Life Cycle Assessment, LCA, of PVC Blood Bag

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Within the of EU Life+ project PVCfreeBloodBag

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eco2win is a consultant agency with the mission to guide businesses and organizations towards social responsibility and sustainable development. eco2win applies quantifiable principles and tools such as LCA to establish improvement processes in the clients' businesses. eco2win translates to 'win-win when economic prosperity is guided by the laws and limitations of ecology'.

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Executive summary

A Life Cycle Assessment (LCA) of a PVC/DEHP[1] blood bag was performed to provide a quantitative overview of the environmental impact of the PVC blood bag over its life cycle. As quantitative reference to the PVC/DEHP blood bag, a fictional blood bag made from the material High Density Polyethylene (HDPE) is used. Since the phthalate DEHP and the plastic HDPE have very similar names the full name High Density Polyethylene will be interchangeably with HDPE throughout the text. The two flow charts in figure E1 represents the studied life cycles.

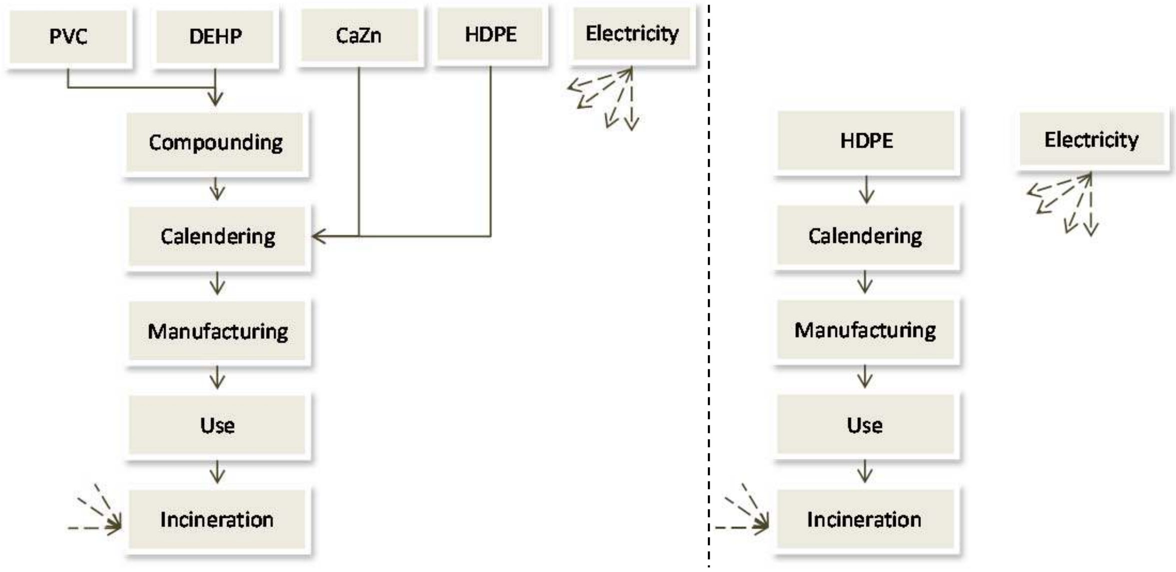

Figure E1 The left flow chart represents the life cycle of the PVC/DEHP blood bag, and the right flow chart represents the life cycle of the HDPE blood bag.

The three main environmental impact categories of a PVC/DEHP blood bag are climate change, impact on human health and resource use. Therefore the environmental impact assessment was focusing on these three impact categories.

The result of the LCA is that the PVC/DEHP blood bag has a substantially higher potential to harm human health, both when analyzing the total life cycle of the blood bags and with regards to the DEHP contamination of transfused blood. This is due to the chlorinated substances occurring in production emissions, in phthalates being transferred to the patient during blood transfusion and due to dioxin emissions in the waste incineration emissions. The HDPE blood bag show a potentially higher impact on resource depletion and climate change. This is due to the higher content of hydrocarbons in the HDPE blood bag. Comparison of the two different ways to incinerate PVC/DEHP blood bags by allowing a higher emission of dioxins or by controlling the dioxin emissions by ensuring a more effective combustion, reveals a trade-off issue, where cleaning of smoke gases increases both the resource use and the contribution to climate change. Figure E2 summarizes the environmental impact on the three impact categories using the 3-axis model.

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[1] PVC = Poly Vinyl Chloride, DEHP = di(2-ethylhexyl) phthalate

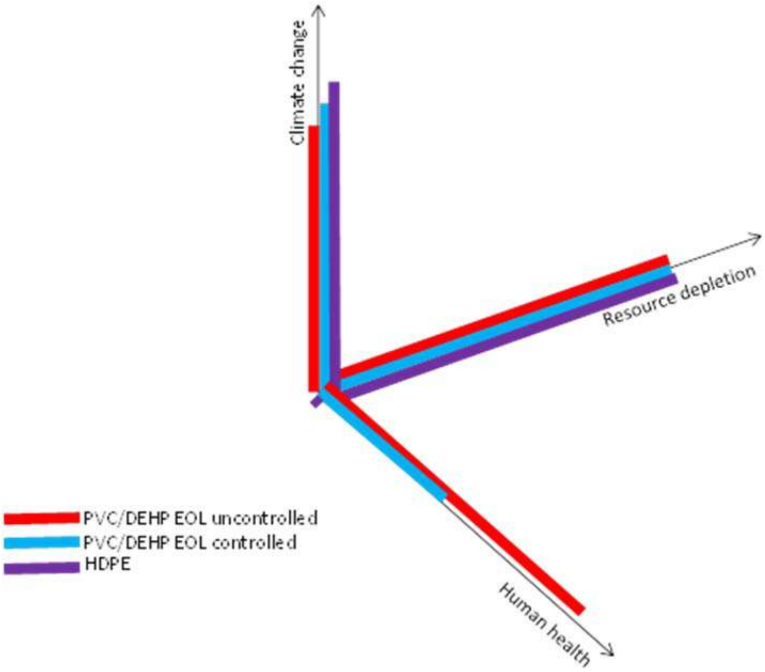

Figure E2. The different impact from the three different alternatives onto the three different impact categories presented as different dimensions in a co-ordination system, the 3-axis approach. A conceptual summary of the graphs for each alternative is indicated onto each axis.

The impact on human health due to blood transfusion gives a very strong indication in the studies. This is due to the direct exposure of a huge amount of the toxic phthalate DEHP within the blood stream of patients. In fact, it is likely that this potential human health impact is even higher, since the sensitivity data used relates to the general population rather than the more sensitive part of the population that is hospitalized and in need of blood transfusion, in specific with regards to newborn babies and chronically ill patients.

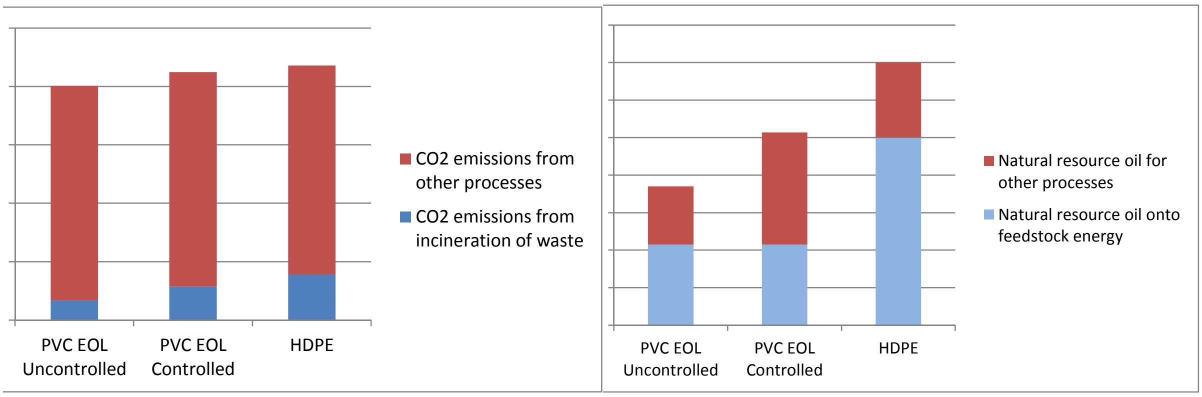

Figure E3 The left diagram shows the carbon dioxide emissions from the life cycle of the three alternatives, each divided into end of life (EOL) waste incineration (lower blue) and the rest of the life cycle (red). The right diagram shows the consumption of the fossil oil divided into oil used for feedstock (lower light blue) and oil used for fuel (upper red). The unit of the left diagram is kg CO2 emitted per life cycle of blood bag and the unit of the right diagram is kg consumed per life cycle of blood bag.

The diagrams in Figure E3 show a strong and expected correlation between the emission of carbon dioxide and the consumption of fossil oil in the blood bags. The lower blue sections of the left diagram shows that the higher emissions of carbon dioxide from the HDPE blood bag is almost all due to the incineration of the blood bag. And the blue sections of the right diagram shows that higher consumption of natural resources is due to a much higher share of the oil in the feedstock than as production fuel, compared with the two alternative ways to incinerate the PVC/DEHP blood bags. The higher carbon dioxide process emissions and the higher consumption of fuel use for the PVC /DEHP blood bag with controlled incineration is due to the need to maintain a higher temperature and more advanced cleaning in the incineration.

The unambiguous recommendation from this study is to change from the PVC/DEHP blood bag towards a blood bag based on only hydrocarbons. But this is true only if the alternative blood bag material meets all other economic and quality criteria associated with the blood bag. Else it is recommended that efforts should be made to exchange as many blood bags as possible due to application, such as expected storage time, patient group or transportation needs.

It is recommended that efforts should be taken to use recycled material when possible, to support innovative ways to material recycle medical waste, to co-generate heat while incinerating waste and in any other way save resources throughout the life cycle of the blood bag.

It is also suggested that bio-plastics may be used in this specific application if material recycling will prove impossible or too expensive.

There are limitations to this study, such as a limited choice of system boundaries presented in figure E1. Many potential recycling and other synergies has been omitted. Some data are old and may not be valid for today’s European production systems, such as the electricity production data. The Plastics Europe data was considered the best available data, but even in that data errors were identified. Some of the applied impact assessment data was old, but the core data was the latest from IPCC and USEtox. The modeling to compare the life cycle impact on populations with health risk during blood transfusion is somewhat unstable, since impact on population is based on statistical averages of large groups of people, whereas health risk during blood transfusion is based on the biological sensitivity on individuals. There are strong relationships between the modeling, but they have different variations and uncertainties. Transports and waste management of ashes from incineration are omitted. Sensitivity analyses have been carried out throughout the study so as to produce a stable result regardless of these limitations.

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Nomenclature

Abbreviation	Explanation
CO2	Carbon dioxide
DALY	Disability Adjusted Life Years
DEHP	Di-2-Ethylhexyl Phthalate or Bis(2-ethylhexyl)phthalate
EDIP	Environmental Development of Industrial Products
EOL	End of life (waste management)
EPS	Environmental Priority Strategy
HCFC	Hydrochlorofluorocarbons
HDPE	High density polyethylene
ISO	International Organization for Standardization
LCA	Life cycle assessment
N2O	Nitrous oxide
PVC	Polyvinyl chloride
VCM	Vinyl chloride monomer

1. Introduction and application

1.1. Purpose of this study

The purpose of this life cycle assessment is to serve as information for the development and establishment of demand and production of PVC free blood bags. It is intended to serve both as information about the actual environmental impact from PVC based blood bags, as well as a reference point for the environmental performance of an alternative blood bag.

To make full use of the purpose of this study it is strongly suggested that similar full comparative life cycle assessments are performed on the real candidates to the PVC free blood bag. This will give the necessary understanding of the environmental hot spots of the alternatives, and it may be used to ensure that the alternative is indeed better from the perspective of the environmental life cycle.

1.2. Introduction to Life cycle assessment – LCA

Life cycle assessment (LCA) is a method to acquire an overview of the environmental impact of a product, function or service. According to the international standard ISO 14040:2006 [ISO 2006] of LCA, LCA is established on seven principles:

- Life cycle perspective
- Environmental focus
- Relative approach and functional unit
- Iterative approach
- Transparency
- Comprehensiveness
- Priority of scientific approach

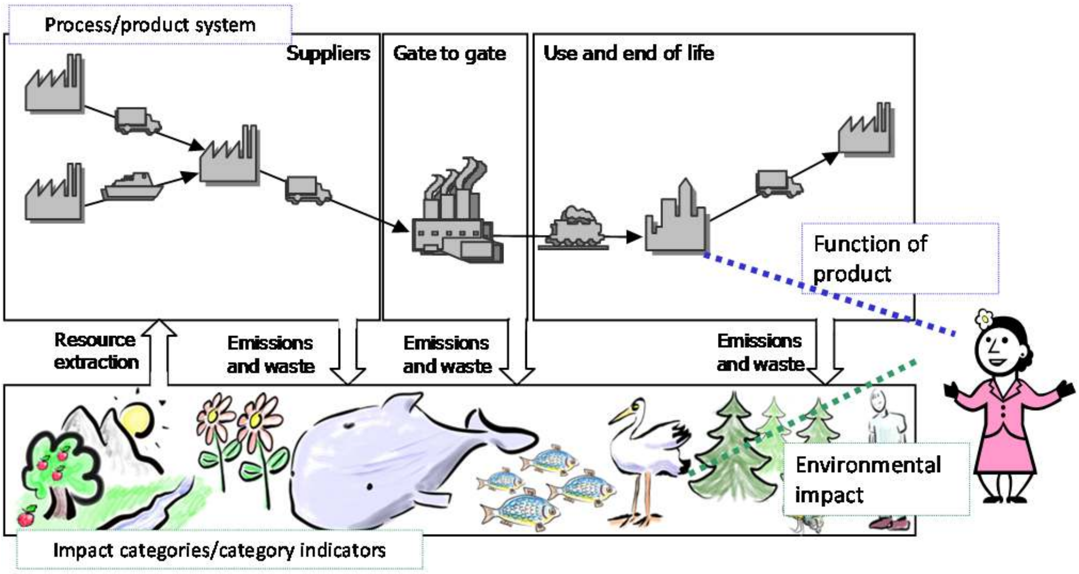

Figure 1 Life cycle assessment (LCA) is a method to acquire an overview of the environmental impact of a product, function or service. [Carlson, Pålsson, 2011]

The scope of the *Process/product system* in Figure 1 exemplifies the meaning of the first principle, the Life cycle perspective. It means that when performing an LCA to assess the environmental impact of the life cycle of a *Function of product* one shall follow the flow of production processes backwards to the extraction of natural resources, and one shall follow the product all the way to the final disposal, such as the waste management or recycling. Figure 1 also exemplifies the second principle, the principle of *Environmental focus*. This principle states that when performing an LCA one shall primarily consider what is important from the environmental point of view, and put the efforts of the study of the life cycle product system based on the environmental relevance. In practice this is done by selecting *Impact categories*, which are representations of the *Environmental impact* (such as global warming potential (GWP), human health and Natural resource depletion) that are considered relevant over the life cycle of the studied product, function or service.

The third principle, the principle of *Relative approach and functional unit*, means that the result of the study should always be related to a numerical entity of relevance to why the study is performed. In this case we are relating the entire study to one blood bag which is stored for thirty days before being used. The principle of *Iterative approach* means that during the study one may find new information which means that one will need to take new decisions about how to work. The principle of *Transparency* means that all choices made and all data used shall be made transparent to a reviewer of the study, hence the many annexes with data in this report. The principle of *Comprehensiveness* means that the study should encompass all environmentally relevant aspects of the object of study. Hence, it would not be sufficient to only study the toxicity aspects of the blood bag, but since the blood bags are made of plastics they also contribute to resource depletion (oil), and since medical waste is incinerated for safety reasons, the plastics contribute to global warming. The principle of *Priority of the scientific approach* means that the LCA study shall be performed in accordance with scientific principles, such as objectivity, neutrality, verifiability and transparency.

In the ISO standard ISO 14040, the framework of LCA is strongly related to its specific application (see Figure 2). This means that an LCA will be different depending on for which purpose the study is made. But the LCA standard also states that there are four consecutive and interdependent phases in each LCA-study. The first phase is the *Interpretation*. In the beginning of the study the phase of interpretation means to understand the application and how it has implications on how the study should be performed. This is to a large extent what this chapter *Introduction and application* describes in this report. During the study the interpretation means to make different choices that leads to a good LCA result that is relevant for the application. At the end of the study the interpretation means to extract the key meaningful results to the application.

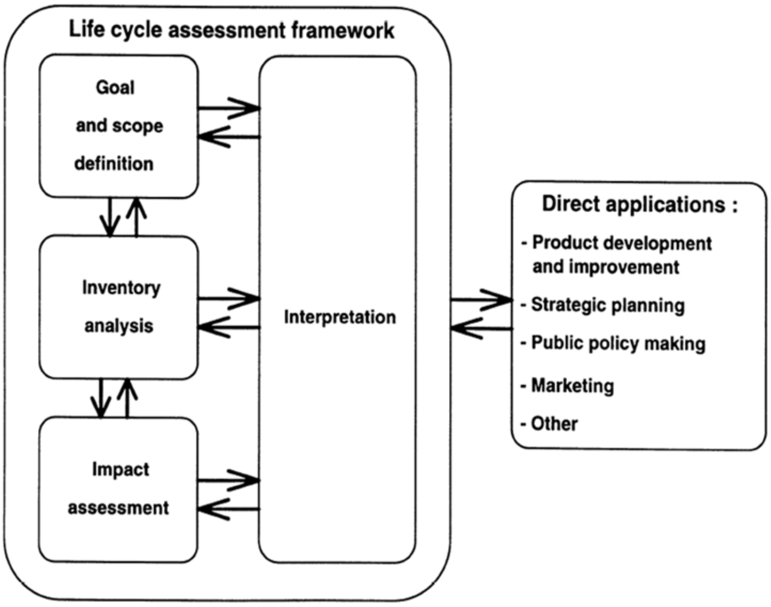

Figure 2 The framework of LCA as described in the international standard ISO 14040:2002 – Environmental management – Life cycle assessment – Framework and principles, Copyright ISO 2006

The second phase is the *Goal and scope*, during which all the decisions about how to perform the study is made and formulated. This means the choice of which processes to include and which to exclude in the product system. Also, the environmental system boundaries are defined, by choice of impact categories, category indicators and data categories. This means that the life cycle of the blood bags is assessed with regards to how certain inflows of natural resources and outflows of emissions (data categories) contributes to climate change, consumes natural resources and contributes to impact on human health (impact categories). This is done by quantifying how much the inflows and outflows contribute to specific indicators within each impact category, for example how much a certain amount of CO_2, N_2O and CH_4 together would contribute in terms of Carbon Dioxide equivalents (CO_2e), how many cases of cancer or other health issues phthalates and dioxins potentially contribute to, and the total resource value of the fossil oil, coal and natural gas reserves. Also, during the goal and scope the types of data sources are defined, and partly identified.

The third phase is the *Inventory analysis*, during which all the data about resource use and emissions during all the process of resource extraction, production, use and waste management are acquired and calculated on the basis of the functional unit. In this study it means that all the data from the processes throughout the life cycle data has been recalculated to be valid for one blood bag stored for 30 days before used.

During the fourth phase, the *Impact assessment*, the resulting data about resource use and emissions for the entire inventory phase is translated in terms of how they impact the chosen impact categories. In this study it means that the different greenhouse gases are added together to quantify the total potential contribution to climate change (expressed in CO_2e), and total potential toxicity is quantified from adding up the chlorinated substances related to the PVC/DEHP together, and due to the strong relationship between plastics and oil, all the fossil fuel consumption is added up as a category indicator that quantifies the total resource consumption. Since the study includes a comparison with HDPE, the same steps are taken also for the blood bag based on that plastic.

As stated earlier, after the impact assessment, the result of the study is interpreted and the result is reported in a form that follows the principles of LCA and is fit to the application. The report you are now reading is such an LCA study report.

1.3. Approach to this study

The initial literature study of this LCA showed that much has been written about the environmental impact of plastics, PVC [Vinylsum, 2012] and of DEHP [DEHP facts, 2012]. Much has also been written about the toxicity aspects of the phthalate DEHP [JRC, 2008] [US food and drug administration, 2002] as well as of the different chlorinated substances throughout the life cycle of both PVC and DEHP [SCENHIR, 2007]. In specific, several papers discussed dioxin emissions from PVC waste incineration and described different options about how to treat PVC [Rijpkema, 1999] and PVC/DEHP waste incineration. Only a few of the references are mentioned here.

It was concluded that to add to this substantial amount of already available knowledge and these many viewpoints in the field, it would be most relevant to perform an LCA that compiles simple quantitative and transparent overview of the environmental hot spots of the life cycle of a PVC/DEHP blood bag. To make the quantitative result meaningful and easy to understand, two reference points are established: One is the relationship between the potential human health impact caused by the transfusion of DEHP-contaminated blood and the human health impact caused by chlorinated substances throughout the life cycle. The other point of reference is an imaginary blood bag based on a simple hydrocarbon plastic. Because High Density Polyethylene (HDPE) is also to a small share part of the PVC/DEHP blood bag, HDPE was chosen as material for the imaginary reference blood bag.

2. Goal and scope

2.1. System boundaries

The system boundary dimensions considered specifically are the

- technical system boundary, which is defined by the included and excluded processes which are described in section 2.1.1
- the environmental system boundary, which is defined by choice of environmental impact categories, described in detail in section 2.1.2.

2.1.1. Technical system boundaries

The flow chart for the PVC/DEHP blood bag is represented in the flow chart in Figure 1. The flow chart is drawn on the basis of the unit processes acquired for the study, which means the lowest level of detail for which the data is acquired. This for example means that the production of *PVC* is just one single data set, which includes data about oil extraction, electricity production, cracking, transports etc., all the way up to PVC resin. The same is true for *DEHP*, *HDPE* and *Calendering* and *Electricity* production. The other processes are modeled as gate to gate data, i.e. on basis of similar data. This is described in detail in section 2.3.

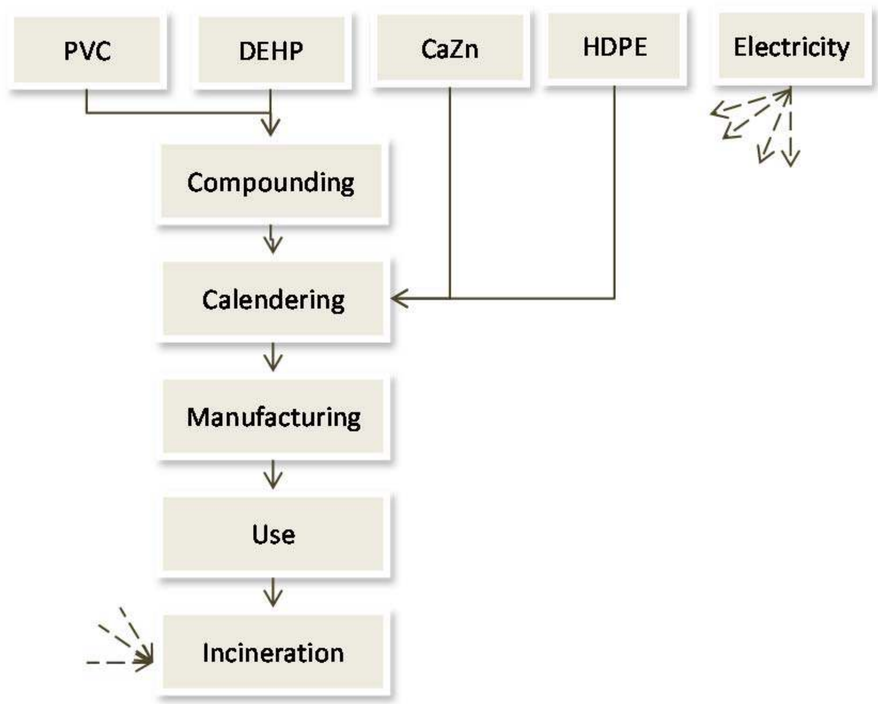

Figure 3 The life cycle flow chart representing the technical system boundary of the PVC/DEHP blood bag.

The flow chart in Figure 3 shows that the PVC/DEHP blood bag consists of PVC and DEHP which is mixed in the *compounding*. There may be different PVC/DEHP ratios of this mix, around 55/45 - 70/30 [SCENHIR, 2007]. The inventory has been calculated for a PVC/DEHP ratio of 65/35.

After the compounding the PVC/DEHP is processed into a sheet appropriate to make bags from. This process is named *calendaring*, it starts with the PVC/DEHP 'clay' in one end and is rolled between cylindrical rolls while mixed with the additives to for the sheet. The additives are 10% CaZn and 3% High Density Polyethylene (HDPE), and so ends up with a PVC/DEHP ratio of 87%.

The PVC/DEHP sheet is then cut out and welded together into blood bags at the *manufacturing* stage. It is estimated that ca 1% of the material is lost during cutting, and that ca 0,1% of the finished blood bags are discarder and disposed due to quality mistakes. This is an assumption for which we have no reference. It should be noted that if this figure is substantially higher, or if it is substantially different for different materials, this may change the result of the study.

The *use* stage takes place after the manufacturing stage. The use stage includes the cold storage of blood and the transfusion. The cold storage is included since the electricity needed for storage may contribute significantly to climate change over the life cycle, and the transfusion is included since the PVC/DEHP blood bag emits DEHP to the blood of the blood receiver. There are several different quantitative estimates for this emission of DEHP into the blood of the receiver, and here is used a moderate estimation of 328 mg per person and full blood bag transfusion (see section 4.3.3). It has been estimated that 1% of the blood bags are discarded due to handling mistakes or blood storage expiration.

After the use, the blood bag goes to *incineration* together with other medical waste. For simplicity and overview it has been considered that the waste during manufacturing and the discarded blood bag due to expiration also goes to the same waste incineration. The incineration of any material with chloride content potentially leads to dioxin emissions. It has been noted that it is today common that the heat generated during the incineration is used to replace an alternative heating system. This is not included here, since it would not add to the clarity of the study. It should be stressed, however, that if it had been accounted for, both the total resource use and the total contribution to climate change are likely to have been lower. It is also well understood that the ashes from the incineration of PVC/DEHP may contain toxic substances that will cause dioxins to leak during the final waste storage at a landfill site potentially affecting soil and groundwater resources (due to vertical and horizontal migration) and maybe surface water in case of a considerable horizontal migration. The latter would also be influenced by the specific landfill site context characteristics (soil type and composition, type of groundwater aquifers, etc.). This again has not been included here. Such data would show to increase the environmental impact of the life cycle of the PVC/DEHP blood bag, but since the uncertainty of the data about the actual amount leaked out would be combined with the uncertainties of the incineration process, it was decided to leave the landfill leakage out.

The compounding, the manufacturing and the use stage are modeled to utilize the same *electricity* production data.

Since the impact from transportation is assumed nearly independent on type of material of the blood bag, explicit transports from the calendaring process and to incineration have not been in included with the study. It should be noted, however, that when striving to minimize the environmental impact of a specific choice of blood bag material, transports are likely to be important.

2.1.2. Environmental system boundaries

Section 1.2 introduces the methodology of LCA and also describes in detail how to set the environmental system boundaries of a study.

The literature study shows that the most significant aspects for the PVC/DEHP blood bag are:

- **Impact on human health:**
  - *The phthalate DEHP*: During blood transfusion the DEHP is leaked into the blood, and exposes the blood receiver to risks for cancer and disturbances in the reproductive systems [SCENHIR, 2007].
  - *Dioxin*: The chlorine content of PVC and DEHP contributes to the potential generation of dioxin during waste generation [Rijpkema, 1999].
- **Consumption of natural resources**
  - *Fossil oil*: Both PVC and DEHP are based on fossil oil, and since the used blood bag is considered as medical waste (biohazard potential) it is incinerated for safety reasons rather than recycled.
- **Contribution to climate change**
  - *Carbon dioxide*: As with natural resources, since PVC and DEHP are produced from fossil hydrocarbons, the incineration of the blood bags contributes to with CO_2 emissions to the atmosphere [Vadas, Nguyen-Ngoc, 2009].

This list of significant aspects is used to define the impact categories and the data categories for the study. It means that the emissions of the phthalate and other chlorinated substances related to the PVC and the DEHP production, and the emissions of dioxin are included in the analysis of potential impact on human health. And it also means that the fossil fuel consumption are included for analysis of potential impact on resource depletion, and the emission of greenhouse gases are included for the analysis of potential impact on climate change.

It is of course understood that there are other impact categories and other data categories that could also have been included to get an even more comprehensive picture, but it was considered that such comprehensiveness would have contributed to neither the clarity nor the result of the study.

It was decided that different impact assessment methods would be used to assess the result of the study, including the EPS method [Steen, 1999], the Eco-indicator method [Goedkoop, Spriensma, 1999], the EDIP method [Wenzel, Hauschild, Alting, 1997] and the USEtox method [USEtox, 2012], as well as the IPCC documents [IPCC, 2012, Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories as well as other IPCC references] for assessing the potential climate impact from different gases.

2.2. Reference blood bag, High Density Polyethylene

To facilitate the quantitative interpretation of the result of the life cycle assessment of the PVC/DEHP blood bag, it was decided to perform a comparative and very similar study on an imaginary PVC-free blood bag, made from only High Density Polyethylene (HDPE). With lack of further knowledge about this blood bag, it was considered likely that this alternative blood bag would have the same weight and in all other aspects have the same life cycle. The difference is based on that it would lack the PVC and DEHP production steps, as well as the CaZn additive, and of course also be without the exposure of DEHP to humans during blood transfusion, and not contributing to dioxin during medical waste incineration.

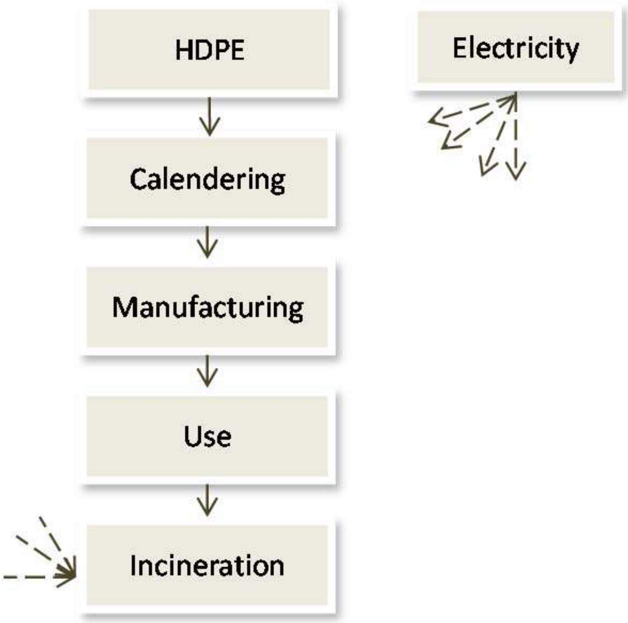

Figure 4 The life cycle flow chart representing the technical system boundary of the High Density Polyethylene (HDPE) blood bag.

To make the studies comparable, as much as possible of the same data is used for the PVC/DEHP studies and for the HDPE, except for the differences associated with the PVC and DEHP.

2.3. Choice of data sources and data categories

2.3.1. LCI data

From having assessed several potential data sources, the choices of LCI data were made as follows:

- Best available and transparent data sources for the key materials PVC, DEHP and HDPE. This means that the data available from the plastics industry, the Plastics Europe database [Ostermayer, Giegrich, 2006] [Ecobilan, 2001]. The data sources were compared with other available data from for example the European ELCD database for the production of these materials, and Plastics Europe data was selected due to transparency and relevance for the study.
- For manufacturing and use of blood bag, several different data sources were combined to estimate key functions, such as welding the PVC/DEHP and holding the blood bags cold. The result is hence a theoretical model value, based on technical data [See *Manufacturing* section under *References for LCI database*].
- Several different sources were assessed to acquire data for the incineration of the blood bags. Since the dioxin emissions are the result of a non-efficient and non-effective incineration process, it is difficult to find data about the actual emission levels. Data for general waste management facilities and technologies was not considered relevant for this specific study, since the connection between the blood bags and the actual dioxin emission levels is very hard to identify or describe. Therefore it was decided to make incineration emission models based on assessment of several different data sources [See *EOL PVC Uncontrolled / EOL PVC Controlled/ EOL HDPE* section under *References for LCI database*].
- Transport of blood bags has been omitted, since impact from transportation is assumed independent on choice of material for the blood bag. It should be stressed, however, that the transportation does have an environmental impact and is relevant when optimizing the environmental performance of the life cycle of a specific blood bag, or when transportation for some reason may be expected to be very different for different material choices.

The data categories to consider are those that relate directly to the three impact categories described in sections 2.1.2 and 2.3.2.

2.3.2. Impact assessment data

2.3.2.1. Impact on human health

The impact assessment of this LCA study focuses especially on the health aspects of the phthalates and chlorinated substances, such as the dioxins. Impact assessment methods with emphasis on human health is applied: the Eco-indicator method [Goedkoop, Spriensma, 1999], the EDIP method [Wenzel, Hauschild, Alting, 1997] and the new USEtox method [USEtox, 2012]. The best documented and most accurately updated database and method is the latter of these three. But this database focuses on chemicals with a CAS number, i.e. chemicals that are produced to be sold. This means that characterization factors, for example for dioxins, cannot be found in the database of this method. Another way to put it is that the USEtox method is blind to dioxins.

To support the interpretation of the result, the impact assessment includes a comparison between health impacts over the life cycle of the blood bag and health impacts from the exposure of the phthalate DEHP during blood transfusion. There are some complications with such a comparison, described in chapter 4.

There are many emissions associated with the chlorinated substances for which there are no characterization data, such as chloride, HCl and many other substances.

It should also be stressed that none of the methods have characterization factors for CaZn, Austinite, which is a lubricant for PVC. It includes a small amount of arsenic, chemical formula $CaZn(AsO_4)OH$. Its toxicity aspects are not known

2.3.2.2. Depletion of natural resources

For plastics products consumption of the natural resources oil and natural gas are most significant. To evaluate not only the consumption, but also the environmental significance of this consumption of fossil fuels, three different impact assessment methods has been used, the EPS method [Steen, 1999], the Eco-indicator method [Goedkoop, Spriensma, 1999] and the EDIP method [Wenzel, Hauschild, Alting, 1997]. The three methods employ somewhat different valuation of the different resources.

2.3.2.3. Contribution to climate change

Contribution to climate change is considered with regards to how much the different greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and freons (HCFC) contribute to climate change, using data published by the IPCC, the Intergovernmental Panel on Climate Change [IPCC, 2012].

3. Inventory

3.1. Data collection

The actual inventory data is presented in a separate library of Excel files, but the LCI-profiles are presented in Annex B.

3.2. Calculations

3.2.1. Assumptions and simplifications

To maintain full transparency throughout the life cycle inventory, all calculations are performed in Microsoft Excel. The calculations are based on the following assumptions and simplifications:

- The PVC/DEHP mix in one blood bag is 65%/35%
- One blood bag weighs 87,5 grams[2]
- A blood bag is stored for 30 days
- The production waste PVC/DEHP and HDPE are incinerated in the same way as the medical PVC/DEHP. A sensitivity analysis has been performed to verify that any realistic waste management profile does not change the result of this study.

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[2] This weight was estimated from data about the mass of a full blood bag, with reference to a blood bag handling routine, stating that the mass of a full 400 ml blood bag is between 509 g and 620 g (Mazin, 2012)

- The electricity production not included in the Plastics Europe data, i.e. the electricity used for manufacturing and use, has been chosen as a generic background electricity production as an average from the OECD countries. A sensitivity analysis has been performed to verify that any other electricity production mixture does not significantly change the comparative result of this study, though it of course may impact the absolute levels of in specific resource consumption and climate change.

3.2.2. Different calculations performed

To produce the relevant information that could be withdrawn from the LCI, according the goal and scope and the data collection, three different life cycle calculations were performed:

A. *Life cycle of PVC/DEHP blood bag with a controlled waste PVC incineration*. The controlled waste incineration means both the existence of emission cleaning technologies as well as that the incineration temperature is higher. Both these circumstances lead to less dioxin emissions, but they instead also consume more other fuel. In a normal waste incineration it is likely that the higher temperature would be maintained with an optimal mixture of other combustible medical waste. To estimate the energy consumption for the higher oxidation temperature and the emission cleaning it is assumed that the energy level is reached by an addition of oil. It is not an entirely realistic assumption, but makes it easy to understand that the oxidation of PVC and the emission cleaning is made on the expense of such an amount of energy resources.
B. *Life cycle of PVC/DEHP blood bag with an Uncontrolled waste PVC incineration*. The uncontrolled waste incineration burns without the additional amount of extra oil, which leads to a lower degree of oxidation, hence much higher dioxin emissions. It also leads to lower emissions of carbon dioxide and lower energy resource consumption.
C. Life cycle of High Density Polyethylene (HDPE) blood bag with a controlled waste incineration. The controlled waste incineration of HDPE means that it burns with the same additional energy as the controlled waste, leading to perfect oxidation and only carbon dioxide emissions.

It should be noted that it is difficult to give a perfect estimation of the emissions and waste incineration energy needed. The data used here are backed up by references about energy and temperature levels for medical waste incineration [See section *EOL*[3] *PVC Uncontrolled / EOL PVC Controlled/ EOL HDPE* under *References for LCI database*] in combination with estimates of emissions from medical waste incineration plants.

The three different life cycle calculations have been combined to provide the following two comparisons:

A-C: Difference in the LCI profile between the PVC/DEHP and the HDPE blood bag

A-B: Difference in the LCI profile between the PVC/DEHP-blood bags depending on the different waste incineration types

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[3] EOL – End of life - Refers here to the waste incineration technology

Calculations had also been performed to identify the share of contribution of climate change gases and fossil fuel resource consumption from the processes throughout the life cycle vs. the feedstock and the waste incineration from the different alternatives.

3.3. LCI profiles and LCI calculation results

In this chapter some diagrams of the LCI profile calculations are presented. The LCI profile data tables are presented in Annex B.

3.3.1. Climate change gases

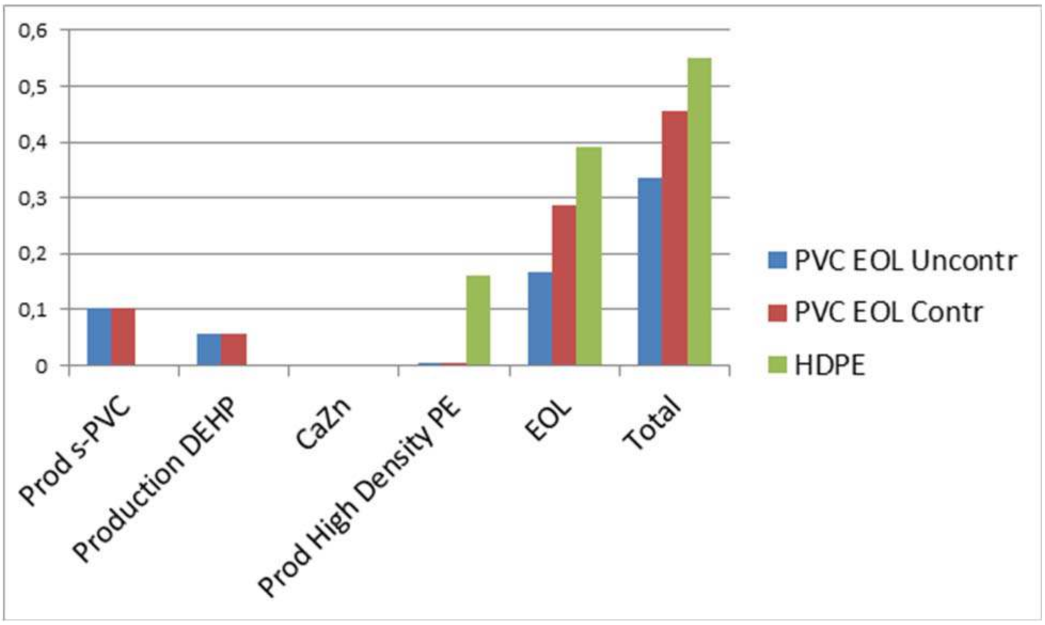

Figure 5 Comparing carbon dioxide emissions from the three alternatives for the key different processes. The diagram shows kg of CO2 emissions per life cycle of blood bag.

The diagram in Figure 5 shows the carbon dioxide emissions from the five key different processes over the three different life cycles of the blood bags. It also shows the three totals of those processes. The same relationship is reflected in the diagram in Figure 6, which shows the total emissions of greenhouse gases for the three different alternatives. The data are presented in table D1 in Annex D.

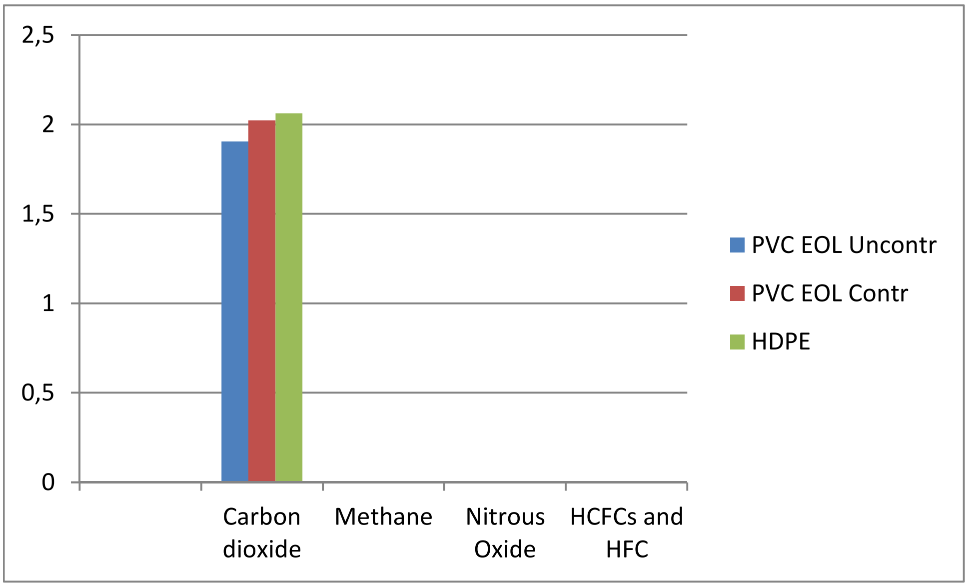

Figure 6 The greenhouse gases emitted from the life cycles of the different alternatives. The diagram shows kg of greenhouse gas emissions per life cycle of blood bag.

The diagrams in Figure 5 and Figure 6 show that the HDPE emits the higher amount of greenhouse gases, and it shows that the reason for this is that it emits its larger carbon content during waste incineration, and because it uses more energy during production than the PVC/DEHP alternative. The diagrams also show that the scenario with a controlled incineration of the PVC blood bag contributes more to climate change than the uncontrolled incineration. This is because of the need for extra energy to acquire a better oxidation. The data are presented in table D2 in Annex D.

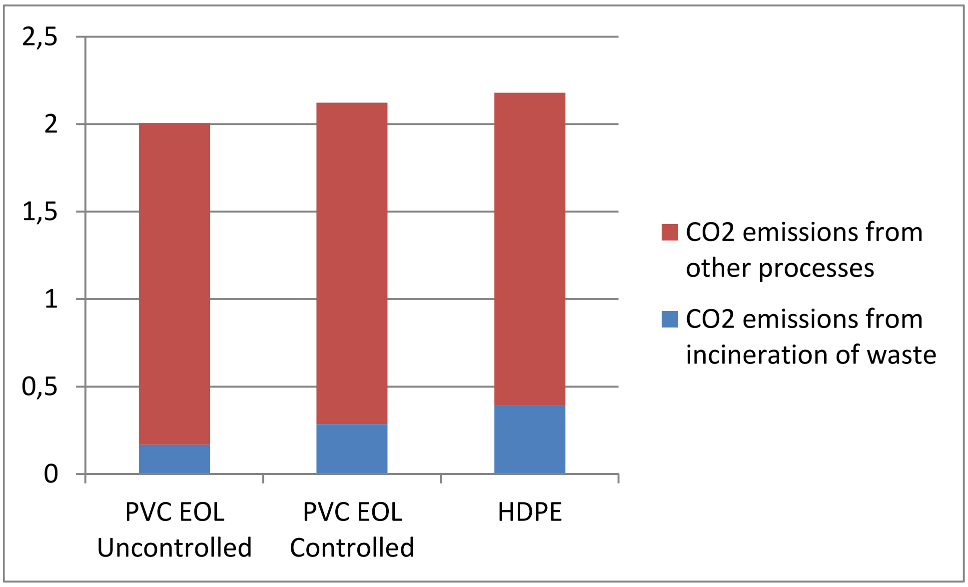

Figure 7 The carbon dioxide emissions from the three alternatives, divided onto incineration vs. the other processes. (compare with Figure 13). The diagram shows kg of CO2 emissions per life cycle of blood bag.

The diagram in Figure 7 shows the contribution for carbon dioxide emission divided between the incineration and the rest of the life cycle of the blood bag. It shows that the High Density

Polyethylene, HDPE blood bag contributes with most carbon dioxide over its life cycle, and that this is mainly due to the final incineration stage.

It should be stressed that the total contribution to climate change would have increased equally for the three alternatives if the transports would have been added to the study. The absolute value for the climate change figures also depend strongly on the choice of data for the electricity production. However, the relative values do not depend on this choice of electricity production.

3.3.2. Emissions of hazardous substances related to chlorinated substances

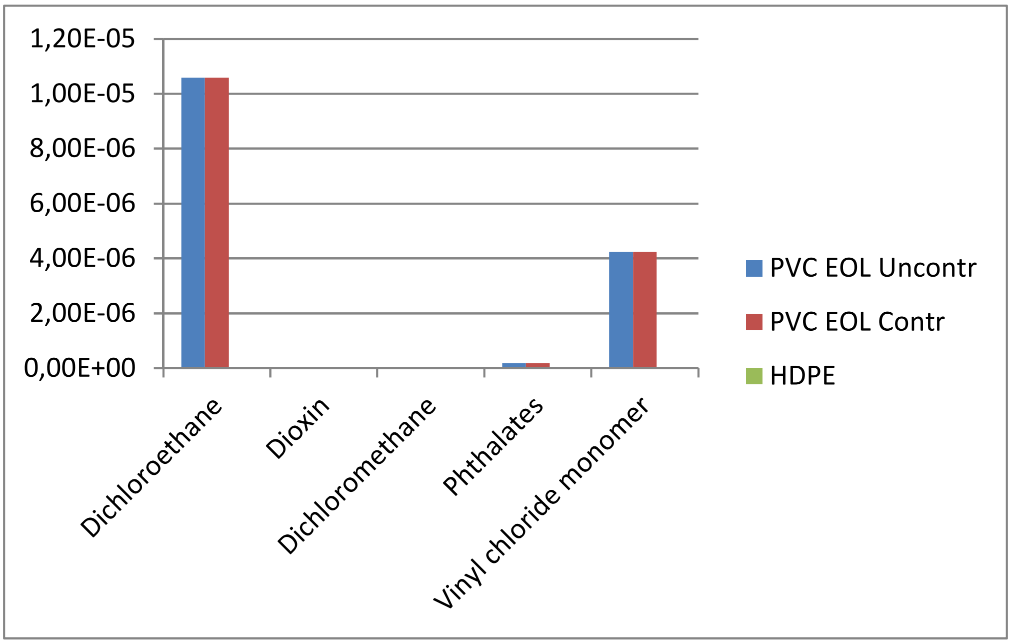

Figure 8 The most significant emissions of chlorinated substances to air. The diagram shows kg of air emissions per life cycle of blood bag.

The diagram in Figure 8 show the amounts of chlorinated substances emitted to air throughout the life cycle of the three different alternatives. As expected it shows clearly that the two PVC cases have higher emissions of dichloroethane and vinyl chloride monomers. It also shows the same for phthalates, even if the figures are much smaller. Data are selected from table D3 in Annex D.

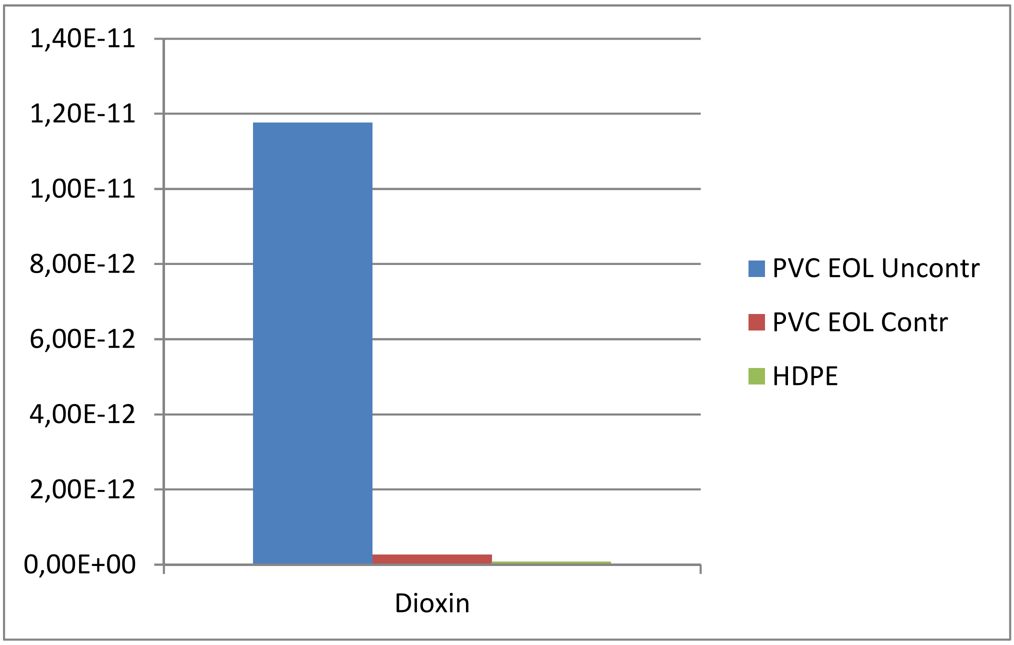

Figure 9 The differences of dioxin emissions to air, mainly from uncontrolled incineration. The diagram shows kg of dioxin emissions to air per life cycle of blood bag.

The diagram in Figure 9 shows the dioxin emissions to air, mainly caused by the incineration processes. The uncontrolled non-optimal oxidation process leads to a very high dioxin emission, while the lower emission value relates to the better incineration. The dioxin emissions to air for the HDPE life cycle are too small to show. Data are selected from table D3 in Annex D.

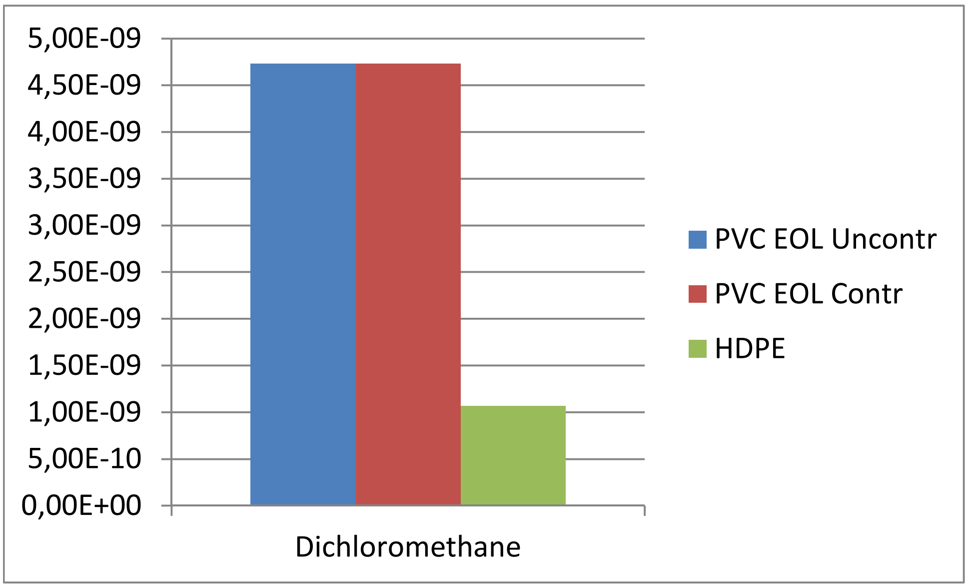

Figure 10 The differences of dichloromethane emissions to air, mainly from the production of the PVC and the DEHP. The diagram shows kg of dichloromethane emissions to air per life cycle of blood bag.

The diagram in Figure 10 shows the dichloromethane emissions to air from the production of PVC/DEHP in comparison to the production of the HDPE. Data are selected from table D3 in Annex D.

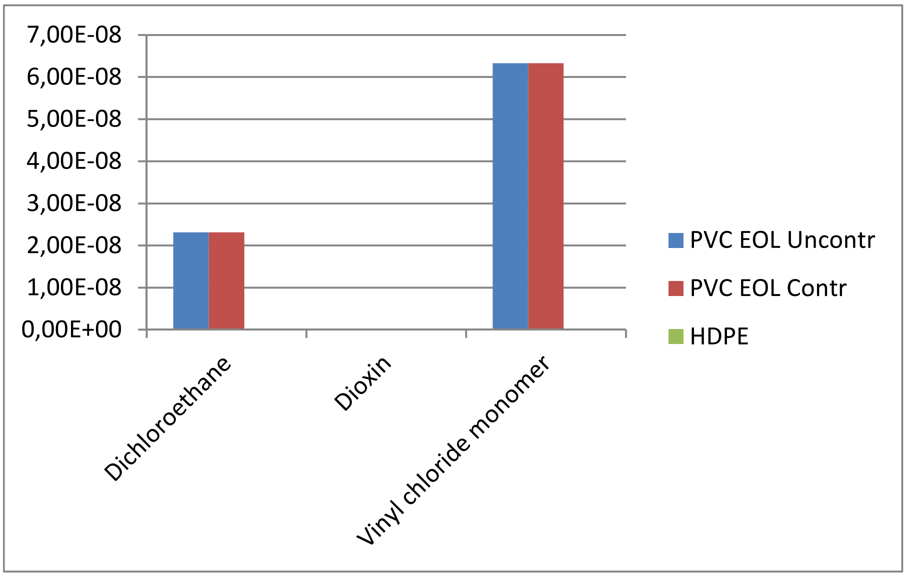

Figure 11 The most significant emissions of chlorinated substances to water. The diagram shows kg of water emissions per life cycle of blood bag.

The diagram in Figure 11 shows the emissions of dioxin to water for the different alternatives.[4]

It was expected that the emissions of chlorinated substances are higher for PVC/DEHP, and the presented tables show this clearly. Data are selected from table D3 in Annex D.

3.3.3. Depletion of natural resources

This section presents diagrams that show the depletion of natural resources by using the fossil fuel consumption for the three different cases.

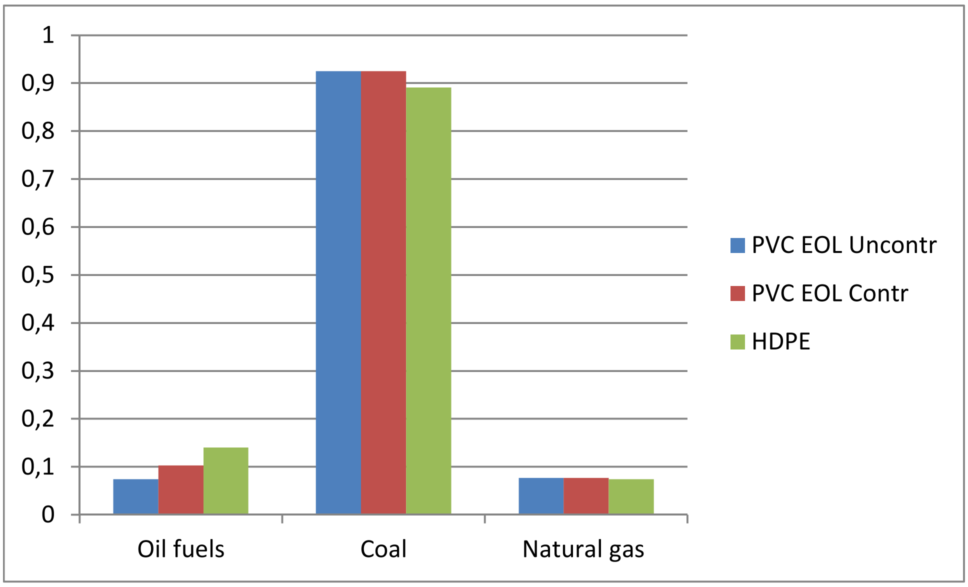

Figure 12 Comparing fossil fuel use from the three alternatives. The diagram shows kg of energyware per life cycle of blood bag.

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[4] It should be noted here that the Plastics Europe data for production HDPE revealed to have an erroneous data for a water emission of dioxins. This water emission could be identified as belonging to a production process with no incineration. It was concluded to be wrong and was therefore nullified.

The diagram in Figure 12 shows that HDPE uses more oil fuel, which is because of its higher content of hydrocarbons. PVC and DEHP are also based on hydrocarbons from oil, but also from natural gas. And they also contain a high amount of chloride, which originates from sea water or rock salt. The relatively high amount of coal is due to the electricity production system. This may vary depending on how the electricity is produced. Data are presented in table D4 in Annex D.

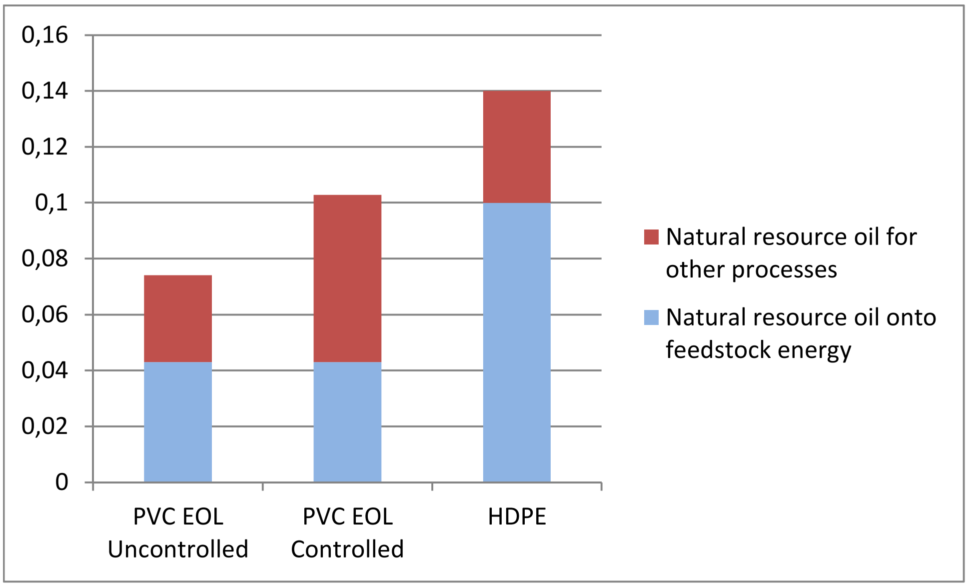

Figure 13 Comparing feedstock and energy use from the three different alternatives (compare with Figure 7). The diagram shows inflow of the natural resource oil in kg per of blood bag.

The diagram in Figure 13 shows that the natural resource oil is distributed between product content (feedstock) and as fuel for energy production in other processes throughout the three different life cycles. It is clear that the oil is used to a higher degree as feedback to the plastics in the HDPE and that it uses less oil than the PVC alternatives as fuel for energy. The figure also shows the differences in fuel use to acquire the better controlled incineration which leads to lower dioxin emissions. The data are presented in table D5 in Annex D.

4. Impact assessment

4.1. Three impact categories

The impact assessment presented here is divided into the three impact categories climate change, human health and natural resource depletion, since these were identified as the significant issues for PVC/DEHP blood bags, and is also suitable for the reference high density Polyethylene blood bag. By maintaining the three impact categories rather than weighting them together, the differences between the alternatives are more transparent. The drawback is that in this case there is a trade-off between the impacts on the different impact categories of the different blood bag alternatives, and the actual choice between which is the better alternative is left to the decision maker.

4.2. Climate change

4.2.1. The impact on climate change

The diagram in Figure 14 shows how different the climate change contribution from the alternative life cycle scenarios of the PVC/DEHP blood bag is in comparison to the High Density Polyethylene, HDPE blood bag.

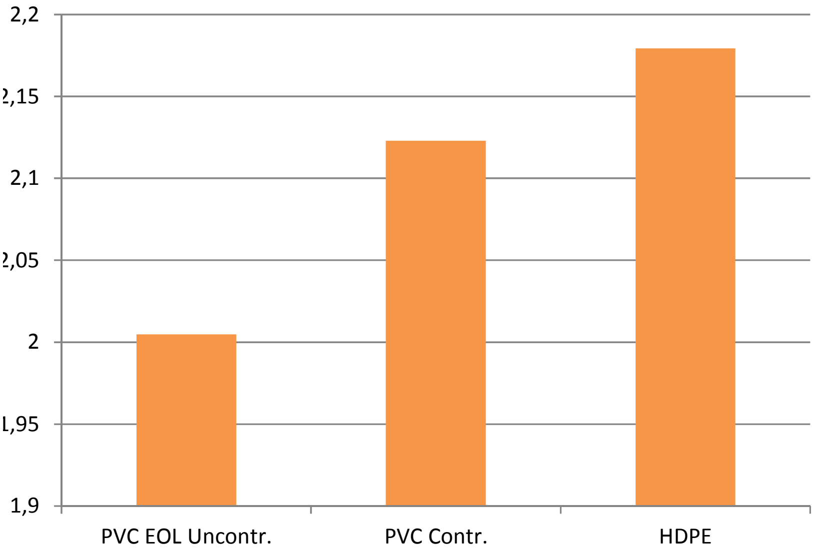

Figure 14 Comparing contributions to climate change between the three alternatives.

The diagram should be compared with Figure 7, which shows almost the same relationship, but only based on carbon dioxide emissions. Data are selected from table D6 in Annex D.

The diagram is presented in the unit of carbon dioxide equivalents (CO_2e), which means that emissions of N_2O, CH_4 and CFCs are recalculated into how much each one contributes in relation to the normalization of CO_2e by applying the corresponding global warming potentials.

4.2.2. Discussion about climate change

There may be different ways to reduce the contribution to climate change from the different alternative life cycles of the blood bags. For example, the energy may be produced using bio fuels or may be more efficiently produced. Much of the virgin fossil oil content in the plastics may be replaced with recycled or bio-plastics, and during incineration it may considered that the heat produced during the incineration replaces a less sustainable solution to heat generation, etc.

This has not been considered here, but it is expected from the reader of this report to identify these potentials themselves. It is of course not acceptable to introduce any new sources for carbon dioxide emissions for any reason, even if it is to substantially reduce severe human health risks as in this case. The potential additional carbon dioxide emissions will most probably in the first place be reduced by the fact that a simpler plastic can be burnt as better fuel in the incineration plants and that the cleaner some gas emissions needs lesser treatment. In the next phase the plastics shall of course be replaced by bio-plastics or recycled material, if possible.

4.3. Human health

Potential human health impact is assessed using different impact assessment methods, and the assessments are performed both over the full life cycle of the different alternatives and by comparing the potential health impact over the life cycle with the health impact from the blood transfusion. The methods used to assess the health impact over the life cycle are the Eco-indicator, the EDIP, and the USEtox method. The USEtox method is also used to compare the potential human health impacts from emissions during the life cycle of the blood bag with the potential human health impacts induced by DEHP contaminated transfused blood (section 4.3.3).

4.3.1. About the three human health impact assessment methods

4.3.1.1. General about human health impact assessment

All the impact assessment methods that are used here have an, in general, similar approach regarding how to quantify the impact on human health. The basis for the quantification is empirical toxicity studies performed in laboratories and which results in quantifications of concentration or amount of a specific substance that causes cancer, impacts reproduction, is lethal, gives skin irritation or is otherwise indicated to disturb the health of the test specimens. On these well-structured laboratory results, the impact assessment methods are formed by a systematic estimation about how an emission eventually causes a concentration in soil or air or water, and how this impacts the health of the general population.

The USEtox characterization data are developed for traded chemicals, which means chemicals that are sold and can be bought and that therefore have a CAS number, such as phthalates. Dioxins, however, are unintended products of inefficient combustion of chlorinated substances, such as PVC and DEHP. They are not available on the market and do not have a CAS number and are therefore not included in the USEtox method. This is the major reason why older data from the two different methods Eco-indicator and EDIP with less degree of scientific consensus are also used to assess the environmental impact of the life cycle. They both have a combined set of characterization data for both the dioxins and for other chemical substances.

4.3.1.2. Eco-indicator

The impact assessment method Eco-indicator uses the term DALY (Disability Adjust Life Years) as category indicator to describe human health impacts. The quantification of DALY is calculated and modeled on the same basis as described in section 4.3.1.1, but is the sum modeled as a sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability. [Goedkoop, Spriensma, 1999]

4.3.1.3. EDIP

The EDIP method follows nearly exactly the general description of human health impact assessment method described in section 4.3.1.1., and results in several contributions to human health toxicity impacts resulting from the media air, water and soil. The actual human health impact summarizes those human health impacts coming from the different media. [Wenzel, Hauschild, Alting, 1997]

4.3.1.4. USEtox

The USEtox method also follows the general description of human health impact assessment method described in section 1.2. In addition, the USEtox method is developed by a group of world leading human toxicology experts and LCA experts in a network [USEtox, 2012] established jointly by UNEP

(United Nations Environmental Programme) and SETAC (Society for Environmental Toxicology and Chemistry).

4.3.2. Comparing the three life cycle alternatives

The diagram in Figure 15 shows the human health impact using the concept of DALY by the impact assessment method Eco-indicator. The diagram in Figure 16 shows the same thing using the the human toxicity concept of the EDIP method. Both these diagrams show the same result, that the dioxin emission from the uncontrolled incineration of PVC has a large impact on the human health over the life cycle of the blood bag. Even when using the controlled incineration with substantially much lower dioxin emissions, these are still very high in comparison to the overall potential life cycle impact on human health compared with the HDPE alternative. Data are selected from table D7 in Annex D.

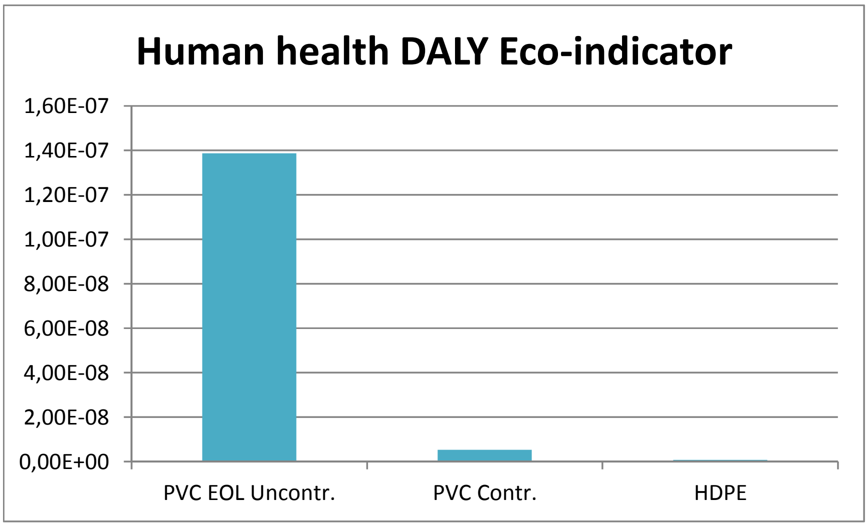

Figure 15 Human health impact in DALY (Disability adjust life years) using the Eco-indicator impact assessment method.

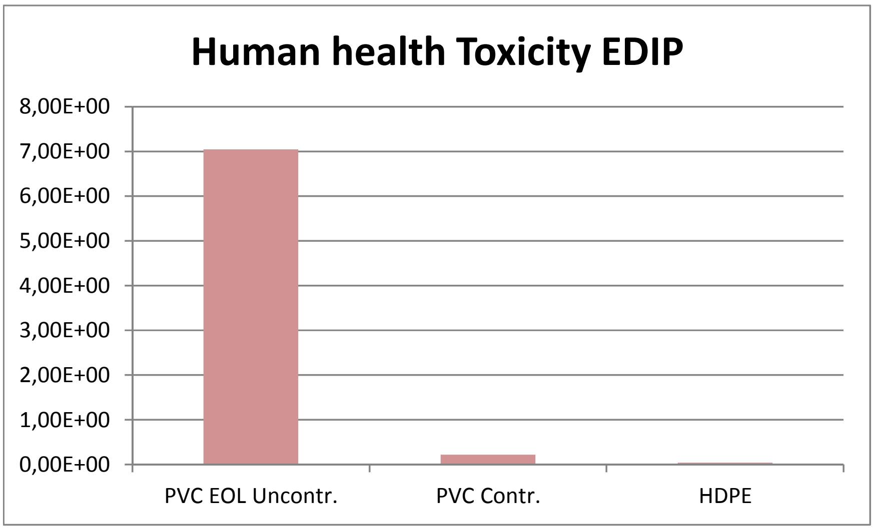

Figure 16 Human health impact in DALY (Disability adjusted life years) using the EDIP impact assessment method.

It should be stressed that the high impacts are directly related to the data and modeling used for waste incineration. Any cleaning of dioxin emissions will be directly reflected in these impact assessment evaluations. A comparison with the diagram in Figure 7 should be regarded however, because a cleaning of dioxin may be expensive with regards to resource consumption and may produce more carbon dioxide that contributes to climate change.

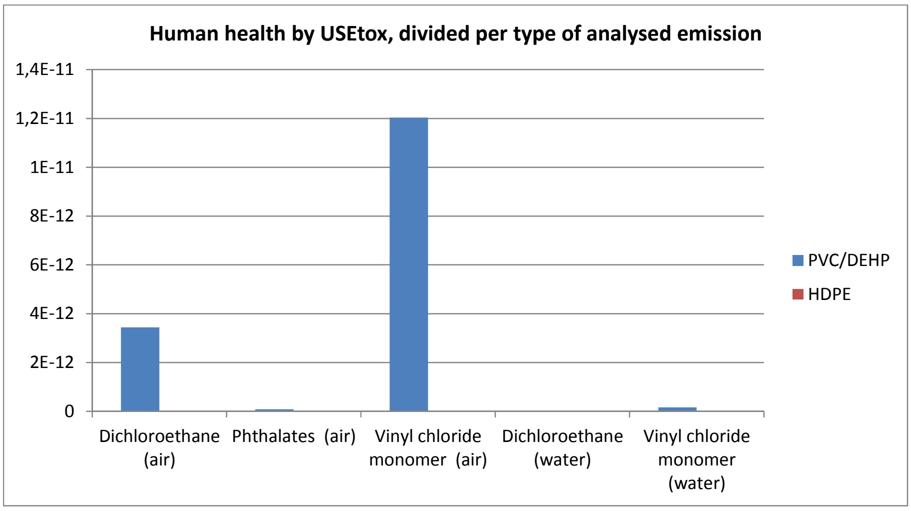

Figure 17 Potential human health impact evaluated by the USEtox method, number of cases, divided per type of analysed emission.

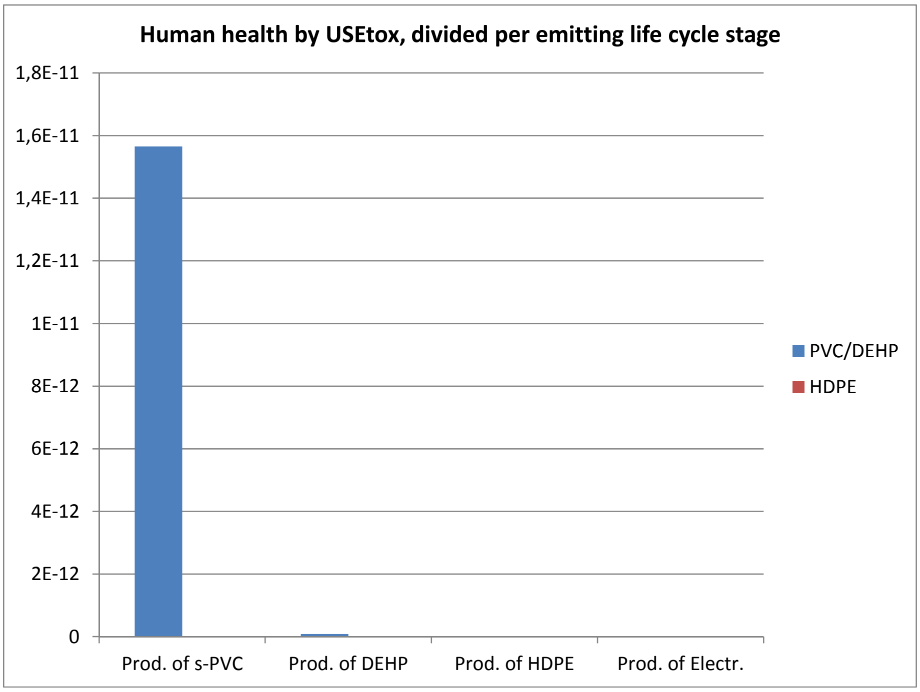

Figure 18 Potential human health impact evaluated by the USEtox method, number of cases, divided per emitting life cycle stage.

By combining the information given in the diagrams of Figure 17 and Figure 18 it is clear that the major potential human health impact from the PVC/DEHP blood bag when using the USEtox method comes from the production of the PVC resin (s-PVC), and that this is mainly caused by the emission of vinyl chloride monomers (VCM). It needs to be stressed that the diagrams also includes the full life cycle process steps of the HDPE blood bag, and that the potential human health impact from this is negligible. Data are selected from table D6 in Annex D.

The reader is reminded about that the USEtox database does not contain data for the dioxin emissions, which is the reason why there is no difference between the two PVC/DEHP cases, where the major human health impact comes from the dioxin emissions presented in the diagrams of Figure 15 and Figure 16.

4.3.3. Comparing impact from life cycle vs. transfusion

As described in section 4.3.1.1, the basic data for the characterization data for life cycle human health impact is the laboratory data about how concentration of substances impacts health on test specimens. This same data is used to assess the exposure risk for these substances during handling, inhalation etc. that is the basis for example for risk classification. Therefore it is at least in theory possible to compare the potential human health impact induced by the total life cycle of a blood bag to the potential human health impact induced by to one patient that receives blood via transfusion of this same blood bag.

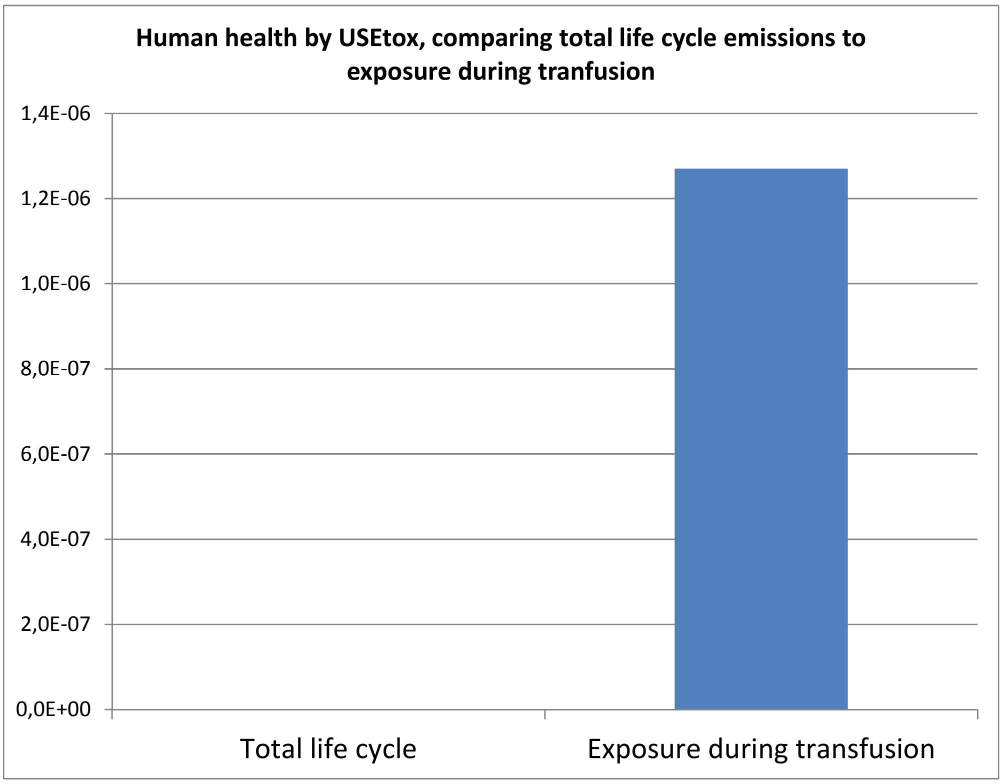

Figure 19 Comparing the potential impact on human health from the total life cycle of a PVC/DEHP blood bag to the potential impact from the transfusion.

The diagram in Figure 19 shows a large difference in the potential impact on human health from blood transfusion. It should be stressed that the bar *Total life cycle*, which is too small to be visible next to the bar showing *Exposure during transfusion* is in fact the sum of the bars in either Figure 17 or Figure 18. Data are selected from table D6 in Annex D. An excerpt of that data is presented in Table 1 below.

Table 1 Human health cases (cancer + non-cancer) per PVC/DEHP blood bag, evaluated by USEtox.

	Human health cases per blood bag
Total life cycle	1,6E-11
Exposure during transfusion	1,3E-06

There are four major problems with this comparison:

- The actual amount of DEHP leaked out to contaminate the blood
- The different sensitivity of different groups of patients
- The application of life cycle impact assessment data intended to populations for a direct exposure to individuals
- The small selection of life cycle impact categories, category indicators and data categories.

Each of those will be better explained in the following.

The actual amount of DEHP leaked out to contaminate the blood
In the study the figures 14-600 mg per transfusion has been used, from the study [See section *Use* under *References for the LCI database*]. These data are estimates, and may depend on storage time and other factors. Here the value 328 mg has been used.

The different sensitivity of different groups of patients
DEHP interferes with hormones that are especially active during growth, hence children are much more sensitive than the average patient [SCENIHR, 2007]. The sensitivity data embedded in the USEtox characterization data is based on the general population rather than on the different sensitive hospitalized groups of the population. It is likely that the potential impact induced by blood transfusion is several exponents higher than what is shown in the figures used here due to such aspects.

The transformation between impact assessment models and risk models
The translation between the life cycle impact assessment characterization data for DEHP and the transfusion characterization data was made with the assumption that inhalation and digestion of a an amount of DEHP would generally not result in 100% uptake in the blood. Instead it was assumed that 75% would end up in the blood. Hence, it was intended that the leakage of DEHP directly in to the blood would have a stronger impact per kg than when inhaled or digested. Therefore the characterization factor for inhalation and digestion of DEHP was multiplied by 1,33 (=1/0,75). Other assumptions may be made to end up with a different result.

The small selection of life cycle impact categories, category indicators and data categories
As has been pointed out several times, the USEtox data encompasses the chemicals with CAS-numbers, but excludes for example dioxins. This gives that the comparisons may have been less contrasting if compatible data for such emission had been used. Also, if an end-point impact assessment model, such as EPS had been applied to calculate human health consequences on also climate change and resource use, another result might have been achieved.

4.3.4. Discussion on human health impact assessment

The assessments performed here on the human health impact comparisons between the PVC/DEHP alternatives and the HDPE alternative shows clearly that if it is possible, the PVC/DEHP alternative should be replaced with an alternative without the health risks. There are health risks at each life cycle stage, and it is not recommended that these risks are managed by end-of-pipe solutions, such as better emission control at production stages and more advanced waste incineration systems, but that they should instead be managed by replacing the type of material used in the blood bag. Maybe is not HDPE a functional material option, but there are many plastics that should be tested. There are very good reasons to try to replace the PVC/DEHP with something less hazardous to human health, and that also meet the same technical quality criteria.

4.4. Natural resources

4.4.1. Evaluating fossil resource consumption

This study is based on the simple assumption made by Plastics Europe that PVC and High Density Polyethylene are based on virgin fossil resources. There are alternatives to virgin fossil resources. The two major categories of alternatives are to use recycled raw material or to use bio-plastics as input. Either alternative in separate or in combination will reduce the need for fossil resources. However, this study is not aiming to assess different options to produce PVC and HDPE. Instead it is considered more useful to identify the fossil resource consumption by the different alternative blood bags, and to propose that any actual choice of blood bag should be produced by the most sustainable option, that is non-fossil raw material.

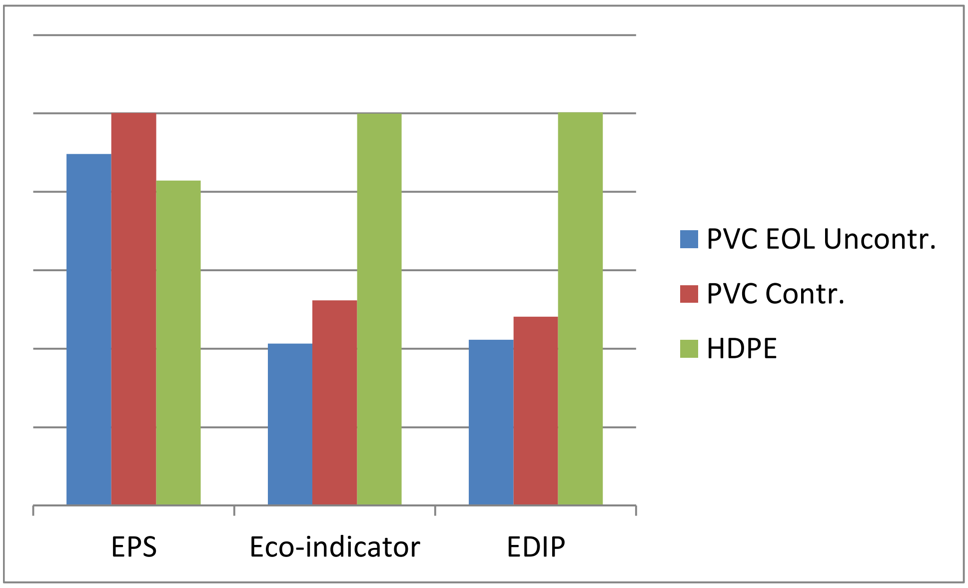

Figure 20 Resource depletion over the life cycle of the three scenarios evaluated using the EPS, the eco-indicator and the EDIP methods. It should be noted that comparisons between the methods makes no sense. The three different methods express resource depletion in *different units*. The diagram is normalized to make it easy to see how the different methods evaluate the alternatives.

The diagram in Figure 20 shows how the different impact assessment methods give different emphasis to different resources. The data are selected from Table D8 in Annex D. The major difference between the evaluation by the EPS method and the other two methods depends on that the EPS method assigns a lower value to the oil resource, based on a faith in the adaptability of the market to utilize other energy and coal resources when the price of oil increases. The Eco-indicator and the EDIP methods assign a relatively high value to fossil oil since oil is considered to be more scarce as an individual resource than both coal and natural gas. Since the PVC/DEHP alternative consumes more electric energy during production and much of the electricity production is based on coal, and since the HDPE alternative contains more oil in the product the actual difference is expected:

- The EPS method gives a relatively low value to fossil oil consumption and a relatively high value to the consumption of any fossil fuel, and since the electricity for the production of the PVC/DEHP alternatives are much based on oil and gas, these alternatives gives the worse result.
- The Eco-indicator and the EDIP methods give a relatively high value to the fossil oil consumption that occurs when utilizing virgin oil as 100% raw material for the HDPE blood bag, and incinerating it in the end.

4.4.2. Alternatives to resource consumption

In the beginning of section 4.4.1 it was mentioned that the assumption to use virgin fossil oil for the different plastics alternatives could be exchanged with for example recycled material and bio-plastics. Such solutions are necessary for any alternative blood bag, since depletion of resources is not sustainable.

There are other options towards reaching a more sustainable level of resource consumption. Some of them will be mentioned here, together with arguments why they were not considered in this study.

Replacing another energy source during incineration

When incinerating the blood bags, the additional generated heat replaces the use of an alternative source of energy to generate this heat, such as oil, coal, wind power or any other source. This alternative was considered but not included, for two reasons. The first reason is that it is likely that such systems are installed already in many places where medical waste is incinerated. And where they are installed, the system depends on the medical waste as fuel. Hence, there is no fuel that is replaced any longer. It is just PVC or HDPE based on virgin fossil fuel being incinerated.

Using more efficient production data for PVC, DEHP, HDPE and electricity

The result from the study would most likely have shown lower consumption of resources if best available, or even best current practice data would have been used all over. However, it was considered more relevant to establish an understanding of the key impact areas of consideration for the blood bags, and to quantify the different impacts and present them, than to have the latest data for all technologies.

To summarize, the goal must be to stop spending fossil resources, to seek to close the recycling loops and use less material all over.

4.5. Discussion about weighting and prioritizations

As has been presented in this chapter, the environmental impact from the different blood bags are assessed using characterization and weighting by the use of different impact assessment methods that helps highlight different aspects of the environmental impact.

In section 4.2 only carbon dioxide equivalents were to quantify the total life cycle contribution to climate change for the different alternatives. In section 4.3 three different methods were used to characterize the potential impact on human health. And in section 4.4 another three different weighting methods were used to summarize different fossil resources into one total figure for each alternative.

Since the quantification of the three impact categories necessarily are made using different category indicators, hence are quantified in different units, they are not directly comparable with each other.

Instead one needs to decide which way to summarize the result. This LCA project does not have the resources to develop and apply a systematic weighting between the different results in order to compare the environmental impacts from resource depletion, human health and climate change. Such systematic default weighting methods are included in the EPS, the Eco-indicator and the EDIP impact assessment methods. But since no single method has been applied or favored in this study, those default methods could not be applied. In fact, since the blood bags show strong differences in the three different impact categories, and since the alternatives are rather contrasting than a matter of degree or nuances, it is suggested than instead of attempting to summarize the different impact categories they should rather be held separate, as separate dimensions. The three dimensional diagram in Figure 21 represents this line of thought, a 3-axis approach.

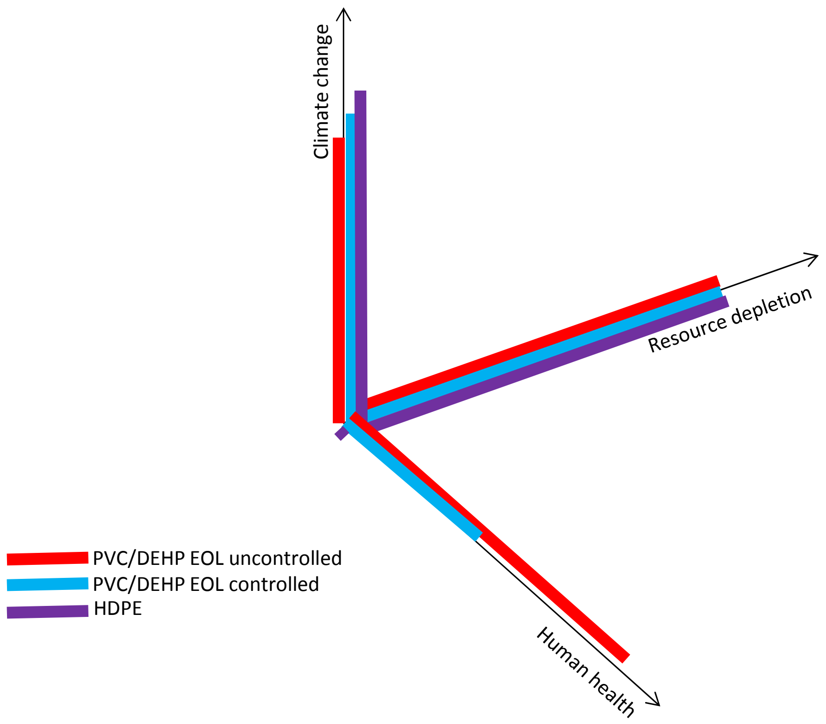

Figure 21 The different impact from the three different alternatives onto the three different impact categories presented as different dimensions in a co-ordination system, the 3-axis approach. A conceptual summary of the graphs for each alternative is indicated onto each axis.

It should be stressed that this 3-axis approach is not intended as a weighting method, but is a graphical and mental support when presenting the quantitative impact assessment onto three separate impact categories to a decision maker, such as a product developer. With the support from Figure 21 the following reasoning about prioritizations follows.

For the PVC/DEHP blood bag there are major environmental issues to consider for all three impact categories. There are practical ways to move ahead concerning depletion of natural resources and impact on climate change, i.e. by introducing more efficient recycling, bio-plastics and co-processing waste incineration and energy generation. But with regards to the many different potential impacts on human health related to the choice of chlorinated material for a blood bag, doubts should be raised as to whether it is either ethical or economical to sustain this choice of material. Questions should be asked if it PVC and DEHP are really necessary, or whether a blood bag with life cycle properties more similar to the HDPE alternative shown in this LCA study could be used instead.

If it can be proven that there is no PVC/DEHP-free alternative to all blood bags, the discussions may instead be focused on improving the blood bag management systems, for example to facilitate that different blood bags can be used for different applications, or that blood need to be stored in the same bag as they are transported. These ideas are given humbly, since the LCA practitioner is not an expert in the field of blood bags or any other medical technique or practice.

5. Interpretation and recommendations

5.1. Interpretation of the life cycle environmental impact

Figure 21 is a simple summary the overall result of the LCA comparison of the three blood bag LCA studies. The PVC/DEHP choice has a substantially higher potential impact on human health, both with regards to the overall life cycle impact and with regards to the potential health impact caused by DEHP contamination in the transfused blood. The HDPE alternative potentially has a higher impact both with regards to resource depletion and to contribution to climate change than the PVC/DEHP alternative. This is due to the higher content of hydrocarbons in the HDPE blood bag. The mixing with chloride in the PVC alternative reduces weight ratio of hydrocarbons. When comparing the two different ways to incinerate PVC/DEHP, i.e. by allowing a higher emission of dioxins or by controlling the dioxin emissions by ensuring a more effective combustion, it is concluded that this leads to a trade-off issue, where cleaning of smoke gases increases both the resource use and the contribution to climate change.

5.2. Recommendations based on the interpretation

It is an unambiguous recommendation from this study to change from the PVC/DEHP blood bag towards a blood bag based on only hydrocarbons. But it needs to be added, that this is true only if the alternative blood bag material meets all other economic and quality criteria associated with the blood bag. If it is not possible to change all blood bags in such a drastic way, it is recommended that efforts should be made to exchange as many blood bags as possible due to application, such as expected storage time, patient group or transportation needs.

Regarding the additional resource depletion introduced when using blood bags based on pure hydrocarbons, it is recommended that efforts should be taken to use recycled material when possible, to support innovative ways to material recycle medical waste, to co-generate heat while incinerating waste and in any other way save resources throughout the life cycle of the blood bag.

It is also suggested that bio-plastics may be used in this specific application if material recycling will prove impossible or too expensive. It should be noted that all the general recommendations and principles related to energy recovery, rational use of natural resources (both renewable and non-renewable) for the traditional petroleum derived materials as HDPE, etc., shall also be applied to the production of bio-plastics or any other alternative material.

5.3. Limitations of the study

The technical system boundaries are limited to the processes of material resource extraction production, manufacturing, use and waste management. Industrial dependencies with for example recycling systems or co-ordination of waste management with heat generation have been omitted. Different analyses of such alternatives would most likely have indicated that it is possible to allocate resource use and contribution to climate change to other functions in the industrial society, hence lowering the relative environmental impact from HDPE. This would not have been far from the real case. However, there is a risk that actual resource depletion and contribution to climate change are rather 'hidden' behind the mathematical elaboration of such systems dependences. Therefore, to acquire a more easily understood report, such systems dependences were cut off, and rather formulated as recommendations.

It should be noted that the electricity data is pretty old, and is basically valid as an average for the OECD-countries. This data has been applied for the electricity consumption for the compounding, the manufacturing and the use stage. Other electricity data would have downscaled all three alternatives almost the same amount. The relative impact on the three impact categories would have changed.

The Plastics Europe data was chosen because of its high quality and because it is accepted as the best data source for plastics data available. However, during the first assessments a very high value of dioxin water emissions was identified for the production of HDPE. At first this high emission was accepted, and the results were pretty hard to interpret. It gave reasons to a more close analysis of the Plastics Europe HDPE data, which identified the dioxin emission from a process where no incineration or combustion seems to occur. It was therefore concluded that this dioxin emission data must be wrong. The dioxin value was set to zero. This is a potential weakness of this study.

Except for the USEtox data, the data for the three impact assessment methods EPS, Eco-indicator and EDIP are pretty old, from the beginning of 2000. This means that some of the characterization data may have been updated or changed. However, it was decided that the changes could not be expected to result in substantially different results. It was decided to instead focus on using the new USEtox characterization data for the most sensitive parts of the study where other uncertainties may be more significant; the blood transfusion and the potential human health impact.

It should be noted that the transports have been omitted from the calendaring stage to then end of life stage. This means that this study is not valid for comparisons of, for example, different geographical location of different producers of blood bags.

The handlings of hazardous waste from the incineration processes are omitted. This would particularly add to the environmental impact from the scenario PVC EOL Uncontrolled, since the less efficient combustion would also lead to a higher amount of dioxins and other chlorinated substances in the ashes. Hence, inclusion of waste management would rather increase the already high contrast of the result.

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Annex A, The life cycle inventory database

The life cycle inventory database is presented separately in a separate library of MS Excel files made available by the publisher of this report.

The list of references used to establish this life cycle inventory database is shown under the separate section *LCI database references* in the *References* section of this report.

Annex B, the LCI profiles

PVC/DEHP blood bag with controlled incineration

Table A1 LCI profile of the PVC/DEHP blood bag with controlled incineration

CLIMATE CHANGE					
Output	Emission	Carbon dioxide	2,02E+00	kg	Air
Output	Emission	Methane	4,51E-03	kg	Air
Output	Emission	Nitrous Oxide	1,51E-05	kg	Air
Output	Emission	HCFCs and HFC	1,09E-08	kg	Air
TOXICITY					
Output	Emission	Dichloroethane	1,06E-05	kg	Air
Output	Emission	Dioxin	2,65E-13	kg	Air
Output	Emission	Dichloromethane	4,73E-09	kg	Air
Output	Emission	Phthalates	1,87E-07	kg	Air
Output	Emission	Vinyl chloride monomer	4,23E-06	kg	Air
Output	Emission	Adult transfusion exposure	3,28E-04	kg	Human
Output	Emission	Dichloroethane	2,31E-08	kg	Water
Output	Emission	Dioxin	1,39E-14	kg	Water
Output	Emission	Vinyl chloride monomer	6,33E-08	kg	Water
RESOURCE USE					
Input	Natural resource	Oil fuels	1,03E-01	kg	Ground
Input	Natural resource	Coal	9,25E-01	kg	Ground
Input	Natural resource	Natural gas	9,63E-02	m3	Ground

Table A2 Division of natural resource oil into feedstock and as fuel energy to processes and transports

Natural resource oil onto feedstock energy	4,30E-02	kg
Natural resource oil for other processes	5,98E-02	kg

TableA3 Division of CO2-emissions from incineration of waste PVC/DEHP waste and from combustion of fuels from processes and transports

CO2 emissions from incineration of waste	2,86E-01	kgCO2e
CO2 emissions from other processes	1,84E+00	kgCO2e

PVC/DEHP blood bag with Uncontrolled incineration

Table A4 LCI profile of the PVC/DEHP blood bag with Uncontrolled incineration

CLIMATE CHANGE					
Output	Emission	Carbon dioxide	1,91E+00	kg	Air
Output	Emission	Methane	4,51E-03	kg	Air
Output	Emission	Nitrous Oxide	1,51E-05	kg	Air
Output	Emission	HCFCs and HFC	1,09E-08	kg	Air
TOXICITY					
Output	Emission	Dichloroethane	1,06E-05	kg	Air
Output	Emission	Dioxin	1,18E-11	kg	Air
Output	Emission	Dichloromethane	4,73E-09	kg	Air
Output	Emission	Phthalates	1,87E-07	kg	Air
Output	Emission	Vinyl chloride monomer	4,23E-06	kg	Air
Output	Emission	Adult transfusion exposure	3,28E-04	kg	Human
Output	Emission	Dichloroethane	2,31E-08	kg	Water
Output	Emission	Dioxin	1,39E-14	kg	Water
Output	Emission	Vinyl chloride monomer	6,33E-08	kg	Water
RESOURCE USE					
Input	Natural resource	Oil fuels	7,41E-02	kg	Ground
Input	Natural resource	Coal	9,25E-01	kg	Ground
Input	Natural resource	Natural gas	9,63E-02	m3	Ground

Table A5 Division of natural resource oil into feedstock and as fuel energy to processes and transports

Natural resource oil onto feedstock energy	4,30E-02	kg
Natural resource oil for other processes	3,10E-02	kg

Table A6 Division of CO2-emissions from incineration of waste PVC/DEHP waste and from combustion of fuels from processes and transports

CO2 emissions from incineration of waste	1,68E-01	kgCO2e
CO2 emissions from other processes	1,84E+00	kgCO2e

High Density Polyethylene blood bag

Table A7 LCI profile of the High Density Polyethylene blood bag

CLIMATE CHANGE					
Output	Emission	Carbon dioxide	2,06E+00	kg	Air
Output	Emission	Methane	5,39E-03	kg	Air
Output	Emission	Nitrous Oxide	1,17E-05	kg	Air
Output	Emission	HCFCs and HFC	1,05E-08	kg	Air
TOXICITY					
Output	Emission	Dichloroethane	9,90E-10	kg	Air
Output	Emission	Dioxin	7,17E-14	kg	Air
Output	Emission	Dichloromethane	1,07E-09	kg	Air
Output	Emission	Phthalates	0,00E+00	kg	Air
Output	Emission	Vinyl chloride monomer	2,12E-10	kg	Air
Output	Emission	Adult transfusion exposure	0,00E+00	kg	Human
Output	Emission	Dichloroethane	5,18E-14	kg	Water
Output	Emission	Dioxin	0,00E+00	kg	Water
Output	Emission	Vinyl chloride monomer	9,46E-13	kg	Water
RESOURCE USE					
Input	Natural resource	Oil fuels	1,40E-01	kg	Ground
Input	Natural resource	Coal	8,91E-01	kg	Ground
Input	Natural resource	Natural gas	9,28E-02	m3	Ground

Table A8 Division of natural resource oil into feedstock and as fuel energy to processes and transports

Natural resource oil onto feedstock ene	1,00E-01	kg
Natural resource oil for other processes	4,00E-02	kg

Table A9 Division of CO2-emissions from incineration of waste PVC/DEHP waste and from combustion of fuels from processes and transports

CO2 emissions from incineration of waste	3,90E-01	kgCO2e
CO2 emissions from other processes	1,79E+00	kgCO2e

Comparison of PVC/DEHP (controlled incineration) and HDPE blood bags

Tabell A10 Comparing LCI profiles of PVC/DEHP (controlled incineration) and HDPE blood bags

CLIMATE CHANGE					
Output	Emission	Carbon dioxide	-2,13E-01	kg	Air
Output	Emission	Methane	-8,83E-04	kg	Air
Output	Emission	Nitrous Oxide	3,40E-06	kg	Air
Output	Emission	HCFCs and HFC	4,01E-10	kg	Air
TOXICITY					
Output	Emission	Cl2	1,16E-07	kg	Air
Output	Emission	Dichloroethane	1,06E-05	kg	Air
Output	Emission	Dioxin	1,93E-13	kg	Air
Output	Emission	HCl	9,69E-06	kg	Air
Output	Emission	Dichloromethane	3,66E-09	kg	Air
Output	Emission	Phthalates	1,87E-07	kg	Air
Output	Emission	Polyvinyl chloride	7,38E-09	kg	Air
Output	Emission	Vinyl chloride mor	4,23E-06	kg	Air
Output	Emission	Other organo chlo	1,55E-10	kg	Air
Output	Emission	Adult transfusion e	3,28E-04	kg	Human
Output	Emission	Chlorine	3,90E-03	kg	Water
Output	Emission	Dichloroethane	2,31E-08	kg	Water
Output	Emission	Dioxin	-9,69E-11	kg	Water
Output	Emission	Vinyl chloride mor	6,33E-08	kg	Water
Output	Emission	Other organo chlo	2,49E-07	kg	Water
RESOURCE USE					
Input	Natural resource	Bio fuels	-1,53E-03	kg	Ground
Input	Natural resource	Oil fuels	-3,94E-02	kg	Ground
Input	Natural resource	Coal	3,40E-02	kg	Ground
Input	Natural resource	Natural gas	3,54E-03	m3	Ground

Comparison of PVC/DEHP controlled vs uncontrolled incinerations

Tabell A11 Comparing LCI profiles of PVC/DEHP Controlled vs Uncontrolled waste incineration

CLIMATE CHANGE					
Output	Emission	Carbon dioxide	6,52E-07	kg	Air
Output	Emission	Methane	0,00E+00	kg	Air
Output	Emission	Nitrous Oxide	0,00E+00	kg	Air
Output	Emission	HCFCs and HFC	0,00E+00	kg	Air
TOXICITY			0,00E+00		
Output	Emission	Cl2	0,00E+00	kg	Air
Output	Emission	Dichloroethane	0,00E+00	kg	Air
Output	Emission	Dioxin	1,15E-11	kg	Air
Output	Emission	HCl	8,61E-05	kg	Air
Output	Emission	Dichloromethane	0,00E+00	kg	Air
Output	Emission	Phthalates	0,00E+00	kg	Air
Output	Emission	Polyvinyl chloride	0,00E+00	kg	Air
Output	Emission	Vinyl chloride mor	0,00E+00	kg	Air
Output	Emission	Other organo chlo	0,00E+00	kg	Air
Output	Emission	Adult transfusion e	0,00E+00	kg	Human
Output	Emission	Chlorine	0,00E+00	kg	Water
Output	Emission	Dichloroethane	0,00E+00	kg	Water
Output	Emission	Dioxin	0,00E+00	kg	Water
Output	Emission	Vinyl chloride mor	0,00E+00	kg	Water
Output	Emission	Other organo chlo	0,00E+00	kg	Water
RESOURCE USE			0,00E+00		
Input	Natural resource	Bio fuels	0,00E+00	kg	Ground
Input	Natural resource	Oil fuels	0,00E+00	kg	Ground
Input	Natural resource	Coal	0,00E+00	kg	Ground
Input	Natural resource	Natural gas	0,00E+00	m3	Ground

Annex C Impact assessment data

Table C1 Carbon dioxide equivalents, based on 100 years from IPCC publication.

IPCC			
CO2	1	kgCO2eq/kg	
CH4	21	kgCO2eq/kg	
N2O	310	kgCO2eq/kg	
HCFC	1500	kgCO2eq/kg	

Other characterization factors used is presented in the Excel files database library published together with this report.

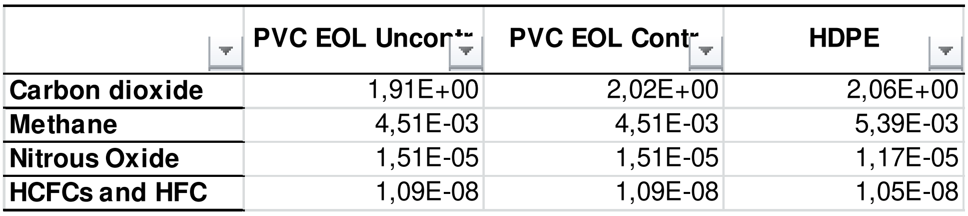
Annex D Calculated tables

Tables representing diagrams shown for climate change gases in section 3.3.1

Table D1 Comparing carbon dioxide emissions from the three alternatives for the key different processes.

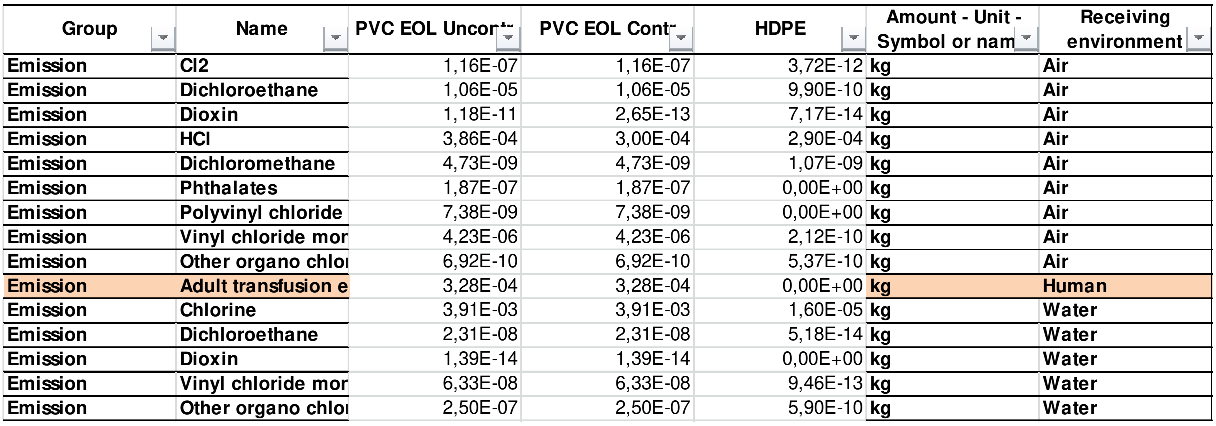
	PVC EOL Uncontr	PVC EOL Contr	HDPE
Prod s-PVC	1,0E-01	1,0E-01	0,0E+00
Production DEHP	5,7E-02	5,7E-02	0,0E+00
CaZn	3,0E-03	3,0E-03	0,0E+00
Prod High Density PE	5,6E-03	5,6E-03	1,6E-01
EOL	1,7E-01	2,9E-01	3,9E-01
Total	3,4E-01	4,5E-01	5,5E-01

Table D2. The greenhouse gases emitted from the life cycles of the different alternatives.



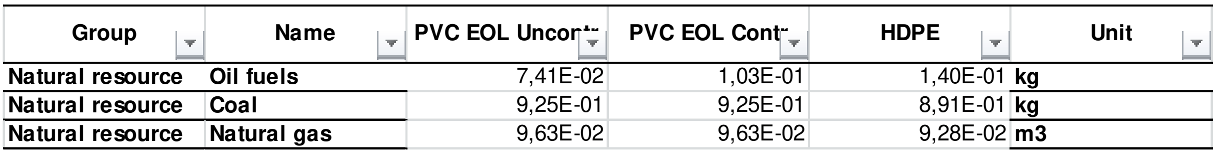
	PVC EOL Uncon	PVC EOL Cont	HDPE
Carbon dioxide	1,91E+00	2,02E+00	2,06E+00
Methane	4,51E-03	4,51E-03	5,39E-03
Nitrous Oxide	1,51E-05	1,51E-05	1,17E-05
HCFCs and HFC	1,09E-08	1,09E-08	1,05E-08

Table D3. The most significant emissions of chlorinated substances to air.



Group	Name	PVC EOL Uncon	PVC EOL Cont	HDPE	Amount - Unit - Symbol or nam	Receiving environment
Emission	Cl2	1,16E-07	1,16E-07	3,72E-12	kg	Air
Emission	Dichloroethane	1,06E-05	1,06E-05	9,90E-10	kg	Air
Emission	Dioxin	1,18E-11	2,65E-13	7,17E-14	kg	Air
Emission	HCl	3,86E-04	3,00E-04	2,90E-04	kg	Air
Emission	Dichloromethane	4,73E-09	4,73E-09	1,07E-09	kg	Air
Emission	Phthalates	1,87E-07	1,87E-07	0,00E+00	kg	Air
Emission	Polyvinyl chloride	7,38E-09	7,38E-09	0,00E+00	kg	Air
Emission	Vinyl chloride mor	4,23E-06	4,23E-06	2,12E-10	kg	Air
Emission	Other organo chlo	6,92E-10	6,92E-10	5,37E-10	kg	Air
Emission	Adult transfusion e	3,28E-04	3,28E-04	0,00E+00	kg	Human
Emission	Chlorine	3,91E-03	3,91E-03	1,60E-05	kg	Water
Emission	Dichloroethane	2,31E-08	2,31E-08	5,18E-14	kg	Water
Emission	Dioxin	1,39E-14	1,39E-14	0,00E+00	kg	Water
Emission	Vinyl chloride mor	6,33E-08	6,33E-08	9,46E-13	kg	Water
Emission	Other organo chlo	2,50E-07	2,50E-07	5,90E-10	kg	Water

Table D4. The consumption of fossil fuel for the three alternatives.



Group	Name	PVC EOL Uncon	PVC EOL Cont	HDPE	Unit
Natural resource	Oil fuels	7,41E-02	1,03E-01	1,40E-01	kg
Natural resource	Coal	9,25E-01	9,25E-01	8,91E-01	kg
Natural resource	Natural gas	9,63E-02	9,63E-02	9,28E-02	m3

Table D5. Division of fossil oil as fuel and as feedstock.

	PVC EOL Uncontrolled	PVC EOL Controlled	HDPE	
Natural resource oil onto feedstock energy	0,04	0,04	0,10	kg
Natural resource oil for other processes	0,03	0,06	0,04	kg

Table D6. Climate change contribution, emission data calculated into CO2-equivalents in the rightmost column with IPCC data from table C1.

				PVC EOL Uncontr	PVC EOL Contr.	HDPE			**2,179245**
Calendering	Output	Emission	Carbon dioxide	2,2E-06	2,2E-06	2,2E-06	kg	Air	2,21E-06
EOL Other waste	Output	Emission	CO2	0,0E+00	0,0E+00	0,0E+00	kg	Air	0,00E+00
EOL HDPE	Output	Emission	CO2	0,0E+00	2,9E-01	3,9E-01	kg	Air	3,90E-01
EOL PVC Uncontrolled	Output	Emission	CO2	1,7E-01	0,0E+00	0,0E+00	kg	Air	0,00E+00
HDPE	Output	Emission	CO2	5,6E-03	5,6E-03	1,6E-01	kg	Air	1,60E-01
s-PVC	Output	Emission	CO2	1,0E-01	1,0E-01	0,0E+00	kg	Air	0,00E+00
CaZn	Output	Emission	CO2	3,0E-03	3,0E-03	0,0E+00	kg	Air	0,00E+00
Electricity OECD	Output	Emission	CO2	1,6E+00	1,6E+00	1,5E+00	kg	Air	1,51E+00
DEHP	Output	Emission	CO2	5,7E-02	5,7E-02	0,0E+00	kg	Air	0,00E+00
TOTAL	**Output**	**Emission**	**Carbon dioxide**	**1,9E+00**	**2,0E+00**	**2,1E+00**	**kg**	**Air**	2,06E+00
HDPE	Output	Emission	CH4	5,0E-05	5,0E-05	1,5E-03	kg	Air	3,05E-02
s-PVC	Output	Emission	CH4	2,3E-04	2,3E-04	0,0E+00	kg	Air	0,00E+00
DEHP	Output	Emission	Methane	1,4E-04	1,4E-04	0,0E+00	kg	Air	0,00E+00
EOL Other waste	Output	Emission	Methane	0,0E+00	0,0E+00	0,0E+00	kg	Air	0,00E+00
Electricity OECD	Output	Emission	Methane	4,1E-03	4,1E-03	3,9E-03	kg	Air	8,28E-02
TOTAL	**Output**	**Emission**	**Methane**	**4,5E-03**	**4,5E-03**	**5,4E-03**	**kg**	**Air**	1,13E-01
DEHP	Output	Emission	N20	6,2E-08	6,2E-08	0,0E+00	kg	Air	0,00E+00
HDPE	Output	Emission	N2O	2,8E-15	2,8E-15	8,1E-14	kg	Air	2,51E-11
s-PVC	Output	Emission	N2O	2,9E-06	2,9E-06	0,0E+00	kg	Air	0,00E+00
Electricity OECD	Output	Emission	N2O	1,2E-05	1,2E-05	1,2E-05	kg	Air	3,61E-03
TOTAL	**Output**	**Emission**	**Nitrous Oxide**	**1,5E-05**	**1,5E-05**	**1,2E-05**	**kg**	**Air**	3,61E-03
Electricity OECD	Output	Emission	HCFC-21	9,4E-09	9,4E-09	9,1E-09	kg	Air	1,36E-05
Electricity OECD	Output	Emission	HCFC-22	1,5E-09	1,5E-09	1,4E-09	kg	Air	2,17E-06
Electricity OECD	Output	Emission	HFC-134a	-3,6E-21	-3,6E-21	-3,5E-21	kg	Air	-5,25E-18
TOTAL	**Output**	**Emission**	**HCFCs and HFC**	**1,1E-08**	**1,1E-08**	**1,1E-08**	**kg**	**Air**	1,58E-05

Table D7. Human health impact assessment calculations, based on impact assessment data presented in Annex C.

Process	Emission	PVC Uncontr.	PVC Contr.	HDPE	Unit	Media	PVC Uncontr.			PVC Contr.			HDPE		
							Eco-ind.	*EDIP*	*USEtox*	*Eco-ind.*	*EDIP*	*USEtox*	*Eco-ind.*	*EDIP*	*USEtox*
							1,39E-07	*7,05E+00*	*1,57E-11*						
HDPE	dichloroethane (DCE) C2H4Cl2	9,0E-14	9,0E-14	2,6E-12	kg	Air		9,0E-11	2,9E-20		9,0E-11	2,9E-20		3E-09	8,5E-19
s-PVC	dichloroethane (DCE) C2H4Cl2	1,1E-05	1,1E-05	0,0E+00	kg	Air		1,1E-02	3,4E-12		1,1E-02	3,4E-12		0	0
Electricity OECD	1,2-Dichloroethane	1,0E-09	1,0E-09	9,9E-10	kg	Air		1,0E-06	3,3E-16		1,0E-06	3,3E-16		1E-06	3,2E-16
TOTAL	**Dichloroethane**	**1,1E-05**	**1,1E-05**	**9,9E-10**	**kg**	**Air**		1,1E-02	3,4E-12		1,1E-02	3,4E-12		1E-06	3,2E-16
EOL Other waste	Dioxin	0,0E+00	0,0E+00	0,0E+00	kg	Air	0,0E+00	0,0E+00		0,0E+00	0,0E+00		0	0	
HDPE	dioxin/furan as Teq	1,1E-34	1,1E-34	3,2E-33	kg	Air	1,3E-30	6,7E-23		1,3E-30	6,7E-23		3,76E-29	2E-21	
s-PVC	dioxin/furan as Teq	2,5E-15	2,5E-15	0,0E+00	kg	Air	2,9E-11	1,5E-03		2,9E-11	1,5E-03		0	0	
Electricity OECD	Dioxin (TCDD)	7,4E-14	7,4E-14	7,2E-14	kg	Air	8,6E-10	4,4E-02		8,6E-10	4,4E-02		8,32E-10	0,043	
EOL PVC Uncontrolled	Total CDD	1,5E-12	4,0E-14	0,0E+00	kg	Air	1,7E-08	8,7E-01		4,6E-10	2,4E-02		0	0	
EOL PVC Uncontrolled	Total CDF	1,0E-11	1,5E-13	0,0E+00	kg	Air	1,2E-07	6,1E+00		1,7E-09	8,8E-02		0	0	
TOTAL	**Dioxin**	**1,2E-11**	**2,7E-13**	**7,2E-14**	**kg**	**Air**	1,4E-07	7,0E+00		3,1E-09	1,6E-01		8,32E-10	0,043	
HDPE	methylene chloride CH2Cl2	1,0E-16	1,0E-16	3,0E-15	kg	Air	4,0E-21			4,0E-21			1,14E-19		
s-PVC	methylene chloride CH2Cl2	3,6E-09	3,6E-09	0,0E+00	kg	Air	1,4E-13			1,4E-13			0		
Electricity OECD	Dichloromethane	1,1E-09	1,1E-09	1,1E-09	kg	Air	4,2E-14			4,2E-14			4,03E-14		
TOTAL	**Dichloromethane**	**4,7E-09**	**4,7E-09**	**1,1E-09**	**kg**	**Air**	1,8E-13			1,8E-13			4,03E-14		
DEHP	Phthalate esters (unspecified)	2,2E-10	2,2E-10	0,0E+00	kg	Air	4,8E-13		9,8E-17	4,8E-13		9,8E-17	0		0
DEHP	Phthalic anhydride	1,9E-07	1,9E-07	0,0E+00	kg	Air	4,1E-10		8,3E-14	4,1E-10		8,3E-14	0		0
TOTAL	**Phthalates**	**1,9E-07**	**1,9E-07**	**0,0E+00**	**kg**	**Air**	4,1E-10		8,3E-14	4,1E-10		8,3E-14	0		0
Calendering	Polyvinyl chloride	7,4E-09	7,4E-09	0,0E+00	kg	Air									
TOTAL	**Polyvinyl chloride**	**7,4E-09**	**7,4E-09**	**0,0E+00**	**kg**	**Air**									
DEHP	VCM	5,9E-16	5,9E-16	0,0E+00	kg	Air	8,0E-21		1,7E-21	8,0E-21		1,7E-21	0		0
HDPE	vinyl chloride monomer (VCM)	1,8E-12	1,8E-12	5,1E-11	kg	Air	2,4E-17		5,1E-18	2,4E-17		5,1E-18	6,98E-16		1,5E-16
s-PVC	vinyl chloride monomer (VCM)	4,2E-06	4,2E-06	0,0E+00	kg	Air	5,8E-11		1,2E-11	5,8E-11		1,2E-11	0		0
Electricity OECD	Vinyl chloride	1,7E-10	1,7E-10	1,6E-10	kg	Air	2,3E-15		4,8E-16	2,3E-15		4,8E-16	2,19E-15		4,6E-16
TOTAL	**Vinyl chloride monomer**	**4,2E-06**	**4,2E-06**	**2,1E-10**	**kg**	**Air**	5,8E-11		1,2E-11	5,8E-11		1,2E-11	2,89E-15		6E-16
Use	Adult transfusion exposure	3,3E-04	3,3E-04	0,0E+00	kg	Human			1,3E-06			1,3E-06			0
TOTAL	**Adult transfusion exposure**	**3,3E-04**	**3,3E-04**	**0,0E+00**	**kg**	**Human**			1,3E-06			1,3E-06			0
HDPE	dichloroethane (DCE)	1,8E-15	1,8E-15	5,2E-14	kg	Water		9,7E-14	1,1E-21		9,7E-14	1,1E-21		3E-12	3E-20
s-PVC	dichloroethane (DCE)	2,3E-08	2,3E-08	0,0E+00	kg	Water		1,2E-06	1,4E-14		1,2E-06	1,4E-14		0	0
TOTAL	**Dichloroethane**	**2,3E-08**	**2,3E-08**	**5,2E-14**	**kg**	**Water**		1,2E-06	1,4E-14		1,2E-06	1,4E-14		3E-12	3E-20
HDPE	dioxin/furan as Teq	0,0E+00	0,0E+00	0,0E+00	kg	Water	0,0E+00	0,0E+00		0,0E+00	0,0E+00		0	0	
s-PVC	dioxin/furan as Teq	1,4E-14	1,4E-14	0,0E+00	kg	Water	1,8E-09	5,0E-02		1,8E-09	5,0E-02		0	0	
TOTAL	**Dioxin**	**1,4E-14**	**1,4E-14**	**0,0E+00**	**kg**	**Water**	1,8E-09	5,0E-02		1,8E-09	5,0E-02		0	0	
DEHP	VCM	1,9E-32	1,9E-32	0,0E+00	kg	Water	3,4E-37		4,8E-38	3,4E-37		4,8E-38	0		0
HDPE	vinyl chloride monomer (VCM)	3,3E-14	3,3E-14	9,5E-13	kg	Water	6,0E-19		8,4E-20	6,0E-19		8,4E-20	1,74E-17		2,4E-18
s-PVC	vinyl chloride monomer (VCM)	6,3E-08	6,3E-08	0,0E+00	kg	Water	1,2E-12		1,6E-13	1,2E-12		1,6E-13	0		0
TOTAL	**Vinyl chloride monomer**	**6,3E-08**	**6,3E-08**	**9,5E-13**	**kg**	**Water**	1,2E-12		1,6E-13	1,2E-12		1,6E-13	1,74E-17		2,4E-18

Table D8. Natural resource depletion, quantified in terms of the category indicator fossil fuels, using the impact assessment methods EPS, Eco-indicator and EDIP

						PVC Uncontr.			PVC Contr.			HDPE		
Process	**Resource**	**PVC Uncontr.**	**PVC Contr.**	**HDPE**	**Unit**	EPS	Eco-ind	EDIP	EPS	Eco-ind	EDIP	EPS	Eco-ind	EDIP
						1,2E-01	7,6E-05	8,1E-06	1,4E-01	9,6E-05	9,2E-06	1,2E-01	1,8E-04	1,9E-05
Calendering	Oil fuels	4,7E-04	4,7E-04	4,7E-04	kg	2,4E-04	3,3E-07	1,8E-08	2,4E-04	3,3E-07	1,8E-08	2,4E-04	3,3E-07	1,8E-08
DEHP	Oil fuels	2,3E-02	2,3E-02	0,0E+00	kg	1,1E-02	1,6E-05	8,9E-07	1,1E-02	1,6E-05	8,9E-07	0,0E+00	0,0E+00	0,0E+00
HDPE	Oil fuels	3,1E-03	3,1E-03	9,1E-02	kg	1,6E-03	2,2E-06	1,2E-07	1,6E-03	2,2E-06	1,2E-07	4,6E-02	6,4E-05	3,5E-06
s-PVC	Oil fuels	2,5E-02	2,5E-02	0,0E+00	kg	1,3E-02	1,7E-05	9,7E-07	1,3E-02	1,7E-05	9,7E-07	0,0E+00	0,0E+00	0,0E+00
Electricity OECD	Oil fuels	1,2E-02	1,2E-02	1,2E-02	kg	6,2E-03	8,7E-06	4,8E-07	6,2E-03	8,7E-06	4,8E-07	6,0E-03	8,3E-06	4,6E-07
EOL HDPE	Oil fuels	1,1E-02	3,9E-02	3,7E-02	kg	5,4E-03	7,5E-06	4,1E-07	2,0E-02	2,8E-05	1,5E-06	1,9E-02	2,6E-05	1,4E-06
TOTAL	**Oil fuels**	7,4E-02	**1,0E-01**	**1,4E-01**	**kg**	3,7E-02	5,2E-05	2,9E-06	5,2E-02	7,2E-05	4,0E-06	7,1E-02	9,8E-05	5,5E-06
Electricity OECD	Hard coal	6,6E-01	6,6E-01	6,3E-01	kg	3,3E-02	2,0E-05	6,6E-06	3,3E-02	2,0E-05	6,6E-06	3,2E-02	1,9E-05	6,3E-06
Electricity OECD	Lignite	2,7E-01	2,7E-01	2,6E-01	kg	1,3E-02	8,0E-06	2,7E-06	1,3E-02	8,0E-06	2,7E-06	1,3E-02	7,7E-06	2,6E-06
TOTAL	**Coal**	9,3E-01	**9,3E-01**	**8,9E-01**	**kg**	4,6E-02	2,8E-05	9,3E-06	4,6E-02	2,8E-05	9,3E-06	4,4E-02	2,7E-05	8,9E-06
Electricity OECD	Natural gas	9,6E-02	9,6E-02	9,3E-02	Nm3	1,1E-01	6,0E-05	5,0E-06	1,1E-01	6,0E-05	5,0E-06	1,0E-01	5,8E-05	4,8E-06
TOTAL	**Natural gas**	9,6E-02	**9,6E-02**	**9,3E-02**	**m3**	0,0E+00	6,0E-05	5,0E-06	0,0E+00	6,0E-05	5,0E-06	0,0E+00	5,8E-05	4,8E-06