Life Cycle Assessment

Of PVC with MCCP

By European producers of PVC cable

Title: Life Cycle Assessment of PVC cable insulation with MCCP and alternatives.
Date: 07/09/2021
Ordered by: Intertek Denmark
Report number: 924
Name of database: MiljogiraffUpdate911

MILJÖGIRAFF

Table of Content

Ordered by: *Intertek Denmark*

Intertek Denmark, www.intertek.com, Vesterbrogade 74, 2. floor, Copenhagen, Denmark, Health, Environmental & Regulatory Services (HERS). Torben Norlem, CHIEF COUNSEL, torben.norlem@intertek.com, +45 2057 7975

Issued by: Miljögiraff AB

Miljögiraff is an environmental consultant specialised in Life Cycle Assessment and Ecodesign. We think that it is a combination of analysis and creativity needed to meet today's challenges. Therefore, we provide Life Cycle Analysis for the evaluation of environmental aspects and design methods for the development of sustainable solutions.

We create measurability in environmental work based on a life cycle perspective on environmental aspects. The LCA methodology establishes the basis for modelling complex systems of aspects with a credible assessment of potential environmental effects.

Miljögiraff is part of a global network of experts in sustainability metrics, piloted by PRé Sustainability.

Abbreviations and expressions

Clarification of expressions and abbreviations used in the report

CO2eq – Carbon dioxide equivalents

EPD – Environmental Product Declaration

GWP – Global Warming Potential

ISO – International Organization for Standardization

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory Analysis

LCIA – Life Cycle Impact Assessment

PCR - Product Category Rules

Environmental aspect - An activity that might contribute to an environmental effect, for example, “electricity usage”.

Environmental effect - An outcome that might influence the environment negatively (Environmental impact), for example, “Acidification”, “Eutrophication” or “Climate change”.

Environmental impact - The damage on a safeguarding object (i.e., human health, ecosystems, health and natural resources).

Life Cycle Inventory (LCI) data – Inventory of input and output flows for a product system

Abstract

Intertek Denmark has assigned Miljögiraff this Life Cycle Assessment of PVC cable insulation with MCCP and alternatives. The report presents the environmental footprint for PVC with MCCP produced by PVC cable manufacturers in Europe from a life cycle perspective using the ISO 14040 standard approach.

The purpose was to ensure a successful submission of the application for RoHS exemption application for use of the substances Medium chain chlorinated paraffins (hereafter: MCCP) used in PVC electrical cable insulation. MCCP is used as plasticer and flameretardent in PVC cables. It is being restricted due to the toxic risks associated with its release to the environment. No realistic alternatives are available and a longer period of development is required.

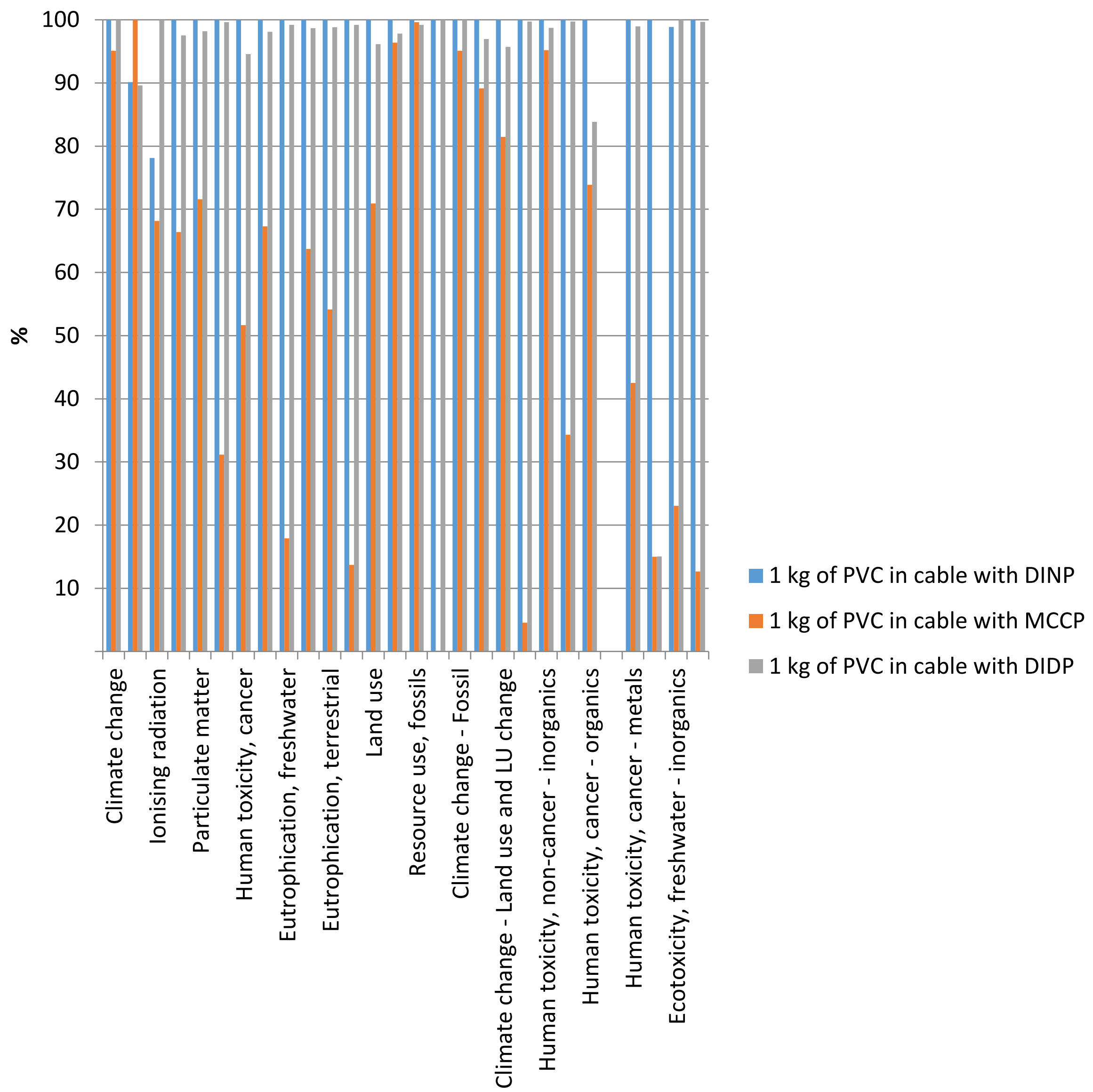
The data on the environmental aspects was collected via a survey to manufacturers and via search in commercial databases and literature.

A survey of 10 large manufacturers of PVC for cables was made by Intertek[1] to know what plastizer and flameretardent, that are used and how they perceive the implications for the shift to other solutions than the restricted chemicals. The same companies was approached with a survey to collect information on the environmental aspects required for this LCA. But none of them decided to answer.

It is assumed that the environmental aspects of manufacturing is similar regardless of the choice of plastizer and flameretardent. This assumption is based on answers from the same survey where responses are that the necessary requirements already taken to handle MCCP, will be sufficient also for the alternatives. So the comparison may be fair anyway.

The comparison indicate that MCCP has lower environmental impact than the alternatives, in all categories of impact categories.
The available information was limited from the manufacturers of PVC insulation and also for the alternatives to MCCP. Some assumptions are made that have relevant uncertainties. Especially the amount of Flame retardant used.
The information about MCCP shows clearly that the dominant aspects are production of raw material Chlorine and Paraffin. In order to reduce the risk of MCCP ending up in the ecosystems, it is critical to have strict control over the end of life of PVC insulated cables with MCCP.

[1] Filename ” 2020_MCCP_questionnaire_summary_1”



Comparing 1 p '1 kg of PVC in cable with DINP', 1 p '1 kg of PVC in cable with MCCP' and 1 p '1 kg of PVC in cable with DIDP';
Method: EF 3.0 Method (adapted) V1.00 / EF 3.0 normalization and weighting set / Characterization

1 Introduction

The report presents the total environmental footprint for PVC with MCCP produced by PVC cable manufacturers in Europe from a life cycle perspective using the ISO 14040 standard approach. The LCA approach harmonises with the Product Environmental Footprint Category Rules published 12 February 2019.

The purpose is to have a basis for application of excemption with the ROHS directive.
MCCP is used as plasticer and flameretardent in PVC cables. It is being restricted due to the toxic risks associated with its release to the environment. No realistic alternatives are available and a longer period of development is required. The purpose was to ensure a successful submission of the application for RoHS exemption application for use of the substances Medium chain chlorinated paraffins (hereafter: MCCP) used in PVC electrical cable insulation.

1.1 General description of context

Samani and van der Meer (2020) LCA studies on flame retardants - A systematic review

A description of 2.2. Chlorinated FR (CFR). The most common type of CFRs (currently on the EU market are chlorinated paraffins (CPs) in the form of middle chain chlorinated paraffins (MCCPs). CPs are commonly used as FR and plasticizers in polyvinyl chloride (PVC) products globally. The release of halogen atoms into the gaseous phase prevents the material to reach the ignition temperature and contributes to retarding of polymer burning.

The Council Regulation 793/93/EEC has labeled MCCPs as dangerous substances and the WFD has listed all CPs as “priority substances” for risk assessment. The Convention for the Protection of the Marine Environment of the North-East Atlantic-OSPAR also monitors MCCPs (and LCCP)(Nyström, 2019). On the other hand, these substances are used as FRs and plasticizers in the other parts of the world without any noteworthy control or prohibition. At the moment, China, Russia and India are the main producers and consumers of MCCPs in the near future (Kobeticova; Cerný, 2018). However, China has also initiated “management methods for the restriction of the use of hazardous substances in electrical and electronic products” in 2016 (PINFA, 2017).

According to the official EU classification MCCP is classified[2] as very toxic to aquatic life with long lasting effects and may cause harm to breast-fed children - MCCP is not classified as carcinogenic and classification as carcinogenic is also not required for categorization as a POP substance (Persisten Organic Polutants as defined in the Stockholm Convention on POPs) as this can also be based on other adverse effects (e.g. allergenic or hypersensitivity properties),
cf. http://chm.pops.int/TheConvention/ThePOPs/tabid/673/Default.aspx .

1.2 General description of product

MCCP is used as plasticer and flameretardent in PVC cables. The alternative DINP and DIDP are also being assessed. Other alternatives that have not been included is Magnesium hydroxide and Aluminium hydroxide.

[2] https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/94445

2 Life Cycle Assessment

The importance of potential environmental impacts associated with the manufacturing and use of products is continuously increasing. A system perspective is required in finding the best environmental strategy for product and business development. That is the reason for the development of methods to better understand and address these impacts. The method for this is Life Cycle Assessment (LCA). It provides the backbone for strategies, management and communication of environmental issues related to products. Different approaches are combined in plans for the development of product and business model (Wendin & Jakobsson, 2019)

The purpose is sustainable development. From a system perspective on products, the circularity of materials and energy is how the system can perpetuate. All incoming and outgoing flows of environmental aspects are considered, and the relevant are measured. When combined in a complete system model, the LCA can be calculated to have the environmental impacts per functional unit, that allows for comparison.

Figure 1: The concept of Life Cycle Assessment.

LCA can assist in;

- identifying opportunities to improve the environmental performance of products at various points in their life cycle,
- informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign),
- the selection of relevant indicators of environmental performance, including measurement techniques,
- marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration).

Some terms are used in the method, that requires clarification:

Environmental aspect - An activity that might contribute to an environmental effect, for example, “electricity usage”.
Environmental effect - An outcome that might influence the environment negatively (Environmental impact), for example, “Acidification”, “Eutrophication” or “Climate change”.

Environmental impact - The damage on a safeguarding object (i.e. human health, ecosystems, health and natural resources).

LCA addresses the environmental aspects and potential environmental impacts) (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

A major part of the environmental impact of a product depends on choices taken during the product development phase, e.g. materials, processes, functionality etc. The basic principles for abatement come from the discipline of cleaner technology, is defined in the concept of Integrated Product Policy (IPP) as:

"All products cause environmental degradation in some way, whether from their manufacturing, use or disposal. LCA management seeks to minimise these by looking at all phases of a products' life-cycle and taking action where it is most effective.
The life-cycle of a product is often long and complicated. It covers all the areas from the extraction of natural resources, through their design, manufacture, assembly, marketing, distribution, sale and use to their eventual disposal as waste. At the same time it also involves many different actors such as designers, industry, marketing people, retailers and consumers. LCA management attempts to stimulate each part of these individual phases to improve their environmental performance.
With so many different products and actors there cannot be one simple policy measure for everything. Instead there are a whole variety of tools - both voluntary and mandatory - that can be used to achieve this objective."

Miljögiraff combines the confidence and objectiveness of the strong and accepted ISO standard, with the scientific and reliable LCI data from ecoinvent and with the world leading LCA software SimaPro for calculation and modeling.

Figure 2, ISO standard combined with reliable data from Ecoinvent and the LCA software SimaPro.

2.1 Limitations

The broad scope of analysing a whole life cycle of a product and the holistic approach can only be achieved at the expense of simplifying some aspects. Thus, the following limitations have to be taken into account as summarised by Guinée (Guinée, o.a., 2004):

- LCA does not address localised aspects, and it is not a local risk assessment tool
- LCA is typically a steady state, rather than a dynamic approach
- LCA does not include market mechanisms or secondary effects on technological development
- LCA regards processes as linear, both in the economy and in the environment
- LCA focuses on environmental aspects and says nothing on social, economic and other characteristics
- LCA involves several technical assumptions and value choices that are not purely science-based

2.2 ISO 14040

In 1997, the European Committee for Standardization published their first set of international guidelines for the performance of LCA. This ISO 14040 standard series has become widely accepted amongst the practitioners of LCA and is continuously being developed along with progressions within the field of LCA (Rebitzer et al. 2003). The guidelines for LCA are described in two documents; ISO 14040, that contains the main principles and structure for preforming an LCA, and ISO 14044, which includes detailed requirements and recommendations. Furthermore, a document containing the format for data-documentation (ISO/TS 14048), as well as technical reports with guidelines for the different stages of an LCA (ISO/TR 14049 and ISO/TR 14047), are available in this standard series. (Carlsson & Pålsson, 2011)

There are four phases in an LCA study; the goal and scope definition phase, the inventory analysis phase, the impact assessment phase and the interpretation phase. Below is a conceptual picture of this in Figure 3.

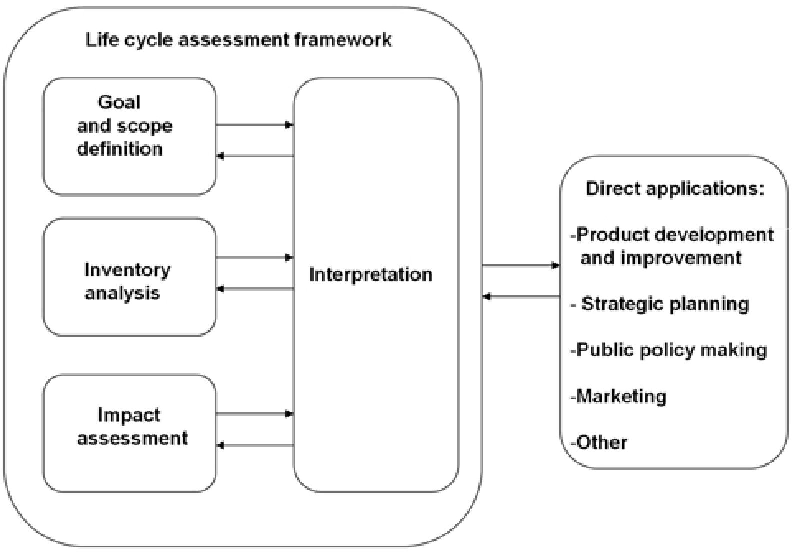


Figure 3. The four phases of the Life Cycle Assessment

1. The first phase is the definition of goal and scope. The goal and scope, including system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.

2. The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.

3. The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

4. Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

3 Goal and Scope

3.1 The aim of the study

The goal was to have the metrics for the environmental impact from a life cycle perspective. The report describes the results in a transparent and reproducible way according to the standard. The results are interpreted a followed by recommendations for mitigating the environmental impact.

The purpose was to ensure a successful submission of the application for RoHS exemption application for use of the substances Medium chain chlorinated paraffins (hereafter: MCCP) used in PVC electrical cable insulation.

The intended audience was public authorities.

3.2 Scope of the Study

3.2.1 Name and Function of the Product/System

The scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied. The scope was from the cradle to the grave, that is all the way from the extraction of raw materials, production, installation, use and service to the waste disposal.

LCA for chemical substance and possible substitute substances in electrical equipment (analytical instrument).

Medium chain chlorinated paraffin (MCCP) used in PVC electrical cable insulation – alternative substances could be Diisononyl phthalate, CAS no. 28553-12-0 (DINP), Di-isodecyl phthalate, CAS No. 68515-48-0 (DIDP), Phosphate esters or antimony oxide.

3.2.2 The Functional Unit and reference flow

The functional unit shall be consistent with the goal and scope of the study. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalised.

Functional unit

1 kg of PVC cable insulation, with plasticer and flameretardent.

Reference flows

- 1 kg of PVC cable with MCCP and alternative substances
    - Diisononyl phthalate, CAS no. 28553-12-0 (DINP),
    - Di-isodecyl phthalate, CAS No. 68515-48-0 (DIDP),
    - Phosphate esters or antimony oxide.

3.2.3 System Boundary

The system boundary determines which processes are included within the LCA. The selection of the system boundary shall be consistent with the goal of the study. The system boundary is chosen in a way to include all contributing processes for the system but at the same time, get an easy system. Therefore there might be a reason to exclude some of the more peripheral processes contributing to minimal environmental effect (so-called "cut-off"). However, the deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study. Any decisions to skip life cycle stages, processes, inputs or outputs are clearly stated, and the reasons and implications for their exclusion are if any explained.

This study goes from cradle-to-grave. That means that all processes needed for raw material extraction, manufacturing, transport, usage and end-of-life are included in the study. The model is described in the chapter about all the life cycle stages, and the data used to represent the different parts are described in detail under the Life cycle inventory (LCI). Figure 4 is an overview of the model.

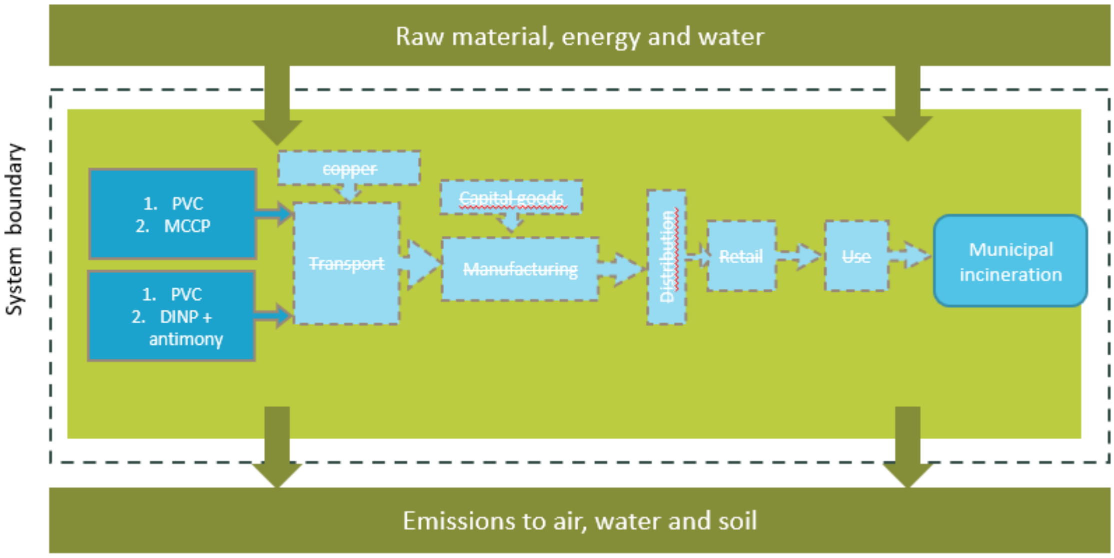


Figure 4. System boundaries for the model of the product system.

In this LCA, boundaries with other systems, and the allocation of environmental burdens between them, are based on the recommendations of the international EPD system[3], which are also in line with the requirements and guidelines of the ISO14040/14044 standards (IEC, 2008). In accordance with these recommendations, the Polluter Pays (PP) allocation method is applied. For allocation of environmental burdens when incinerating waste, this implies that all the processes in the waste treatment phase, including emissions from the incineration are allocated to the life cycle in which the waste is generated. Following procedures for refining of energy or materials used as the input in a following/receiving process, are allocated to the next life cycle.

[3] EPD (Environmental Product Declarations) by the International EPD Cooperation (IEC)

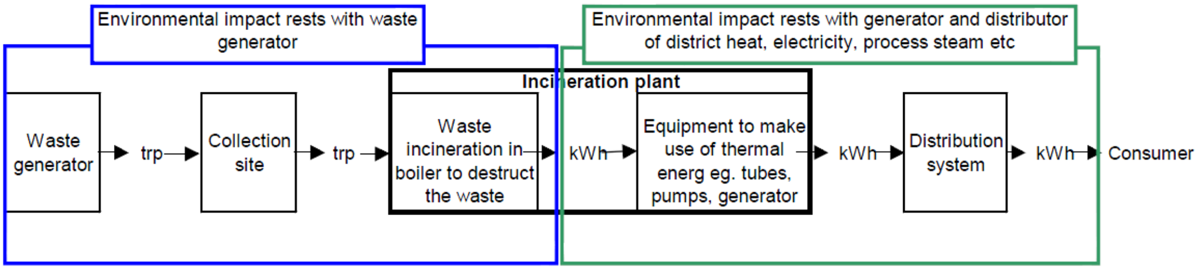


Figure 5: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here in regards to incineration of waste and resulting energy products (Image from IEC, 2008, p14).

In the case of recycling, environmental burdens are accounted for outside of the generating life cycle and have thus been allocated to the subsequent life cycle which uses the recycled materials as input.

Avoided materials due to recycling have therefore not been considered in the main scenario. This in accordance to the ISO recommendations. In other words, only if the generating life cycle do use recycled material as input material will it account for the benefits of recycling.

Raw materials, production, manufacturing use and disposal are included in the study.

3.2.4 Allocation procedure

The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below:

Step 1: Wherever possible, the allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes or expanding the product system to include the additional functions related to the co-products.
Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.
Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

In this assessment, an economic allocation is done as far as possible. When other allocations are used, it is expressed if it may be significant to the results. Allocation of waste is described in ISO 14044 section 4.3.4.3.3 (ISO, 2006).

Waste is allocated in accordance with the method Allocation cut-off by classification in accordance with EPD guidelines (The International EPD® System, 2015).

3.2.5 Method of Life Cycle Impact Assessment (LCIA)

The LCIA methods are chosen to give a comprehensive and multifaceted picture of the environmental effects of the different materials life cycle. In total, 19 different environmental effect categories will be used to give a different perspective on the environmental burden.

The **Environmental Footprint 3.0 method** is the most recently updated, the most comprehensive and the best adapted to all the environmental effects that are recommended by the PCR. Environmental Footprint 3.0 is especially harmonized with the demands from EN 15804:2012+A2:2019. More information about the impact assessment method can be found in Appendix 1.

The **CML method** is the reference for impact categories used in the international EPD system (Instructions 3.01, 5830). It has two different sub methods, CML 2001 baseline [4] and CML-IA non baseline, to handle variations in different PCRs. The version is version 4.7 (Aug 2016)

For external communication, Environmental Product Declaration (EPD) is recommended. The General Program Instructions (Instructions 3.01, 5830) and the Product Category Rules of EPD is the main basis for the choice of which environmental effect categories to include. The methods used to calculate them are listed below. The life cycle impact assessment (LCIA) was made with the LCA-software SimaPro[5]. In this software, databases with generic LCI data (i.e. ecoinvent[6]) and several readymade LCIA-methods are included. The impact categories, category indicators and characterisation models used are determined by the demands stated in ISO 14040 (2006a). The implementation of the methods in SimaPro is called EF method (2019).

Table 1. Impact categories, indicators and methods used in the study. Non- Construction products [7]

Impact category	abbreviation	Category indicator	Method
Acidification potential (fate not included)')	AP	Kg SO_2 equivalents / kg	CML 2001 non-baseline version 4.7
Eutrophication potential	EP	Kg PO_4 equivalents / kg	CML 2001 baseline version 4.7
Climate Change-total	GWP total	Kg CO_2 equivalents	CML 2001 baseline version 4.7 (IPCC 2013 GWP 100)
Climate Change-fossil	GWP fossil	Kg CO_2 equivalents	CML 2001 baseline version 4.7 (IPCC 2013 GWP 100)
Climate Change-biogenic	GWP biogenic	Kg CO_2 equivalents	CML 2001 baseline version 4.7 (IPCC 2013 GWP 100)
Climate Change-land use and land use change	GWP luluc	Kg CO_2 equivalents	CML 2001 baseline version 4.7 (IPCC 2013 GWP 100)
Photochemical oxidant creation potential	POC	Kg NMVOC eq./ kg	EF 3.0 based on ReCiPe 2008
Abiotic resource depletion, elements	ADe	kg Sb eq / kg	CML 2001 baseline version 4.7
Abiotic resource depletion, fossil fuels	ADf	MJ	CML 2001 baseline version 4.7
Water Depletion	WD	M3	AWARE 1.03

3.2.6 Data requirements

The manufacturing stage will be represented with specific data. That means that all data concerning material, energy and waste are specifically modelled for the prerequisites of the manufacturing facility

[4] CML-IA Characterisation Factors - Leiden University (universiteitleiden.nl)
[5] SimaPro Version 9.1.1.1 described at support.simapro.com.
[6] ecoinvent v3.6, ecoinvent
[7] Indicators | EPD International (environdec.com)

and the technology that are used. Data concerning raw material suppliers will be regionalised depending on the country or geographical region the supplier comes from.

For the other life cycle stages, general data is used. General data means that material or energy are represented using average LCI data from ecoinvent 3.6. Figure 6 shows the system boundaries for this study.

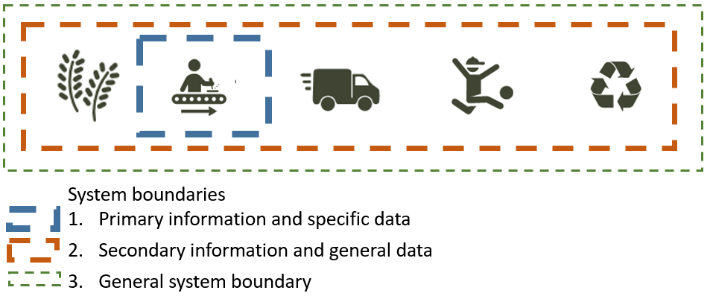
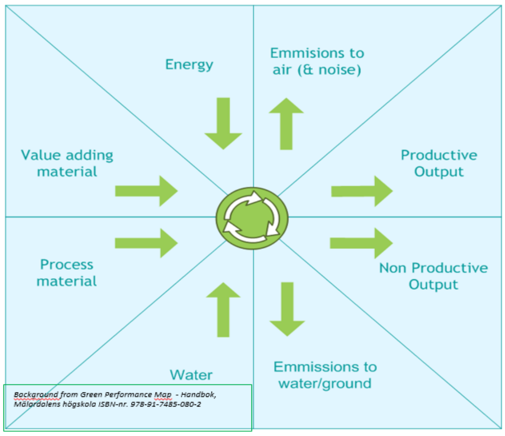


Figure 6. System boundaries and life cycle phases.

The level of depth depends on the availability of inventory data. By using general data from certified organisations, the fidelity and amount of Life Cycle Inventory (LCI) data increase very much. It is crucial, however, to understand those specific producers may differ significantly from general practice and average data.

The following requirements are used (see below) for all the central LCI data. The more peripheral aspect may deviate from the DQI based in the rule for "cut off".



Time period: **2014 and after**
Geography: **Europe, Western**
Technology: **Average technology or BAT**[8]
Representativeness: **Average from a specific process**
Multiple output allocation: **Physical causality**
Substitution allocation: Not applicable
Waste treatment allocation: Not applicable
Cut-off rules: **Less than 1% environmental relevance**
System boundary: **Second order (material/energy flows including operations)**
The boundary with nature: **Agricultural production is part of the production system**

Figure 7 Environmental System Analysis as standard for data to be collected.

[8] BAT (Best Available Technology or Best Available Techniques) signifies the latest stage in development of activities, processes and their method of operation which indicate the practical suitability of particular techniques as the basis of emission limit values, linked to environmental regulations, such as the European Industrial Emissions Directive (IED, 2010/75/EU) . In determining whether operational methods are BAT, consideration is given to economic feasibility and the availability of techniques to carry out the required function. The BAT concept is closely related to BEP (Best Environmental Practice), which is the best environment-friendly company practice.

3.2.7 Data quality and representativeness

Both the data quality and the representativeness of the data are important to fulfill the goal and scope of the study. All data for the production of the materials (A1) has been collected from literature studies and by Intertek in a survey from producers of PVC cables. No specific data could be used, available generic data was used mainly provided by ecoinvent 3.6 (2019). The assessment of data quality and representativeness is summarized in Table 5.

Table 5 Data quality assessment for the study. The main data sources used can be found in Appendix 2

Aspect	Notes
Data quality assessment scheme	The data quality level and criteria from the PEF category rules has been applied in this study
Geographical coverage	EU countries
Technological representativeness	Generic data based on plant averages
Time-related coverage	Within 10 years
Validity	yes
Plausibility	Comparison with other generic data on PVC.
Precision	Material and energy flows quantified based on generic data from the ecoinvent 3.6 database.
Completeness	Data accounts for all known sub-processes.
Consistency, allocation method, etc.	Allocation follows a physical causality in line with EN 15804.
Completeness and treatment of missing data	No data is found missing.
Final result of data quality assessment	Data quality as required in EN15804 is met.

3.2.8 Assumptions

Assumptions that are general to the entire LCA are:

• choice of energy model: (e.g. regional averages obtained from the Ecoinvent LCI database or according to specific conditions);

• choice of transport model: (e.g. regional averages from Ecoinvent (Michael Spielmann, Christian Bauer, Roberto Dones & Matthias Tuchsmid, 2007)or according to specific conditions calculated according to the Network for Transport and the Environment (NTM).

• EcoInvent processes that contain market funds such as “Diesel burned in building machine {GLO} | market for | Cut-off, U ”contains generic shipments from producer to end customer. Therefore, these data sets have no further transport.

Specific assumptions are presented in the section for the life cycle inventory, see section 4, Inventory of environmental aspects (LCI).

3.2.9 Type of critical review

A critical review is necessary to allow for external communication and comparison with results from other studies. This is a public study with comparative assertions.

4 Life cycle inventory (LCI)

In the inventory analysis, the product system is defined and described. At first, the material flows and relevant processes required to the product system are identified. Secondly, environmentally relevant data, (i.e. resource inputs) emissions and product outputs for the system components are collected and interpreted. Third, the calculation is made with respect to the contribution of each system component to the overall system.

On behalf of Torben Norlem at Intertek (torben.norlem@intertek.com) Marcus Wendin at Miljögiraff AB (marcus@miljogiraff.se) ask you to provide information for the environmental assessment of PVC electrical cable insulation. The method used is Life Cycle Assessment (LCA). The purpose is to have required LCA results for the application of an extended period of dispense for using Medium chain chlorinated paraffin (MCCP) as the plasticizer and flame retardant.
Collection of data on environmental aspects regarding chemical substance and possible substitute substances in electrical equipment (analytical instrument). Alternatives considered:

- Medium chain chlorinated paraffin (MCCP) used in PVC electrical cable insulation.
- Alternative substances could be Diisononyl phthalate, CAS no. 28553-12-0 (DINP),
- Di-isodecyl phthalate, CAS No. 68515-48-0 (DIDP),
- Phosphate esters or antimony oxide.

The data on the environmental aspects was collected via a survey to manufacturers and via search in commercial databases and literature.

Table 2: Database (libraries) of data on lifecycle inventories of environmental aspects per materials and processes

DATABASE	MCCP	DINP/DIDP	ANTIMONY
ECOINVENT	Not found. Possible proxy: Epoxidized vegetable oil, glycidyl ether or organophosphorous compounds Chlorine gas, Unbranched paraffin fractions, Nitrogen	triphenyl phosphate	
GABI DATABASES			
IDEA		phthalic plasticizers	antimony trioxide
PLASTICS EUROPE ECO-PROFILES		ECPI Eco-profile	
IBU EPD DATABASE			
EPD INTERNATIONAL DATABASE			
ÖKOBAUDAT			

INIES	
GOOGLE SCHOLAR	
GLAD	

A literature review was made to understand the context and what issues are critical. The following articles was studied:

Abstract Gluge et al. (2016) Environmental Risks of Medium-Chain Chlorinated Paraffins (MCCPs) - A review (Glüge et al., 2021)

Baitz et al. (2003) LCA of PVC and of principal competing materials. (Gmbh, n.d.)

ECPI (2015) Eco-profile DINP. (Declarations & Manufacturers, 2015)

EFCR (2015) EPD Concrete admixtures Plasticisers and Superplasticisers. (EFCR, 2015)

Fantke and Ernstoff (2018) LCA of Chemicals and Chemical Products. (Ernstoff, 2018)

Guida et al. (2020) Chlorinated paraffins in the technosphere - A review. (Guida et al., 2020)

Hischier et al. (2005) Establishing Life Cycle Inventories of Chemicals Based on Differing Data Availability. (Hischier et al., 2005)

Li (2007) LCA DEHP and alternatives. (Li, 2013)

Samani and van der Meer (2020) LCA studies on flame retardants - A systematic review. (Samani & van der Meer, 2020)

van Mourik et al. (2016) Chlorinated paraffins in the environment - a review on their production, fate, levels and trends between 2010 and 2015. (Mourik, 2019).

4.1 Product content declaration

This part describes all the different components, packaging materials and substances of very high concern.

Table 3 Content declaration MCCP

Product components	Weight (kg)	Post-consumer material (weight-%)	Renewable material (weight-%)
PVC	0,94	0,94	0
MCCP	0,06	0,06	0
Substances of potential concern (SVHC)[9]	Weight (mg)	Weight-% (versus the product)	exceeds 0.1%
Ethylene oxide	0,6	0,1%	
Anti oxidants (2,6-Di-tert.-butyl-4-methylphenol)	2,4	0,2%	
Chelating agent (tris (nonylphenyl) phosphite)	2,4	0,2%	
UV stabiliser (2-(2-hydroxy-5-methyl-phenyl)-2H-benzotriazole)	1,2	0,1%	
Hydrazine	1,2	0,1%	
Sulfur hexafluoride	0,0114	0,0%	

SVHC and the Candidate List of SVHC are available via the European Chemicals Agency [10].

[9] Substances that potentially are listed on SVOC.

[10] Candidate List of substances of very high concern for Authorisation - ECHA (europa.eu)

4.2 Raw material

This part describes all the different raw material needed for the manufacturing of the components of the plastic part of the cables.

4.2.1 Commercial MCCP compound

The production of MCCP is described in a previous LCA for INEOS (Rosa Cuellar Franca, 2014). It was used to define the environmental aspects. The grade average from 45-52% chlorine was used. No allocation was made to the co products due to unknown economic values.

Figure 8 System of environmental aspects of producing MCCP (Rosa Cuellar Franca, 2014).

Table 4 Environmental aspects of producing commercial MCCP compound (Rosa Cuellar Franca, 2014).

Products	
Cereclor	1000
HCL36	512
Hypochlorite	6,73
Materials/fuels	
Chlorine dioxide {RER}| market for chlorine dioxide | Cut-off, U	Chlorine
Paraffin {GLO}| market for | Cut-off, U	Paraffins
Nitrogen, liquid {RER}| air separation, cryogenic | Cut-off, U	60
Bisphenol A epoxy based vinyl ester resin {GLO}| market for | Cut-off, U	2,88
Ethylene oxide {RER}| market for ethylene oxide | Cut-off, U	0,01
Glycerine {CH}| esterification of rape oil | Cut-off, U	0,09

DINP proxy	0,04
DINP proxy	0,03
Benzo[thia]diazole-compound {GLO}| market for | Cut-off, U	0,02
Neutralising agent, sodium hydroxide-equivalent {GLO}| market for | Cut-off, U	4,68
Hydrazine {RER}| market for hydrazine | Cut-off, U	0,02
Water, deionised {CH}| water production, deionised | Cut-off, U	1058
Lubricating oil {RER}| market for lubricating oil | Cut-off, U	0,00019
Sulfur hexafluoride, liquid {RER}| market for sulfur hexafluoride, liquid | Cut-off, U	0,00019
Glass wool mat {GLO}| market for | Cut-off, U	0,00192
Activated carbon, granular {GLO}| market for activated carbon, granular | Cut-off, U	0,05
Electricity/heat	

Sour gas, burned in gas turbine {GLO}| market for | Cut-off, U	54
Heat, from steam, in chemical industry {RER}| market for heat, from steam, in chemical industry | Cut-off, U	192
Municipal waste collection service by 21 metric ton lorry {GLO}| market for | Cut-off, U	TransportWaste
Emissions to air	
Chlorine	
Hydrogen chloride	
Paraffins	
Chlorinated paraffins	
Waste to treatment	
Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, U	842
Inert waste, for final disposal {CH}| treatment of inert waste, inert material landfill | Cut-off, U	WeightLandfill
Municipal solid waste {IT}| treatment of, incineration | Cut-off, U	WeightIncineration
Input parameters	
Chlorine	1038
Paraffins	500
DistLandfill	200
DistIncineration	200
WeightLandfill	0,05
WeightIncineration	0,39
Calculated parameters	

TransportWaste	DistLandfill*WeightLandfill+DistIncineration*WeightIncinerati

4.2.2 DINP and DIDP

The DINP was based on a reference from Ecoprofiles (Declarations & Manufacturers, 2015).

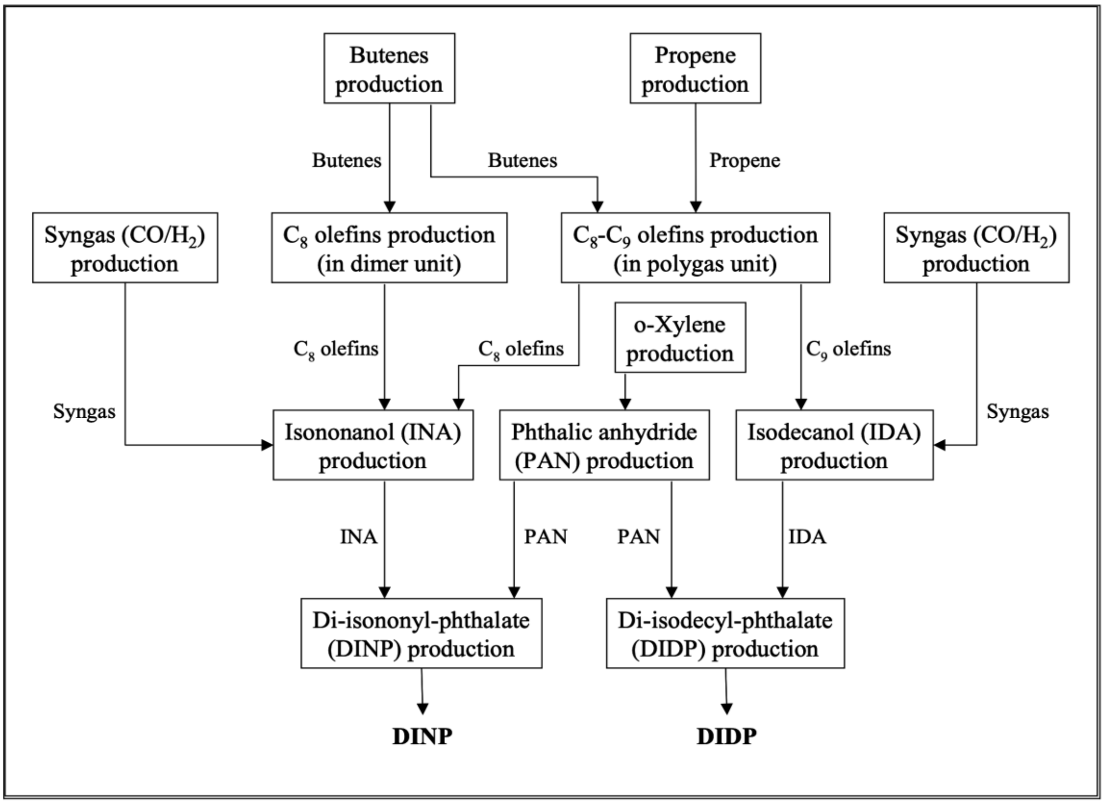


Figure 4-9: Schematic flow diagram for the production of DINP and DIDP (ECPI, 2001)

Figure 9 Schematic flow diagram for production of DINP and DIDP [11].

[11] https://ec.europa.eu/environment/waste/studies/pdf/pvc-final_report_lca.pdf ECOBILAN, Eco-profile of high volume commodity phthalate esters (DEHP/DINP/DIDP). 2001, The European Council for Plasticisers and Intermediates (ECPI).

4.2.3 Antimony oxide (ATO)

Antimony(III) oxide is the inorganic compound with the formula Sb2O3. It is the most important commercial compound of antimony.

(From Wikipedia). As of 2010, antimony(III) oxide was produced at four sites in EU27. It is produced via two routes, re-volatilizing of crude antimony(III) oxide and by oxidation of antimony metal. Oxidation of antimony metal dominates in Europe. Several processes for the production of crude antimony(III) oxide or metallic antimony from virgin material. The choice of process depends on the composition of the ore and other factors. Typical steps include mining, crushing and grinding of ore, sometimes followed by froth flotation and separation of the metal using pyrometallurgical processes (smelting or roasting) or in a few cases (e.g. when the ore is rich in precious metals) by hydrometallurgical processes. These steps do not take place in the EU but closer to the mining location.

Re-volatilizing of crude antimony(III) oxide[edit]
Step 1) Crude stibnite is oxidized to crude antimony(III) oxide using furnaces operating at approximately 500 to 1,000 °C. The reaction is the following:

$2\ Sb_2S_3 + 9\ O_2 \rightarrow 2\ Sb_2O_3 + 6\ SO_2$
Step 2) The crude antimony(III) oxide is purified by sublimation.

Oxidation of antimony metal[edit]
Antimony metal is oxidized to antimony(III) oxide in furnaces. The reaction is exothermic. Antimony(III) oxide is formed through sublimation and recovered in bag filters. The size of the formed particles is controlled by process conditions in furnace and gas flow. The reaction can be schematically described by:

$4\ Sb + 3\ O_2 \rightarrow 2\ Sb_2O_3$

The available LCI data is for pure antimony, so the molecular weight is used to calculate the weight of antimony. The result is 42% which is also used in the LCA model.

Table 5 Calculation of Sb share molecular weight.

substance	*mole*	*Molar weight (g/mole)*	*weight (g)*	*share*
Sb2	2	121,8	244	84%
O3	3	16,0	48	16%
Sb2O3	1	292	292	100%
Sb	1	121,8	122	42%

4.3 Manufacturing

A survey of 10 large manufacturers of PVC for cables was made by Intertek[12] to know what plastizer and flameretardent, that are used and how they perceive the implications for the shift to other solutions than the restricted chemicals. The same companies was approached with a survey to collect information on the environmental aspects required for this LCA. But none of them decided to answer.

It is assumed that the environmental aspects of manufacturing is similar regardless of the choice of plastizer and flameretardent. This assumption is based on answers from the same survey where responses are that the necessary requirements already taken to handle MCCP, will be sufficient also for the alternatives. So the comparison may be fair anyway.

Table 6 Model of PVC cable with MCCP.

PRODUCTS		
1 KG OF PVC IN CABLE WITH MCCP	1	p
MATERIALS/ASSEMBLIES		
POLYVINYLCHLORIDE, BULK POLYMERISED {GLO}| MARKET FOR | CUT-OFF, U	PVC	kg
CERECLOR	MCCP	kg
PROCESSES		
TRANSPORT, FREIGHT, LORRY 16-32 METRIC TON, EURO5 {RER}| MARKET FOR TRANSPORT, FREIGHT, LORRY 16-32 METRIC TON, EURO5 | CUT-OFF, U	DistMCCP	kgkm
INPUT PARAMETERS		
MCCPSHARE	1	Share of Plasticicer that is MCCP
PLASTISISER	0,06	Share of PVC that is plasticiser. 6 % according to the file 2020_MCCP_questionnaire_summary_1
GLYCIDYL	0,5	glycidyl ether
RSLPVCCABLE	10	years [2020_MCCP_questionnaire_summary_1]
DISTMCCP	200	km estimation
CALCULATED PARAMETERS		

[12] Filename " 2020_MCCP_questionnaire_summary_1"

OTHERORGANIC	(1-MCCPshare)*Plastisiser
PVC	1-Plastisiser
MCCP	MCCPshare*Plastisiser

Table 7 Model of PVC cable with DINP.

PRODUCTS			
1 KG OF PVC IN CABLE WITH DINP	1	p	Diisononyl phthalate, CAS no. 28553-12-0 (DINP)
NONOXYNOLS ARE PRODUCED BY ETHOXYLATION OF ALKYLPHENOLS AND VARY IN THE NUMBER OF REPEATING ETHOXY (OXY-1,2-ETHANEDIYL) GROUPS RESULTING IN NONOXYNOL-4, NONOXYNOL-7, NONOXYNOL-9, NONOXYNOL-14, NONOXYNOL-15, NONOXYNOL-18, NONOXYNOL-40, NONOXYNOL-30 AND NONOXYNOL-50. OTHER SYNONYMS ARE POLYETHYLENE GLYCOL (PEG)-7 NONYL PHENYL ETHER, PEG-14 NONYL PHENYL ETHER, PEG-18 NONYL PHENYL ETHER AND PEG-50 NONYL PHENYL ETHER. THE PRECURSOR NONYLPHENOL IS DERIV			
MATERIALS/ASSEMBLIES			
POLYVINYLCHLORIDE, BULK POLYMERISED {GLO}| MARKET FOR | CUT-OFF, U	PVC	kg	
GLYCINE {GLO}| MARKET FOR | CUT-OFF, U	Glycidyl	kg	
DINP PROXY	Plastisiser	kg	DINP: Nonoxynols are produced by ethoxylation of alkylphenols and vary in the number of repeating ethoxy (oxy-1,2-ethanediyl) groups resulting in Nonoxynol-4, Nonoxynol-7, Nonoxynol-9, Nonoxynol-14, Nonoxynol-15, Nonoxynol-18, Nonoxynol-40, Nonoxynol-30 a
ANTIMONY {GLO}| MARKET FOR | CUT-OFF, U	FlameRetardent	kg	Antimony(III) oxide. Antimony(III) oxide is the inorganic compound with the formula Sb_2O_3. It is the most important commercial compound of antimony.
PROCESSES			
INPUT PARAMETERS			
PLASTISISER	0,5		
FLAMERETARDENT	0,1		
CALCULATED PARAMETERS			
PVC	1-Plastisiser-FlameRetardent		

The composition of DINP is not found in the generic databases. Instead, the reaction formula was used as a basis for finding the more basic chemicals behind it.

A close proxy was estimated to Dinonylphenol ethoxylate (DNPE) C44O12H45 (approx.) and is modelled as a mixture of the substances included in the reaction. The proportion of each is estimated because we do not know the molar ratio.

Table 8 DINP composition as modelled in SimaPro.

Raw material	share	comment
2,4-di-tert-butylphenol	30%	Represent Alkyl phenol
Ethylene oxide	60%	Represent polyethyleneoxide (CAS 25322-68-3)
Phosphate fertilizer, as P2O5 from citric acid production	10%	Fosfate

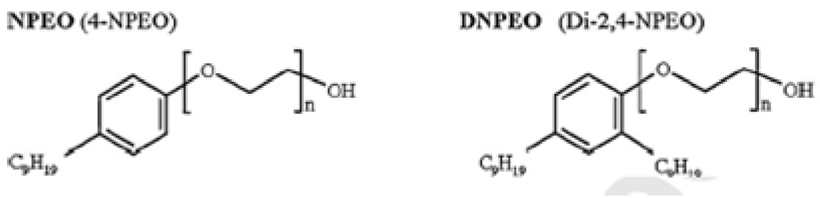


Figure 10 Molecular structure of ethoxylated nonylphenol.

Table 9 Model of PVC cable with DIDP.

1 KG OF PVC IN CABLE WITH DIDP	1	P
MATERIALS/ASSEMBLIES		
POLYVINYLCHLORIDE, BULK POLYMERISED {GLO}| MARKET FOR | CUT-OFF, U	PVC	kg
ANTIMONY {GLO}| MARKET FOR | CUT-OFF, U	FlameRetardent*ShareSb	kg
METHYLENEDIPHENYL DIISOCYANATE (MDI)/EU-27	Plastisiser	kg
PROCESSES		
INPUT PARAMETERS		
PLASTISISER	0,06	
GLYCIDYL	0	glycidyl ether
FLAMERETARDENT	0,08	Given by assigner Intertek
SHARESB	0,42	molecular weight
CALCULATED PARAMETERS		
PVC	1-Plastisiser-FlameRetardent	

4.4 End-of-Life

The end of life stage is a life cycle stage that in general, includes the waste of the product. The end of life stage shall include the dismantling of the product and the transport to the end of the life treatment plant. If recycled to a new product, the environmental aspects of processing the secondary material, are allocated to the new products lifecycle.

The disposal scenario in Europe is assumed to be similar as in Sweden. In Sweden the share of electronic products that reach municipal recycling is >80% (Elkretsen, 2020). One of the largest actors for treatment of cables in Sweden is Stena Recycling in Halmstad. In this process the cables are pelled of to recover the metal and sending the remaining fraction of plastic, to incineration.

The transport from user to disposal is included represented by 40 km lorry with payload 16 ton and emissionstandard Euro 5.

The electricity consumed in peeling the cables is set to 0,066 kwh per kg cable, based on study from 2004 documented in ecoinvent. European electricity mix was used (Electricity, medium voltage {ENTSO-E}| market group for | Cut-off, U).

To represent the disposal scenario for the remaining fraction of plastic, a generic dataset from ecoinvent 3.6 was used, Municipal solid waste (waste scenario) {SE}| treatment of municipal solid waste, incineration | Cut-off, U. It separates the PVC into incineration (Waste polyvinylchloride {CH}| treatment of, municipal incineration | Cut-off, U) and the remaining (ie MCCP) is sent to incineration of a general material mix (Municipal solid waste {NO}| treatment of, incineration | Cut-off, U).

5 Life cycle impact assessment (LCIA)

5.1 Results

In this part the result from the different environmental impact assessment methods will be presented. The result from the method Environmental Footprint 3.0 (EF), Midpoint and Endpoint will be presented.

Sankey diagrams are used to display the results as flow diagrams where the thickness of the arrows reflects the relative amount of that flow. All the nodes cannot be displayed at the same time and still be possible to see, due to the vast amounts of background data. Therefore, a cut off is used to show only the nodes that contribute with more than the "cut-off".

5.1.1 Commercial MCCP compound

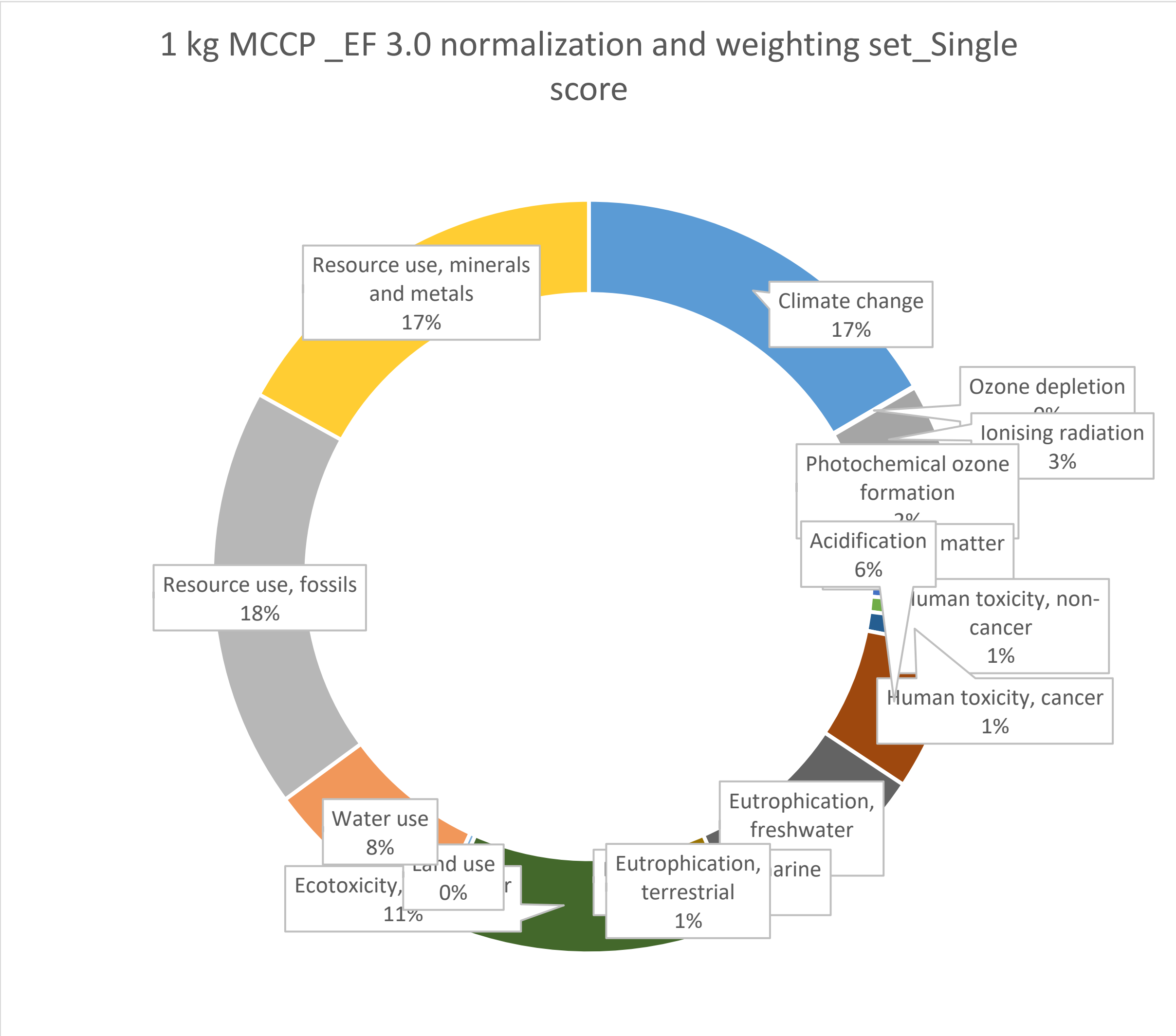


Figure 11 Environmental Footprint of weighted impact categories (MCCP).

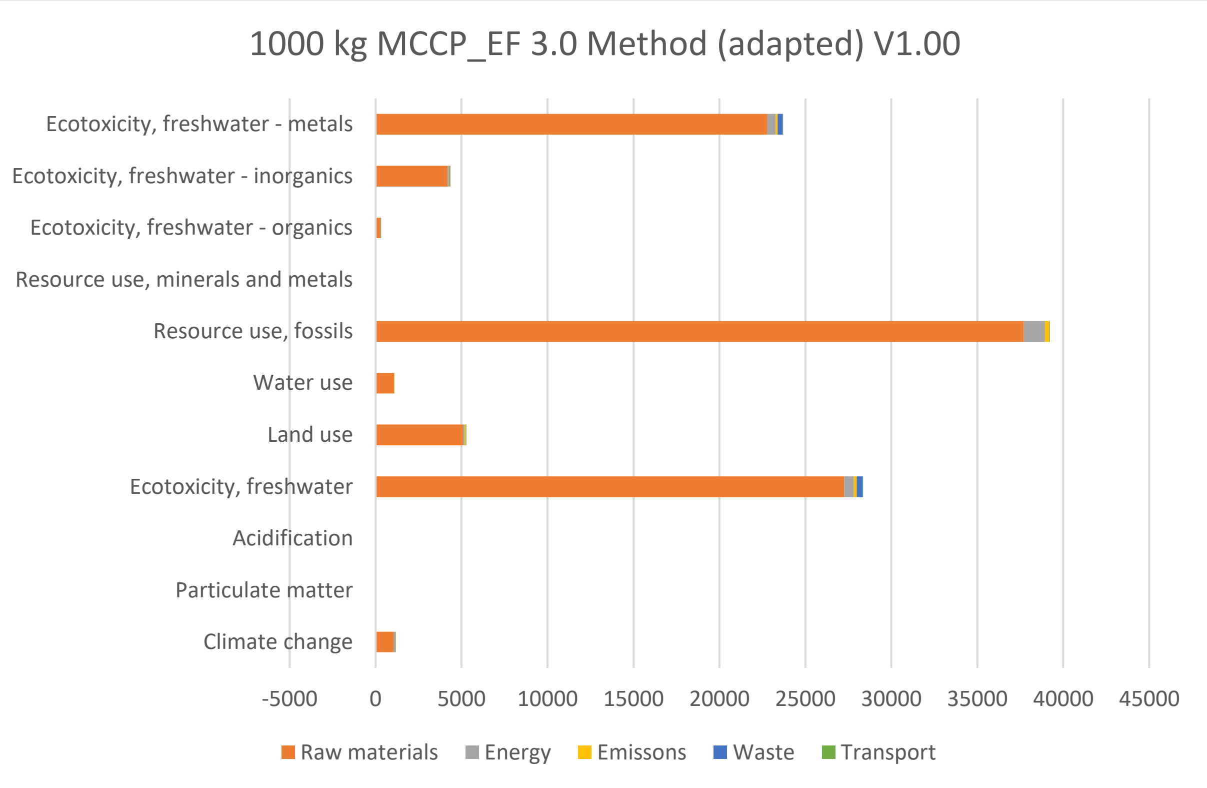


Figure 12 Environmental Footprint per category of aspect (MCCP).

Table 10 Environmental Footprint per 1 ton MCCP.

Impact category	Unit	Total	Raw materials	Energy	Emissons	Waste	Transport
Climate change	kg CO2 eq	1151	1045	86	19	1	0
Ozone depletion	kg CFC11 eq	0	0	0	0	0	0
Ionising radiation	kBq U-235 eq	280	276	3	1	0	0
Photochemical ozone formation	kg NMVOC eq	5	4	0	0	0	0
Particulate matter	disease inc.	0	0	0	0	0	0
Human toxicity, non-cancer	CTUh	0	0	0	0	0	0
Human toxicity, cancer	CTUh	0	0	0	0	0	0
Acidification	mol H+ eq	9	7	2	1	0	0
Eutrophication, freshwater	kg P eq	1	1	0	0	0	0
Eutrophication, marine	kg N eq	2	1	0	0	0	0
Eutrophication, terrestrial	mol N eq	15	13	1	2	0	0
Ecotoxicity, freshwater	CTUe	28333	27255	566	171	339	1
Land use	Pt	5255	5082	104	63	6	0
Water use	m3 depriv.	1045	1075	1	0	-32	0
Resource use, fossils	MJ	39201	37711	1230	254	5	2
Resource use, minerals and metals	kg Sb eq	0	0	0	0	0	0
Climate change - Fossil	kg CO2 eq	1143	1038	86	19	1	0
Climate change - Biogenic	kg CO2 eq	6	6	0	0	0	0
Climate change - Land use and LU change	kg CO2 eq	1	1	0	0	0	0
Human toxicity, non-cancer - organics	CTUh	0	0	0	0	0	0
Human toxicity, non-cancer - inorganics	CTUh	0	0	0	0	0	0
Human toxicity, non-cancer - metals	CTUh	0	0	0	0	0	0
Human toxicity, cancer - organics	CTUh	0	0	0	0	0	0
Human toxicity, cancer - inorganics	CTUh	0	0	0	0	0	0
Human toxicity, cancer - metals	CTUh	0	0	0	0	0	0
Ecotoxicity, freshwater - organics	CTUe	307	272	18	16	0	0
Ecotoxicity, freshwater - inorganics	CTUe	4337	4192	66	44	35	0
Ecotoxicity, freshwater - metals	CTUe	23690	22791	482	112	304	1

In 1 kg of PVC cable insulation, only 6% MCCP is used. The results for this amount is presented below. The diagram show that the dominant contribution to environmental impact, comes from Chlorine and Paraffin. Only the impact categories that contribute significantly are included (see).

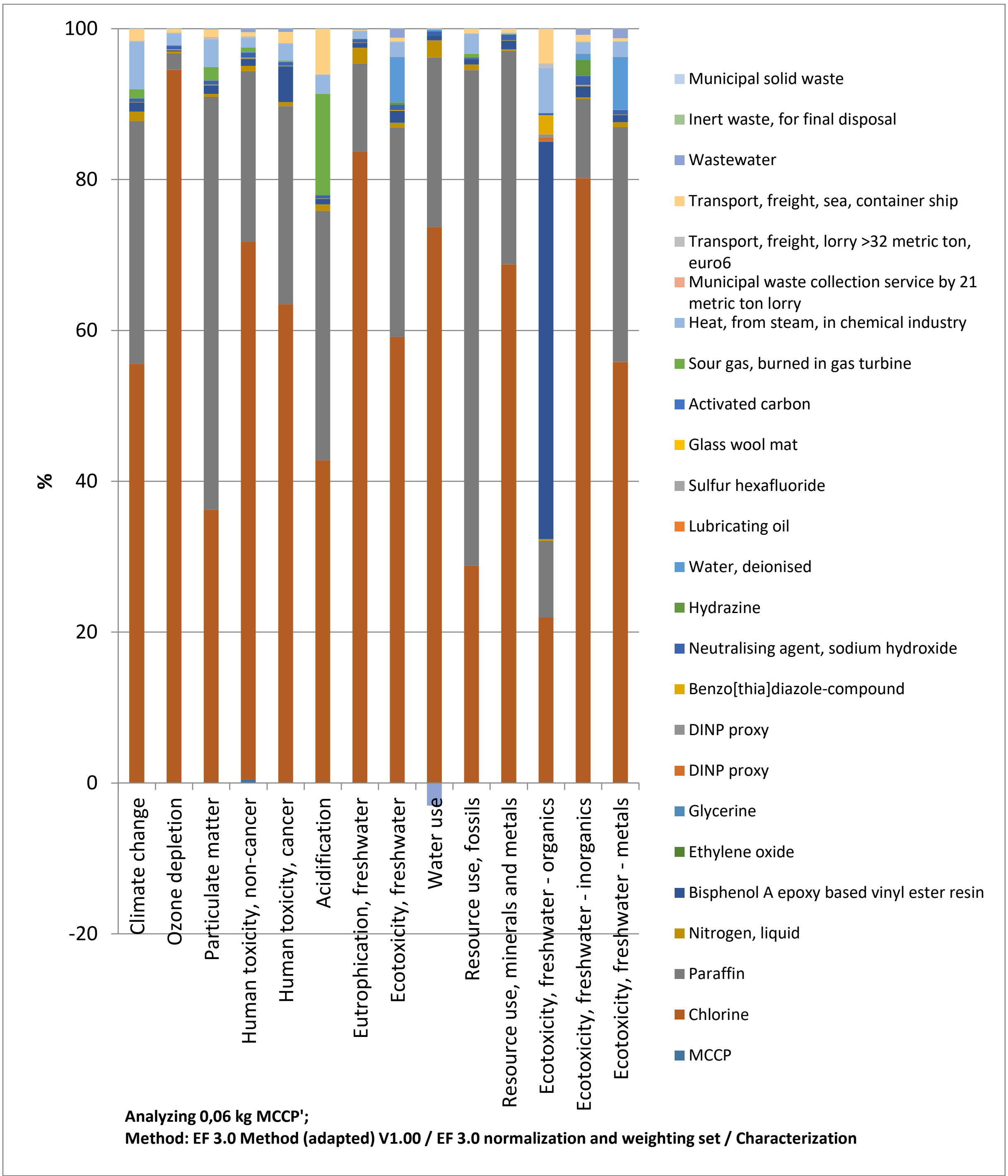


Figure 13 Environmental Footprint per impact category for MCCP in 1 kg PVC cable insulation with MCCP.

Table 11 Environmental Footprint per impact category for MCCP in 1 kg PVC cable insulation with MCCP.

IMPACT CATEGORY	UNIT	TOTAL
CLIMATE CHANGE	kg CO2 eq	0,069046
OZONE DEPLETION	kg CFC11 eq	3,89E-08
IONISING RADIATION	kBq U-235 eq	0,016792
PHOTOCHEMICAL OZONE FORMATION	kg NMVOC eq	0,000272
PARTICULATE MATTER	disease inc.	3,27E-09
HUMAN TOXICITY, NON-CANCER	CTUh	1,16E-09
HUMAN TOXICITY, CANCER	CTUh	4,07E-11
ACIDIFICATION	mol H+ eq	0,000567
EUTROPHICATION, FRESHWATER	kg P eq	3,98E-05
EUTROPHICATION, MARINE	kg N eq	9,1E-05
EUTROPHICATION, TERRESTRIAL	mol N eq	0,000917
ECOTOXICITY, FRESHWATER	CTUe	1,700004
LAND USE	Pt	0,315325
WATER USE	m3 depriv.	0,062676
RESOURCE USE, FOSSILS	MJ	2,352054
RESOURCE USE, MINERALS AND METALS	kg Sb eq	1,78E-06
CLIMATE CHANGE - FOSSIL	kg CO2 eq	0,068602
CLIMATE CHANGE - BIOGENIC	kg CO2 eq	0,00036
CLIMATE CHANGE - LAND USE AND LU CHANGE	kg CO2 eq	8,45E-05
HUMAN TOXICITY, NON-CANCER - ORGANICS	CTUh	4,36E-11
HUMAN TOXICITY, NON-CANCER - INORGANICS	CTUh	2E-10
HUMAN TOXICITY, NON-CANCER - METALS	CTUh	9,26E-10
HUMAN TOXICITY, CANCER - ORGANICS	CTUh	1,39E-11
HUMAN TOXICITY, CANCER - INORGANICS	CTUh	0
HUMAN TOXICITY, CANCER - METALS	CTUh	2,67E-11
ECOTOXICITY, FRESHWATER - ORGANICS	CTUe	0,018401
ECOTOXICITY, FRESHWATER - INORGANICS	CTUe	0,260225
ECOTOXICITY, FRESHWATER - METALS	CTUe	1,421378

5.1.2 PVC Cable with MCCP

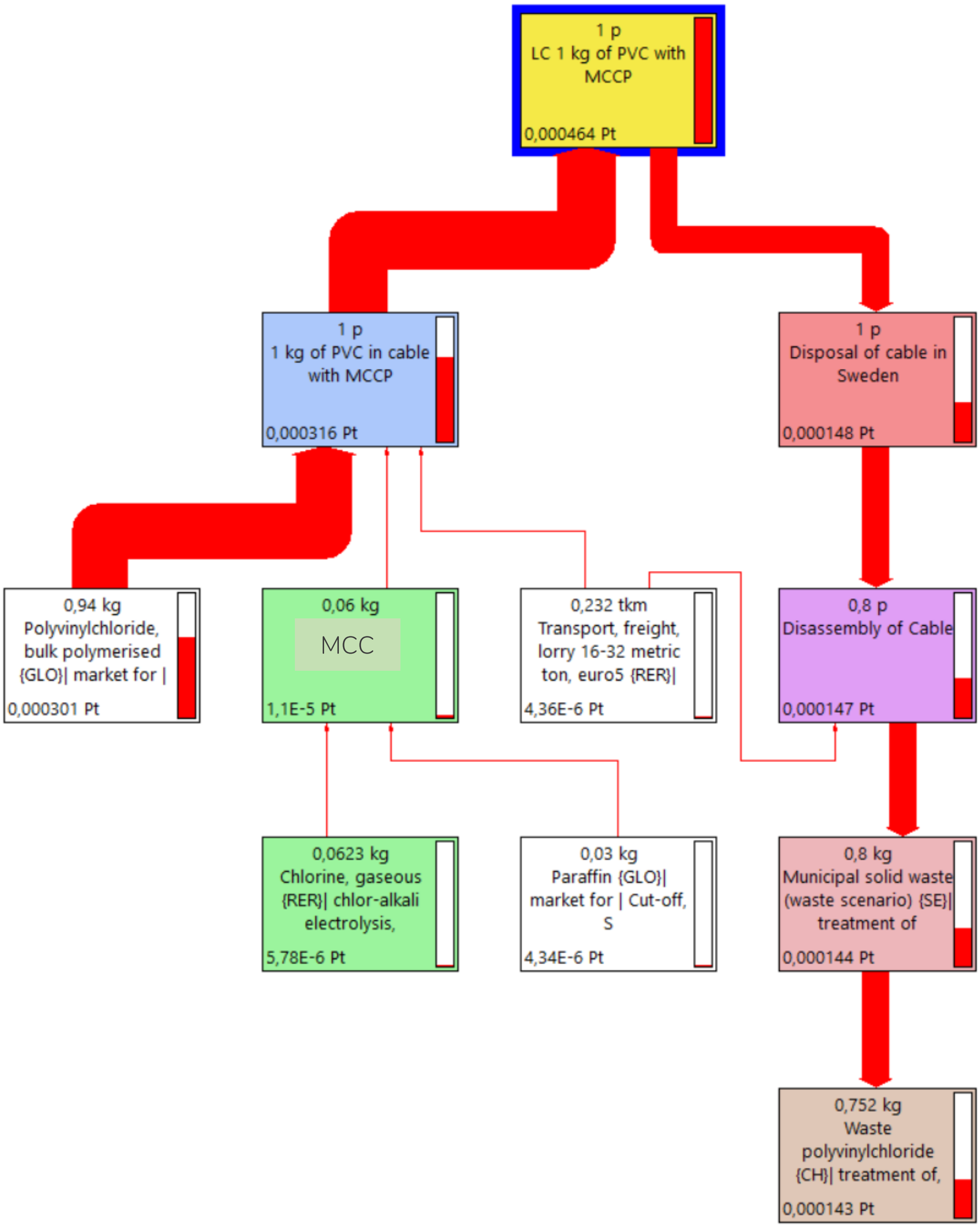


Figure 14 Sankey diagram. Environmental Footprint per lifecycle of 1 kg PVC cable insulation with MCCP. Cut off 0,5%.

Table 12 Environmental Footprint per lifecycle of 1 kg PVC cable insulation with MCCP.

IMPACT CATEGORY	UNIT	TOTAL	1 KG OF PVC IN CABLE WITH MCCP	MUNICIPAL SOLID WASTE (WASTE SCENARIO) {SE}| TREATMENT OF MUNICIPAL SOLID WASTE, INCINERATION | CUT-OFF, S
CLIMATE CHANGE	kg CO2 eq	5,7	4,0	1,7
OZONE DEPLETION	kg CFC11 eq	0,0	0,0	0,0
IONISING RADIATION	kBq U-235 eq	0,4	0,4	0,0
PHOTOCHEMICAL OZONE FORMATION	kg NMVOC eq	0,0	0,0	0,0
PARTICULATE MATTER	disease inc.	0,0	0,0	0,0
HUMAN TOXICITY, NON-CANCER	CTUh	0,0	0,0	0,0
HUMAN TOXICITY, CANCER	CTUh	0,0	0,0	0,0
ACIDIFICATION	mol H+ eq	0,0	0,0	0,0
EUTROPHICATION, FRESHWATER	kg P eq	0,0	0,0	0,0
EUTROPHICATION, MARINE	kg N eq	0,0	0,0	0,0
EUTROPHICATION, TERRESTRIAL	mol N eq	0,1	0,0	0,0
ECOTOXICITY, FRESHWATER	CTUe	373,1	292,0	81,1
LAND USE	Pt	15,7	14,3	1,5
WATER USE	m3 depriv.	3,6	3,2	0,4
RESOURCE USE, FOSSILS	MJ	98,4	93,9	4,5
RESOURCE USE, MINERALS AND METALS	kg Sb eq	0,0	0,0	0,0
CLIMATE CHANGE - FOSSIL	kg CO2 eq	5,7	4,0	1,7

CLIMATE CHANGE - BIOGENIC	kg CO2 eq	0,0	0,0	0,0
CLIMATE CHANGE - LAND USE AND LU CHANGE	kg CO2 eq	0,0	0,0	0,0
HUMAN TOXICITY, NON-CANCER - ORGANICS	CTUh	0,0	0,0	0,0
HUMAN TOXICITY, NON-CANCER - INORGANICS	CTUh	0,0	0,0	0,0
HUMAN TOXICITY, NON-CANCER - METALS	CTUh	0,0	0,0	0,0
HUMAN TOXICITY, CANCER - ORGANICS	CTUh	0,0	0,0	0,0
HUMAN TOXICITY, CANCER - INORGANICS	CTUh	0,0	0,0	0,0
HUMAN TOXICITY, CANCER - METALS	CTUh	0,0	0,0	0,0
ECOTOXICITY, FRESHWATER - ORGANICS	CTUe	122,8	122,7	0,1
ECOTOXICITY, FRESHWATER - INORGANICS	CTUe	166,5	93,3	73,3
ECOTOXICITY, FRESHWATER - METALS	CTUe	83,7	75,9	7,8

5.1.3 PVC Cable with DINP, antimony oxide (ATO)

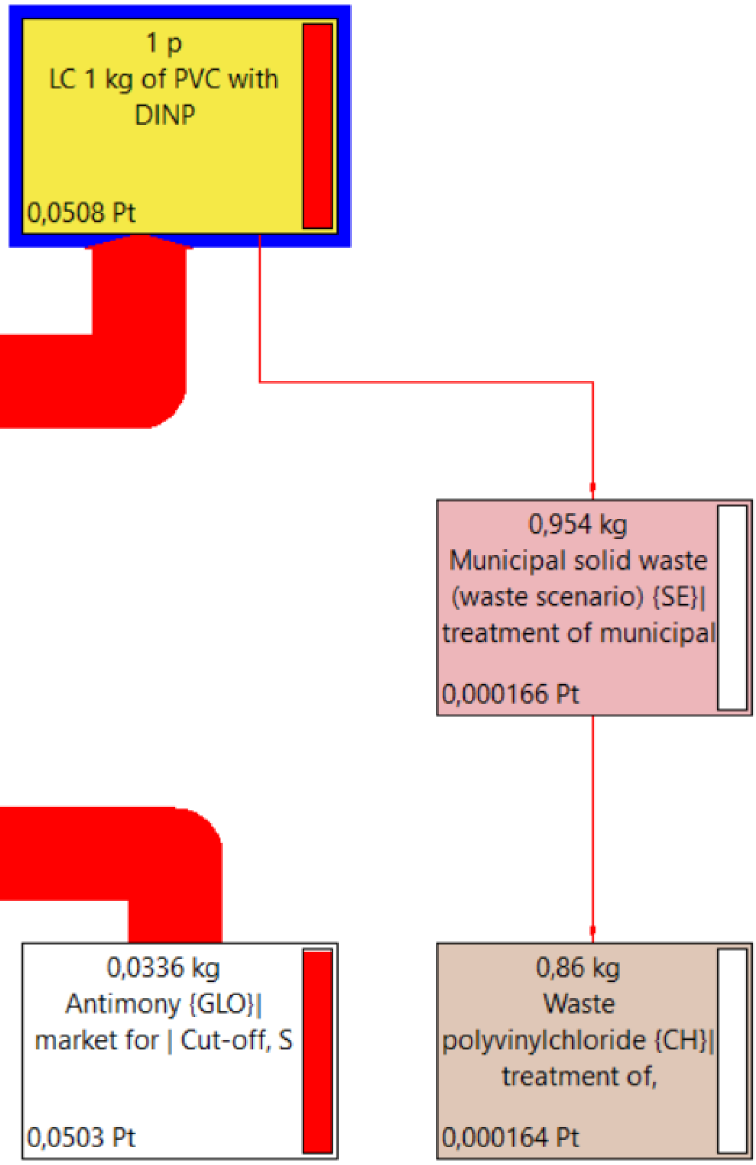


Figure 15 Sankey diagram. Environmental Footprint (single score) per lifecycle of 1 kg PVC cable insulation with DINP. Cut off 0,07%.

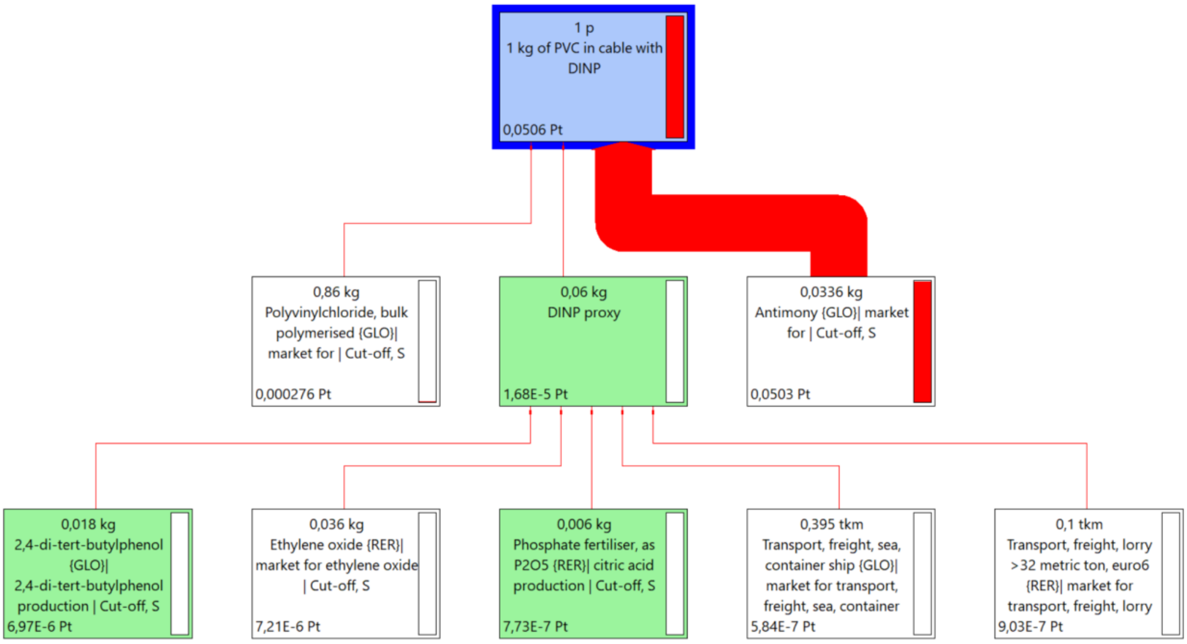


Figure 16 Sankey diagram. Environmental Footprint (single score) per lifecycle of 1 kg PVC cable insulation with DINP. Cut off 0%.

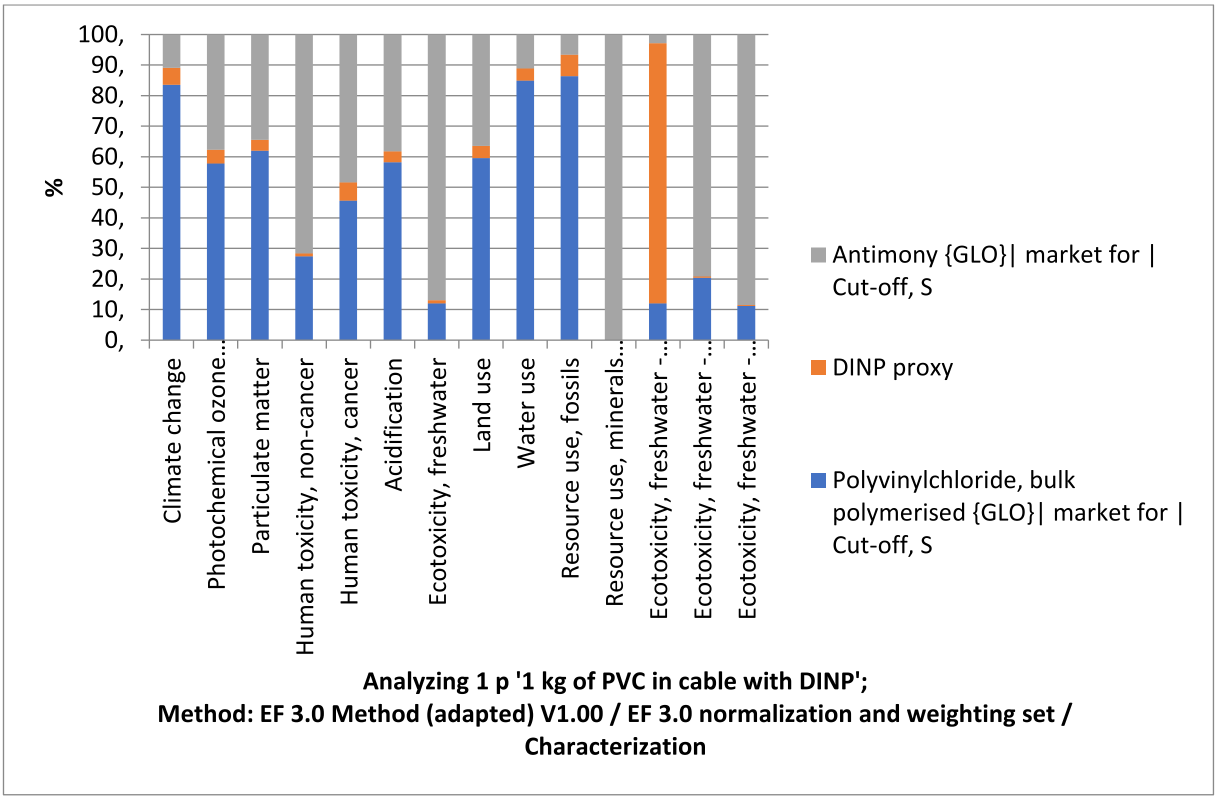


Figure 17 Environmental Footprint per impact category for PVC cable insulation with DINP and Sb.

Table 13

IMPACT CATEGORY	UNIT	TOTAL
CLIMATE CHANGE	kg CO2 eq	4,8
OZONE DEPLETION	kg CFC11 eq	0,0
IONISING RADIATION	kBq U-235 eq	0,3
PHOTOCHEMICAL OZONE FORMATION	kg NMVOC eq	0,015
PARTICULATE MATTER	disease inc.	0,000
HUMAN TOXICITY, NON-CANCER	CTUh	0,000
HUMAN TOXICITY, CANCER	CTUh	0,000
ACIDIFICATION	mol H+ eq	0,022
EUTROPHICATION, FRESHWATER	kg P eq	0,005
EUTROPHICATION, MARINE	kg N eq	0,005
EUTROPHICATION, TERRESTRIAL	mol N eq	0,056
ECOTOXICITY, FRESHWATER	CTUe	514,9
LAND USE	Pt	13,6
WATER USE	m3 depriv.	2,3
RESOURCE USE, FOSSILS	MJ	62,5
RESOURCE USE, MINERALS AND METALS	kg Sb eq	0,0
CLIMATE CHANGE - FOSSIL	kg CO2 eq	4,8
CLIMATE CHANGE - BIOGENIC	kg CO2 eq	0,0
CLIMATE CHANGE - LAND USE AND LU CHANGE	kg CO2 eq	0,0
HUMAN TOXICITY, NON-CANCER - ORGANICS	CTUh	0,0
HUMAN TOXICITY, NON-CANCER - INORGANICS	CTUh	0,0
HUMAN TOXICITY, NON-CANCER - METALS	CTUh	0,0
HUMAN TOXICITY, CANCER - ORGANICS	CTUh	0,0
HUMAN TOXICITY, CANCER - INORGANICS	CTUh	0,0
HUMAN TOXICITY, CANCER - METALS	CTUh	0,0
ECOTOXICITY, FRESHWATER - ORGANICS	CTUe	2,7
ECOTOXICITY, FRESHWATER - INORGANICS	CTUe	159,7
ECOTOXICITY, FRESHWATER - METALS	CTUe	352,5

Impact category	Unit	Total	1 kg of PVC in cable with DINP	Municipal solid waste (waste scenario) {SE}| treatment of municipal solid waste, incineration | Cut-off, S
Climate change	kg CO2 eq	4,8	2,7	2,1
Ozone depletion	kg CFC11 eq	0,0	0,0	0,0

Ionising radiation	kBq U-235 eq	0,3	0,2	0,1
Photochemical ozone formation	kg NMVOC eq	0,015	0,012	0,002
Particulate matter	disease inc.	0,000	0,000	0,000
Human toxicity, non-cancer	CTUh	0,000	0,000	0,000
Human toxicity, cancer	CTUh	0,000	0,000	0,000
Acidification	mol H+ eq	0,022	0,019	0,003
Eutrophication, freshwater	kg P eq	0,005	0,005	0,000
Eutrophication, marine	kg N eq	0,005	0,004	0,001
Eutrophication, terrestrial	mol N eq	0,056	0,048	0,008
Ecotoxicity, freshwater	CTUe	514,9	379,7	135,2
Land use	Pt	13,6	11,4	2,2
Water use	m3 depriv.	2,3	1,8	0,5
Resource use, fossils	MJ	62,5	55,3	7,2
Resource use, minerals and metals	kg Sb eq	0,0	0,0	0,0
Climate change - Fossil	kg CO2 eq	4,8	2,7	2,0
Climate change - Biogenic	kg CO2 eq	0,0	0,0	0,0
Climate change - Land use and LU change	kg CO2 eq	0,0	0,0	0,0
Human toxicity, non-cancer - organics	CTUh	0,0	0,0	0,0
Human toxicity, non-cancer - inorganics	CTUh	0,0	0,0	0,0
Human toxicity, non-cancer - metals	CTUh	0,0	0,0	0,0
Human toxicity, cancer - organics	CTUh	0,0	0,0	0,0
Human toxicity, cancer - inorganics	CTUh	0,0	0,0	0,0
Human toxicity, cancer - metals	CTUh	0,0	0,0	0,0
Ecotoxicity, freshwater - organics	CTUe	2,7	2,6	0,1
Ecotoxicity, freshwater - inorganics	CTUe	159,7	36,8	122,9
Ecotoxicity, freshwater - metals	CTUe	352,5	340,2	12,3

5.1.4 PVC Cable with DIDP, antimony oxide (ATO)

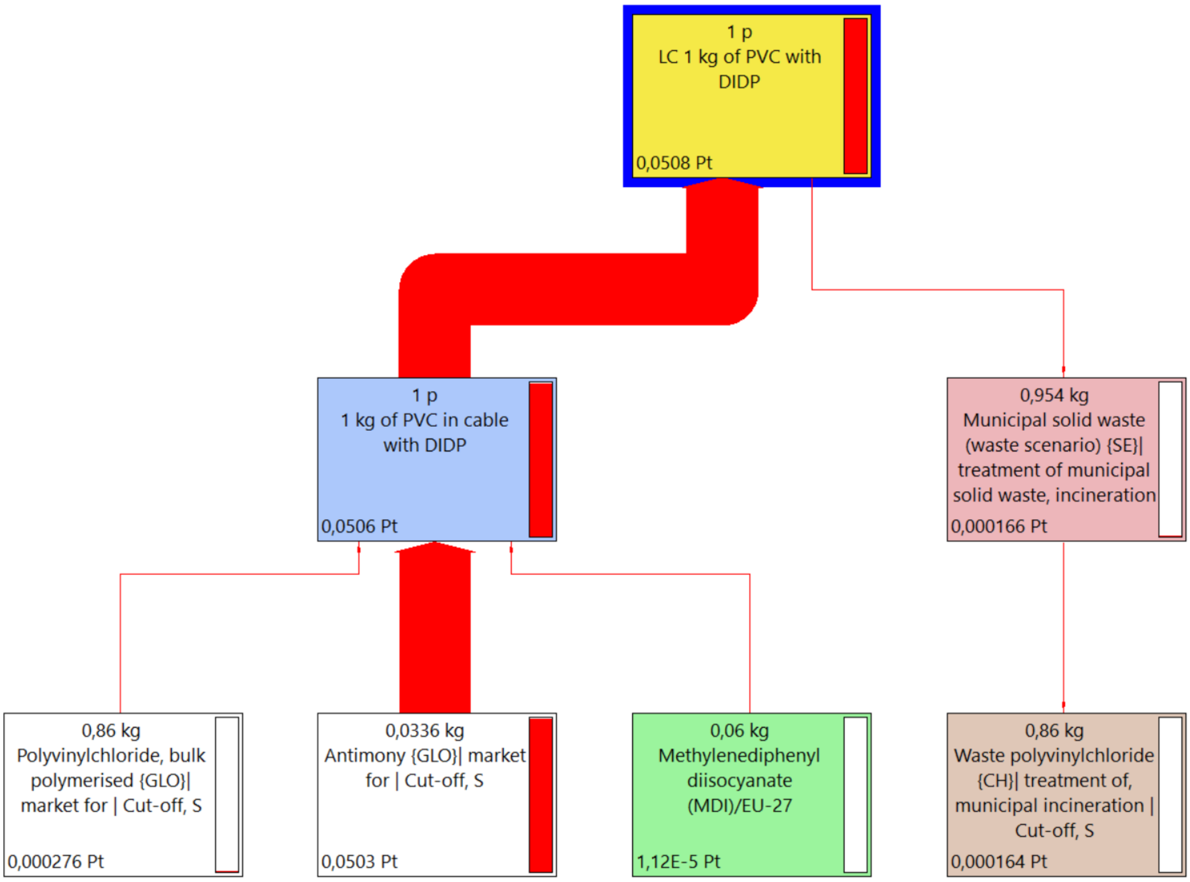


Figure 18 Sankey diagram. Environmental Footprint (single score) per lifecycle of 1 kg PVC cable insulation with DIDP. Cut off 0%.

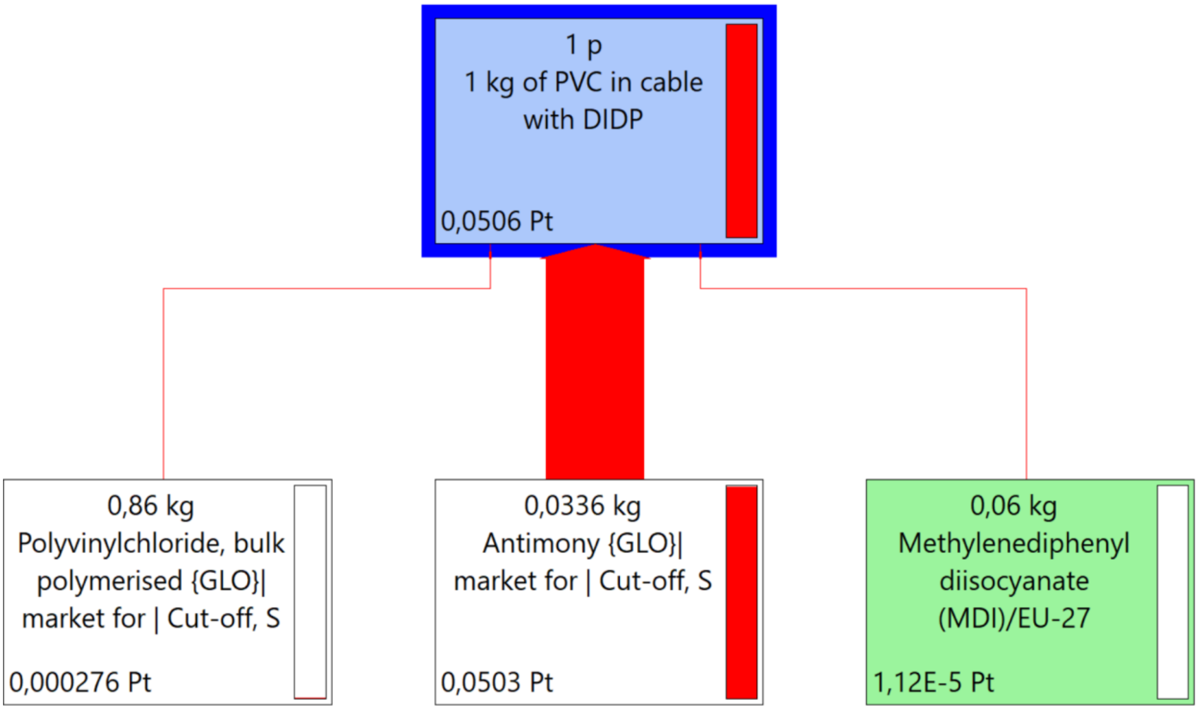


Figure 19 Sankey diagram. Environmental Footprint (single score) for 1 kg PVC cable insulation with DIDP. Cut off 0%.

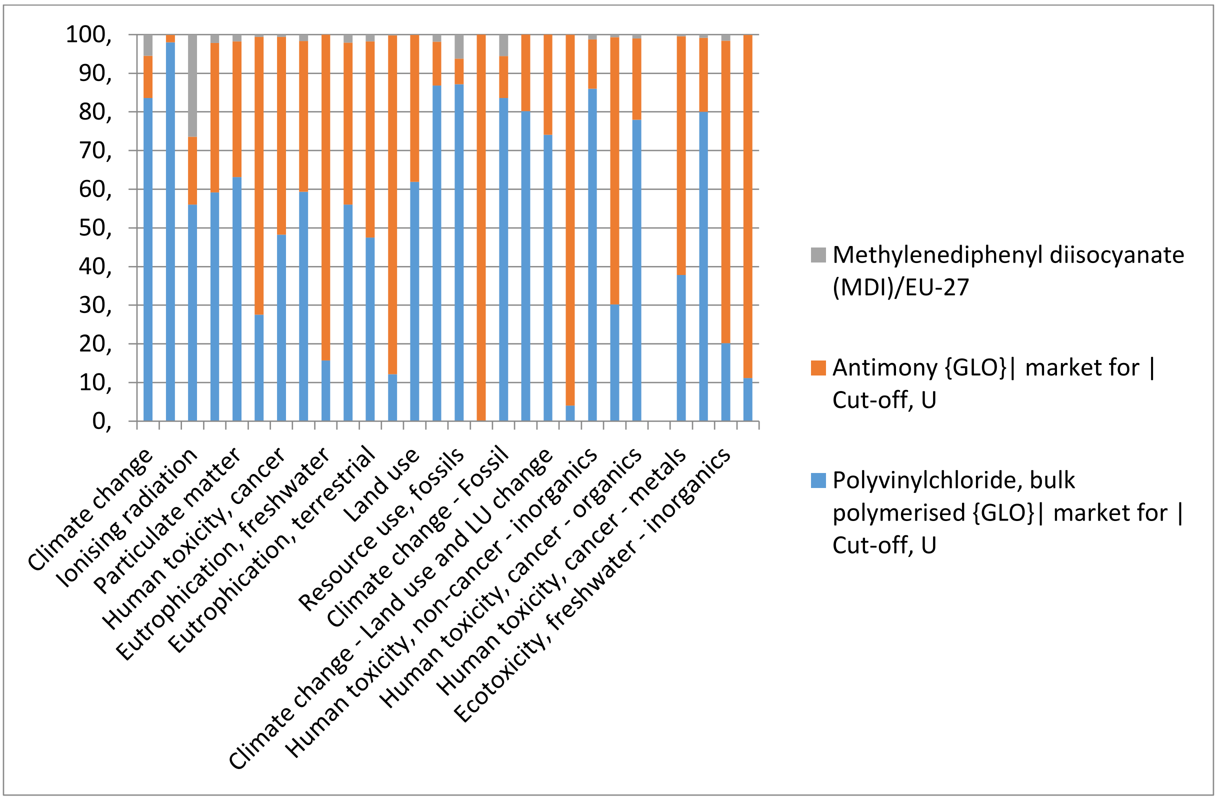


Figure 20 Environmental Footprint per impact category for 1 kg PVC cable insulation with DIDP.

Table 14 Environmental Footprint per impact category for 1 kg PVC cable insulation with DIDP.

IMPACT CATEGORY	UNIT	TOTAL	POLYVINYLCHLORIDE, BULK POLYMERISED {GLO}| MARKET FOR | CUT-OFF, U	ANTIMONY {GLO}| MARKET FOR | CUT-OFF, U	METHYLENEDIPHENYL DIISOCYANATE (MDI)/EU-27
CLIMATE CHANGE	kg CO2 eq	2,74	2,29	0,30	0,15
OZONE DEPLETION	kg CFC11 eq	0,00	0,00	0,00	0,00
IONISING RADIATION	kBq U-235 eq	0,28	0,16	0,05	0,07
PHOTOCHEMICAL OZONE FORMATION	kg NMVOC eq	0,01	0,01	0,00	0,00
PARTICULATE MATTER	disease inc.	0	0	0	0
HUMAN TOXICITY, NON-CANCER	CTUh	0	0	0	0
HUMAN TOXICITY, CANCER	CTUh	0	0	0	0
ACIDIFICATION	mol H+ eq	0,019	0,011	0,007	0,000
EUTROPHICATION, FRESHWATER	kg P eq	0,005	0,001	0,004	0,000
EUTROPHICATION, MARINE	kg N eq	0,004	0,002	0,002	0,000
EUTROPHICATION, TERRESTRIAL	mol N eq	0,05	0,02	0,02	0,00
ECOTOXICITY, FRESHWATER	CTUe	376,72	45,77	330,17	0,78
LAND USE	Pt	10,94	6,78	4,15	0,01

WATER USE	m3 depriv.	1,75	1,52	0,20	0,03
RESOURCE USE, FOSSILS	MJ	54,86	47,80	3,65	3,41
RESOURCE USE, MINERALS AND METALS	kg Sb eq	0,04	0,00	0,04	0,00
CLIMATE CHANGE - FOSSIL	kg CO2 eq	2,73	2,28	0,30	0,15
CLIMATE CHANGE - BIOGENIC	kg CO2 eq	0,01	0,01	0,00	0,00
CLIMATE CHANGE - LAND USE AND LU CHANGE	kg CO2 eq	0,0023	0,0017	0,0006	0,0000
HUMAN TOXICITY, NON-CANCER - ORGANICS	CTUh	0,0000	0,0000	0,0000	0,0000
HUMAN TOXICITY, NON-CANCER - INORGANICS	CTUh	0,0000	0,0000	0,0000	0,0000
HUMAN TOXICITY, NON-CANCER - METALS	CTUh	0,0000	0,0000	0,0000	0,0000
HUMAN TOXICITY, CANCER - ORGANICS	CTUh	0,0000	0,0000	0,0000	0,0000
HUMAN TOXICITY, CANCER - INORGANICS	CTUh	0,0000	0,0000	0,0000	0,0000
HUMAN TOXICITY, CANCER - METALS	CTUh	0,0000	0,0000	0,0000	0,0000
ECOTOXICITY, FRESHWATER - ORGANICS	CTUe	0,40	0,32	0,08	0,00
ECOTOXICITY, FRESHWATER - INORGANICS	CTUe	37,22	7,51	29,13	0,58
ECOTOXICITY, FRESHWATER - METALS	CTUe	339,10	37,94	300,96	0,20

5.1.5 Comparison of alternatives

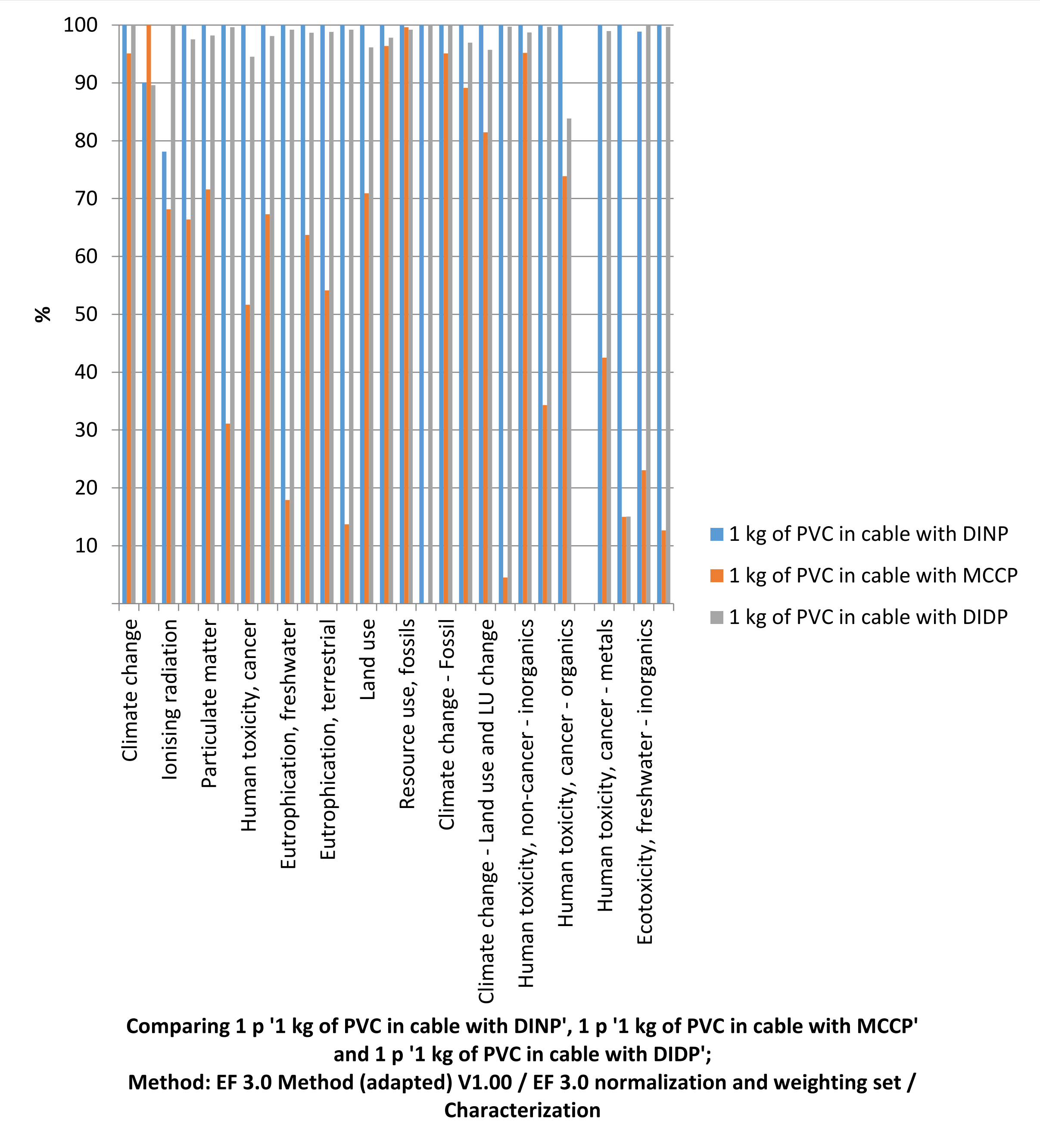


Figure 21 Environmental Footprint per impact category for PVC cable insulation with MCCP, DINP and DIDP.

Table 15 Environmental Footprint weighted score per impact category for PVC cable insulation with MCCP, DINP and DIDP.

IMPACT CATEGORY	UNIT	1 KG OF PVC IN CABLE WITH DINP	1 KG OF PVC IN CABLE WITH MCCP	1 KG OF PVC IN CABLE WITH DIDP
TOTAL	mPt	50,62	0,32	50,62
CLIMATE CHANGE	mPt	0,07	0,07	0,07
OZONE DEPLETION	mPt	0,00	0,00	0,00
IONISING RADIATION	mPt	0,00	0,00	0,00
PHOTOCHEMICAL OZONE FORMATION	mPt	0,01	0,01	0,01
PARTICULATE MATTER	mPt	0,02	0,02	0,02
HUMAN TOXICITY, NON-CANCER	mPt	0,01	0,00	0,01
HUMAN TOXICITY, CANCER	mPt	0,00	0,00	0,00
ACIDIFICATION	mPt	0,02	0,01	0,02
EUTROPHICATION, FRESHWATER	mPt	0,08	0,01	0,08
EUTROPHICATION, MARINE	mPt	0,01	0,00	0,01
EUTROPHICATION, TERRESTRIAL	mPt	0,01	0,01	0,01
ECOTOXICITY, FRESHWATER	mPt	0,17	0,02	0,17
LAND USE	mPt	0,001	0,001	0,001
WATER USE	mPt	0,013	0,013	0,013
RESOURCE USE, FOSSILS	mPt	0,07	0,07	0,07
RESOURCE USE, MINERALS AND METALS	mPt	50,12	0,07	50,12

Table 16 Environmental Footprint absolute score per impact category for PVC cable insulation with MCCP, DINP and DIDP.

IMPACT CATEGORY	UNIT	1 KG OF PVC IN CABLE WITH DINP	1 KG OF PVC IN CABLE WITH MCCP	1 KG OF PVC IN CABLE WITH DIDP
CLIMATE CHANGE	kg CO2 eq	2,7	2,6	2,7
OZONE DEPLETION	kg CFC11 eq	0,00	0,00	0,00
IONISING RADIATION	kBq U-235 eq	0,2	0,2	0,3
PHOTOCHEMICAL OZONE FORMATION	kg NMVOC eq	0,012	0,008	0,012
PARTICULATE MATTER	disease inc.	0,000	0,000	0,000
HUMAN TOXICITY, NON-CANCER	CTUh	0,000	0,000	0,000
HUMAN TOXICITY, CANCER	CTUh	0,000	0,000	0,000
ACIDIFICATION	mol H+ eq	0,019	0,013	0,019
EUTROPHICATION, FRESHWATER	kg P eq	0,005	0,001	0,005
EUTROPHICATION, MARINE	kg N eq	0,004	0,003	0,004
EUTROPHICATION, TERRESTRIAL	mol N eq	0,048	0,026	0,048
ECOTOXICITY, FRESHWATER	CTUe	379,7	52,1	376,7
LAND USE	Pt	11,4	8,1	10,9
WATER USE	m3 depriv.	1,8	1,7	1,8
RESOURCE USE, FOSSILS	MJ	55,3	55,1	54,9
RESOURCE USE, MINERALS AND METALS	kg Sb eq	0,04226	0,00006	0,04226
CLIMATE CHANGE - FOSSIL	kg CO2 eq	2,7	2,6	2,7
CLIMATE CHANGE - BIOGENIC	kg CO2 eq	0,0088	0,0079	0,0086
CLIMATE CHANGE - LAND USE AND LU CHANGE	kg CO2 eq	0,0024	0,0020	0,0023
HUMAN TOXICITY, NON-CANCER - ORGANICS	CTUh	0,0000	0,0000	0,0000
HUMAN TOXICITY, NON-CANCER - INORGANICS	CTUh	0,0000	0,0000	0,0000
HUMAN TOXICITY, NON-CANCER - METALS	CTUh	0,0000	0,0000	0,0000
HUMAN TOXICITY, CANCER - ORGANICS	CTUh	0,0000	0,0000	0,0000
HUMAN TOXICITY, CANCER - METALS	CTUh	0,0000	0,0000	0,0000
ECOTOXICITY, FRESHWATER - ORGANICS	CTUe	2,6	0,4	0,4
ECOTOXICITY, FRESHWATER - INORGANICS	CTUe	36,8	8,6	37,2

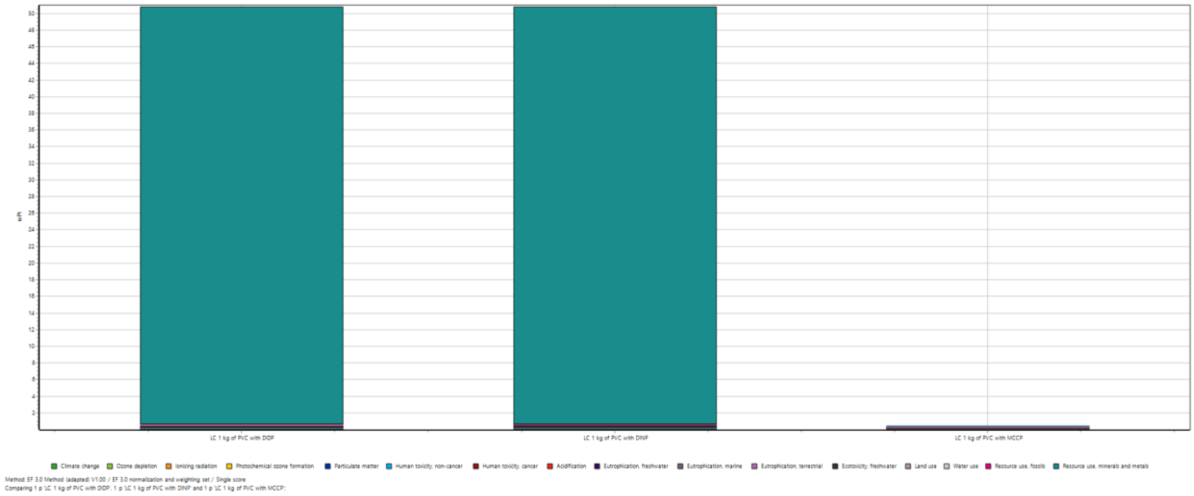


Figure 22 Comparison_Life cycle_1 kg of PVC with MCCP, DINP, DIDP_EF Single score

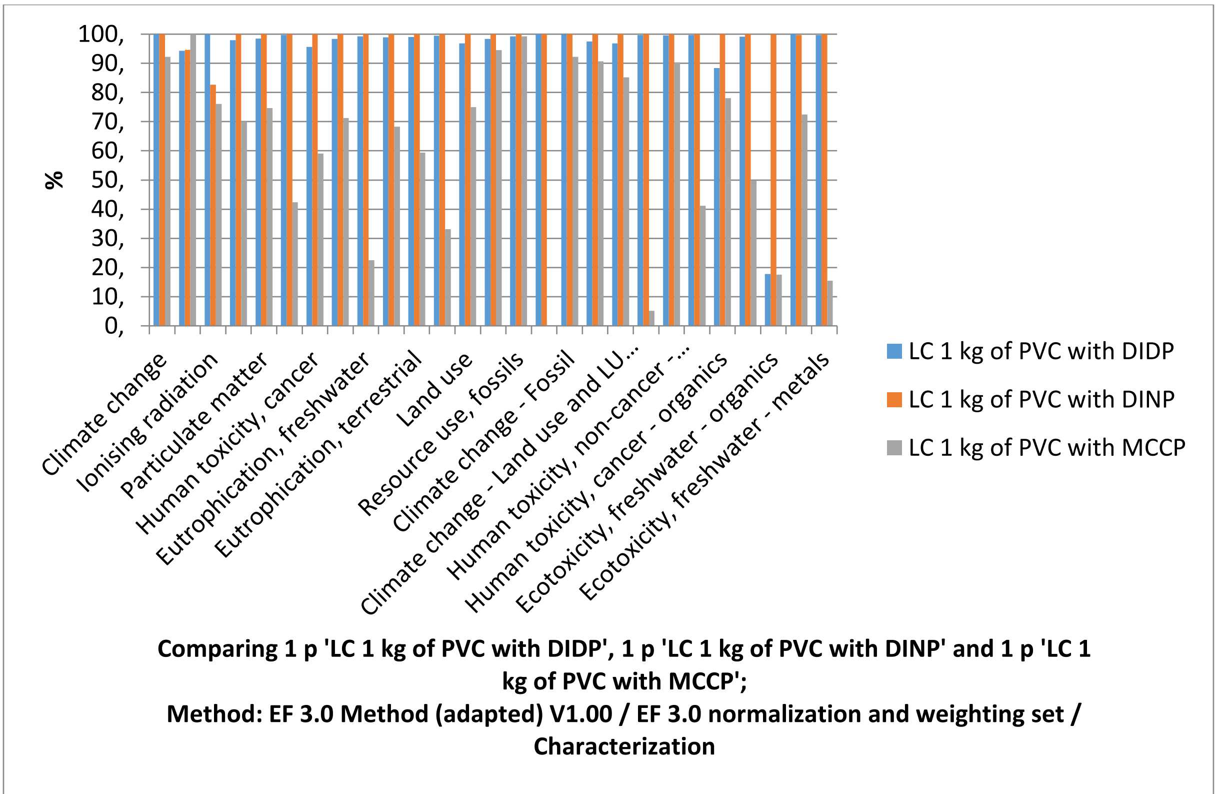


Figure 23 Comparison_Life cycle_1 kg of PVC with MCCP, DINP, DIDP_EF _per category

5.2 Method for impact assessment

The methods used for assessing the life cycle impact is called Environmental Footprint 2.0.

Some terms are used below that require clarification:

- Environmental aspect: An activity that might contribute to an environmental effect, for example "electricity usage".
- Environmental effect: An effect that might influence the environment negatively (Environmental impact), for example, "Acidification", "Eutrophication" or "Climate change".
- Environmental impact: The generated damage on a value we want to protect, for example damage on human health, biological diversity etc.

A simple example which incorporates all of the above could be a scenario, where a person drives 1km in a car. This scenario is a direct depiction of an environmental aspect with several different environmental impacts.

> An **environmental aspect** can be carbon dioxide emission. This can contribute to the **environmental effect** Global warming which might lead to the **environmental impact** of flooding, draught and landslide.
> Another environmental aspect could be the consumption of oil that contributes to the environmental effect of resource depletion.

5.2.1 Classification and characterization

Determining what an environmental aspect may contribute to is called *classification*, i.e. use of water contributes to water depletion. How much an aspect contributes to it is called *characterisation*, i.e. usage of 1 ton river water contributes by the factor 1 to water depletion.
Adjusting to how critical that is in a specific area depends on the current environmental load, pressure from resource consumption and the eco system´s carrying capacity. This is done through *normalisation*.

5.2.2 Weighting

To compare between different environmental effects and identifying "hot spots", a term called *weighting* is applied. The calculated environmental effect is weighted together to form an index called "*single score*" which describes the total environmental impact.
Because weighting involves subjective weighting (by an expert panel) it is recommended for internal communication only. The risk is mistrust if the choice of weighting method used leads to results which benefit the upsides and hide the "downsides for the analysed product. For external communication only *Single issues* should be communicated.

The Environmental Footprint method involves two stages of mechanism. The first stage is called classification and characterization and calculates how much an 'environmental aspect' contributes to a specific 'environmental effect'. Stage two mechanism is called weighting and calculates together all the results from stage one to create a summary result where each 'environmental effect' category is given a score, see Figure 15.

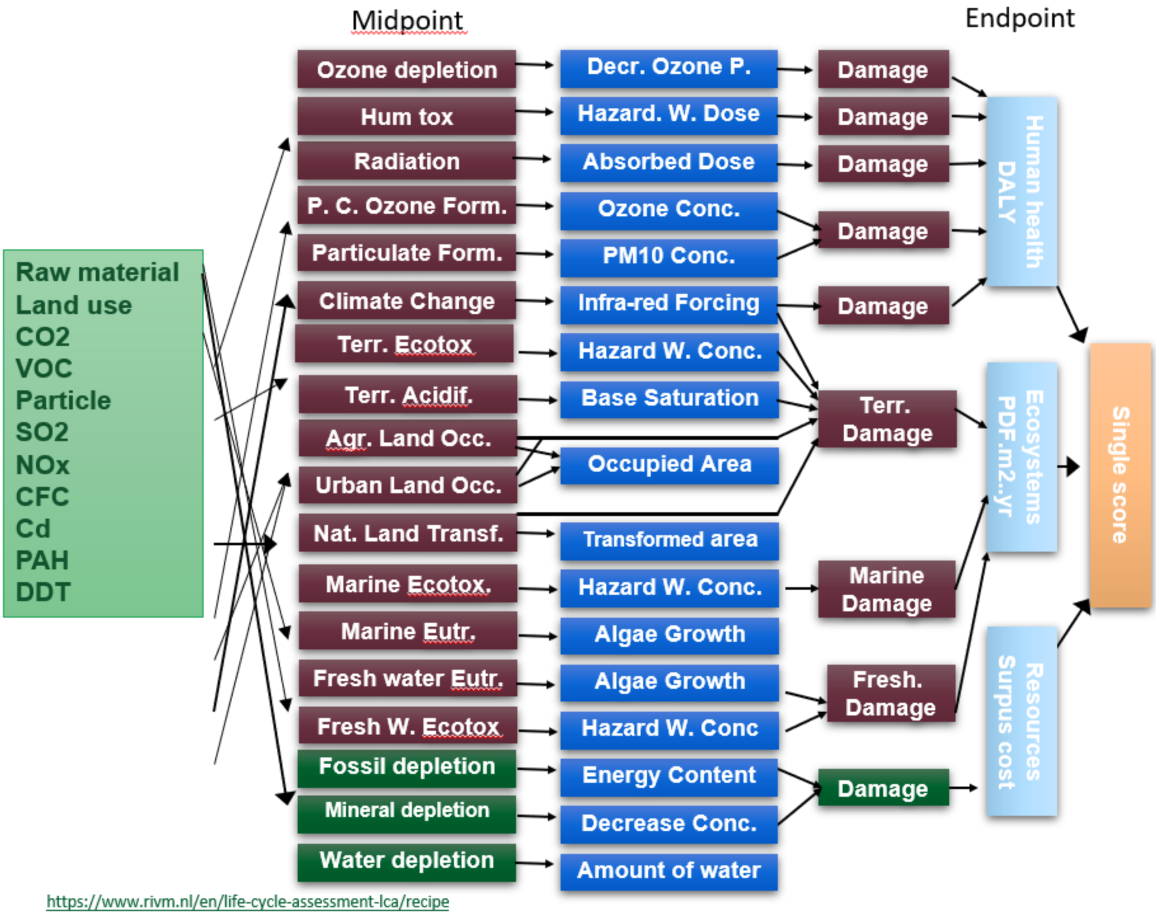


Figure 24, example of a harmonised midpoint-endpoint model for 18 environmental effects, linking to human health, ecosystem damage and resource depletion.

For example, in assessing the environmental impact of the activity 'driving a car', the aspects 'dust from road and tyres' (PM10 emissions) and 'combustion of gasoline' (CO_2 emissions) were assessed. Dust for the contribution to the environmental effect category “damage on respiratory organs” and combustion for the contribution to “climate change”. The results are two Midpoint scores. The two scores were then combined by calculating how much they contribute to damage the safeguard objects; Human health, Ecosystem and Resources, to arrive at the final endpoint, a single score.

For a more detailed description see Appendix 2.

5.2.3 Single issues

In contrast to weighted results which are the combined results from many different environmental effect categories, single issue focuses on just one issue. It is important to break out some single issues that are relevant for the analysed product both considering the environment and marketing. All the different environmental effect categories will still be accounted for in the weighted result.

IPCC 2013 is the successor of the IPCC 2007 method, which was developed by the Intergovernmental Panel on Climate Change. It contains the climate change factors of IPCC with a timeframe of 100 years and calculates the single issue climate change potential.

5.3 Impact categories

Environmental Footprint divides the whole environmental impact of the life cycle in 19 different impact categories. All these different categories represent different environmental aspects. Every aspect is then assigned points that represent how serious the environmental aspect is, the higher the score the more serious the environmental aspect. In the end all the different categories are added together to weigh the whole life cycle. The different categories with the connecting impact category unit can be seen in Table 17.

Table 17 impact category name and unit in environmental footprint 3.0.

Impact category name	*Unit*
Climate change	kg CO2 eq
Ozone depletion	kg CFC11 eq
Ionising radiation, HH	kBq U-235 eq
Photochemical ozone formation, HH	kg NMVOC eq
Respiratory inorganics	disease inc.
Non-cancer human health effects	CTUh
Cancer human health effects	CTUh
Acidification terrestrial and freshwater	mol H+ eq
Eutrophication freshwater	kg P eq
Eutrophication marine	kg N eq
Eutrophication terrestrial	mol N eq
Ecotoxicity freshwater	CTUe
Land use	Pt
Water scarcity	m3 depriv.
Resource use, energy carriers	MJ
Resource use, mineral and metals	kg Sb eq
Climate change - fossil	kg CO2 eq
Climate change - biogenic	kg CO2 eq
Climate change - land use and transform.	kg CO2 eq

Climate change: Climate change causes a number of environmental mechanisms that affect both the endpoint human health and ecosystem health. Climate change models are in general developed to assess the future environmental impact of different policy scenarios. Baseline model of the IPCC 2013 + some factors Calculated from JRC.
For further reading about substances relevant as “green house gases” refer to Wikipedia[13].

Impact indicator: Global Warming Potential 100 years

Ozone layer: The characterisation factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). These are recalcitrant chemicals that contain chlorine or bromine atoms. Because of their long atmospheric lifetime they are the source of chlorine and bromine reaching the stratosphere. Chlorine atoms in chlorofluorocarbons (CFC) and bromine atoms in halons are effective in degrading ozone due to heterogeneous catalysis, which leads to a slow depletion of stratospheric ozone around the globe.

Impact indicator: Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.

[13] Greenhouse gas - Wikipedia

Ionizing radiation: This describes the damage to Human Health related to the routine releases of radioactive material to the environment.

Impact indicator: Ionizing Radiation Potentials: Quantification of the impact of ionizing radiation on the population, in comparison to Uranium 235.

Photochemical ozone formation: Impact indicator: Photochemical ozone creation potential (POCP): Expression of the potential contribution to photochemical ozone formation.

Impact indicator: Photochemical ozone creation potential (POCP): Expression of the potential contribution to photochemical ozone formation.

Respiratory inorganics: Fine Particulate Matter with a diameter of less than 2,5 μm (PM2,5) represents a complex mixture of organic and inorganic substances. PM2,5 causes health problems as it reaches the upper part of the airways and lungs when inhaled. Secondary PM2,5 aerosols are formed in air from emissions of sulphur dioxide (SO2), ammonia (NH3), and nitrogen oxides (NOx) among others (World Health Organisation, 2003). Inhalation of different particulate sizes can cause different health problems.

Impact indicator: Disease incidence due to kg of PM2.5 emitted

Cancer human health effects: Impact indicator: Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme).
USEtox consensus model (multimedia model). No spatial differentiation beyond continent and world compartments. Specific groups of chemicals require further works (cf. details in other sections).

Impact indicator: Comparative Toxic Unit for human (CTUh) expressing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogramme).

Acidification: Atmospheric deposition of inorganic substances, such as sulphates, nitrates, and phosphates, cause a change in acidity in the soil. For almost all plant species there is a clearly defined optimum of acidity. A serious deviation from this optimum is harmful for that specific kind of species and is referred to as acidification. As a result, changes in levels of acidity will cause shifts in species occurrence (Goldcorp and Spriensma, 1999, Hayashi et al. 2004). Major acidifying emissions are NOx, NH3, and SO2

Impact indicator: Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems, to which acidifying substances deposit.

Eutrophication: Aquatic eutrophication can be defined as nutrient enrichment of the aquatic environment. Eutrophication in inland waters as a result of human activities is one of the major factors that determine its ecological quality. On the European continent it generally ranks higher in severity of water pollution than the emission of toxic substances. Aquatic eutrophication can be caused by emissions to air, water and soil. In practice the relevant substances include phosphorus and nitrogen compounds emitted to water and soil as well as ammonia (NH3) and nitrogen oxide (NOx) emitted to air.

Impact indicator freshwater: Phosphorus equivalents: Expression of the degree to which the emitted nutrients reaches the freshwater end compartment (phosphorus considered as limiting factor in freshwater).

Impact indicator: Nitrogen equivalents: Expression of the degree to which the emitted nutrients reaches the marine end compartment (nitrogen considered as limiting factor in marine water).

Impact indicator: Accumulated Exceedance (AE) characterizing the change in critical load exceedance of the sensitive area, to which eutrophying substances deposit.

Ecotoxicity freshwater Impact indicator: Comparative Toxic Unit for ecosystems (CTUe) expressing an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m3 year/kg).

Land occupation: The land use impact category reflects the damage to ecosystems due to the effects of occupation and transformation of land. Although there are many links between the way land is used and the loss of biodiversity, this category concentrates on the following mechanisms:
1. Occupation of a certain area of land during a certain time;
2. Transformation of a certain area of land.
Both mechanisms can be combined, often occupation follows a transformation, but often also occupation occurs in an area that has already been converted (transformed). In such cases the transformation impact is not allocated to the production system that occupies an area.

The soil quality index is the result of the aggregation, performed by JRC, of the 4 indicators provided by the LANCA model as indicators for land use (Fazio et al. 2018). The four indicators biotic production, groundwater replenishment, erosion resistance and mechanical filtration are aggregated in a dimensionless soil quality index (SQI).

Impact indicator: Soil quality index

Water scarcity: Water is a scarce resource in many parts of the world, but also an abundant resource in other parts of the world. Unlike other resources there is no global market that ensures a global distribution. The market does not really work over big distances as transport costs are too high. Extracting water in a dry area can cause very significant damages to ecosystems and human health.

Impact indicator: m3 water eq. deprived.

Resource use: ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). Depletion model based on use-to-availability ratio. Full substitution among fossil energy carriers is assumed.

ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, v. 4.8 (2016). Depletion model based on use-to-availability ratio. Full substitution among fossil energy carriers is assumed.

Impact indicator: Abiotic resource depletion fossil fuels (ADP-fossil); based on lower heating value
Impact indicator: Abiotic resource depletion (ADP ultimate reserve)

5.4 LCA Software

The software SimaPro 9.1 [5] was used during the completion of this study.

SimaPro, developed by PRé Consultants, is the world's leading LCA software chosen by industry, research institutes and consultants in more than 80 countries. SimaPro is a powerful tool for calculations of complex product systems and in-depth comparisons of life cycles with documentation that conform to the ISO 14000 standard.

6 Interpretation

6.1 Conclusions

The comparison indicate that MCCP has lower environmental impact than the alternatives, in all categories of impact categories.
The available information was limited from the manufacturers of PVC insulation and also for the alternatives to MCCP. Some assumptions are made that have relevant uncertainties. Especially the amount of Flame retardant used.
The information about MCCP shows clearly that the dominant aspects are production of raw material Chlorine and Paraffin. In order to reduce the risk of MCCP ending up in the ecosystems, it is critical to have strict control over the end of life of PVC insulated cables with MCCP.

7 References

Baumann, H., & Tillman, A. (2004). *Liftarens guide till LCA.* Lund, Sweden: Studentlitteratur ISBN: 91-44-02364-2.

Carlsson, R., & Pålsson, A.-C. (2011). *Livscykelanalys – ringar på vattnet.* . SIS Förlag 978-91-7162-652-3.

Commission, E. (2019). *PHOTOVOLTAIC MODULES USED IN PHOTOVOLTAIC POWER SYSTEMS FOR ELECTRICITY GENERATION.* European Commission.

ecoinvent, Hirschier, R., Weidema , B., Althaus , H.-J., Bauer , C., Doka , G., . . . Wernet , G. (2009). *Code of practice. ecoinvent report No. 2.* St. Gallen: Swiss Centre for Life Cycle Inventories.

Fazio, S. C. (2018). *Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods.* European Commission, Ispra, 2018, ISBN 978-92-79-76742-5.

Frischknecht, R. e. (2003). *Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent 2000.* Duebendorf, CH: Swiss Centre for LCI. Hämtat från www.ecoinvent.ch

Frischknecht, R., Jungbluth, N., Althaus, H., Doka, G., Dones, R., Hischier, R., . . . Spielmann, M. (2007). *Implementation of Life Cycle Impact Assessment Methods: Data v2.0. ecoinvent report No. 3.* Dübendorf, Switzerland: Swiss centre for Life Cycle Inventories.

Goedkoop, M., Heijungs, R., Huijbregts, M., Schryver, A., Struijs, J., & Zelm, R. v. (2009). *ReCiPe 2008-A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level.* Holland.

Guinée, J., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., Koning, A. d., . . . Sleeswijk, A. (2004). *Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards.* Kluwer Academic Publications.

Hirschier, R., Weidema , B., Althaus , H.-J., Bauer , C., Doka , G., Dones , R., . . . Wernet , G. (2015). Code *of practice. ecoinvent report No. 3.2.* St. Gallen: Swiss Centre for Life Cycle Inventories.

ISO. (2002). *Environmental management — Life cycle assessment — Data documentation format. ISO/TS 14048:2002.* Generva, Switzerland: International Organization for Standardization.

ISO. (2006a). *Environmental Management – Life cycle assessment – Principles and framework. 14040:2006.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2006b). *Environmental Management – Life cycle assessment – Requirements and guidelines ISO 14044:2006.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2012b). *Environmental management -- Life cycle assessment -- Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis. ISO/TR 14049:2012.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2014a). *Environmental management—water footprint—principles, requirements and guidelines. ISO 14046:2014.* Geneva, Switzerland: International Organization for Standardization.

ISO. (2014b). *Environmental management—life cycle assessment—requirements and guidelines for organizational life cycle assessment. ISO/TS 14072:2014.* Geneva, Switzerland: International Organization for Standardization.

Declarations, E. P., & Manufacturers, E. P. (2015). Eco-profiles and Environmental Product Declaration of the European Plastics Manufactures. Di-isononyl phtalate (DINP) ECPI January 2015. *ECPI European Council for Plasticiser and Intermediates, January*, 1–31.

EFCR. (2015). *EPD Concrete admixtures Plasticisers and Superplasticisers*.

Elkretsen. (2020). *Avfall Till Resurs* (p. 32). Elkretsen.

Ernstoff, F. and. (2018). *LCA of Chemicals and Chemical Products*. https://doi.org/10.1007/978-3-319-56475-3

Glüge, J., Schinkel, L., Hungerbühler, K., Cariou, R., & Bogdal, C. (2021). *Environmental Risks of Medium-Chain Chlorinated ParaDns (MCCPs): A Review Terms & Conditions*. 1–5. https://doi.org/10.1021/acs.est.7b06459

Gmbh, P. E. E. (n.d.). *Final Report - Life Cycle Assessment (LCA) of PVC and of principal competing materials*.

Guida, Y., Capella, R., & Weber, R. (2020). Chlorinated paraf fi ns in the technosphere : A review of available information and data gaps demonstrating the need to support the Stockholm Convention implementation. *Emerging Contaminants*, *6*, 143–154. https://doi.org/10.1016/j.emcon.2020.03.003

Hischier, R., Hellweg, S., Capello, C., & Primas, A. (2005). *ecoinvent : Materials and Agriculture Establishing Life Cycle Inventories of Chemicals Based on Differing Data Availability*. *10*(Lci), 59–67.

Instructions 3.01, G. P. (5830). *International EPD® System*. http://www.environdec.com/

ISO. (2006). ISO 14044:2006. *Environmental Management - Life Cycle Assessement - Requirements and Guidelines, ISO 14044, International Organization for Standardization*. https://doi.org/10.1007/s11367-011-0297-3

Li, Y. (2013). *Life Cycle Assessment To Di-2-Ethylhexyl Phthalate (DEHP), Applications and Potential Alternatives*. 94.

Michael Spielmann, Christian Bauer, Roberto Dones, P. S. I., & Matthias Tuchsmid, E. L. (2007). Transport Services Data v2. In *Transport Services Data v2* (Vol. 3, Issue 5). https://doi.org/10.1016/0140-3664(80)90150-4

Mourik, V. (2019). *Chapter 2 Chlorinated paraffins in the*.

Nyström, J. (2019). *The OSPAR list of chemicals for priority action Suggestions for future actions* (pp. 1–70). Osbar Commission. https://www.ospar.org/documents?v=40953

Rosa Cuellar Franca, H. J. and A. A. (2014). *LCA of Cereclor by INEO*.

Samani, P., & van der Meer, Y. (2020). Life cycle assessment (LCA) studies on flame retardants: A systematic review. *Journal of Cleaner Production*, *274*, 123259. https://doi.org/10.1016/j.jclepro.2020.123259

The International EPD® System. (2015). *General introduction to product category rules in the international EPD system* (pp. 1–19). The International EPD® System.

Wendin, M., & Jakobsson, M. (2019). *VERIFIERING FÖR HÅLLBAR TILLVÄXT - METODRAPPORT: Vol. 1.0*. https://doi.org/10.13140/RG.2.2.18586.29124

8 Appendix

Appendix 1, Methods for Impact Assessment

Classification

Classification means that all categories of data are sorted into different categories of environmental effects. Readymade methods for this have been used in order to evaluate a broader perspective and find the most potential categories. The mostly used methods being Ecoindicator and EPS. These methods include also characterisation (and weighting described further).

The aim with the characterisation is to quantify each element's contribution to the different categories of environmental effect, respectively. To do this, each category of environmental effect is multiplied with characteristic factors which are specific for the data- and the category of environmental effect. The result from the characterisations gives answer about what or which emissions that leads to a significant environmental influence. For each characteristic factor calculates the potential environmental influence which could arise if an element released to the environmental or if a resource is consumed.

Classification and characterisation are where all items in the inventory are assigned to the effect it is likely to have on the environment.

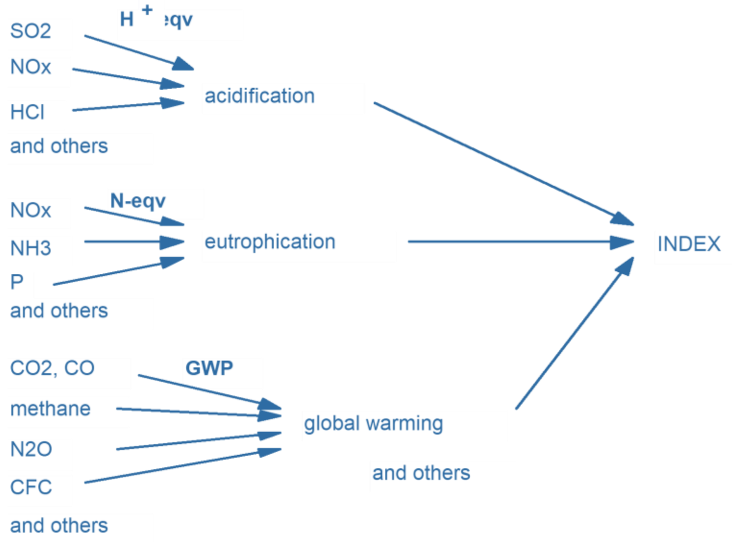


Figure 25: An illustration of the Impact Assessment of an LCA.

When this link is determined, we call it an environmental aspect. This environmental aspect has to be linked between the environment and the process before you can say that it is established and that the process is unsustainable. In the early stages of Lifecycle Assessment substances that were found in the inventory was assigned to environmental aspects. In order to reach for the ultimate goal of sustainability, it is important also to describe the local and global environment. Environmental aspects that may have an impact are located and after that, the link to the inventory and to the process path features may be analysed and established.

Weighting
The results of an LCA may depend on the method for impact assessment. There are a few different models to assist in the assessment of the environmental impacts connected to the life cycle, e.g. ecological scarcity (ECO), the environmental theme method (ET), ECO indicator (EI), ReCiPe and the Environmental Priority Strategies in Product Design (EPS) method.
Weighting method implies that all of the data classes are weighted together so that only one number is expressed for the weighting method. The different data categories are weighed from some form of valuations principle. The basis of valuation could be either individual or a community's political and/or morality valuations. The weighting expresses the relation between values in the community and variations in nature. The more effect or deviation an environmental aspect has from the valuations, the higher weighting value gets the environmental aspect [Lindahl et al. (2002)].
The basis of valuations which are used to develop weighting methods could be; political decisions, technical-financial conditions, nature conditions, effects of the health, panels, and studies of behavioural patterns. In a weighting method, there is either one or a combination of valuation basis. Since the basis of valuations varying for each weighting method, a comparison between different methods will give a shifting in the result [Lindahl et al. (2002)].
The mostly used weighting methods are collected in the book "The Hitch Hiker's Guide to LCA", written by Baumann H. & Tillman A-M. (2004), and the most important are presented below:
Ecoindicator'99: is a weighting method based on the distance-to-target principle, and the target is established as environmental critical loads 5 % ecosystem degeneration, or similar. Ecoindicator'99 are determined from three different cultural perspectives; hierarchism, egalitarian and individualist. Average value from the three cultural perspectives has been calculated and is used in this study. Ecoindicator'99 is based on Goedkoop and Spriensma (1999) [Baumann H. & Tillman A-M. (2004)].
EPS 2000: is different from the two other weighting methods above in that case that it is not based on the distance-to-target principle. Instead, this method is based on the willingness-to-pay for avoiding damages on environmental safeguard subjects. The EPS method is especially suitable for the assessment of global impacts, such as climate change potential and resource depletion. The EPS indices are prepared by a group at the Chalmers University of Technology and a steering committee from the industry in Sweden.

Impact assessment method ReCiPe

ReCiPe LCIA Methodology Life cycle assessment (LCA) is a methodological tool used to quantitatively analyse the life cycle of products/activities. ISO 14040 and 14044 provide a generic framework.
After goal and scope has been determined, data has been collected, an inventory result is calculated. This inventory result is usually a very long list of emissions, consumed resources and sometimes other items. The interpretation of this list is difficult. An LCIA procedure, such as the ReCiPe method is designed to help with this interpretation.
The primary objective of the ReCiPe method is to transform the long list of inventory results, into a limited number of indicator scores. These indicator scores express the relative severity on an environmental impact category. In ReCiPe we determine indicators at two levels:

Eighteen midpoint indicators
Three endpoint indicators

ReCiPe uses an environmental mechanism as the basis for the modelling. An environmental mechanism can be seen as a series of effects that together can create a certain level of damage to, for instance, human health or ecosystems. For instance, for climate change, we know that a number of substances increase the radiative forcing. This means heat is prevented from being radiated from the Earth to space. As a result, more energy is trapped on Earth, and temperature increases. As a result of

this we can expect changes in habitats for living organisms, and as a result of this species may go extinct.
From this example, it is clear that the longer one makes this environmental mechanism, the higher the uncertainties get. The radiative forcing is a physical parameter that can be relatively easily measured in a laboratory. The resulting temperature increase is less easy to determine, as there are many parallel positive and negative feedback. Our understanding of the expected change in habitat is also not complete, etc.

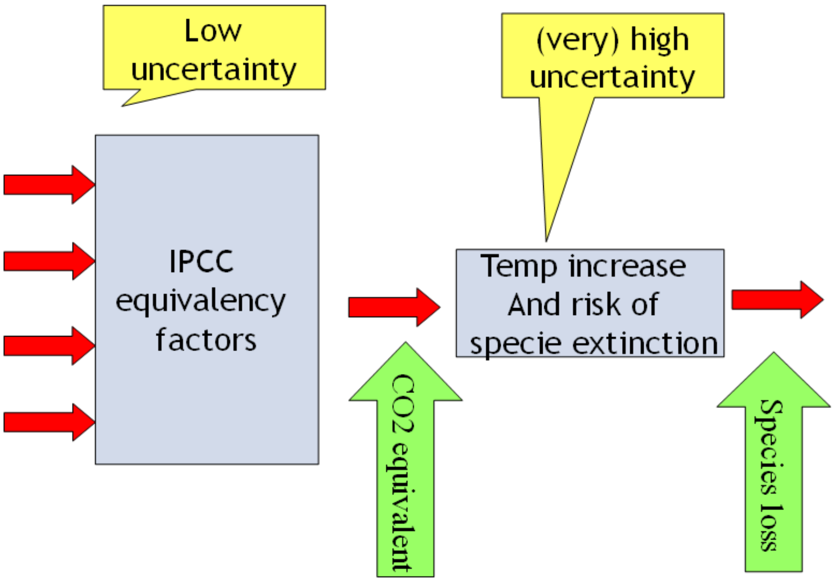


Figure26: Example of a harmonised midpoint-endpoint model for climate change, linking to human health and ecosystem damage.

So the obvious benefit of taking only the first step is the relatively low uncertainty.
ReCiPe combines mid- and endpoints
In ReCiPe we indeed calculate eighteen of such midpoint indicators, but also calculate three much more uncertain endpoint indicators. The motivation to calculate the endpoint indicators is that the large number of midpoint indicators is very difficult to interpret, partially as there are too many, partially because they have a very abstract meaning. How to compare radiative forcing with base saturation numbers that express acidification? The indicators at the endpoint level are intended to facilitate easier interpretation, as there are only three, and they have a more understandable meaning
The idea is that each user can choose at which level it wants to have the result:

Eighteen robust midpoints, that are relatively robust, but not easy to interpret
Three easy to understand, but more uncertain endpoints:
Damage to Human health
Damage to ecosystems
Damage to resource availability

The user can thus choose between uncertainty in the indicators, and uncertainty on the correct interpretation of indicators.
The figure below provides the overall structure of the method

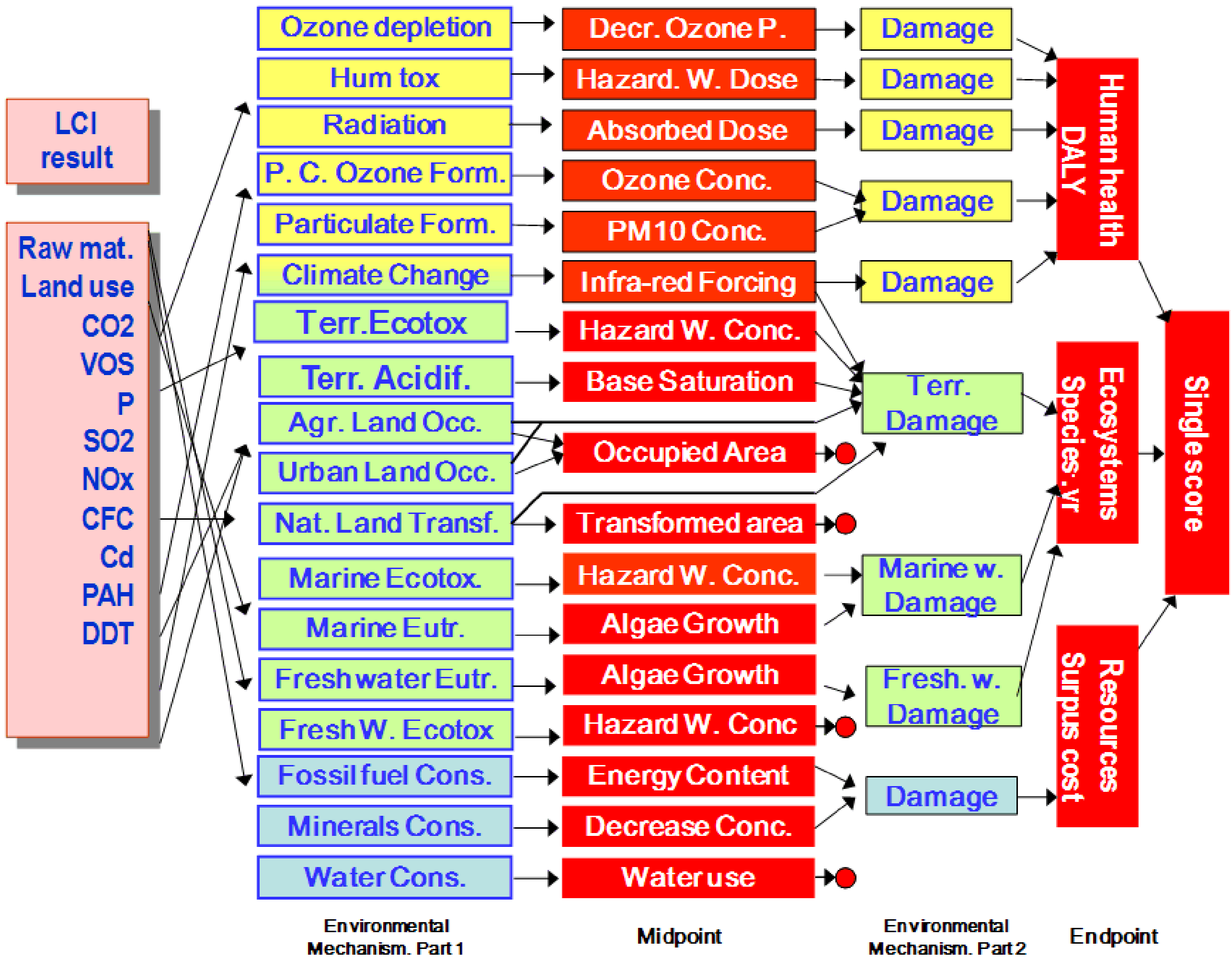


Figure27: ReCiPe Characterisation links.

A closer description of the different environmental effect categories calculated with ReCiPe Method can be seen below:

Climate change: Climate change causes a number of environmental mechanisms that affect both the endpoint human health and ecosystem health. Climate change models are in general developed to assess the future environmental impact of different policy scenarios. For ReCiPe 2008, we are interested in the marginal effect of adding a relatively small amount of CO2 or other greenhouse gasses, and not the impact of all emissions.

Ozone layer: The characterisation factor for ozone layer depletion accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone depleting substances (ODS). These are recalcitrant chemicals that contain chlorine or bromine atoms. Because of their long atmospheric lifetime they are the source of Chlorine and Bromine reaching the stratosphere. Chlorine atoms in chlorofluorocarbons (CFC) and bromine atoms in halons are effective in degrading ozone due to heterogeneous catalysis, which leads to a slow depletion of stratospheric ozone around the globe.

Acidification: Atmospheric deposition of inorganic substances, such as sulphates, nitrates, and phosphates, cause a change in acidity in the soil. For almost all plant species there is a clearly defined optimum of acidity. A serious deviation from this optimum is harmful to that specific kind of species and is referred to as acidification. As a result, changes in levels of acidity will cause shifts in species occurrence (Goldcorp and Spriensma, 1999, Hayashi et al. 2004). Major acidifying emissions are NOx, NH3, and SO2

Eutrophication: Aquatic eutrophication can be defined as nutrient enrichment of the aquatic environment. Eutrophication in inland waters as a result of human activities is one of the major factors that determine its ecological quality. On the European continent, it generally ranks higher in the severity of water pollution than the emission of toxic substances. Aquatic eutrophication can be caused by emissions to air, water and soil. In practice, the relevant substances include phosphorus and nitrogen compounds emitted to water and soil as well as ammonia (NH3) and nitrogen oxide (NOx) emitted to air.

Toxicity: The characterisation factor of human toxicity and ecotoxicity accounts for the environmental persistence (fate) and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. Fate and exposure factors can be calculated by means of 'evaluative' multimedia fate and exposure models, while effect factors can be derived from toxicity data on human beings and laboratory animals (Hertwich et al., 1998; Huijbregts et al., 2000).

Particulate matter formation: Fine Particulate Matter with a diameter of smaller than ten μm (PM10) represents a complex mixture of organic and inorganic substances. PM10 causes health problems as it reaches the upper part of the airways and lungs when inhaled. Secondary PM10 aerosols are formed in air from emissions of sulphur dioxide (SO2), ammonia (NH3), and nitrogen oxides (NOx) among others (World Health Organisation, 2003). Inhalation of different particulate sizes can cause different health problems.

Land occupation: The land use impact category reflects the damage to ecosystems due to the effects of occupation and transformation of the land. Although there are many links between the way land is used and the loss of biodiversity, this category concentrates on the following mechanisms:
1. Occupation of a certain area of land during a certain time;
2. Transformation of a certain area of land.
Both mechanisms can be combined, often occupation follows a transformation, but often occupation occurs in an area that has already been converted (transformed). In such cases, the transformation impact is not allocated to the production system that occupies an area.

Ionising radiation: This describes the damage to Human Health related to the routine releases of radioactive material to the environment.

Water depletion: Water is a scarce resource in many parts of the world, but also a very abundant resource in other parts of the world. Unlike other resources, there is no global market that ensures a global distribution. The market does not really work over big distances as transport costs are too high. Extracting water in a dry area can cause very significant damages to ecosystems and human health.

Fossil depletion: The term fossil fuel refers to a group of resources that contain hydrocarbons. The group ranges from volatile materials (like methane) to liquid petrol, to non-volatile materials (like coal). There is a highly politicised debate on the availability of conventional (liquid) oil, and this makes it difficult to obtain reliable, unbiased data. The spectrum of views ranges from the Peak-oil movement (www.aspo.org or peak-oil.com) to international organisations like the International Energy Agency (IEA), or commercial organisations like the Cambridge Energy Research Agency (CERA). Therefore it is hard to determine the seriousness of the depletion of oil, and which model to use, for this category, the IEA model is used.

Appendix 2, IPCC 2013

Direct solar radiation heats the Earth. The heated crust emits heat radiation which partially are absorbed by gases, known as greenhouse gases, in the Earth's atmosphere. Some of this heat radiation rays back to Earth and heat the Earth. This natural greenhouse effect is essential for life on Earth. However, because of human activity, the presence of greenhouse gases in the atmosphere, such as carbon dioxide, methane, and nitrous oxide, have increased. This affects the natural radiation balance, which leads to global warming and climate changes.

The potential impact on the climate is calculated using the IPCC 2013 GWP 100 v.1.03 (IPCC, 2013), model Global Warming Potential, GWP. The impact of climate gases is expressed as carbon dioxide equivalents, CO2 eq. It is the most established scientific method. It has been implemented in other methods, such as GHG protocol and ReCiPe, but then with adaptions.

Appendix 3, Cumulative Energy Demand, CED

Cumulative Energy Demand (CED) is a method to calculate direct and indirect use of energy resources, commonly referred to as *primary energy*. Characterisation factors are given for the energy resources divided into five impact categories:

- Non-renewable, fossil
- Non-renewable, nuclear
- Renewable, biomass
- Renewable, wind, solar, geothermal
- Renewable, water

Some studies add also energy from waste as an indicator. This is not done here and thus input of energy resources might be less than the end energy (heat and electricity) delivered by the system.

Normalisation is not a part of this method. To get a total ("cumulative") energy demand, each impact category is given the weighting factor 1 (Frischknecht, et al., 2007).

Appendix 4, ecoinvent

Ecoinvent is one of the world-leading databases with consistent, open, and updated Life Cycle Inventory Data (LCI).

With several thousand LCI data sets in the fields of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction and packaging materials, basic and precious metals, metals, IT and electronics and waste management, ecoinvent offers the most comprehensive international LCI database.

Ecoinvents high-quality LCI data sets are based on industrial data and have been compiled by internationally recognised research institutes and LCA consultants.

Appendix 5, SimaPro model