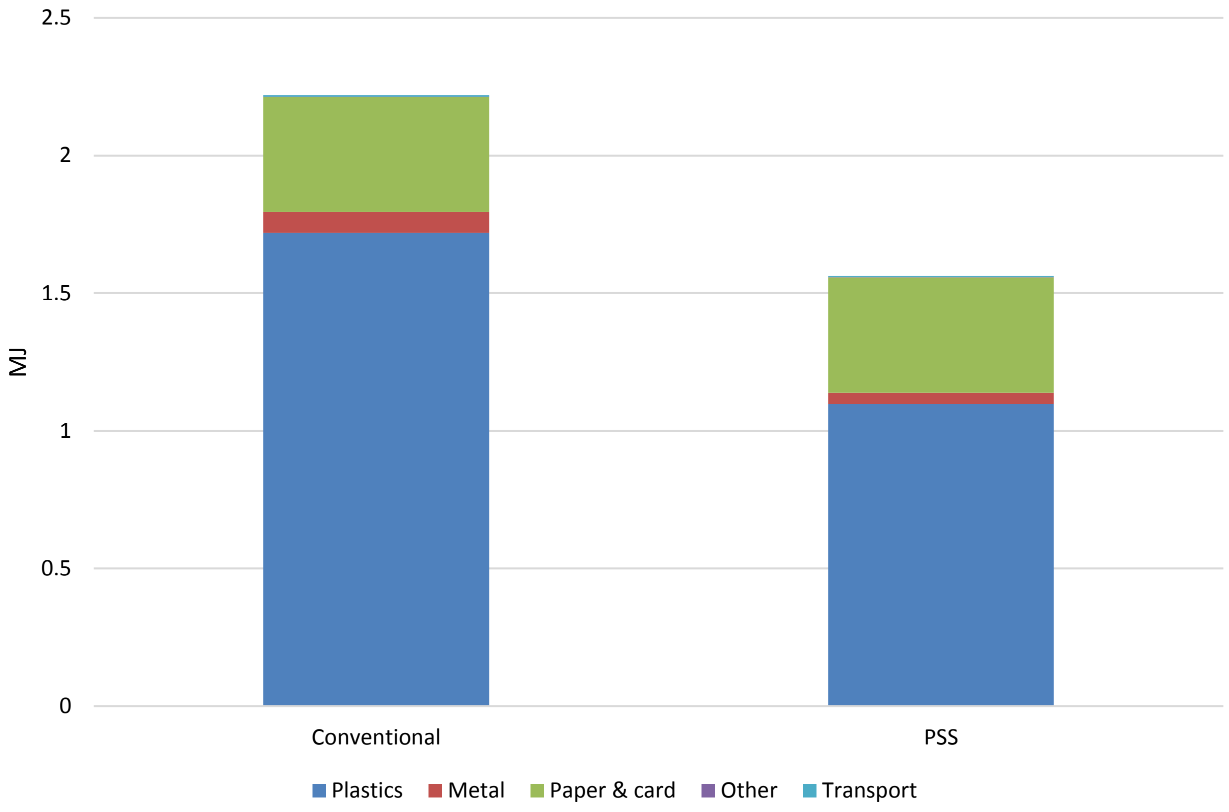

Figure A1.3: Use of energy resources from the air for conventional and PSS: partial breakdown

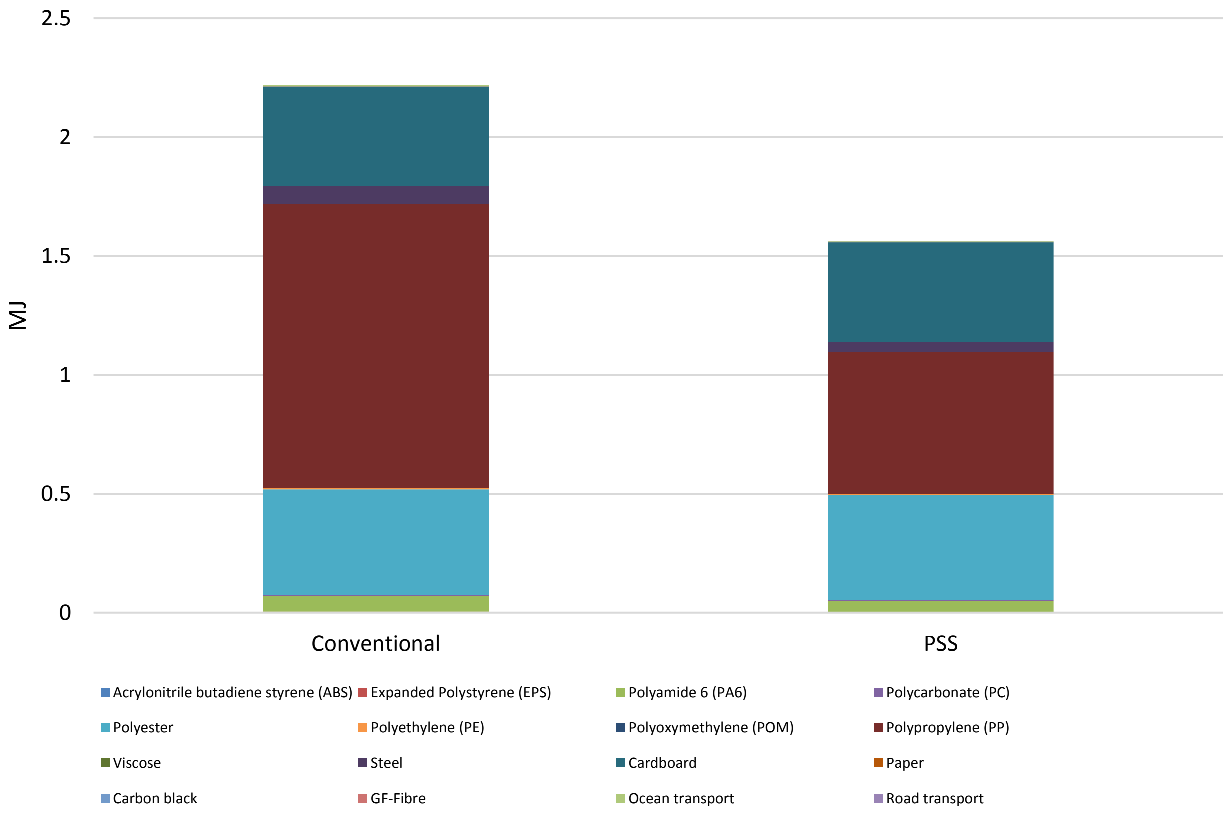

Figure A1.4: Use of energy resources from the air for conventional and PSS: full breakdown

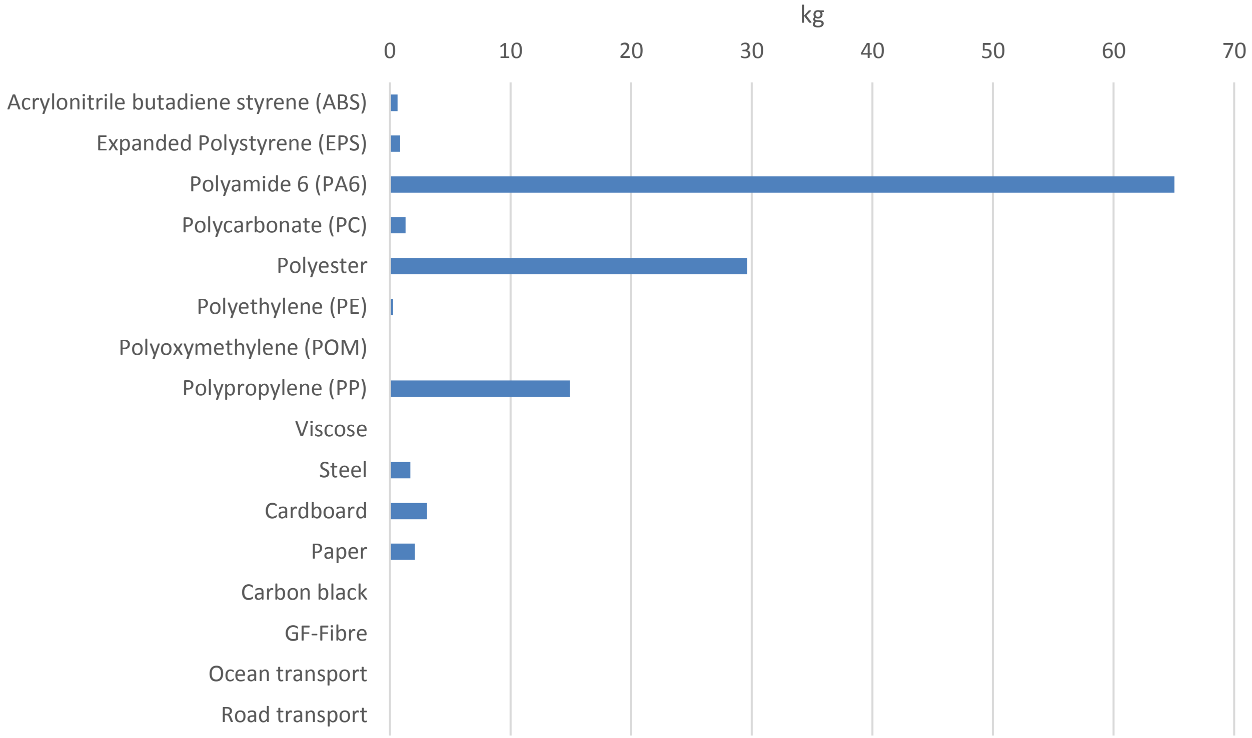

Figure A1.5: Consumption intensity: Material resources from the air used per kg

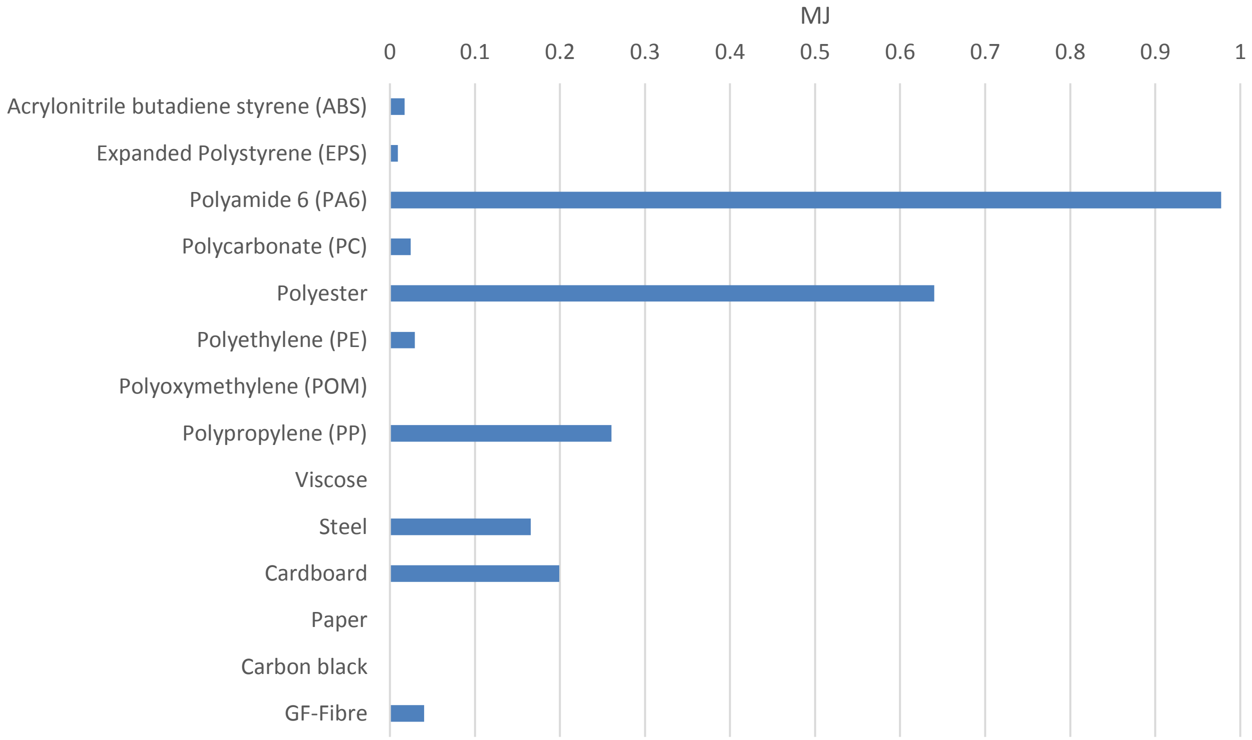

Figure A1.6: Consumption intensity: Energy resources from the air used per kg

A2. Resources from the ground

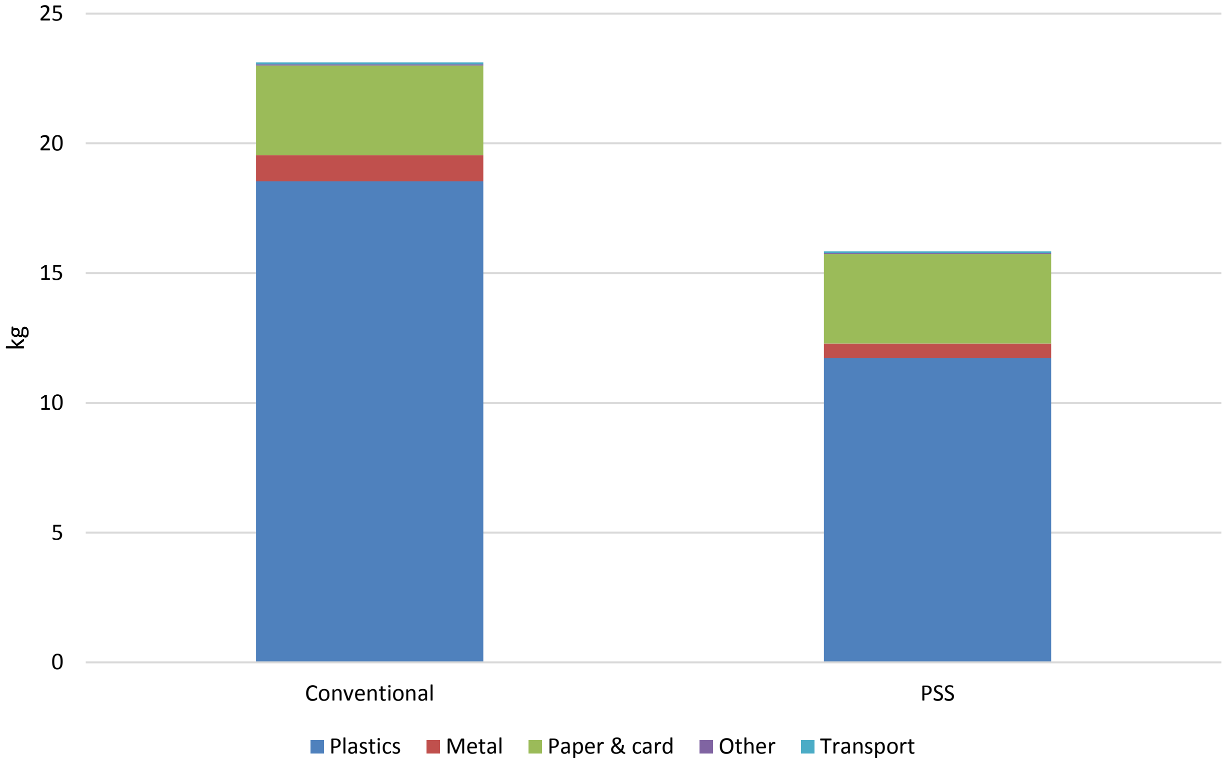

Figure A2.1: Use of material resources from the ground for conventional and PSS: partial breakdown

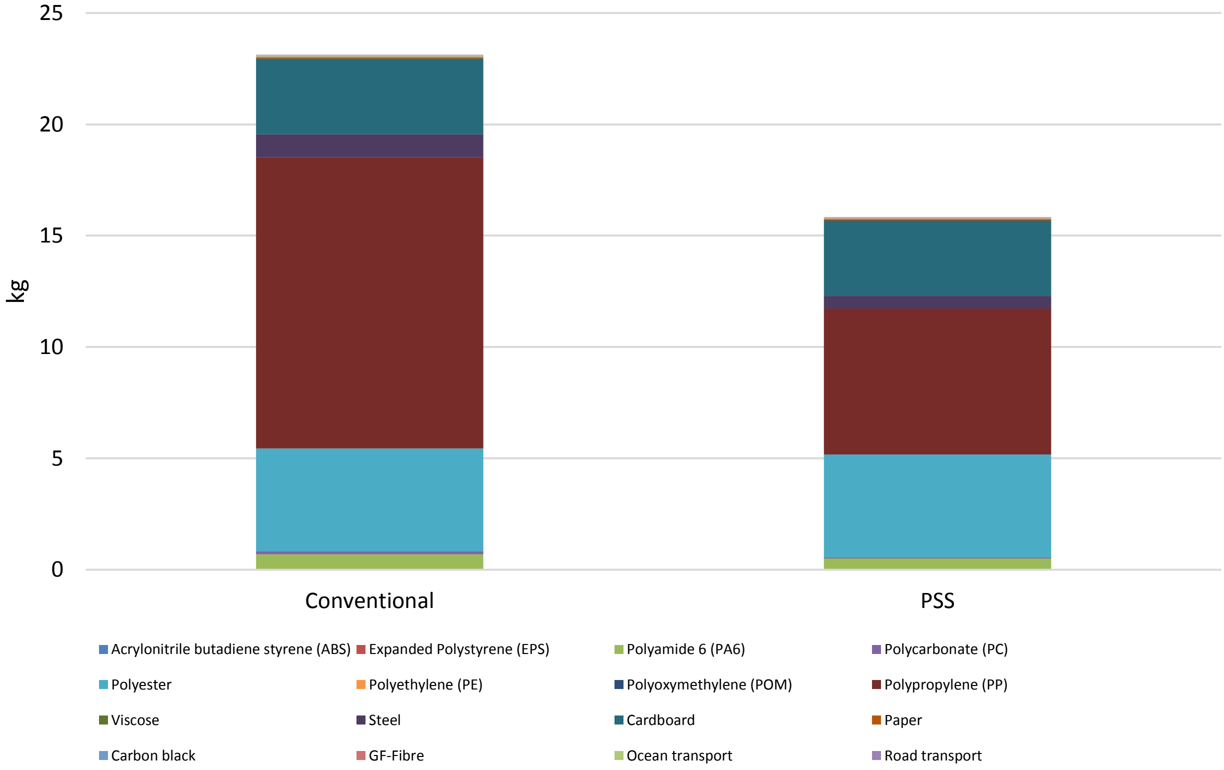

Figure A2.2: Use of material resources from the ground for conventional and PSS: full breakdown

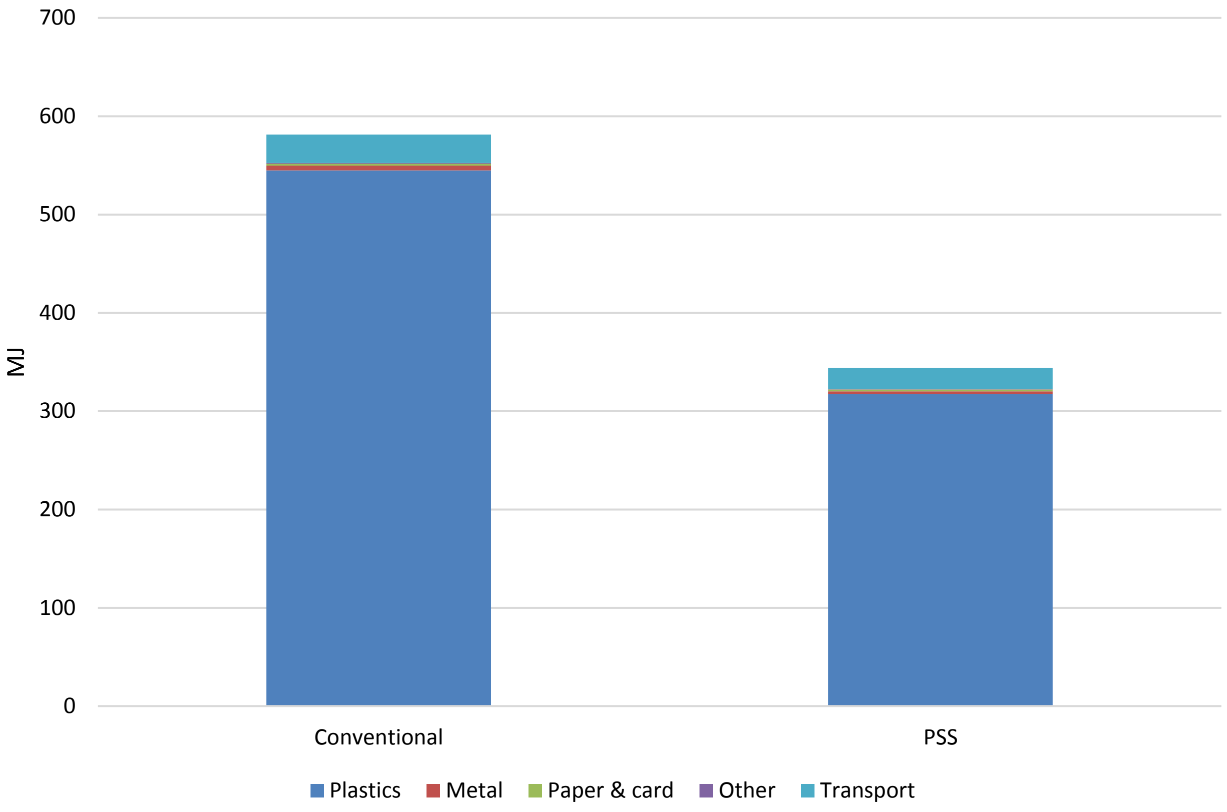

Figure A2.3: Use of energy resources from the ground for conventional and PSS: partial breakdown

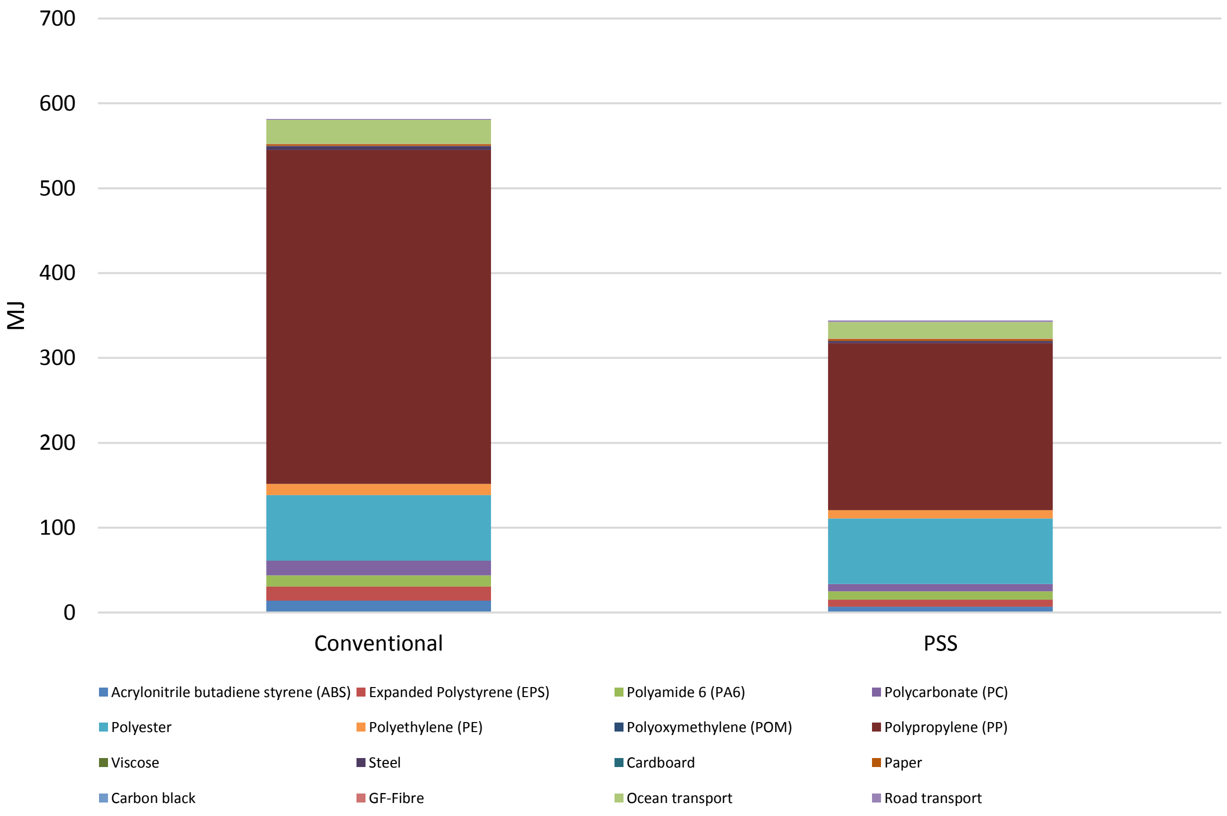

Figure A2.4: Use of energy resources from the ground for conventional and PSS: full breakdown

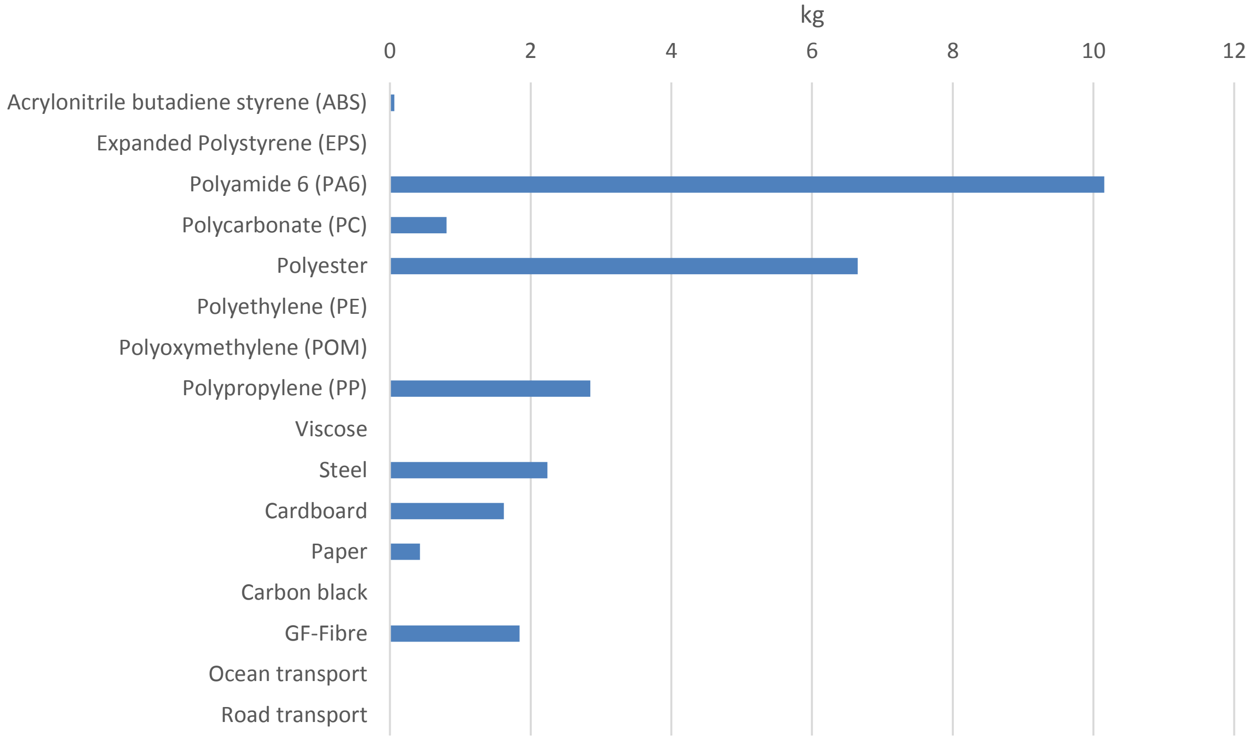

Figure A2.5: Consumption intensity: Material resources from the ground used per kg

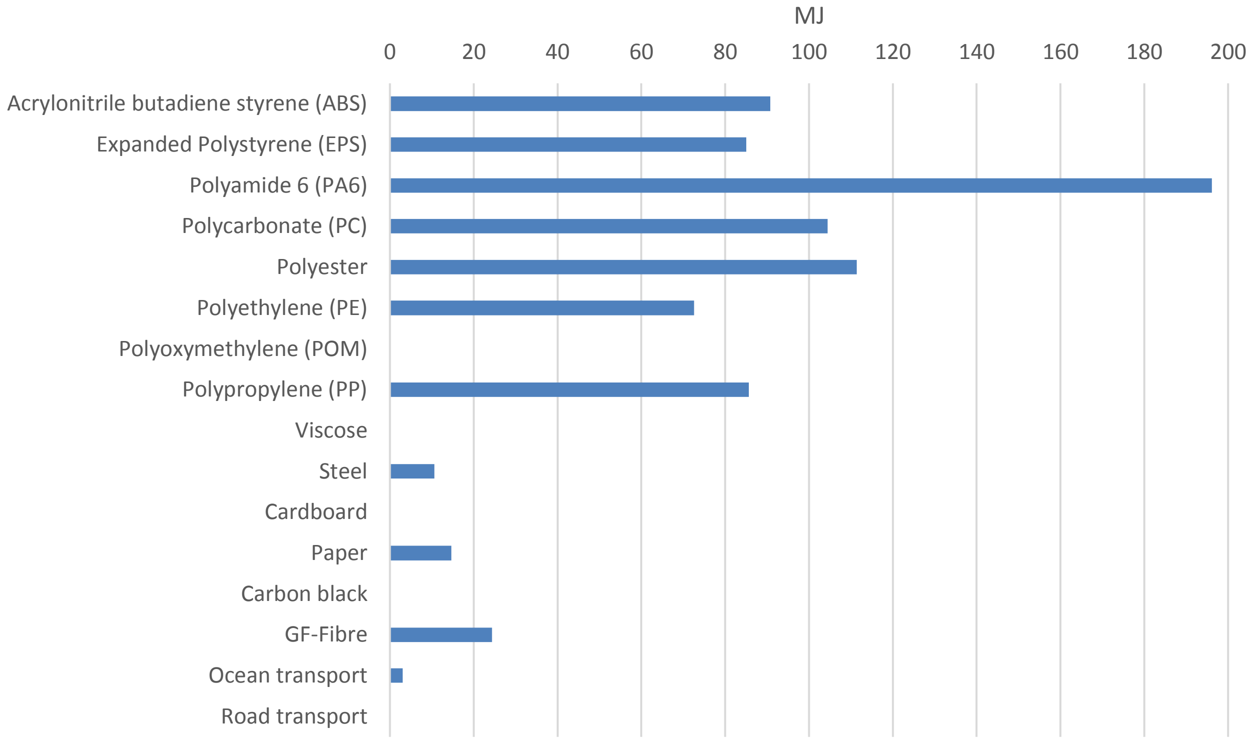

Figure A2.6: Consumption intensity: Energy resources from the ground used per kg

A3. Resources from water

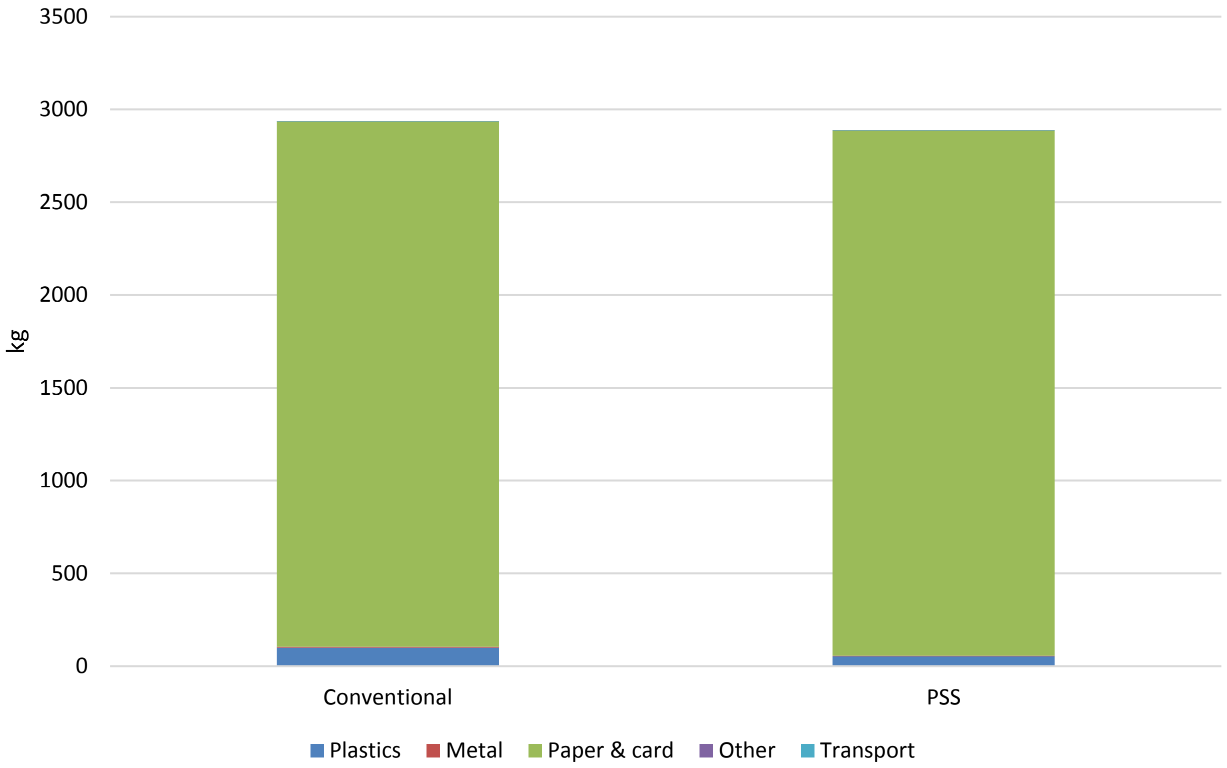

Figure A3.1: Use of material resources from water for conventional and PSS: partial breakdown

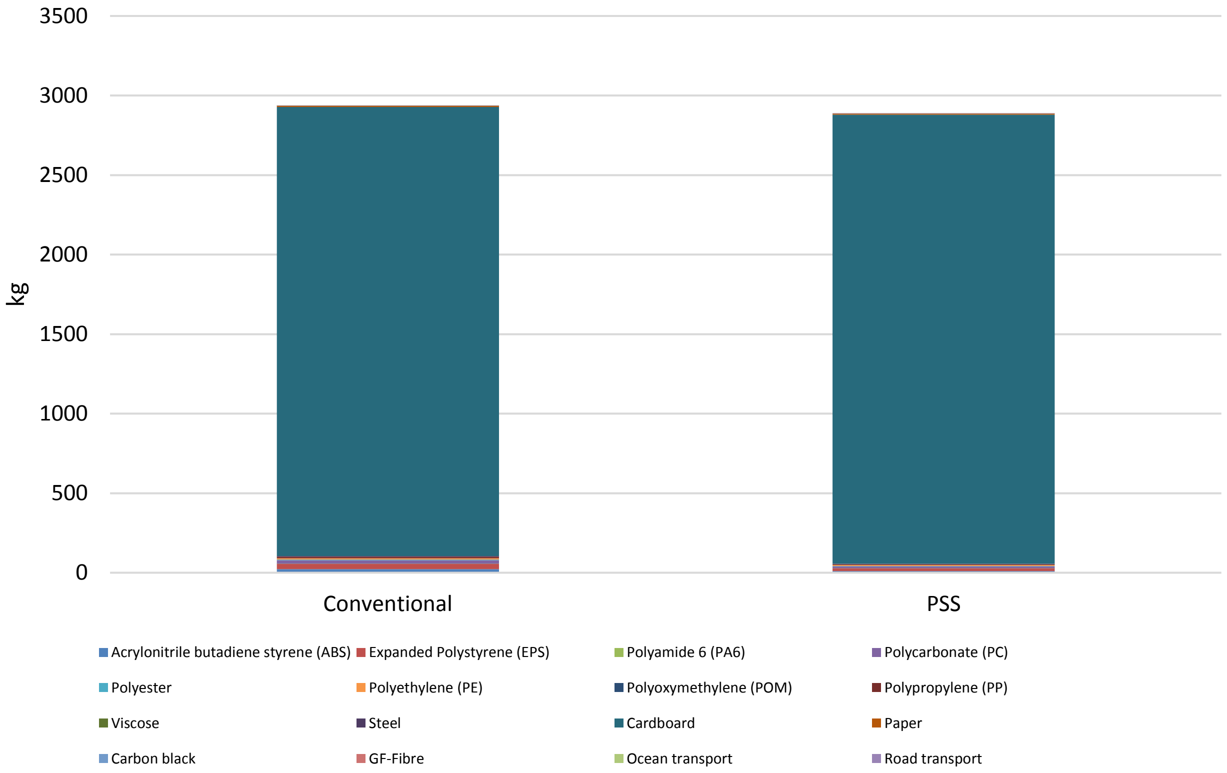

Figure A3.2: Use of material resources from water for conventional and PSS: full breakdown

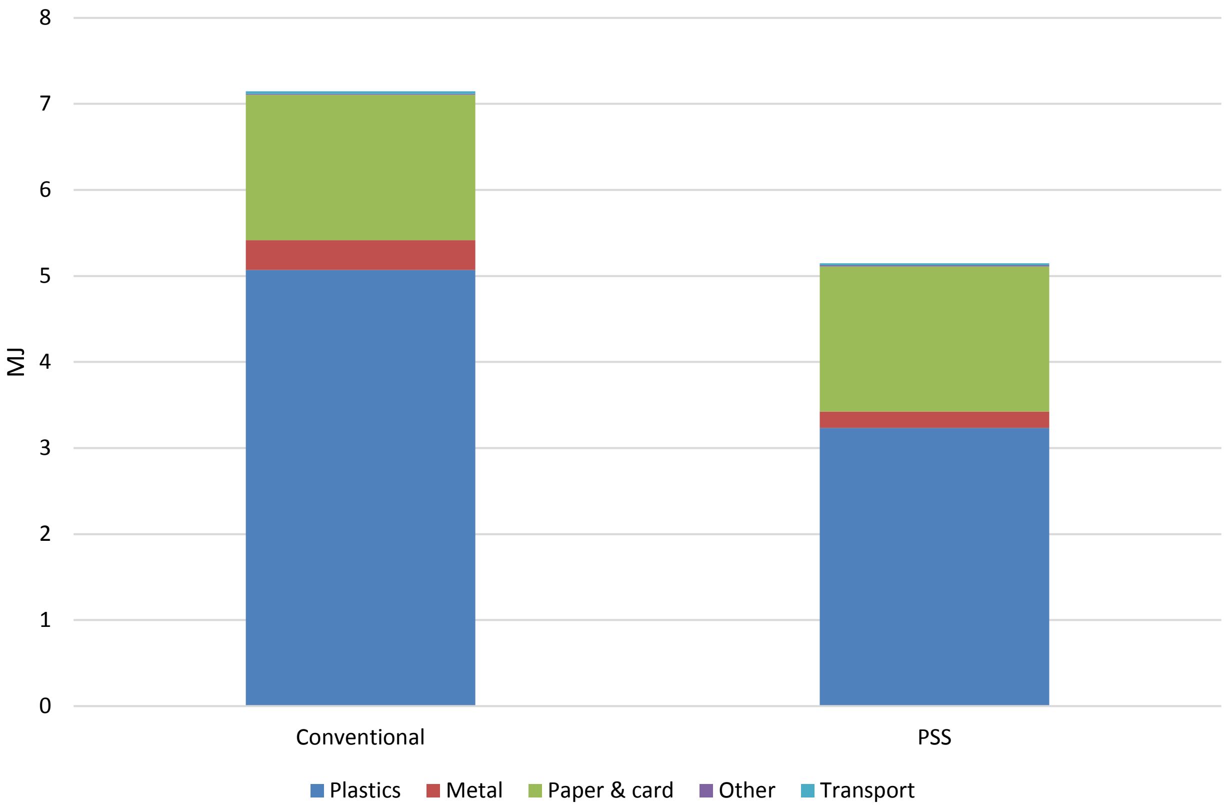

Figure A3.3: Use of energy resources from water for conventional and PSS: partial breakdown

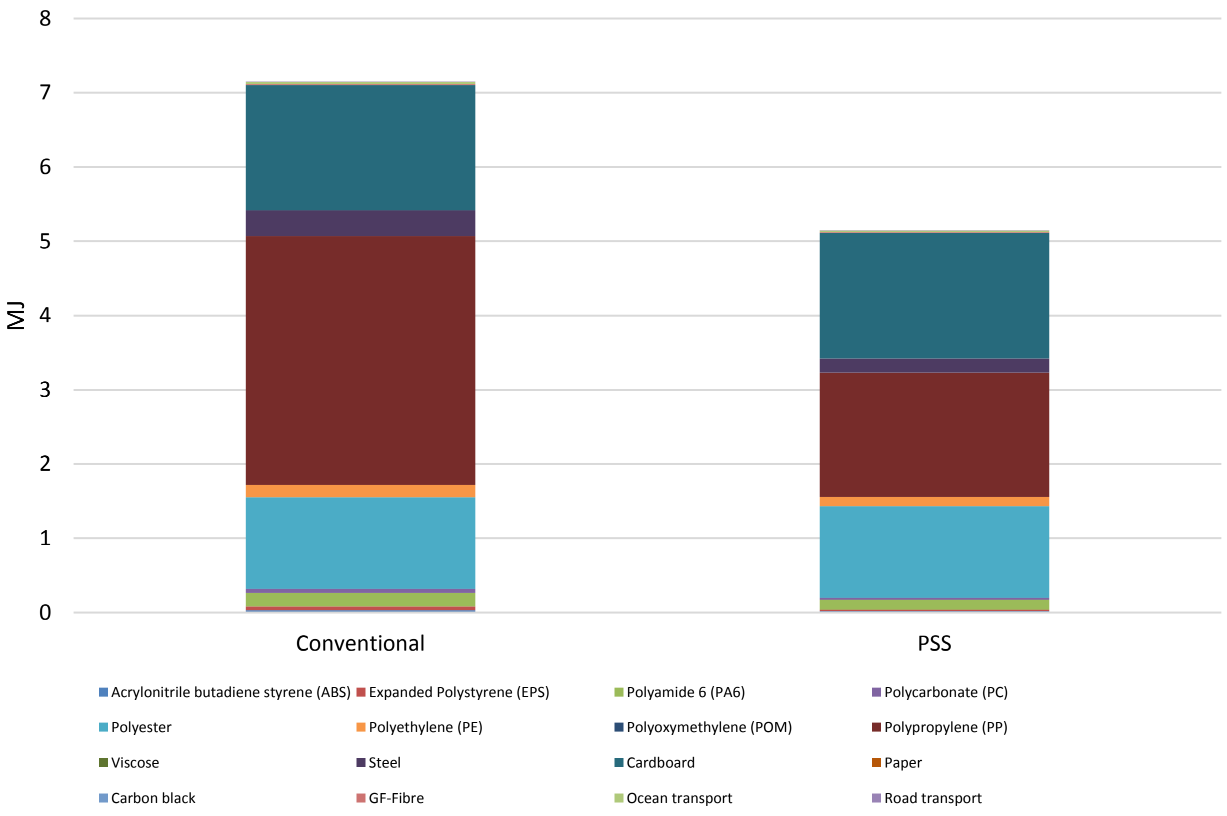

Figure A3.4: Use of energy resources from water for conventional and PSS: full breakdown

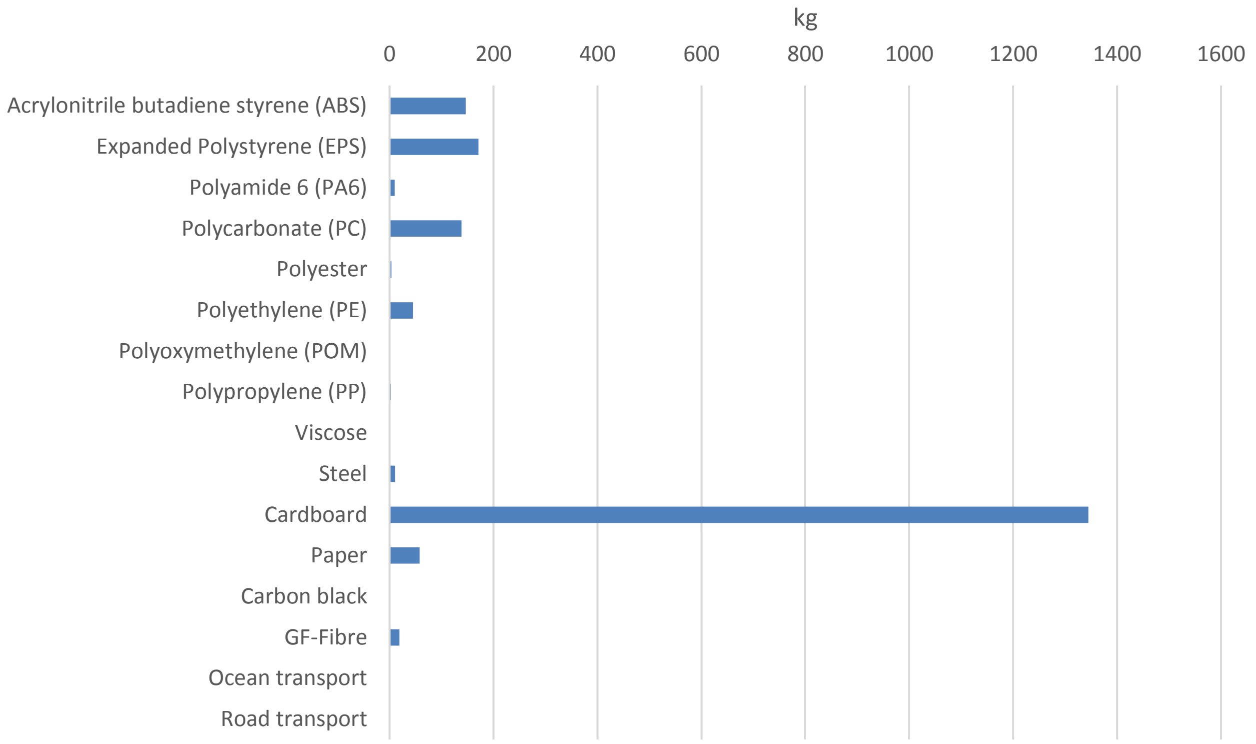

Figure A3.5: Consumption intensity: Material resources from water used per kg

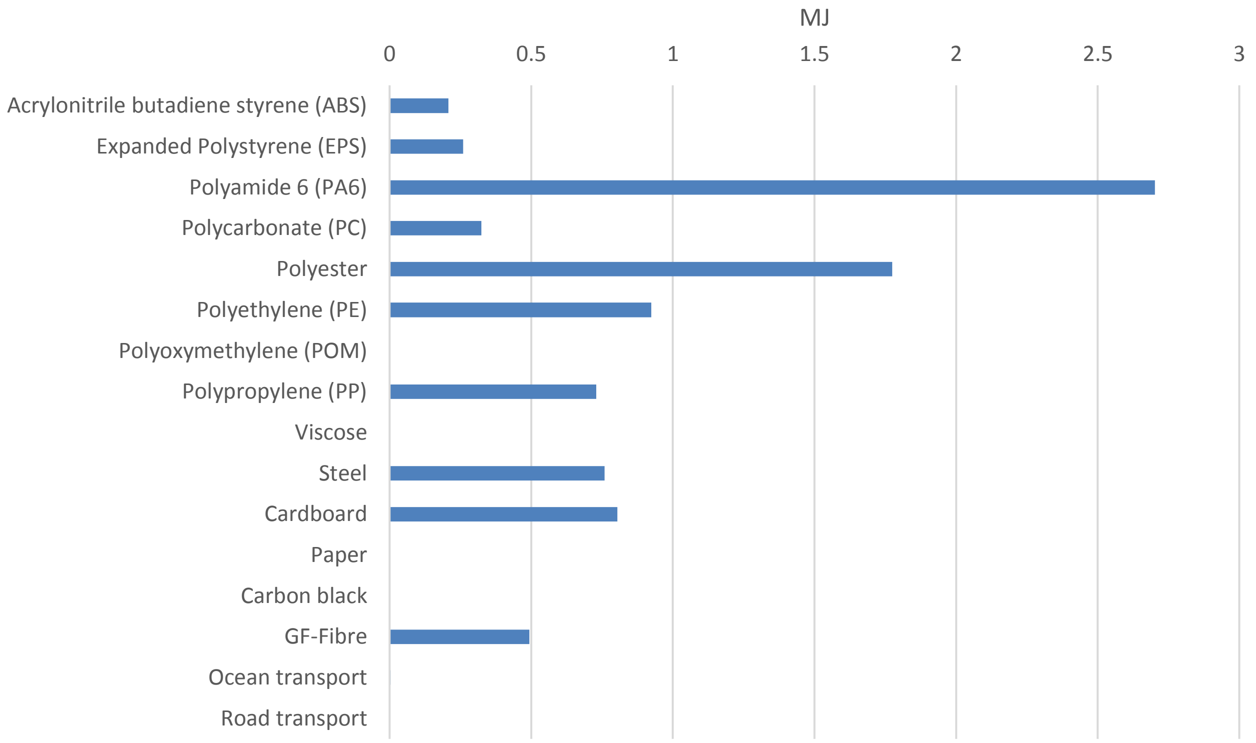

Figure A3.6: Consumption intensity: Energy resources from water used per kg

A4. Resources from the biosphere

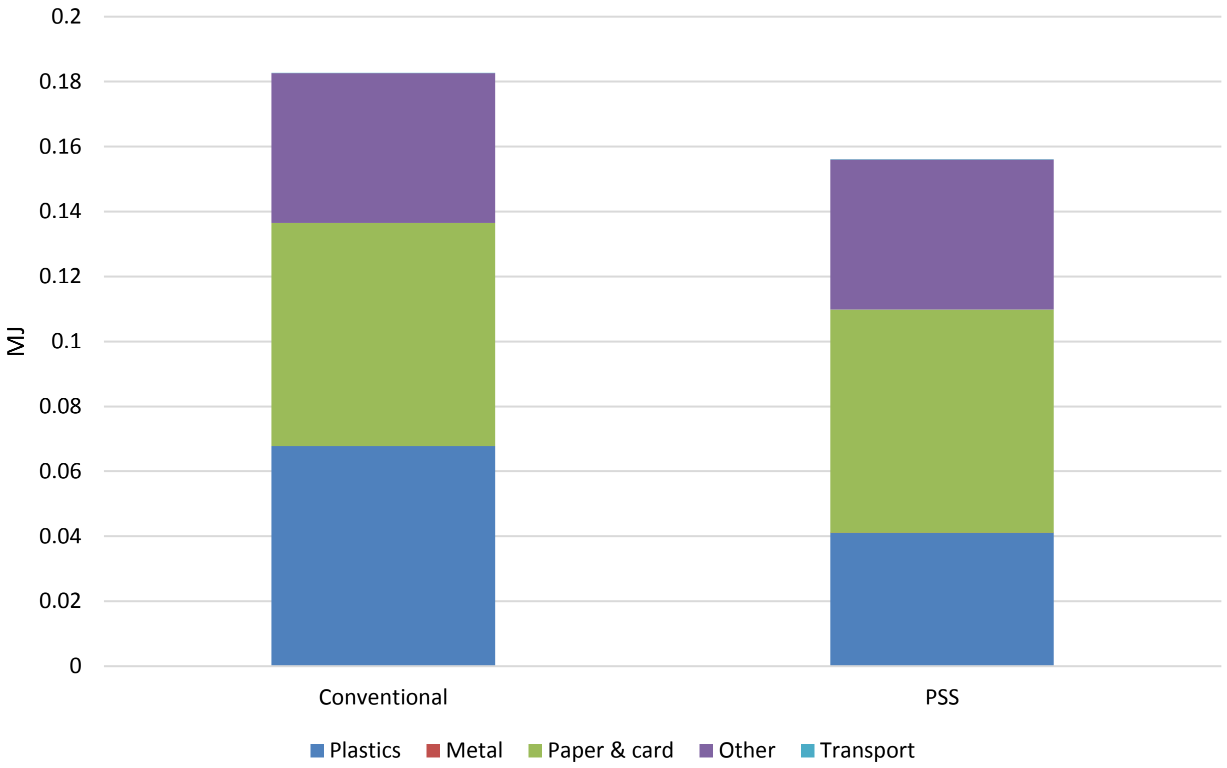

Figure A4.1: Use of energy resources from the biosphere for conventional and PSS: partial breakdown

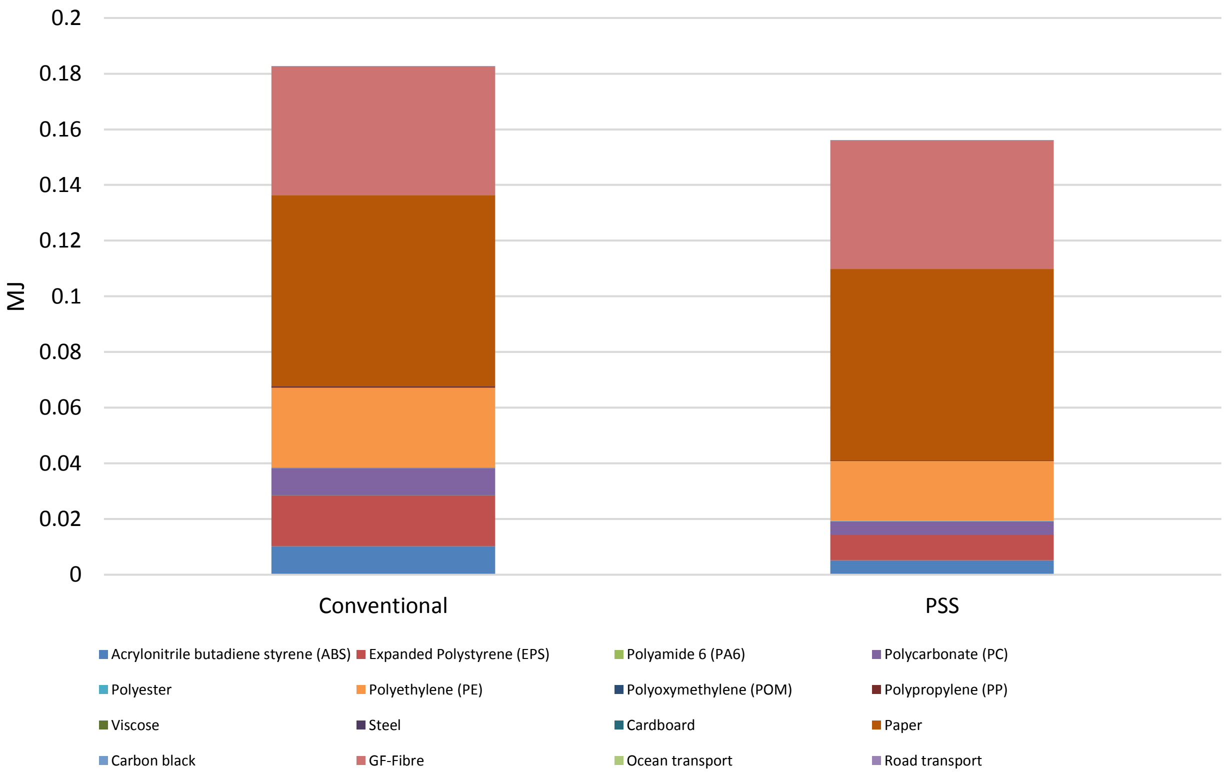

Figure A4.2: Use of energy resources from the biosphere for conventional and PSS: full breakdown

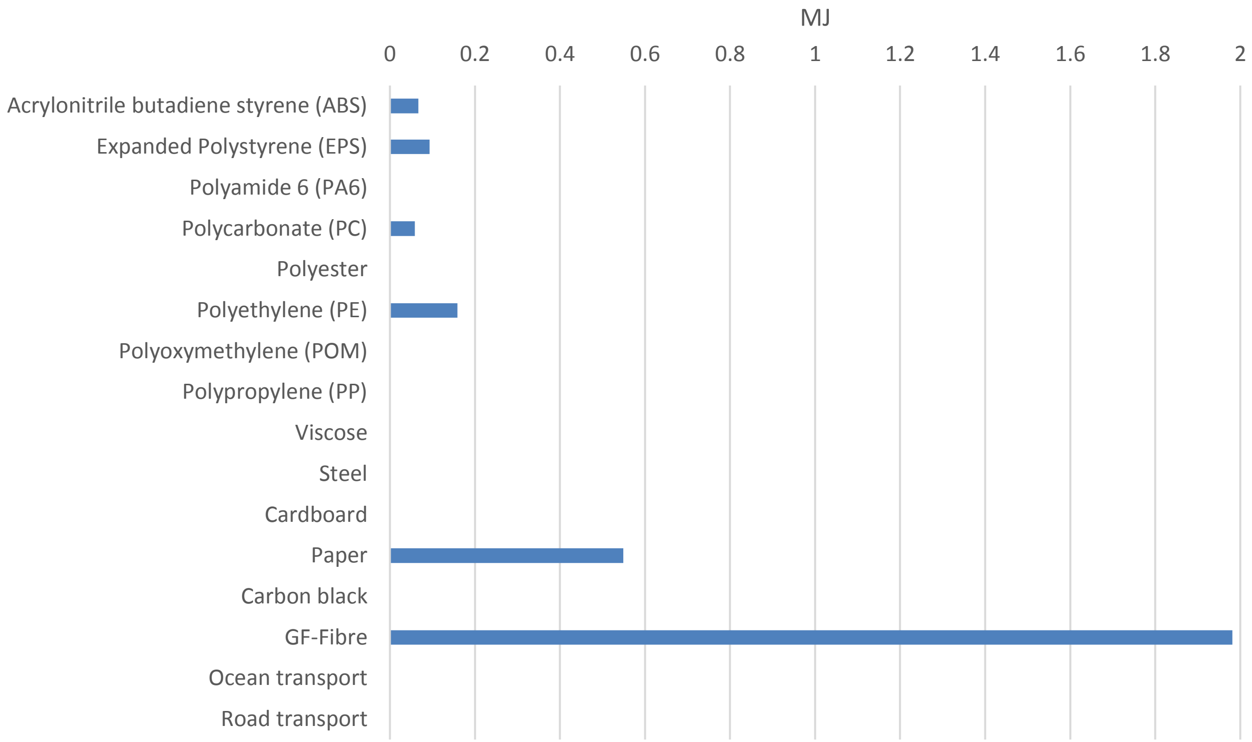

Figure A4.3: Consumption intensity: Energy resources from the biosphere used per kg

Appendix B. Emissions charts

B1. Emissions to the air

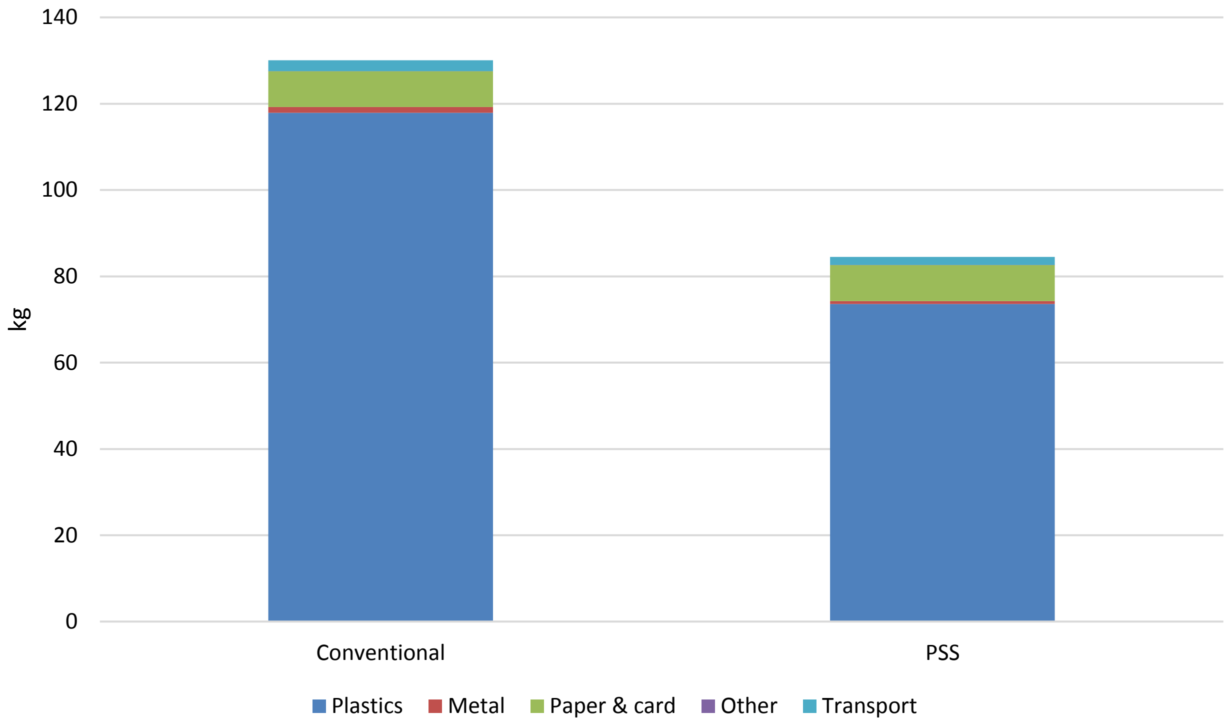

Figure B1.1: Emissions to the air for conventional and PSS: partial breakdown

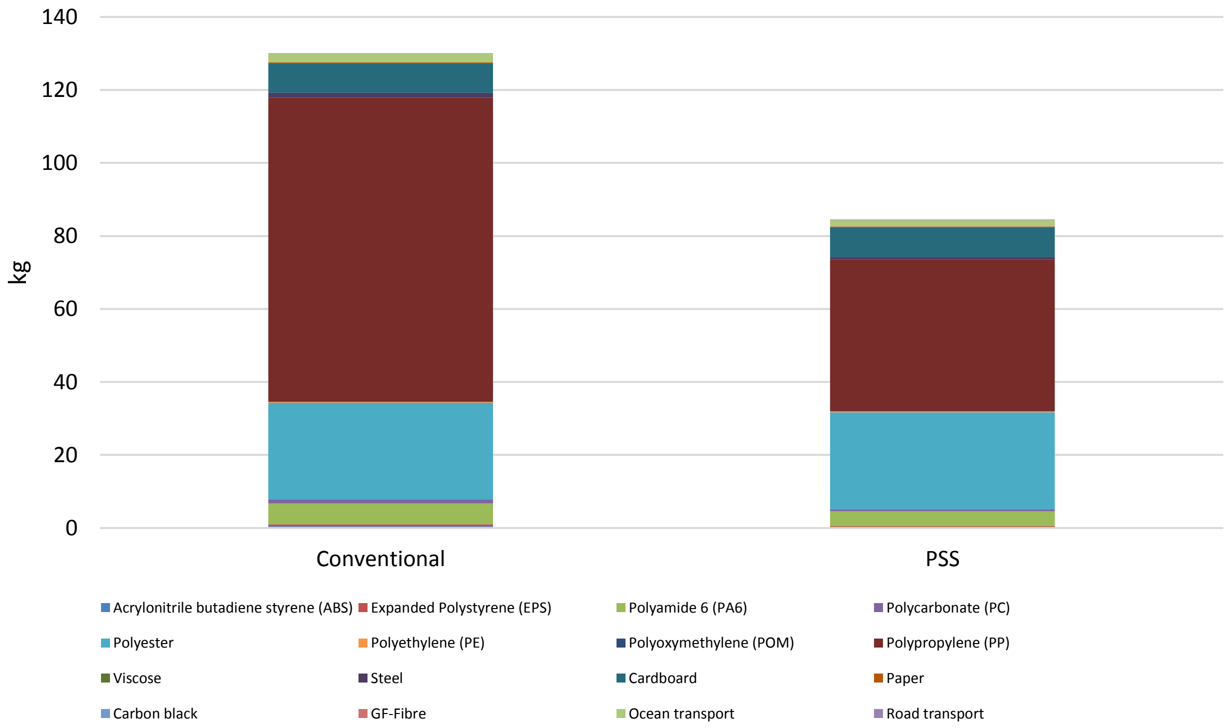

Figure B1.2: Emissions to the air for conventional and PSS: full breakdown

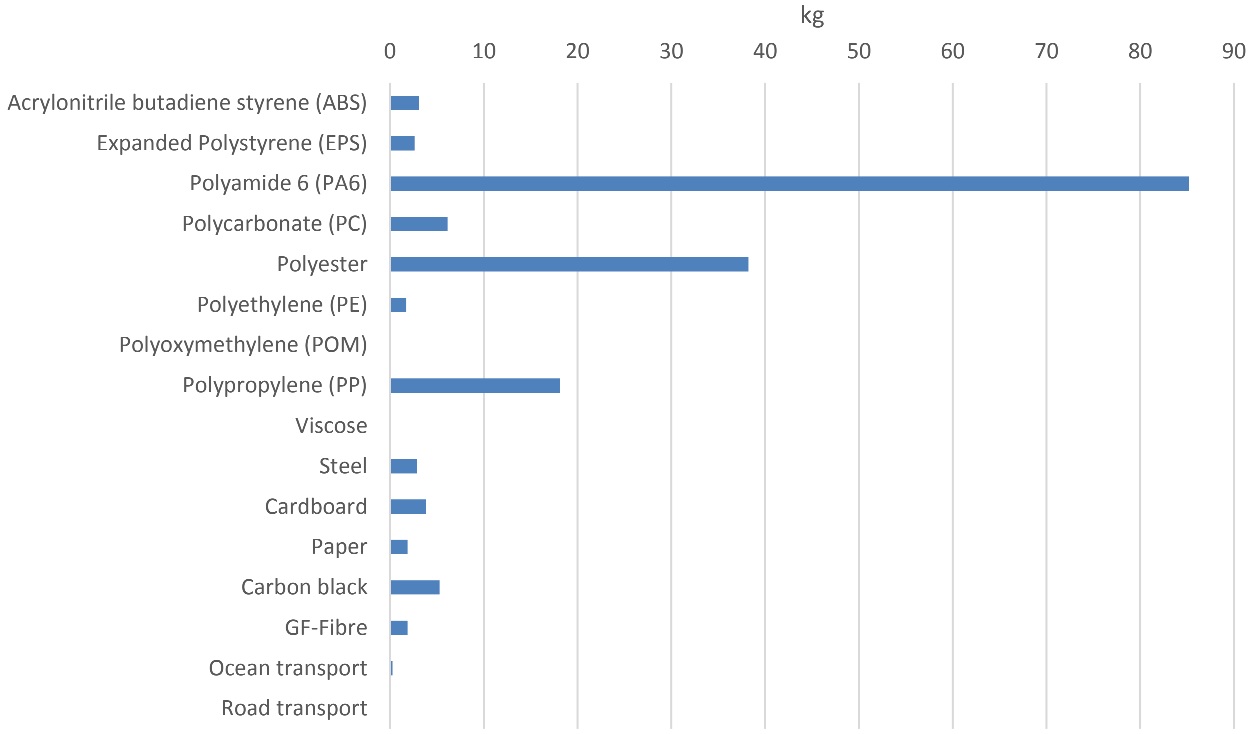

Figure B1.3: Emissions intensity: Emissions to the air per kg

B2. Emissions to the soil

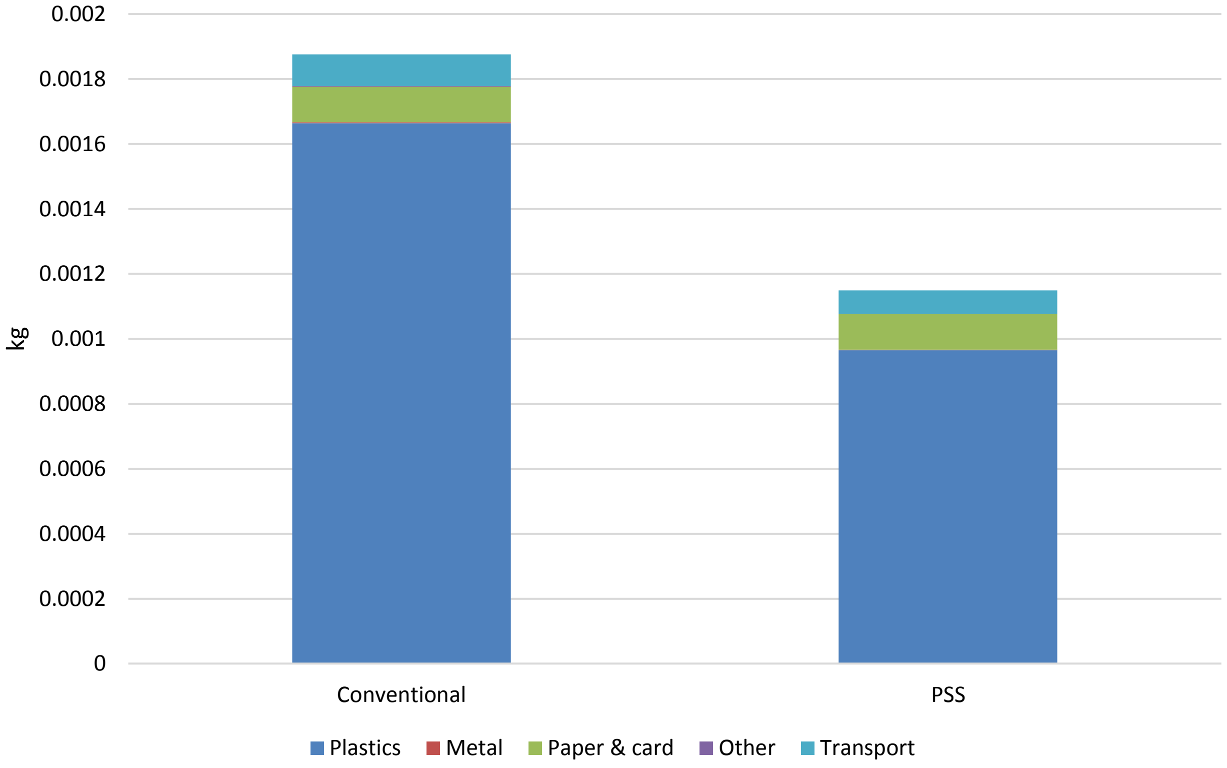

Figure B2.1: Emissions to the soil for conventional and PSS: partial breakdown

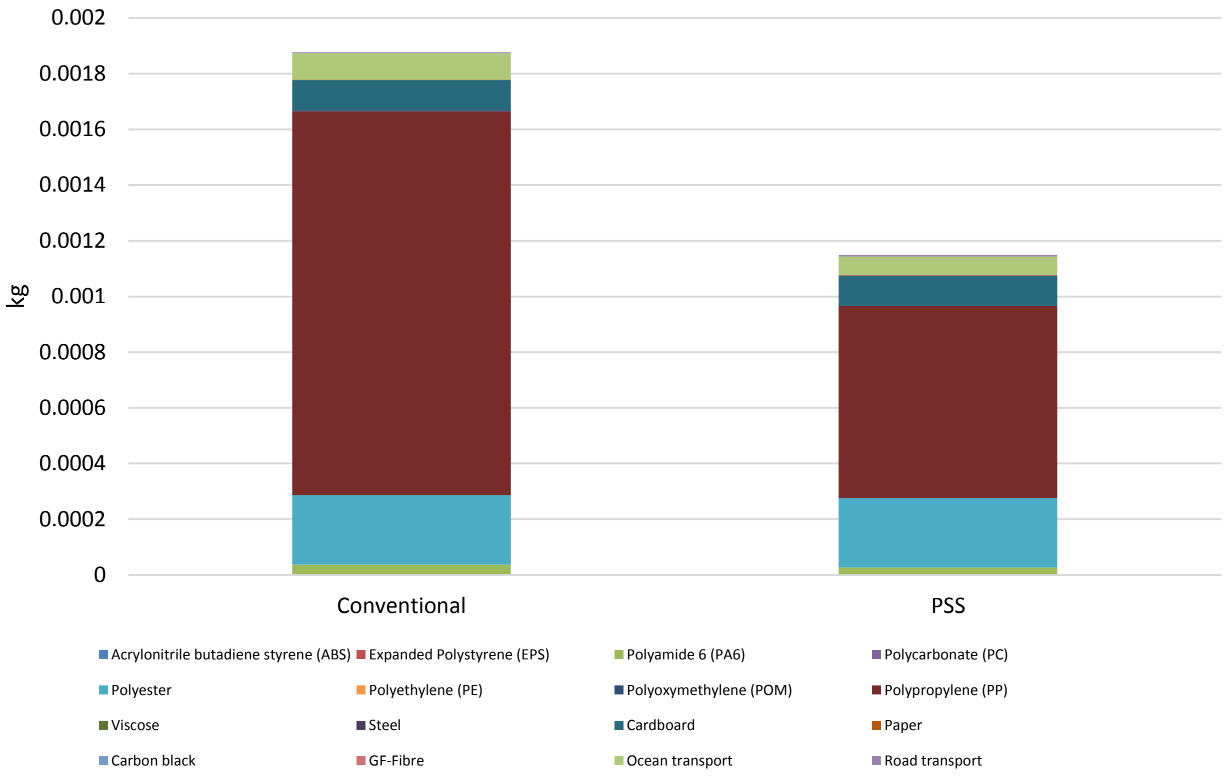

Figure B2.2: Emissions to the soil for conventional and PSS: full breakdown

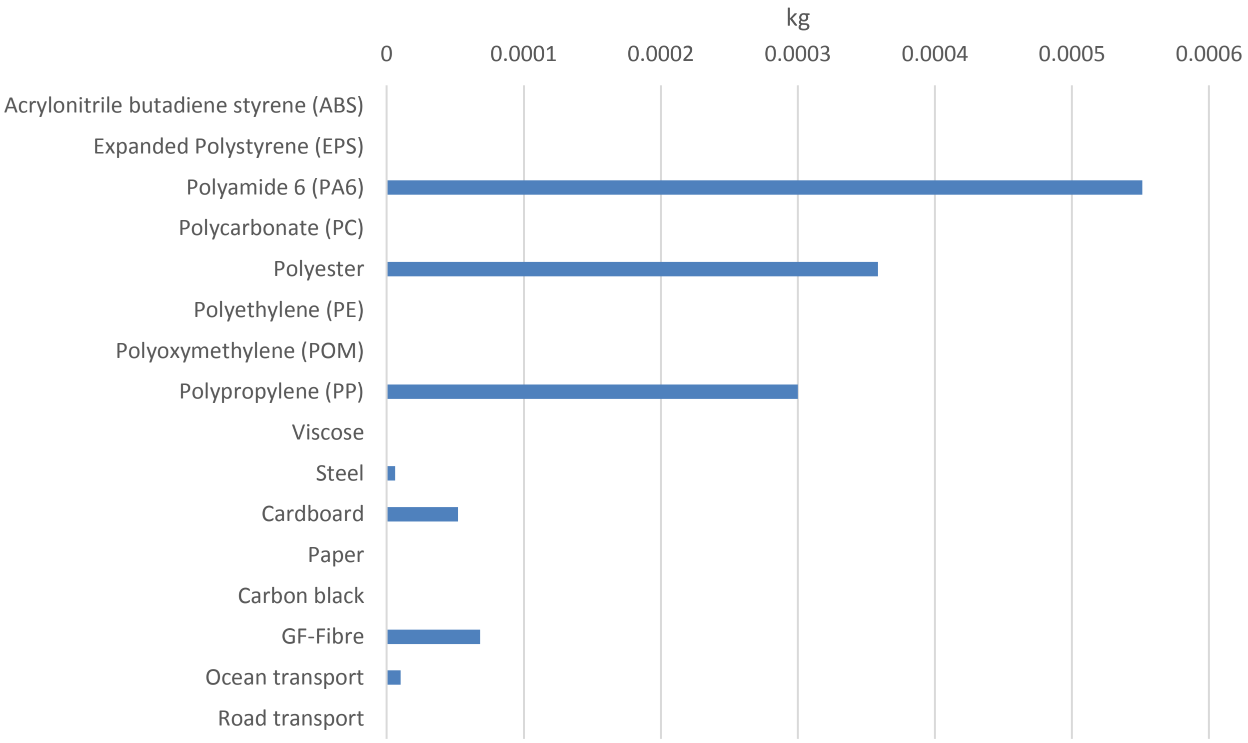

Figure B2.3: Emissions intensity: Emissions to the soil per kg

B3. Emissions to water

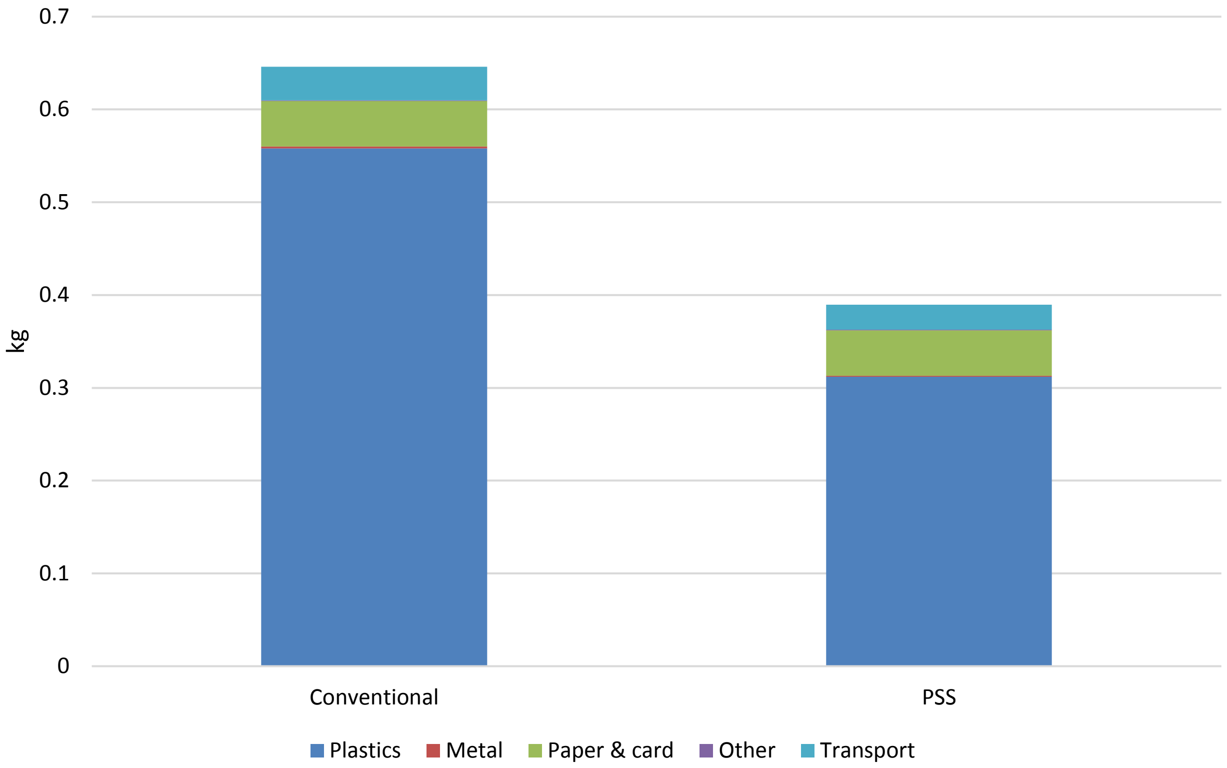

Figure B3.1: Emissions to water for conventional and PSS: partial breakdown

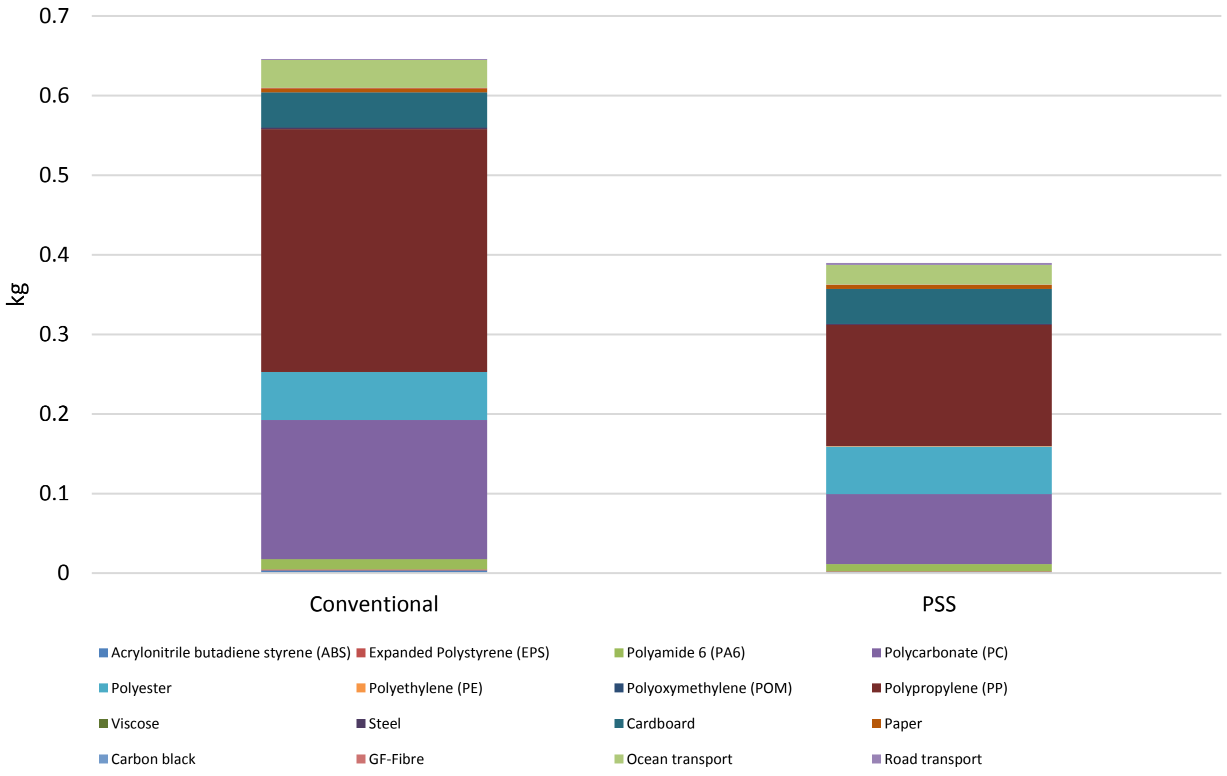

Figure B3.2: Emissions to water for conventional and PSS: full breakdown

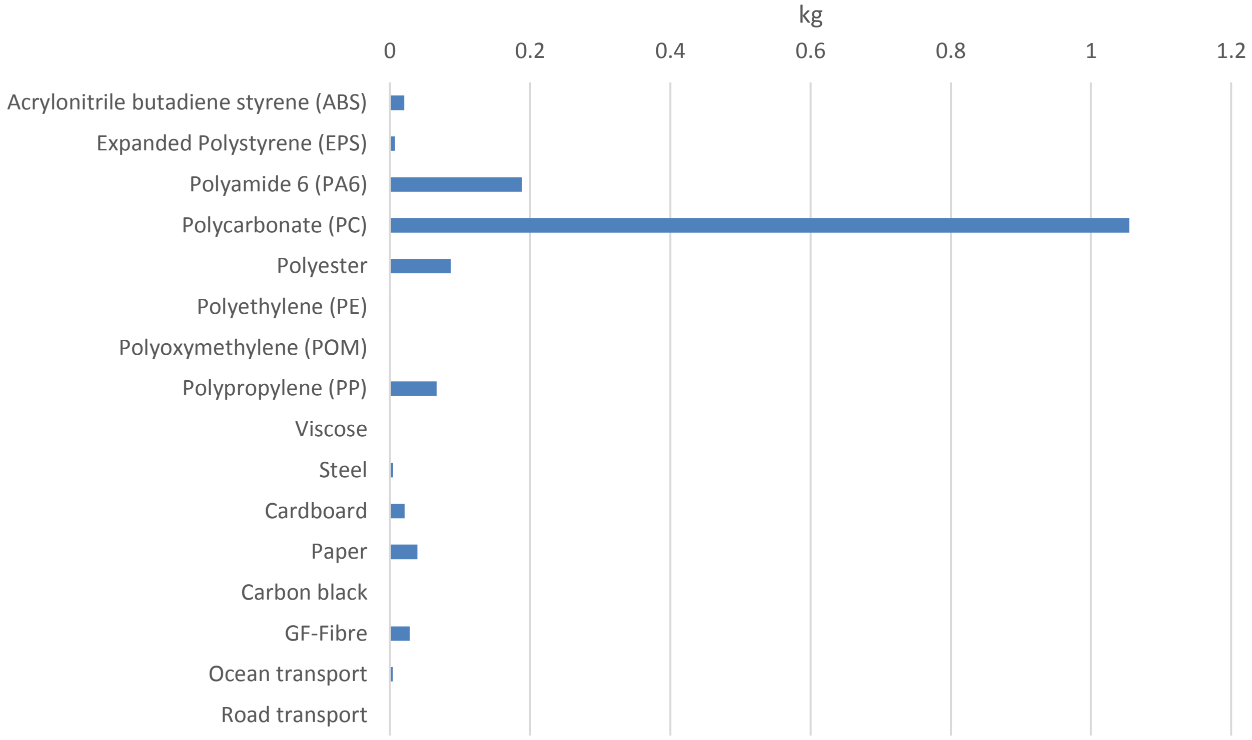

Figure B3.3: Emissions intensity: Emissions to water per kg

Appendix C. Impact charts

C1. Overview

C1.1. Comparison of conventional to PSS

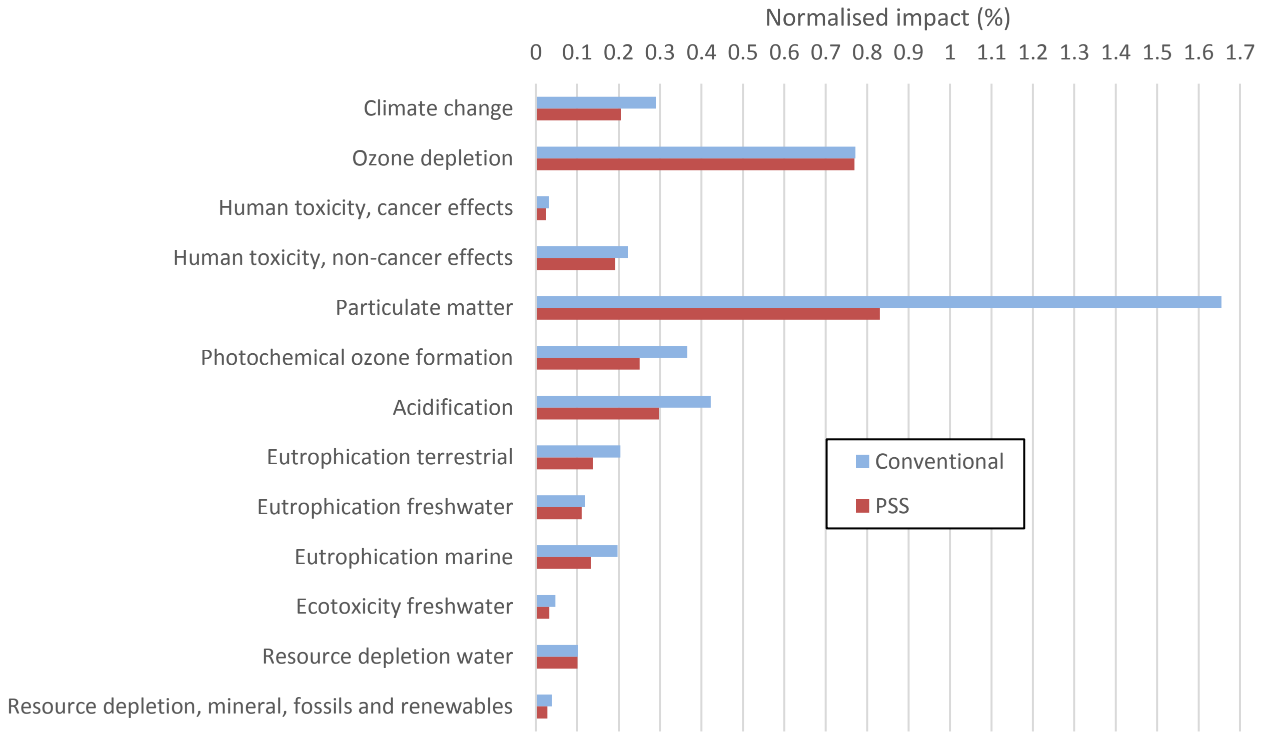

Figure C1.1: NI: Conventional and PSS car seats (2 uses)

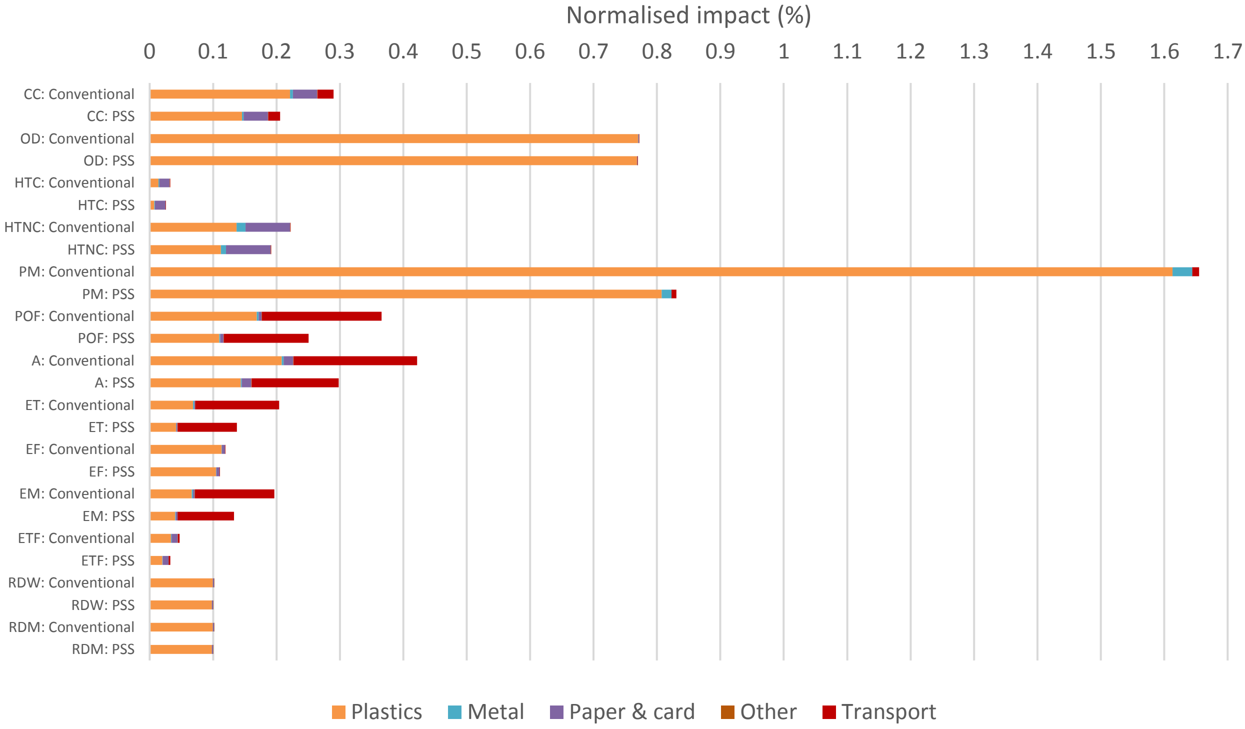

Figure C1.2: NI: Conventional and PPS car seat (2 uses): partial breakdown

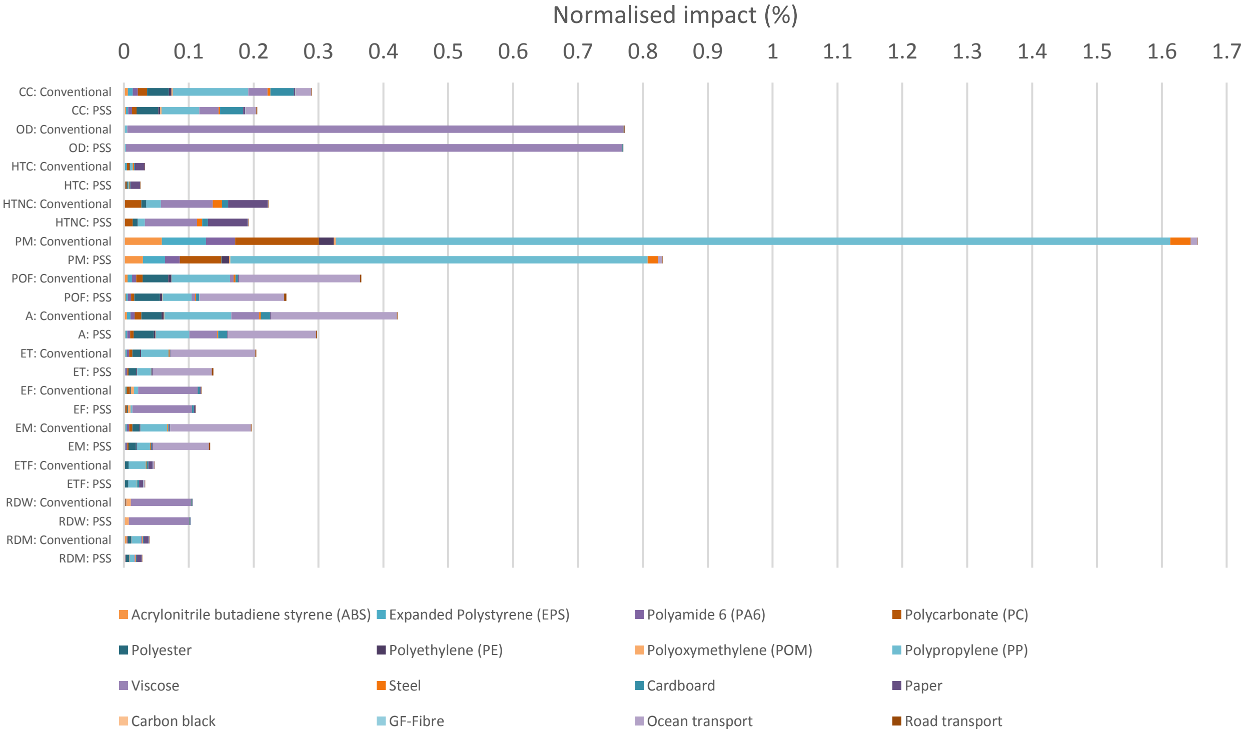

Figure C1.3: NI: Conventional and PPS car seat (2 uses): full breakdown

C1.2. Difference between conventional and PSS

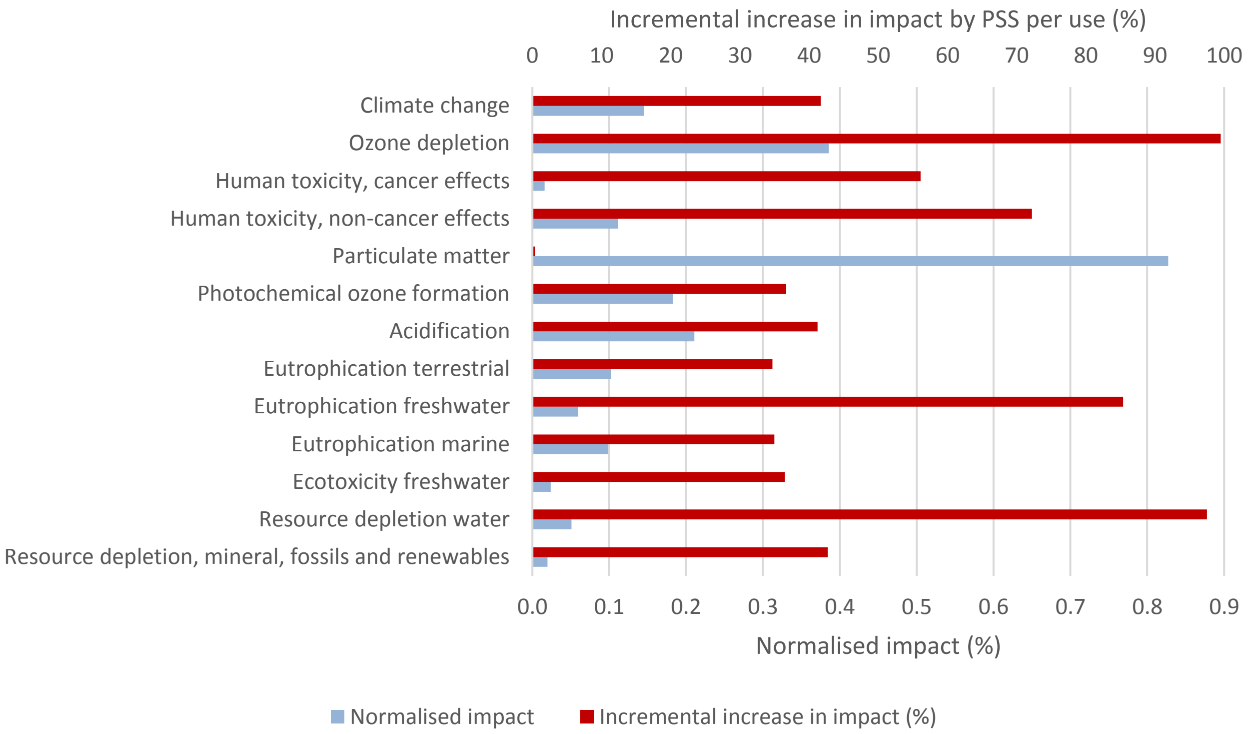

Figure C1.4: NI: Conventional car seat and Incremental increase in impact by the PSS

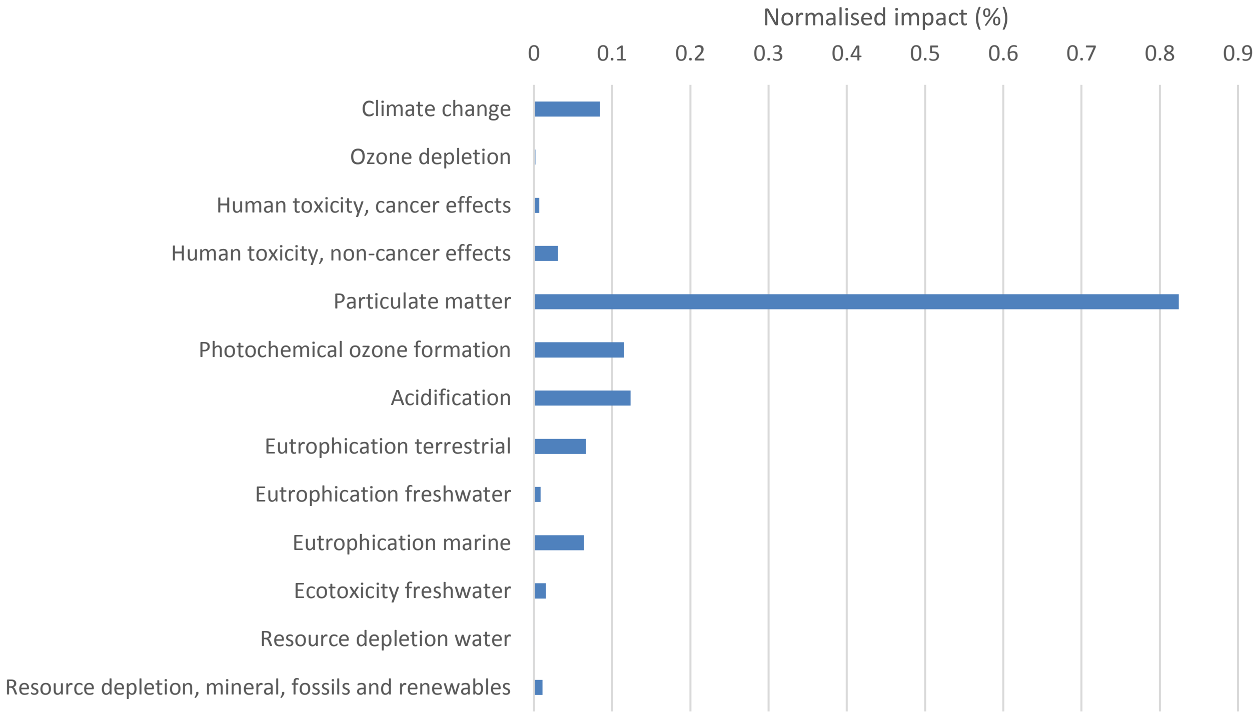

Figure C1.5: Difference in NI: Conventional and PSS car seats (2 uses)

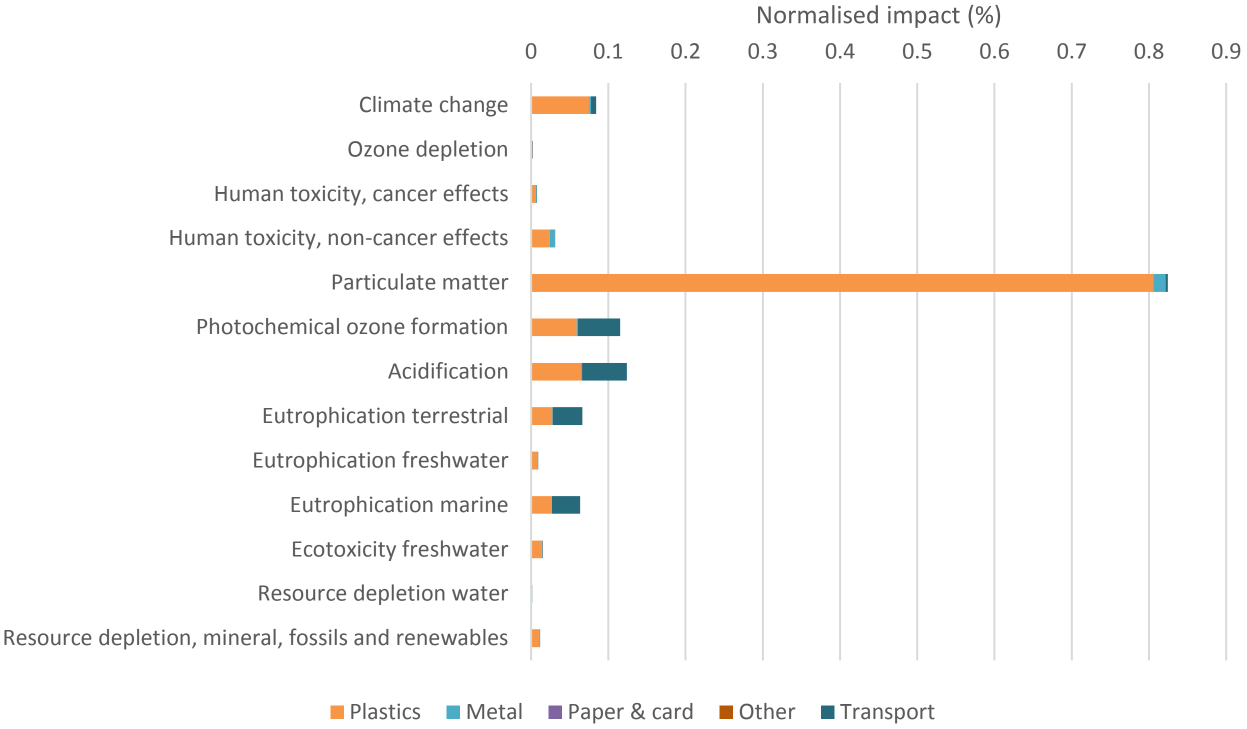

Figure C1.6: Difference in NI: Conventional and PPS car seat (2 uses): partial breakdown

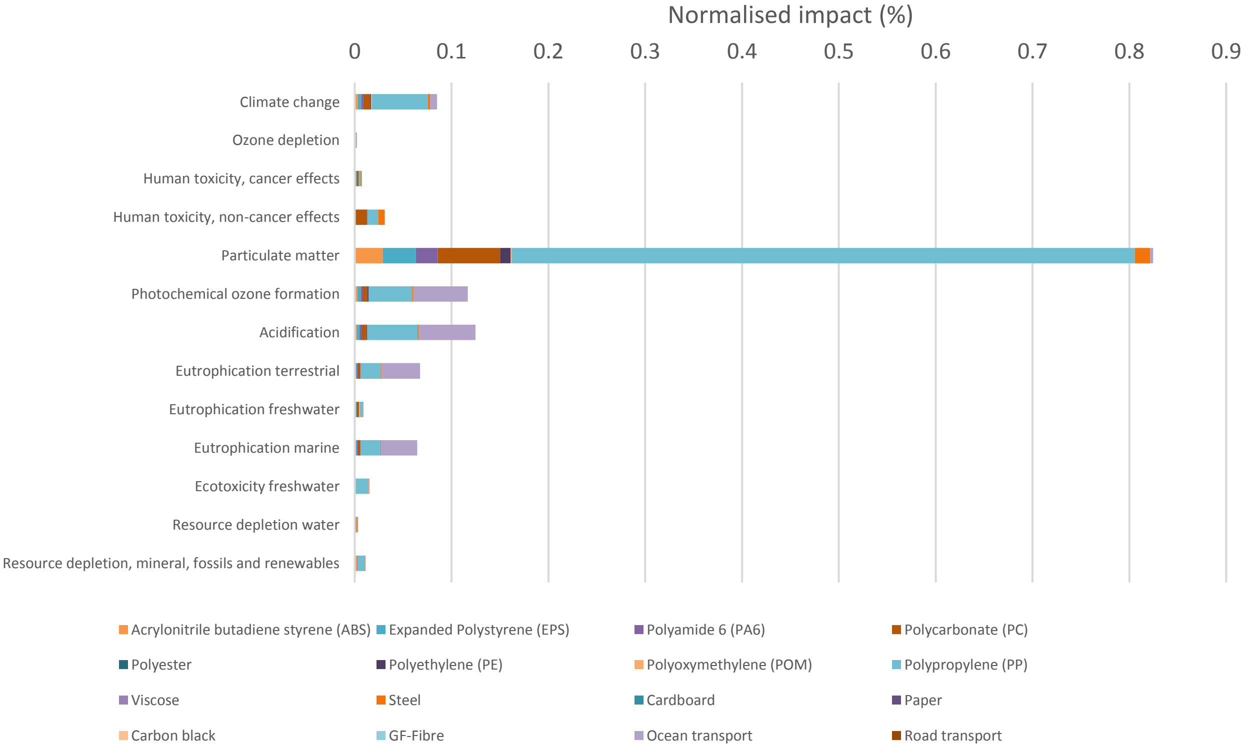

Figure C1.7: Difference in NI: Conventional and PPS car seat (2 uses): full breakdown

C1.3. Impact intensity

C1.3.1. Impact intensity by impact

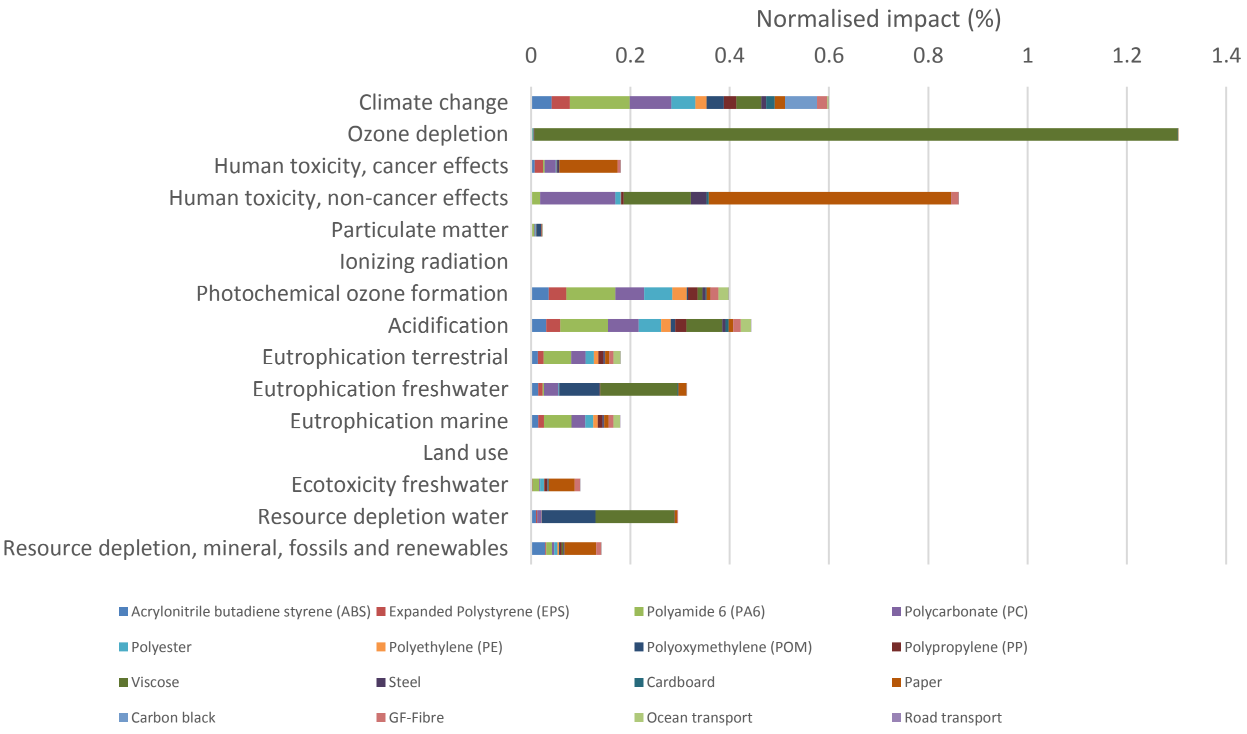

Figure C1.8: NI per kg (by impact)

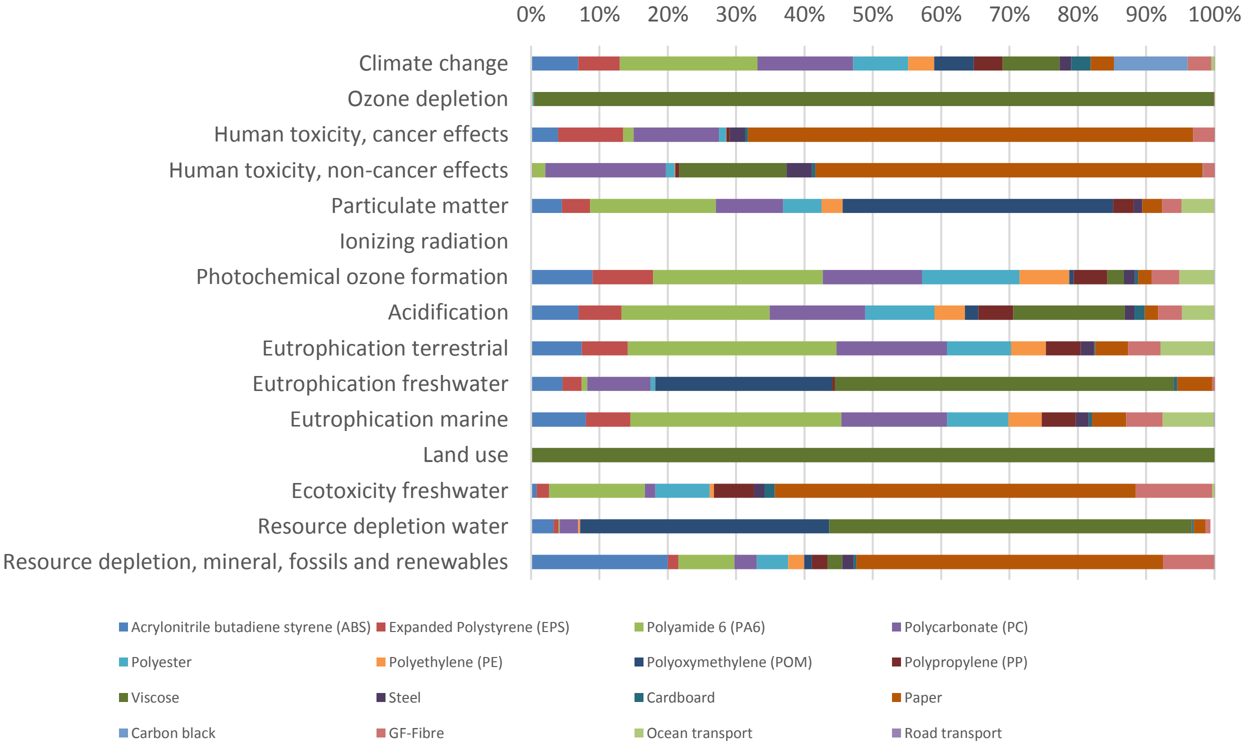

Figure C1.9: Proportion of NI per kg (by impact)

C1.3.2. Impact intensity by substance

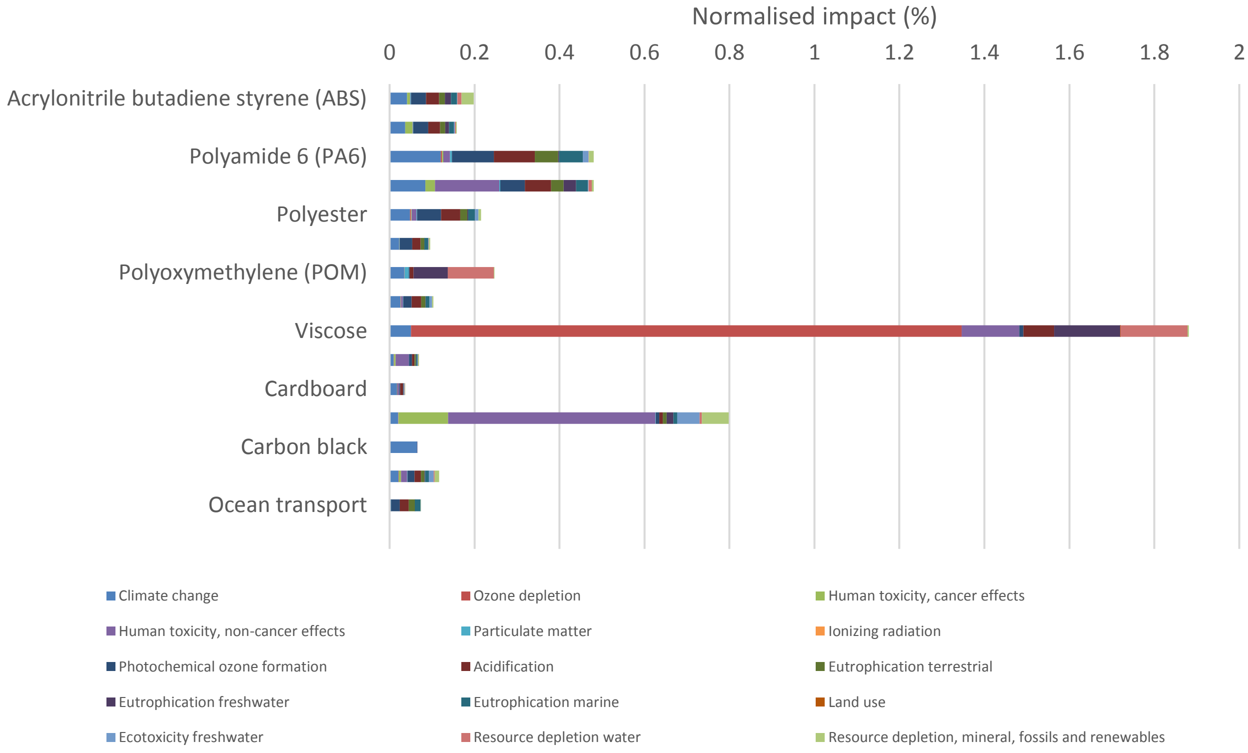

Figure C1.10: NI intensity: impact per kg (by material)

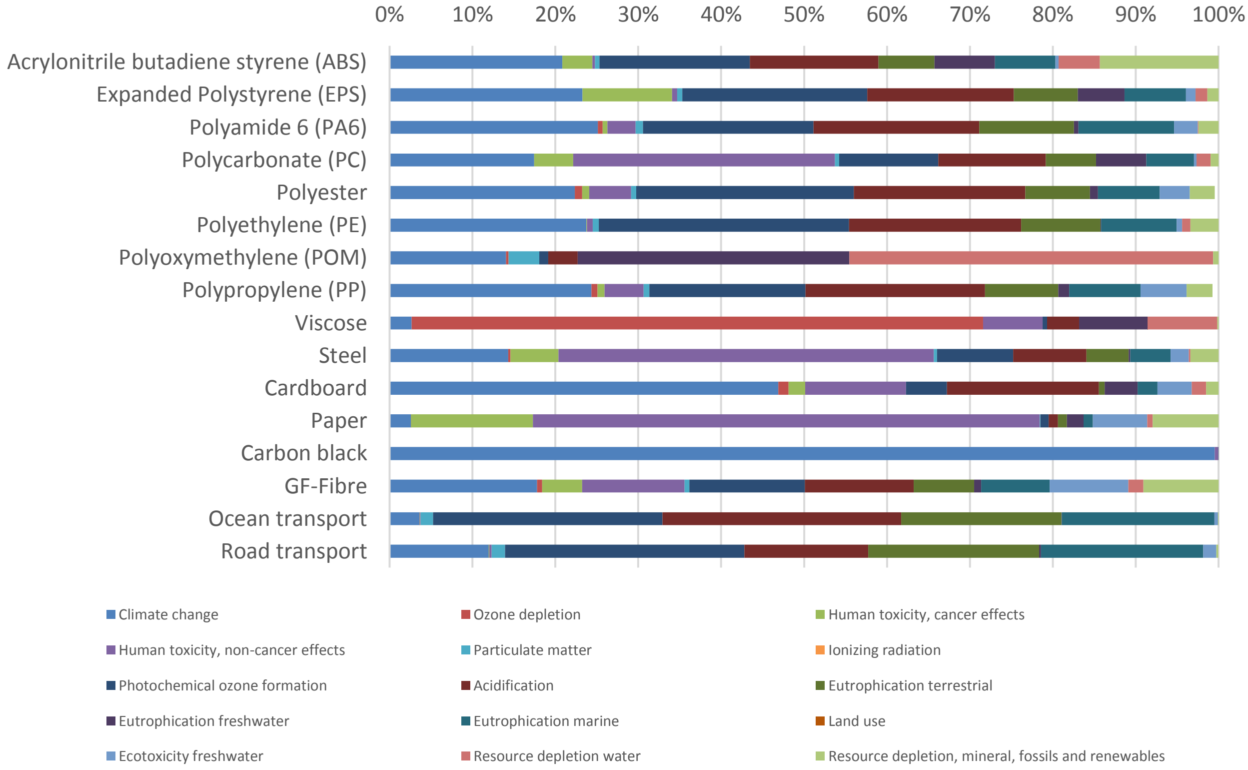

Figure C1.11: Proportion of NI per kg (by material)

C2. Climate change

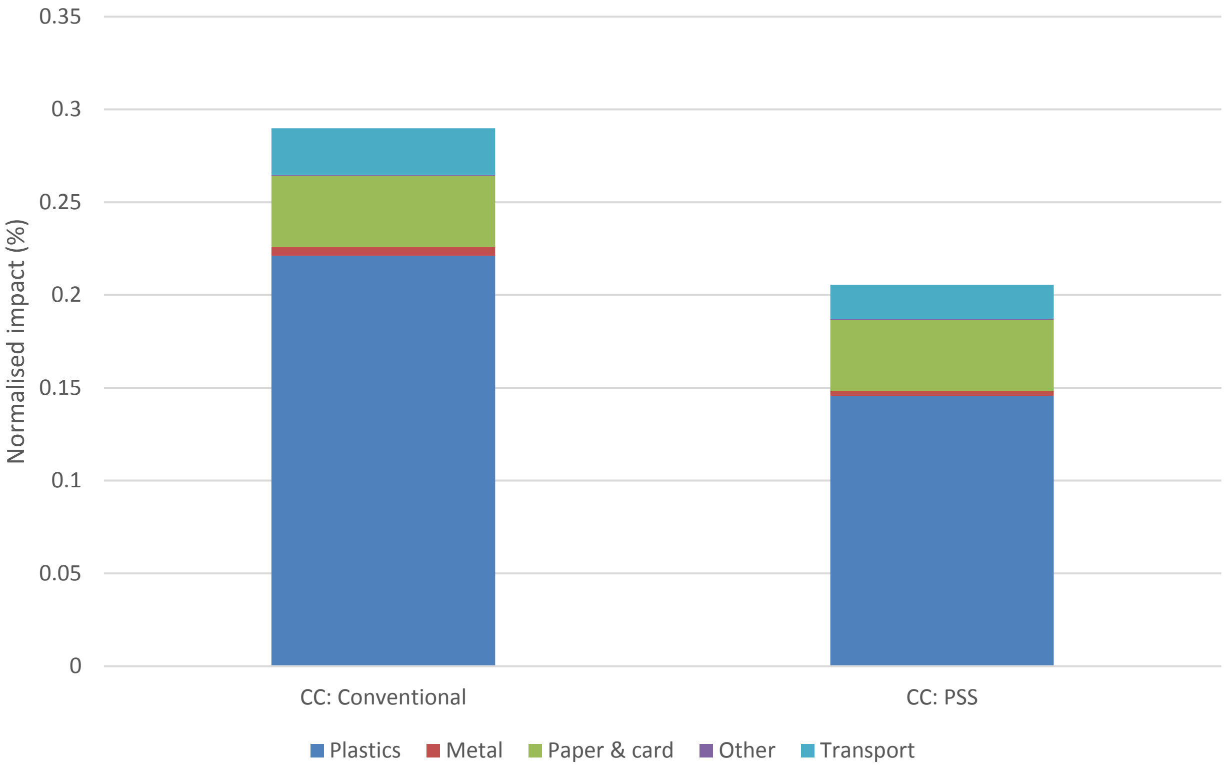

Figure C2.1: NI: Climate change: Conventional & PSS: partial breakdown

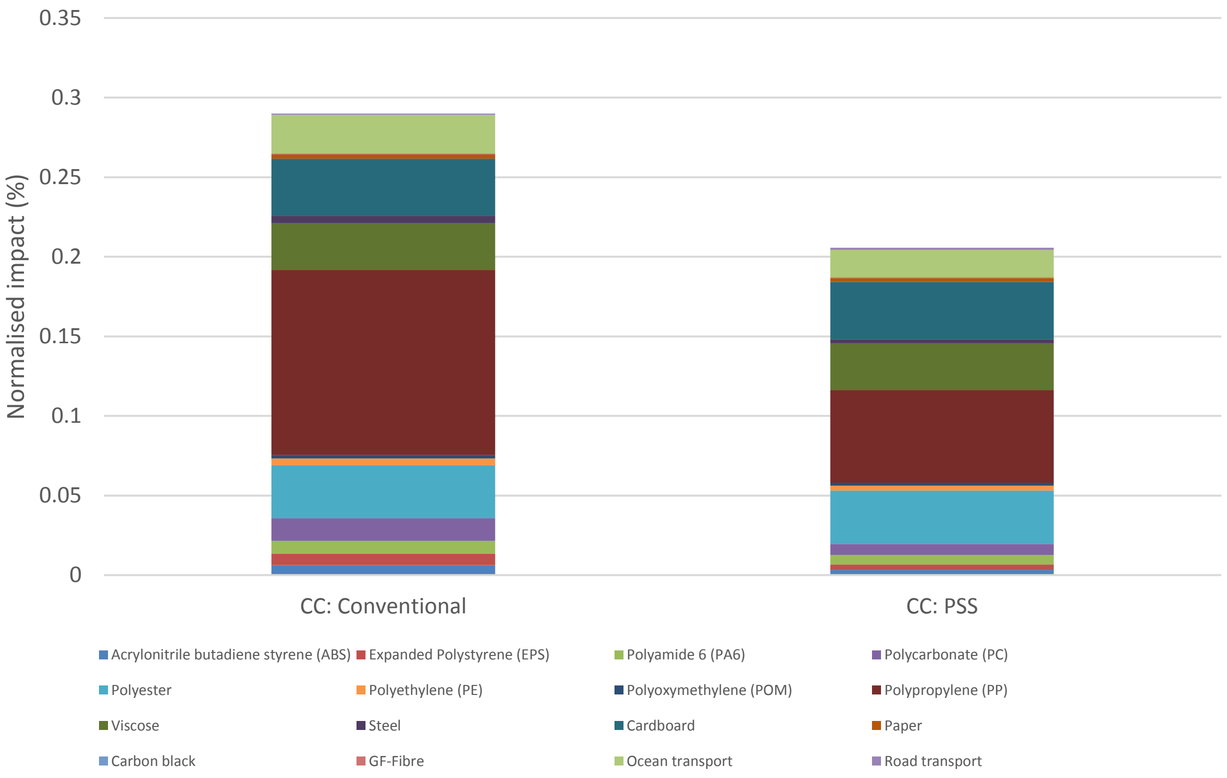

Figure C2.2: NI: Climate change: Conventional & PSS: full breakdown

C3. Ozone depletion

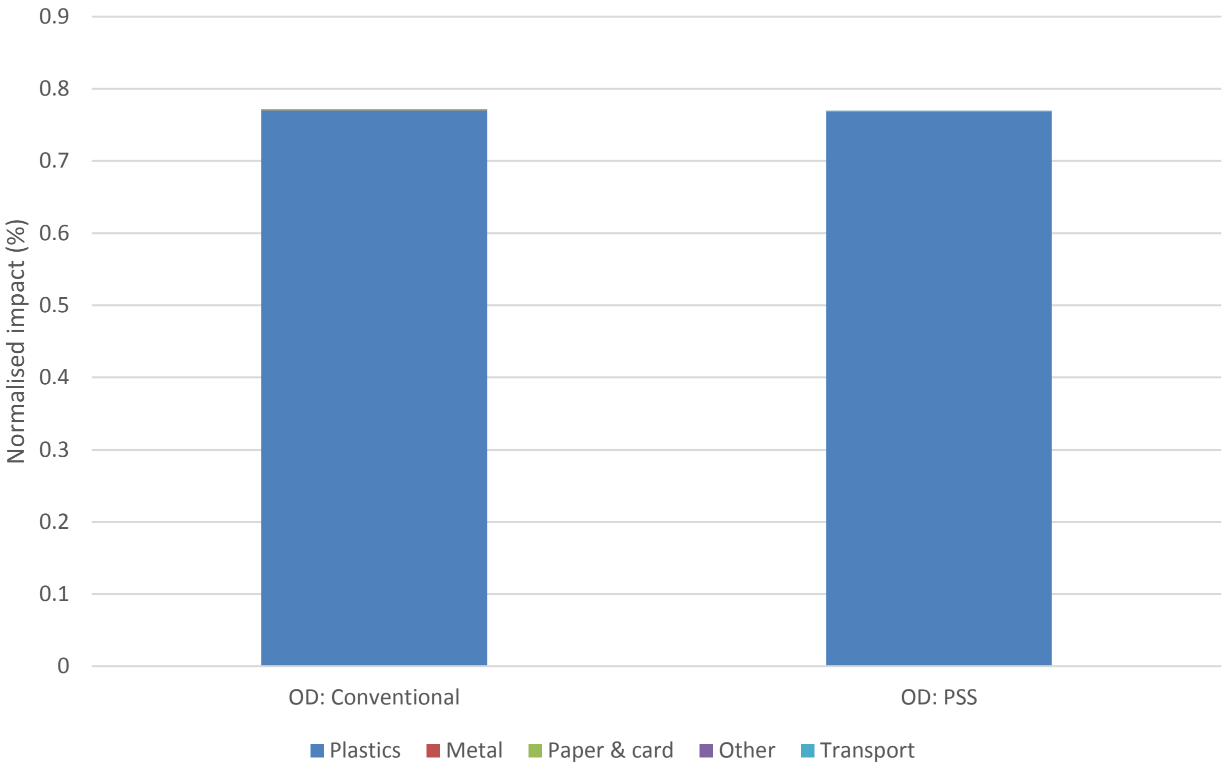

Figure C3.1: NI: Ozone depletion: Conventional & PSS: partial breakdown

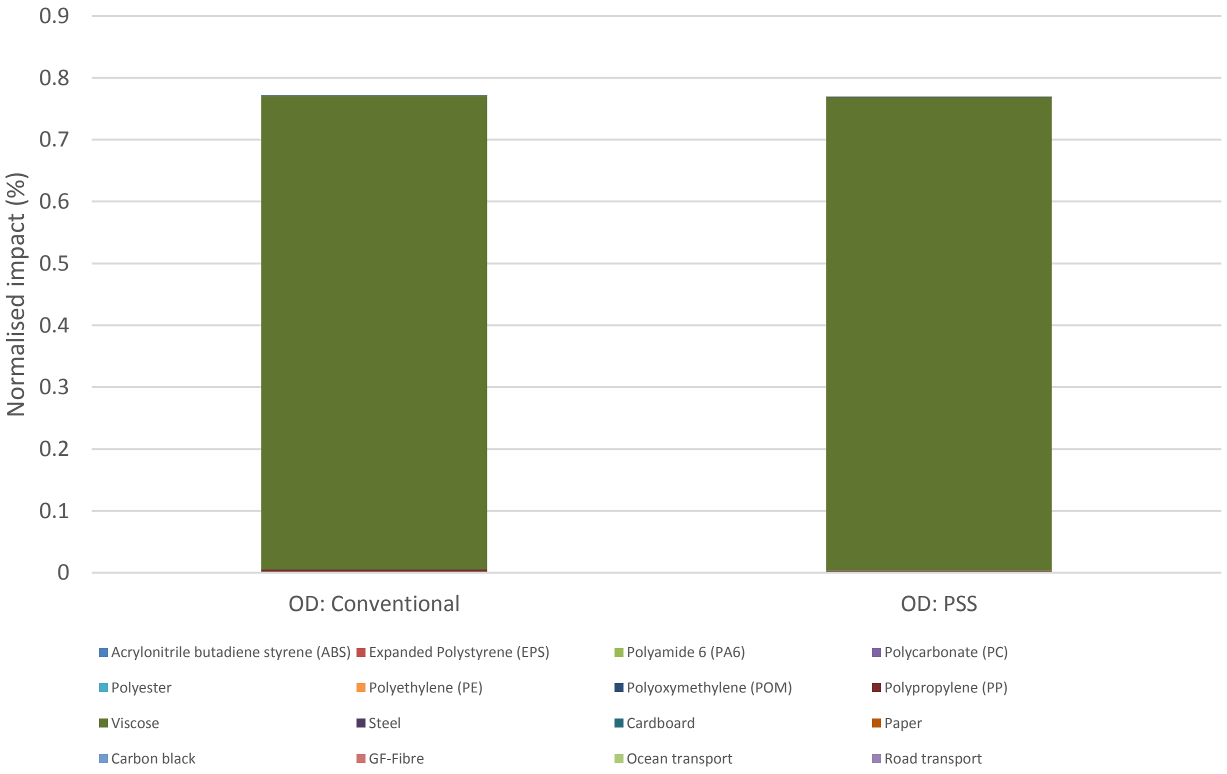

Figure C3.2: NI: Ozone depletion: Conventional & PSS: full breakdown

C4. Human toxicity, cancer effects

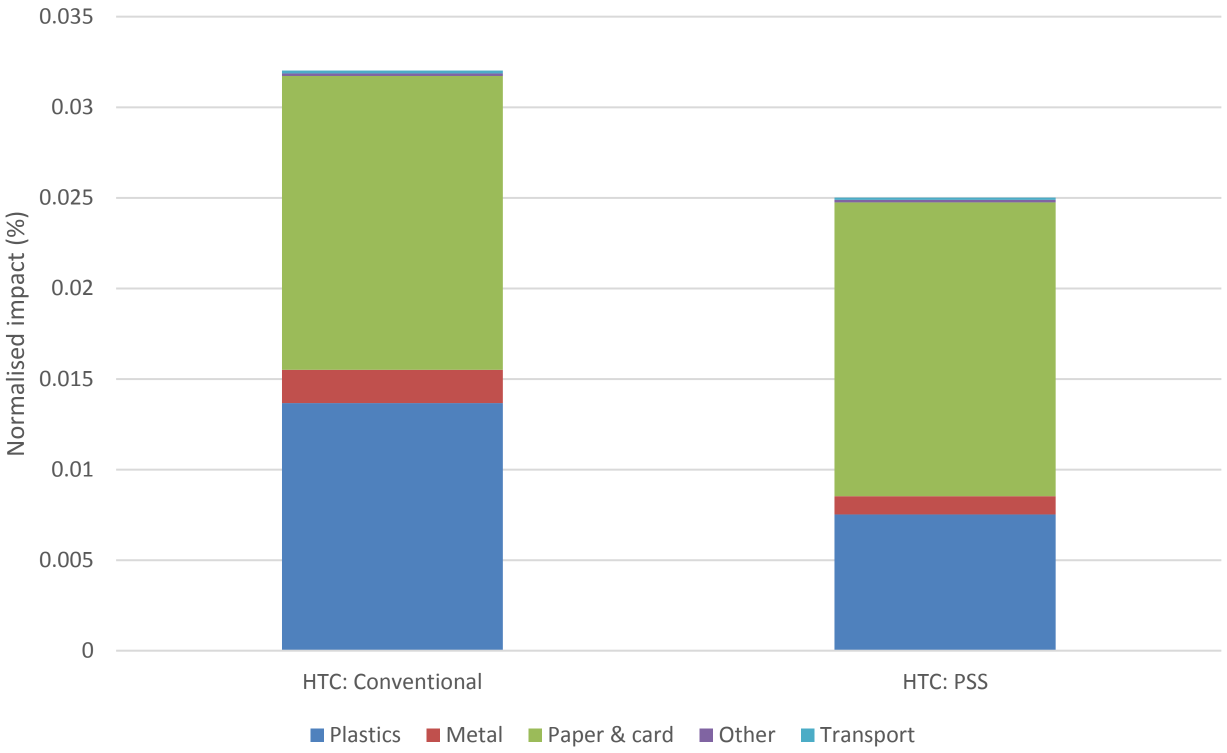

Figure C4.1: NI: Human toxicity, cancer effects: Conventional & PSS: partial breakdown

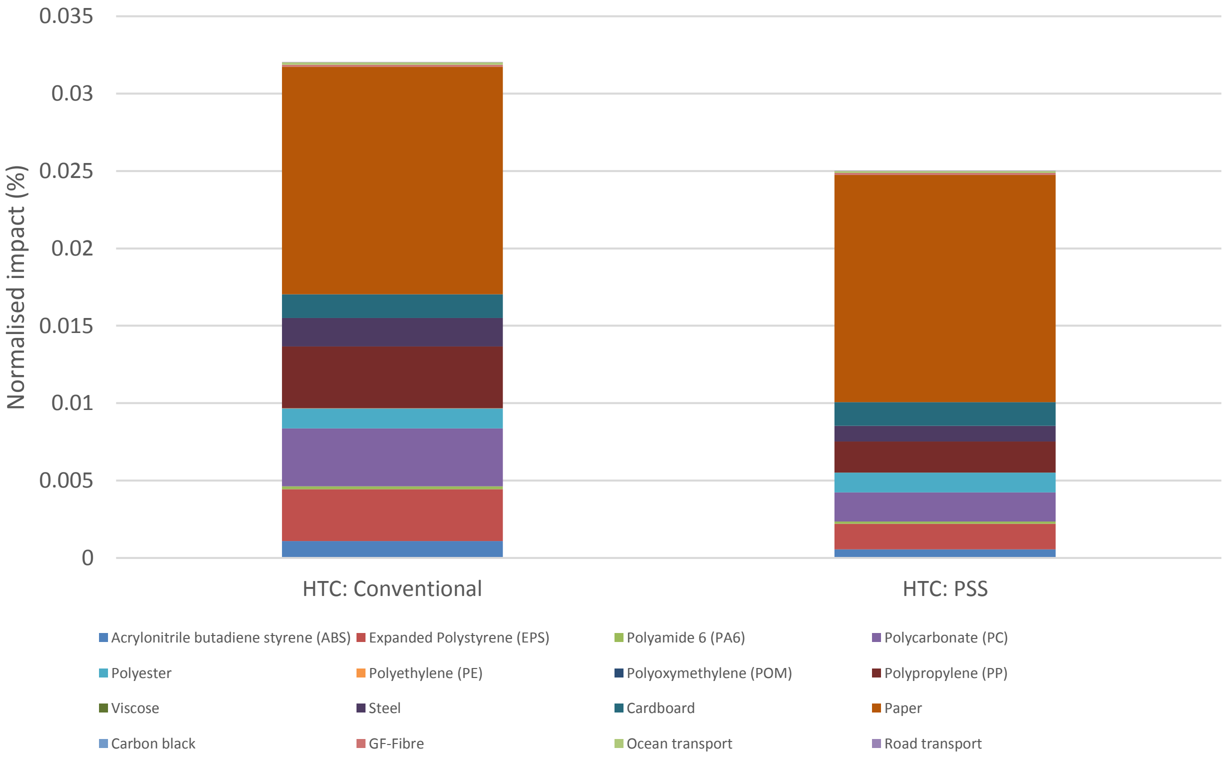

Figure C4.2: NI: Human toxicity, cancer effects: Conventional & PSS: full breakdown

C5. Human toxicity, non-cancer effects

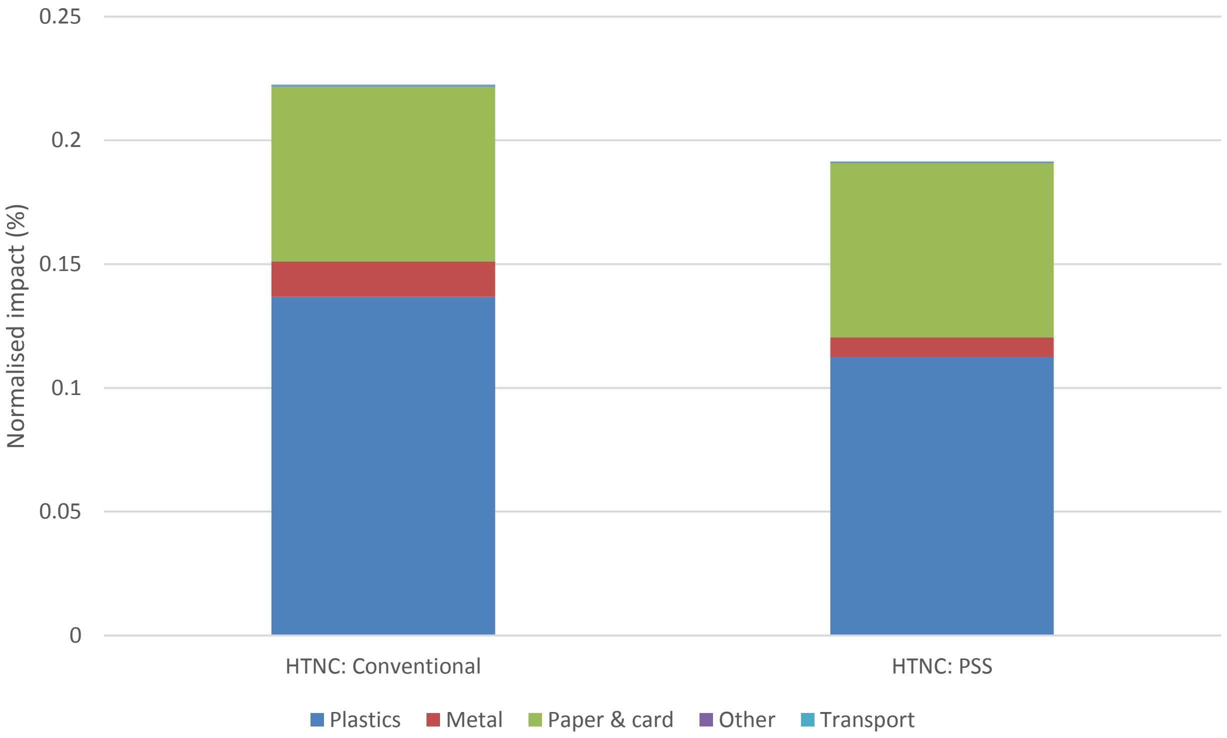

Figure C5.1: NI: Human toxicity, non-cancer effects: Conventional & PSS: partial breakdown

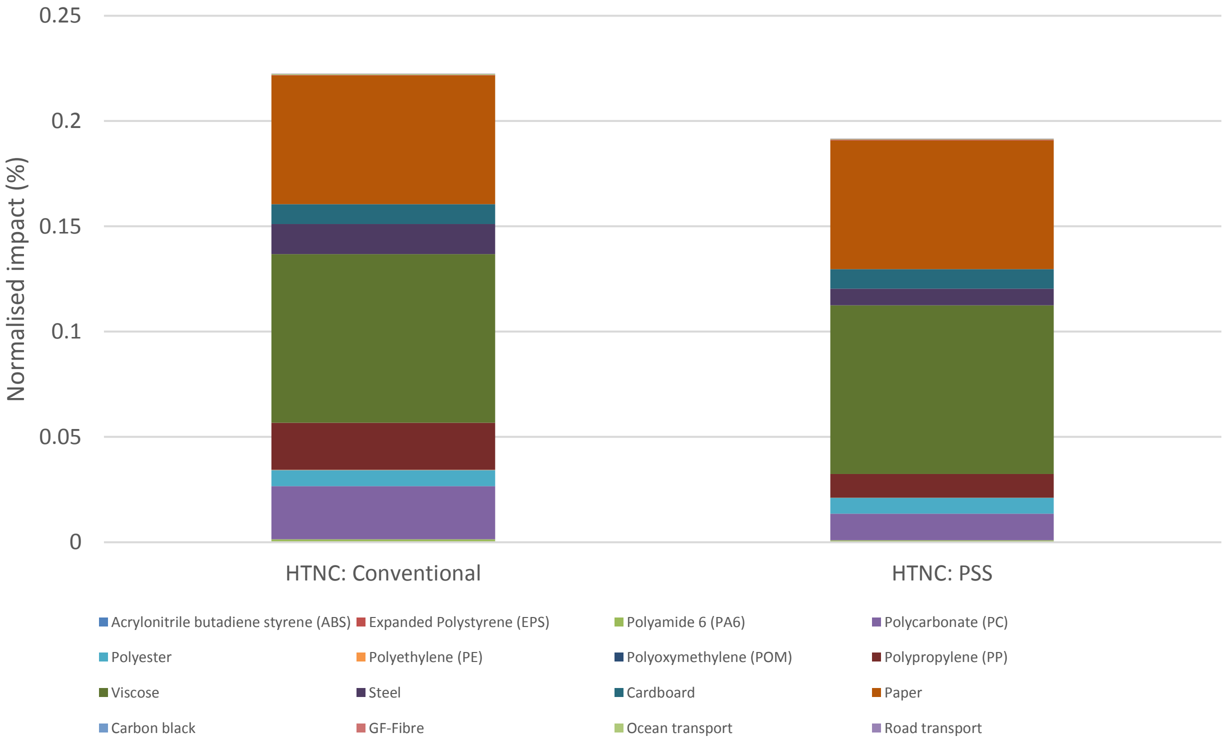

Figure C5.2: NI: Human toxicity, non-cancer effects: Conventional & PSS: full breakdown

C6. Particulate matter

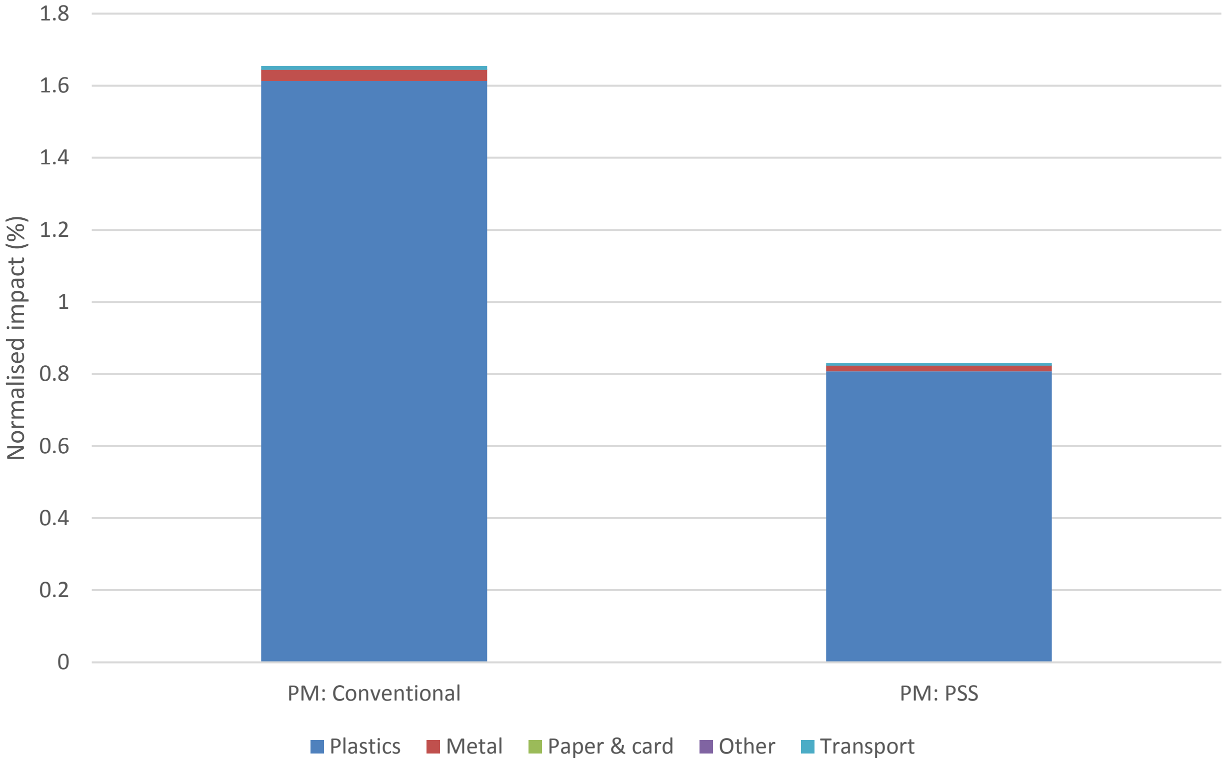

Figure C6.1: NI: Particulate matter: Conventional & PSS: partial breakdown

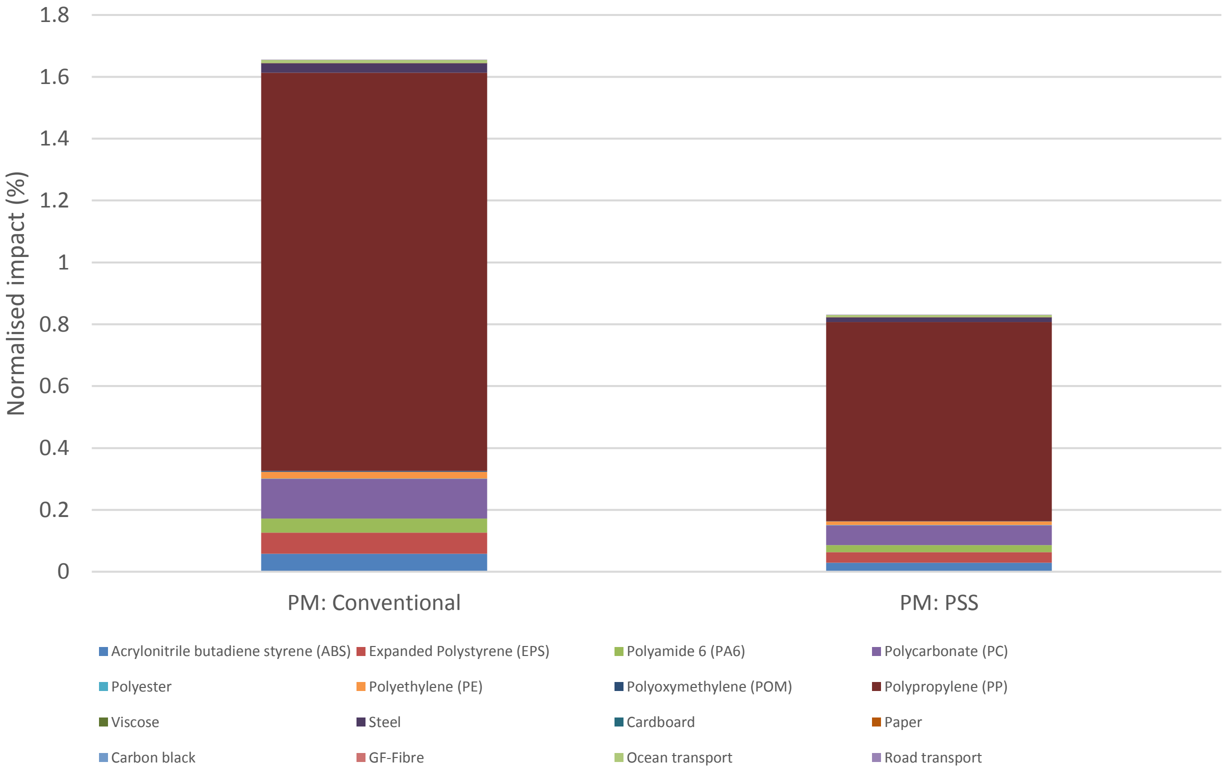

Figure C6.2: NI: Particulate matter: Conventional & PSS: full breakdown

C7. Photochemical ozone formation

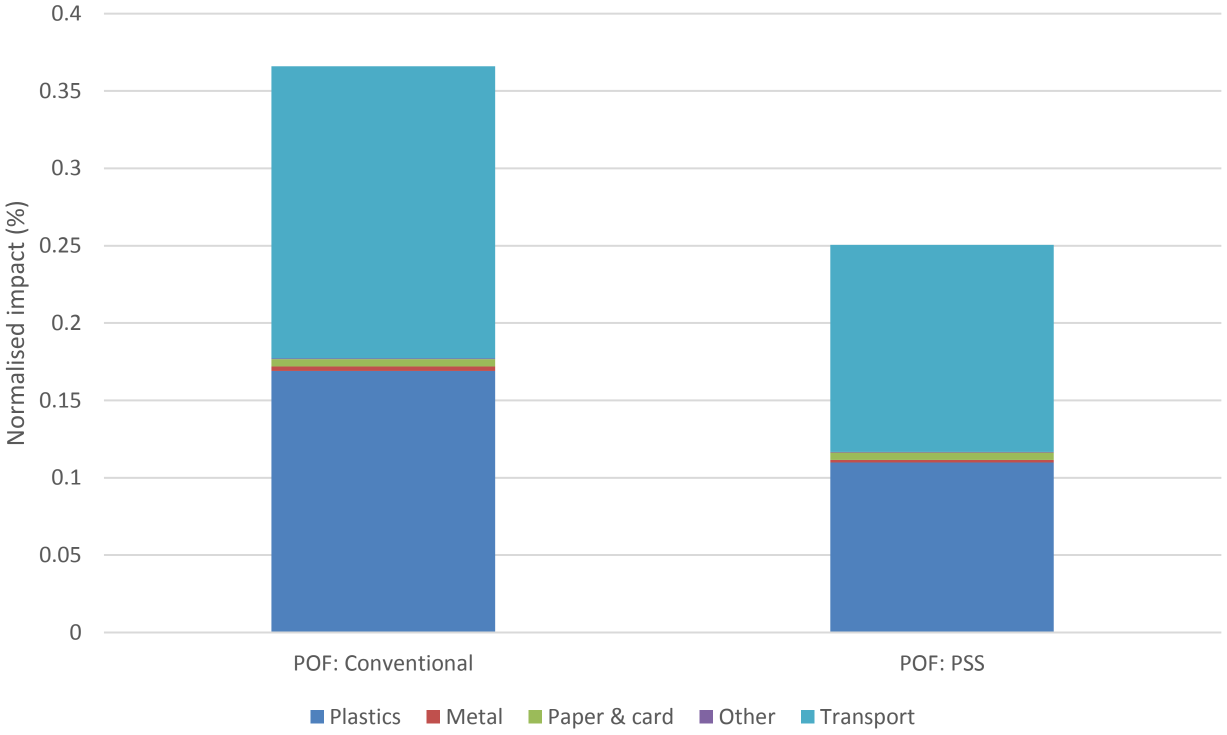

Figure C7.1: NI: Photochemical ozone formation: Conventional & PSS: partial breakdown

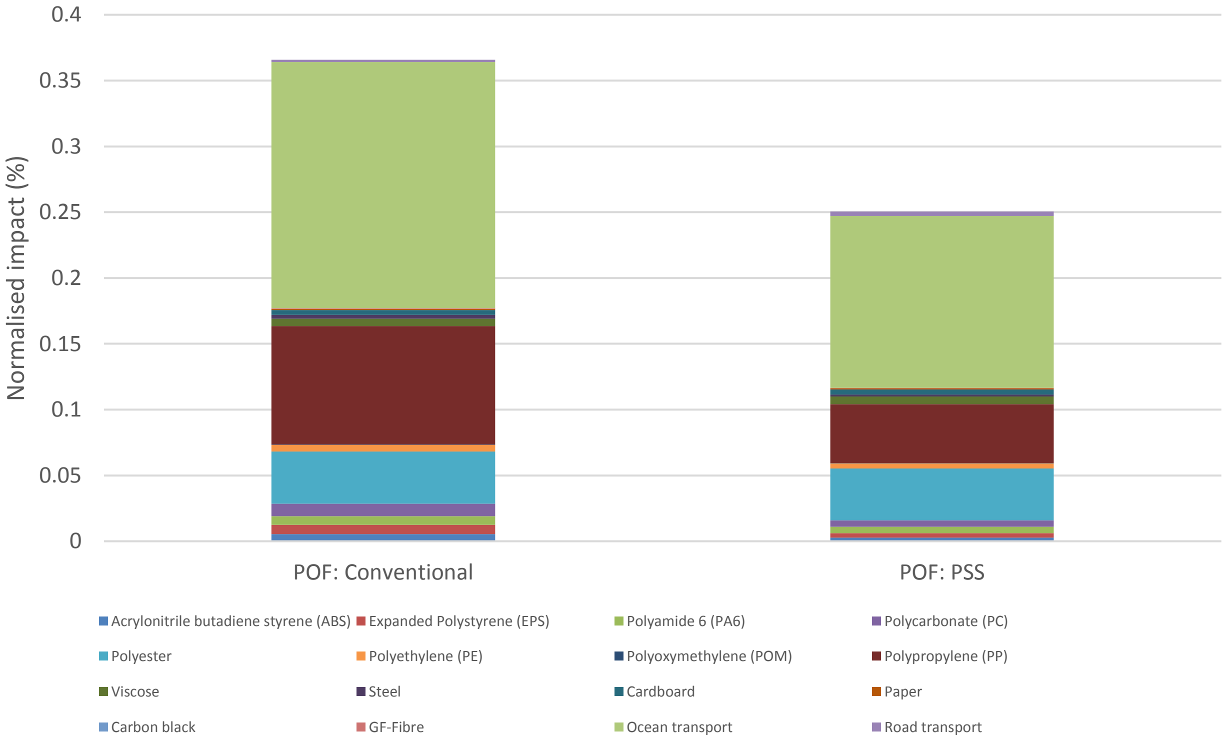

Figure C7.2: NI: Photochemical ozone formation: Conventional & PSS: full breakdown

C8. Acidification

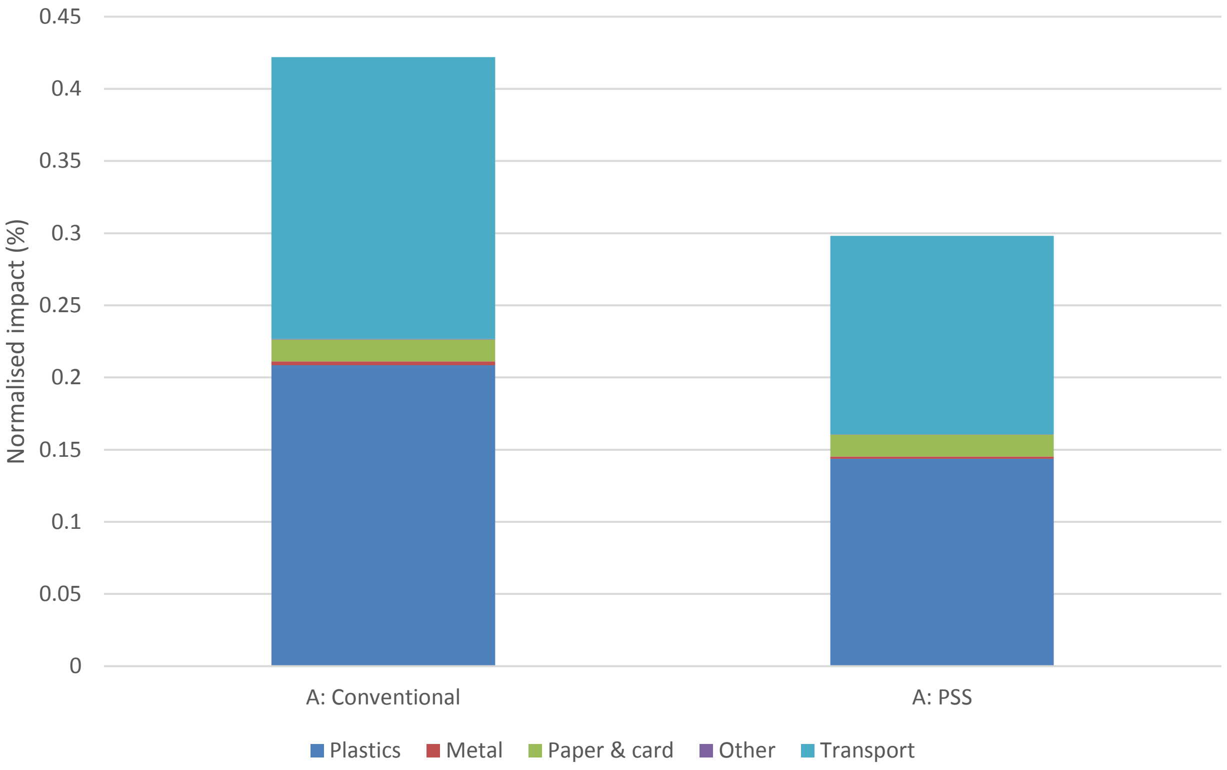

Figure C8.1: NI: Acidification: Conventional & PSS: partial breakdown

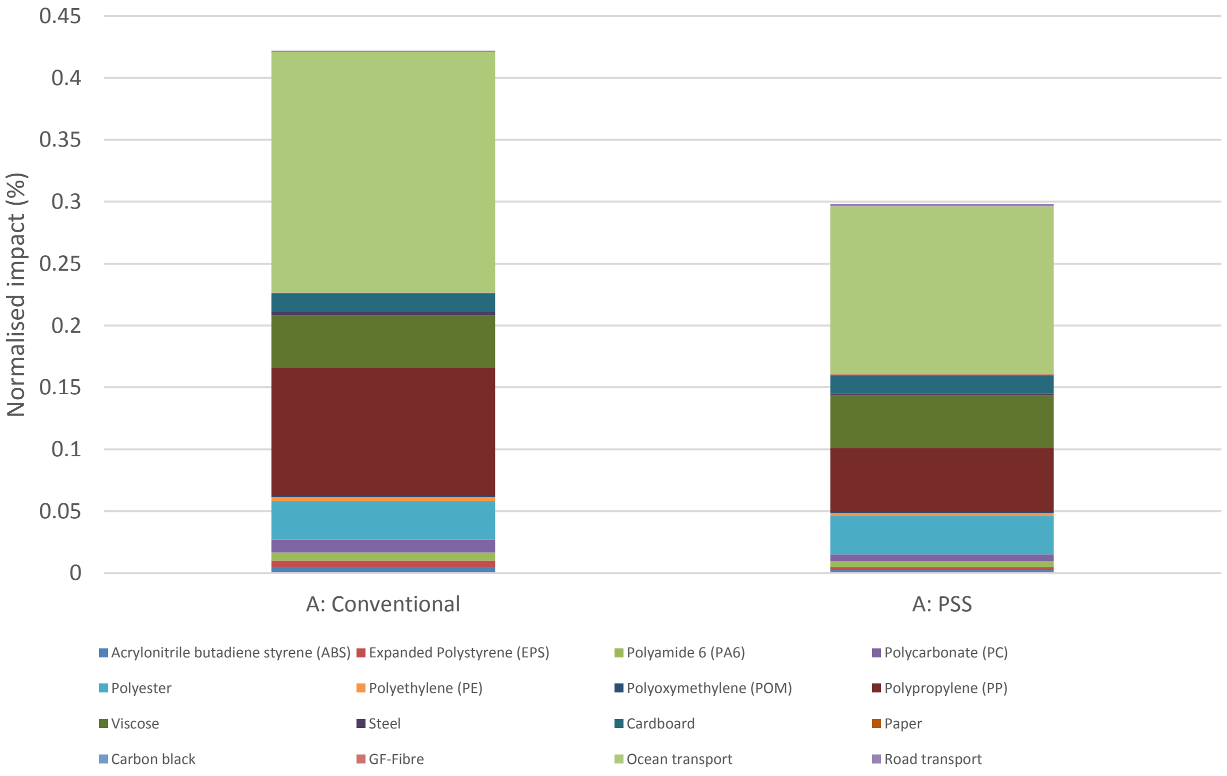

Figure C8.2: NI: Acidification: Conventional & PSS: full breakdown

C9. Eutrophication terrestrial

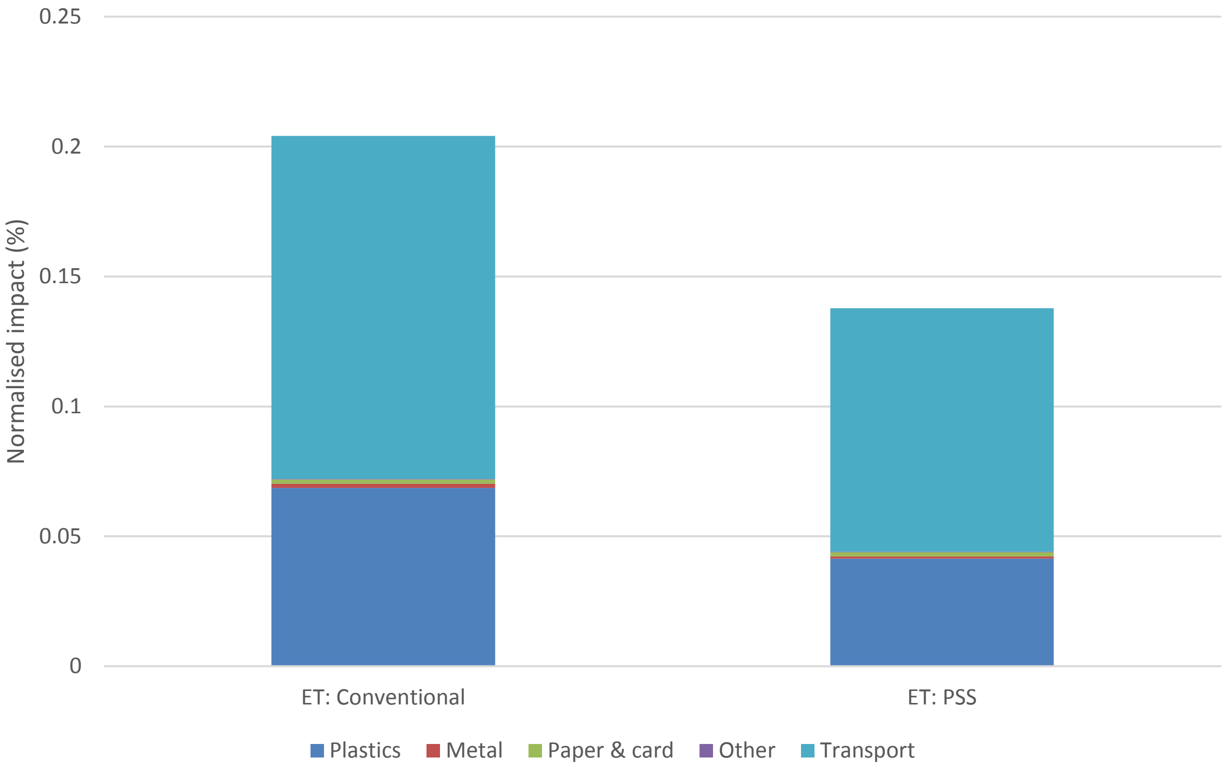

Figure C9.1: NI: Eutrophication terrestrial: Conventional & PSS: partial breakdown

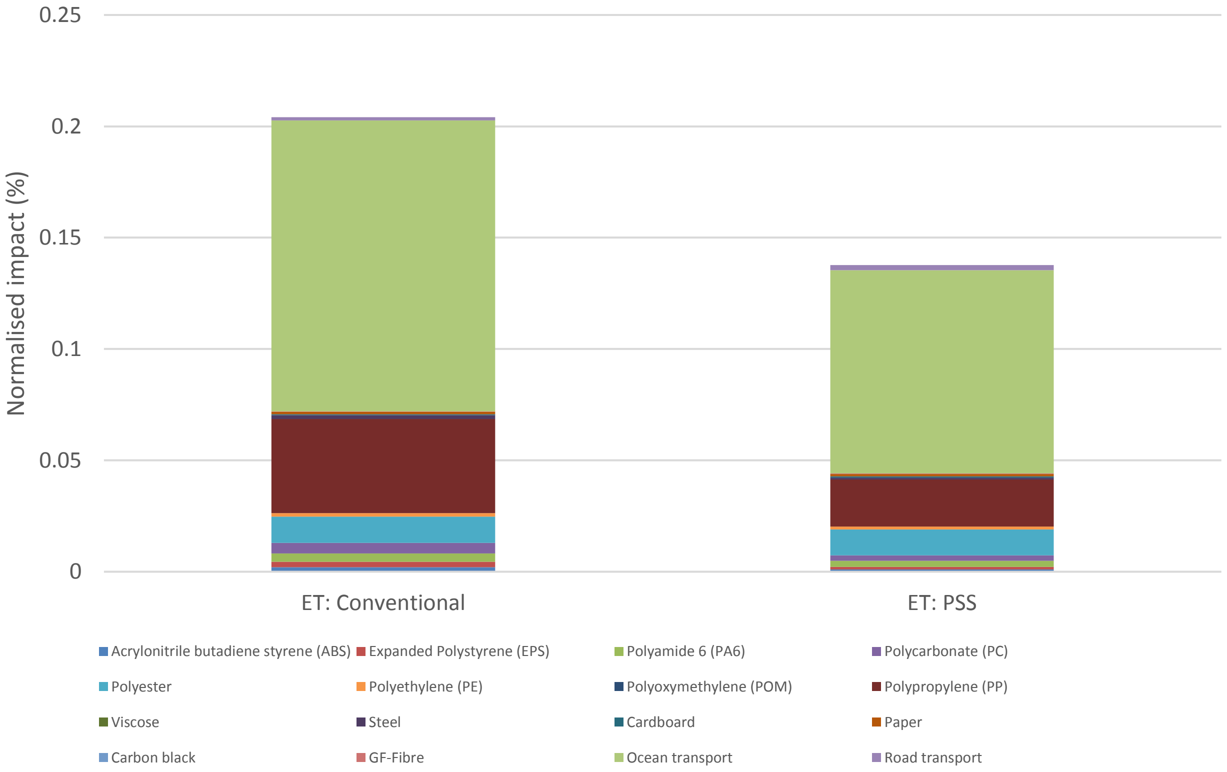

Figure C9.2: NI: Eutrophication terrestrial: Conventional & PSS: full breakdown

C10. Eutrophication freshwater

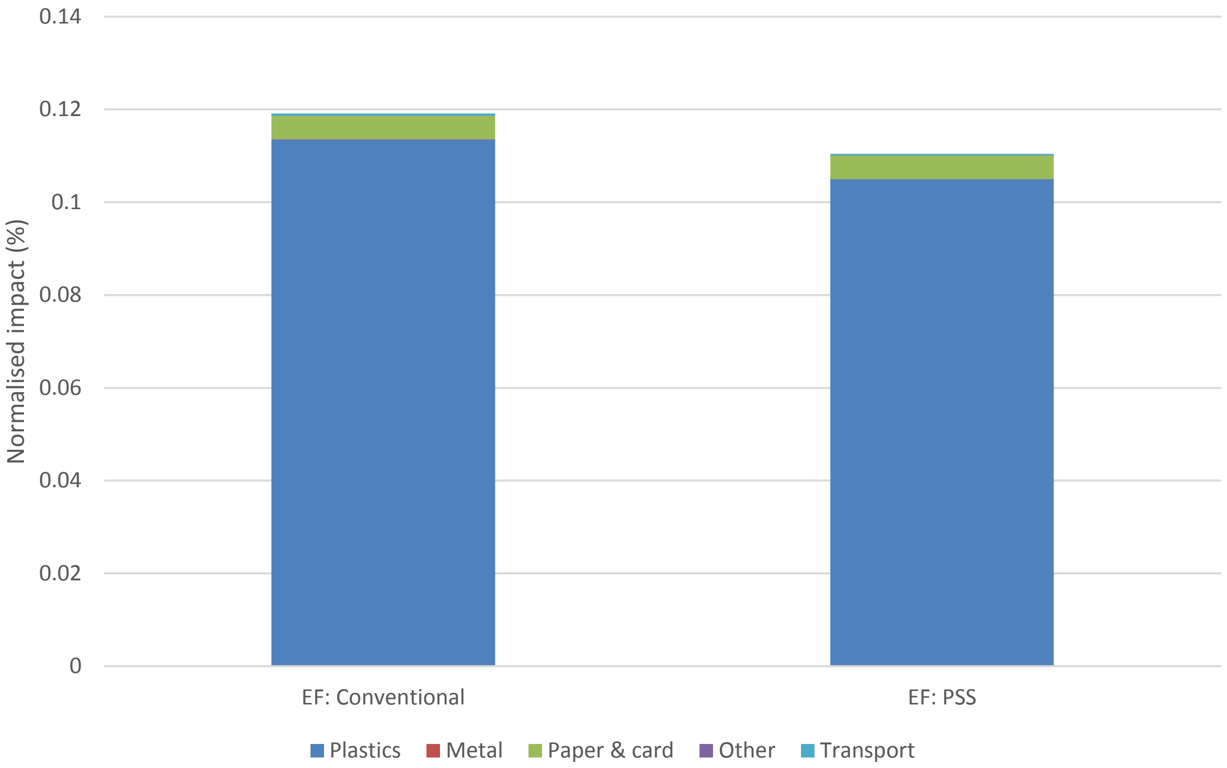

Figure C10.1: NI: Eutrophication freshwater: Conventional & PSS: partial breakdown

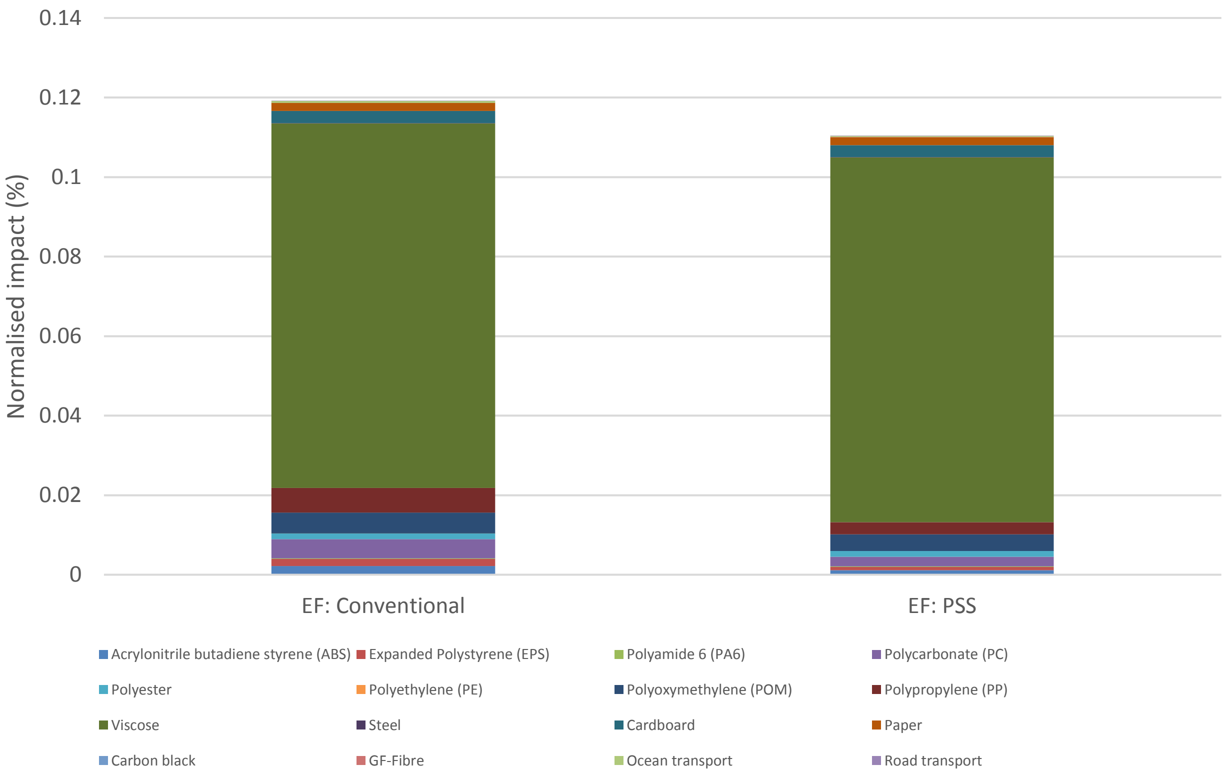

Figure C10.2: NI: Eutrophication freshwater: Conventional & PSS: full breakdown

C11. Eutrophication marine

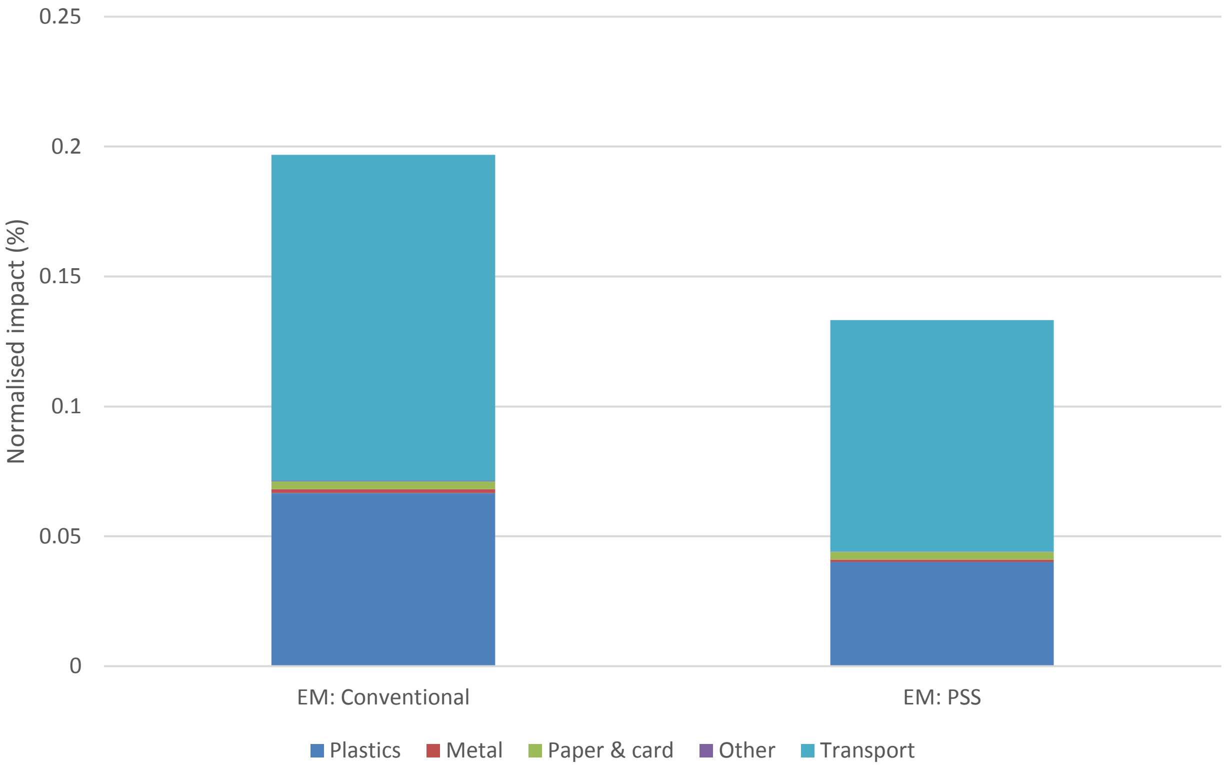

Figure C11.1: NI: Eutrophication marine: Conventional & PSS: partial breakdown

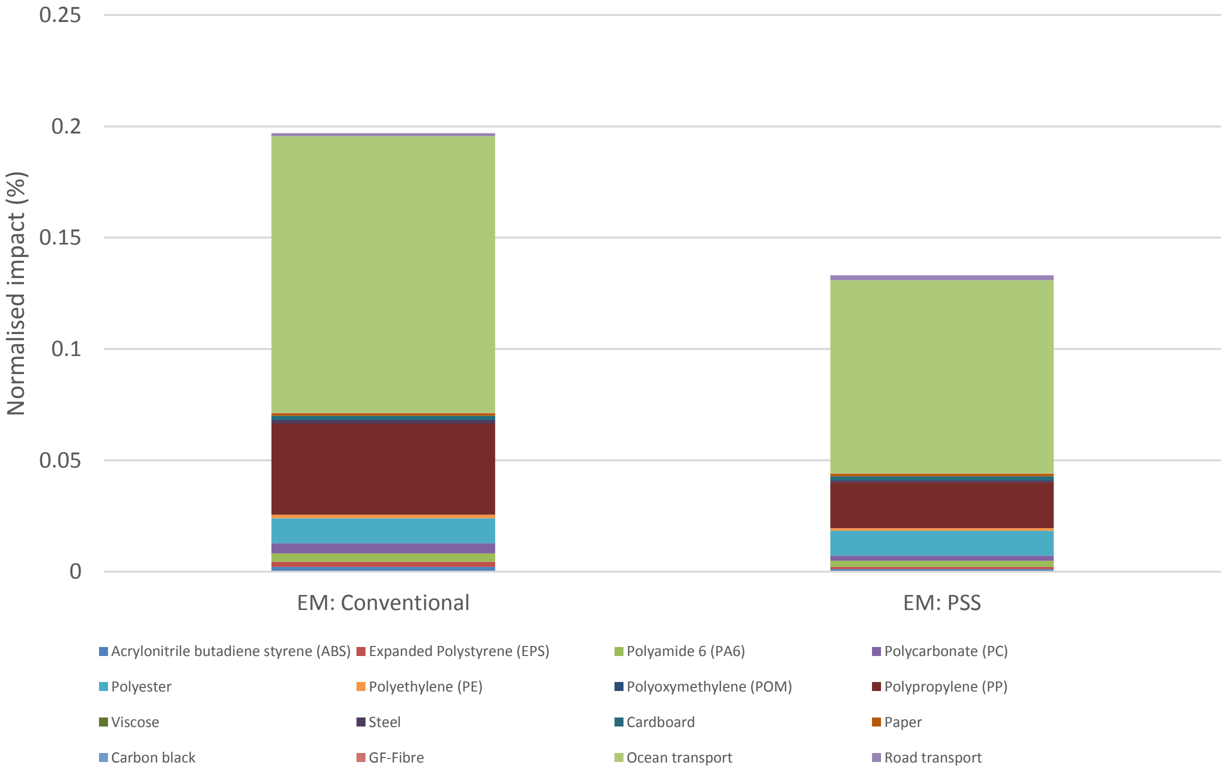

Figure C11.2: NI: Eutrophication marine: Conventional & PSS: full breakdown

C12. Ecotoxicity freshwater

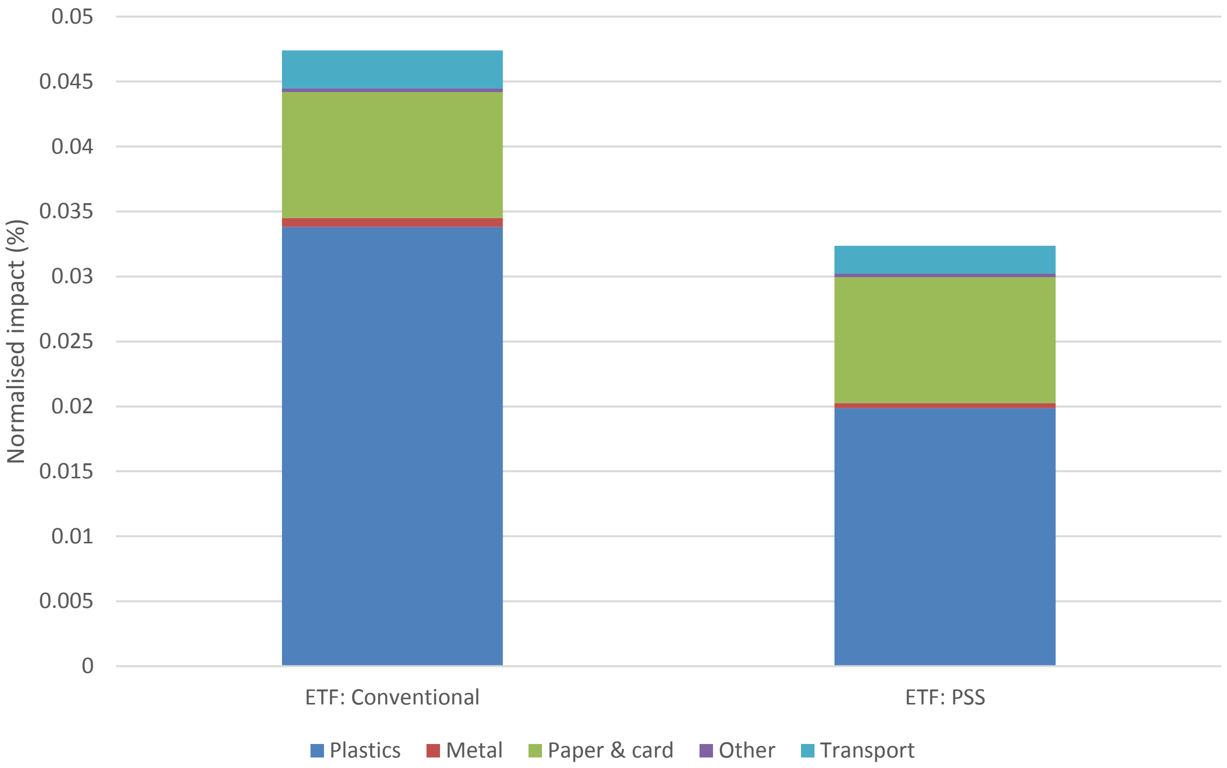

Figure C12.1: NI: Ecotoxicity freshwater: Conventional & PSS: partial breakdown

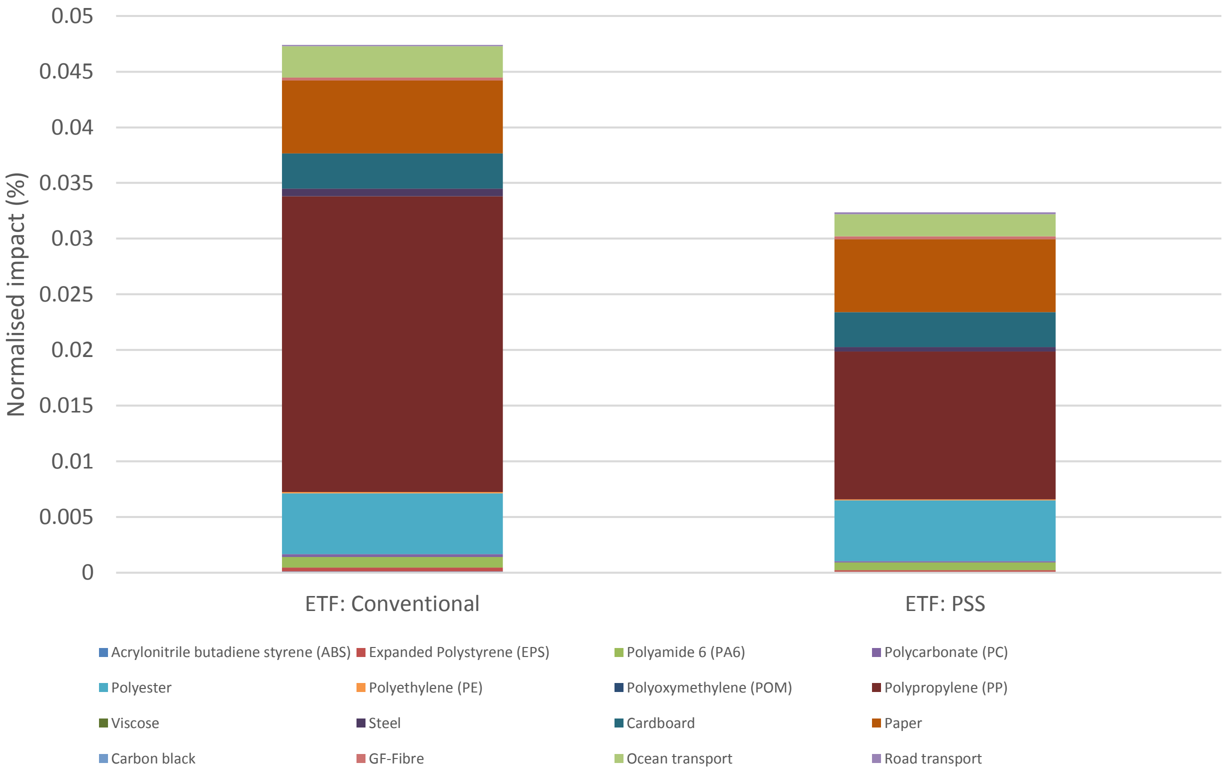

Figure C12.2: NI: Ecotoxicity freshwater: Conventional & PSS: full breakdown

C13. Resource depletion water

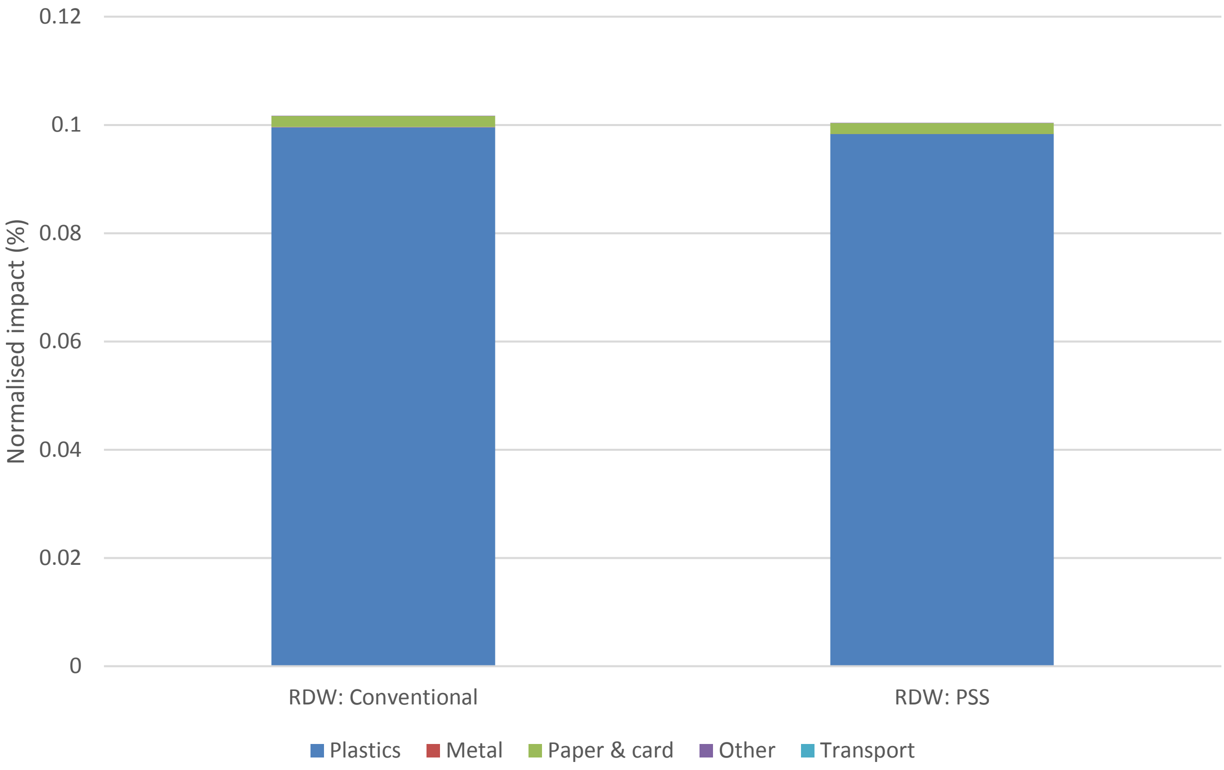

Figure C13.1: NI: Resource depletion water: Conventional & PSS: partial breakdown

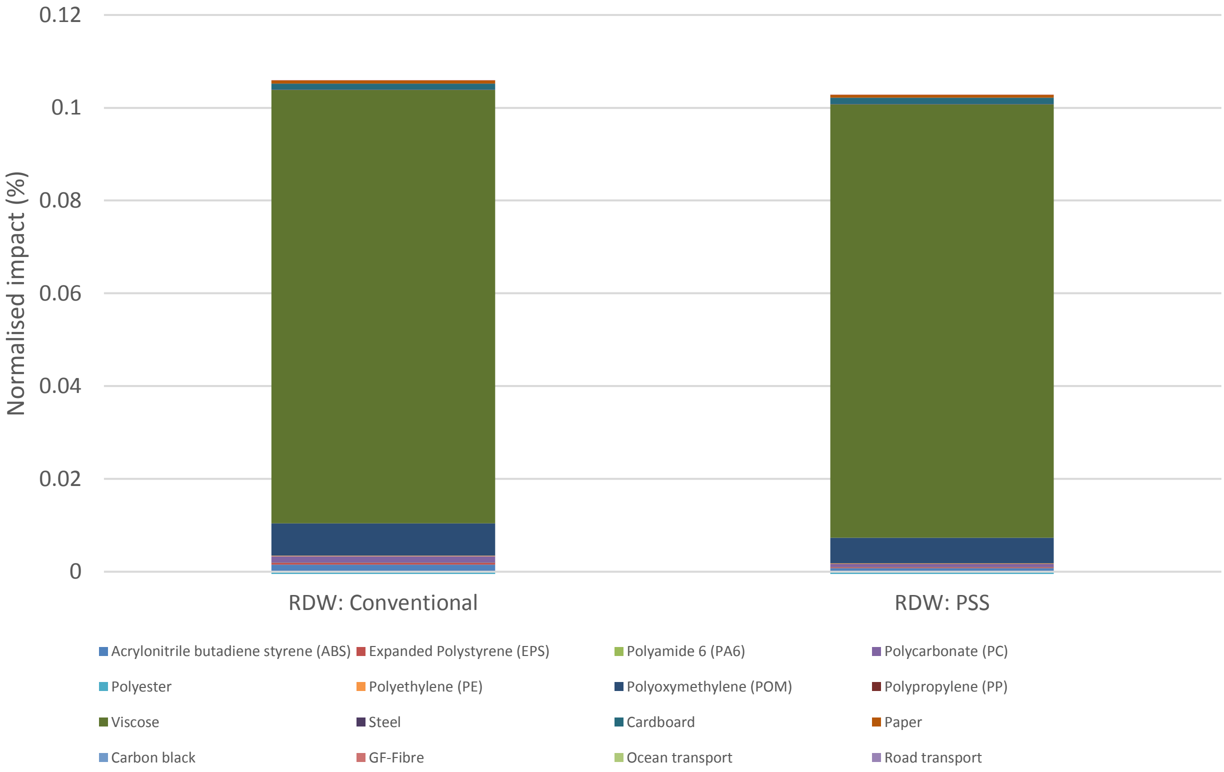

Figure C13.2: NI: Resource depletion water: Conventional & PSS: full breakdown

C14. Resource depletion, mineral, fossils and renewables

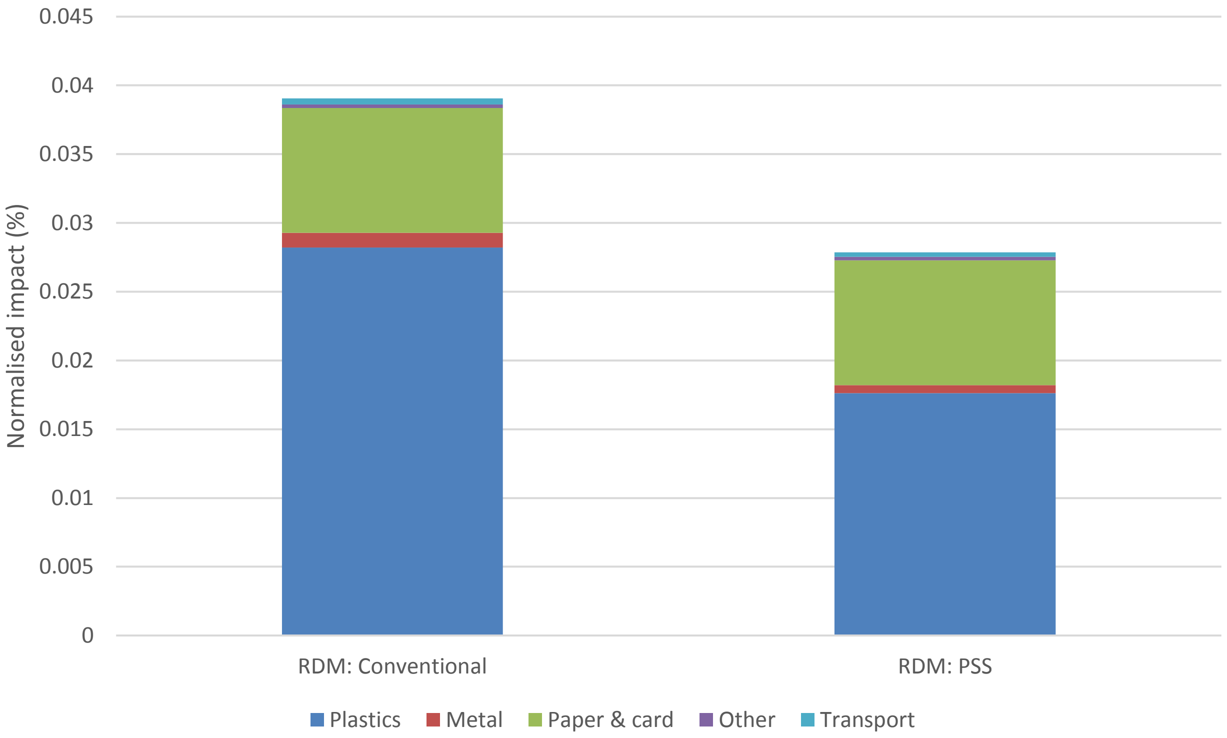

Figure C14.1: NI: Resource depletion, mineral, fossils & renewables: Conventional & PSS: partial breakdown

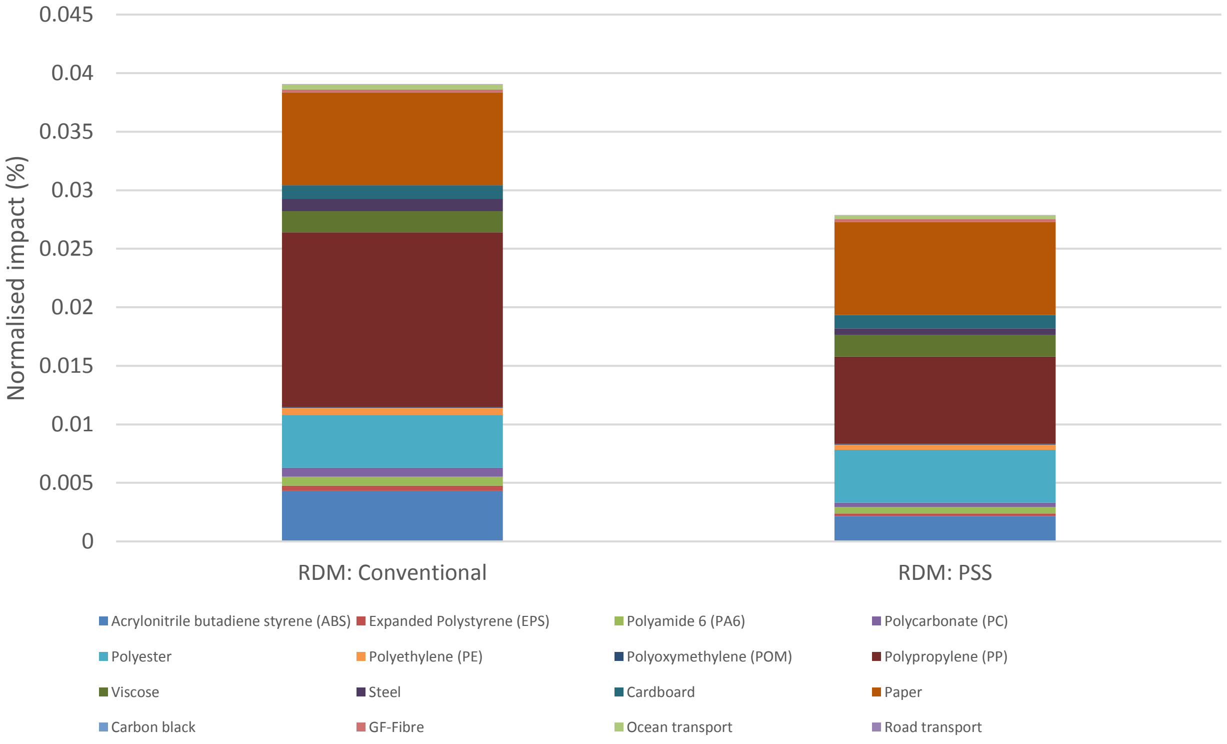

Figure C14.2: NI: Resource depletion, mineral, fossils & renewables: Conventional & PSS: full breakdown

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