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Final Report

Life Cycle Assessment of PVC and of principal competing materials

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Nomenclature

Abbreviation	**Explanation**
ABS	Acryl-Butadiene-Styrene
AETP	Aquatic Eco-Toxicity Potential
AgPR GbR	Arbeitsgemeinschaft PVC-Bodenbelag-Recycling
AP	Acidification Potential
APME	Association of Plastic Manufacturers in Europe
ARGUS	Arbeitsgruppe Umwelt Statistik TU Berlin
ATBC	O-Acetyl Tributyl Citrate
BAT	Best Available Technology
BBP	Butyl-Benzyl Phthalate
B-PET	Hydroxyl end group Blocked PET
BUWAL	Swiss Agency for the Environment, Forests and Landscape
CAV	Critical Air Volume
CEPI	Confederation of European and Paper Industries
CML	Centrum voor Milieukunde, Universiteit Leiden
COC	Cyclic Olefin Copolymer
COD	Chemical Oxygen Demand
CSERGE	Centre for Social and Economic Research on the Global Environment
CSG	Council of State Governments
CSTEE	Scientific Commitee On Toxicity, Ecotoxicity and The Environment
DBP	Di-Butyl Phthalate
DEHA	Di-2-Ethylhexyl Adipate
DEHP	Di-2-Ethylhexyl Phthalate
DETR	Department of Environment, Transport and the Regions
DFE	Design for Environment
DIDP	Di-Isodecyl Phthalate
DINP	Di-isononyl Phthalate
DSD	Duales System Deutschland AG
ECPI	European Council for Plastics
ECVM	European Council of Vinyl Manufacturers
EDC	Dichloroethane
EDIP	Environment-Dependent Interatomic Potential
EEA	Ethyle Ethyl Acrylate
EoL	End of Life
EP	European Parliament
EPA	Environmental Protection Agency
EPDM	Ethylene-Propylene-Elastomers
EPS	Expanded Polystyrene
E-PVC	Emulsion Polyvinyl Chloride
ESPA	European Stabilisers Producers Association
EU	European Union
EuPC	European Plastic Converters
EVA	Ethylene-Vinylacetate-Copolymers
EVC	European Vinyl Corporation
FEFCO	European Federation of Corrugated Board Manufacturers
FR	Flame Retardant
GWP	Global Warming Potential

Abbreviation	**Explanation**
HDPE	High Density Polyethylene
HTP	Human Toxicity Potential
IKP	Institute for Polymer Testing and Polymer Science
IPP	Integrated Product Policy
IPU	Inter-Parliamentary Union
ISO	International Standard Organisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low Density Polyethylene
LPDE	Low-density Polyethylene
MA	Methacrylate
MPW	Mixed Plastic Waste
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
MVR	Müllverwertung Rugenberger Damm GmbH & Co. KG
NBR	Nitrile Butadiene Rubber
NGO	Non-Governmental Organisation
NMVOC	Non-Methane Votatile Organic Compounds
NP	Nutrification Potential
NR	Natural Rubber
ODP	Ozone Depletion Potential
PA	Polyamides
PAH	Polycyclic Aromatic Hydrocarbons
PB	Polybutadiene
PBT	Polybutadien-Terephthalates
PC	Polycarbonates
PC/ABS	PC/Acryl-Butadiene-Styrene
PCB	Polychlorinated Biphenyls
PCDD	Polychlorierte Dibenzodioxine
PCDF	Polychlorierte Dibenzofurane
PE	Polyethylene
PE/PVDC	Polyethylene/Polyvinylidene chloride
PEC/PNEC	Predicted Effect Concentration/Predicted Non-Effect Concentration
PEG	Polyethylene Glycol
PE-HD	Polyethylene High Density
PEI	Polyetherimide
PE-S2	Polyethylene Barium Sulphate Stabilized
PET	Polyethylene Terephthalate
PEX	Polyethylene (crosslinked)
PI	Polyimide
PIB	Polyisobutene
PMMA	Polymethylmethacrylate
POCP	Photochemical Ozone Creation Potential
POM	Polyoxymethylene
PP	Polypropylene
PP/COC/PP	PP/Cyclic Olefin Copolymer/PP-Layer-Compound

Abbreviation	Explanation
PP/EPDM	PP/Ethylene-Propylene Elastomers
PPE	Polyphenylene Ether
PP-GF	Polypropylene (glass fibre reinforced)
PPS	Polyphenylene Sulfide
PrEn	Primary Energy
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl Chloride
SB	Styrene Butadiene Copolymer
SBR	Styrene Butadiene Rubber
SETAK	Society of Environmental Toxicology and Chemistry
SMA	Styrene Malenic Anhydride Copolymer
SMC	Sheet Molding Compound
SME	Small and Medium Enterprises
S-PVC	Suspension Polyvinyl Chloride
SVZ	Sekundärrohstoff Verwertung Zentrum
SZFF	Schweizerische Zentrale für Fenster- und Fassadenbau
TETP	Terrestrial Eco-Toxicity Potential
TGD	Technical Guidance Document
TOC	Total Organic Carbon
TPE	Thermoplastic Elastomers
TPU	Thermoplastic Polyurethane
TWA	Time Weighted Average
TXIB	2,2,4-Trimethyl-1,3-Pentanediol-Diisobutyrate
UBA	Umweltbundesamt (German Environmental Protection Agency)
UBP	Ecological Scarcity Method
US	United States
UV	Ultra-Violet
VCM	Vinyl Chloride Monomer
VOC	Volatile Organic Compound
VROM	Ministry for Housing, Regional and the Environment of the Netherlands

Executive Summary

The overall goal of the study was to compile an overview of the publicly available information on Life Cycle Assessments (LCA) on PVC and competing materials, for a variety of applications, in order to assess existing information and to identify information gaps.

LCA comparisons should be undertaken at application level rather than at material level. Depending on the kind of product, the environmental impact during use or after end-of-life can be even more important than the environmental impact of material production (e.g. fuel saving light-weight parts in automotive applications or use phase effects of the cleaning of flooring materials). Approximately 100 LCAs related to PVC have been identified, with only 30 making comparisons at the application level.

Many of the reviewed LCAs do not fulfil all requirements outlined by ISO 14040 ff.

LCAs are strongly goal and scope dependant. Therefore, two studies on the same product system may give different conclusions. LCAs do not aim to evaluate the effects of exposure and hazard related data in the way Risk Assessments do. LCAs identify the important environmental aspects and stages over the life cycle and Risk Assessments analyse exposure and hazard related information. However, they can both be used within one tool-box.

The following general conclusions on PVC and its life cycle can be drawn:

- **Within the PVC life cycle chain, the production of intermediates**, particularly the processes from the extraction of crude oil and rock salt up to VCM production, **plays a major role** for the environmental impacts.
- From a PVC life cycle perspective, the production of stabilisers and plasticizers plays a significant role, whereas the production of pigments offers a comparatively low optimisation potential, because of the small volumes used.
- Some **new technologies** exist, e.g. mechanical recycling based on selective dissolution, **for recycling PVC** in an **economically feasible** way. However, currently only a small amount of PVC post consumer waste is being recycled. Incineration, in conjunction with municipal waste disposal, is a simple option that allows for the partial recovery of energy and substances, if state-of-the-art technology is applied.
- Regarding the **positive effects of increasing recycling rates**, **mechanical recycling** (or material recycling), which loops the material back directly into new life cycles, substitutes, to a certain extent, the processes of resource extraction, intermediate production and granulation/polymerisation during the production of virgin material. **Chemical recycling** (feedstock recycling) is another option of recycling PVC into another life cycle.
- In contrast to some metals, the recycling market of plastics, and therefore the demand in secondary material, is not yet established in an adequate way. Nevertheless, today and in the near future we see a mix of mechanical and chemical recycling pathways and state-of-the-art disposal routes as the most favourable way to optimise the environmental impacts of PVC and competing materials.
- The **user will not accept recycled products with lower optical or aesthetic quality** (colour, surface quality), even if the technical quality (mechanical properties, dura-

bility) is the same. This is especially true for building, electronic and automotive products.

The most important applications of PVC are in the building and construction sector (windows/shutters, sheets, flooring and pipes), the electric and electronic equipment sector (predominantly cables), the transport sector (plastisols, artificial leather, dashboards, structural parts) and the packaging sector (non-beverage packaging). A remarkable amount of LCA information is available for building materials and products, but a strong dependence on the specific results and the goal and scope of the studies case-by-case remains.

The main findings concerning sector- and application-specific LCAs of PVC and its competitors are:

- For **windows**, one of the most important PVC applications, the **available studies** conclude that there is no “winner” in terms of a preferable material since most of the studies conclude that none of the materials has an overall advantage for the standard impact categories. The **most promising potential** for lowering environmental impacts **of windows** is expected through the **optimisation of the design.** Therefore the choice of material is of rather minor importance, as long as the material can provide the required system quality of the window.
- Most **flooring application** studies conclude that linoleum has comparable or slightly fewer environmental impacts compared to PVC flooring of equivalent quality in the production phase. One study (IPU 0013) states that wooden flooring tends to have lower impacts than PVC and linoleum, but is more demanding in the use and maintenance phase. There is little LCA information about carpeting, a main competitor for flooring applications.
- For **roofing applications** the available study concludes that a higher quality of the systems (thermal conductivity per thickness of roofing sheet layers) as well as the accuracy of the laying and maintenance processes has a large influence on the reduction of environmental impacts. The study reports that some polymer solutions tend to have lower environmental impacts than competitive systems.
- The **results on pipes are very heterogeneous**. Some studies see clear advantages for concrete and fibre cement pipes, some report clear advantages for polymer pipes such as PVC and PE, some conclude that the material plays no role as long as no cast iron is chosen.
- The only **toy applications** requiring significant amounts of PVC are applications such as inflatable toys, paddling pools and rubber boats/rafts. The potential risks associated with the misuse of toys (e.g. ingestion, sucking or chewing) are of particular concern. However, an LCA cannot analyse these risks properly, therefore, these concerns should be addressed using other tools, such as risk assessment.
- **Few comparative LCA studies** pertaining to **consumer goods** are available. No useful general conclusions on material comparisons could be drawn.
- The **relevance of PVC in packaging is decreasing**. PVC bottles tend to have comparable impacts to those of PET bottles; however, the market share of PVC bottles in Europe is now minor.

- In the **transport sector** (incl. automotive) many comparative LCA studies including PVC alternatives have been performed. However, these studies are confidential and were not available for analysis in this study.
- **PVC cable** does not seem to have significant competitors in many cable applications, therefore few PVC cable LCA studies exist. Recycling processes have been in place for some time, due to the high economic value of the recovered copper and aluminium. Economically feasible options exist for the recycling of recovered PVC.

No comparative LCA studies exist for materials used **in medical applications**, and little environmental optimisation in medical products has taken place thus far. Taking this into consideration, together with the large amount of waste produced by hospitals as a result of waste medical products, the potential of comparative LCA studies identifying methods for environmental improvement is expected to be high.

Extended Summary

Following an invitation for tenders by the European Commission, a consortium led by PE Europe GmbH carried out a comparative study entitled “Life cycle assessment of PVC and of principal competing materials”.

The overall goal of the study was to compile an overview of the publicly available information on Life Cycle Assessments (LCA) on PVC and competing materials, for a variety of applications, in order to assess existing information and to identify information gaps.

The overall scope of the study included the gathering of information from all relevant information sources within the EU. A structured survey of existing relevant LCA studies was carried out. A specific procedure for the identification and acquirement of these studies was thereby developed. Furthermore, a systematic characterisation and critical assessment scheme was developed and applied.

The LCA studies that assess the applications of PVC and competing materials on a system level were analysed in detail. An application matrix, which includes market share information, provided an overview of the relevance of studies and also helped to identify potential inconsistencies.

An overview of the “Overall life cycle impacts of PVC” was compiled, discussing the relevant LCA components and life cycle phases of PVC products. The “Socio-economic costs and benefits” were also analysed.

The following **general conclusions** concerning **LCA in decision-support** can be drawn:

- LCA comparisons should be undertaken at application level rather than at material level, particularly for political decision-support. LCAs on application level are more comprehensive and draw a complete picture of the environmental impacts over the life cycle. At application level, LCAs can show correlations of production phase, use phase and end-of-life treatment. Important impacts of the material production, use, disposal and recycling should be included. This is not to say that LCAs at material level are expendable, they appear to be, however, an insufficient measure for decision-support since material production is only one stage of the life cycle.

  → Comparisons made solely on the basis of mass (e.g. 1kg PVC vs. 1kg wood) tend to be misleading in this context. It is important to take into account the application type and the influence on use and end-of-life when making environmental comparisons.

- Depending on the kind of product, the environmental impact during use or after end-of-life can be even more important than the environmental impact of material production (e.g. fuel saving light-weight parts in automotive applications or use phase effects of the cleaning of flooring materials).

  → The **influential phases of an application** throughout a life cycle **must be identified individually** according to the situation.

- Even if a material has less environmental impact during production, it is not necessarily environmentally favourable. Furthermore, advanced materials with a greater environmental impact in the production phase can have a much lower impact in the use phase due to a better system quality (e.g. less weight, longer durability, lower maintenance frequency, lower thermal conductivity). For example, within the automotive and building industry, a better system quality potentially leads to greater impacts during production but to lower overall impacts due to the importance of an optimised use phase (e.g. heating energy or fuel consumption).

→ This **trade-off situation between production and use phase impacts** must be dealt with on at least an application level (if possible on a case-by-case basis). Therefore, the question “Which material is produced in the most environmentally friendly way?” is only of importance <u>after</u> suitable materials (that fulfil the requirements of an environmentally optimised use phase) are identified.

- Approximately 100 LCAs related to PVC have been identified, with only 30 making comparisons at the application level.

  → The aim of the majority of the studies is the analysis of product systems rather than the identification of suitable materials for analogous applications.

- **LCAs are strongly goal and scope dependant**. Therefore, two studies of the same product system may give different conclusions. This is likely to occur if boundary conditions vary (i.e. individual environmental priorities due to national, regional or local differences), if different data sources are applied (e.g. primary data collection or literature data) or if the intended use of the results is different (weak-point analysis in production, optimisation approach in product development or dominance analysis of life cycle phases).

  → A transparent goal and scope description is important to be able to interpret the results of LCAs correctly. If LCAs are properly interpreted, the dependency on goal and scope is not a weakness or inconsistency but more a flexibility to quantify aspects within a given application from different viewpoints.

- LCAs do not aim to evaluate the effects of exposure and hazard related data in the way Risk Assessments do. Risk Assessments aim to estimate the probability of all possible adverse (or undesirable) effects that would occur related to single specific anthropogenic activities on a local or process related scale. Hence they do not account for the complete life cycle. LCAs aim to quantify and allocate the relative contribution of each stage of the life cycle of complex product systems to environmental impacts. LCA also allows comparisons between equivalent stages of life cycles (i.e. the use phase of a PVC product and the use phase of an alternative product).

  → Thus, even though LCA cannot tell us whether the use of a product is ’safe‘, it does provide us with **important information concerning** the impact assessment scores of the **relative contributions** of entire (partly extreme complex) or partial product life cycles to specified impact categories.

  → **LCA and Risk Assessment** are separate tools aiming at different goals. LCAs identify the important environmental aspects and stages over the life cycle and Risk Assessments analyse exposure and hazard related information. However, they can both be used within one tool-box.

- Many of the LCAs reviewed do not fulfil all requirements outlined by ISO 14040 ff.

  → Studies were either undertaken before the standards were enforced or aspects were neglected due to time or information limitations..

These **general conclusions** regarding **LCA in decision-support** are the basis for the understanding of the specific findings.

The following **specific conclusions** concerning **LCA of PVC and of principal competing materials** can be drawn:

- The dominant applications of PVC are in the building and construction sector (windows/shutters, sheets, flooring and pipes), the electric and electronic equipment sector (predominantly cables), the transport sector (plastisols, artificial leather, dashboards, structural parts) and the packaging sector (non-beverage packaging).

  → The studies show that PVC has a wide range of applications, but only in a few does it contribute a large market share (in comparison to other materials of the same product) or contribute a large PVC mass to the application.

- The **overall impacts of PVC products appear to depend not only on the production** of PVC itself but also on the application characteristics (type of compound, use phase impact, product durability, recyclability). For instance, the overall environmental impacts of systems may only become apparent when the use phase is taken into account. Therefore, general statements regarding environmental performance of a PVC product should only be made with reference to the application level and with all life cycle stages taken into account.

  → When PVC products are compared with alternatives, the inclusion of use phase effects is particularly important for long-lasting products (e.g. windows and flooring).

- The studies show that **within the PVC chain, the production of intermediates**, particularly the processes from the resource extraction of crude oil and rock salt up to the VCM production, **plays a major role** for the environmental impacts. Energy consumption and emissions from PVC compounding and processing are relatively low. The production of fillers is relatively undemanding in terms of energy and has a relatively low potential impact on the environment. From a PVC life cycle perspective, the production of stabilisers and plasticizers plays a significant role, whereas the production of pigments offers a comparatively low optimisation potential, because of the small volumes involved.

  → Therefore, specific and actual information on the production steps and import situation of intermediates of PVC (and most other materials as well) is important. Where literature data is used, as opposed to primary data collection, it is to clarify whether the literature data is technologically, geographically and chronologically representative enough to guarantee quality results.

- Some **new technologies** exist, e.g. mechanical recycling based on selective dissolution, **for recycling PVC** in an **economically feasible** way. Incineration, in conjunction with municipal waste disposal, is a simple option that allows for the partial recovery of energy and substances, if state-of-the-art technology is applied. However, currently only a small amount of PVC post consumer waste is recycled.

  → From a product related life cycle perspective, it would generally be favourable to increase the amount of recycled PVC entering new life cycles. Recycling and disposal pathways that are assessed within LCAs show fewer environmental impacts when compared with landfilling. Most of the studies report that an increase in recycled material and its respective use leads to improved life cycle impacts since the production impacts of virgin material (and the related intermediates, see above) can be lowered by substituting some of the virgin material with recycled material.

- Regarding the **positive effects of increasing recycling rates**, mechanical recycling (or material recycling), which loops the material back directly into new life cycles, substitutes, to a certain extent, the processes of resource extraction, intermediate production and granulation/polymerisation during the production of virgin material. It is well known that **mechanical recycling** demands a certain stable quality of the recycled good. **Chemical recycling** (feedstock recycling) is another option for recycling PVC into a new life cycle. Therefore, only resource extraction and intermediate production of the virgin material is substituted. Chemical recycling generally allows certain quality variations in the input. **The energy recovery** within an incineration is more or less a disposal path, being the most effective way to recover energy and a fraction of chemicals. However, it is of course the least demanding in terms of quality variations of the input as PVC can be incinerated as part of a mixed waste fraction. Common to both of these options is that the “critical mass streams” of post-consumer waste are required in order to operate the recycling technologies in a feasible manner, from an economical and a technical point of view. In contrast to some metals, the recycling market of plastics, and therefore the demand in secondary material, is not yet established in an adequate way.

  → Nevertheless, today and in the near future, a mix of mechanical and chemical recycling pathways and state-of-the-art disposal routes seems to be the most favourable way to optimise the environmental impacts of PVC and competing materials. This conclusion also accounts for the fact that long-lasting products will always be entering end-of-life with a certain time lag and are influencing the quality variation of the post-consumer waste. Furthermore, it is considered that even in the future it may neither be suitable nor feasible to treat all post-consumer waste (separation, cleaning with respective energy use and emissions) for mechanical recycling to yield quality secondary products (but of course the most promising share of it).

- A further important restraint of increasing the use of secondary material is often recognised if results of LCAs are discussed within optimisation strategies of products: The **user will not accept recycled products with lower optical or aesthetic quality** (colour, surface quality), even if the technical quality (mechanical properties, durability) is the same. This is especially true for building, electronic and automotive products.

The following **specific conclusions** concerning **sector and application specific LCAs of PVC and its competitors** can be drawn:

- A remarkable amount of LCI information is available for building materials and products, but a strong dependence on the specific results and the goal and scope of the studies case-by-case remains.

- For **windows**, one of the most important PVC applications, the **available studies** differ in methodology but **come to comparable conclusions**. All studies compare at least the three alternatives; PVC, wood and aluminium windows. Two studies compare wood/aluminium with further materials; one with steel, stainless steel and non-ferrous metal and another with polypropylene. The stainless steel and the non-ferrous metal windows seem to have potentially more impact than all other frame materials (which can be easily reproduced due to the relatively high demanding metal extraction and processing route). All analysed studies (that contained data and models[1] of a high enough quality for the study to be acknowledged) concluded that any worthy competing frame material (PVC, aluminium, wood/aluminium and wood) has its individual strengths and weaknesses. Furthermore, it can be concluded that none of the acknowledged studies nominated a “winner” in terms of a preferable material. Most of the studies conclude that none of the materials have overall (but individual) advantages in the related standard impact categories.

- It appears that the **most promising potential** for lowering environmental impacts **of windows** is expected to be through the **optimisation of the design** and specific construction processes, which means increasing the quality of the windows with respect to their main function of saving heating energy in the use phase (e.g. lowering the specific heat loss). Raising the amount of secondary material used, or lowering the amount of material required for the same function, may be another ground for optimisation of the constructions. Therefore the choice of material is of rather minor importance, as long as the material can provide the required system quality of a window.
- Most **flooring application** studies conclude that linoleum has comparable or slightly fewer environmental impacts when compared with PVC flooring of equivalent quality in the production phase. One study (IPU 0013) states that wooden flooring tends to have lower impacts than PVC and linoleum, but is more demanding in the use and maintenance phase. All analysed studies claim the importance of the use phase due to detergent or chemical use in cleaning and maintenance. The study IPU 0042 concentrates on the use phase and suggests that PVC might have advantages over linoleum in this phase and that the absolute demand seems to be strongly dependent on the context of the individual application (private use, professional use, industrial use). Therefore, the use phase should be analysed in more detail to obtain a representative judgement. Some studies are already considering this in adequate detail. There is little LCA information about carpeting, a main competitor, within this application.
- For **roofing applications** the available study concludes that higher quality of the systems (thermal conductivity per thickness of roofing sheet layers) as well as the accuracy of the laying and maintenance processes have a large influence over the reduction of environmental impacts. Additionally, the study concludes that ‘green roofing’ (e.g. planting on the roof) further decreases environmental impacts because of the subsequent longer lifetime of the roofing systems. Three polymer solutions (one PVC system and two competing systems) have the potential to perform better, with similar environmental impacts on global warming, acidification and ozone formation over the life cycle. The study reports that some polymer solutions tend to have lower environmental impacts than competitive systems.
- The **results on pipes are very heterogeneous**. Some studies see clear advantages for concrete and fibre cement pipes, some report clear advantages for polymer pipes such as PVC and PE, some conclude that as long as it is not cast iron, material plays

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[1] The study IKP AT-11 claimed polypropylene windows are best, but data quality and methodology were determined as weak. Therefore, this conclusion is in contrast with all the other studies and is evaluated as inadequate.

no role. Some studies that analysed a variety of impacts report very specific advantages and disadvantages of the different materials. Most of the studies do not take into account the digging, laying, installation and maintenance. These processes are expected to be relevant, at the very least, for underground pipes due to secondary energy use and the emissions associated with digging and laying. Two studies conclude that no material preferences for pipes can be stated, moreover, that no generalisations on ‘best materials’ are adequate, as the best choice is dependant on the local situation. Important technical parameters influencing the LCA of pipes are durability/maintenance, intended duration of use, the maintenance intensity and the weight/diameter of the pipes. Cast iron waste water pipes seem to be disadvantageous in comparison to PVC or concrete pipes. This is due to the fact that cast iron has relatively high impacts in production and their weight makes laying them rather energy-intensive.

- Despite the heterogeneous results, some general conclusions on the environmental impacts of pipes can be drawn. Digging, laying, installation and use have to be included in the LCA studies of pipes. Reduction of the weight of pipes will most likely lead to less environmental impact (less material needed, easier to lay). The use of recycling material would also lead to less environmental impact and is possibly easier than in other applications as no strict aesthetic requirements exist (especially for underground pipes). Leakage has a high impact, therefore the durability and mechanical properties of the pipes are of great importance.
- The only **toy applications** requiring significant amounts of PVC are applications such as inflatable toys, paddling pools and rubber boats/rafts. The potential risks associated with the misuse of toys (e.g. ingestion, sucking or chewing) are of particular concern throughout the studies. However, an LCA cannot analyse these risks properly therefore these concerns should be addressed using other tools, such as risk assessment.
- **Few comparative LCA studies** pertaining to **consumer goods** are available. Studies on clothing and furniture may, however, be of importance. The user most often determines the life span of such goods using fashion as a criterion. Intensive reuse of these goods inside and outside the EU is common. No useful general conclusions on material comparisons could be drawn.
- The **relevance of PVC in packaging is decreasing**. PVC bottles tend to have comparable impacts to those of PET bottles; however, the market share of PVC bottles in Europe is now minor. As expected, results of packaging LCA studies are dependent upon the intended function of the packaging (e.g. protective or decorative), the take-back or disposal system available for the packaging and the content to be packaged. More weight gives glass bottles a clear disadvantage in the transport phase. When special properties (e.g. an oxygen barrier) are required for packaging, PVC seems to have advantages. When few special properties are required, polyolefins tend to be advantageous. Recycling (and even automatic sorting) of any type of plastic packaging waste is no longer a major technical problem, but rather an economic one, since collecting and recycling systems have to be established, aiming for sorted plastics of a certain (constant) mass stream and quality.

- In the **transport sector** (incl. automotive) many comparative LCA studies including PVC alternatives have been performed. However, these studies are confidential and were not available for analysis in this study. Some companies within the automotive industry have been active in the LCA field for the past 15 years. There are, therefore, **few 'obvious' potentials** that are not yet realized since much is already known about material and system comparisons. Today's activities concentrate on 'forecasting' environmental impacts of selected materials and designs prior to the production of parts and systems.
- **PVC cable** does not seem to have significant competitors in many cable applications; therefore few PVC cable LCA studies exist. Recycling processes have been in place for some time, due to the high economic value of the recovered copper and aluminium. Economically feasible options exist for the recycling of recovered PVC.
- **No comparative LCA studies** exist for materials used **in medical applications** and little environmental optimisation in medical products has taken place thus far. Taking this into consideration, together with the large amount of waste produced by hospitals as a result of waste medical products, the potential of comparative LCA studies identifying methods for environmental improvement is expected to be high.

To summarise, the better, or the more comprehensive, the life cycle of a product is modelled, the more parameters and effects influence the environmental impact of a product.

LCA is a useful tool in

- supporting the understanding of the important processes within the life cycle.
- identifying weak points and optimisation potentials of analysed life cycles, to further decrease the environmental impacts of the respective products.
- identifying measures to effectively reduce environmental impacts
- preventing the shifting of environmental problems to other stages in the life cycle

Comprehensive LCAs therefore deal with various important parameters over the life cycle of products, of which the kind of material (and the related production processes) is only one single parameter. The material choice is often discussed as it is a straight-forward parameter which can easily be communicated. However within LCA, the material choice may be important but is often simply one parameter among many inter-dependent parameters.

LCA approaches can easily indicate the importance of material choices within a given life cycle and quantify the effects of possible alternatives. Therefore, material choices on case-to-case bases are often carried out and are accepted.

However, if LCAs are intended to be used for the overall evaluation of preferable material alternatives of a certain product group, it would be necessary to clearly define a representative life cycle for this product This must represent all possible uses and application situations in an adequate and sufficient way. If not, then no useful or comprehensive overall comparison of the alternatives is possible and a decrease in the environmental impact due to chosen preference would be unlikely. The definition of such a representative life cycle is missing today, and it is doubtful that such a representative life cycle can be defined since the individual advantages and disadvantages of different material alternatives are most often a result of specific boundary conditions and application cases.

1 Background, Goal and Scope

In July 2000, the Commission adopted a Green Paper on the Environmental Issues of PVC. This was followed by a commitment to assess the impact of PVC on the environment using an integrated approach.

Apart from an approach based on PVC and additives in waste management, the question of potential substitution for certain PVC applications was raised.

Comparisons at material production level are insufficient as significant environmental impacts or benefits of materials may occur during the use and recycling stages. Hence only a comparison considering the entire life cycle of a material can show the full picture. LCA is a powerful tool for the analysis and optimisation of a product over its life cycle and is effective in broadly implementing life cycle thinking. The EU Commission concludes for Integrated Product Policy (IPP):

LCAs provide the best framework for assessing the potential environmental impacts of products currently available. They are therefore an important support tool for IPP. [IPP 2003]

Therefore, Life Cycle Assessments, preferably according to ISO 14040 ff (which is the International Standard on LCA and therefore guarantees a certain quality of results), are of primary interest.

Additionally, the level of current optimisation of a material should be considered. A material, which has been optimised continually over time, may show a lower potential for further improvement than a less optimised material.

Furthermore, it is recognised that potential substitutes or alternatives have to be compared at an application level, because important effects are related to the specific application of a material (e.g. weight reduction, reduction of energy consumption in mobile applications, maintenance), and are not limited to the production of the material.

Therefore, application of an adequate Goal and Scope in the Life Cycle Assessments must be verified.

From a technical point of view PVC is an interesting material, as its properties can be modified according to different demands. Consequently, it is used in a variety of different products. A large number of materials can be used as alternatives to PVC because of its versatility and range of applications. These alternatives are called “competing materials”. Minimally, the following competing materials used in comparable applications can be identified:

- stainless steel, steel, cast iron, aluminium, copper, zinc
- ABS, acrylics, COC, composites, EPDM, EVA, glass fibre (coated), melamine paper, multi-layer polyolefin, PA, PA (coated), PB, PB rubber, PBT, PC, PC (transparent), PC/ABS, PE, PE/PVDC, PET, PEX, PI, PIB, PMMA, polyester, polyester (coated), polymer bitumen, polystyrene, PP, PP/COC/PP, PP/EPDM, PP-GF, PS (non transparent), PUR, PUR (all coated), rubber, SB, silicones, SMA, SMC, TPE, TPU, varnish (epoxy, acryl, alkyd, PUR),
- cork, cotton, cardboard, latex, leather, linoleum (soft), paper, silk, wood, wooden flooring, wool, veneer

- concrete, ceramics, bituminous sheets, fibre cement, glass, laminate, mineral plaster, natural stone, stoneware, clay, tiles (hard)

Although it would be favourable to have comparative information on all competing materials within prevalent applications, it is neither useful nor possible to compare all materials within one study. A prioritisation is necessary, to be able to cover the most prevalent topics concerning principal competitors of PVC.

Therefore, the most prevalent materials within widespread applications have to be assessed.

To date, much effort has been put forth in comparative analyses and Life Cycle Assessment (LCA) of PVC and alternative materials for various applications; however, it should be noted that the methodologies used were not always comparable and results were often conflicting. This was especially the case where studies were not undertaken in accordance with ISO standards 14040 ff. This holds true for many “older” studies that were published before the Standard itself.

To introduce the non-expert reader to LCA, some basic information is provided here. Further elementary as well as continuative information can be found in the standards themselves: ISO 14040, ISO 14041, ISO 14042, ISO 14043.

LCA is a method used to evaluate the environmental burdens associated with a product, process, or activity which includes the identification of energy, materials and substances used and emissions and wastes released to the environment, over the whole life cycle of the product, process or activity. The life cycle represents all relevant interventions and measures of

- resources extraction,
- transports,
- energy supply,
- production,
- use and
- end-of-life

of the product, process or activity under study. All relevant interventions and measures must be within the system boundaries[2]. The boundary conditions[3] determine the circumstances related to geographical, temporal and technical representativeness of the system. With this method, a variety of environmental effects, such as

- resource and energy consumption,
- global warming,
- acidification,
- stratospheric ozone depletion,

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[2] The system boundaries determine which unit processes shall be included within the LCA. Several factors determine the system boundaries, including the intended application of the study, the assumptions made, cut-off criteria, data and cost constraints, and the intended audience.

[3] Boundary conditions specify the country, time frame and background database used for e.g. energy and transport systems of the related system.

- tropospheric ozone creation and
- toxicity aspects

and other important, commonly and internationally accepted environmental issues, can be analysed and optimised for the entire life cycle of a product. The product is defined by its functional unit[4]. A correct and responsible application of the method provides quality results, which are widely accepted, provided it follows the standardised and co-ordinated procedures of ISO 14040 ff.

LCA does not, as a rule, produce clear-cut, straightforward assertions, but rather diverse and complex results. It supports the process of decision-making by making complex issues transparent. The ISO 14040 defines an LCA as follows:

LCA is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

The roots of LCA extend back to 1974. In Switzerland, Germany and the United States of America approaches were developed by academics to enable energetic and environmental calculations - besides the existing cost calculations – within the company and product planning process. These developments were driven primarily by the “energy crisis” of this decade. In the late 1980s, industry and governmental institutions increasingly recognised the benefits of a life cycle approach. Recycling issues and product responsibility issues were becoming more understood from an environmental point of view. In the early 1990s, a wave of different research projects related to life cycle analysis began. The growing application of LCA led to the call for standardisation. A common state-of-the-art practise was defined by international scientific organisations. The standardisation process was finalized in 1998 and 2000 with the release of the ISO standards ‘ISO 14040 ff’. For further details we refer to Eyerer 1996).

According to ISO 14040 the application of an LCA can assist in:

- identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
- decision-making in industry, governmental or non-governmental organisations (e.g. strategic planning, priority setting, product or process design or redesign);
- selecting the relevant indicators of environmental performance, including measurement techniques;
- marketing (e.g. an environmental claim, ecolabelling scheme or environmental product declaration).

LCA methodology developed over time. It started as an academic method to analyse industrial process chains under new conditions. Today, LCA is applied in various departments of larger companies that use it to optimise their products. Furthermore, LCA is offered as a service by specialised consulting companies or institutions. Hence, LCA has become part of everyday life. Besides method transparency, data availability is also important. In the past, LCA projects were extremely time and cost intensive, as basic LCA data had to be gathered. Over the years, several databases have been developed. As a result, today’s LCAs are less

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[4] The functional unit is the (precisely) quantified performance of a product system for use as a reference unit in a life cycle assessment study (e.g. 1 window system 1,48 m*1,23 m in size with a heat transfer coefficient of 1,3 W(m^2K) made of PVC, wood or aluminium as frame materials)

time and cost intensive, as a lot of information is already gathered and stored in databases and offered to a growing spectrum of users[5]. Today, the updating and broadening of the databases is gaining importance. The method itself has gained further importance due to the existence of these databases, and with the development of software tools for LCA, which together reduce the time required to produce results.

In industry, LCA is currently used mainly to forecast production processes and to support decisions in the development and design-phase of products and processes. In addition, it is used to screen and decide on strategies to fulfill takeback and recycling regulations.

The nature of LCA allows for the integration, modelling and analysis of nearly any parameter or effect of interest. Therefore, LCA is successfully applied in research, development and optimisation. The software supported analysis of various parameters results in a broader coverage of impacts and effects over the life cycle.

However, not every user or performer of an LCA (academia, industry or government) is interested in all parameters, effects or impacts. It may be that the user only has enough time and money to optimise some of the impacts. Or perhaps he wants to calculate only the impacts that he is responsible for.[6] As a result, various studies analysing a comparable product may come to different conclusions. This is usually not a result of misuse[7] or improper modelling. It is a matter of the Goal and Scope of the study. The definition of Goal and Scope of an LCA is an important task. It enables flexible use of the tool for a variety of users. This ensures the application of life cycle-thinking and life cycle-related decisions for a wide field of the society. The main users of the LCA tool are companies, industrial associations, academia and governmental bodies. Non-governmental organisations are not known to be primary users of the tool.

Today’s LCA software tools allow for modelling and analysis according to the need of the individual user. Linear or non-linear input-output dependencies, parameter variations and scenario calculations are possible in a user friendly way. As a result, the application area of LCA has grown.

Consequently, differing results from comparable products can result from the broad application of LCA when used to solve various problems of the same material. Usually they are based on different views. Proper documentation of these views is mandatory. Normally, misuse is easily identifiable.

Summarising, the main strengths of LCA are

- the possibility to consider many parameters, impacts and effects;
- the flexibility of use to solve various problems and questions;
- the broad user field due to available support from software and databases.

“The drive for simplicity, should not neglect the complexity that characterises a problem”.

Material choices based on a life cycle-perspective are made regularly with the help of LCA, on a case-by-case basis. When it is strategically decided that an LCA should be carried out

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[5] The data is not necessarily free of charge, but is publicly available.

[6] This is covered by the ‘Goal and Scope’ of the study.

[7] Like any tool or method, LCA can be misused on purpose, but misuse can usually be identified quiet easily if the study is undertaken according to the standards [ISO 14041], [ISO 14049]

over a certain time period, complicated questions can be answered much easier as time goes by.

Also, if some ‘rules’ are followed such as:

- applying the same ‘Goal and Scope’
- comparing the materials at the same application level
- covering the important influencing parameters, impacts and effects over the life cycle
- and the use of a consistent background database (energy, transport, resource mining)

the results will be comparable and will only differ if one of the parameters used is varied.

Hence, with the development of the standardised method of LCA, LCA results can be used to obtain material decisions or choices with a “holistic”, “comprehensive” and “objective” life cycle view.

1.1 Goal of the study

The overall goal of the study is to compile an overview of the available life cycle information on PVC and competing materials within respective applications, to assess the information, identify gaps and to prepare information for decision support within the Commission.

The specific goals of the study are to provide the Commission with:

- available information on the life cycle impacts of PVC from resource extraction to disposal;
- a comprehensive catalogue of all existing life cycle assessments and equivalent evaluations of PVC and products made of PVC;
- a comprehensive catalogue of all existing life cycle assessments and equivalent evaluations, where PVC applications are compared with principal alternatives;
- a matrix of PVC applications with the market share and PVC mass flows, for assessing the significance of comparisons between PVC and possible alternative solutions as well as to identify gaps and their relevance.
- a systematic characterisation and a critical assessment including the results of the relevant assessments/evaluations as well as an assessment of the validity of the basic assumptions;
- an overview of existing information on the economic and social implications (cost, performance, effects on SMEs, jobs, etc.) of a potential policy approach to encourage substitution of PVC in particular applications, with a summary of key findings; and
- an assessment of gaps in the availability of adequate data and an indication of the most effective means to fill them.

1.2 Scope of the study

The overall scope of the work involved contacting all relevant information sources within the EU for life cycle related environmental information on PVC and competing materials in comparable applications, as well as to collect and assess the identified information.

The scope included studies:

- that were life cycle assessments or dealt with socio-economic topics;
- that focused on comparative LCAs of PVC versus competitor applications; and
- that were compiled within the last 20 years.

Annex 1 shows an overview of the contacted organisations and their individual responses.

1.3 Market situation

In the last few decades the consumption of PVC has increased. Reasons for this may include the facts that PVC

- is reasonably priced
- allows for a high degree of freedom in design
- is easy to process
- can be used in various applications;
- is UV-stable;
- is recyclable and
- has a relatively low primary energy demand and resource consumption in production.

The following figures provide some insight into the development of PVC applications over the last two to five decades.

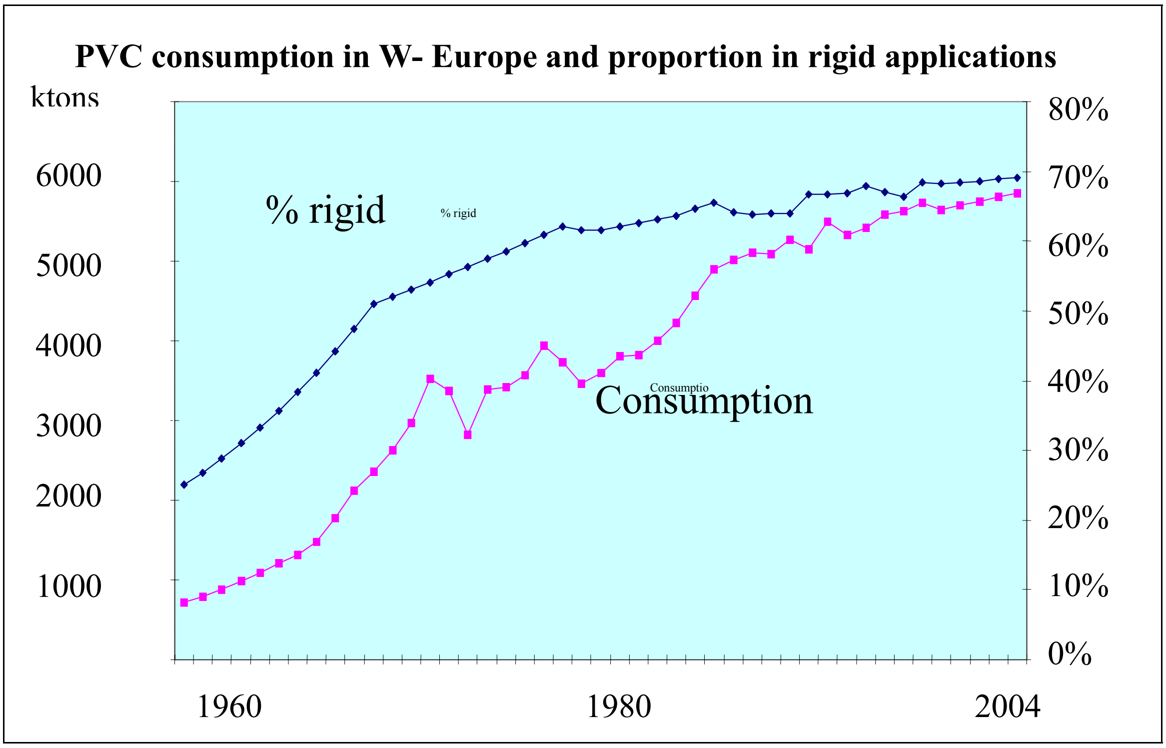

Figure 1-1: **Development of PVC resin consumption in W-Europe and proportion in rigid applications [ECVM 2003]**

The increase in overall PVC consumption is primarily related to an increase of rigid PVC applications.

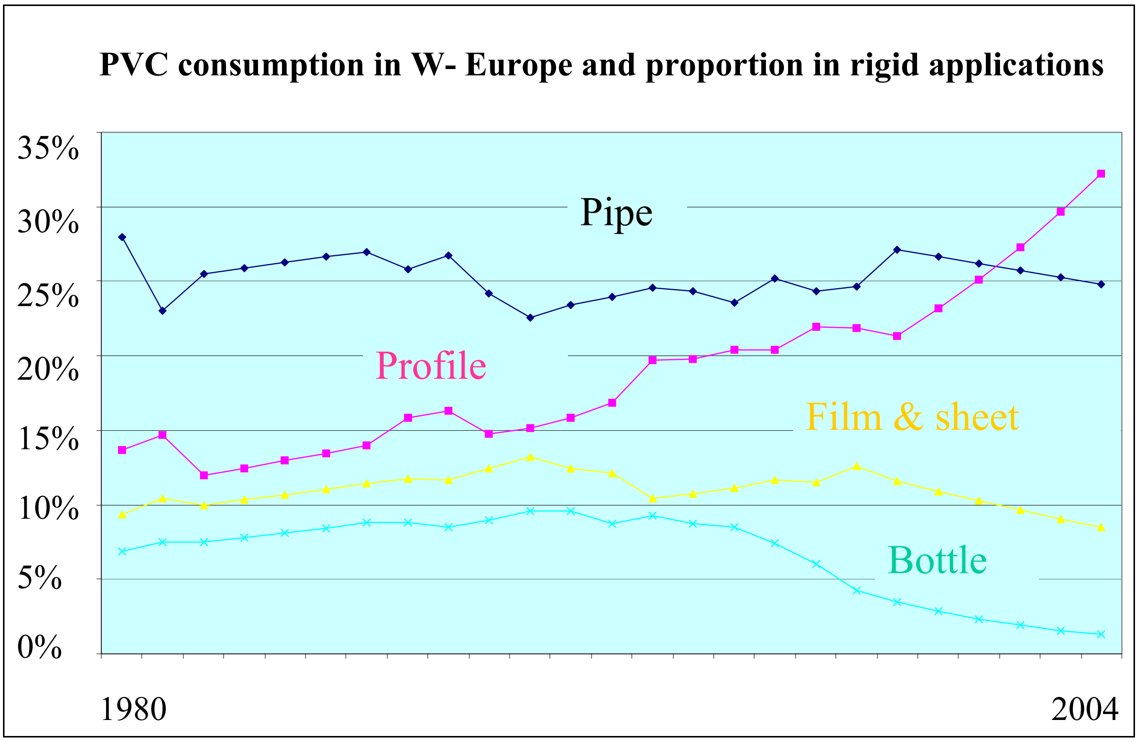

Figure 1-2 **PVC resin consumption; Development in rigid applications [ECVM 2003]**

Within rigid applications the percentage of PVC in ‘pipes’ and ‘films & sheets’ is rather stable, whereas ‘profiles’ show a significant increase, and the consumption share of ‘bottles’ decreases.

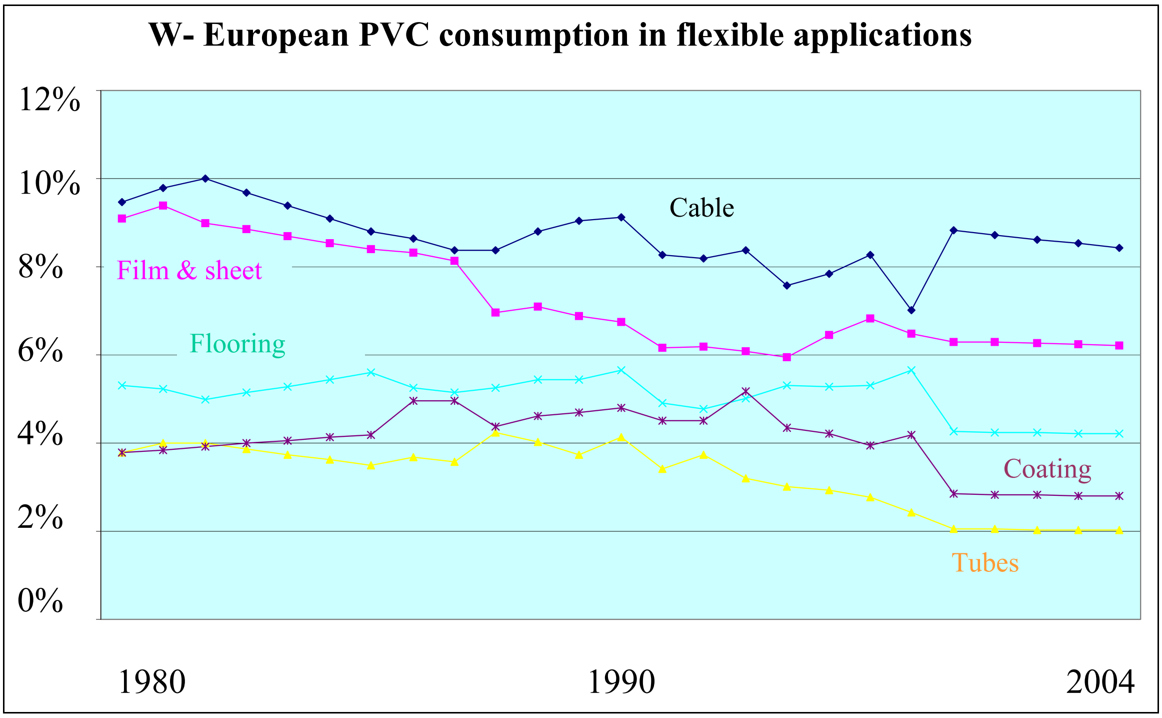

Figure 1-3 **PVC resin consumption; Development in flexible applications [ECVM 2003]**

In flexible applications, the consumption share of ‘cables’, ‘flooring’ and ‘coating’ is more or less stable over time. Consumption shares of ‘films & sheets’ and ‘tubes’ decrease.

In summary, the majority of PVC is used in **durable products** (soft and rigid) such as window profiles and frames, roofing sheets, cable insulation and floor coverings. Durable products make up at least 84% of PVC applications (by mass).

The number of durable products made from PVC is increasing, whereas the number of non-durable products made from PVC, like packaging, is expected to remain (approx.) at its current level short-term but is expected to slowly decrease in the long-term.

Generally, a further increase in the production and consumption of plastics is forecasted for the future. It is, therefore, evident that PVC is gaining importance as a material for durable products, especially in the building and construction industry.

2 Response analysis

In order to identify LCA studies relevant for this report, 262 parties have been contacted. In total, 189 had no information available relating to the project. Therefore, 73 potentially have information available or are known to have information. Ten organisations of the 73 did not answer at all. From the remaining 63 organisations, 11 (about 15%) did not provide any information for different reasons. 52 organisations (approx. 71%) had information available and provided one or more studies to the project group.

Hence, almost two thirds of the organisations, which had information available, were willing to provide it for this study.

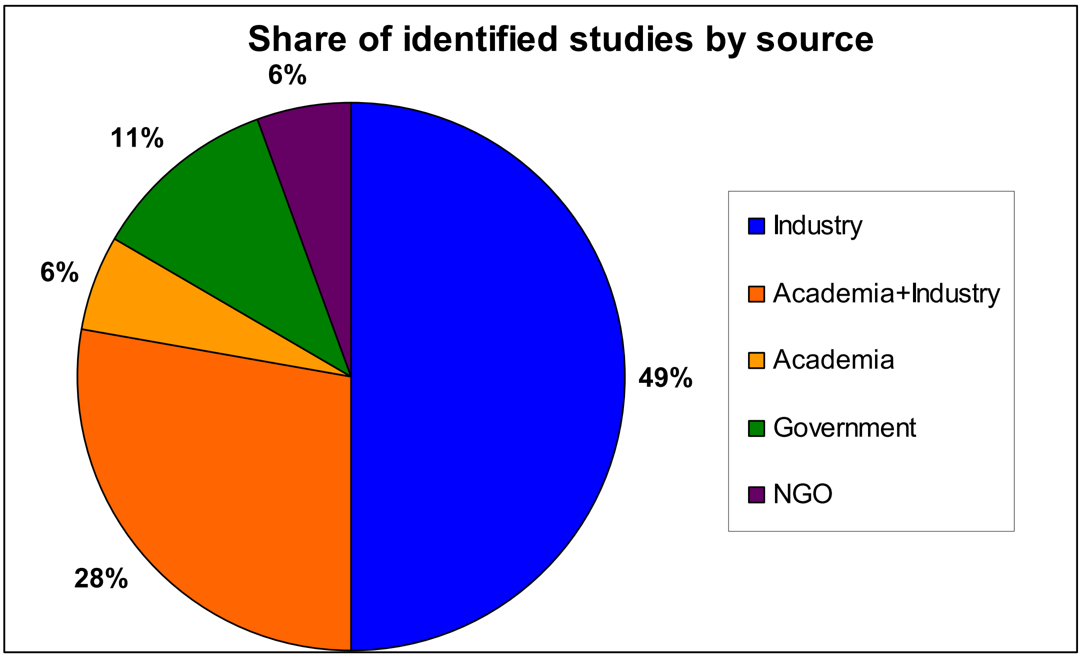

Figure 2-1: Share of identified and published studies (relative values)

The contractor (consortium of PE Europe, IKP University of Stuttgart, IPU and Randa Group) recognised that industry has commissioned or carried out a large number of LCA studies for internal use. Today, LCA is used in industry to support decision-making in R&D and production, as well as in management. Hence, a lot of studies carried out are NOT published and remain confidential because the results are considered a “competitive advantage”.

It was also recognised that industry associations have commissioned a large number of studies. The goal and scope of these studies are of interest to the entire branch. To enable companies to participate in these projects, confidentiality agreements for sensitive data are used, techniques are applied to aggregate information before disclosing it to the public, and independent critical reviews are carried out. Nevertheless, adequate and detailed documentation is mandatory. Following these practices ensures an effective way to protect company-specific information while allowing high-quality primary data to be incorporated into projects. Hence, studies containing aggregated information are more likely to be published.

In general, the studies carried out by **associations or companies** comprise a well-defined and comprehensively characterised (technical) system description of processes. The beneficial and disadvantageous aspects of certain processes, products, applications or design choices are often discussed on a ‘pros and cons level’. The results are very much related to the specific product level. The probability that high-quality primary data is used within those studies is higher, because data supply is relatively abundant. Of course, the problem remains that specific studies (or specific results) are not disclosed to the public.

The studies provided by **academia** (universities and research institutes) were mainly undertaken for industry or together with companies. Even in basic research, LCA is used for practical applications.

Studies received from **government bodies** mostly looked at broader topics rather than specific products or systems. The primary target was to provide information related to product groups or branches.

Fewer studies were received from **NGOs**. Studies from NGOs were mainly ‘meta studies‘ which were not individual studies themselves, but rather reviews, summaries or conclusions of other studies that had already been carried out. Therefore, studies from NGOs do not enlarge the data pool with new information. Furthermore, most of the ’meta studies‘ tend to lack a ‘pros and cons’ discussion of the different aspects from a life cycle perspective (see chapter 1).

3 Method for assessing the LCA studies

This chapter describes the background and structure of the method used (see section 3.1), which was developed and compiled to assess the available information, and also describes the specific modules of the method in detail (see section 3.2).

Because of the breadth of different PVC applications (discussed in chapter 1), it was necessary to prioritise in order to concentrate on the most relevant PVC studies and the studies of PVC's principal competitors. A detailed table, which describes the applications and lists competing materials, is shown and discussed in section 3.2.4 (see page 43 for the application matrix). Applications include, for example, windows, flooring and cable insulations.

3.1 Background and structure of the assessment procedure

The first step taken to structure the large amount of information collected was to check the relevance of the PVC application, as it can vary significantly between applications.

For example:

- Approximately 12% of all PVC produced within the EU is used in the production of wastewater and rainwater pipes; and
- PVC is a dominant material in wastewater and rainwater pipe production.

Alternatively, there are PVC applications, which play a minor role:

- Less than 0.1% of the PVC produced in the EU is used in the production of non-inflatable toys.
- The market share of PVC within the non-inflatable toys segment is relatively negligible.

Therefore, a method to assess the available information is needed in order to prioritise the studies dealing with applications in which PVC is prevalent. That does not necessarily mean that the information of the latter case was neglected, but it is less relevant within this study.

It was observed that in most cases, studies are only undertaken if a specific interest for the information exists. Therefore, the availability of studies or information on a significant market segment is more likely.

Nevertheless, the objective was to document all available information, without pre-selecting or pre-assessing the studies. During the first stage of the project the amount of available life cycle related PVC studies turned out to be large.

The steering committee of the study gave priority to:

- ‘Classic‘ LCA studies (according to ISO 14040 ff) and
- within the ’Classic‘ LCAs, studies directly comparing PVC applications with competing applications of a different material (e.g. PVC window compared to wooden window)

This priority setting reflects the aim of the consortium to objectively compare PVC applications with the application of its principal competitors, within the given time frame.

The adherence of a certain study to existing standards can be checked systematically.

The procedures of critical reviews normally include systematic checks, to see whether studies follow the rules and guidelines of the standards. Nevertheless, these systematic checks of critical reviews cannot by applied to all prioritised studies within this report for two primary reasons. To perform a critical review of a study, the reviewer has to have a discussion with the authors of the study to gather necessary background information on e.g. the system, the model and the used software and data. Given the timeframe for this project, it was naturally impossible to do this for the more than 30 prioritised studies, since in general, the effort for a critical review should be between 10% and max. 20% of the effort required for the completion of the entire project. This estimate is given provided that, in addition to the reviewed study, further appropriate background information and documentation exists. Hence, in this context (approx. 100 studies for systematic characterisation and over 35 studies for systematic characterisation and critical assessment in the limited amount of time) the adherence-check with the standards had to be streamlined according to important indicators. The important indicators selected are documented and commented on in the applied method (see section 3.2.2 “Systematic Characterisation” on page 40 and section 3.2.3 ”Critical Assessment“ on page 41).

The following is a summary of some of the **key features of the LCA methodology according to the ISO 14040 ff standards**. This may provide a better understanding as to why differing results between LCAs do not necessarily mean that quality between the studies differs.

- LCA studies should systematically and adequately address the environmental aspects of product systems, from raw material acquisition to final disposal.
- The depth of detail and time frame of an LCA study may vary to a large extent, depending on the definition of goal and scope.
- The scope, assumptions, description of data quality, methodologies and output of LCA studies should be transparent. LCA studies should discuss and document the data sources, and be clearly and appropriately communicated.
- Provisions should be made, depending on the intended application of the LCA study, to respect confidentiality and proprietary matters.
- LCA methodology should be amenable to include new scientific findings and improvements in state-of-the-art technology.
- Specific requirements are applied to LCA studies that are used to make a comparative assertion that is later disclosed to the public.
- There is no scientific basis for reducing LCA results to a single overall score or number, since trade-offs and complexities exist for the systems analysed at different stages of their life cycle.
- There is no single method for conducting LCA studies. Organizations should have the flexibility to implement LCA practically, as established in this International Standard, based upon the specific application and the requirements of the user.

Rather than guiding the user in a strict fashion, the standard provides a framework for a high-quality life cycle analysis. Life Cycle Assessment has the potential to solve complex questions within complex systems; the responsibility of using Life Cycle Assessment in an adequate manner remains with the user. The standards explicitly aim to avoid restricting possible analysis methods with strict rules.

A Life Cycle Assessment should include a definition of the goal and scope, an inventory analysis, an impact assessment and an interpretation of results. LCA results may be useful inputs for a variety of decision-making processes. Applications of LCA, such as the examples listed in Figure 3-1, are outside the scope of the International Standard. Life cycle inventory studies should include a definition of goal and scope, an inventory analysis and an interpretation of results. The requirements and recommendations outlined by the International Standard, with the exception of those provisions regarding impact assessment, also apply to life cycle inventory studies.

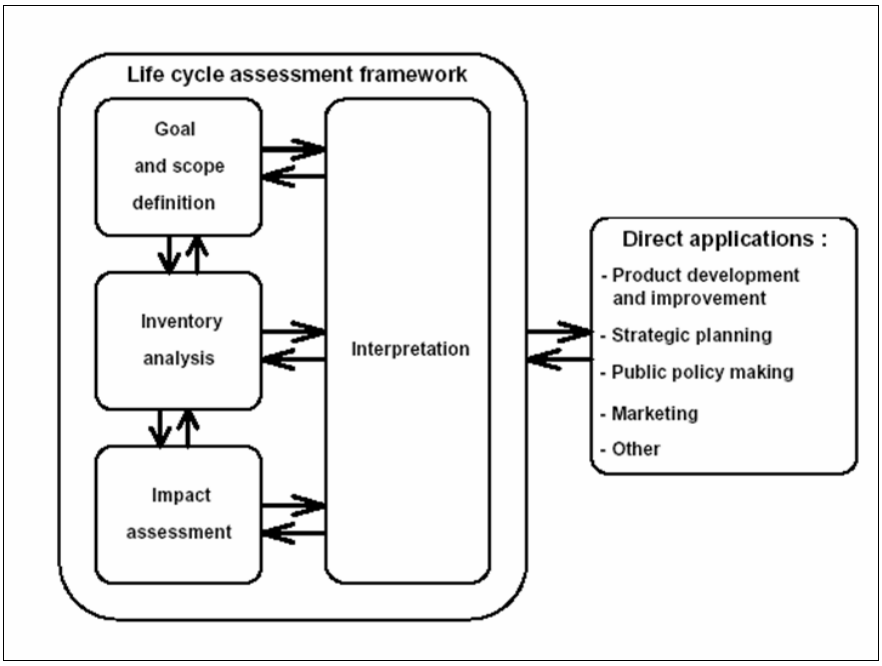

Figure 3-1: Phases of an LCA, ISO 14040

Monitoring the validity of the results is complex, as the life cycle, even of comparable products, can be modelled in different ways, depending on the goal and scope of the study. Two different studies, analysing the same product, can both be in accordance with the standards, even if their results differ. The standards make very clear that use of the LCA method at different levels of detail is allowed (and even encouraged) with different goal and scope definitions (to make LCA available for a broad range of users and therefore, provide a flexible tool for improvements and optimisations). Making assumptions is allowed by the standards, so long as the points mentioned above are transparently documented within the study. Validity of study results is checked during critical reviews, but this is not an option within the current study, as explained above.

Nevertheless, it is possible to evaluate the results according to the background information given in the studies, to compare it with other information and to check the plausibility of statements and results using existing experience or database information.

Some **key features** that come from **experience through “everyday practice”** are provided (besides the general guidelines of the standards). These can be used to **distinguish, in our view, high quality LCAs from low quality LCAs** based on “best available practice”:

- A precise description of the technical system under study within the goal and scope is mandatory

If the technical system is not properly understood and described by the performer of a LCA, the probability of improper results increases drastically. Technical knowledge of the product, product qualities and properties, involved process technologies and possible alternative process technologies is necessary.

- The functional unit must be comparable

This means that results based on the sole assessment of different materials can not be used for comparisons on a product level. High quality LCAs only compare alternatives on an application level with comparable functional units.

- The processes that have been included, and those that have been excluded, must be clearly stated.

Depending on the goal and scope, not all processes are relevant to the study. Inclusion of an explicit statement about the relevance or irrelevance of each process increases the value of a study.

- A description of the background data used for energy, transport, and resource extraction required by the system under study should be included.

This can be a description of previously or newly collected data or the documentation of available (public or other professional) data sets. It is important to consistently use documented background data. When comparisons are made, the use of different background data sets from different sources may result in a high risk of improper interpretation of the results. The differences may result from differing background data sets, rather than from the differences between the compared technologies or products.

- The life cycle should be properly covered, based on the goal and scope of the study.

Depending on the goal and scope of the study, not necessarily all phases of the life cycle have to be covered. If all phases are not covered quantitatively, the important aspects and parameters, which may influence an LCA that includes all phases, should be discussed qualitatively.

- Specific data should reflect the actual situation precisely and adequately

LCAs are data intensive. It is not always possible for all relevant life cycle data to be collected for a new study. Therefore, average or representative data is used in many LCAs. Nevertheless, specific data (or primary data) of the specific core processes is usually more precise and up-to-date when collected as part of the study.

- Consistent data should be used for processes that are not included in the primary collection of data.

LCA typically involves (depending on the degree of detail and the goal and scope) several hundred to thousands of different processes over the product or system life cycle. The growing availability of databases and software tools allows for the comprehensive modelling of these complex process networks. Use of databases and software tools speeds up the effort of conducting LCAs. The source of the secondary information and data sets used (that are not the subject of a primary data collection by the users themselves) should be clearly documented.

- An adequate set of environmental impacts should be selected and presented.

A comprehensive LCA should include an adequate set of environmental impacts. This set can be composed of an accepted set of environmental impacts (e.g. Global Warming, Acidification, Nutrification, Stratospheric Ozone Depletion, Tropospheric Ozone Creation, Human Toxicity). Furthermore, the set of environmental impacts can be complemented with specific, typical or important single emissions (e.g. regulated key emissions of a particular branch).

- A discussion of the selected set of environmental impacts should be included.

From our experience a comprehensively performed LCA seldom produces trivial, straightforward, stable and reproducible results that are valid for all products comparable to the product under study. Therefore, sole results like “A is more environmentally friendly than B” tend to be of low quality. A comprehensive and reliable LCA usually produces results like “A is more environmentally friendly than B, if the system properties are set to C, D and F”. One strength of LCA is its ability to show behaviour in relation to various environmental impacts of complex systems. Therefore, in our opinion, understanding how the system behaves should be the main goal, as this understanding is the most important basis for optimisations and improvements.

- Environmental Single Score Indicators[8] tend to be of lower significance than adequate sets of environmental impacts.

If Single Score Indicators are used to present results of an LCA, much information can be lost. For communication to non-experts this might be adequate, but the standards clearly state that there is no scientific basis for reducing LCA results to a single overall score or number as trade-offs and complexities exist for the systems analysed at many different stages of their life cycle.

Summarising, all detected studies are documented in a comprehensive catalogue (documentation sheets) and the procedure used to choose and assess the most relevant studies follows some basic rules.

1. Priority settings of the steering committee are applied after an overview of all available studies is available. This reflects the consortium’s aim to compare PVC applications with its principal competitors on the most objective basis within the given time frame.
2. A streamlined adherence-check with the existing international standards is performed and documented using the Systematic Characterisation scheme and the Critical Assessment.
3. It is checked, to see whether the key features of a quality-LCA are included.
4. A study is further characterised, even if the priority settings of the steering committee are not directly matched, or if the study addresses an important aspect not yet covered, or if the study has been ranked as important in relation to the goal of the study.

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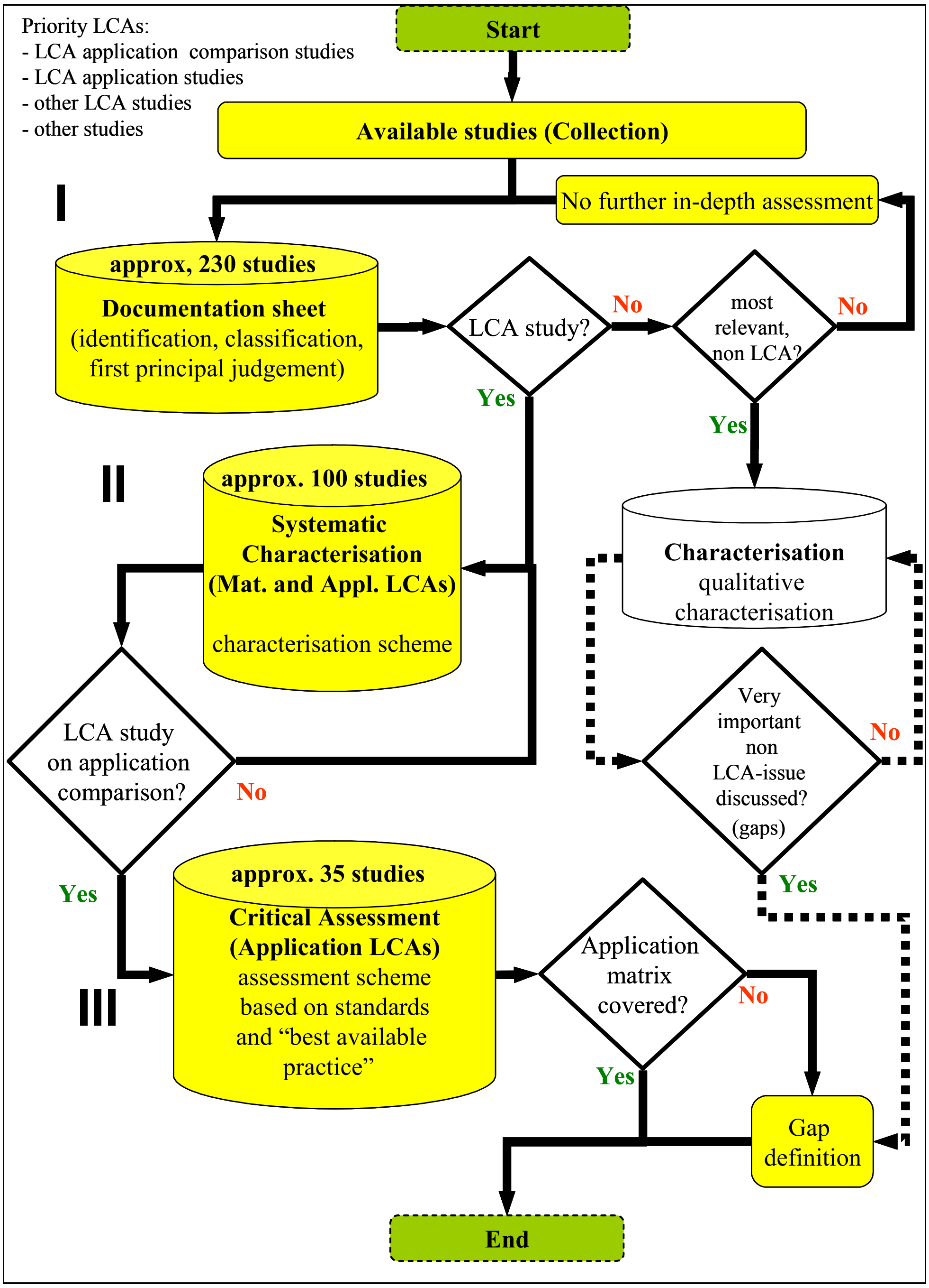
[8] Single Score Indicators are indicators that assess and evaluate various environmental impacts using one aggregated number for the overall environmental performance of a product. This method includes subjective value settings.

The criteria discussed above and the summarised basic rules are applied throughout this project.

The following figure shows an overview of the method that was used to structure and assess the information gathered for this project.



for documentation sheet see section 3.2.1

for systematic characterisation see section 3.2.2

for critical assessment see section 3.2.3

for application matrix see section 3.2.4

Figure 3-2: Information flow within the three-pillar assessment procedure of documentation (I), Characterisation (II) and Assessment (III).

All identified life cycle related studies (approximately 230) **were summarised in a documentation sheet (I)**. The documentation sheet identifies the study and specifies the content.

The documentation sheets of studies that are further characterised and assessed (approximately 40) are provided together with the sheets of the “Systematic Characterisation” procedure and the related “Critical Assessment” procedure in chapter 5. The documentation sheets of all other studies are provided in the annex.

All ‘Classic’ LCA studies (approximately 100) related to the topic **were taken to the systematic characterisation (II)** procedure for further assessment. Following the systematic characterisation procedure, the LCA studies were characterised according to the key features of the standards (see point 2 on page 36); on goal and scope, life cycle inventory, life cycle impact assessment and life cycle interpretation.

Non-LCA studies did not undergo a further in-depth assessment. Exceptions were made for studies or information that covered important topics or provided any other important information with respect to the goal of the study (see point 4 on page 36). This information is characterised in a quantitative way and is used to fill existing information gaps for PVC and LCA.

Next, **all LCA studies describing an application of PVC** compared with a competing material (approximately 35) underwent **critical assessment (III)**. The critical assessment goes beyond the systematic characterisation. The assessment describes **life cycle phases, cut-off criteria, important assumptions, data quality, background data used, environmental impacts covered** and if applicable, the possible **influence of these points on the results**. Furthermore, the **overall requirements of ISO** were checked and the study was assessed from a ‘best available practise point of view‘ (see point 3 on page 36) according to the opinion and experience of the authors. Finally, a **summary of the conclusions** and recommendations are given.

Together, the documentation sheet (I), the systematic characterisation (II) and the critical assessment (III) represent the assessment method. The three pillars are independent submodules of one assessment.

Parallel to the above mentioned assessment method, the extent to which comparative LCA studies of PVC applications fulfil the applications listed in the **application matrix** (see chapter 3.2.4 on page 43) was also analysed. The application matrix is checked sector by sector to see whether prioritised studies exist and whether gaps occur.

It was not possible to cover all sections of the application matrix with relevant studies (see chapters 5.1 to 5.8). The primary reason is the lack of comparative studies. In some cases, the market share of PVC products in certain applications is very low (e.g. agricultural sector), hence industry may have more interest in performing studies in other sectors, where the results of LCAs can be used more effectively. Another reason is that in some sectors, despite numerous studies existing, studies are not publicly available, as they are used internally for optimisation purposes (e.g. automotive sector).

Nevertheless, the largest number of available PVC studies was found for the most important PVC application sector, building and construction.

The matrix was completed by using studies from the pool of studies, for which the systematic characterisation was done, where possible and appropriate. This procedure ensured that reliable coverage of all PVC application fields deemed relevant.

For the sectors where few or no studies were available, the experience of the participating consortium was used to support conclusions and concluding evaluations of the respective sector.

The coverage of the matrix is therefore, either **sufficient**, when conclusive information on competing PVC application LCAs of the sector are included (if studies exist and if the studies are appropriate), or insufficient. An evaluation of the **significance of the insufficient coverage** related to this sector is given in the summary of each sector and, if significant, existing **gaps are identified**.

3.2 Specific modules of the procedure

In this section the three sub-modules and the application matrix are explained and discussed in further detail.

3.2.1 Documentation sheet

The documentation sheet informs the reader about all identified studies related to the topic. Information on content and quality of the study is given, together with all relevant information necessary to identify and obtain the studies.

Table 3-1 shows the documentation sheet. For the most relevant studies, the documentation sheet is supplemented by the “Systematic Characterisation” and the “Critical Assessment”. These studies are listed in chapter 5. The other documentation sheets as well as the other “Systematic Characterisations” can be found in the annex.

Table 3-1: Documentation sheet including explanations

<table>
<tr><td>Kind of report</td><td>Study, article, paper or brochure</td></tr>
<tr><td>Title</td><td>self-explanatory</td></tr>
<tr><td>Scope of investigation</td><td>Description of the coverage of the study</td></tr>
<tr><td>Year of publication</td><td>self-explanatory</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>self-explanatory</td></tr>
<tr><td>Institution or Company</td><td>Information about the parties that performed the study</td></tr>
<tr><td>Contractor/ Address</td><td>Contact information of the contractor</td></tr>
<tr><td>Authors</td><td>self-explanatory</td></tr>
<tr><td>Availability/Publisher</td><td>Contact information of the publisher or publishing organisation</td></tr>
<tr><td>ISBN</td><td>self-explanatory</td></tr>
<tr><td>Keywords</td><td>Collection of keywords that outline the study</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th></th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td>X</td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td></td></tr>
</table>
Ticks mark the analysed phases and kind of data.</td></tr>
<tr><td>Comparison with alternatives</td><td>Short description of the alternatives, if compared with the PVC (material or application), within the study.</td></tr>
<tr><td>Reported data</td><td>Description of the reported data</td></tr>
<tr><td>Short description of the study</td><td>self-explanatory</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>80%</td><td>Specific/own/new data</td><td>20%</td></tr>
</table>
Ticks (or percentages) mark the three blocks (nature / impacts / data).</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competiting material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td>X</td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Ticks mark the initiator and the kind of LCA. A comment outlines further treatment of the study.</td></tr>
</table>

The documentation sheet is applied to all identified studies and outlines the subject, content and quality of the study with respect to the given goal and scope. The documentation is designed for use with systematic characterisation and critical assessment procedures for an in-depth assessment. However, it can also be used as a 'stand-alone' or 'quick reference' feature for all available life cycle related information on PVC.

3.2.2 Systematic Characterisation

The systematic characterisation procedure further informs the reader about the identified LCA studies.

Table 3-2: Systematic characterisation of the LCA study (fictitious example for clarification purposes)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
Main technical systems properly described	X
Function analysed	PVC manufacturing
Functional unit	1 kg
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	
recycling	X
transportation	X
Allocation (mass/energy/price/energy)	mass and price
System Expansion	
Substitution	
Data categories described	
Primary energy consumption	Sufficient or insufficient
Air emissions	Sufficient or insufficient
Water emissions	if insufficient, why? (COD missing)
Waste categories	not reported
Impacts	
Global warming	X
Acidification	
Nutrient enrichment	
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	X
Toxicity, eco	
other:	
Data characterisation and quality	
time	self-explanatory
geography	self-explanatory
technology	average or specific
Critical review performed	X
Evaluation	
Normalisation	X
Weighting	
other methods	eco-efficiency

The characterisation is based on the check of ’standard information‘ which is commonly used in “best available practice” LCA studies (keeping in mind the differences between “goal and scope” of the individual studies, and the chosen “level of detail”). Where applicable, ticks indicate if typical information is given or missing. Data categories are described to show the type of information used in the study.

3.2.3 Critical Assessment

According to the given prioritisation, all LCAs comparing PVC with competitors at an application level undergo the Critical Assessment. The following table explains the critical assessment procedure. As previously noted, the critical assessment should be interpreted together with the documentation and systematic characterisation sheets.

Table 3-3: Critical assessment of LCA studies comparing competitors within applications (fictitious example for clarifications purposes)

Goal description in short	• self-explanatory	
Valuation of the goal	• The goal is sufficiently/insufficiently and clearly/unclearly described.	
Scope of study	• Adequate system boundaries for PVC and wood: entire life cycles, including transportation and maintenance. • Not included: installation • Window: 1.65 x 1.3 m, two casements • Duration: 30 years	
Life cycle phases	• Production and use phase considered. Disposal/recycling discussed separately. • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• German Power Mix considered. • Waste scenarios analysed: landfill, incineration and recycling • Assumptions done are clear and understandable, not having a great influence on the conclusions. It must be noted that some assumptions reflect the situation in Germany (Year 2000).	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• No information on allocations.	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are stated.	
Inventory	• Important topics of LCI model are discussed. • Sensitivity of inventory parameters is not discussed. • Database used: APME 1998 • Database of Software System used: GaBi • No gaps of important impacts.	
Impact Assessment	• The methodology of impact assessment is not exactly described, but simply mentioned. Nevertheless, references are presented. The assessment methodology agrees with ISO 14042. If not, comments are given as to why not.	
Environmental impacts included	• The impact categories included are appropriate to fulfil the goal. • Contribution to eutrophication impact due to air/wastewater emissions in energy generation and PVC manufacture in comparison to wood. • Damage potentials from lead and cadmium stabilisers are important in this context due to the possibility of uncontrolled release (especially disposal). • No differences in total energy consumption between PVC and wood windows.	
Weighting of environmental parameters	• No weighting is performed	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff are met.	

Furthermore, for each study analysed within the Critical Assessment, a summary of the key conclusions and the comments of the consortium are provided. Key conclusions can only be drawn when they are either drawn within the study itself and are reproducible, or if the information to draw key conclusions is available in the study.

If possible, key conclusions are drawn from different viewpoints to provide objective decision support. A fictitious example is given below:

The study comes to the following key conclusions:

- In short and medium–term, PVC presents low environmental risks because of low air and ecotoxic wastewater emissions, which can be harmful to health and the environment.
- In the long term, PVC can present potential threats to health and the environment from lead and cadmium stabilisers.

The study explains to manufacturers:

- For industrial accidents, the frequency of industrial accidents is lower for the PVC window product chain than for the alternative window.

The study explains to users:

- During the time period considered, no negative effects on the users of PVC windows are noticed.

The study explains to third parties:

- For window applications, the highest potential environmental impact of PVC is related to the type of stabilisers used in the PVC compound rather than to the production of the PVC polymer itself.

3.2.4 Application matrix

The prioritisation procedure included a check of the relevance of the analysed product according to the “application matrix”. This matrix shows the relevant and less relevant fields of application of PVC products based on two factors:

1. The share to total PVC mass (in %) expressed as the compound that is used in this application (e.g. 9% of all PVC used within Europe is applied in window frames)
2. The market share of PVC within this application related to competing materials of the same application (e.g. PVC has a major market share within windows, whereas it has only minor market share in agricultural foils).

The distinction between these factors is similar to the distinction between material and application view.

If, for example, the goal is to reduce the environmental impact of PVC applications by environmentally optimising the production of the material (or compound), applications containing a high mass percentage of total PVC profit most.

If, on the other hand, the goal is to reduce the environmental impact of PVC within a specific application, the most efficiently optimised applications are those in which PVC has a major market share.

Nevertheless, during the identification and collection of the different studies, it became clear that it is possible to perform Systematic Characterisations on all collected LCAs and Critical Assessments on all identified application comparisons.

Hence, the matrix was finally only needed secondarily to prioritise studies, as all LCA studies could be further analysed. But the matrix is important for evaluating the significance of existing gaps, related to missing LCAs of application comparisons among the various applications.

The structure of the application matrix was discussed internally in the project group, including the LCA-plastic experts from the different partners. Various representatives from associations and industries were asked to comment on the structure and to provide information on the actual market situation. Therefore, a realistic picture of the market share of PVC in relation to competing materials of specific applications from a European perspective can be drawn. In particular, the following companies and organisations provided information which assisted in the creation of the application matrix and provided information on the PVC market:

- ECVM (European Council of Vinyl Manufacturers)

- APME (Association of Plastics Manufacturers in Europe)
- Solvay Management Support GmbH
- Solvay Plastic Sector
- EVC (European Vinyl Corperation)
- Vinnolit GmbH + Co KG
- Tecpol Technologieentwicklungs GmbH

To our knowledge (and the knowledge of the above-listed) the following table lists the **“maximum” number of possible PVC applications** and potential competing materials for individual applications.

For some of the listed applications, the market relevance of PVC in the specific applications is very low or negligible because other materials are used more often.

Table 3-4: Application matrix of PVC

Sector	**PVC Application**	**principale competing materials**	**share of used PVC mass**	**market share of PVC**
building and construction:				
profiles and sheets (rigid)	window frames	**wood, aluminium,** steel, PUR, polyolefins	9%	major
	cladding	**aluminium,** steel, fibre cement, **wood**	9%	major
	sheets	acrylics, glas, **PS (non transparent), PC (transparent)**		
	conduits, shutter, rails, skirts	ABS, PS, SB, PP, PMMA, PC, wood, metals		
sheets and foils (flexible)	flooring (incl. Sport)	carpet, wooden flooring, laminate, **linoleum (soft),** polyolefins, **tiles (hard),** natural stone, rubber, cork	8%	major (soft) medium (total)
	roofing sheets	**bituminous sheets,** PIB, EPDM, **PE,** EVA	1%	major
	membranes	**polyolefins,** polyester (coated)/ glassfiber (coated)/ PA (coated)	1%	major
	wallpaper	**paper,** mineral plaster, acrylics	2%	medium
pipes and fittings	waste-/rain-water	polyolefins, cast iron, concrete, stoneware/clay, Cu, Al, Zn	12%	major
	drinking water	(stainless) steel, copper, **polyolefins,** PB, ABS	4,5%	medium
	gas pipes	**polyolefines**	< 0,5%	small
	irigation and draining pipes	polyolefines	2,5%	major
toys/sports goods:				
	dolls, bath ducks, snorcle	polyolefins, wood	< 0,1%	small
	inflatable beach toys, balls, paddling pools	**rubber,** polyolefins	3%	major
	rubber boats, rafts	composits, PUR, **rubber**		
	building blocks, play figures	polystyrene, polyolefins	negl.	negl.
	camping/tents	**rubber,** TPE	< 0,5%	medium
	luggage	lether, cotton, **polyester,** ABS, PUR	1%	medium
consumer goods:				
furniture	edge protection, furniture profiles	**wood,** ABS	1,5%	medium
	coating	melamine paper, veneer, vanish (exoxy, acryl, alcyd, PUR)	0,5%	major
	garden hoses		1,5%	major
	garden furniture	wood, steel, aluminium, polyolefines, PA	negl.	negl.
clothing	wellingtons, ski boots	leather, PA, **EVA, rubber**	2%	medium
	soles/bottoms	**leather,** PUR		
	rain covers	cotton, **PUR,** polyester, PA (all coated)	< 0,5%	small
	fashion ware	wool, **polyester,** cotton, PA, silk, latex		
office equipment	transparancies, trays, folders	**polyolefines,** PS, cardboard	2%	medium
	credit cards	PET, ABS	< 0,5%	major
household goods	shower curtains	cotton, polyester	< 0,5%	major
	packaging-/electrical tapes	PET, PI, PP	1%	major
	sealants	**silicons,** PUR, TPE	< 0,5%	medium
packaging:				
container	bottles	**PET, glass,** polyolefins, ceramics	1,5%	small
	food packs	PET, aluminium, paper, **polystyrene, polyolefine,** PA	6,5%	medium
	shrink foils	**polyolefins,**		small
	blister packs	COC, **PP/COC/PP,** PE/PVDC, paper		medium
transport:				
cars and trucks	plastisol (sealing, underbody protection)	polymer bitumen, PB rubber, SMA, Zn	2,5%	major
	parts	**PP-GF, PP/EPDM, PP**, PB, PBT, PC/ABS, SMC, PC, PA	1%	small
	tarpaulins	acrylics, PUR (all coated)	0,5%	major
	dashboard	**PP,** PP/EPDM, leather, **PUR**	1,5%	medium
	artificial leather	PUR, leather, cotton, wool, polyester		major
	cable harness	PE-X, TPU	1%	major
yachting	foams, fenders, ...	wood, PUR	< 0,5%	major
trains	seat covering	PUR, **polyester**	< 0,5%	small
electric- and electronic equipment:				
	cables	**PE, PEX**, rubber, TPE, PP	11%	major
	casings	**ABS, PC, PS**, polyolefine (all with FR), metals	0,5%	small
	cable ducts	polyolefins		major
medical applications:				
	blood and infusion bags and medical devices	**multilayer polyolefins,** glass	0,5%	major
	gloves	**rubber,** PU		
agriculture:				
	green houses sheets	polyethylene, glass, PMMA	negl.	negl.
	foils	**polyolefines**	< 0,5%	small
others				
	undefined		~ 7,5%	
		sum	**100%**	

The “share of PVC mass” in the table represents the compounded mass (including the polymer and all additives).

The **building and construction** sector is by far the most important PVC sector. It comprises almost 50% of applications in relation to the applied mass flow. The share of PVC mass used in this application is the highest in the matrix and the market share of PVC in relation to competing materials is most often “major”. **Window frames**, claddings, sheets and conduits/shutter/rails/skirts are all part of this application field, as well as **flooring** (including sport flooring). Another important PVC application in the building sector is piping. Approximately 12% of applied PVC goes into **wastewater and rainwater pipes**, and the competitive market share for this application is considered “major”.

The sector of **electric and electronic equipment** also plays an important role, as shown in Table 3-4. **Cable applications** comprise of approximately 11% of the market in terms of all PVC mass, and PVC holds a major market share in comparison to competing materials.

For **toys and sports goods,** only the **inflatable products** play a role. This application accounts for approximately 3% of the PVC mass and a major market share relative to its competitors.

Within **consumer goods,** some major market shares, in relation to the competitors, are reported, but mass streams for these applications **are rather small** (shoes and office equipment show some relevance).

In terms of applied PVC mass, the **packaging sector** plays a role, whereas the market share in relation to its competitors is medium to small.

In the **transport sector** (including cars, trucks, yachts, and trains), PVC is mostly used in small amounts for numerous applications like plastisol sealings or underbody protection, body parts, tarpaulins, dashboards, artificial leather, cable harnesses, foams, fenders and seat coverings. In some applications within the transport sector, PVC is the major material in comparison to competitors, and **plastisols** and **artificial leather** play a larger role in terms of applied mass share.

Within **medical applications** PVC plays a major role, but the mass streams are small.

Agricultural applications are negligible in this context.

In summary, the application matrix was used for three important tasks. First, to provide an overview of the PVC market and to make relevancy transparent in terms of two indicators (see point 1 an 2 on page 43). Second, to identify possible gaps related to missing LCAs in comparable applications. Third, to evaluate the significance of these gaps.

4 Summary of overall life cycle impacts of PVC polymer

4.1 Introduction

The aim of this part of the report is to discuss the overall life cycle impacts of PVC polymer[9]. Of the large number of studies collected for this project, most of them dealing with products, all of them showed that PVC products have specific impacts (as do all products made of any materials) which can not be described with generalizations. Nevertheless, the life cycle can be structured in different phases in order to describe the PVC life cycle from a ‘top-down’ view in a simplified way (see Figure 4-1). A general PVC life cycle does not exist, because the specific variations in the compound account for specific life cycle segments.

To present the PVC life cycle effectively, chapter 4 is divided into three phases: the production phase (of the main components of PVC products, including raw materials), the use phase and the end-of-life phase. Considering the wide range of products made of PVC, and based on the studies collected for the project, only the most representative product groups will be discussed in detail here. These product groups include windows, pipes, cables, flooring and packaging. These products were chosen on the basis of their consumption in Europe (see Table 4-1) and the number of studies available in these areas.

Keep in mind that the facts reported here are primarily based on the LCA studies documented in this final report; inclusion of further information is beyond the scope of this study. Nevertheless, if additional or updated information, not covered by the studies, was available within the knowledge pool of the project group, this was also included.

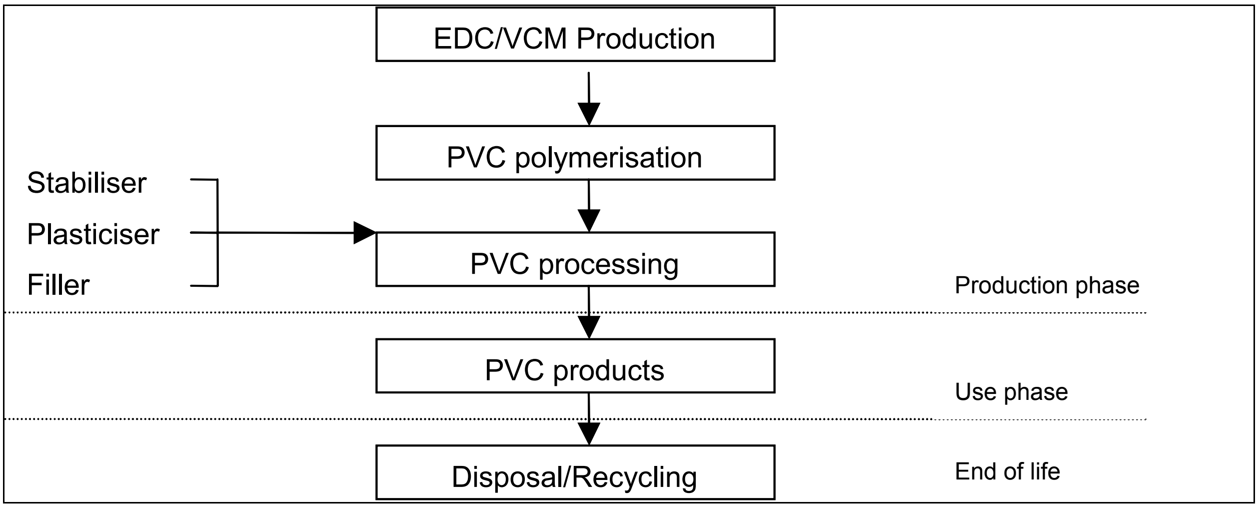


Figure 4-1: **Life cycle stages of PVC products**

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[9] An overview of important aspects from a life cycle perspective is aimed here. A description of the PVC life cycle in a detailed way is NOT required; this would to go beyond the scope. For detailed analyses on the specific impacts of the individual PVC life cycle see the respective studies mentioned in the text.

Table 4-1: PVC polymer consumption in the EU by product group (RANDA EU.005)

Use / Application	Percentage	Average life-time (years)
Building	57	10 to 50
Packaging	9	1
Furniture	1	17
Other household appliances[10]	18	11
Electric/Electronic	7	21
Automotive	7	12
Others	1	2 to 10

The percentages listed in this figure slightly differ from those of Table 3-4 on page 45, because the numbers for the year 2000 (from the RANDA EU.005 study) are smaller than those for the year 2003 and this table is based on PVC polymer whereas Table 3-4 is based on PVC compound.

4.2 Production phase

4.2.1 Overview of the production stage

Pure PVC is a hard, brittle material which degrades at around 100ºC and is sensitive to deterioration under the influence of light and heat. Pure PVC is therefore supplemented with additives which improve its service life properties and allow it to be processed. With the right combination of additives, it is possible to tailor the material for various applications. There are many types of additives. Examples include: (RANDA EU.010)

- plasticisers (especially phthalic acid esters or phthalates)
- pigments (titanium white, lead chromates)[11]
- heat and light stabilisers (usually organic compounds based on lead, tin, zinc, barium, a number of organic antioxidants and co-stabilisers, *cadmium*)[12]
- lubricants (wax, fatty alcohols, fatty acid esters)
- fillers (chalk, china clay, talcum, magnesium oxide)
- flame retardants (antimony trioxide, aluminium hydroxide, magnesium oxide, chloroparaffins), these are rarely used since PVC itself is relatively flame retardant
- impact modifiers; and
- fibres used as reinforcing materials (rarely used for PVC)

Table 4-2 contains the typical composition of various PVC products.

In terms of weight, plasticisers are the most significant additives for soft PVC. The plasticiser content of so-called “flexible PVC” normally accounts for 20 to 40% of the weight of the PVC product, but there are also plasticised PVC formulas which consist of more than 60%.

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[10] „Other consumer products“

[11] cadmium pigments are forbidden by Directive 91/338, except for safety marking, since 1994

[12] cadmium is not used anymore since 2001 by the companies bound by the Voluntary Commitment of the PVC Industry

From a chemical viewpoint, PVC is a thermoplastic polymer based on chlorinated hydrocarbons. Figure 4-2 provides an overview of the production processes leading from raw materials to finished products (RANDA EU.003)

PVC is produced from two primary raw materials, ethylene and chlorine. These react to form ethylene dichloride (EDC) which, upon cracking, yields vinyl chloride monomer (VCM). Free radical polymerisation is used to produce the PVC polymer itself.

The two most important polymerisation techniques are suspension polymerisation and emulsion polymerisation, leading to the production of S-PVC and E-PVC, respectively. These two types of PVC polymer have different properties and are used for distinct applications. The S-PVC process yields granules of polymer of 100 to 200 microns in diameter, which are used in processes such as injection moulding, extrusion and PVC film manufacture (RANDA EU.003). Here, S-PVC is analysed in more detail, as it is more commonly used. The difference between S- and E-PVC is rather small, as the type of polymerisation has a low impact on the overall performance of the PVC over its life cycle.

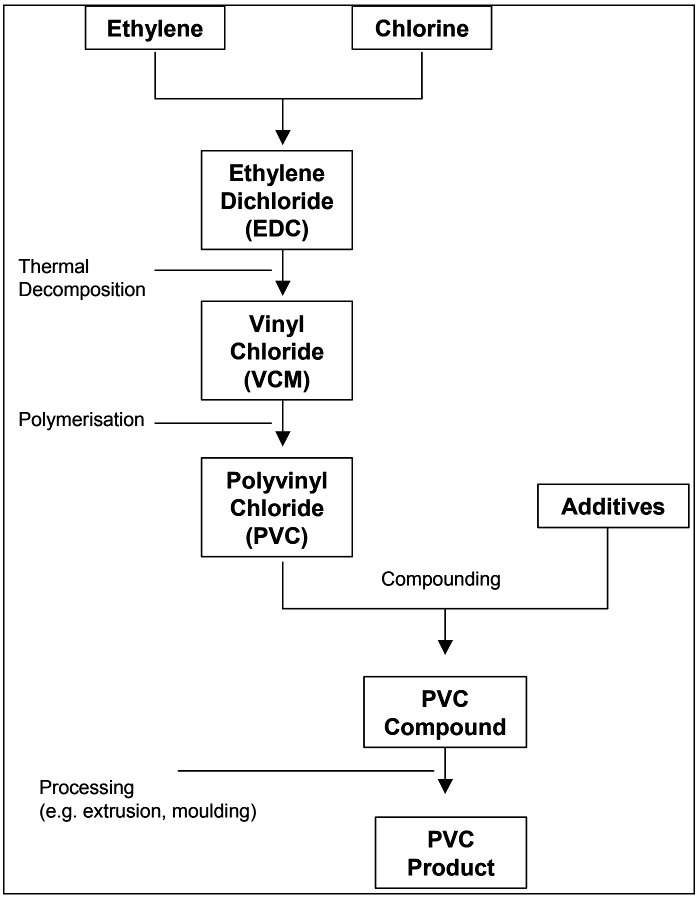

Figure 4-2: Overview of PVC product manufacture (RANDA EU.003)

Table 4-2: Typical composition of PVC compounds (RANDA EU.003)

	Component Share (weight - %)				
Application	**PVC polymer**	**Plasticiser**	**Stabiliser**	**Filler**	**Others**
Rigid PVC applications					
Pipes	98	-	1 - 2	-	-
Window profiles (lead stabilised)	85	-	3	4	8
Other profiles	90	-	3	6	1
Rigid films	95	-	-[13]	-	5
Flexible PVC applications					
Cable insulation	42	23	2	33	-
Flooring (Calender)	42	15	2	41	0
Flooring (paste, upper layer)	65	32	1	-	2
Flooring (paste, inside material)	35	25	1	40	-
Synthetic leather	53	40	1	5	1

The compositions may vary according to different producers and different production years.

The following chapters describe general environmental facts on the production of PVC, as well as the more LCA-specific ‘impact categories’. The LCA impact information was taken from the GaBi 4 database, as the published LCI data of APME does not support this type of analysis. The GaBi results are cross-checked with APME data and possible differences are documented. GaBi is a professional software system designed for life cycle engineering and life cycle assessment that was developed by IKP (University of Stuttgart) together with PE Europe GmbH since 1992.

4.2.2 Production of ethylene and chlorine

Definition: The raw materials for PVC are petroleum (which contributes to 43% of the polymer weight) and rock salt (57%). Petroleum is refined to naphtha, which is then cracked to form ethylene. Chlorine is obtained from rock salt through an electrolytic process.

Manufacture: Ethylene is produced, together with a variety of co-products, by the steam cracking of naphtha or natural gas liquids. The natural gas liquids contain ethane, butane and propane and when they are pyrolysed the products are ethylene and propylene. Ethylene production via steam cracking is a basic chemical process. The ethylene used as an intermediate in PVC production is the minor portion of the chemicals produced during this process. Products from the steam cracker are used as intermediates for a variety of other products.

Thirty percent of the chlorine produced in Germany is used for Vinylchloride (VCM) and EDC (dichloroethane) production [57]. Chlorine is produced by the electrolysis of a salt solution or brine. During electrolysis chlorine is produced at the anode while sodium or caustic soda and hydrogen are produced at the cathode. The products of the electrode processes must be kept separately; otherwise they will react to form unwanted by-products. Either chemical or physical separation is employed. Today, there are three different commercial electrolysis processes available: the amalgam process, the diaphragm process and the membrane process.

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[13] approx. 0,5% stabiliser. This is apparently included in the 5% value “others”.

The amalgam process requires a higher consumption of electrical power than the diaphragm or membrane processes but produces a purer and more concentrated caustic soda solution. Substantial quantities of steam are required to concentrate the caustic soda solutions, produced by the diaphragm and membrane cells, to the concentration levels that are produced by the amalgam process. The Best Available Technology (BAT) for chlorine manufacture is recognised to be the membrane process [31], which consumes less electricity compared to the amalgam and diaphragm processes.

Environmental impact: Emissions from ethylene production are released to air and water. They consist primarily of ethylene and propylene emissions to air, and methanol and propane/butane emissions to water. Other emissions, such as Total Organic Compound (TOC), Sodium Hypochlorite (NaOCl), etc. are also present [31].

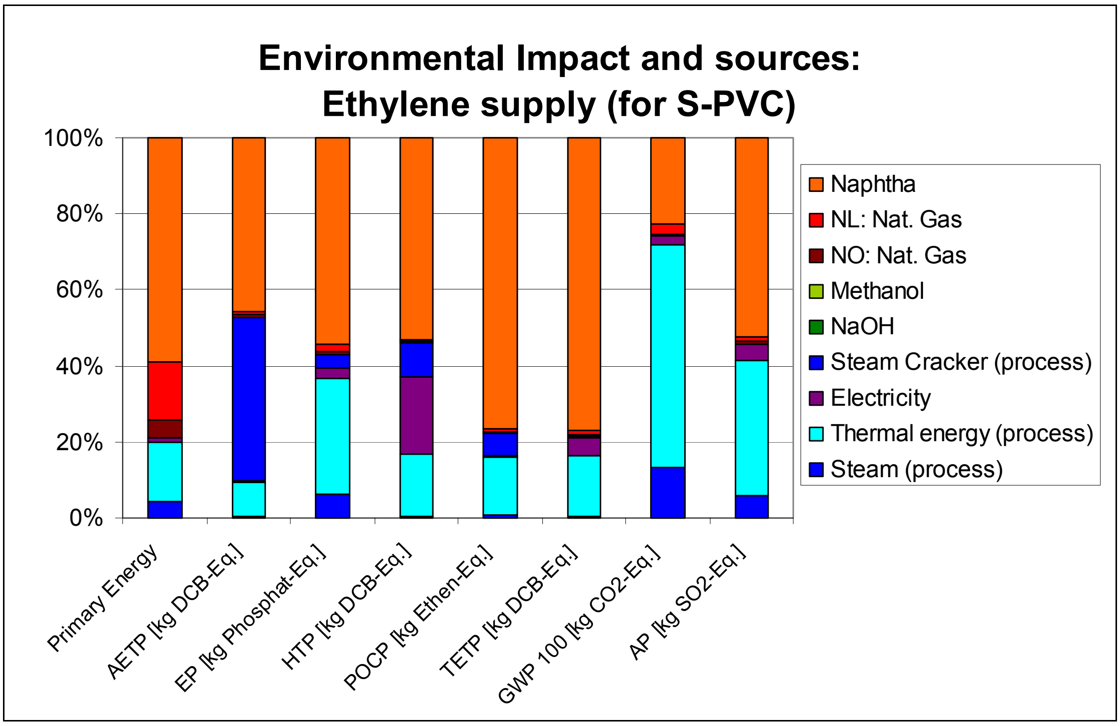

Figure 4-3: Environmental Impact of Ethylene Production [21]

During chlorine production, emissions of chlorine and hydrogen are possible from all three processes (amalgam, diaphragm and membrane). Mercury can be emitted from the amalgam process only. Asbestos fibres within the diaphragm process are a potential workplace hazard but the existence of the fibres as such presents no environmental problem, since the fibres are chemically inert and no release during regular use appears. The diaphragm keeps the products of electrolysis separate while allowing the passage of electric current. A matter of concern is the handling and disposal of the diaphragm [31]. Mercury disposal on-site can affect the water, air and soil in the plant neighbourhood, posing a hazard to plant operators and to the people and animal life living near the plant. Chlorine as a toxic gas has a potential environmental impact, if released to the environment.

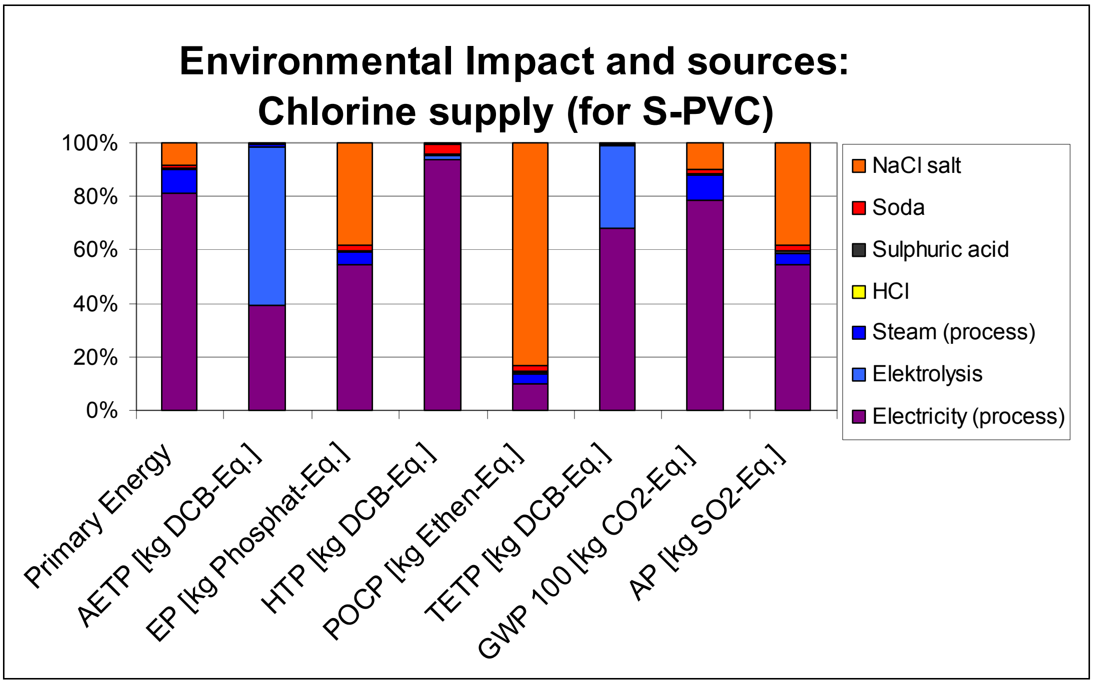

Figure 4-4: Environmental Impact of Chlorine Production [21]

Figure 4-3 and Figure 4-4 show the environmental profile of these materials in impact categories. In the case of ethylene, naphtha occupies a major part in all impact categories, especially Photochemical Ozone Creation Potential (POCP). This is mainly due to the processing of crude oil, which causes VOC emissions.

The high consumption of electricity is the main characteristic of the electrolysis process for the production of chlorine (see Figure 4-4), causing CO_2 and SO_2 emissions, which result in a high Global Warming Potential (GWP) and Acidification Potential (AP). In comparison to the other process steps, the electricity production of the electrolysis process also results in a high Human Toxicity Potential (HTP). The German Environmental Protection Agency considers the mercury emission from the production of chlorine with the amalgam process and the electricity consumption (its production and supply for the electrolysis) as the main environmental factor of concern for the chlorine production process [57]. New installations of electrolysis processes have be operated with the membrane process.

A step-by-step shift to the membrane process for chlorine electrolysis is in progress. This is seen as a major step to further reduce environmental impacts of chlorine production.

Risk characterisation: In the case of PVC, the production of chlorine plays a very important role and it is a continuing topic of discussion in the assessment of risk. Information regarding exposure: limits and areas of exposure, risks to the environment and health should be mentioned. Moreover, the production of the petrochemical part of PVC, as for all plastics, includes various risks: sea pollution from drilling to shipping, and risks associated with explosive gases such as ethylene.

Risk characterisation is not a primary task within LCA, as LCA deals with potential impacts of regular operation. Today, initial approaches are in development that address the integration of risk aspects into LCA. Nevertheless, existing methods, such as Risk Assessment, are more suitable to answer specific questions related to the risks of chlorine.

4.2.3 Vinyl Chloride Monomer (VCM) and Dichloroethane (EDC)

Definition: Ethylene and chlorine react to form 1,2-dichloroethane, which at high temperatures decompose into vinyl chloride and hydrochloric acid. The hydrochloric acid is fed back into the process to react again with ethylene to form 1,2-dichloroethane (IKP-NL-3).

Manufacture: The vinyl chloride monomer (VCM) is produced from ethylene, chlorine and oxygen through the following global reaction: (RANDA EU.010)

$2\ CH_2{=}CH_2 + Cl_2 + ½\ O_2 \rightarrow 2\ CH_2 = CHCl + H_2O$

Alternatively, EDC (dichloroethane) is prepared by direct chlorination or oxychlorination.

In direct chlorination, ethylene and chlorine are used:

$CH_2{=}CH + Cl_2 \rightarrow CH_2Cl\text{-}CH_2Cl$

EDC acts as a solvent. The two gaseous reactants are added in approximately equal measures to the solution at around 50ºC. The heat of reaction is used to evaporate the EDC that is produced. Iron chloride is used as a catalyst.

In oxychlorination, ethylene, hydrogen chloride and oxygen are used.

$CH_2 = CH_2 + 2HCl + 1/2O_2 \rightarrow CH_2Cl\text{-}CH_2Cl + H_2O$

This reaction occurs at 220 - 240ºC under increased pressure (4 bar). Copper chloride is used as a catalyst.

The EDC that is produced is cooled and then washed with water and caustic soda to remove HCl, Cl_2 and water-soluble contaminants. Water is removed from the EDC through distillation.

In the above reactions, chloroethane, trichloromethane, tetrachloromethane, 1,1,2-trichloroethane and tetrachloroethane are produced as by-products, as well as trace amounts of chlorinated aromatics including traces of dioxin. The occurrence of dioxins is not included in the environmental impacts of LCAs. The EDC is cleaned of these contaminants through distillation. The total by-products account for less than 2.5% by mass.

After being treated, the EDC is converted into VCM by pyrolysis at approximately 500ºC and 10 bar.

$CH_2Cl\text{-}CH_2Cl \rightarrow CH_2 = CHCl + HCl$

This produces various chlorinated and non-chlorinated by-products. These are put back into the process together with non-reacted EDC. The HCl that is released is usually reused in the oxychlorination process. During the process, solid waste is released in the form of carbon from process filters, calcium chloride from the drying of process flows, and sewage sludge.

Environmental impact: As a result of the EDC/VCM process several chlorinated hydrocarbon byproducts are formed. This can be seen in the Human Toxicity Potential (HTP) represented in Figure 4-5. It is generally recognised that dioxins can be formed during the production of EDC by oxychlorination. Emissions of EDC, VCM and metals from the oxychlorination catalysts require attention. As with most chemical production processes, adequate measures with regard to emissions and waste have to be taken into consideration. (RANDA EU.010).

The European industry also signed a Charter in 1995 [50].

The German Environmental Protection Agency reports emissions to air and water and reports chlorine-containing residues resulting from the synthesis of EDC and VCM [57]. The EDC and VCM emissions to air and AOX emissions (adsorbable halogenated organics) to water are considered to be low and the residues are treated in special incinerators.

From our point of view, the environmental life cycle impacts of the synthesis step of EDC/VCM production, within the life cycle of PVC, are relatively low. EDC/VCM is considered carcinogenic, but the amount of emission to the environment (after offgas and wastewater treatment) is considered to be at a low level today and the substances are not stable in the environment.

The treatment of the chlorine-containing residues from VCM production in hazardous waste incineration plants is technically feasible and must not result in significant environmental impacts, if processed properly. Flue gas treatment, recovery of energy and/or substances like HCl, are both state-of-the-art in modern production facilities of Western European standard.

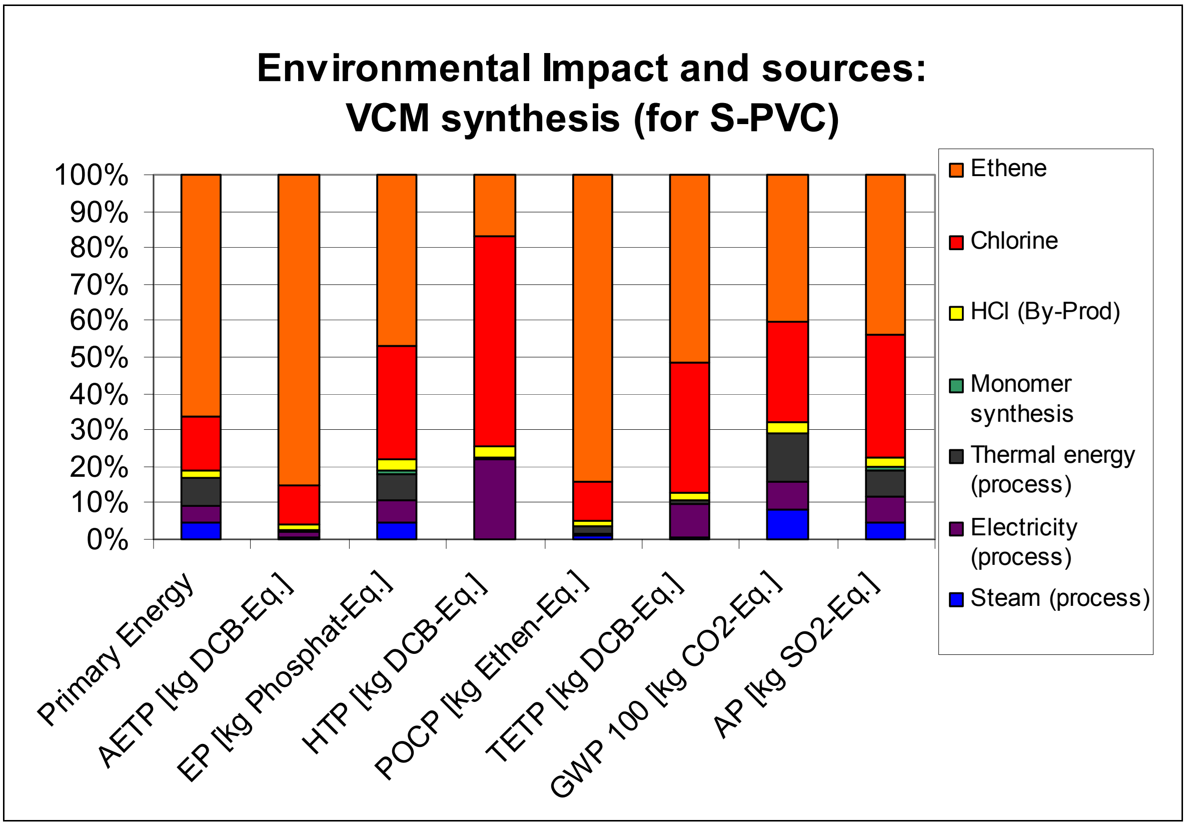

Figure 4-5: Environmental impact of VCM production [21]

<u>Risk characterisation:</u> The study RANDA EU.010 states that, based on existing knowledge, environmental risks from EDC/VCM production are considered low, provided state-of-the-art abatement technology and management is applied. However, in the newly enlarged European Union, EDC/VCM may also be produced via old processes in facilities that are not-state-of-the-art. Therefore, emissions of VCM, EDC, dioxins and other substances that have been measured and identified as potential emissions will be close to or below the negligible risk level in modern facilities, and may vary over a wide range in old facilities. The following measures are of importance:

- Waste: solid waste and sludge can contain organohalogens, including dioxins, therefore incineration is preferable to landfilling. With certain destruction technologies, such as gas-phase hydrogenation, the by-product HCl can be re-used in the process or refined to a commercial product.

- Water: advanced wastewater treatment should prevent emissions of halogenated hydrocarbons like EDC and dioxins in treated effluents. Residues from those treatments may undergo further treatment to destroy possible captured contaminants.
- Air: proper emission reduction-measures are necessary to ensure that VCM and EDC emissions and possibly other contaminants will be close to or below the negligible risk level.

4.2.4 PVC polymerisation

Description of the process: The vinyl chloride is converted into a PVC granulate in one polymerisation step (IKP NL-3). Polymerisation can be carried out using different methods (mass polymerisation, suspension polymerisation, emulsion and microsuspension polymerisation). Mass polymerisation takes place in the presence of light, a liquid monomer, heat or small amounts of initiators. This process is used in order to obtain transparent and brilliant resins. Emulsion polymerisation includes the formation of a water monomer emulsion by using tensides and initiators. Reducing agents are sometimes used to accelerate the process. The polymer obtained in this way is not pure. During suspension polymerisation the monomer is roughly dispersed in water by using an impeller agitator. This process produces relatively big porous particles (0.1 - 0.2 mm diameter), able to absorb large amounts of plasticiser. The polymer is separated from the water by centrifugation and is dried with heated air.

In the suspension polymerisation process VCM is fed to a reactor in doses, together with a suspension stabiliser, a pH buffer, an anti-foam agent and an initiator (e.g. organic peroxides). VCM reacts to form PVC as follows: (RANDA EU.010)

$n\ CH_2 = CHCl \rightarrow CH2 - CHCl - CH2 - CHCl -$

When a conversion rate of 80 to 90% is reached, the polymerisation is stopped with the aid of an inhibitor. After recovery of unconverted VCM, the suspension is filtered. Residues of VCM are then stripped with open steam and transported to a gasometer. In addition, all water flows with VCM content undergo stripping before being pumped to a water treatment plant.

The VCM-free suspension is processed into dry PVC powder by centrifugation and drying. The air used for this is released into the atmosphere via a bag filter. VCM is recovered from various gas flows containing VCM with the aid of a condenser. PVC is produced in batches. Before the reactor is refilled it is first rinsed with water to remove residues of PVC.

Environmental impact: Energy consumption for the production of 1 kg of PVC is 57.2 MJ (20.7 MJ/kg feedstock requirement and 36.5 MJ/kg process-energy requirement) (IKP-D-19). This information is considered consistent, as it is taken from the database of the professional LCA software system GaBi, which underwent several cross-checks with industry and other professional users in academic organisations. Within the polymerisation, only low concentrations of residual monomer within the polymer are desired. Using intensive degassing processes within the polymerisation steps the concentration of residual monomers can be reduced to <1ppm at suspension polymerisation, <5ppm at emulsion and <2ppm at bulk polymerisation [57].

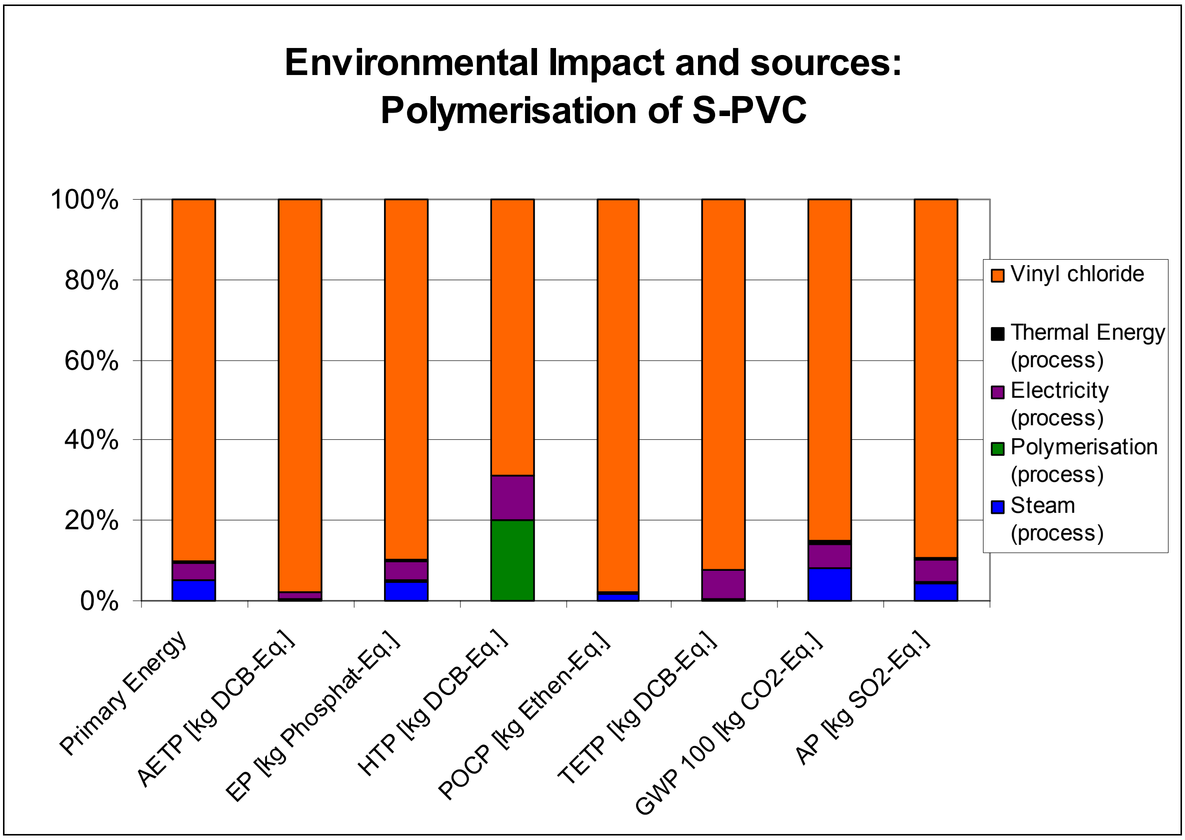

Figure 4-6: Environmental Impact of PVC polymerisation [21]

VCM is the primary contributor to all impact categories (see Figure 4-6). The analysis considers the extraction of raw materials and shows that the process steps from raw material extraction to the synthesis of VCM contributes most to the environmental burden.

Looking at the upstream processes of the VCM synthesis, it is clear that the processes involved in ethylene production (steam cracker, refinery and crude oil supply) consume the most energy. The primary energy required for the ethylene production chain is approximately three times as high as the primary energy required for the chlorine route (including electrolysis).

A summary of the facts presented in sections 4.2.2-4.2.4 can be seen in Figure 4-7.

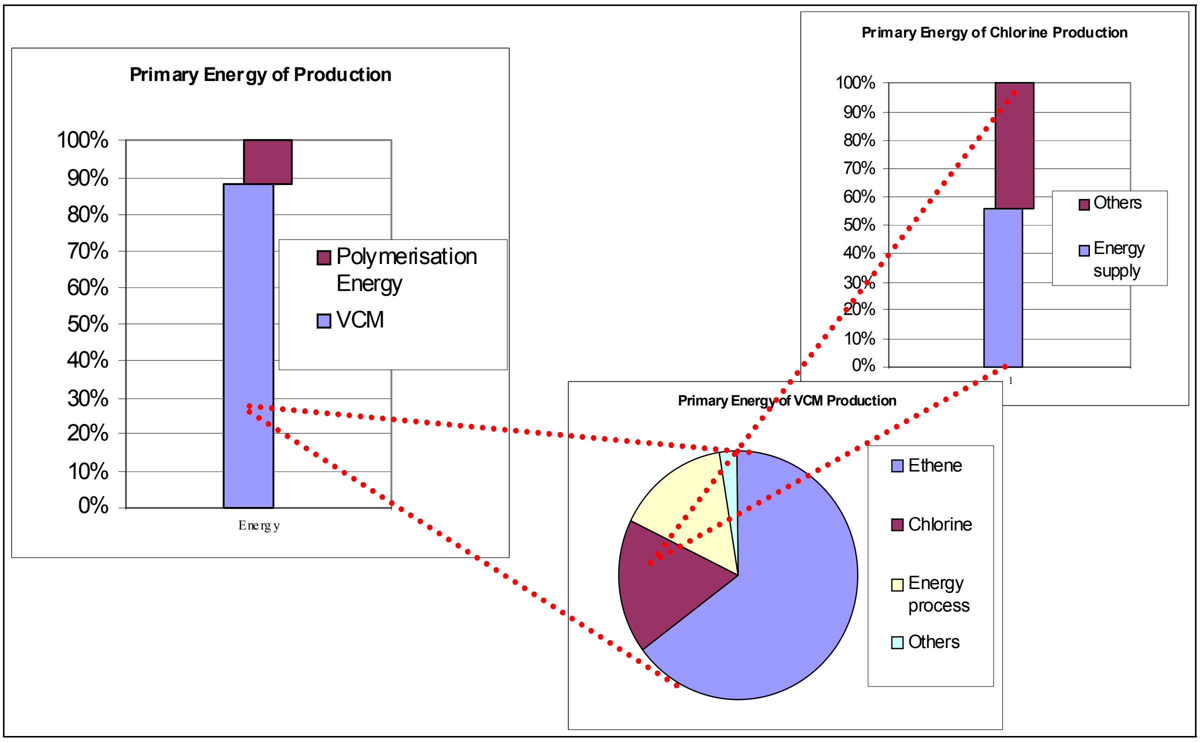

Figure 4-7: Scheme of primary energy consumption in the production of PVC [21]

Risk characterisation: Based on existing knowledge, the environmental risks of PVC production are considered low, provided state-of-the-art technology and management is applied. Therefore, emissions of VCM and other substances will be close to or below the negligible risk level. The following measures are of importance (RANDA EU.010):

- Waste: PVC-coagulate should be incinerated as hazardous waste.
- Water: adequate stripping can ensure virtually zero emissions of VCM to water.
- Air: proper emission-reduction measures are necessary to ensure that VCM emissions will be below maximum acceptable risk level and close to or below the noise rating.
- Products: efficient stripping must ensure minimal VCM residue in the final polymer.

From an LCA point of the view, the environmental “risks” of PVC polymerisation are relatively low, provided state-of-the-art technology and management are both applied. In other words: PVC polymerisation is not a priority for optimisation within the process chain of PVC products, as relatively little energy and materials are needed and a relatively low amount of emissions are released.

4.2.5 Additives: Stabilisers

Definition: A stabiliser is a complex mixture designed to prevent degradation from heat or UV light. These are also added to the PVC polymer to prevent thermal degradation and hydrogen chloride evolution during processing. All PVC is stabilised through the addition of stabilisers. The most important group of stabilisers are presented in Table 4-3. More detailed information about lead stabilisers will be given, since they represent approximately 60% of the total consumption of stabilisers (RANDA SP.002). More information as well as developments by year of stabiliser use can be obtained from the “Progress reports” on the Vinyl 2010 initiative [50].

Table 4-3: List of stabilisers for different PVC applications

Stabiliser Type	Main Use
Lead stabiliser	Pipes, cables, profiles for construction.
Tin organic stabiliser	Mainly rigid products (>95%), including food-contact use.
Ba/Zn or Ca/Zn liquid systems are used in flexible PVC, whilst solid systems are used in rigid PVC as lead replacements in addition to their traditional use in medical and food-contact applications.	Wide range flexible PVC application, calendered sheet, flooring, etc. Ca/Zn penetration in pipes and profiles is increasing. Ba/Zn is the dominant type of stabiliser in flooring in 1996 in Sweden (IPU.0019). Ca/Zn to a minor extent.

Epoxidised soybean oil is used as a co-stabiliser and plasticiser in many applications. An example for flooring can be found in (IPU.0019).

Manufacture: Basic (alkaline) lead sulphates are produced by reacting lead oxides with sulphuric acid or a sulphate solution [49]. Once the lead stabiliser is incorporated into the PVC matrix, it is no longer bio-available. The compounded PVC can also be shipped in granular form to processors, which will mould, extrude, or by other means manufacture the part into its final shape. The parts can then be assembled to form the final product, such as a window frame. During these steps, little or no dust is generated; hence, exposure is not generally a concern [52].

Environmental impact: According to UBA (Umweltbundesamt, Germany) during the last 15 years in Germany 200.000 t of lead compounds have been used in PVC products as stabilisers (IKP-D-42). Due to the substitution of cadmium compounds by lead for use as PVC stabilisers, the share of lead compounds used has risen, from 8,500 t in 1985 to 9,600 t in 1990.

PVC products are comparatively durable. Therefore, these products result in a temporally delayed emergence of the lead and cadmium stabilisers in end-of-life products. 3,000 t of cadmium and some 100.000 t of lead are incorporated in PVC products in Europe (IKP-D-42). Furthermore, about 14.500 tonnes of mixed metal solid stabilisers and 16,400 tonnes of liquid stabilisers were used in 1998 in Europe. Among these types of stabilisers, calcium/zinc and barium/zinc systems are the most commonly used [61].

From our point of view, the environmental impact of the lead used to stabilise PVC products, is only of concern for specific end-of-life options. During the use phase, no significant potential environmental impact can be identified if the products are properly used. If the PVC is mechanically recycled into new products, the lead is used as a stabiliser again and incorporated into the polymer matrix. If PVC is chemically recycled, basic substances, such as salt, lead and coke, are recovered and may be used elsewhere. If the PVC is incinerated, the lead ends up the filters and is dumped into special facilities.

Risk Characterisation: The principal risks presented by stabilisers are exposure to and ingestion of dust. For years, "dust-free" or "one-pack" formulations have been used. These combine the stabiliser with lubricants and other additives, where appropriate, to produce a low- or non-dusting product.

Exposure to lead in the plastics industry can occur during the mixture of additives and during cleaning.

The current EU maximum exposure concentration of lead compounds in air is 0.15 mg/m^3. As a further precaution, occupational physicians monitor exposure with biological samples as required by the EU Directive. The maximum level of lead allowed by the EU in blood is 70 µg/dl for men and 40 µg/dl for women. Nevertheless, in the EU Directive, 70 µg/dl is the binding limit value. Some countries permit only up to 40 µg/dl for men and 20 µg/dl for women.

Modification of equipment, adequate ventilation, use of personal protection equipment such as dust masks, clothes and gloves, work place cleaning, and high personal hygiene standards assist in the control of risk exposure.

The typical lead content in major applications is:

Pipes	0.75%
Wires and cables	1.6%
Window profiles	2%

In conclusion, the risk of diffused losses to the environment, or of consumer exposure, is minimized by the PVC encapsulation effect that immobilises the lead stabiliser and prevents it from harming people or the environment [52].

For certain applications, including toys, medical products and food packaging, there are specific regulations in place to ensure safety by requiring the use of alternative stabilisers such as Ca/Zn. These alternatives are included in either a positive list or as positive approvals, and lead stabilisers are not used at all in these applications.

Actions (Vinyl 2010, 2001) [50]:

- The European Stabilisers Producers Association (ESPA) is carrying out an EU risk assessment of lead stabilisers, in conjunction with an assessment of all uses of lead and its compounds. This is a voluntary programme, with the Netherlands acting as Shadow Rapporteur on behalf of the Member States in the framework of the EU Existing Substances Directive. This is the first example of a group of chemicals being dealt with in this manner.
- ESPA and the European Plastics Converters (EuPC) committed to the replacement of lead stabilisers to achieve the following reduction targets, based on 2000 consumption levels:
    - 15% reduction by 2005;
    - 50% reduction by 2010; and
    - 100% reduction by 2015.

4.2.6 Additives: Plasticisers

Definition: Plasticisers are organic compounds, which separate polymer chains, allowing them to move in relation to one other and thereby improve elasticity. The most common plasticisers are presented in Table 4-4.

Table 4-4: List of main plasticisers and their product applications

Plasticiser Type	Main Use
Phthalates	Flooring, cable, wire, films and sheets
Adipates	Flooring, cable, cling film
Trimellitates	Products which are exposed to high temperatures, e.g. cables in engine rooms

The most commonly used plasticiser are phthalates, of which di-2-ethylhexyl phthalate (DEHP) has traditionally accounted for 50% of European phthalate use. Others include di-isononyl phthalate (DINP), di-isodecyl phthalate (DIDP), di-butyl phthalate (DBP) and butyl-benzyl phthalate (BBP). Like most plasticiser, phthalates are organic esters. They are produced through the reaction of a carboxylic acid and an alcohol (RANDA EU.003). New statistics from to the European Council for Plasticisers and Intermediates (ECPI) shows a decreasing DEHP (37%) share and an increasing DINP/DIDP (48%) share in the phthalate market in 2001.

Phthalates also made up 95% of the total use of plasticisers in Sweden in 1994. They were distributed among different product groups: Flooring 44%, Cable and wire 30%, Coated products (excl flooring) 7%, Film and foil 15%, Hoses and profiles 0.3%, Others 4% (IPU.0019).

Flexible PVC can contain up to 60% plasticiser when used as a coating and in very soft products. On average, flexible PVC contains about 30% plasticiser.

Manufacture [4]: The overall production route of the final phthalate esters can be summarised in the following steps:

- manufacture of phthalic anhydride from o-Xylene by oxidation;
- manufacture of C8 olefins and C9 olefins from propene and butenes in polygas or dimer units, produced in either steam-cracking process or in petrochemical plants;
- manufacture of the three oxo alcohols: 2-ethylhexanol from n-butylaldehyde made by reacting propene and syngas, isononyl alcohol from C8 olefins and syngas, and iso-decyl alcohol from C9 olefins and syngas;
- manufacture of three high volume commodity phthalate esters by esterification between the phthalic anhydride and the corresponding alcohol.

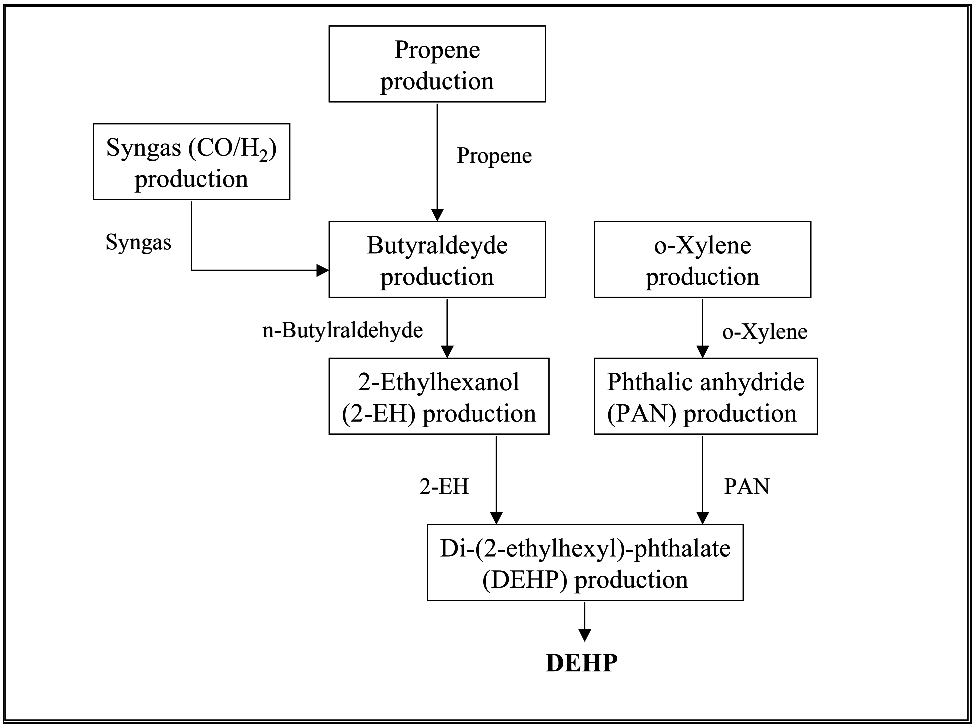

Figure 4-8: Schematic flow diagram for the production of DEHP (ECPI, 2001)

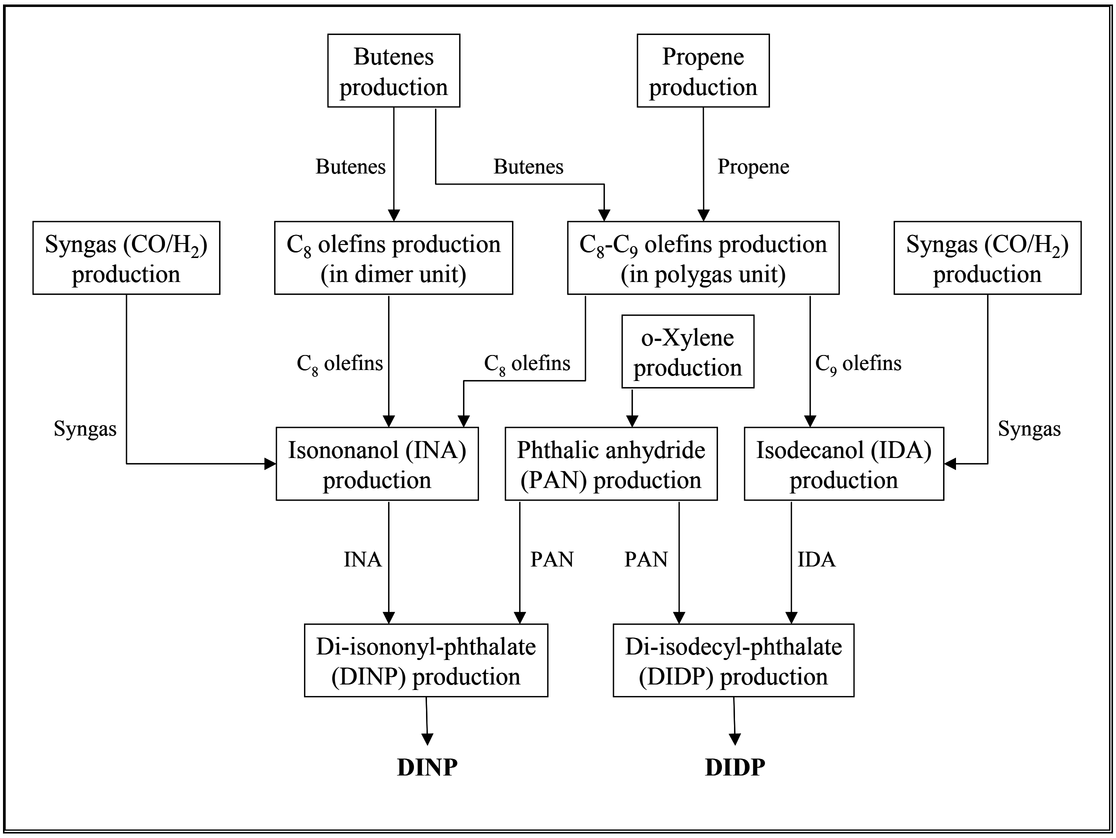

Figure 4-9: Schematic flow diagram for the production of DINP and DIDP (ECPI, 2001)

Environmental Impact:

Emissions during the production process are low, estimated at 4 to 5 t/a to air and water. According to the ‘Eco-profile of high volume commodity phthalate esters’, prepared for ECPI by ECOBILAN in 2001 [4], the total gross energy required to produce 1 kg of high-volume commodity phthalate esters is 71.09 MJ.

Risk Characterisation:

Exposure can occur during the addition of plasticiser, especially through air emissions in the coating and calendering processes. Emissions from the cleaning of the machinery come in addition. These emissions can be prevented by an appropriate combination of filters and ventilation in closed systems.

Direct entry of plasticisers into the hydrosphere occurs through municipal and industrial wastewater.

For the general population, the main source of exposure is dietary, including drinking water, followed by inhalation of air. Food contains DEHP, especially in fat, for example in fish, milk, and oil. Environmental contamination by this agent results from losses during manufacturing, packaging, storing and from flexible PVC articles.

Maximum occupational exposures to DEHP, mainly by inhalation, are generally set at 0.7 mg/kg/d when the workplace air concentrations meet the TWA (Time Weighted Average) standard for 8 h (usually 5 mg/m^3).

Recently new risk assessments of phathalates are undertaken by European Chemicals Bureau. The risk assessment of DINP (no classification), DIDP (no classification) und DBP (category 2 classified) are completed and published (e.g. see http://ecb.jrc.it/existing-chemicals/).

For DEHP and BBP (benzyl butyl phthalate) the new risk assessment is not completed. Meanwhile DEHP is classified according category 2 (see directive 2003/36/EC).

For DNOP (di octyl phthalate) no risk assessment was carried out, because only traces were detected in toys.

Specifically for DINP, for which concerns have been expressed about children's exposure via toys, the risk assessment conducted by the European Union found that exposures from consumer products, including toys, are unlikely to pose a risk to adults, infants or newborns. On the other hand, a US study, the SCIENTIFIC COMMITTEE ON TOXICITY, ECOTOXICITY AND THE ENVIRONMENT (CSTEE) did see a need for risk reduction measures regarding the use of DINP in toys. However, the DINP has no classification according to the recent risk assessments.

The sector should continue to improve the scientific database of products according to Responsible Care principles and use the database to propose improvements based on the results of EU risk assessments.

4.2.7 Additives: fillers

Definition: Mainly inert materials such as calcium carbonate (chalk), talc, kaoline, magnesium oxide, etc., used to improve some mechanical properties of PVC as well as to reduce costs.

Manufacture: The most common filler used in PVC formulations is chalk [31]. Limestone is mined, sieved, ground and conditioned. The main input is energy and the main outputs are emissions from the energy supply. (IKP-CH-16)

Environmental Impact: The environmental impacts from the production of filler materials are minor compared to those from PVC production. Therefore, a higher share of fillers in PVC products tends to result in a better environmental profile. The main environmental impacts are caused by emissions from energy supply and fuel combustion. (IKP-CH-16)

There are no reports on the effects of fillers in PVC during the use phase. In the end of life phase, fillers do not significantly affect material recycling. For example, purification steps are made a little more complex, but they do no result in significantly higher environmental impacts. In waste incineration, the presence of fillers results in more ash and a lower net calorific value of the combustible material.

Risk characterisation: Inorganic fillers like calcium carbonate (chalk), talc, kaolin or magnesium oxide are not toxic, and specific risk information is not reported in the studies.

4.2.8 Additives: pigments

Definition: Insoluble compounds that are used to colour products. A variety of colours are obtained by mixing different pigments. One of the most important pigments is titanium dioxide. It is used as a base for many colours (IKP-NL-1).

Manufacture: The chloride process and the sulphate process are used to produce titanium dioxide from limonite.

Environmental Impact: The production of titanium dioxide using the chloride process requires high energy consumption (70 MJ/kg) and produces a large amount of chemical waste (2.3 kg/kg) (IKP-NL-1).

Risk characterisation: No information was found on this aspect in the studies collected.

4.2.9 PVC processing

Once PVC (granules or powder) has been mixed with the required additives, some form of heating is usually required. This binds the PVC particles together and helps to incorporate the additives into the polymer matrix. During heating, some molecules of PVC become freed and become entangled. Upon cooling, these recrystallise to form a three-dimensional structure, a process known as gelation or fusion. (RANDA EU.003)

Numerous techniques are used to process the various PVC compounds into the wide range of final products:

- Extrusion
- Injection moulding
- Calendering
- Blow moulding
- Rotational moulding
- Dip moulding
- Coating process to produce PVC plastisols

Environmental Impact: Emission of plasticisers to the external environment from PVC processing is estimated by Cadogan et. al. (1994) to be 0.02 - 0.07% of the total mass of plasticiser used, and is highest from the calendering process (IPU.0017).

During manufacturing it is estimated that 91% of plasticiser emissions are released to air, and 7% directly to water. Evaporation, followed by air transport, and wet and dry deposition, are said to be the major routes for emissions to the environment. It is possible that this transport is global, as DEHP has been found in traces in Antarctic sediments. (IPU.0017)

Energy consumption for different processing methods is shown in table 4-5. (IPU.0017)

Table 4-5: Energy consumption for different processing methods (Tötsch, Gaensslen, 1992. Based on Kindler, Nikles, 1980)

Processing method	Energy consumption (MJ/kg)
Film extrusion	3 - 6
Film calendering	6
Pipe extrusion	3 - 5
Blow moulding	5 - 15
Injection moulding	5 - 15

4.2.10 Manufacture of PVC products

In this section, as mentioned previously, only the most prevalent product groups are discussed.

4.2.10.1 Window frames

In 1996, the materials used in window frames in Germany were (IKP-D-6):

- PVC 49%
- Wood 28%
- Aluminium 20%
- Wood-aluminium 3%

This confirms the importance of PVC in this market.

Average composition: The average composition of a PVC Window frame is shown in Table 4-6.

Table 4-6: Average composition of a PVC-Window frame

	IPU.0015	IKP-D-6
PVC	59.3%	78.1%
Stabiliser		
- lead phosphate and stearate	1.8%	
- Ca/Zn		5.5%
Plasticiser		
Filler		5.1%
- powdered limestone	3.65%	
Pigment - titanium dioxide	2.54%	3.4%
Steel	19.76%	
Aluminium	3.49%	
Acrylate rubber	4.38%	6.8%
Nitrile or PVC	4.01%	
Petroleum wax and fatty acid ester	1.12%	1.1%

Production process: The manufacturing of the window frames involves the following steps: (IKP-D-6)

- Extrusion of PVC granulate to form a window-frame profile
- Mitre off the profile
- Adding vents for drainage and for the attachment of fittings
- Welding of nooks and removal of weld seams
- Assembly of fittings, glazing and seals
- Assembly of window frame and casement.

Environmental impact: The amount of primary energy required for the production and recycling of a PVC window frame is considerably larger than that for a wooden window frame.

However, when taking into account the Global Warming Potential of each, it becomes clear that the difference is not that big because part of the required energy is embedded in the PVC material itself. (IKP-D-6)

The low value of the Photochemical Ozone Creation Potential for PVC is worth noting. PVC windows need no special surface treatment. Additionally, the hydrocarbons emitted from the material during production are treated with exhaust air cleaning systems for workplace security and environmental reasons, and hence, do not reach the environment. (IKP-D-6)

The stabilisers based on Ca/Zn compounds, considered in the IKP-D-6 study, are not toxic. But the production processes of the PVC material continue to dominate the ecological impact in this category. The production of the pigment titanium dioxide (TiO_2) adds to the toxicity potential.

Recycling is a crucial issue for the life cycle of PVC window frames. A controlled closed-loop recycling scenario results in considerably lower environmental impacts. However, closed-loop recycling can only work in growing PVC markets, i.e. if the amount of recycling material is lower than the amount of material needed (IKP-D-6). In addition, problems may arise in closed loop recycling because of the fast enhancement of stabiliser systems that may lead to non-compatible stabiliser systems appearing in the same recycling material. This problem, however, is not prevalent at the moment, as the most common stabilisers are compatible and can therefore be mixed together. Co-extrusion with a cover layer of virgin material could solve this problem for non-compatible stabilisers.

4.2.10.2 Pipes

According to IPU.0019, in 1996 23% of sewer pipes in Sweden were made of PVC. In Germany, the use of PVC pipes in 1993 for various pipe applications was as follows (IKP DE-42):

- Wastewater pipes 45%
- Pipes for laying of cables 18%
- Freshwater pipes 18%
- Pipes for drainage 9%
- Other pipes 9%

Average composition: Composition of pipes varies depending on the producer and the application. The following average compositions were provided in the studies collected:

Table 4-7: Average composition of sewer pipes in mass %

	(IPU.0015)	(IKP-NL-3)
PVC	92.1	94
Stabiliser		
- tribasic lead sulphate	1.4	
- dibasic lead stearate	0.5	
- lead stearate	0.2	1.1
- calcium stearate	0.4	
- lead stabiliser		
- tin stabiliser		
Plasticiser		
Filler		3.8
- powdered limestone	4.70	
Stearic acid	0.1	
Synthetic hard wax	0.1	
Paraffin (lubricant)		0.7
Pigment		
- Carbon black	0.5	0.02
- Titanium oxide		0.2

The IPU.0019 study provides a different composition. A share of 0.75% lead-stabiliser or 0.3 - 0.4% tin-stabiliser is estimated. Further, 0.1% synthetic hard wax is required, but no plasticiser is needed. The IPU.0032 study lists 1.9% stabiliser and 0.15 - 0.20% lead pigment content in red/brown pipes.

PVC can consist of virgin and/or recycled material. A French study (RANDA FR.001) compares pipes made from virgin PVC and 9.3% recycled PVC with pipes containing primary zinc and 40% recycled zinc (see chapter 5.1.4 for details).

Production process: Again, the production process varies by producer, application and composition of the pipe. For example, as described in the IKP CH-5 study, unplasticised PVC powder is mixed with additives in hot mixers prior to processing. Additives are contained in the PVC granules upon delivery. Material is then converted into pipes by extrusion or into fittings by injection moulding.

Typical diameters and weights for water pipes are: (IKP-AT-5)

150 mm = 6,32 kg/m_{pipe}

250 mm = 6,59 kg/m_{pipe}

400 mm = 16,81 kg/m_{pipe}

A scheme for the production of PVC pipes can be seen in Figure 4-10.

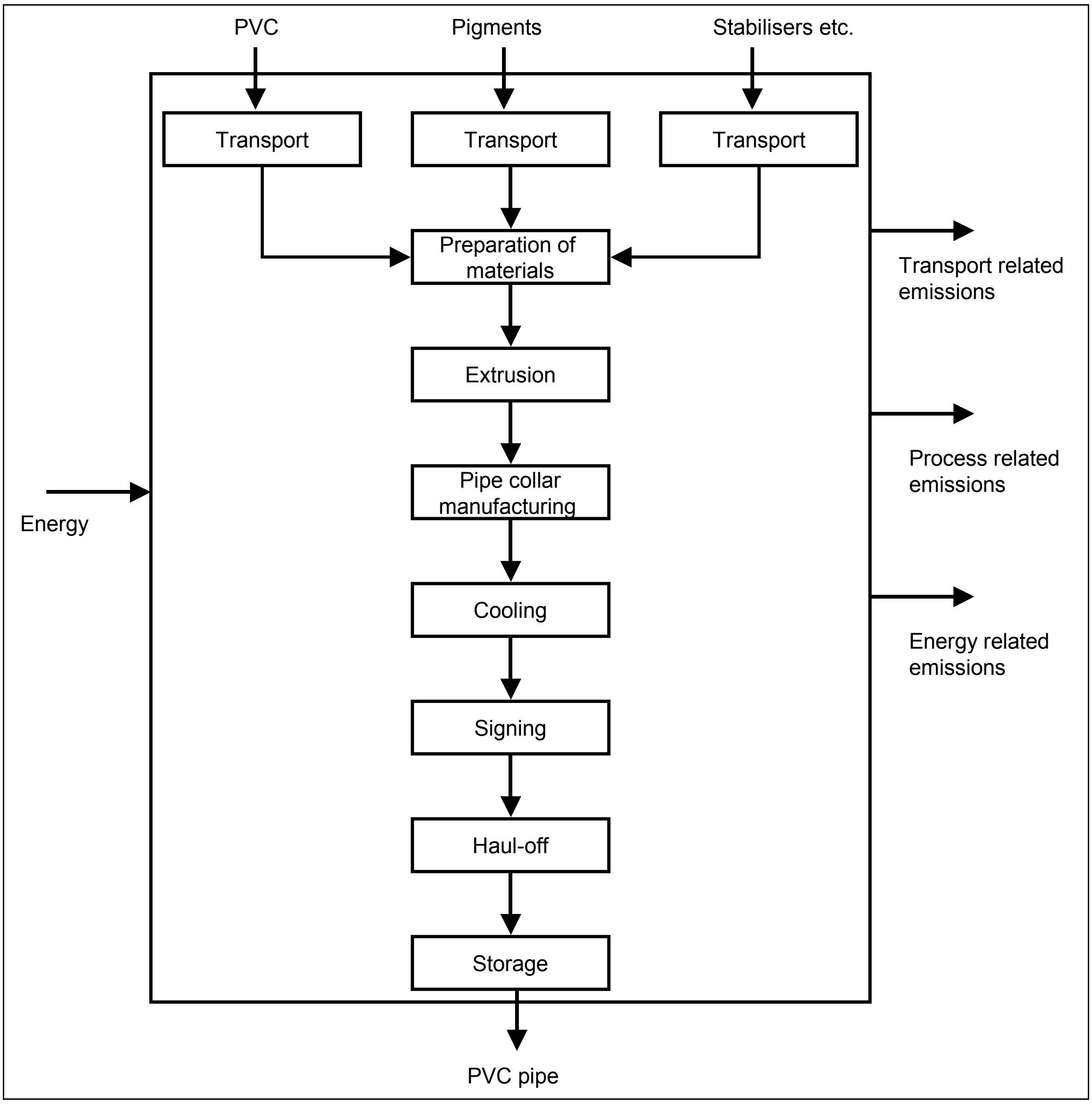

Figure 4-10: Schematic flow diagram for the production of Pipe (IKP-AT-5)

Environmental impact: The environmental impacts of pipes vary with composition and application. Some impacts included in the studies examined were: contribution to the greenhouse effect, photochemical ozone formation, acidification, eutrophication, air and water pollution, depletion of abiotic resources, aquatic eco-toxicity and human toxicity.

Pipes composed of virgin PVC or recycled PVC have lower impacts than those containing zinc or recycled zinc (RANDA FR.001). Primary zinc and mixed zinc coated steel pipes used 1.6 times the amount of non-renewable resources than virgin and recycled PVC pipes. Furthermore, primary zinc pipes consumed 3.4 times and recycled zinc almost double the amount of mineral material required by virgin PVC and recycled PVC pipes. However, zinc pipes consumed less than half the amount of water required by PVC pipes (RANDA FR.001).

Recycled zinc pipes for gutter and rainwater contribute twice the amount to the greenhouse effect than recycled or virgin PVC pipes contribute. Additionally, 40% recycled zinc pipes contribute more to ozone formation, acidification and eutrophication than PVC pipes do. For air and water emissions as a whole, recycled zinc pipes contribute almost 3 times more than recycled PVC pipes. Overall, PVC or recycled PVC pipes score higher in all categories than zinc pipes, with the exception of the water consumption category (RANDA FR.001).

For potable water and sewage disposal pipes, HDPE and unplasticised PVC systems contribute a greater amount to eutrophication and acidification than other materials (IKP-CH-5). Cast iron and stoneware systems contribute considerably to greenhouse potential. The same study also concludes that a preference for a particular material cannot be justified on the basis of LCA results alone. Furthermore, the following results from the IKP-CH-5 study are worth noting:

The results based on 1 metre lengths of pipe show stoneware, rather than PVC, to be an ecologically advantageous material over a large nominal width range.

However, if a complete wastewater line system in a factory is examined, PVC is among the most beneficial materials for pipes in ecological terms, given a similar use period. This is concluded despite the fact that the study determines PVC to be not scientifically durable as it is burdened by CO_2 emissions from an assumed decomposition of the material. Only if it is assumed that stoneware pipes will have a useful life twice as long as that of PVC pipes (which is hardly the case in reality), does the balance shift in favour of stoneware.

For potable water and sewage systems, HDPE pipes required the greatest amount of energy for production, followed by PVC, and lastly by cast iron. Greenhouse potential was highest for cast iron pipes, followed by HDPE and PVC pipes. Acidification and eutrophication potential were higher for PVC pipes and lower for cast iron pipes for both sewage and potable water systems.

The IKP CH-13 study compares pipe materials for drainage and sewage applications. The study compares vitrified clay, concrete, reinforced concrete, reinforced concrete with protection against corrosion, cast iron, HDPE and PVC. Vitrified clay required the least amount of energy for production, while cast iron required the most. CO_2 emissions are lowest for PVC and HDPE production; however, these levels increase if decomposition is taken into account. Plastics as organic materials are eventually decomposed to CO_2, H_2O and solid residual substances. This effect is only significant if extensive time frames are taken into consideration.

Overall, the IKP CH-13 study concludes that for energy, the consumption level depends on the diameter and useful life of the pipe. This can also be verified in the IPU.0032 study. Vitrified clay and plastics have lower energy consumption rates for small pipes. Larger pipes require less energy when made from concrete, followed by vitrified clay, cast iron and plastics. However, when concrete pipes include corrosion protection, they fall to the level of plastics. CO_2 emissions are approximately analogous. If it is assumed that the pipes are not replaced during the use phase, vitrified clay becomes the preferred material (IKP-CH-13).

Table 4-8: Primary energy consumption during the life cycle of PVC sewer pipe in MJ/m pipe (IPU.0032)

	PVC	Pipe prod.	Laying	Transport	Total
Diameter 110mm	69	20	74	1.2	165
Diameter 160mm	118	34	81	2	236
Diameter 250mm	210	60	197	4	474

When compared with concrete pipes, the environmental impact of PVC pipes is generally much higher, due to the high energy consumption during the production process of virgin PVC granulate (IKP-NL-3).

The association FKS (IKP-NL-4) comes to different conclusions. The FKS study using the Thalmann aggregation method, concludes that PVC and concrete pipes are environmentally equivalent (PVC pipes show better values than concrete in energy consumption, air pollution and volume of solid waste and worst value in water pollution and exhaustion of raw materials). The difference between the study results is due to the fact that FKS assumes a higher energy consumption in the production of concrete pipes, than the Intron Report does (IKP-NL-3). Comparing virtified clay pipes and PVC pipes class 34 (length: 10 metres, weight: 13,5 kg), the Intron report concludes that vitrified clay scores better in the categories of raw-material depletion, energy use emissions and waste production. When compared with 3-layer PVC, vitrified clay pipes are the worst in the categories of energy consumption, and non-hazardous waste production (IKP-NL-3). The FKS report concludes that there is no significant difference between recycled PVC pipes and vitrified clay from an environmental point of view.

Another Dutch study on gas distribution pipeline systems, which included all life cycle stages, (production of raw materials, production of components, construction of the pipeline system, use and end of life), did not find a significant difference between the environmental performance of PVC and that of polyethylene-80 pipes (IKP-NL-12).

Regarding energy consumption during the production process, extrusion consumes 3 to 6 MJ/kg electricity (RANDA IT.021).

The Austrian Study (IKP-AT-5) states that the share of environmental impacts from the production of the pipes is low compared to PVC production including its production chain. But it should be noted that the study does not include additives. Primary energy requirements for a 150mm diameter pipe are given in the results:

Primary energy for production of PVC including production chain: 183 MJ/m_{pipe}.

Primary energy for production of the pipe: 14.6 MJ/m_{pipe}

Compared to the other pipes made from concrete, PE-HD, cast iron or ceramics, the PVC pipes are disadvantageous in terms of primary energy consumption, dust emissions and hydrocarbon emissions.

Possibilities for environmental improvement according to (IKP-AT-5) include:

- Pipe weight reduction through enhancement of mechanical stability.
- Use of recycled material in production. First experiences with wastewater pipes look promising (statement from 1996). Recycling of pipes was not included in the study because no information was available.

In the study IKP-NL-7, the impacts of different pipe alternatives are compared but no interpretation is given (see chapter 5.1.4 for further details on the study).

4.2.10.3 Cables

According to the IPU.0019 study, PVC is mostly used for low voltage (<1kV) installation cable. Advantages of using PVC for this application include: the fact that PVC cable is difficult to ignite, it is UV resistant and it copes well with mechanical stress.

Average composition: Two average compositions of cables are shown in Table 4-9. In general, the percentage of plasticisers present in cables differ according to the function for which the cable is employed:

Plasticisers (insulation)	23 - 33%
(coating)	33 - 44%

Table 4-9: Average composition of cables

	(IPU.0020) 1996	(EX EU-01) 2003
	%	%
PVC	57	39
Stabiliser		
- lead sulphate		
- Ca-Zn (instead of Pb)		
- tri basic lead sulphate	2	2
- lead stearate	0.5	
Plasticiser		
-phthalates	23 DEHP	26
-adipates		
Filler		
- powdered limestone/chalk	17	31
Pigments		1
- lead based		
Stearic acid/wax	0.1	
Chloroparaffins		1

According to the IPU.0019 study, the use of lead sulphate (1-3%) as a stabiliser has been falling since 1995. Ca/Zn (3-4%) is used instead. In red and yellow cables, lead based pigments may be used.

The presence of fire retardants, including antimony trioxide 0.5-2% and aluminium hydrate 20 - 30%, is also possible.

Production process: Cables are usually produced through an extrusion process. Extrusion is one of the most convenient and least expensive fabrication methods. The melted polymer is forced through a nozzle, the shape of which determines the shape of the object. (IPU.0077)

Environmental impact: The typical amount of energy required for the extrusion process is about 3-5 MJ per kg cable. Typical plasticiser loss to air from the extrusion processes is 0.02-0.007%. During the manufacture of PVC products, some emissions of VOC and small losses of heavy metals from stabilisers and pigments can also be expected. Stabiliser and pigment losses are possible due to cleaning of equipment and unintended dispersion, particularly if granular material is used.

4.2.10.4 Flooring

PVC flooring is normally divided into homogenous and heterogeneous flooring (built around carrier). Heterogeneous flooring is used where there is a need for quietness (e.g. domestic) and homogenous flooring where there is a need for durability and hygiene (public) (IPU.0019).

PVC flooring made up 51% of total flooring sales in Sweden in 1994. (IPU.0019)

Average composition:

PVC	25%
Filler	45%
Plasticiser	28%
Pigments and stabilisers	2%

(RANDA IT.021)

NOTE: Filler can represent up to 50% of the total product weight.

Mass of floor

Public flooring: 3 kg/m^2 (IPU.0015), 2.5 - 3 kg/m^2 (IPU.0013)

Domestic flooring: 1.3 kg/m^2 (IPU.0013)

Domestic flooring is foamed, unlike public flooring, hence, its lower density. (IPU.0013)

Table 4-10: Average composition of flooring in % mass

	(IPU.0015)	(IPU.0013) Domestic floor	(IPU.0013) Public floor
PVC	34.8	55	46.6
Stabiliser		1.5	1.1
- lead phosphate and stearate			
- Barium Zinc organic	0.4		
- co-stabiliser			
Plasticiser		27	18.1
- dioctyl phthalate	11.2		
Filler		6	26
- powdered limestone	51		
Epoxidised ester	1.1		
Calcium stearate	0.15		
Calcium ester	0.1		
Backing		4	
Chemical additives		3.3	3.4
Pigments		2.5	2.3
- titanium dioxide	1.25		
Solvents		0.4	
Lacquer chemicals		0.3	1.0
PUR		0.3	
Foil			1.5

The main stabiliser used in flooring is barium-zinc (0.5-1.5%) (IPU.0019). In some cases, tin and calcium/zinc are also used. The IPU.0017 study indicates that the calendering process uses 23% of the plasticiser, while spread coating uses 29 - 38%.

Production process: PVC for flooring is produced by suspension polymerisation. Through this method, a 60 micron granulometry powder is obtained (RANDA IT.021).

Once the polymer has been obtained, the production of the flooring proceeds and a PVC "curtain" or PVC "squares" are created. Manufacturing of homogenous PVC plastic floors requires the following phases:

- addition of stabilisers to the PVC powder;
- filler addition;
- homogenisation with plasticisers and pigments; and
- creation of PVC sheet or PVC tiles by calendering or extrusion.

Environmental impact: The environmental impact of the transformation phase of PVC is low. The water is only used for cooling, therefore it does not contain pollutants. The energy consumption varies depending on the kind of product manufactured. For calendering, the energy consumption (electricity) is about 6 MJ/kg, whereas the foil extrusion consumes from 3 to 10 MJ/kg [5] (RANDA IT.021). According to Caesar (1992) [2] (IKP-NL-1), the energy requirement for cushion vinyl manufacture is 8.0 MJ/m^2. More than 80% of the energy requirements of cushion vinyl can be attributed to the production of PVC (45%) and plasticisers (35%) (IKP-NL-1).

Air emissions (primarily CO and CO_2) are mainly due to energy use, but are also produced through the incineration at end-of-life. Water emissions occur through the production of synthetic materials. No soil emissions have been reported (IKP-NL-1).

Energy consumption and emissions for average PVC flooring, shown in Table 11 of the study, are presented here: (IPU.0013)

Energy use:

Electricity	8,74 MJ/m^2
Fuel oil 1 + diesel	3,2 MJ/m^2
Fuel oil 4	1,31 MJ/m^2
Plasticiser waste incinerated	0,28 MJ/m^2

Emissions to air (not from fuel):

N-methyl-pyrrolidone	1.4 g/m^2
Dioctyl phthalate	0.22 g/m^2
CH_4	2.77 g/m^2

Solid Waste:

Sector specific waste	131 g/m^2
Non-sector specific waste	126 g/m^2
Hazardous waste	5.2 g/m^2

Waste produced during the laying process of PVC flooring (so-called "offcuts") is estimated at 10% of the total mass (IPU.0013). Offcuts are usually collected for recycling.

In the same study (IPU.0013), the data gaps mentioned were: environmental impacts of lubricants, foaming agents, stabilisers, flame proofing agents, solvents, lacquer chemicals and surface treatments.

4.2.10.5 Packaging

Average composition: The two types of PVC used for the application of packaging are hard and soft PVC. Hard PVC is more commonly used than soft PVC. Applications of hard PVC include pharmaceutical packaging, food packaging, water and detergent bottles or technical packaging. Soft PVC is mainly used for packaging fresh meat, called “Cling-Film”, or for gaskets in crown caps [51].

The advantages of PVC films include its barrier quality for oxygen and flavouring substances, its transparency, and its high durability. With specific addition of plasticisers and fillers these desired qualities can be emphasised. Depending on the specific application, several mixtures are possible.

This is also the case for pipe applications. Packaging composition is dependent on the producer and the application. An average composition is presented in Table 4-11.

Table 4-11: Average composition of packages in % mass

	(IPU.0015)
	Collation tray (rigid product)
PVC	92.5
Stabiliser	
- octyl tin mercaptide	1
Plasticiser	
- dioctyl phthalate	
Filler	
- powdered limestone	
Lead pigment	
Polyethylene wax	1.5
Methyl methacrylate	5

The IPU.0019 study reports that in a 1996 study from Sweden, PVC foils contain 20% plasticisers (DEHP/DIDP), 6% lead pigment and more than 2% stabilisers. This is not representative for all situations. Lead is no longer used in packaging. The use of heavy metals in packaging is banned by Directive 94/62. The IPU.0017 study indicates a 17 - 23% content of plasticiser in PVC wrapping film.

Stabilisers such as Ba-Zn and Ca-Zn can replace lead and tin stabilisers. Barium/zinc is not approved for food-contact packaging, whereas tin stabilisers are widely used in rigid PVC food-contact applications and medical packaging and are listed in the relevant EU Directive (e.g. 89/109/EEC).

Production process: PVC is a plastic material with good processing capabilities. These are, for example, extrusion of profiles and sheets, calendering of sheets or films, injection moulding of special parts or blow moulding of bottles. Rigid-PVC products do not include plasticisers, but every PVC product includes stabilisers and, if desired, colouring agents as well [51].

In addition to the direct packaging of products, outer or secondary packaging can also be made of PVC. A schematic flow diagram of the production of PVC packaging is shown in Figure 4-11.

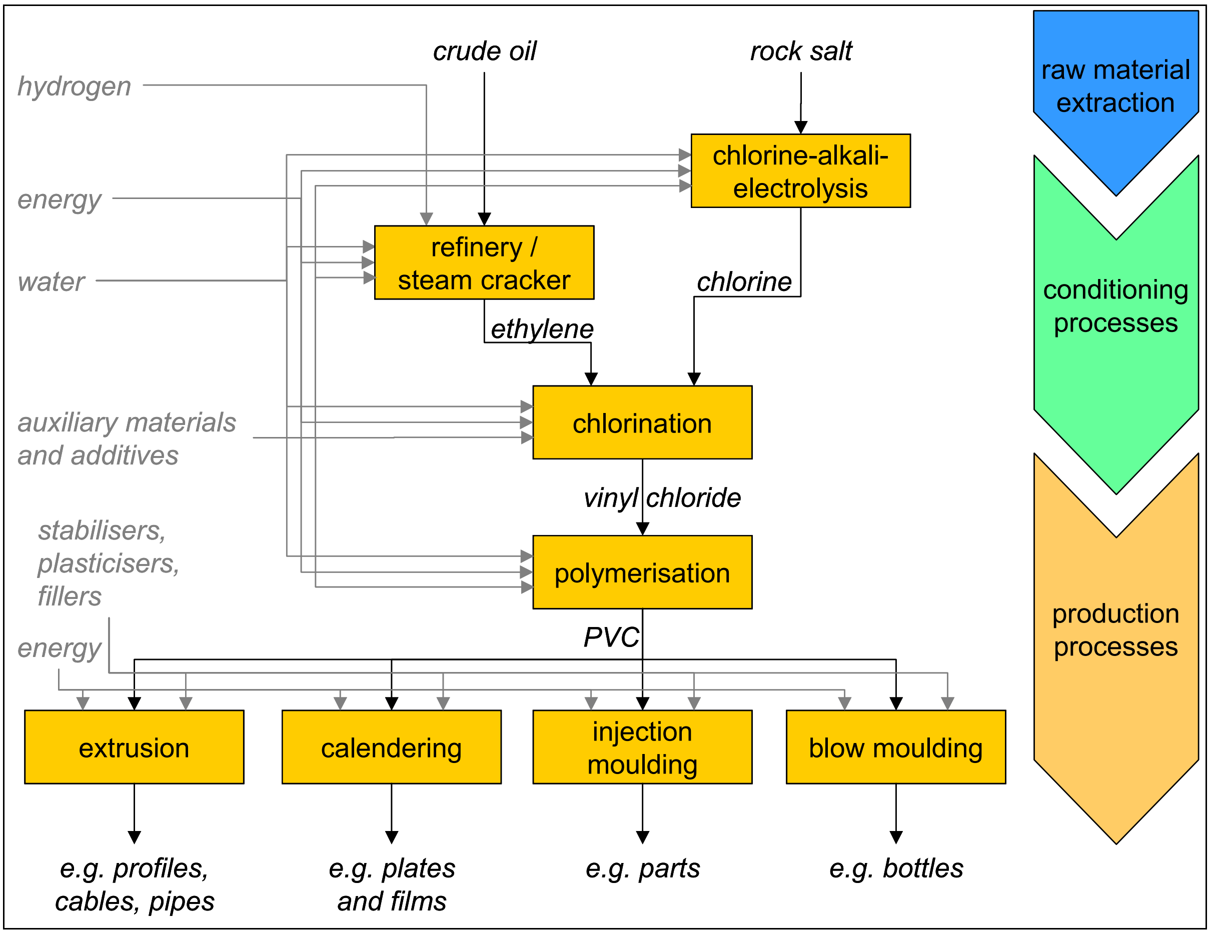

Figure 4-11: **Schematic flow diagram of the production of packaging**

Environmental impact: Environmental impacts of PVC in packaging applications result mainly from the production process of PVC. From the extraction and processing of raw materials to the production of PVC granulate, numerous processing steps are necessary which contribute the largest portion to the environmental effects of the PVC life cycle. The remaining manufacturing steps necessary to form the final product contribute little to these effects.

Most of the impacts are caused by emissions to air and water. The studies about PVC as packaging material mainly use the methodology of critical loads to show the environmental impacts. The main reference study is the BUWAL 132 (IKP-CH-14), from which most of the other studies source their inventory data. Emissions contributing the most to overall impacts are hydrocarbons, nitrogen oxide and sulphur dioxide emissions to air. It should be noted that the database of most of the studies is relatively old, using data from the early 1990s.

As the production processes from raw material extraction to PVC granulate for packaging applications is similar to that of other PVC products, the environmental effects are also similar. In the reviewed studies, the final shaping process varies, the use phase is not included, and the recycling processes are equivalent to those of other PVC products. An important difference is in waste collection, which differs between packaging (collection together with other municipal waste fractions) and other PVC applications.

Packaging is collected together with other municipal waste fractions, other PVC applications are often collected separately because of concentrations of products in one place e.g. windows, pipes, flooring, etc.

However, in the reviewed studies this portion of the life cycle is not addressed separately, and none of the studies consider waste collection as environmentally important.

The environmental impacts of the production phase are calculated and shown in, for example, BUWAL 250 (IKP-CH-16) and BISCHOFF (IKP-D-52).

According to a 1997 study from the Instituto de Agroquímica y Tecnología de Alimentos – CSIC (RANDA SP.005), the most critical phase of the life cycle of plastic PVC bottles, with regard to water effluents, is the production phase. Additionally, for other plastic materials such as LDPE and PET, which use the highest quantity of oil, the emissions from the raw material extraction phase have more of an impact. The other phases of the life cycle of the product do not generally produce liquid effluents.

The main primary energy consumption (almost 100%) for PVC bottle applications occurs in the production phase (not split in material and manufacturing).

4.3 Use phase

A distinction is usually made between short-life and long-life applications and between rigid PVC and flexible PVC (with a high percentage of plasticiser). The RANDA EU.010 study states that ‘metals like lead and cadmium used in additives and stabiliser systems are immobilised’. The fact that leaching of lead and cadmium from PVC does not occur, has been confirmed by another more recent study commissioned by the EU Directorate General Enterprise [33]. The study contains a review of results from several experimental studies and concludes that, although ‘some sources [33] suggest that lead might be mobilised’ this cannot be considered a matter of concern because:

- industry committed itself to phase out the use of cadmium stabilisers in 2001 (however, this commitment does not include imports of PVC from third world countries)
- the phaseout of lead by 2015 is part of the voluntary commitment of the vinyl industry.

The possibility of lead leaching is not taken into account in the assessed LCA studies. However, IKP-NL-3 refers to a study carried out by the Pré Office [59] which found that ‘lead is released when PVC pipes are used’.

RANDA EU.010 highlights two environmental points of attention in the use stage:

- Emissions to water: It is estimated that the emissions from phthalate-containing flexible PVC in direct contact with water occur at a rate of about 1% a year (Randa EU 010)[14]
- Emissions to air: It is estimated that the emissions from phthalate-containing flexible PVC to air occur at a rate of about 0.1% a year; products with small surface contact lose 0.01% a year. One of the areas of discussion concerning PVC is the formation of dioxins in accidental fires. It should be pointed out that in a conventional life cycle assessment study, risk factors such as accidental spills or fires are normally not considered. Therefore, no quantitative information on this topic could be obtained from the LCA assessed studies. However, some of the ‘life cycle’ related studies considered tackled this fact by providing information from other sources. The RANDA EU.010 study, for instance, supplies the following data: “An uncontrolled burning of 200 kg of

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[14] We understand this figure as 1% of total phtalathes in the PVC compound

> PVC in Sweden was reported to result in 3 mg of dioxin." This is the same range as for the uncontrolled burning of wood. Greenpeace mentions higher dioxin formation rates of PVC than reported in Sweden. However the carcinogenic risk from PAH (polycyclic aromatic hydrocarbons) and the acute toxic impact of CO at an uncontrolled fire is much higher than from dioxins. PAH and CO occur in any fire, whether a chlorine source is present or not.

Table 4-12 describes the service life of the different types of existing PVC products.

Table 4-12: Distribution of PVC materials in relation to PVC service life (RANDA EU.001 and IPU.0017)

Service life	Applications	Life	% wt
Short life	Packaging, medical applications, stationery	< 2 years	15%
Medium life	Wall covering, flooring, footwear	2 to 10 years	17%
Long life	Flooring, wire and cable covering, furniture, automotive	10 to 20 years	26%
Extra long life	Pipes, window profiles, cables, roof liners	> 20 years	42%

4.3.1 Use phase – Window Frames

The lifetime of PVC window frames is assumed to be 30 years (IPU.0015) and the heat loss values are assumed to be 2.57 $W/(m^2*K)$ (IPU.0015).

In the IKP-D-6 study, the average lifetime of a window is assumed to be 40 years. THe long use phase means its effects have a much higher impact than products with a comparatively short use phase, like packaging. It is indicated that the length of the window use phase is highly dependent on user behaviour. Maintenance that replaces the weakest component of the system can extend the lifespan of the whole product considerably. With normal care and maintenance the frame material is not the limiting factor of the lifespan of a window. Usually, changes in the utilisation of the building, optical requirements, thermal conductivity requirements or leakage, lead to the replacement of the window.

Windows and facades do not consume materials or energy during their use phase but are part of the "building" system and have a direct effect on the energy requirements for heating and cooling of the building. With PVC designs, low thermal conductivity can be achieved because of the low thermal conductivity of the material in combination with multi-chamber profiles. (IKP-D-6)

Wooden window frames need internal and external painting every 5 years, which results in emissions. No maintenance is mentioned for PVC window frames (IPU.0015).

The low impact of Photochemical Ozone Creation Potential is worth noting where VOC based paint systems are used. PVC windows need no special surface treatment during production, in comparison to wood windows that have to be coated (IKP-D-6).

According to this same study (IPU.0015), the use phase consumes the most primary energy, and generates the most CO_2 and NOx emissions (see chapter 5.1.5 for details).

4.3.2 Use phase – Pipes

The use phase of pipes for water transport is quite long (40 to 80 years). This phase includes periodical maintenance, which involves high pressure cleaning. The comparative LCA evaluated did not include the use phase within the system boundaries, as it is similar to that of pipes made from other materials (IKP-NL-3). This study did not include possible leaching of chemicals (mainly additives of PVC) during the use phase in the system boundaries.

In normal use situations, the stabiliser is locked into the PVC matrix. However, some extraction from the surface can be caused by running water. The extraction is highest in the beginning when the product is put into service, but after an initial period of time the extraction falls to a low level. Tests of lead stabilised pipes for drinking water showed stabiliser losses of 0.035 – 0.024 mg Pb/l after one week, 0.024 – 0.016 mg Pb/l after 2 weeks, 0.017 - 0.011 mg Pb/l after 3 weeks and 0.14 – 0.009 mg Pb/l after 4 weeks. The levels vary with pipe diameter. A study in the Netherlands showed losses of 0,1 mg Pb/l after 5 days of exposure to running water, dropping to 0.0001 mg Pb/l after 20 days. (IPU.0017)

Regarding gas-distribution pipelines, the highest impact during the use phase is due to gas leakages, which contribute to photochemical oxidant formation and global warming potential categories (IKP-NL-12).

No additional significant impacts were found to occur during the use phase. However, the study IKP CH-13 notes that during the specified useful lifetime of the materials studied (vitrified clay, concrete/reinforced concrete, reinforced concrete with erosion protection, cast iron, PVC, HDPE) vitrified clay showed the lowest energy-consumption levels.

The use phase of the pipes is covered in the study IKP-AT-5 by a sensitivity analysis covering different scenarios of pipe laying and of leakages during the use phase. For example, the energy associated with the laying process for a 250 mm diameter pipe is given here:

Laying in a sand bed: 21 MJ/m_{pipe}

Laying on a support of concrete: 123 MJ/m_{pipe}

Laying in a full coating of concrete: 225 MJ/m_{pipe}

Clearly, the pipe laying process is an important decision for the user.

The ecological impact of leakage from waste water pipes is not irrelevant; leakage is associated with Chemical Oxygen Demand (COD) in emissions of waste water. The COD (e.g associated with inorganic and organic compounds of the waste water) can be large compared to the emissions from the production phase (IKP-AT-5).

Sewer pipes require virtually no maintenance during the use phase (IPU.0032). They should be constructed to be ‘self-cleaning’. When this is not the case the pipes need frequent sluicing (washing down). The quality and duration of the self-cleaning is mostly dependent on the quality of the work when installing the pipes, rather than the material of the pipes. There is no documentation on the consumption of energy and water related to sluicing, or on any differences for this process between the materials presented.

4.3.3 Use phase – Cables

The IPU.0019 study states that phthalates can be emitted directly to air and soil during the cable use phase. The dioxin formation in the case of real fires is expected to play a minor role in the total emissions to the environment (IPU.0017). No statements about PVC in comparison to other materials, related to the use phase of this application, could be found in the studies collected.

4.3.4 Use phase – Flooring

The use phase for PVC flooring varies greatly. The IKP-NL-1 study reports that an average floor covering is used for about 8 years, although its technical lifetime could be longer. After removal, the floor covering is generally disposed of. According to the IKP-D-19 study, observed and reported lifetimes vary between 7 and 40 years. Another study (RANDA IT.021) reports lifetimes of 10 to 15 years for PVC flooring without a polyurethane layer and between 20 and 25 years for PVC flooring with a polyurethane layer. Within the use phase, cleaning and maintenance of the flooring should also be taken into account. The average maintenance time is usually once every five years (RANDA IT.021).

The environmental impacts of this phase are mainly due to VOC emissions contained in glue and adhesives used for fixing flooring. According to the RANDA IT.021 study, the maximum VOC emission varies from 40 to several hundreds of µg/m^{2}h, depending on the kind of floor. The most common VOCs emitted are: phenol, 2-ethyhexanol, 1-butanol, toluene, 1,2,4-trimethylbenzene, ethylbenzene, o.m.p.-xylene, decane, formaldehyde, diethylene glycol monobutyl ester, DEHP, and TXIB (2,2,4-trimethyl-1,3-pentanediol-diisobutyrate and ammonia).

The same study (RANDA.021) remarks that qualitative and quantitative composition of VOC emissions varies depending on the kind of flooring, the relative humidity and the temperature.

Regarding maintenance operations, the study (RANDA IT.021) states that emissions are due to:

- washing by using water and a neutral detergent.
- the use of detergents that contain ammonia and chlorine and can chemically react with the flooring surface.
- the application of floor polish products, which may contain silicone resins, solvents and chlorine compounds. The study points out that floor polishing is usually done every 3 to 6 months.

In this study (RANDA IT.021), no comparison with other materials was presented.

Furthermore, uncontrolled combustion of PVC, such as during accidental building fires, results in the emission of carcinogenic substances (RANDA IT.021).

IKP AT-2 also mentions that high quality PVC flooring, coated with PUR, needs much less maintenance.

Insulation properties of floor coverings may have a positive “impact” during the use phase. According to the IKP-NL-1 study, cushion vinyl floors and linoleum floors, allow an energy saving of 4 to 21 MJ per m^2 of flooring.

The maintenance of public floors in Sweden is discussed in the IPU.0042 study. Thirty-six different scenarios are calculated combining different use scenarios with PVC and linoleum.

Three “application specific context parameters” have to be estimated before it is possible to quantify the use phase:

1. Frequency of frequent maintenance: 1 - 7 times a week

2. Frequency of periodical maintenance: 0.25 - 2 times a year
3. Expected service life of a floor: 5 to 40 years

Periodical maintenance can be limited to three concepts:

1. Wax system covering the whole floor with a protective layer of polymers,
2. Polish system which fills in only the inequalities in the floor with wax,
3. Untreated system where the PVC floor itself is covered with a polyurethane surface.

Regular maintenance is more complex, involving the use of:

1. Mechanical scouring
2. Reusable mops
    a. Wet mopping
    b. Moisture mopping
    c. Dry mopping
3. Disposable mops

The life span assumed for PVC flooring was 20 years and impacts from the use phase proved to be significant or larger than those from the flooring production. It concludes that these impacts are very much dependent on other things, aside from the flooring material, such as the chosen maintenance method, expected service life, and expected maintenance intervals (IPU.0042).

Plasticisers can be released directly to air and to cleaning agents during cleaning (IPU.0019).

Waste water from washing of PVC floors contained 1.8 - 2.5ug/l of phthalates. Related to area of floor washed, the value is 451 - 630 ug/m^2 floor (IPU.0017).

4.3.5 Use phase – Packaging

In the IKP-CH-16 and IKP-D-52 studies, the use phase is not discussed for PVC packaging materials. For some returnable bottles of alternative materials (e.g. returnable glass bottles) the need for new bottle caps and labels in the use phase is accounted for, along with the bottle cleaning process required for their reuse. PVC use in returnable bottles is not stated. Transport activities in the use phase only affect the returnable packaging materials. In such cases, transport is considered part of the use phase.

Environmental and health effects associated with the migration of plastic monomers or plasticisers in PVC, from the packaging material to the packed good (e.g. food), are not considered. Further information about European legislation for plastic materials in food packaging is also available [3].

In the IPU.0017 study, migration of 45-150 mg DEHA /kg to cheese after 10 days of storage is reported.

Low-fat fresh meat contained 1-10 mg DEHA /kg and more fatty meat contained 20 mg DEHA /kg. In some specific cases the meat contained up to 100 mg DEHA /kg (IPU.0017).

In blood bags, blood contained 59 ug DEHP /ml (IPU.0017).

4.4 Disposal/Recycling phase

This section covers the 'end of life' phase of PVC. The fact that both the production and use phases generate many different types of waste, together with the fact that different disposal programs exist for each PVC product group, make this section rather complex. In calculating impacts, all of these points must be taken into consideration.

Two major groups of PVC waste types must first be distinguished (RANDA EU.005):

- Pre-consumer waste. This waste category includes waste generated during the production of final and intermediate PVC products (production waste), and installation waste from the handling or installation of PVC products. PVC pre-consumer waste as a group is comparatively easy to recycle, particularly because it can be collected separately in defined qualities, and hence, has a high recycling rate in practice.
- Post-consumer waste. The recycling of post-consumer waste is generally more difficult to realise since the waste occurs in the form of products (end-of life products such as pipes, window frames, and packaging) and hence, in more or less mixed-waste fractions, or as part of composite materials[15]. Depending on the specific products, PVC in waste can occur as a more or less pure material fraction (in "mono fractions") which can be extracted from the waste stream by sorting (e.g. bottles, pipes, some films, some profiles). Alternatively, PVC can form a part of composite products or materials which must be subjected to disassembly or mechanical treatment processes in order to extract PVC (e.g. windows, car components, floorings, cables). Both PVC "mono fractions" and composite products/materials can be collected separately (i.e. in product specific collection systems) or in mixed fractions together with other materials (e.g. packaging waste, municipal solid waste). For "mixed" and "composite" products, the Vinylloop and a number of feedstock recycling processes have been developed.

The same study states that under current conditions, 82% of PVC post-consumer waste is landfilled, and 15% is incinerated. Recycling rates are therefore very low, at only 3% of available post-consumer waste, mainly due to high collection, separation and processing costs. The following PVC product groups can be distinguished in post-consumer waste:

- Construction products (pipes, windows, flooring, etc.), which end up in construction and demolition waste streams;
- Consumer and technical products (packaging and rigid film applications, etc.) which arrive as (mixed) municipal solid wastes or (mixed) packaging wastes;
- Electric/electronic products forming the so-called electro/electronics waste whose major share arrives at municipal solid wastes;
- Other products ending up in special waste flows (e.g. hospital and agricultural wastes)

Further considerable amounts of waste are created in the recycling of automobiles (shredder residues) and cables from cable dismantlers (insulations).

There is no linear dependency between annual PVC consumption and annual PVC waste creation, because there is a considerable "time lag" between PVC consumption and PVC

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[15] Note: the main challenge in post consumer recycling for any material (not just PVC) is not the recycling technology itself, but rather the set up of a cost effective collection and sorting scheme.

waste production. This is due to the fact that a major part of PVC consumption is in the form of long-duration products with lifetimes of up to 50 years or more.

4.4.1 Incineration

Process Description : Waste incineration is generally comprised of combustion, heat recovery, and gas and liquid-effluent treatment (RANDA EU.001).

The study performed by Bertin Technologies (RANDA EU.001) on the influence of PVC on the quantity and hazardousness of flue gas residues from incineration, came to the following conclusions:

- End-of-life PVC, when dealt with by incineration, mainly involves municipal waste incinerators, as hazardous waste incinerators and cement kilns do not take PVC rich wastes. PVC is also present in incinerated hospital waste;
- Because of the wide range of uses of PVC there is a correspondingly wide range of performance properties, and hence formulations required. The content of pure PVC (resin) within the various formulations varies from 44% to 93%;
- PVC influence on MSW composition is mainly related to the chlorine content of the waste to be incinerated: PVC is responsible for 38 to 66% of the chlorine content in MSW.
- 10% of Cd in MSW is attributable to PVC. This problem will however diminish since Cadminium is no longer being used in PVC in the EU.
- The PVC influence on lead content in MSW is assumed to be less than 1%.
- The presence of PVC in MSW has a direct effect on the quantity of chlorine in the raw gas and therefore on the corresponding gas treatment required. The higher chlorine content in the gas requires additional neutralisation agent supply and therefore affects the quantity of residues or effluents generated by the different gas-treatment systems (dry, semi-dry and wet).

The IPU.0017 study shows that the content of PVC also contributes to the emission of dioxins and heavy metals. Dioxin emissions were reported in 1989 to be 19.5ug TEQ/ton (Toxicity Equivalents) waste based on more than 200 samples. More recent studies (e.g. “PVC Recovery Options, Concept for Environmental and Economic System Analysis” [54] or “PVC and municipal solid waste combustion: Burden or benefit?” [55]) conclude that the presence of PVC has no significant effect on the amount of dioxins. The EU Commission in its Green Paper on PVC takes this into consideration as well. Leachate from flue gas treatment residue contained up to 11 mg Pb/l and 0.2-2 mg Cd/l. (IPU.0017)

The leaching of heavy metals from PVC is considered to be low compared to the leaching of heavy metals from corrosion of other municipal waste (IPU.0017).

Phthalates can be burned to form CO_2 and water and are not expected to cause any environmental effects when incinerated (IPU.0017).

This study also mentions that the energy recovery from PVC incineration is approximately between 550 kWh and 1600 kWh of electricity, and that the average total chlorine content in incinerated waste is a measured 5.4 g/kg.

4.4.2 Landfill

Environmental Impacts:

A study by ARGUS (RANDA EU.002) on the behaviour of PVC in landfills, determined the following about PVC waste:

- phthalates are released from PVC material under landfill and under soil buried conditions;
- DEHP was detected in the condensate of gaseous emission from lysimeters with and without incubated PVC;
- fingerprint analysis from gaseous emissions from lysimeters indicated differences between those with incubated PVC and blank control;
- microbial growth was identified in plasticized PVC;
- mechanical properties of plasticized and rigid PVC samples, investigated through tensibility tests, changed during incubation conditions; and
- molecular weight distribution of the PVC polymer of a thin flexible packaging foil changed under thermophilic aerobic conditions.
- The authors included landfill fires into the analysis and found that PVC in landfills is contributing to the formation of dioxine. For dioxin formation carbon, chlorine and metal components are needed. PVC is not the only source of carbon and chlorine in landfill waste, hence other waste components in landfill fires do contribute as well (like other organics, plastics, wood and food waste containing chlorine in table salt).

A recent PhD thesis on Phthalates (Phthalates in Landfill Leachates by Susanne Jonsson, IPU.0070) shows that phthalate acid diesters are degraded or at least transformed in landfills. Furthermore, degradation products are less toxic than the mother compound.

Softeners migrate or are washed out of PVC in landfills. PVC polymer is inert. Lead is released only very slowly (IPU.0020).

The study [57] indicates that emission factors for lead are quite uncertain, as they depend on factors such as the weather and hydrological conditions, the way the site is controlled and the composition and amount of waste. In the study, a leakage rate of 0.23% is used, a value which is taken from another source [60] which can only be applied to ‘free lead’. For most lead inflows, the study multiplies this value by a corrosion factor in order to obtain the mobilised fraction. Note that the study assumes that lead in PVC remains stable. However, the lead stabiliser of the incinerated PVC is considered to be free, and leakage is assumed to be 0.23% per year.

A study from 2001 analysed the long-term behaviour of PVC in landfills. The PVC underwent the characteristic stages of development in a landfill, being subject to leaching and biodegradation. As a result of the extensive observation period, the fate of PVC products and their additives in landfilled waste could be assessed. Degradation of the PVC polymer was not observed. Vinyl chloride in landfill gas does not originate from PVC products, but from volatile chlorinated carbons, such as perchloroethylene. Plasticisers differ considerably in their behaviour: some are subject to losses, depending both on their compatibility with the polymer matrix and their anaerobic biodegradability. However, due to microbial transformation, concentrations of plasticisers in the leachate are, not correlated with losses. Phthalates and their degradation products may occur transiently at low concentrations. In contrast, the release of stabilisers appears to be attributable to superficial leaching. Concentrations of phthalates in leachate can not usually be distinguished from the background concentration. Any losses of additives tend to increase at elevated temperatures. The contribution of PVC products to the inventory of heavy metals in municipal solid waste is low. However, PVC products do constitute major sources of phthalic and organotin compounds. Findings of both phthalic and organotin compounds cannot solely be ascribed to post-consumer PVC products in landfilled waste. Therefore, other waste components must be taken into consideration, particularly dispersed pollutants conveyed by sewage sludge. There is no immediate need for action with respect to the target substances found in landfill leachate. A conservative PEC/PNEC comparison for the raw and undiluted leachate indicates no environmentally hazardous concentrations of phthalic and organotin compounds in landfill leachate. All things considered, PVC products do not constitute a substantial impact on the toxicity of landfill leachate and gas. Additional technical measures specifically directed at PVC products in contrast to overall municipal solid waste, such as a requisite special pre-treatment or a material-specific containment, do not appear to be warranted. Provided that landfills are operated appropriately and responsibly in accordance with present technical regulations, landfilling is an acceptable intermediate disposal option for PVC products. In the long-term view, the landfill disposal of waste materials needs to be reduced in favour of more efficient waste prevention and recovery strategies. Eco-efficiency assessments should indicate whether recovery or disposal is the optimum solution in a given case [56].

4.4.3 Recycling

According to the result of an ECVM survey and the information received from EU member states, approximately 520 ktons of pre-consumer and post-consumer PVC wastes are recycled every year: (RANDA EU.005)

- About 80% (420 ktons) of the recycled PVC wastes are pre-consumer wastes. This represents about 85% of total pre-consumer PVC waste produced.
- Recycling of post-consumer PVC wastes is still at a very low level in the EU. In 2000, about 100 ktons of PVC wastes were recycled. This represents about 3% of post-consumer PVC waste.
- Post-consumer PVC recycling consists mostly of cable and packaging waste. Cable recycling and a considerable part of packaging recycling is mixed plastic recycling, hence, only recyclates of low commercial value are produced.
- High-quality mechanical recycling for post-consumer waste (i.e. production of pure PVC recyclates) exists for single product groups (bottles, pipes, window frames) but only in very low quantities.

The IPU.0017 study presents some applications for rigid and flexible PVC recyclate, shown in Tables 4-13 and 4-14:

Table 4-13: Application for rigid PVC recyclate (APME/ECVM, 1995)

End-of-life product	New product type
Bottles	Non-food bottles Pipes Profiles Injection moulding
Pipes	Pipes
Window profiles	Window profiles

Table 4-14: Application for soft PVC recyclate (APME/ECVM, 1995)

End of life product	New product type
Flooring	Flooring
Cables	Industrial flooring General purpose compounds[16]
Roofing membranes	Membranes Liner

The energy required for recycling PVC is 1,000 kWh/t. (IPU.0017)

The IPU.0019 study also states that lead and tin stabilisers cannot be mixed when recycling products.

4.4.3.1 Mechanical Recycling

Mechanical treatment processes aim at the (more or less) automatic separation of pure fractions of PVC and other materials and the production of recyclates with a defined particle size. Generally the mechanical treatment process consists of shredding units for size reduction, separation units to extract specific sizes or materials from the main material flow (e.g. magnetic drums to separate ferrous metals), and mills and extruders to convert the separated fractions into re-granulates (RANDA EU.005).

Life cycle assessments on the recycling of PVC and plastics are only available for a limited number of products and recycling routes. Nevertheless, from the available results of selected recent studies, the study determines the following general evaluation: (RANDA EU.005)

- For production wastes, cut-offs and post-consumer wastes from which PVC can be separated easily, mechanical recycling provides an environmental advantage.
- Mechanical recycling of mixed plastic fractions provides environmental advantages only if it is feasible to sort out plastic materials which can be used in applications typical for plastics. The environmental performance of the recycling of mixed plastics to produce recyclates for the manufacture of products to substitute concrete, wood or other non-plastic applications, is generally lower than the performance of other waste-management routes such as energy recovery or feedstock recycling.

The general situation regarding ecological and health risks associated with mechanical recycling of PVC can be summarised as follows: (RANDA EU.005)

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[16] This application will lead to a spread of heavy metals

- Collection, sorting and treatment of plastics wastes are not associated with specific "new" risks related to the exposure of workers and environment to hazardous substances.
- Some PVC products like window frames, pipes and cables, contain heavy metal stabilisers, which (as single substances) are toxic (especially cadmium and lead compounds). The evaluation of the associated risks has been a matter of controversy; since the heavy-metal compounds are fixed in the PVC matrix, a release of the toxic substances to the environment is not possible, but releases may occur during the production of stabilisers, the compounding of PVC, waste disposal (incineration, landfill) and accidental fires. In general, the quantities that can be released in this way are low compared to other sources of heavy metal emissions. Therefore, the environmental and health risk of the stabilisers are regarded as not relevant by some experts. Others argue that for precautionary reasons, toxic and persistent substances like heavy metals should specifically be extracted from the technosphere and disposed of safely to avoid risks to health and the environment. Generally, the risks must be regarded as less critical in "product-to-product" recycling systems (i.e. recyclates from window profiles are exclusively used in new window profiles or similar products of comparable quality in the building sector) than in "open" systems where the recycling material is used in a variety of other products, thus having no control over the substance flow.
- In the past, polychlorinated biphenyls (PCB) were added to PVC cable compounds for some high-voltage cables to increase the insulation performance, and for low-voltage cables as flame retardant and plasticisers. A fraction of the cables contained in electric/electronic devices are recycled in recycling systems for electronic wastes. Consequently, PVC recyclates from cable recycling and electric/electronic wastes recycling can be contaminated with PCB, which is brought into the products produced with the related recyclates. In contrast to heavy metals, which are fixed in the plastic matrix, PCB can be released from the plastics, thus constituting a chronic risk potential for health. PCB in products is subject to statutory regulations. Recyclers and users of the recyclates control the PCB content of the materials to comply with the legal concentration limits.

4.4.3.2 Chemical Recycling

According to a study carried out in 1999 (RANDA EU.006), most of the initiatives for chemical recycling of PVC-containing plastic waste are still in the research phase. This is summarised in Table 4-15. In principle, PVC waste can be available in two ways: as a mixed plastic waste (MPW) fraction (with a rather low PVC content), or as a PVC-rich plastics fraction.

Table 4-15: A review of options for chemical recycling of MPW and PVC-rich waste, including cement kilns in 1999 (RANDA EU.005)

Technology	Status	Capacity	Future potential
Mixed plastic waste			
Texaco (NL)	Pilot/on hold	-	Uncertain *
Polymer cracking (UK)	Pilot/on hold	-	Uncertain *
BASF (D)	Closed in 1996	15 ktpa before 1996	-
VEBA (D)	Closed by 2000-01-01	87 ktpa before 2000	-
Blast furnaces	Operational (D)	162.5 ktpa in 1998	5 Mio tpa in the EU**
SVZ (D)	Operational	110 ktpa in 1998	
Cement kilns	Operational		3 Mio tpa in the EU**
PVC-rich waste			
BSL (D)	Operational	15 ktpa in 1999	
Linde (D/F)	Pilot under constr.	2 ktpa in 2001	15 ktpa > 2005 ?
NKT (DK)	Pilot under constr.	< 1 ktpa in 1999	15 ktpa in future ?

The same study provides a qualitative environmental comparison between the waste-management technologies for MPW and PVC-rich waste. The comparison was made on the basis of LCA studies of chemical recycling, incineration studies, material and energy recovery processes of organic wastes, and data given on individual technologies.

For PVC-rich waste, due to data gaps, it is not possible for the study to indicate a clear environmental “winner” among the chemical recycling technologies under consideration. For mixed plastic waste it is stated that:

- The Texaco, Polymer Cracking, VEBA and BASF processes all produce mainly liquid organics or gases that “replace” primary oil- or gas-based resources;
- The processes of Sekundärrohstoff Verwertung Zentrum (SVZ), blast furnaces and cement kilns all use the MPW as a replacement for coal;
- Municipal Solid Waste Incineration (MSWI) uses the calorific value of the MPW to produce heat and/or electricity;
- Mechanical recycling uses the MPW as a replacement of primary plastic resin. High-quality mechanical recycling is not considered, as a rather pure waste is needed.

Overall, the study concludes that most chemical recycling processes may be somewhat more advantageous than incineration in an MSWI. Energy recovery is simply too low there. LCAs indicate that processes with the fewest pre-treatment requirements have the most advantages. Also, processes that recycle the chlorine content in PVC may have some advantages over those that do not.

4.4.4 Waste management for each application

4.4.4.1 Window Frames

In the IKP-D-6 study, various recycling scenarios are considered. Incineration with energy recovery, specifically thermal recycling with a credit for energy produced, is an option, in addition to different scenarios of open-loop or closed-loop material recycling with material credits. The German Gathering System has been in place in Germany since 1991 to take back and reuse window profiles [1].

4.4.4.2 Pipes

Existing Methods:

Plastic pipes are usually disposed of thermally by incineration (with energy recovery) or recycled into granulate. Waste incineration is comprised of combustion, heat recovery and gas and liquid effluent treatment (RANDA EU.001). In the IPU.0015 study, PVC pipe is assumed to be landfilled, and according to another study, IPU.0032, in Denmark sewer pipes are left in the ground after use. In Germany, a recycling initiative for pipes became effective in 1994 [1]. The “Kunststoffrohrverband” association and the “Gütegemeinschaft Kunststoffrohre” association operate these recycling schemes. Additional activities include the TEPPFA – Project (running from 2000-2005) setting up collection and mechanical recycling schemes for pipes and fittings in all EU countries [50].

Environmental Impacts:

Study IKP CH-5 on potable water and sewage pipes notes that due to the long life of pipes, disposal scenarios are of no significance. The authors considered the collection of meaningful inventory analysis data for disposal scenarios impossible. Additionally, the RANDA FR.011 study notes that PVC pipe waste from the end of life phase does not decompose.

Study IKP CH-13 notes that plastics, as organic materials, eventually decompose into CO_2, H_2O and solid residual substances. Plastics decompose within a relatively short period of time when they are combusted after use. However, decomposition takes decades when plastics are put in landfills. The carbon content, however, will always decompose into CO_2. Thus, when calculating plastic CO_2 emission you must consider the percentage caused by decomposition. It is estimated that 30% of total CO_2 emissions are derived from decomposition.

Overall, energy consumption remains the same for vitrified clay and concrete when recycling is taken into account; however it is reduced for plastics and cast iron. With a significant increase in recycling rates, plastic energy consumption can be reduced. Within the given goal and scope of the RANDA FR.011 study, the amount of energy needed for the recycling of plastics and cast iron compared to the potentially saved or substituted energy due to the use of a secondary product, is lower compared to the energy needed for concrete and vitrified clay recycling. Concrete and vitrified clay need approximately the same amount of energy to be recycled, as can be later substituted due to the further use of the recycled material. Plastics and cast iron save potentially more energy through the substitution of virgin raw materials, than they require to be recycled.

4.4.4.3 Cables

Polymeric waste from cable is contaminated mainly by copper (Cu) and aluminium (Al). Thus it is difficult to recycle with conventional mechanical recycling techniques and some incineration plants do not accept it. Hence, it is landfilled or stored intermediately while awaiting the development of treatment processes (IPU.0020). Thirty ktons of cable waste is already being recycled per year (Randa EU 005). New technologies in mechanical and feedstock/chemical recycling processes, which proved their capability to handle cable waste (EX EU-01) [54], are able to cope with recycling related problems.

4.4.4.4 Flooring

It is assumed that PVC flooring in Sweden is incinerated, even though it may also be landfilled. This is done due to lack of LCI data on the landfilling of PVC products. The option to incinerate 100% of the PVC is one scenario within this study. It is not intended to mirror reality. The scenario is calculated to gain an understanding about the potential benefit of recovering energy from PVC products (see more details of IPU.0013 in chapter 5.1.2).

In Germany, the Syndicate of PVC and flooring producers have gathered flooring for reuse through the PVC-flooring-recycling program (AgPR GbR) since 1990 [1].

4.4.4.5 Packaging

Existing Methods:

Recycling and recovery options for plastic packaging include mechanical recycling, feedstock recycling and energy recovery. The chemical composition of plastic remains largely unchanged during mechanical recycling. Substituting a product made of virgin plastic with one made of mechanically recycled plastic conserves the energy content of the recycled plastic and the energy originally used in its manufacture.

Feedstock recycling converts plastic into raw materials and exploits its energy content. The feedstock recycling methods examined were: fixed-bed gasification with lignite, fluid-bed gasification with lignite, thermolysis of plastics into petrochemical products, use as a reducing agent in blast furnaces, and hydrogenation. Energy recovery exploits plastic energy content by creating heat and electricity. Energy recovery options examined were: fluid-bed combustion (monocombustion), and waste incineration with partial recovery of useful energy (IKP D-11).

The IPU.0020 study reported that in 1993 in Sweden, 50% of packaging waste containing PVC was incinerated and 50% was landfilled. The PVC collation tray was assumed to be landfilled (IPU.0015).

Environmental Impacts:

The Fraunhofer study (IKP D-11) points out that the above-mentioned options performed better environmentally, than the option of landfill disposal in terms of their use of energy resources, eutrophication, acidification and municipal solid waste. Each kilogram of plastic waste recycled or recovered avoided up to a kilogram of municipal solid waste, in comparison to the landfill scenario.

Mechanical recycling processes that substituted plastic products performed the best in the study. These processes have the potential to conserve much of the energy contained in waste plastic and process energy used for manufacturing. However, this can only be achieved with optimised processes that use one-to-one substitution of recycled product for virgin material. Additionally, these processes require single-resin waste input and are thus, not suitable for mixed plastics.

Feedstock recycling and energy recovery performed moderately well in the IKP D-11 study, with good potential for conservation of a large portion of energy content in plastic waste. These two processes can also recycle and recover relatively heterogeneous and contaminated plastic waste.

The most promising option noted in feedstock recycling and energy recovery was the use of the waste as a reducing agent in blast furnaces, in thermolysis to form petrochemical products, and in energy recovery through fluid-bed combustion. Fixed-bed gasification, fluid-bed gasification and waste incineration performed significantly worse. Mechanical recycling processes that use mixed plastic fractions as a substitute for wood or concrete products showed the worst performance.

In terms of the greenhouse effect, fluid-bed gasification, fixed-bed gasification and waste incineration yielded increased emissions compared to landfilling.

RANDA FR.006, a report on packaging waste by Coopers & Lybrand, concludes that technological, market, logistical and regional or local conditions determine the preferred disposal method (reuse, recycling or recovery) to a large extent. They term this “conditional preference”.

In a study carried out by Ecobilan for the City of Paris (RANDA FR.004) about the recycling of PVC and PET bottles, the impacts of the selective collection scenario were minimal and did not substantially modify the general economy of plastics nor the management of the residues. The functional characteristics of products made from recycled materials were the same as those made from virgin materials.

RDC Environment, along with Pira, published a report in March 2003 (RANDA FR.005) regarding the achievement of reuse and recycling targets for different packaging materials within the framework of Directive 94/62/EC. One of the main conclusions was that the selective collection of packaging and packaging waste is a better option than treatment together with unsorted waste. For household packaging, separate curbside collection was preferred and separate collection for industrial packaging was also favoured.

An example of the calculation of environmental inventory from the recycling of plastic wastes from packaging materials is given in BUWAL (IKP-CH-16). The inventories for PE, PP, PS, PET and PVC are each calculated based on the actual recycling situation in Switzerland, a scenario with 100 % waste incineration, and a scenario with 100 % landfill disposal. A specific discussion of the results is not provided.

The case study of PVC treatment in a waste incineration plant is given in the IKP-D-26 study. The emissions were measured and evaluated over a longer period of time according to legal requirements and specific waste input compositions. A special feature of the studied waste incineration plant is a HCl-rectification-facility. The specific results of the measurement are that 2 % PVC in the waste fraction can be processed without any problems. The burning of PVC did not lead to higher concentrations of heavy metals, PCDD, PCDF or PCB in clean gas or products from the flue gas cleaning.

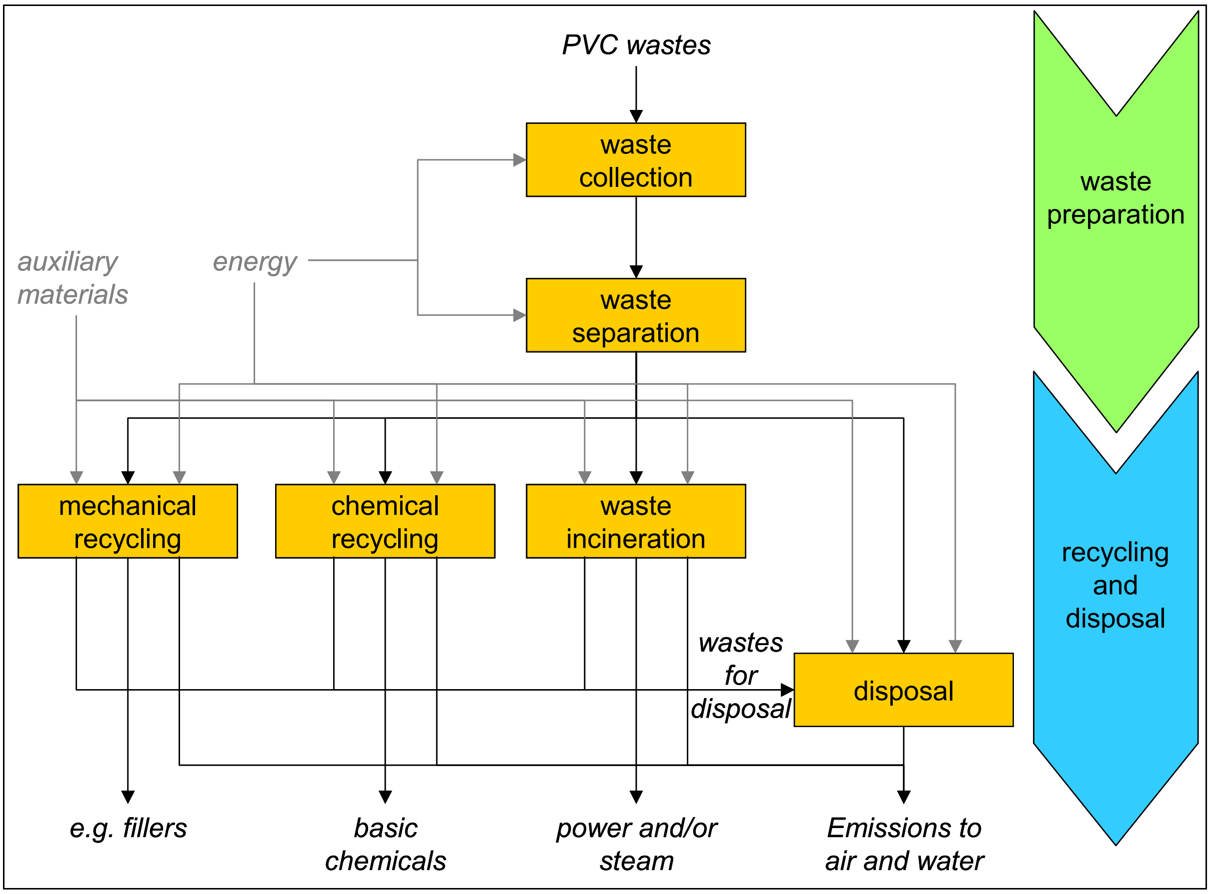

Figure 4-12: **End-of-life phase of PVC products**

4.5 Conclusions of the life cycle impacts of PVC

In this section, the potential overall life cycle impacts of PVC are discussed. Taking into consideration the high product dependency of the studies, an analysis based on all phases or ‘modules’ of the life cycle of PVC in a ‘top-down’ view was performed. Conclusions regarding the life cycle phases - production, use and disposal/recycling - are discussed in the following paragraphs. Comments relating to different applications follow. Lastly, gaps and overall conclusions are pointed out.

In the production phase, the manufacturing of VCM had the greatest load on all impact categories. This can be explained by its specific consumption by unit weight of polymer, a common occurrence in polymerisation processes as well as the numerous processes involved from the extraction of raw materials to the manufacture of the final product. Regarding the use of additives, despite their high percentage in the composition of flexible PVC, much information about risk or references to risk assessment studies was found, but very little was found about their life cycle, e.g. energy and material consumption, or emissions.

The use phase varies greatly with the application of the product and the length of its service life, therefore no general conclusions about this can be made. Although the use phase is a very important step of the product life cycle, especially in the case of durable products, not many studies deal with this phase in their analyses. As a consequence, no concrete statements can be made as to whether the greatest burden on the environment is contributed by the production or use phase.

The PVC recycling rate for post consumer waste (in the year 2000) is relatively low in the European Union, representing only 3%, in comparison to landfilling (82%) and incineration (15%). This is mainly due to high collection and separation costs. Nevertheless, this rate is expected to increase. The number of studies covering this issue as well as initiatives from different producers, such as for windows or flooring in Germany, show that there are many possibilities for improvement and that good results can be achieved. Moreover, the Vinyl 2010 Voluntary Commitment, in effect since 2000, involves the entire material life cycle and all key markets. In terms of mechanical recycling, for example, the commitment is to recycle at least 50% of the collectable available quantity of pipe, fittings and window profile waste by 2005. [50]

In the building sector (windows, pipes, flooring, cables), PVC is used due to its stability and long life. It requires minimum care and maintenance during the use phase. However, this long lifetime could present a barrier to recycling. Materials deteriorate over time, new technologies are developed, and new restrictions on substances are imposed. With long duration products, old products containing prohibited substances continue to be present in the market. This can pose a problem for recycling of PVC. Moreover, sometimes it is not possible to identify when the product was produced.

In the packaging sector, mostly rigid PVC is used. In food packaging, special attention is given to the approval and compliance of the entire formulation. The migration of plastic monomer or plasticiser and all additives from PVC to the packed good is strictly monitored and regulated. In the end of life phase, PVC is collected together with other packaging waste. In Germany, through the Duales System Deutschland AG (DSD), this waste is collected for recycling. According to “HTP Ingenieurgesellschaft für Aufbereitungstechnik und Umweltverfahrenstechnik in Aachen, Germany” 1995 approx. 683.000 t of PVC waste were reported in Germany. Approx 329.000 t of PVC waste disposed and approx. 354.000 t of PVC waste were recycled. Approx. 25.000 t per year of the recycled PVC waste is packaging waste related to the DSD system.

Cables represent a minor market of PVC in the electronic and automotive sector. Not many impacts were reported from their production and use phases. In the end of life phase, contamination by copper (Cu) and aluminium (Al) are still a problem, but new mechanical and feedstock/chemical recycling technologies are being developed, to cope with these problems.

In general, the databases used to describe PVC production in many of the reviewed studies, were based on APME (1990/94), BUWAL (1990/95) or IKP (1994) data. Since the end of 2002 an ecoprofile of PVC, based on data collected in 1998/1999, has been available on the APME website, however, it was not used as the basis of the available studies. Unfortunately, studies using more recent data could not be found. Moreover, there are very few studies, which consider or deal with the use phase of PVC products in detail. Regarding the disposal phase, the majority of studies deal with the material itself (PVC) and not with specific products. Apart from some specific initiatives, such as PVC-flooring-recycling (AgPR GbR, the German Gathering System for take-back and reuse of window profiles), or Vinyl 2010 (for the development of novel recycling technologies, efforts to set up collection schemes for the non-regulated waste streams and to build new recycling capacities), post-consumer PVC waste normally enters the waste stream with general plastic waste. This is either waste landfilled, incinerated or recycled. Therefore, specific treatment for each product is normally not reported.

The following table gives a general overview of the most important aspects of the overall life cycle impacts of PVC, when possible. Keep in mind when comparing PVC with other materials for specific applications, that the most important aspects to consider within an LCA are the composition of the PVC compound, the kind of application, the functional unit, the boundary conditions and the inclusion of the entire life cycle. Without taking these aspects into account, no consistent statements about the environmental advantages and disadvantages of alternative applications or competing materials can be made.

Production phase
- VCM production contributes to the impact categories to a great extent; - Ethylene production (including steam cracking, refinery and crude oil supply) requires the most primary energy (approx. 2/3 of the total required energy) within the VCM production chain. - The chlorine route consumes almost 1/6 of the total required primary energy, whereby it is approx. equally distributed throughout the chlorine route which encompasses the raw material supply from rock salt until the process steps of the electrolysis. The rest of the required energy is consumed within the chlorination process of VCM. - Concerning other environmental impacts such as acidification, eutrophication, global warming and the toxicity potentials, Ethylene production and Chlorine production contribute a comparable amount. For tropospheric ozone creation, Ethylene production, due to the steam cracking and refinery processes, is a main contributor to VOC emissions. Thermal process energy generation and electricity show a relatively low contribution to these impact categories, with a maximum of 15%. - Concerning chlorine production, the main contributor to all environmental impacts is electricity consumption for the electrolysis process. Electricity consumption is expected to decrease, with the planned installation of more membrane processes, which consume considerably less electricity. The impacts of the rock salt supply are between 5 and max. 25%. - The main contributor to impacts within the ethylene supply chain of VCM production is related to the steam cracking of the input naphtha. Thermal energy demand, as well as the up-stream refinery processes, are primary contributors to all of the above mentioned environmental impacts. - Emissions and energy consumption during PVC compounding are relatively low. PVC processing has a rather low impact, due to its simplicity. - The production of fillers (most commonly chalk) is relatively undemanding in terms of energy and has a rather low potential impact on the environment. - From a life cycle perspective, the production of stabilisers and plasticizers play a relevant role. The production processes of these additives have improved through better energy efficiency and the reduction of process related emissions during the synthesis of the products. This may lead to a significant optimisation of the performance of PVC over its life cycle. Pigments offer a comparatively low optimisation potential from the view point of LCA. The amount of pigment used in PVC compounds is low; therefore the potential influence on an optimisation is low as well.

Production phase (cont.)

Measures:

- Generally, the reduction of consumed material, without compromising functionality, offers some potential environmental optimisations.
- If the mechanical property requirements of the PVC product allow for a higher content of fillers, a better environmental profile is expected due to the relatively low impacts of the filler production steps (see above).
- Co-extrusion of recycled PVC material (as core material without optical requirements) with a surface layer of primary PVC (for when aesthetic requirements are very high). This technique can be used for different applications like window frames and pipes and offers the potential for improving the overall impact of the PVC products over their life cycle.
- VCM emissions during polymerisation can be minimised most effectively by installing so-called “close-lid operations”, or in other words, if VCM processing occurs within a closed loop production process. Most modern processes apply this technique.
- Enhancing the use of membrane processes for the electrolysis of chlorine may offer potential for optimisation from a life cycle viewpoint.
- Ethylene production contributes significantly to all impacts. Hence, shifting steam cracking inputs from approximately 77% naphtha and 23% natural gas feed, to a higher share of natural gas, would decrease the amount of thermal energy required for the steam cracker process, due to higher energy efficiency. Therefore, the VCM production chain could also benefit from this measure.
- ESPA and EuPC have committed to stop using cadmium and to replace lead stabilisers within a fixed time scale with intermediate reduction targets.

Use phase

- PVC products are highly durable; durable products are potentially replaced less frequently. This usually has a positive influence on the PVC life cycle.
- Maintenance efforts required for PVC products are usually relatively low. PVC material requires little maintenance and repair due to its chemical, mechanical and thermal properties. This also has a positive influence on the environmental performance of the life cycle.
- Maintenance methods and intervals, and expected product service life are parameters with a primary influence on the environmental impact of the use phase. PVC generally performs well in terms of this parameter.
- Lead/cadmium used as additives are immobilised during use.
- Losses of plasticiser (VOC emissions) to water and to ambient air are possible. Studies on "indoor-air quality" on a local level may be able to answer questions related to the relevance of these emissions. These emissions do not play a significant role from a life cycle viewpoint.
- Given the relatively short life time of the use phase for packaging materials, this phase does not play a significant role for those products.
- When PVC products (as well as most alternative materials) require certain auxiliary materials in the installation process (like glues or other related materials), the environmental performance of the PVC use phase can be influenced, due to the production of the auxiliary material and to the diffusion of volatile compounds from these materials over time.
- Due to the chlorine content of PVC, the material is "intrinsically" flame retardant. This may make it unnecessary, or less called-for, to treat PVC additionally. However, additional treatment also depends on the type of product produced and how it is applied.
- Due to PVC's comparatively low density, and the ease with which its mechanical properties can be altered, its potential to serve in light-weight applications is considerably higher than that of its competing materials of a higher density. The potential to improve product life cycle impacts in light-weight applications is especially high for mobile applications (like cars or other means of transportation).

<u>Measures</u>:

- If product quality is increased in terms of higher durability, while demands in maintenance decrease, the environmental performance will be positively influenced in most cases.
- The users of the products should be informed about their ability to influence the proper performance of the products during the use phase. The potential of the user to negatively influence the performance of the part during the use phase is relatively high for products like window frames.
- For the transport sector the use of materials that support light-weight concepts is still a major target.

End of Life phase

Remarks:

- The only possible advantage of land filling would be the simple technical operation. The main drawbacks besides (long-term) emissions to air, water and soil, are the limited amount of available landfill volumes, no secondary product output and no (or negligible) recovery of energy or resources.
- The main advantage of incineration is the reduction of waste masses and the separation into different fractions, while being able to process mixed waste fractions. Modern incinerators yield not only electricity and heat but also hydrochloric acid and metals as valuable recovered products. The main disadvantages from a life cycle point of view are the generation of hazardous waste (mainly ashes) that have to be disposed of accordingly and relatively energy demanding flue gas treatment processes. Further, it is not possible to directly gain secondary material, but only intermediate products. Important are a proper flue gas treatment and an adequate fate of the residual ashes. Therefore most importantly, parts of the energy production chain can be can be substituted by the products of incineration.
- Feedstock recycling has the main advantage of being able to separate different contents of substances (elimination of undesired substances or concentration of valuable substances). Therefore different outputs (e.g. organic intermediates, coke, lead, salts) can be gained according to the specific demand situation for secondary recovered products. Further, the feedstock technologies can usually cope with a certain variation in the input. A variation in the input composition leads (in most cases) to a variation in the distribution of the output (the secondary feedstock). The main disadvantage from a life cycle point of view is the decomposition of the initial material, which makes it impossible to directly gain secondary material, but a least the production chain from resources to the chemical intermediates can be substituted by the products of feedstock recycling.
- The main advantage of mechanical or material recycling is the direct gain of secondary polymer material, which can potentially be re-used in comparable applications. Therefore material recycling can substitute the largest share of the polymer production chain – from resource extraction to the granulation process. The main disadvantage of mechanical or material recycling is the dependency on a relatively stable input composition because the quality of the recycled product is particularly vulnerable to input impurities. Consequently, mixed wastes can seldom be processed.
- In terms of the life cycle, the end-of-life phase plays an important role. This importance is not primarily due to environmental impacts of the treatment or recycling processes; compared to resource extraction, energy generation and production processes, the end-of-life processes have more often than not lower environmental impacts. The importance is due to the different type and quality of recovered materials and energy, which are substituting different production steps of virgin or primary materials and energy according to their specific quality. Hence the more production steps that are substituted, the better the environmental improvement will be. Therefore material recycling not only saves resources, but saves many production and transport steps and their respective environmental impacts too.

End of Life phase (cont.)

- Due to the fact that mixed plastic waste with or without PVC has a low potential to be used again as secondary material in “high quality” applications (like windows, sheets, foils etc.), the recycling rate of post-consumer PVC waste is still low. Neither automatic nor hand sorting seems to be effective today to separate mixed polymers. From a technical and environmental point of view it may be advantageous to reduce the amount of mixed plastic waste by establishing individual recycling routes for the different plastics. However the economic feasibility (available mass streams, market for secondary material) of these possible measures must be considered.
- Four primary options for end-of-life PVC treatment exist. Landfilling, thermal treatment (with energy recovery), chemical recycling (most material recovery) and mechanical recycling.
- Independently from the type of recovery or recycling option, all options are better than landfilling, because various parts of the products can be used in further life cycles and can substitute primary materials.
- The most effective recovery or recycling option depends on the market situation, the composition of the waste stream, the demand for these recovered products and on the local or national regulative situation.
- From a life cycle perspective, the effectiveness of an environmental improvement increases if the quality of the recycled product is higher and therefore can be applied in the production of new products (decreasing the demand of primary produced material).
- The management of PVC as a resource plays a decisive role in the environmental assessment. In landfills, the carbon content of the waste product is “stored”, although long-term fixation is uncertain. Landfilling of plastic waste is not a long-term disposal option in most EU member states. Although no EU member state bans landfilling, efforts to restrict landfilling of combustible waste are ongoing in several member states. Policies of other member states allow the landfilling PVC if it is not recyclable. Incineration processes use the embodied energy of the polymer, while recycling processes recover the material itself or its feedstock.
- Another important aspect is the “value” of the received recovery or recycling products generated from the different recovery options. Whether a product can substitute a raw material of a comparable substance - relative to a complete conventional production chain - or not, is significant from an environmental point of view. From an economic perspective, the value or characteristic of the reclaimable product, compared to conventional production, plays an important role. Hence, recycled PVC products positively influence the environmental performance most when the quality of the respective product is comparable to the quality of the primary product. This of course implies that the recycling processes do not cause disproportionately high impacts in their operation.
- Recent studies show that the presence of PVC has no significant effect on the amount of dioxins released through incineration of plastic waste.
- PVC products are a source of phthalic and organotin compounds in landfills, but contribute little to the inventory of heavy metals. Further, the effect on the quality of the leachate seems to be rather small.

End of Life phase (cont.)
Measures: - Vinyl 2010 Voluntary Commitment of the European Vinyl Industry. - Specific recycling initiatives of different countries or companies for recycling PVC products. If the companies are able to use recycled material of their own composition (additives, colour, etc.) the potential to use the recycled material in high-quality applications increases. - Regulated waste streams for packaging, automotive and electrical and electronic appliances have recovery targets that have to be met by plastics specifically or by all materials, including plastics and therefore also PVC.

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5 Assessment of studies

The assessment of the studies has been performed according to sector or application. The available studies are grouped according to their respective sector. Studies analysed within the critical assessment are listed first. All available information on the LCA studies within the different sectors is listed (documentation sheet[17], systematic characterisation as well as the critical assessment). Summaries of each sector considered are provided.

The documentation sheet and the systematic characterisation of the remaining LCA studies are grouped according to the respective sector in the annex. In addition, the documentation sheets of all other studies related to the respective sector are also listed in the annex.

5.1 Building and Construction

The building and construction sector is the most important for PVC applications. Approximately 50% of all PVC produced is used for applications in this sector.

Within this sector profiles and rigid sheets (window frames, cladding), flexible sheets (flooring, roofing), and pipes are the major applications. Due to the prominence of these applications, numerous studies have been carried out within this sector.

Table 5-1 provides an overview of the market share situation of the building sector. Principal competing materials are in bold.

Table 5-1: Overview of the building and construction sector

Sector	PVC Application	principal competing materials (PCM)	percent of total PVC mass used	market share of PVC
building and construction:				
profiles and sheets (rigid)	window frames	**wood, aluminium,** steel, PUR, polyolefins	9%	major
	Cladding	**aluminium,** steel, fibre cement, **wood**	9%	major
	Sheets	acrylics, glass, **PS (non transp.), PC (trans.)**		
	conduits, shutter, rails, skirts	ABS, PS, SB, PP, PMMA, PC, wood, metals		
sheets and foils (flexible)	flooring (incl. Sport)	**carpet, wooden flooring,** laminate, **linoleum (soft),** polyolefins, **tiles (hard),** natural stone, rubber, cork	8%	major (soft) medium (total)
	roofing sheets	**bituminous sheets,** PIB, EPDM, **PE,** EVA	1%	major
	membranes	**polyolefins,** polyester (coated)/ glassfiber (coated)/ PA (coated)	1%	major
	Wallpaper	**paper,** mineral plaster, acrylics	2%	medium
pipes and fittings	Waste/rain water	polyolefins, cast iron, concrete, stoneware/clay, Cu, Al, Zn	12%	major
	drinking water	(stainless) steel, copper, **polyolefins,** PB, ABS	4.5%	medium
	gas pipes	**Polyolefines**	< 0.5%	small
	irrigation and draining pipes	Polyolefines	2.5%	major

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[17] To prevent an overload of redundant information, the documentation sheet, the systematic characterisation and the critical assessment scheme are integrated into the text and not further labelled as tables.

5.1.1 Rigid profiles and sheets: Windows

The principal competing materials of PVC in window frame applications are aluminium and wood. Steel, PUR and polyolefins play a less important role.

Different materials applied as window frames (IKP AT-6)

Documentation sheet (IKP AT-6)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Ökologische Betrachtung der Fenster-Werkstoffe Kunststoff, Aluminium, Holz</td></tr>
<tr><td>Scope of investigation</td><td>Consideration of different materials as window frames in terms of environmental aspects</td></tr>
<tr><td>Year of publication</td><td>1994</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>Österreichischer Arbeitskreis Kunststoff-Fenster Arsenal,
Objekt 212, Franz-Grill-Str. 5, 1030 Wien, Austria</td></tr>
<tr><td>Contractor/ Address</td><td>See above</td></tr>
<tr><td>Authors</td><td>Elisabeth Novak</td></tr>
<tr><td>Availability/Publisher</td><td>Österreichischer Arbeitskreis Kunststoff-Fenster Arsenal,
Objekt 212, Franz-Grill-Str. 5, 1030 Wien, Austria</td></tr>
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Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td>X</td><td>Qualitative</td><td>X</td><td>Qualitative</td><td>X</td></tr>
<tr><td>Quantitative</td><td></td><td>Quantitative</td><td></td><td>Quantitative</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison of window frames made of different materials:
PVC / aluminium / wood</td></tr>
<tr><td>Reported data</td><td></td></tr>
<tr><td>Short description of the study</td><td>Environmental analysis of different materials in window frames in consideration of the whole life cycle – regarding the manufacturing of the materials, the production of the window profile, the assembly of the window, maintenance of the window frame during use as well as recycling and disposal of the windows. Based on energy data and data regarding the critical air volume[18].</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>80%</td><td>Specific/own/new data</td><td>20%</td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

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[18] Critical Air Volume is a Life Cycle Impact Assessment Method

Systematic Characterisation (IKP AT-6)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	
Goal, description of	
Application/use of results	
Aim of study	x
Target group of study	
Scope, description of	
Main technical systems properly described	x
Function analysed	Windows
Functional unit	not explicitly stated
System boundaries include:	
materials	x
energy	x
production	x
use	*x*
disposal	x
recycling	x
transportation	x
Allocation (mass/energy/price/exergy)	mass
System Expansion	yes
Substitution	x
Data categories described	
Primary energy consumption	x
Air emissions	x
Water emissions	x
Waste categories	x
Impacts	
Global warming	
Acidification	
Nutrient enrichment	
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	primary energy, critical air volume
Data quality	
time	no considerations
geography	no considerations
technology	no considerations
Critical review performed	
Evaluation	
Normalisation	no
Weighting	no
Other methods	no

Critical Assessment (IKP AT-6)

Goal description in short	• An investigation of the environmental load over the whole life cycle of window profiles from PVC, aluminium and wood.	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• Comparison between PVC, aluminium, and wooden window frames. • System boundaries are not clearly defined. • Functional unit is not described.	
Life cycle phases	• All life cycle stages included • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which MAY affect conclusion	X
Important assumptions	• Average electricity production of Austria applied • No emissions from landfilling of PVC • Reused PVC uses 30% of the energy of virgin PVC. • All PVC not reused is landfilled, i.e. no incineration of PVC. • Energy consumption only as primary energy. No emissions. • Unknown whether the assessment in this study is directly comparable to the other study on aluminium, wood and PVC (IKP-AT 11). Mentioned however, as having same system delimitations from BUWAL. • All production waste is reused internally in production. • No emissions from reuse of old PVC windows • etc.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• No general considerations. • Critical air/water volume – volume of air polluted up to emission-permitted value used for emissions of compounds to air. • Not transparent which compounds are released and in what amounts.	
Data requirements	• No discussion of completeness, representativeness precision level, consistency or reproducibility.	
Inventory	• Database used: ETH and Buwal. • Database from a Software System: Unknown • Gaps of important impacts: Water emissions are excluded due to lack of data.	
Impact Assessment	• Not performed – only Critical Air Volume, i.e. characterization but no fate and exposure modeling. Could be seen as a very simple model, where compound stays in the air compartment.	
Environmental impacts included	• Primary energy use (no emissions from here) • Critical air volume	
Weighting of environmental parameters	*Not possible to evaluate the influence of the weighting on the overall result*	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. No impact assessment, no third party report, no considerations of data requirements, low transparency.	

The study comes to the following key conclusions:

- PVC is the material with the lowest energy consumption
- Aluminium is the material with the highest energy consumption
- If properly recycled, the energy consumption of aluminium is lowered almost to the energy consumption level of wood.
- The extent of material recovery after use can seriously affect the outcome of the assessment, both in terms of total energy consumption and critical air volumes.
- For critical air volumes, PVC and wood are almost equal. Aluminium is the worst.
- Proper recovery of PVC can reduce its impacts, rendering it the preferable material. Proper recycling of Aluminium can reduce its impacts to levels lower than those of wood.
- Improvement potentials exist for all solutions.

The study focuses on primary energy consumption. Some emissions over the life cycle are covered by the “Critical air/water volume” impact method. However, because the type and amount of compounds released over the life cycle are not transparent in this study, it is not possible to assess the appropriateness of its judgement on critical air volumes.

The finding that PVC has the lowest energy consumption is obvious, as only primary energy consumption is considered for this screening study. PVC is based to a certain extent on chlorine, which shows a low consumption of primary energy in production. In aluminium production, electricity demand for the electrolysis process is a main contributor to primary energy consumption. The demand for wood for the wooden frame can also be equated to primary energy consumption (of the regenerative material wood).

The results are not very detailed and the data used is to a large extent from literature. However, it should be kept in mind that the goal and scope call for only a screening of the life cycle of different window applications.

<u>The study recommends to manufacturers</u>:

- Improve recycling and use of secondary materials.

The use of secondary materials (recycled materials) most often influences the results of a LCA positively, because it reduces the required amount of primary virgin material (and its related production processes).

<u>The study explains to users</u>:

- PVC and aluminium frames need no maintenance (only cleaning is required), whereas wood frames require painting/lacquer every 3-5 years.

For the user, this is an important point, as painting of the wooden frames is their responsibility.

<u>The study explains to third parties:</u>

- PVC is a good solution.
- When demolishing buildings there is still (environmentally) valuable material left in window frames

Table 5-2 summarises the analysed impacts, Primary Energy (PrEn), Critical Air Volume (CAV), and wastes:

Table 5-2: Summary of the analysed impacts of IKP AT-6

IKP AT-6	Wood window frame	PVC window frame	Al window frame	Impact
Production	Medium a little higher than PVC	Lowest, a little lower than wood	Highest, approx. twice that of PVC and wood	PrEn
	Lowest, almost half of PVC	Medium, double of wood	Highest, three times PVC and six times wood	CAV
	Highest, six times PVC	Medium	Lowest, half of PVC	Total waste
	Highest amount, 100% recovery possible	Lowest amount, 30% recovery	Lowest amount, 50% recovery	Usable waste
Use	Approx. 20% of primary energy in production	None	None	PrEn
	Approx. 20% of production	None	None	CAV
	No information	None	None	Total waste
Total life cycle depending on disposal (%-recovery)	Unchanged, wood is not recovered	From equal with wood to half of wood in primary energy depending on recovery %	Approx. twice the primary energy as PVC, independent of recovery percentage. From twice the primary energy to equal with wood depending on recovery %	PrEn
	Unchanged, wood is not recovered	From equal with wood to 10% of wood in CAV depending on recovery %	Approx 2.5 the CAV than PVC independent of recovery percentage. From 2.5 times the CAV down to half of wood depending on recovery %	CAV

Assessment of PP, PVC and aluminium/wood window frames (IKP AT-11)

Documentation sheet (IKP AT-11)

Kind of report	Study
Title	Ökologische Betrachtung von PP-Fenstern
Scope of investigation	Environmental assessment of PP window frames – compared to PVC and aluminium/wood window frames
Year of publication	2000
Ref. year(s) of assessment	
Institution or Company	Institut für Industrielle Ökologie, Rennbahnstr. 29C/3, A-3100 Sankt Pölten
Contractor/ Address	IFN-Internorm Bauelemente GmbH & Co KG, Ganglgutstr. 131, A-4050 Traun, Austria
Authors	A. Windsperger, S. Steinlechner
Availability/Publisher	Institut für Industrielle Ökologie, Rennbahnstr. 29C/3, A-3100 Sankt Pölten, Austria
ISBN	-
Keywords	
Life cycle phases Qualitative/Quantitative	
Comparison with alternatives	Comparisons between windows made of PP and PVC and those made ofbetween PP and aluminium/wood
Reported data	LCA
Short description of the study	Environmental assessment of PP windows – compared to PVC and aluminium/wood windows – on basis of inventory results considering the whole life cycle.
Expert judgement	
Comments related to further assessment	Comment: Suggested for **systematic characterisation**

Life cycle phases Qualitative/Quantitative:

Production phase	**X**	**Use phase**	**X**	**End of life**	**X**
Qualitative		Qualitative		Qualitative	
Quantitative	X	Quantitative	X	Quantitative	X

Expert judgement:

Brochure-like		Scientific-like	X
Selected/limited impacts		Main/high variety of impacts	
Generic data/literature data	80%	Specific/own/new data	20%

Comments related to further assessment:

Initiator		**LCA**	
X	Industry		PVC/competitor material
	Academia		part of PVC compound
	Government		material PVC/comp. comparison
	NGO		PVC/competitor application
		X	application PVC/comp. comparison
			Other than LCA

Comment: Suggested for **systematic characterisation**

Systematic characterisation (IKP AT-11)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	unknown
Goal, description of	
Application/use of results	
Aim of study	x
Target group of study	
Scope, description of	
main technical systems properly described	X
Function analysed	Window
Functional unit	1 window incl glass, time unknown
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	mass and energy
System Expansion	No
Substitution	No
Data categories described	
Primary energy consumption	yes
Air emissions	No
Water emissions	No
Waste categories	yes
Impacts	
Global warming	No
Acidification	No
Nutrient enrichment	No
Tropospheric Ozone Formation	No
Stratospheric Ozone Depletion	No
Toxicity, human	No
Toxicity, eco	No
other:	waste
Data quality	
time	1996
geography	Not stated
technology	Industry average
Critical review performed	No
Evaluation	
Normalisation	No
Weighting	No
other methods	No

Critical Assessment (IKP AT-11)

Goal description in short	• An investigation of the environmental load over the whole life cycle of a PP window profile. • To compare the above with a government study on PVC, aluminium and wood window profiles (IKP AT-10).	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• Comparison between PP and PVC, aluminium, and wood window frames. • System boundaries are clearly defined • Functional unit is properly described.	
Life cycle phases	• All life cycle stages included. • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	X
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which may affect conclusion	X
Important assumptions	• Energy consumption only as primary energy • The assessment in this study seems not to be comparable to the study (IKP AT-10 on aluminium, wood and PVC, due to differing degree of detail.	
Valuation of scope	• The scope is appropriate to fulfil the goal of a screening for a PP-window, but not as a comparison to the 1997 study (IKP AT-10), degree of detail is different.	
Methodology	• No general considerations	
Data requirements	• No discussion of completeness, representativeness precision level, consistency or reproducibility.	
Inventory	• Database used: ETH and Buwal. • Database from a Software System: Unknown • Gaps of important impacts: Emissions of substances normally contributing to human and ecotoxicity are listed but not evaluated.	
Impact assessment	• Not performed	
Environmental impacts included	• No quantification of impacts.	
Weighting of environmental parameters	• *Not possible to evaluate the influence of the weighting on the overall result*	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. No impact assessment, no third party report, etc.	

The study comes to the following key conclusions:

- The PP window frame in general has the lowest emissions with low to medium ranking in all measured categories. However, there is a difference in the age of the data. The PP window frame is the “new” product for which a comparison with existing products is desired. Hence, data for this window frame is new and data for the other materials is older. No effort is made to update the data, as only a screening of the new material is desired.
- No conclusions are drawn on the other materials in the study.

Therefore, comparisons to PVC, aluminium and wood from the study IKP AT-10 seem inappropriate.

The study explains to manufacturers:

- There are possible alternatives to PVC, with better environmental performances.

The study explains to users:

- There are possible alternatives to PVC, with better environmental performances.

The study explains to third parties:

- There are possible alternatives to PVC, with better environmental performances.

System boundaries and the analysed impacts must be comparable and transparent for comparative conclusions to be of value. This is not the case in this comparison. Therefore, the conclusions are of low value.

Table 5-3 summarises the analysed impacts:

Table 5-3: Summary of the analysed impacts of IKP AT-11

IKP AT-11	PP	Wood/aluminium	Aluminium	Wood	PVC	Impacts
Total life cycle	Lowest	Highest, three times that of PP, alu., and PVC	Low, only a little higher than PP	Medium	Low, only a little higher than PP and equal til alu.	Materials
	Medium, but significantly lower than wood/alu. and PVC	Highest, 2.5 times PVC and alu.	Medium, equal to PVC	Lowest, 20% of PP and 13% of wood/alu. and PVC	Medium, equal to alu.	Energy
	Low to medium in general, except CO where PP is highest	Low to medium in general, no significant difference from PP	Highest in general, except HCl	Lowest in general	Medium to highest in general	Emissions to air (CO, CO2, SO2, NOx, CxHy, HCl)
	Lowest	Low in COD, medium in metals	lowest in COD, highest in metals	Medium in COD, lowest in metals	Highest in COD, low in metals	Emissions to water (COD, metals)
	Lowest, one third of wood/alu.	Highest	Low, equal to PVC, a little higher than PP	High, a little lower than wood/alu.	Low, equal to alu., a little higher than PP	Waste

PVC, wood, wood-aluminium, and aluminium window frames over their whole life cycle (IKP D-6)

Documentation sheet (IKP D-6)

<table>
<tr><td>Kind of report</td><td>Project report</td></tr>
<tr><td>Title</td><td>Ganzheitliche Bilanzierung von Fenstern und Fassaden</td></tr>
<tr><td>Scope of investigation</td><td>PVC, wood, wood-aluminium, and aluminium window frames over their whole life cycle</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1994 to 1997</td></tr>
<tr><td>Institution or Company</td><td>Institut für Kunststoffprüfung und Kunststoffkunde (IKP), University of Stuttgart,
Hauptstr. 113, D-70771 Echterdingen, Germany</td></tr>
<tr><td>Contractor/ Address</td><td>Verband der Fenster- und Fassadenhersteller e. V.,
Bockenheimer Anlage 13, D-60322 Frankfurt, Germany</td></tr>
<tr><td>Authors</td><td>J. Kreißig, M. Baitz, M. Betz, W. Straub</td></tr>
<tr><td>Availability/Publisher</td><td>Verband der Fenster- und Fassadenhersteller e. V.,
Bockenheimer Anlage 13, D-60322 Frankfurt, Germany</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>PVC, Wood, Aluminium, Wood-aluminium window frames, facade, LCA</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Wood, Wood-Aluminium, Aluminium, PVC</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to describe the environmental impacts, with all relevant influencing factors during the whole life cycle of windows and facades. Areas for optimisation are pointed out. The study presents also two scenarios: near future (year 2000) and future.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td></td><td>Specific/own/new data</td><td>100%</td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation.
</td></tr>
</table>

Systematic Characterisation (IKP D-6)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	window constructions, different sizes
Functional unit	1 window construction including glass and fittings, size and function specified
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	mass, energy, price
System Expansion	
Substitution	credits for recycled goods
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	X
other:	
Data quality	
time	1993 to 1996
geography	Germany
technology	specific
Critical review performed	
Evaluation	none
Normalisation	
Weighting	
other methods	

Critical Assessment (IKP D-6)

Description of goals	• Full description of the system along the life cycle • Analysis of weak points and potential for optimisation • Integration of many partners from the construction sector to find standards • Cooperation with the “Verband der Fenster- und Fassadenhersteller”, an industry association. • Inclusion of a best available technology scenario for strategic planning in industry	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• Window and facade systems • adequate system boundaries • Functional unit: Specific typical window construction including glass and fittings, size (1.24m x 1.48m) and function specified	
Life cycle phases	• Production, use phase of 40 years and recycling scenarios are covered • During the use phase maintenance and repair are covered, that ensure the lifetime of 40 years • Heating losses and gains from sun radiation are included in the use phase. • Different material recycling and energy recycling scenarios covered according to material. • The whole systems including glass and fittings are covered	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Landfills are not part of the system. The amount of waste is stated. • Wood products are considered as CO_2 –neutral over the life cycle • All systems reach the same specific heat loss value • German boundary conditions	
Valuation of scope	• The scope is appropriate to fulfil the goals	
Methodology	• Allocations and credits all fully discussed and well documented • System and boundaries fully discussed and well documented	
Data requirements	• Data checked on plausibility and completeness • Data sources all specified and well documented, high quota of directly industry-based data	
Inventory	• Extensive description of the technical system (important for comparability) • Sensitivity analysis of window size and location of the window • Database and software GaBi used	
Impact Assessment	• Model used and the different impact categories fully described • Model fully fulfils the requirements	
Environmental impacts included	• All commonly-accepted impact categories included • Interpretation of the results for the different recipients not fully developed	
Weighting of environmental parameters	• No normalisation • No weighting	
Overall ISO 14040 ff requirements	• The requirements of ISO 14.040 ff. are met	

The study comes to the following key conclusions:

- The use phase is dominant in most impact categories due to heating energy losses and gains from sun radiation. The portion of total potential environmental impact associated with the manufacturing phase for the window frames of each material is between 5% and 40%. Thus, 60% to 95% of the total potential environmental impact arises from the use phase (compensation for heat transmission).
- Insulation glazing during window frame manufacture contributes significantly to potential environmental efficiency due to its high mass fraction.
- Recycling (PVC, Al) of the systems, and incineration with heat recovery (wood), both lead to environmental advantages.

The study is based on detailed data collected from manufacturers in the window industry. The study was a multi-client study including various producers of all analysed kinds of window frames. Therefore, data representativeness is high for the German market. Comparability is also high, as all data included in the study was primarily gathered or taken from the same background database.

The study explains to manufacturers:

- The environmental impact of window frames is not dominated by the use of a single material. Contributions to the different impact categories show that no construction conditions have significant advantages or disadvantages in all categories. The influence of the size of the window and the installation location (e.g. north or south facing) indicates that the choice of material for the frame has a limited effect on the overall assessment, if the period of use is included.

This implies that every material has individual weak points and optimisation potentials, based on its individual construction.

- All window frames assessed in the study showed potential for further improvement from an environmental point of view.
- Recycling of aluminium and PVC is the basis for environmental improvement of these window frames.
- While aluminium recycling is economically viable, the market for recycled PVC is still in need of development.

In addition to the positive aspects associated with the use of secondary (recycled) materials in window frames, the improvement of the design of the window from a thermal (heat loss) point of view to save energy during a long use phase (here 40 years) is very attractive.

- There is a considerable impact associated with the surface treatment of the wood window frame when VOC based paint systems are used. An advantage of using the wood frame is the lower global warming potentials, as the wood material within the construction is CO_2-neutral over its life cycle.

In contrast to fossil or other non-renewable resources like crude oil and bauxite, wood is a renewable resource. Furthermore, CO_2 is bound during the growth of the biomass. Nevertheless, the wood window frame requires frequent surface treatment during the use phase to maintain its technical and thermal properties.

The study explains to users:

- Since the use phase is dominant due to heating energy losses and gains from sun radiation, it is important to buy windows with good insulation characteristics.

All analysed window frames (PVC, aluminium, aluminium-wood, and wood) provided a very good standard of insulation characteristics at the time of the study.

The study explains to third parties:

- From a LCA point of view, material restrictions do not seem to be suitable for achieving ecological improvements in the window sector, as no construction is advantageous in all impacts, and the improvement potentials from an environmental point of view are mostly related to the construction.

Table 5-4 and Table give quantitative and qualitative overviews of aspects and impacts of the analysed studies.

Table 5-4: Potential environmental impacts related to the production, use and recycling of the window frames normalised to 100% of the highest contributing material in production per impact

IKP D-6	**PVC production**	**PVC recycling**	**Alu production**	**Alu recycling**	**wood production**	**wood use**	**wood recycling**
Global warming	51%	-5%	**100%**	-23%	25%	1%	4%
Nutrification	*51%*	*-2%*	***100%***	*-8%*	*46%*	*1%*	*8%*
Acidification	55%	-2%	**100%**	-20%	58%	1%	5%
Summer smog	*18%*	*0%*	*28%*	*-4%*	***100%***	*15%*	*-1%*
Municipal waste	**100%**	-9%	74%	41%	34%	4%	32%
Hazardous waste	*11%*	*0%*	*9%*	*-1%*	***100%***	*1%*	*36%*
Primary energy non- renewable	55%	-3%	**100%**	-25%	34%	2%	-3%
Primary energy renewable	*7%*	*-2%*	*69%*	*-30%*	***100%***	*0%*	*-2%*

The following examples are given as clarification of the percentages in Table 5-4. In the production phase, the aluminium frame contributes most in terms of GWP (100%), whereas PVC contributes only 51% as much of this impact and wood only 25% as much. In the recycling phase the aluminium frame has, in this case, the potential to save -23% GWP related to 100% GWP in production, if secondary material is further used (PVC has -5% and wood 4%).

Further qualitative information is provided. In the production phase, complete window systems including glass, seals, fitting etc. are compared.

Table 5-5: Environmental impacts of production, use and recycling from IKP D-6

PVC window	**Al window**	**Wood window**	**Al / Wood window**	**Impacts**
The global warming is considerably higher than for the wood window.	Considerable share of the global warming emissions comes from the use of energy for the electrolysis of aluminium	Since wood is a renewable resource and therefore incorporates CO2 during the growing, CO2 emissions during the production phase are considerably lower than for the other materials. A significant share of the global warming emissions comes from the production of window glass.	See Al/wood	**Global warming**
	Significant share of emissions from PA 6.6[19] fittings			**Eutrophication**
	Significant share of emissions from PA 6.6 fittings			**Acidification**
Low summer smog emissions, no coating of the PVC surface is needed.		The coating of the wood surface causes significant emissions in the category of eco-toxicity. Even water-based paint systems do not manage to substitute solvents entirely, and not all possible paint systems give enough protection for window applications.	Part of the surface protection of the wood window profile is due to the aluminium construction. Because of this, less paint for wood protection is needed, which lowers the summer smog emissions.	**Summer smog**
No maintenance needed	No maintenance needed	Coating needed	No maintenance needed	**Use phase**
Material recycling considered with 12% and a 70% future scenario	Material recycling considered with 30% and a 70% future scenario	100% Thermal recycling considered	The separation of the wood and aluminium feasible and recycling of both materials possible**.**	**Recycling**

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[19] PA 6.6 is a specific polyamide made from adipic acid and hexamethylenediamine

Ecolables for windows (IKP D-31)

Documentation sheet (IKP D-31)

<table>
<tr><td>Kind of report</td><td>Report</td></tr>
<tr><td>Title</td><td>Erarbeitung einer Vergabegrundlage für ein nationales Umweltzeichen Fenster</td></tr>
<tr><td>Scope of investigation</td><td>Ecolabels for windows</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1997 to 1999</td></tr>
<tr><td>Institution or Company</td><td>Institut für Kunststoffprüfung und Kunststoffkunde (IKP), University of Stuttgart, Hauptstr. 113, D-70771 Echterdingen, Germany</td></tr>
<tr><td>Contractor/ Address</td><td>Umweltbundesamt, Postfach 33 00 22, 14191 Berlin, Germany</td></tr>
<tr><td>Authors</td><td>Institut für Kunststoffprüfung und Kunststoffkunde (IKP)</td></tr>
<tr><td>Availability/Publisher</td><td>Institut für Kunststoffprüfung und Kunststoffkunde (IKP), University of Stuttgart, Hauptstr. 113, D-70771 Echterdingen, Germany</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>ecolabel, windows, LCA</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
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</td></tr>
<tr><td>Comparison with alternatives</td><td>aluminium, wood, aluminium/wood, PVC for window frames</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The study shows LCA analyses of aluminium, wood, aluminium/wood and PVC window frames over the whole life cycle in aggregated impact categories. Detailed inventory data is not available, the focus of the study is to identify environmental weak-points in the life cycle to give a basis for the awarding of ecolabels (according to ISO 14024) for window constructions.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>40%</td><td>Specific/own/new data</td><td>60%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. Comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. Comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
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Comment: Suggested for systematic characterisation
</td></tr>
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Systematic Characterisation (IKP D-31)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	ISO14024
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	
Scope, description of	
main technical systems properly described	X
Function analysed	Windows
Functional unit	1 window incl. glass for 30 y
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	not stated
System Expansion	not stated
Substitution	not stated
Data categories described	
Primary energy consumption	X
Air emissions	
Water emissions	
Waste categories	
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	
Data quality	
time	stated in related background studies
geography	stated in related background studies
technology	stated in related background studies
Critical review performed	no
Evaluation	
Normalisation	no
Weighting	no
other methods	

Critical assessment (IKP D-31)

Goal description in short	• To develop criteria for environmental labelling (type 1) according to ISO14024 for windows (both frame and glass) including whole life cycle.	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• Comparison between windows with frames made of aluminium, wood, aluminium/wood and PVC • System boundaries are clearly defined in background study, and this study refers hereto for system boundaries. • Functional unit is clearly described.	
Life cycle phases	• All phases included • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	(X)
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Ecotoxicity and human toxicity not included as indicators. • All windows assumed recycled.	
Valuation of scope	• The scope is appropriate to fulfil the goal. Relevant criteria for ecolabeling can be delivered.	
Methodology	• No general statements, Criteria developed on basis of LCA and lifetime considerations	
Data requirements	• No general statements. • No discussion of completeness, representativeness precision level, consistency and reproducibility.	
Inventory	• Databases used: LCA information taken from background studies • Database from a Software System: GaBi Software • Gaps for important impacts: Ecotoxicity and human toxicity not included • No discussion on sensitivity of important parameters or of excluded parameters.	
Impact Assessment	• CML	
Environmental impacts included	• See valuation of scope	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of a full LCA according to ISO 14040 ff were not met. No impact assessment, no discussions on data quality, no critical review.	

The study comes to the following key conclusions:

- The study does not make any comparative conclusions based on single materials. The goal is to define criteria for each individual material to be included for evaluation in environmental labelling.

Overall comments are based on the data presented:

- The main impacts are in the production of the materials/window frames for all materials.
- The aluminium frame has the highest consumption of primary energy, and consequently global warming, acidification and nutrient enrichment. The other materials are almost equal in these impacts.
- Generation of summer smog is highest for wood/aluminium and wood frames and lowest for aluminium and PVC.

The study can not be used to draw conclusions on the comparison of different materials used in window frames, but may be used to weigh the importance of different processes and parameters that have to be analysed.

<u>The study explains to manufacturers</u>:

- An important factor for the windows is the achievable lifetime. A longer lifetime diminishes impacts from material supply, manufacturing and disposal of the window, because fewer replacements are needed over time. This is only valid if maintenance is less demanding in comparison to replacement, which is normally the case.
- Another important factor for the windows is the recyclability of its components and materials. Therefore, using highly recyclable materials for the windows is recommended.

- Easy installation of the window into the wall is preferable, as the more complicated it is, the more time and money it requires.
- During the window frame lifetime, ease of maintenance and repair as well as endurance of insulation capability and tight fittings are important to maintain from an environmental point of view.
- Information for the user is important. The user should know how to perform proper maintenance and how to use the window in the least demanding manner.

It seems to be obvious that the user has a huge influence on the performance of the window over its lifetime. Nevertheless, most studies do not include the influence of the user on the overall performance of the window.

- The use of Calcium/Zinc stabilisers is recommended.

<u>The study explains to users (Inhabitants of houses)</u>:

- Ensure proper maintenance to keep heat shield functions intact.

<u>The study explains to third parties</u>:

- Proper care and use of the window during the use phase (see above) is of utmost importance for minimizing its life cycle impacts.

Hence, the quality of the whole window system is of more importance, than a certain material choice.

Table 5-6 summarises the analysed impacts:

Table 5-6: Summary of the analysed impacts of IKP D-31

IKP D-31	**Wood/aluminium**	**Aluminium**	**Wood**	**PVC**	**Impacts**
Production	Medium	Highest, 60-70% higher than wood/alu. and PVC	Lowest, half of PVC and wood/alu.	Medium, equal to wood/alu.	Total primary energy
	Medium	Highest, twice the impact of wood/alu.	Lowest, half of PVC and wood/alu.	Medium, equal to wood/alu.	Global warming
	Medium	Highest, approx. 50% higher than other three	Medium, equal to wood/alu.	Medium, equal to wood/alu.	Acidification
	Medium	Highest, approx. 50-100% higher than other three	Medium, equal to wood/alu.	Medium, equal to wood/alu.	Nutrient enrichment
	Highest, more than double of alu. and PVC	Lowest	Highest, more than double of alu. and PVC, equal to wood/alu.	Lowest, equal to alu.	Photochemical ozone formation
Use	Of overall low importance	Of overall low importance	Of overall low importance	Of overall low importance	
Disposal (note all impacts are negative/crediting)	Medium	Highest	Low	Low	Total primary energy
	Medium	Highest	Low	Low	Global warming
	Low	Important	Negligible	Low	Acidification
	Low	Important	Negligible	Low	Nutrient enrichment
	Low	Low	Negligible	Low	Photochemical ozone formation

LCA of windows (PVC, aluminium, wood) (IKP AT-10)

Documentation sheet (IKP AT-10)

Kind of report	Summary report
Title	Ökologische Betrachtung von Fenstern aus verschiedenen Werkstoffen
Scope of investigation	LCA of windows (PVC, aluminium, wood)
Year of publication	1997
Ref. year(s) of assessment	
Institution or Company	Forschungsinstitut für Chemie und Umwelt TU Wien, Getreidemarkt 9, A-1060 Wien
Contractor/ Address	Amt der NÖ Landesregierung, Abteilung Umweltrecht, Landhausplatz 1, Haus 16, A-3109 St. Pölten, Austria
Authors	
Availability/Publisher	Amt der NÖ Landesregierung, Abteilung Umweltrecht, Landhausplatz 1, Haus 16, A-3109 St. Pölten, Austria
ISBN	-
Keywords	windows, PVC, aluminium, wood, LCA, CML, method of the critical volume
Life cycle phases Qualitative/Quantitative	see table below
Comparison with alternatives	Windows made of PVC / wood / aluminium
Reported data	LCA
Short description of the study	The study presents LCA results regarding windows made of different materials – PVC, aluminium and wood. The results of the inventory analysis are evaluated according to the CML method and the method of the critical volume.
Expert judgement	see table below
Comments related to further assessment	see table below

Life cycle phases Qualitative/Quantitative:

Production phase	**X**	**Use phase**	**X**	**End of life**	**X**
Qualitative		Qualitative		Qualitative	
Quantitative	X	Quantitative	X	Quantitative	X

Expert judgement:

Brochure-like		Scientific-like	X
Selected/limited impacts		Main/high variety of impacts	X
Generic data/literature data	80%	Specific/own/new data	20%

Comments related to further assessment:

Initiator		**LCA**	
	Industry		PVC/competitor material
X	Academia		part of PVC compound
	Government		material PVC/comp. comparison
	NGO		PVC/competitor application
		X	application PVC/comp. comparison
			Other than LCA

Comment: Suggested for **systematic characterisation**

Systematic characterisation (IKP AT-10)

Overall frame of study	
ISO 14040 ff	(X)
Code of practice	no
Other	no
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	windows
Functional unit	one window
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	mass/energy
System Expansion	not specified
Substitution	not specified
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	X
other:	critical loads
Data quality	
time	1997
geography	Austria
technology	average
Critical review performed	not specified
Evaluation	
Normalisation	not specified
Weighting	not specified
other methods	not specified

Critical Assessment (IKP AT-10)

Description of goals	• Identification of the main environmental effects of a window's life cycle. • Window size: 1,23 x 1,48 m • Considered materials: Aluminium, PVC, wood	
Valuation of the goal	• The goal is sufficiently described.	
Scope of study	• Life cycle assessment of windows made of aluminium, wood or PVC. • The necessary data is collected together with window manufacturers and additional data is taken form literature • Life time: 30 years	
Life cycle phases	• Production, including raw material extraction, processing, transports and the window production • Use phase • End-of-life phase with recycling and disposal	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Expenses of infrastructure facilities are not analysed. • Impacts and credits due to use of secondary material and residual material are not modelled. • The end of life is covered for all materials. • Materials with minor relevance are neglected • Not quantifiable values are not considered (e.g. social aspects). • Glass is NOT considered	
Valuation of scope	• The scope is appropriate to fulfil the goal	
Methodology	• Use of a special methodology ("card-index-methodology")	
Data requirements	• Data requirements are not stated in detail • Data sources are specified and described in detail • Precision level, completeness, consistency and reproducibility are not stated.	
Inventory	• Important topics of LCI model are discussed. • Sensitivity of inventory parameters is discussed. • No gaps in important impacts • Literature data from different sources (BUWAL 1991, APME 1993/1994, GWW 1994, ETH 1995, BmfwA 1993/1994, EEA 1996)	
Impact Assessment	• CML methodology and critical loads methodology • The assessment methodology is not fully in line with ISO 14042. The study was performed before the publication of the standard.	
Environmental impacts included	• CML impacts (raw materials, global warming, ozone depletion, human- and eco-toxicity, photochemical ozone creation, acidification, eutrophication • Critical loads (air and water)	
Weighting of environmental parameters	• No weighting is performed	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff are met	

The study comes to the following key conclusions:

- Emissions from aluminium and PVC window frame production are mainly indirect (resulting from upstream processes from material and energy production) and from wood window frames are mainly direct (from the window production itself).
- The contribution of distribution (transportation) to the overall environmental profile is low
- For the aluminium frame, the main emissions are due to aluminium production. To reduce emissions, a higher share of recycled (secondary) material is necessary (the study assumes the use of 85% secondary aluminium).

This 85% recycled aluminium content scenario is rather high (or optimistic) compared to the amount of recycled aluminium used in the average production of aluminium frames, but possible. Higher than average recycled aluminium content would be difficult to achieve, but as no credits are given for the use of secondary material, the modelling of environmental impact seems appropriate. Due to the shorter life span of (only) 30 years, compared to the studies IKP D-6 and D-31 with 40 years, the impact of the use phase within the whole life cycle is smaller. The impact of providing the needed energy due to the heat losses through the window is not modelled (heating energy supply via e.g. gas, oil and the respective emissions).

- The environmental effects of PVC windows result mainly from the production of PVC-granulate and of steel parts (used as a reinforcement structure in the frame). Higher recycling rates for PVC and steel reduce the emissions (in the study a recycling rate of 70 % is assumed for PVC).

The recycling rate of 70% is not unrealistic for the near future, but is not representative of current average rates.

- The environmental effects from the production of wooden window frames are lower than from its competitors. Significant environmental effects result from raw material demand (renewable resources), organic solvents, chemical oxygen demand and wastes.

Based on the experience of the project team, the study's conclusion is correct for Global Warming Potential (GWP), primary energy from non-renewable resources and municipal waste masses. For Eutrophication Potential (EP) the values of PVC and wood window frames are about the same. For Acidification Potential (AP), Photochemical Ozone Creation Potential (POCP) and hazardous waste the wood windows results in a higher impact (compare e.g. Table 5-4, but keep in mind that this table shows production, use and recycling)

- The use phase dominates the life cycle, contributing 50-95% of all impacts on average. The most relevant factor in the use phase is heat loss. Required heat is produced via natural gas and fuel oil heating.

<u>The study explains to manufacturers</u>:

- Increasing recycling rates can help to reduce emissions significantly. Also, increasing window life time reduces the overall life cycle impacts.

The use of recycled material can substitute primary material and the increase of window life time reduces the frequency of replacements. However, this is only valid if required maintenance contributes little to life cycle impacts.

<u>The study explains to users</u>:

- High quality windows with low heat losses help to save energy.

The (environmental) potentials of high quality windows are high to our knowledge. Therefore, we recommended that the available materials be used in the most innovative ways, by exploiting their individual technical and environmental strengths.

<u>The study explains to third parties</u>:

- The boundary conditions of LCA studies significantly influence the overall results. Sensitivity analyses help to identify these influences.

If the results are dominated only by the boundary conditions, the chosen system boundaries may be inappropriate, as significant aspects may not be included in the core analysis.

Table 5-7 summarises the analysed impacts.

Table 5-7: **Summary of the analysed impacts of IKP AT-10**

IKP AT-10	**PVC window**	**Al window**	**Wood window**	**Impacts**
Production phase	Approx. 54 kg raw material consumption (23,7 % fossil fuels, 75,8 % minerals, 0,5 % renewable resources)	Approx. 49 kg raw material consumption (13,4 % fossil fuels, 86,6 % minerals, 0 % renewable resources)	Approx. 114 kg raw material consumption (4,4 % fossil fuels, 0 % minerals, 95,6 % renewable resources)	Raw material consumption
	1029 MJ/window	1978 MJ/window	181 MJ/window	Energy demand
	46 kg CO2-eq.	126 kg CO2-eq.	9 kg CO2-eq.	Global Warming Pot.
	267 g CxHy	236 g CxHy	88 g CxHy	Photochemical Oxidants Creation Pot.
	464 g	1075 g	40 g	Acidification Pot.
	42 g	34 g	5 g	Eutrophication Pot.
Use phase	10 733MJ/window (same use phase for all windows assumed)	10 733MJ/window (same use phase for all windows assumed)	10 733MJ/window (same use phase for all windows assumed)	Heat losses
Recycling	70 % material recycling	85 % material recycling	100 % thermal recycling	recycling rate

LCA comparison of eight window constructions in Switzerland (IKP CH-17)

Documentation sheet (IKP CH-17)

<table>
<tr><td>Kind of report</td><td>Book</td></tr>
<tr><td>Title</td><td>Ökologische Bewertung von Fensterkonstruktionen</td></tr>
<tr><td>Scope of investigation</td><td>LCA comparison of eight window constructions in Switzerland</td></tr>
<tr><td>Year of publication</td><td>1996</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1992 to 1995</td></tr>
<tr><td>Institution or Company</td><td>EMPA Eidgenössische Materialprüfungs- und Forschungsanstalt</td></tr>
<tr><td>Contractor/ Address</td><td>Schweizerische Zentrale für Fenster- und Fassadenbau (SZFF),
Postfach 213, 8953 Dietikon, Switzerland</td></tr>
<tr><td>Authors</td><td>Klaus Richter, Tina Künniger, Kaspar Brunner</td></tr>
<tr><td>Availability/Publisher</td><td>EMPA Eidgenössische Materialprüfungs- und Forschungsanstalt,
Überlandstr. 129, CH-8600 Dübendorf</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>window constructions, LCA, material comparison, Life Cycle</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
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</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison done between all alternatives</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>LCA with detailed data collection for eight compared window constructions (materials: aluminium, steel (hot zinc dipped and chromated), high-grade steel, bronze, wood/aluminium, wood, PVC). Numerous scenario analyses. Old data sources.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>20%</td><td>Specific/own/new data</td><td>80%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (IKP CH-17)

Overall frame of study	
ISO 14040 ff	x
Code of practice	
Other	
Goal, description of	
Application/use of results	x
Aim of study	x
Target group of study	x
Scope, description of	
main technical systems properly described	x
Function analysed	Window frames made of Al, steel, stainless steel, bronze, PVC and wood
Functional unit	1 window (1650x1300mm). Further details concerning the functional unit to dimension, physical attributes and construction are given
System boundaries include:	
materials	x
energy	x
production	x
use	x
disposal	x
recycling	x
transportation	x
Allocation (mass/energy/price/exergy)	mass
System Expansion	not reported
Substitution	not reported
Data categories described	
Primary energy consumption	x
Air emissions	not reported
Water emissions	not reported
Waste categories	x
Impacts	
Global warming	x
Acidification	x
Nutrient enrichment	x
Tropospheric Ozone Formation	x
Stratospheric Ozone Depletion	x
Toxicity, human	x
Toxicity, eco	x
other:	
Data quality	
time	1994
geography	Switzerland/Germany
technology	specific
Critical review performed	
Evaluation	
Normalisation	not reported
Weighting	not reported
other methods	

Critical Assessment (IKP CH-17)

Description of goals	• self-explanatory	
Valuation of the goal	• The goal is sufficiently described.	
Scope of study	• 1 window • 1650x1300mm • Further details concerning the functional unit to dimension, physical attributes and construction are given.	
Life cycle phases	• The whole life cycle	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Size of order is assumed to comprise of 20 windows: all cutting and input data calculations are based on this assumption. • Maintenance is just considered for the surface treatment – not of interest for the PVC windows.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• No information on allocations.	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are stated.	
Inventory	•	
Impact Assessment	• Heijungs et al. 1992: impact-oriented classification	
Environmental impacts included	• Global warming potential • Ozone depletion potential • Photochemical ozone creation potential • Acidification potential • Nutrification potential • Human toxicity potential • Terrestrial eco-toxicity potential • Primary energy demand • Waste categories	
Weighting of environmental parameters	• Not reported	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff are met.	

The study comes to the following key conclusions:

- By far the largest contributors to environmental impacts are the compensation for heat loss during the period of use, and the production of the structural window frame materials (as a result of the large quantitative proportion). Ecological improvements would result from frames with improved k-values (reduction of heat losses) and from narrow window frame structures.
- Scenarios with the maximum recycling and re-use rates have the lowest environmental effects (with all metals and with PVC). It is recommended that closed-loop recycling be implemented vigorously for all frame materials. Windows with metal and PVC frames could then achieve a comparable eco-profile to that of windows with indigenous pine wood frames. However, wood frames have distinct ecological weaknesses in the parameters of ‘human toxicity’ and ‘hazardous waste’, because of surface treatment.
- Ecological importance is given to the development of environmentally safe protective coatings for wood frames.
- The results show that there is no single material and no single structure which has clear advantages or clear drawbacks in all impact areas investigated.
- The highlighted scenarios show that even more favourable overall ecological evaluations can be achieved by skilled implementation of the options outlined for each of the window constructions examined.
- The authors state explicitly that a “material ban and usage bans have no objectively founded legitimisation”.

The PVC manufacturing data used in the study originates from 1994[20]. Since then, hydrocarbon emissions and energy requirements for the manufacture of PVC have decreased, in particular contributions to the acidification and nutrification potential. Thus, PVC material would emerge with even better results from a comparative life cycle assessment study on window frame structures under current conditions. Nevertheless, there have also been improvements in producing the other materials as well.

The study explains to manufacturers:

Ecological improvements should be directed towards the further reduction of heat losses through the frames and towards a narrower frame structure design. This is significant for PVC because the particularly good processibility of this material already enables, for example, narrow multi-chamber profiled frames which fulfil both of the aforementioned improvement parameters. Other ecological improvements can be achieved through PVC recycling.

The study explains to users:

From an ecological viewpoint each system has different strengths and weaknesses over its entire life cycle. In the use phase, wooden window frames tend to need more maintenance.

The study explains to third parties:

Window frames made from PVC prove themselves to be ecologically competitive in this study.

Table 5-8 summarises the analysed impacts:

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[20] This issue is of importance to other LCA's in this study as well. LCA's often only reflect past situations and are then not suited to show the development in a near or more distant future. This point should be borne in mind. If institutions publish and frequently update eco-profile data (e.g. like APME for polymers) these developments (e.g. that concerning PVC the modern membrane electrolysis plants are substituting older amalgam ones) can be taken into consideration, if adequate information on competing material is available as well.

Table 5-8: Summary of the analysed impacts of IKP CH-17

IKP CH-17	Al window	Steel window	Stainless steel	Non-ferrous metal	Wood - Al window	Wood window	PVC window	Potential Impacts
Production phase	Medium, wide range of GWP for different Al windows	Medium, medium range of GWP for different steel windows	High, medium range of GWP for different stainless steel windows	Highest contribution to GWP	Low, medium range of GWP for different wood-Al windows	Lowest, low range of GWP for different wood windows	Low, low range of GWP for different PVC windows	**Global Warming, GWP**
	Medium to high, very wide range of ODP for different Al windows	Medium, low to medium range of ODP for different steel windows	Highest, medium range of ODP for different stainless steel windows	Medium	Low, medium range of ODP for different wood-Al windows	Lowest, low range of GWP for different wood windows	Medium, low range of ODP for different PVC windows	**Ozone Depletion, ODP**
	Low	Low	Highest	Low	Low	Low	Low	**Acidification , AP**
	Low to medium, wide range of EP for different Al windows	Medium, medium range of EP for different steel windows	Highest, medium range of EP for different stainless steel windows	High	Low, medium range of EP for different wood-Al windows	Lowest, low range of EP for different wood windows	Low to medium, wide range of EP for different PVC windows	**Eutrophication, EP**
	Medium, wide range of POCP for different Al windows	Medium, medium range of POCP for different steel windows	Highest, medium range of POCP for different stainless steel windows	High	Low, medium range of POCP for different wood-Al windows	Lowest, low range of POCP for different wood windows	Medium, wide range of POCP for different PVC windows	**Photochemical Ozone Creation, POCP**
	Low to medium, wide range of HTP for different Al windows	Medium, medium range of HTP for different steel windows	Highest, medium range of HTP for different stainless steel windows	High	Low, medium range of HTP for different wood-Al windows	Lowest, low range of HTP for different wood windows	Low to medium, wide range of HTP for different PVC windows	**Human Toxicity, HTP**
	Medium to highest, very wide range of ATP for different Al windows	Medium, wide range of ATP for different steel windows	Medium, wide range of ATP for different stainless steel windows	Medium	Low to medium, medium range of ATP for different wood-Al windows	Lowest, low range of ATP for different wood windows	Low to medium, medium range of ATP for different PVC windows	**Aquatic Toxicity, ATP**
	Low to medium contribution to PE, wide range of PE for different Al windows	Medium contribution to PE, low range of PE for different steel windows	High contribution to PE, low range of PE for different stainless steel windows	Highest contribution to PE	Medium contribution to PE, low range of PE for different wood-Al windows	Lowest contribution to PE	Lowest contribution to PE, low range of PE for different PVC windows	**Primary Energy**
	Low to high, very wide range of hazardous waste for different Al windows	Highest, low range of hazardous waste for different steel windows	Lowest	Low	Medium to highest, wide range of hazardous waste for different wood-Al windows	Medium to highest, wide range of hazardous waste for different wood windows	Low to medium, wide range of hazardous waste for different PVC windows	**Hazardous waste**
Use phase	No statement	No statement	No statement	No statement	No statement	No statement	No statement	
Recycling	No statement	No statement	No statement	No statement	No statement	No statement	No statement	

Summary for Window Frames:

The principal competing materials in this market are PVC, wood and aluminium. Steel, stainless steel, wood/aluminium, ferrous metals and other polymers play a minor role.

Materials used for window frames have to fulfill quality aspects like mechanical stability and low thermal conductivity. A certain flexibility in the design is advantageous; however, flame resistance is mandatory for some applications. The use phase (function, maintenance demands and durability) is the most important part of the life cycle of windows. Therefore, the quality of the window frame structures is key to the optimisation of their life cycle. From a LCA perspective any further optimisation processes within the life cycle must be undertaken with respect to the use phase.

Design flexibility and low heat-transfer coefficients of PVC windows are possible. Steel inlays ensure mechanical stability. Windows made of other polymers must be made flame resistant by other means (e.g. adding halogenated substances). Unfortunately, only one study on window frames made of other polymers (PP) could be identified, which was not of comparable quality due to data and system boundary restrictions. Hence a quantitative comparison is not possible. However, it is believed that an addition of flame retardants will significantly influence the overall production impacts. Aluminium window frames and wooden window frames require no additional flame retardants.

Recycling offers the potential to save primary energy and materials for all window frames. These are especially important potentials for PVC and aluminium. The recycling of PVC and aluminium (and the use of secondary material) can significantly improve their environmental performance. Producers need to construct recycling systems (if not already existent), to be able to work with their own compounds of specific polymers to produce secondary PVC of a higher quality. Further improvement of the recycling and use of secondary materials seems possible and advantageous.

Maintenance related to painting does not apply to PVC and aluminium windows. Wooden windows need to be painted at certain intervals. No studies could be identified that analysed wooden windows treated with oil instead of coating/paint. But this is not expected to be a major gap. Oil, like the coatings, consists of hydrocarbons as well. Therefore, the major impact POCP (summer smog) may not be significantly better for oil. Furthermore, oil treated windows make up a smaller share of the market.

Lifetime of the product is an important parameter as well. Wood is a natural material and incorporates CO_2 from the atmosphere, but the natural production of wood and its harvesting causes environmental consequences (e.g. cultivating, harvesting, drying, transport) as well. There are few detailed forestry LCA models or studies of wood products to refer to. Single studies exist, but they do not sufficiently cover all aspects of forestry. Therefore, LCAs tend to underestimate the impacts of the wood and forestry industry, in comparison with the mostly well analysed important materials of “conventional” industry.

Most of the studies conclude that no material has advantages in all impact categories. Highest potentials for improvement are expected in the optimisation of the frame structures (e.g. lowering the specific heat loss, raising the amount of used secondary material or lowering the amount of material needed for the same function). This is an important result, as the improvement of the quality of the windows resulting from an easy maintenance schedule and good heat loss performance are the most relevant parameters in the life cycle.

Most interesting from the environmental optimisation point of view are optimisations of the complete constructions (synergy of different materials). Each material shows individual weaknesses and strengths. Hence, in complex parts like window frames, the optimisation of the structures (e.g. the synergistic use of different materials) contributes the most to overall environmental optimisation.

No significant gaps were identified for windows. All principal competing materials within the application of windows are sufficiently analysed. While each study has a specific “Goal and Scope” the key conclusions are comparable and not usually conflictive.

Further studies should be undertaken to improve new designs before they actually enter the market. The goal should be related to specific questions on or details of specific structures. This can potentially lead to improved optimisation of structures. Further studies concerning general aspects and retrospective comparisons of windows are not recommended, as sufficient information about the life cycle of standard windows is available.

5.1.2 Flexible sheets and foils: Flooring

The principal competing materials of PVC within flooring are linoleum and carpet for soft applications, and tiles and wooden flooring for hard applications.

Sustainability assessment of PVC floor coverings (IKP AT-2)

Documentation sheet (IKP AT-2)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Zur Nachhaltigkeit von Fußbodenbelägen</td></tr>
<tr><td>Scope of investigation</td><td>Sustainability assessment of PVC floor coverings</td></tr>
<tr><td>Year of publication</td><td>2002</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>GUA - Gesellschaft für umfassende Analysen GmbH,
Sechshauserstr. 83, A-1150 Wien, Austria</td></tr>
<tr><td>Contractor/ Address</td><td>API PVC und Umweltberatung GmbH, Dorotheergasse 6-8/14, A-1010 Wien, Austria</td></tr>
<tr><td>Authors</td><td>Evelin Milleret, Harald Pilz</td></tr>
<tr><td>Availability/Publisher</td><td>GUA - Gesellschaft für umfassende Analysen GmbH,
Sechshauserstr. 83, A-1150 Wien, Austria</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>sustainability, “Welfare Cost-Benefit Analysis”, PVC, floor covering</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Information about compared alternative floor coverings anonymized</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Sustainability assessment of products considered as an example floor coverings. The assessment comprises all relevant environmental, economic and social effects regarding the whole life cycle. The study focuses on the relevant impacts of floor coverings – esp. PVC floor coverings - in terms of sustainability.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>60%</td><td>Specific/own/new data</td><td>40%</td></tr>
</table>
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<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (IKP AT-2)

Overall frame of study	
ISO 14040 ff	(X)
Code of practice	no
Other	sustainability
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	flooring
Functional unit	Flooring for 1 schoolhouse (representative for a public building)
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	not specified
System Expansion	not specified
Substitution	not specified
Data categories described	all categories aggregated to prevention costs
Primary energy consumption	not specified in detail
Air emissions	not specified in detail
Water emissions	not specified in detail
Waste categories	not specified in detail
Impacts	aggregated to environmental costs
Global warming	not specified in detail
Acidification	not specified in detail
Nutrient enrichment	not specified in detail
Tropospheric Ozone Formation	not specified in detail
Stratospheric Ozone Depletion	not specified in detail
Toxicity, human	not specified in detail
Toxicity, eco	not specified in detail
other:	environmental costs
Data quality	
time	2002
geography	Germany
technology	average
Critical review performed	not specified
Evaluation	
Normalisation	no
Weighting	no
other methods	Welfare Cost-Benefit Analysis

Critical Assessment: Zur Nachhaltigkeit von Fußbodenbelägen (IKP-AT-2)

Description of goals	• Sustainability comparison of alternative flooring materials. The main influencing factors on sustainability evaluation of flooring materials are analysed, taking as an example PVC and linoleum, to prepare a basis for further sustainability evaluations of other flooring material	
Valuation of the goal	• The goal is briefly described in the introduction chapter of the study.	
Scope of study	• Life cycle analysis of flooring material from “cradle to grave” • Sustainability comparison of flooring materials	
Life cycle phases	• Material production • Build in • Use phase • End-of-life phase (material recycling, waste incineration, disposal)	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Laying is assumed to be same for all considered materials • Dioxin production in waste incineration is not coupled to the chlorine input. It is assumed that the PVC share in the municipal waste fraction is relatively constant and average emissions from waste incineration are assumed • Detergents are not considered in detail • Other assumptions are not reported in detail	
Valuation of scope	• The scope is appropriate to fulfil the goal	
Methodology	• The used methodology is described in detail. • “Welfare Cost-Benefit” Analysis has been used	
Data requirements	• No explanation of data requirements is stated	
Inventory	• The inventory data of emissions to air and water is listed in a table • For further analysis, only aggregated inventory data and monetary inventory data is available	
Impact Assessment	• The environmental impacts are shown as aggregated environmental costs • A detailed analysis of different impact categories is not given	
Environmental impacts included	• Environmental costs	
Weighting of environmental parameters	• A weighting is done by connecting the inventory data to environmental cost data in the Welfare Cost-Benefit Analysis.	
Overall ISO 14040 ff requirements	• ISO 14040 ff requirements are not exactly met in every detail • The methodology requirements mentioned were to get a result of the sustainability comparison of different flooring materials. Therefore, the ISO 14040 methodology was not taken as template for the study.	

The study comes to the following key conclusions:

- The goal was to assess the overall sustainability of comparative flooring materials and to establish a methodology for further comparisons. This goal was not fully accomplished. Further studies are necessary to form a better database, to consider more alternative materials, and to perform more sensitivity analyses.
- Environmental costs account for less than 1 % of the total costs.
- High quality materials are of higher costs in the production phase, but of lower costs in the overall life cycle.
- The use phase, including cleaning, accounts for approximately 50% of total costs in the case of high quality materials, and approximately 75% in the case of low quality materials.

The study explains to manufacturers:
Optimising potentials of flooring materials lie in the fields of:

- system optimisation for the interaction of flooring materials and detergents.
- optimisation of the life time by improving quality (easier cleaning and optical stability).
- optimisation of economic and ecologic aspects e.g. by developing PVC flooring with a high share of filler material and a very dense surface.

The study explains to users:

- The use phase, and thereby, the use of detergents, is very important to life cycle sustainability. User behaviour should include the purchase of high quality flooring materials with lower cleaning expenses, and the purchase of more environmentally friendly detergents.

The study explains to third parties:

- The methodology for sustainability analyses is not yet fully established, therefore, further studies are necessary. The outcomes of the monetary sustainability analysis are, that the use phase dominates, high quality flooring materials with low production cost result in the lowest overall costs and that the costs for environmental effects and waste treatment are extremely low (approx. 1 % of the total life cycle costs). The comparison of different quality classes shows advantages of high-quality products as a result of clearly lower expenses in the use phase and only small additional expenditures in the production phase. The comparison of alternative materials (PVC and linoleum) in the same quality class does not show significant differences.

Table 5-9 summarises the analysed impacts:

Table 5-9: Summary of the analysed impacts of IKP AT-2

IKP AT-2	High quality PVC flooring	Low quality PVC flooring	High quality alternative flooring	Low quality alternative flooring	Impact
Production phase	Average portion of environmental production costs: 0,70 %	Average portion of environmental production costs: 0,33 %	Average portion of environmental production costs: 0,17 %	Average portion of environmental production costs: 0,11 %	Aggregated environmental costs
	Average portion of other production costs: 47 %	Average portion of other production costs: 24 %	Average portion of other production costs: 49 %	Average portion of other production costs: 26 %	Aggregated environmental costs
Use phase	Average portion of environmental use phase costs: 0,01 %	Average portion of environmental use phase costs: 0,30 %	Average portion of environmental use phase costs: 0,01 %	Average portion of environmental use phase costs: 0,31 %	Aggregated environmental costs
	Average portion of other use phase costs:50 %	Average portion of other use phase costs:74 %	Average portion of other use phase costs:50 %	Average portion of other use phase costs:73 %	Aggregated environmental costs
Recycling	Average portion of environmental recycling costs: 0,16 %	Average portion of environmental recycling costs: 0,12 %	Average portion of environmental recycling costs: 0,05 %	Average portion of environmental recycling costs: 0,03 %	Aggregated environmental costs
	Average portion of other recycling costs: 2 %	Average portion of other recycling costs: 2 %	Average portion of other recycling costs: 1 %	Average portion of other recycling costs: 1 %	Aggregated environmental costs

Life Cycle assessment of flooring materials (IPU 000.0013)

Documentation sheet (IPU 000.0013)

<table>
<tr><td>Kind of report</td><td>Article</td></tr>
<tr><td>Title</td><td>Life cycle assessment of flooring materials: Case study</td></tr>
<tr><td>Scope of investigation</td><td>Three types of floor covering. One type contains PVC.</td></tr>
<tr><td>Year of publication</td><td>1997</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>Unknown</td></tr>
<tr><td>Institution or Company</td><td>Technical Environmental Planning, Chalmers University of Technology, S-412 96, Gothenburg, Sweden.</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Jönsson, Å., Tillman, A-M., Svensson, T.</td></tr>
<tr><td>Availability/Publisher</td><td>Building and Environment, Vol. 32, No. 3 (1997)</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>Lifecycle assessment, Floor coverings, Environment.</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison of three types of floor coverings: Linoleum, Vinyl flooring (with PVC) and solid wood flooring.</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Standard LCA on three types of floor covering</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>80%</td><td>Specific/own/new data</td><td>20%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (IPU 000.0013)

Overall frame of study	
ISO 14040 ff	
Code of practice	X
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Flooring of building
Functional unit	1m^2 of floor during 1 year of operation
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	assumed no recycling
transportation	X
Allocation (mass/energy/price/exergy)	mass and price
System Expansion	
Substitution	
Data categories described	
Primary energy consumption	only secondary energy considered
Air emissions	not described
Water emissions	not described
Waste categories	X
Impacts	
Global warming	
Acidification	
Nutrient enrichment	
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	
Data quality	
time	not stated
geography	Sweden
technology	not stated
Critical review performed	not reported
Evaluation	
Normalisation	-
Weighting	-
other methods	EPS, Environmental theme method and Ecological scarcity method

Critical Assessment (IPU 000.0013)

Goal description in short	• To make a specific comparison of floor covering materials • To develop a methodology for LCA of building materials	
Valuation of the goal	• The goal is sufficiently and clearly described in background report.	
Scope of study	• Somewhat adequate system boundaries - Electricity production excluded due to lack of data. - Excluded similar adhesives from linoleum and vinyl flooring. However, conservative against wood flooring which still turns out best. - Cleaning and maintenance excluded. Assumed to be independent of floor type when only considering domestic use • Additives in very small amounts excluded. • Only floor covering. Not including function of carrying weight • All materials assumed incinerated with energy recovery – also PVC material. • Duration: 1 year	
Life cycle phases	• Cleaning and maintenance excluded. Assumed to be independent of floor type when considering only domestic use • Conclusions can be drawn from the included LCA stages. However, the effect of not including production of electricity is unclear – see scope above. • The results are not split up in life cycle phases, i.e. not possible to see most important phases.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	(X)
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• See “scope of study”. • Unclear power mix from article • All material assumed incinerated with energy recovery as no data is available on landfilling. Dioxin formation excluded due to lack of data certainty. • Assumptions are clear and understandable, but the influence on the conclusion from the article it is not clear.	
Valuation of scope	• The scope is appropriate to fulfil the goal of a comparative assessment. • Improvement options of LCA found but no further comments on the methodology development.	
Methodology	• Allocation mentioned as *“…in proportion to the physical parameter most closely reflecting the economic value, which in most cases resulted in weight being used”*	
Data requirements	• The scenarios describe a Swedish situation and the data are mentioned as being applicable to the average situation. • Other data on precision level, completeness, representativeness, consistency and reproducibility are not found.	
Inventory	• No discussions on LCI model. • Sensitivity of inventory parameters are not discussed, only scenario analyses. • Data used: Production data from specific producers. APME 1998 • Database used for generic data: Unknown • Database from a Software System: LCAIT • Lack of data on electricity production is an important gap.	
Impact Assessment	• Impact assessment is carried out via three different methods; - EPS, - CML Environmental Theme method adapted to Swedish environmental policy objects - Ecological scarcity method adapted to Swedish environmental policy objects. • Methodologies of assessment are not transparent. Probably does not agree with ISO 14042.	
Environmental impacts included	• Only total scores from three methods, and calculated relative to flooring material with lowest impacts. • The included impact categories are appropriate to fulfil the goal of the comparative assessment of flooring materials (as one solution scores lowest or almost lowest in all methods) but not for methodological considerations.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• Work is carried out according to “SETAC Code of Practice”	

The shortage of data is considered greatest for the production of long distance raw materials for linoleum such as resin, jute and cork. In the case of vinyl flooring, environmental loads were omitted for a number of additives. It was generally more difficult to obtain data for processes taking place outside of Sweden than for processes taking place in Sweden.

The study comes to the following key conclusions:

- Based on both the inventory data and the three impact assessment methods, the solution with the lowest environmental impacts is wooden flooring.
- No clear distinction between vinyl flooring and linoleum is possible based on the quantitative inventory results. However, when taking into account the assessment of environmentally hazardous substances linoleum is probably preferable.
- Conclusions may not apply to the use of floor covering for professional use, as maintenance can not be assumed similar in this case. The results will probably look more advantageous for PVC, as maintenance is more frequently required in the case of professional use. This is important to look into for future work.
- More research is needed on the impacts of cleaning, care and maintenance during the use phase of the floor.

<u>The study explains to manufacturers</u>:

- The lifetime of the product is important. Providing better data related to expected lifetime can improve the environmental profile of the product.

<u>The study explains to users</u>:

- Wooden flooring has the lowest environmental impacts. The daily maintenance processes may be major factors in the environmental profile of a floor.

<u>The study explains to third parties</u>:

- Lifetime length and daily maintenance are governing factors in the assessment of flooring.

Table 5-10 summarises the analysed impacts. No explicit distinction between life cycle stages is made; thus, results cover only the whole life cycle of flooring. Furthermore, the used impact methods are “end-point oriented[21]” and, therefore, more detailed "mid-point related[21]" results such as global warming etc. are not noted in the report.

Table 5-10: Summary of the analysed impacts of IPU 0013

IPU 0013	Linoleum flooring	Vinyl flooring	Solid wood flooring	Impacts
Total Life cycle	Higher than wood and slightly lower than PVC	Higher than wood, but maintenance not sufficiently modelled	Lower, but probably due to simple maintenance model	endpoints

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[21] ”End points“ are safe guard subjects e.g. ”human health“ and ”ecosystem health“. The mid-points are the accepted environmental impact potentials. Methods that use ”End points“ aggregate the various environmental impact potentials further, leaving fewer indicators, which are easier to interpret. But the “End points“ include a much higher uncertainty, due to assumptions in the existing models.

Maintenance of floors (one containing PVC) (IPU 056.0042)

Documentation sheet (IPU 056.0042)

Kind of report	Article – submitted to International Journal of Life Cycle Assessment
Title	On the significance of the usage phase in a LCA -Application on floor coverings
Scope of investigation	Maintenance of floors (one containing PVC)
Year of publication	Not yet published - submitted to International Journal of Life Cycle Assessment
Ref. year(s) of assessment	1999
Institution or Company	KTH Dep. of Building Sciences, Div. of building materials, Kunglika Tekniska Högskolan, 100 44 Stockholm, Sweden
Contractor/ Address	
Authors	Paulsen, J.
Availability/Publisher	KTH Dep. of Building Sciences, Div. of building materials, Kunglika Tekniska Högskolan, 100 44 Stockholm, Sweden
ISBN	
Keywords	Maintenance of floors, LCA use phase

Life cycle phases

Qualitative/Quantitative

Production phase		**Use phase**	**X**	**End of life**	
Qualitative		Qualitative		Qualitative	
Quantitative		Quantitative	X	Quantitative	

Comparison with alternatives	Linoleum floors
Reported data	LCA
Short description of the study	LCA field study on maintenance and cleaning of floors in a professional context

Expert judgement

Brochure-like		Scientific-like	X
Overall/screening		Profound	X
Selected/limited impacts		Main/high variety of impacts	X
Generic data/literature data	30%	Specific/own/new data	70%

Comments related to further assessment

Initiator		**LCA**	
	Industry		PVC/competitor material
X	Academia		part of PVC compound
	Government		material PVC/comp. comparison
	NGO		PVC/competitor application
		X	application PVC/comp. comparison
			Other than LCA

Comment: Suggested for **systematic characterisation**

Systematic characterisation (IPU 056.0042)

Overall frame of study	
ISO 14040 ff	x
Code of practice	
Other	
Goal, description of	
Application/use of results	x
Aim of study	x
Target group of study	
Scope, description of	
main technical systems properly described	x
Function analysed	Floor covering
Functional unit	1 m^2 of floor covering in whole lifetime
System boundaries include:	
materials	(x)
energy	x
production	x
use	x
disposal	
recycling	
transportation	(x)
Allocation (mass/energy/price/exergy)	*performed but method unknown*
System Expansion	no
Substitution	no
Data categories described	
Primary energy consumption	x
Air emissions	
Water emissions	x
Waste categories	
Impacts	
Global warming	x
Acidification	x
Nutrient enrichment	x
Tropospheric Ozone Formation	x
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	Only as grams of chemical
other:	Water, primary energy and waste
Data quality	
time	No specific statement, 1995 and before
geography	No specific statement, probably Sweden
technology	No specific statement, probably Swedish average
Critical review performed	no
Evaluation	
Normalisation	no
Weighting	no
other methods	

Critical assessment (IPU 056.0042)

Goal description in short	• To develop an LCA method for building products, focusing on the use stage. • To assess whether the use phase of floor covering can be omitted from overall life cycle analysis. • To assess whether the choice of floor covering has an influence on the use stage.	
Valuation of the goal	• The goal of the study is not clearly stated.	
Scope of study	• System boundaries are not totally clear. • Functional unit is maintenance of 1m^2 of floor covering during its service life. • Several other parameters have to be chosen to give final functional unit (type and frequency of frequent maintenance, type and frequency of periodic maintenance etc.). This results in analyses covering only selected scenarios.	
Life cycle phases	• Main focus is use stage. • Cut-offs in material and manufacturing • Several transports are neglected. • Disposal not included • Conclusions related to the goal can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	X
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion (considering the goal of the study)	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• No emissions from electricity consumption as it is produced from hydropower and nuclear power plants. • No knowledge on fuel type for heating of water, hence no emissions are included. • Production of maintenance machines are excluded • Disposal excluded.	
Valuation of scope	• The scope is appropriate to fulfil the goal. Further development is however appropriate.	
Methodology	• Mentioned that allocation is performed but not clear how. • Swedish average electricity mix	
Data requirements	• Discussion of completeness, representativeness. • No statements on precision level, consistency and reproducibility. However, data use and assumptions are clear and transparent.	
Inventory	• No general considerations on sensitivity and uncertainty. • Through various scenarios the use stage parameters are assessed. • Database used: APME for plastic components. • Database from a Software System: Not used • Gaps of important impacts: Ecotoxicity is only included in g of compound used. Furthermore, no consideration on re-distribution after use. • Human toxicity not included.	
Impact Assessment	• Nordic guideline on LCA • The methodology of assessment does agree with ISO 14042. However, impact categories are excluded due to lack of data (e.g. human toxicity and ecotoxicity)	
Environmental impacts included	• Human and ecotoxicity (except mass of chemical) is not included • All other relevant impacts are included.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. No third-party report is included although consensus discussions are performed with relevant stakeholders. No comments from here mentioned.	

The study concludes that although a limited number of “average” product systems (36 systems) can be constructed, three parameters are necessary:

- Frequency of periodic maintenance;
- Frequency of regular maintenance;
- Expected service life.

This means that an actual assessment can not be performed before the building context is known.

This is a very important conclusion. The building context determines which material has the most adequate technical properties to perform best from an environmental viewpoint.

The study comes to the following key conclusions*:*

- The environmental impact of floor covering maintenance is important and is sometimes associated with larger impacts than the production of floors. The frequent practice of leaving out the use phase (including maintenance) when assessing floor covering is not true here.
- The type of floor covering has an influence on the impacts of maintenance. In general, the impacts for linoleum are larger than those for PVC in periodical maintenance. However, the best choice of floor covering depends on the application context.
- Significant data gaps still exist. The handling of chemical substances is only modelled on a “per kg dry substance” basis. The varying toxicity, and varying exposure routes etc. of chemicals are, thus, not accounted for.

<u>The study explains to manufacturers</u>:

- More data is needed. Extension of service life of floors with low maintenance requirements can significantly lower life cycle impacts.

<u>The study explains to users</u>:

- Maintenance has a significant impact on the overall life cycle of the flooring.

<u>The study explains to third parties</u>:

- The general practice of not including maintenance in the use stage when comparing materials, and especially building materials, is probably not valid.

Table 5-11 summarises the analysed impacts. Only the use phase is analysed.

Table 5-11: Summary of the analysed impacts of IPU 0042

IPU 0042	Linoleum flooring	PVC flooring	Impacts
Production phase	Not analysed	Not analysed	
Use phase	In general the impacts from linoleum are larger than for PVC in use phase. However, very dependent on application context, see description in summary below critical assessment scheme.	And vice versa	Various environmental impacts modelled but explicitly presented
Recycling	Not analysed	Not analysed	

Summary for Flooring:

For soft applications in flooring, carpet, PVC and linoleum are the main materials. For the respective hard applications tiles, natural stone, laminate and wood are widely used.

One comparative study focuses on the use phase (maintenance). It concludes that the use phase can influence the overall result even more than the production phase and that PVC seems to have advantages from this point of view. This conclusion is also supported by economic assessments.

Focusing on the use phase, the main influencing parameters are dependent on the type of building and use patterns. Service life and frequency of periodic and regular maintenance are the most important parameters. Therefore, no general recommendation can be given.

One comparative study concludes that wood might be the most favourable material, but did not take into account maintenance or servicing. Linoleum and PVC seem to have comparable environmental performance in the production phase, when comparing the same quality level of products.

The production of the materials and of the sheets is influential for environmental results, but the application may influence the results more significantly. Hence, studies that neglect floor laying and possible maintenance or service of the applications are inconclusive.

Existing comparative studies agree that the recycling of the materials has a beneficial influence on the overall performance of the products.

For flooring applications, PVC is currently being discussed from the view-point of indoor air quality. This aspect is not covered in state-of-the-art life cycle assessments. The relevance of this impact should be analysed in future assessments not only for PVC, but for possible alternative materials as well.

The most favourable environmental optimisation approach seems to be the increase in product quality, which can decrease the impacts during the use phase through reduced maintenance or servicing requirements. However, actual use phase length of flooring is often shorter than the possible lifetime length for fashion reasons.

Further studies should include maintenance or servicing and should take into account that significant differences in quality (durability/resistance) between products exist. Including these factors can influence the overall result of a LCA.

Significant gaps relative to flooring material can be identified in the analysis of carpet. Carpet has a major market share and is, therefore, an effective material to focus on for optimisations within this application.

Although a study on maintenance was identified, a second gap within this application is further detailed information about maintenance and cleaning processes. The significance of the use phase (incl. maintenance and cleaning) of durable products is most often not negligible and often even high.

Little is known about the performance and relevance of the use phases of the various options. The carpet demands electricity and filter materials due to vacuum cleaning and produces solid waste. In comparison, many hard applications require water and chemicals for wet cleaning and produce waste water. A comprehensive analysis of this subject is recommended from a LCA point of view.

5.1.3 Flexible sheets and foils: Roofing

The principal competing materials of PVC within roofing applications are Bituminous sheets and Polyethylene Sheets. Polyisobutylene, EPDM and EVA play a less important role.

Ecological evaluation of flat-roof systems (IPU 000.0016)

Documentation sheet (IPU 000.0016)

<table>
<tr><td>Kind of report</td><td>Company report for internal optimisation</td></tr>
<tr><td>Title</td><td>Ecological evaluation of flat roof systems</td></tr>
<tr><td>Scope of investigation</td><td>Flat roof systems.</td></tr>
<tr><td>Year of publication</td><td>1999</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>Unknown</td></tr>
<tr><td>Institution or Company</td><td>Carbotech AG</td></tr>
<tr><td>Contractor/ Address</td><td>Sarnafil International AG, Sarnen</td></tr>
<tr><td>Authors</td><td>Dr. Dinkel, F., Dr. Waldeck, B.</td></tr>
<tr><td>Availability/Publisher</td><td>confidential report</td></tr>
<tr><td>ISBN</td><td></td></tr>
<tr><td>Keywords</td><td>Flat roof systems</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td><table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th></th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td>X</td><td>Qualitative</td><td></td><td>Qualitative</td><td>X</td></tr>
<tr><td>Quantitative</td><td></td><td>Quantitative</td><td></td><td>Quantitative</td><td></td></tr>
</table></td></tr>
<tr><td>Comparison with alternatives</td><td>Bitumen, glass fibre</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>LCA-like report, but figures/graphs etc. given relative to “sustainability goals”. Not transparent</td></tr>
<tr><td>Expert judgement</td><td><table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td>X</td><td>Profound</td><td></td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>80%</td><td>Specific/own/new data</td><td>20%</td></tr>
</table></td></tr>
<tr><td>Comments related to further assessment</td><td><table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for **systematic characterisation**</td></tr>
</table>

Systematic Characterisation (IPU 000.0016)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	Requirements for sustainability
Goal, description of	
Application/use of results	
Aim of study	X
Target group of study	
Scope, description of	
main technical systems properly described	
Function analysed	Flat roof systems
Functional unit	1 m^2 of flat roof for 25 years
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	unknown
System Expansion	no
Substitution	no
Data categories described	
Primary energy consumption	not described
Air emissions	yes
Water emissions	yes
Waste categories	yes
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	Resources
Data quality	
time	Not stated
geography	Manufacturers’ data from Europe
technology	Not stated, but probably present average
Critical review performed	
Evaluation	
Normalisation	No
Weighting	No
other methods	Environmental Impact Potential and Eco-indicator 95

Critical Assessment (IPU 000.0016)

Goal description in short	• To identify potential for improvement • To compare with other solutions on the market	
Valuation of the goal	• The objective/goal of the study is clearly stated	
Scope of study	• System boundaries for PVC and other materials are clear. "*All significant stages back to raw material production and related emissions are calculated*". Elaborated further in appendix and seems sufficient. • Functional unit is 1m^2 of flat roof for 25 years. • 8 different solutions to flat roof included • Eco and human toxicity included in qualitative assessment of materials, which is not very transparent	
Life cycle phases	• Use phase excluded for comparison since products deliver the same service in the use phase. Otherwise all phases included • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	X
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Products deliver the same service in use phase • In general, not very thorough description, i.e. important assumptions might be hidden. • Production and use in countries with high safety standards, hence accidents not included.	
Valuation of scope	• The scope is somewhat appropriate to fulfil the goal as toxicity is included qualitatively.	
Methodology	• No information on allocations. • No information on power mix	
Data requirements	• No description of precision level, completeness, representativeness, consistency and reproducibility.	
Inventory	• Sensitivity analysis carried out for a few important parameters; recovery of materials, lifetime and inclusion of heating in use stage • Database used: ETH • Database from a Software System: Not known • Gaps of important impacts: Ecotoxicity and human toxicity are included only qualitatively and included in overall assessment of "material quality"	
Impact Assessment	• CML used for impact assessment • Aggregation of impacts to one single value performed with • - Environmental Impact Points (Swiss Environmental Targets) • - Eco-indicator 95 • The methodology of the assessment does not conform with ISO 14042. Lack of descriptions of reasons for impact models, data quality, impact categories, and literature references.	
Environmental impacts included	• The included impact categories are not appropriate to fulfil the goal. Toxicity categories are handled within a "material quality" parameter. Significant impacts are expected within toxicity categories.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. Lack of descriptions, literature sources, reasons for model choices. All in all not transparent. Furthermore, eco- and human toxicity are only included within a qualitative aggregated parameter.	

The study compares 10 different flat roof constructions, 2 of which include liners containing PVC. The total amount of PVC in the 2 constructions is approx. 0.9 kg PVC/m^2 roof.

The study comes to the following conclusions, not related to material choice:

- A clear optimisation potential is to increase the thermal insulation layer thickness.
- The service life of the roof is calculated based on the top sealing. However, more significant is the quality of the work done in constructing the roof.
- Lifetime of the roof can be prolonged by using "roof greening", i.e. planting on the roof, which is available at low costs.

The study concludes the following on material related choices:

- It is important to ensure recovery of materials, especially synthetic plastics.
- The best choice for thermal insulation is expanded polystyrene (EPS).
- The best top sealing is a synthetic plastic.

The study concludes the following on the selection of roof construction choices:

- The recommended solution is a 4 layer combination of glass fibre textiles, expanded polystyrene and 2 layers of synthetic compounds (not PVC) as seals (solution 5 in summary table).

<u>The study explains to manufacturers</u>:

- The takeback of materials is important. In terms of industrial accidents, the frequency of industrial accidents is lowest in the PVC production chain.

<u>The study explains to users</u>:

- The quality of work when flat roof is constructed and maintained is important as it may prolong the roof lifetime. Lifetime can also be extended by having plants on roof/green roof.

Table 5-12 summarises the analysed impacts.

Table 5-12: Summary of the analysed impacts of IPU 0016

IPU 0016	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
	with PVC	**with PVC**	**no PVC**	**no PVC**	**no PVC**	**no PVC**	**no PVC**	**no PVC**	**no PVC**	**no PVC**	**Impacts**
TLC	medium	low	low	medium	low	medium	high	high	medium	low	Global warming
	low	low	low	low	low	medium	medium	high	medium	low	Ozone formation
	medium	low	low	medium	low	medium	medium	high	low	low	Acidification

Major elements of roof solutions

Bottom	PE barrier	PE barrier	PE barrier	PE barrier	PE barrier	Bitumen seal	Bitumen seal	Polymer bitumen	PE barrier	PE barrier	
	Mineral fibre	EPS	EPS	Mineral fibre	EPS	EPS	PUR	Foam glass	EPS	EPS	
	PVC liner	Glass textile	E/P liner	E/P and $Al(OH)_x$ liner	Glass textile	Bitumen laminated	Bitumen laminated	Bitumen	Bitumen laminated	HDPE/ carbon black/ paraffin oil seal	E/P = Ethylene/ Propylene
Top		PVC liner	Gravel		E/P liner and $Al(OH)_x$ liner	Polymer bitumen	Polymer bitumen	Polymer bitumen, gravel	PET felt		$Al(OH)_x$ = Al-hydroxide

Summary for Roofing:

The principal competing products for roofing sheets are bitumen, PVC and PE, other polymers like PP, PIB, EPDM and EVA are less important.

Because production and recycling dominate results, it is clear that a longer lifetime of the roofing sheets leads to environmental benefits. The comparison of different bitumen roofing sheets has shown only small differences in production impacts when taking the final roof as the relevant functional unit.

The differences between bitumen and PVC are expected to be rather small when the assessment is carried out for a specified use time period. For both bitumen and PVC, the recycling/end-of-life scenario has a strong influence on the LCA results, but the representativeness of the data used for recycling and end-of-life treatment in the study is rather low.

New recycling technologies like Vinyloop® for PVC could change overall results if included in a study for flat roofs.

For bitumen roofing, a thinner construction may have environmental benefits if the lifetime is comparable.

Green roofs in general could extend the lifetime of the sheets and, therefore, result in environmental benefits.

Gaps can be identified for the comparison of PVC roofing with polyolefin roofing and roofing material with a minor market share. It is expected that the polyolefin roofing would probably be advantageous relative to environmental impacts from production, but the durability of PVC within this outdoor application during the use phase could make it the preferred solution.

5.1.4 Pipes: Water and Gas Pipes

The principal competing materials of PVC within pipe applications are concrete/stoneware, cast iron, zinc and copper for waste/rain water pipes and polyolefins for all other kinds of pipes.

Environmental analysis considering pipes of different materials (IKP AT-5)

Documentation sheet (IKP AT-5)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Ökologischer Vergleich von Rohren aus verschiedenen Werkstoffen</td></tr>
<tr><td>Scope of investigation</td><td>Environmental analysis considering pipes made of different materials for the application in civil engineering</td></tr>
<tr><td>Year of publication</td><td>1996</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>Forschungsinstitut für Chemie und Umwelt TU Wien, Chemie- u.Masch.Inst.,
Getreidemarkt 9, A-1060 Wien, Austria</td></tr>
<tr><td>Contractor/ Address</td><td>Landesregierung Niederösterreich Landhausplatz 1, 3109 St. Pölten, Austria</td></tr>
<tr><td>Authors</td><td></td></tr>
<tr><td>Availability/Publisher</td><td>Landesregierung Niederösterreich Landhausplatz 1, 3109 St. Pölten, Austria</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td></td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td></td></tr>
<tr><td>Qualitative</td><td>X</td><td>Qualitative</td><td>X</td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison of pipes made of different materials:
concrete, concrete/PVC, fiber-cement, PEHD, PVC, cast iron, stoneware</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The study compares the environmental impact of pipes made of different materials and defined diameter over the whole life cycle, in terms of their application in civil engineering. The sensitivity analysis, interpretation of data and identification of environmental weak points is part of the study. In addition, two evaluation methods – the SETAC method and the method of the critical volume – are applied to the inventory data.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>100%</td><td>Specific/own/new data</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic characterisation (IKP AT-5)

Overall frame of study	not specified
ISO 14040 ff	X
Code of practice	
other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	pipes for fresh water and waste water
Functional unit	1m, 3 diameters
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	
recycling	
transportation	X
Allocation (mass/energy/price/exergy)	mass, energy
System Expansion	
Substitution	energy credits
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	also method of critical loads performed
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	not relevant
Toxicity, human	X
Toxicity, eco	X
other:	Resources
Data quality	
time	1991 to 1994
geography	Austria
technology	materials production average, pipe production and use specific
Critical review performed	No
Evaluation	No
Normalisation	
Weighting	
other methods	

Critical Assessment (IKP AT-5)

Description of goals	• Comparison of pipes with different diameters during their complete life cycle for the boundary conditions of Austria • Giving a basis for future industry strategy and discussion between industry and their customers • Giving criteria for governmental decisions	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• pipes for freshwater and wastewater • adequate system boundaries • functional unit: 1m of pipe, 3 diameters covered	
Life cycle phases	• Production and use phase. Recycling of the pipes not included because no information available.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Austrian boundary conditions • All competing materials have the same life span. • No fillers, pigments, stabilisers etc. covered “because of low share”	
Valuation of scope	• The scope is appropriate to fulfil the goal	
Methodology	• Allocations and credits all fully discussed and well-documented • System and boundaries fully discussed and well-documented	
Data requirements	• Data requirements and quality not specified BUT: one system taken out of the study because of a lack of quality data • Data sources all specified and well-documented, high quota of directly industry-based data	
Inventory	• Description of the technical system, but not fully developed	
Impact Assessment	• Description of used model and the different Impact Categories not fully elaborated • As an alternative, the concept of critical loads is performed. • The conclusions are drawn from the inventory level, not from the impact assessment level • Model fulfils the requirements	
Environmental impacts included	• All commonly-accepted impact categories included • Interpretation of the results for the different recipients not fully developed	
Weighting of environmental parameters	• No normalisation • No weighting	
Overall ISO 14040 ff requirements	• The requirements of ISO 14.040 ff. are met.	

The study comes to the following key conclusions:

- Material production is the dominant life cycle phase.
- Transport, installation and use phase of the systems are not important contributors to LCA results.

<u>The study explains to manufacturers</u>:

- Reduction of pipe weight would lead to environmental advantages.

This finding is often valid for all kinds of products, but when interpreting comparative results one has to take into consideration, that the reduction of a certain mass of different materials (PVC pipe and concrete pipe reduced by *x* kg) leads to a reduction of most environmental potentials. The density, transport and laying efforts as well as avoided production (due to the saved material) often differ significantly for each of the different materials.

- Recycled material should be used in production

This finding is obvious, but if or to what extent used pipes may contribute as a source of secondary material in production is not clearly stated. During long use phases, the quality of the materials can be affected (e.g. diffusion into material, contamination, oxidation).

Table 5-13 summarises the analysed aspects and impacts for a pipe diameter of 250mm, but first, some overall remarks are stated. As the methodology for impact assessment was not fully developed at the time the study was undertaken, the conclusions of the study are drawn from the inventory level. Within the production phase, the energy consumption of the various materials differs considerably. The amount of energy for logistics is low for all of the materials. Significant differences arise in the use of raw materials and in the respective source (minerals or fossil). Significant differences also arise in dust emissions. Emissions originate primarily in the material production phase. Pipe production and logistics are not significant contributors to LCA impacts. The differences in the amount of carbon monoxide emissions are mainly from the material production phase. The pipe production phase is only relevant for iron and stoneware pipes. The logistics are not significant. The CO_2 emissions are relatively similar for all materials, only the concrete/PVC pipe shows some higher emissions.

In the use phase, the influences of pipe laying and water leakage (freshwater and wastewater) are considered independently of the material. A sensitivity analysis was performed, as different laying methods are available for pipe materials and data gaps exist for the leakage associated with different pipe materials. The study concludes that the transport, installation and use phases of the systems are not important. We doubt this, because in our opinion the material properties and the installation, in combination with the considered materials, have significant influence on the lifetime length and maintenance efforts (e.g. easy to reach, easy to repair, easy to replace, repair intervals).

Table 5-13: Summary of the analysed impacts of AT-5

IKP AT-5	Concrete	Concrete/ PVC	Fibre-cement	PE-HD	PVC	Cast iron	Stoneware	Impacts
Production	Low	Medium	Low	Medium	Medium	Medium	Highest	**Energy demand**
	High raw, mainly minerals.	High, mainly minerals.	Medium, mainly minerals.	Medium raw, mainly fossil fuel.	Medium, fossil fuel and minerals.	Low raw ores and fossil fuel.	High, mainly minerals.	**Raw material consumption**
	Low	High, mainly from raw materials (fossil fuel chain)	Low	High, mainly from raw materials (fossil fuel chain)	High, mainly from raw materials (fossil fuel chain)	Low	Medium	**Dust**
	Medium	Medium	Medium	Low	Medium	Low	High	**CO**
	Medium, mainly from raw materials	High, mainly from raw materials	Medium, mainly from raw materials	Medium, mainly from raw materials	Medium, mainly from raw materials	Medium, mainly from pipe production.	Medium, mainly from pipe production.	**CO2**
	Low, mainly from logistics	High, mainly from raw material production (fossil fuel chain)	Low, mainly from pipe production.	Medium, mainly from raw material production (fossil fuel chain)	Highest, mainly from raw material production (fossil fuel chain)	Low, mainly from logistics	Medium, mainly from pipe production.	**SO2 and NOx**
	Low	Medium	Low	High	High	Low	Low	**CxHy**
	Medium consumption	Medium consumption	Low consumption	Low consumption	Low consumption	Low consumption	High consumption	**Water**
	Low, mainly from raw materials	Low, mainly from raw materials	Low, mainly from pipe production	Low, mainly from raw materials	Medium, mainly from raw materials	High, but significant part is slag use in cement ind.	Medium, mainly from pipe production	**Solid waste amounts**
Use	see text	see text	see text	see text	see text	see text	see text	
Recycling	not avail.	not avail.	not avail.	not avail.	not avail.	not avail.	not avail.	

Environmental comparison of sewage pipes of different materials (IKP CH-6)

Documentation sheet (IKP CH-6)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Ökobilanz von Rohren zur Hausentwässerung</td></tr>
<tr><td>Scope of investigation</td><td>Environmental comparison of domestic sewage pipes of different materials</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1996 to 1998</td></tr>
<tr><td>Institution or Company</td><td>Geberit International AG, Schachenstr. 77, 8645 Jona, Switzerland</td></tr>
<tr><td>Contractor/ Address</td><td>Geberit International AG, Schachenstr. 77, 8645 Jona, Switzerland</td></tr>
<tr><td>Authors</td><td>Geberit International AG</td></tr>
<tr><td>Availability/Publisher</td><td>Geberit International AG, Schachenstr. 77, 8645 Jona, Switzerland</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>domestic sewage pipes, LCA, inventory analysis</td></tr>
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Qualitative/Quantitative</td><td>
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<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison done between all alternatives (cast iron, fibre-cement, ABS, PP, PE, PVC)</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Detailed inventory analysis aggregated on 1m of pipe as functional unit. Environmental aspects are summarised with the Eco-Indicator 95 method. Extensive description of data, quality, production procedure and weak-point analyses. Use phase has been omitted.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
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<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. Comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. Comparison</td></tr>
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Comment: Suggested for systematic characterisation
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Systematic Characterisation (IKP CH-6)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Pipes
Functional unit	1m of pipe
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	X
transportation	(X)
Allocation (mass/energy/price/exergy)	not stated
System Expansion	not stated
Substitution	not stated
Data categories described	
Primary energy consumption	no
Air emissions	no
Water emissions	no
Waste categories	no
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	(X)
Toxicity, eco	(X)
other:	waste
Data quality	
time	1995 to 1998
geography	Europe
technology	1990 and forward
Critical review performed	internal review
Evaluation	
Normalisation	Ecoindicator 95
Weighting	Ecoindicator 95
other methods	UBP97

Critical Assessment (IKP CH-6)

Goal description in short	• To compare environmental loads from sewage pipes made from different materials. • To allow the constructor to make ecological choices when planning buildings • To determine hot spots in the life cycle of pipes • To make a report with definite statements, in the shortest possible time, still keeping transparency and reproducibility. • To communicate with stakeholders	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• Comparison between sewage pipes of virgin iron, scrap iron, (Eternit), PVC, ABS, PP PEHD, PE-S2 • System boundaries are clearly defined. • Functional unit is clearly described. Exclusion of lifetime of pipes is discussed.	
Life cycle phases	• Use stage, laying of pipe and removal of pipe not included. • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	(X)
Important assumptions	• Lifetime of pipe not included, i.e. same lifetime of all materials. • Laying, maintenance and removal not included, i.e. to be assumed the same. • Fittings etc. not included, i.e. assumed the same for all materials. • Three points above may affect the conclusion in more or less “all” directions. • 0% reuse of pipes in plastic materials and 100% reuse of iron pipes. Different reuse percentages may lower or increase impacts. • Western European average electricity (UCPTE) power mix.	
Valuation of scope	• The scope is appropriate to fulfil the goal of a screening LCA. In depth results can not be given.	
Methodology	• Two methods used: Ecological scarcity 97 and Eco-Indicator 95.	
Data requirements	• Stated that preferably current data approved by specialists is used. Use of data from “generally approved” sources. • Overall quality of data material is discussed. • No discussion of completeness, representativeness precision level, consistency and reproducibility.	
Inventory	• Databases used: ETH (1996) and Buwal (1998). • Database from a Software System: Unknown • Gaps of important impacts: - Dioxin formation during incineration of PVC is not included (this will increase impacts from PVC if included) • Only “pure PVC” is assessed, i.e. use of stabilizers etc. (e.g. lead) in PVC is not included (this will increase impacts from PVC if included). • Very limited discussion on sensitivity of important parameters and of excluded parameters (see gaps of importance).	
Impact Assessment	• Two methods used: Ecological scarcity 97 and Eco-Indicator 95.	
Environmental impacts included	• Dioxin from incineration of PVC is not included. Resource consumption from e.g. lead or cadmium stabilizer in PVC is not included.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. Only an internal review is performed, no detailed discussion of data quality.	

The study comes to the following key conclusions:

- Sewer pipes made of cast iron (both virgin and recycled) have higher environmental impacts than any of the other alternatives.

This may be explained by the emissions from the iron casting process, the remelting process, and the pipe production process, which are significant contributors. The production of the pipes and the virgin iron processing are especially important life cycle stages.

- For the other materials covered in the study the material production stage is the major life cycle contributor. The pipe production process, especially for the polymers, is relatively simple and produces fewer emissions.

- For all materials besides cast iron the differences are too rare to differentiate them on an environmental level.

This is not only due to similar production processes, but rather more due to the chosen “One Point Indicator” method that aggregates all impacts into one “environmental value”.

- The disposal phase is negligible for all pipes except PVC pipes.

<u>The study explains to manufacturers, users (constructors of sewers) and third parties</u>:

- Iron pipes have the highest environmental impacts; choose a material other than iron for sewer pipes. The present study can not differentiate between other pipes on an environmental level.

The fact that “One Point Indicator” methods were used, makes it impossible to explicitly indicate, which environmental impact is related to which activity. Only overall environmental values can be described. Table 5-14 summarises the analysed impacts.

Table 5-14: Summary of the analysed impacts of CH-6

IPK CH-6	Cast iron (virgin)	Cast iron (recycled)	Fibre cement	PVC	ABS	PP	PEHD	PE-S2	Impacts
Raw material production	Highest total impacts, more than 10 times any other product	negligible	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	One point indicator (see critical assessment)
Pipe manufacturing	Highest total impacts, same as recycled cast iron, more than 15 times any other product	Highest total impacts, same as virgin cast iron, more than 15 times any other product	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	Lowest, little difference from other pipes except cast iron	One point indicator
Use phase	Not included	Not included	Not included	Not included	Not included	Not included	Not included	Not included	
Recycling	Lowest	Lowest	Lowest	Highest, but still low	Medium, but still very low	Medium, but still very low	Medium, but still very low	Medium, but still very low	One point indicator

LCA of pipes from concrete, PVC and clay (IKP NL-3)

Documentation sheet (IKP NL-3)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Ökobilanz für Rohre aus Beton, Ton, PVC
Environmental profile and environmental measures of a concrete external sewer [Intron report No. 95027]
Environmental profile and environmental measures of an external sewer of PVC and vitrified clay in comparison to concrete [Intron report No. 95195]</td></tr>
<tr><td>Scope of investigation</td><td>LCA of a concrete external sewer and LCA of PVC and vitrified clay compared to concrete.</td></tr>
<tr><td>Year of publication</td><td>1995</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1994 to 1995</td></tr>
<tr><td>Institution or Company</td><td>INTRON (Insituut voor Materiaal- en Milieu-onderzoek)</td></tr>
<tr><td>Contractor/ Address</td><td>Beton-Industrie</td></tr>
<tr><td>Authors</td><td></td></tr>
<tr><td>Availability/Publisher</td><td>INTRON B.V., P.O. Box 5187, 6130 PD SITTARD, Netherlands</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>LCA, concrete external sewer, PVC, vitrified clay</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>PVC, concrete, vitrified clay</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Each of the two studies describes a complete LCA of concrete, PVC and vitrified clay sewer. The inventory data are not included.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
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<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. Comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. Comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for **systematic characterisation**
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</table>

Systematic Characterisation (IKP NL-3)

Overall frame of study	
ISO 14040 ff	-
Code of practice	-
Other	CML methodology/method developed under contract from the Ministry by VROM (Ministry for Housing, Regional and the Environment of the Netherlands) and chosen by the Environmental Council on Construction.
Goal, description of	
Application/use of results	Not reported
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	sewage pipes
Functional unit	Two functional units: - 1 km external sewer of a mixed system, functioning on a gravity-fed basis in an area that is not susceptible to settling, which collects rainwater and wastewater and transports it through the residential neighbourhood in the direction of a main sewer, based on pipes with an external diameter of 300 mm and a designed service life of 40 years - 1 representative meter of sewer pipe with an internal diameter of 300 mm which can be applied in a gravity-fed sewer for the collection of rainwater and municipal waste water. The second definition of the functional unit is provided in order to achieve a comparison exclusively between pipes (tanks are excluded).
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/price/energy)	In the discard phase: economic principles
System Expansion	
Substitution	
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	X
other:	abiotic raw-materials depletion; odour (quantified only in the production phase); noise (quantified only in the production phase) qualitative assessment of harm to landscape and ecosystems
Data quality	
time	1994 to 1995
geography	The Netherlands
technology	Average
Critical review performed	
Evaluation	
Normalisation	X
Weighting	
other methods	

Critical Assessment (IKP NL-3)

Description of goals	•Comparison of external sewers made of PVC, vitrified clay and concrete.	
Valuation of the goal	•The goal is sufficiently and clearly described.	
Scope of study	•Adequate system boundaries for PVC and competing materials (concrete and vitrified clay). Transportation in and between phases is also taken into consideration. Life cycle phases clearly defined. •The functional unit is clearly described. Capital goods and their maintenance not taken into account. Production of substances not intended as product, and otherwise would have had to be dumped, not considered (blast furnace slag, fly ash, sandy clay, loam, flint, pyrite, slate).	
Life cycle phases	•For concrete: production, construction, use and maintenance phase and discard phase. Transport in and between the phases included. •For PVC and vitrified clay only the “distinguishing phases” considered: production, transport to the construction site, transport from the construction site to the processor and waste processing. Laying, periodic cleaning and removal after discard excluded.	
Level and cut-offs	•Full LCA with high degree of specific/own data	•X
	•Screening LCA with high degree of specific/own data	•
	•Screening LCA with high degree of generic/literature data	•
	•Minor cut-offs/incompleteness which are not likely to affect conclusion	•X
	•Major cut-offs/incompleteness which are likely to affect conclusion	•
Important assumptions	•The pipes are removed before the end of their technical service. •Rubber sealing rings are dumped. •“Regranulate” generated through processing is reused for the triple-layer pipes. •Regarding energy data on vitrified clay pipes, it is assumed that energy savings of 5% have been made since 1983. •Environmental impact of installation (laying) is the same for all materials. •Transport distances: 50 km from the processing to the construction site. •Composition of PVC pipes: 94% PVC granulate, 3.8% slaked lime (filler), 1.1% lead salts (stabilisers), 0.7% paraffin (lubricant), 0.2% titanium oxide (pigment) and 0.02% carbon black. •Composition of vitrified clay pipes: 96.4% vitrified clay, 0.3% polyurethane (ring), 0.5% polyester (ring), 1.3% quartz (ring filler material), 1.5% glazing. •It is assumed that 100% of the concrete is recycled. •It is assumed that the vitrified clay pipes go to a crusher installation. As it is not known what percentage is being crushed and dumped, the same scenario is followed as for concrete. Therefore, based on economic criteria, 23.6% of the environmental impact of the crushing is attributed to the sewage system. This is relatively favourable for vitrified clay pipes, as mixed granulate are regarded as less valuable than concrete granulate. •Production and use of PVC lubricants (0.2% weight) not taken into account.	
Valuation of scope	•The scope is appropriate to fulfil the goal.	
Methodology	•No detailed information on allocation. •No information on cut-off rules. •No detailed information on the methodology used, references are given (method developed under contract from the Ministry by VROM and chosen by the Environmental Council on Construction).	
Data requirements	•Only the Dutch situation is taken into account. The study attempts to obtain and use the most recent data. Data are taken from the association of producers. •Precision level, completeness, consistency and reproducibility are not clearly stated.	
Inventory	•Important topics of LCI model are discussed. •Sensitivity of inventory parameters is not discussed •Data from two Dutch producers of concrete sewage systems: data from 1994 and 1995. •Database used: APME 1994; RIVM, 1992 (spin REPORT); I Boustead, under contract of Feugrès, 1983. •Gaps regarding the use phase: possible leaching from different kinds of pipes (in the use phase) is not taken into account; however this is not likely to affect the main results of the study.	
Impact Assessment	•The impact assessment methodology is not described. Nevertheless, references are presented. •This is a summary of a more extensive study. There is no evidence that the methodology of the assessment does not agree with ISO 14042. In fact, the study was carried out before the publication of the standard. •Normalisation referred to the global environmental pollution	
Environmental impacts included	•The included impact categories are appropriate to fulfil the goal. •Concrete, PVC solid-wall, 3-layer PVC and vitrified clay-gas pipes.	
Weighting of environmental parameters	•No	
Overall ISO 14040 ff requirements	•The study was performed before the publication of the ISO 14040 standards series.	

The available document is an abbreviated version of the two original extended reports. One of the reports (Intron report number 95027) provides an LCA of a concrete external sewer. The second one (Intron report number 95195) contains two LCA studies of a PVC and a vitrified clay sewer. In these LCAs, only "distinguishing aspects" of the life cycle are taken into consideration. This refers to production, transport to the construction site, transport from the construction site to the processor and waste processing/recycling. Life cycle phases that do not lead to differences between the three materials considered (laying, periodic cleaning and removal after discard) are omitted from this study. The functional unit, system boundaries and assumptions are established on the same criteria for the three materials studied.

Impact assessment is carried out by quantifying both the "environmental effects" (listed in the systematic characterisation table) and the "environmental measures" determined based on the proposals of the Environmental Measures in Construction project group of the Environmental Council on Construction: energy (first order), raw materials, waste (normal and hazardous) and emissions.

The study comes to the following key conclusions:

- **Energy consumption has a pivotal role in determining environmental impacts of sewer pipes. Raw material processing and emissions are directly related to energy consumption. Thus, the estimation used for the energy consumption of the three materials considered, plays a significant role in the results and conclusions of the study.**
- Concrete pipes score better than PVC and vitrified clay pipes on all environmental measures and impact categories considered.
- Despite high energy consumption levels, vitrified clay emissions are lower than those of PVC. This is probably due to the use of cleaner energy sources (natural gas).

<u>The study explains to manufacturers</u>:

- Concrete pipes involve lower energy costs and raw material consumption, and produce fewer emissions than vitrified clay and PVC pipes.

<u>The study explains to users</u>:

- Concrete pipes are preferable from an environmental point of view.

<u>The study explains to third parties</u>:

- LCA shows that large diameter (300mm) concrete pipes are better, from an environmental point of view, compared with PVC and vitrified clay pipes. With regard to air emissions, vitrified clay pipes are better than PVC pipes.

Table 5-15 summarises the analysed impacts.

Table 5-15: Summary of the analysed impacts of IKP NL-3

Life cycle phases	Concrete	PVC	Vitrified clay
Production	Production of rubber rings is predominantly responsible for the environmental effect “odour”.	Odours arise due to the additive titanium TiO_2.	“Odour” mainly caused by the production of PUR rings.
	Energy consumption is mainly due to the production of Portland cement clinker and the crushing of cement.	Highest consumption of energy, mainly due to the production of virgin PVC granulate.	
	Cement production makes a considerable contribution to acidification (41% of the whole life cycle of the material).		
Laying and removal	Laying and removal of the sewers play a major role in the environmental measure “energy” (21 and 26% of the life cycle), followed by cement production.	Not assessed	Not assessed
	The contribution of these phases to photochemical oxidant formation is also important (21 and 36% of the life cycle).		

Life cycle of waste water pipes from PVC, concrete and HD-PE (IKP NL-11)

Documentation sheet (IKP NL-11)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Milieubeoordeling Rioolbuizen</td></tr>
<tr><td>Scope of investigation</td><td>Life cycle of wastewater pipes made from PVC, concrete and HD-PE</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>Institute for Environmental Studies (IVM) and TNO-STB</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Michiel van Drunen, Arnold Tukker</td></tr>
<tr><td>Availability/Publisher</td><td>Institute for Environmental Studies (IVM), Vrije Universiteit, De Boelelaan 1087,
1081 HV Amsterdam, Netherlands;
TNO-STB Schoemakerstraat 97, 2628 VK Delft, Postbus 6030, 2600 JA DELFT, Netherlands</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>LCA, wastewater pipes</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
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</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Wastewater pipes made from concrete, HD-PE</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>LCA study about wastewater pipes.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
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<tr><td>Generic data/literature data</td><td>70%</td><td>Specific/own/new data</td><td>30%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
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<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
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Comment: Suggested for systematic characterisation
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Systematic Characterisation (IKP NL-11)

Overall frame of study	not specified *
ISO 14040 ff	
Code of practice	
Other	
Goal, description of	none
Application/use of results	
Aim of study	
Target group of study	
Scope, description of	
main technical systems properly described	
Function analysed	waste water system for flats
Functional unit	21 flats
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	not specified
System Expansion	
Substitution	Mass and energy credits for recycling of the used pipes. The credits are directly subtracted from the production of the materials. All materials are calculated with a share of 30% recycling material.
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	X
Toxicity, eco	X
other:	X
Data quality	
time	not specified
geography	not specified
technology	not specified
Critical review performed	
Evaluation	none
Normalisation	
Weighting	
other methods	

Critical assessment (IKP NL-11)

Description of goals	• To find out about possible impacts of a ban on PVC and the performance of alternatives	
Valuation of the goal	• The description of goals is not fully developed. Most of the goals deal with the socio-economic methodology that needs to be developed. The ecological part of the study has no goal definition of its own, but conclusions can be drawn considering the overall goals of the study.	
Scope of study	• wastewater system for flats • system boundaries not described • The functional unit is not properly described	
Life cycle phases	• Production and end of life covered	
Level and cut-offs	• Full LCA with high degree of specific/own data	(X)
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	not documented
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• All materials are calculated with a share of 30% recycling material. • No other information about assumptions	
Valuation of scope	• Both goal and scope are not described properly, so no evaluation can be given.	
Methodology	• No information on methodology, such as allocations; mass and energy credits for recycling of the used pipes.	
Data requirements	• no data requirements set • data sources not specified	
Inventory	• no proper description of the technical system • no sensitivity analysis performed	
Impact Assessment	• used model not described	
Environmental impacts included	• All commonly-accepted impact categories included • No interpretation of the results given	
Weighting of environmental parameters	• no weighting performed • Interpretation of the results for the different recipients not fully developed	
Overall ISO 14040 ff requirements	• The ecological part of the study is obviously a short version (factsheet) of the original study. Important descriptions and information are missing. The **available document does not fulfil the ISO requirements.**	

Strictly speaking, this is not an LCA study. Existing studies (environmental and socio-economic) are analysed with the aim of developing a method for evaluation that includes all knowledge about the topic. The basis for the ecological part is a study performed by Van Drunen and Tukker 2000, of which NL 11 obviously is the abstract.
A full version of this study is not available.

The study comes to the following key conclusions:

- Interpretation of the results for the different target groups is not fully developed. The different alternatives are compared impact wise, giving no interpretation. Overall, concrete appears to have a lower impact than PVC and PE. PVC shows disadvantages with regard to human toxicity.

Table 5-16 is a summary of the analysed impacts. No distinction of the production phase or of recycling is made and only aggregated data is reported. For the concrete pipes, the large global warming impact is surely due to the cement process, which releases significant amounts of CO_2. It is surprising that concrete pipes result in the lowest energy consumption, considering that the cement kilns should be within the system boundaries. As the system boundaries and cut-offs are not sufficiently described, a transparent analysis is difficult to achieve. The high values for concrete pipes within the impact of Eutrophication are often due to energy conversion or the agrarian process (fertiliser use), but this does not correspond with the stated low energy demand for concrete pipes.

Table 5-16: Summary of the analysed impacts of NL-11

IKP NL-11	Concrete pipe	HD-PE pipe	PVC pipe	Impact
Production and recycling	highest amount of eutrophication, but comparable with other materials	Comparable with other materials	lowest amount of eutrophication, but comparable with other materials	**Eutrophication**
	highest amount of global warming, but comparable with PE-HD	comparable with concrete	lower amount, about 75% of concrete	**Global warming**
	low amount of energy consumption, about 25% of HD-PE	highest amount of energy consumption	high amount of energy consumption	**Energy consumption**
	lowest amount of acidification, about 60% of PVC	medium acidification	highest amount of acidification	**Acidification**
	low summer smog, about 20% of PE-HD	highest amount of summer smog, but comparable with PVC	comparable with PE-HD	**Summer smog**
	high eco-toxicity	medium eco-toxicity, comparable with PVC	comparable with PE-HD	**Eco-toxicity**
	lowest amount of human-toxicity, about 40% of PVC	medium human-toxicity	highest amount of human-toxicity	**Human-toxicity**
	low amount of waste, about 15% of PE-HD	highest amount of waste, but comparable with PVC	comparable with PE-HD	**Waste**
Use phase	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE	

Environmental Life Cycle Analysis of Gas Distribution Systems (IKP NL-12)

Documentation sheet (IKP NL-12)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Environmental Life Cycle Analysis of Gas distribution Systems</td></tr>
<tr><td>Scope of investigation</td><td>12.7 km high pressure transport network of steel, polyethylene, and a 100 km low-pressure distribution network of nodular iron, polyethylene or PVC.</td></tr>
<tr><td>Year of publication</td><td>1995</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1992</td></tr>
<tr><td>Institution or Company</td><td>Gastec NV with support of Centre of Environmental Science (CML-S&P)</td></tr>
<tr><td>Contractor/ Address</td><td>EnergieNed, Utrechtseweg 310, 6812 AR Arnhem, Postbus 9042, NL-6800 GD Arnhem, Netherlands</td></tr>
<tr><td>Authors</td><td>Drs. H.C.L.M. Kraak (CML-S&P), Dr. G. Huppes (Gastec NV), ing. J.B.W. Wikkerink (CML-S&P)</td></tr>
<tr><td>Availability/Publisher</td><td>GASTEC NV, Dutch Center of Gas Technology Postbus 137, NL-7300 AC Apeldoorn, Netherlands</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>gas distribution, LCA, pipeline, steel, PE, nodular iron, PVC</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Steel, PE, nodular iron, PVC</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>A quantified LCA of different gas distribution systems applied in the Netherlands is performed - from the extraction of basic resources to the final disposal of used materials. The study concludes that there are only small differences found between the individual pipeline systems analysed.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td></td><td>Specific/own/new data</td><td>100%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
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Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (IKP NL-12) (part 1)

Systematic Characterisation	**IKP NL-12**
Overall frame of study	
ISO 14040 ff	
Code of practice	Provisional SETAC Code of Practice
Other	CML terminology[22]
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
Main technical systems properly described	X
Function analysed	Gas-transportation network (high pressure) for 10,000 households: steel, polyethylene 100, polyethylene 80 and crosslinked PE pipes. Distribution network (low pressure) for 10,000 households: nodular iron, modified and unmodified PVC, polyethylene.
Functional unit	The transportation of 20 million m^3 of natural gas per year, from an intake station to 10,000 service connection points, based on a peak load of 15,000 m^3 per hour.
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X[23]
transportation	X
Allocation (mass/price/energy)	Economic service as defined in the functional unit, economic materials or useful energy
System Expansion	
Substitution	
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X

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[22] In the CML terminology, an environmental life cycle analysis is made up of five components, which together form a comprehensive structure. Each of these components provides a result, which can be used on it's own. These results are known as *environmental indicators*. The main environmental indicator used in this study for comparing the different product alternatives is the *environmental profile with it's effect scores,* which is the output of component three – classification - (CML terminology). In the table below differences in terminology between SETAC and CML are listed:

Code of Practice Sesimbra – April 1993	**Guide + Background LCA – October 1992**
Goal definition and Scoping	Goal definition
Inventory analysis	Inventory analysis
Impact assessment: - Classification - Characterisation - Valuation	Impact assessment: - Classification - Evaluation
Improvement assessment	- Improvement analysis

[23] All product systems are analyzed up to the point at which recycled materials are being reused in the product systems of other products. Environmental interventions caused in later stages of the existence of these products are not included.

Systematic Characterisation (IKP NL-12) (part 2)

Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	X (ecotoxicity aquatic)
other:	abiotic depletion potential; odour threshold limit
Data quality	
time	late 1980s to early 1990s
geography	For "downstream" processes, mainly European data were used (electricity production, raw material production, material production processes). For "upstream" processes, mainly Dutch data were used (construction, use and disposal operations)
technology	Average and specific technology used (in the more "downstream" processes, i.e. further from the final product under consideration), whereas in the more "upstream" processes (i.e. closer to the final product), company specific data was dominantly used.
Critical review performed	The study was assessed by an "expert group" consisting of representatives from material producing industries and pipeline producers across Europe and user companies from the Netherlands.
Evaluation	
Normalisation	X
Weighting	
other methods	Sensitivity analysis

Critical Assessment (IKP NL-12)

Description of goals	• To supply an overview of the potential environmental effects of pipeline systems used for gas transport and distribution in The Netherlands, by using a “cradle to grave” LCA approach.	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• Adequate system boundaries for different materials: entire life cycles, including transportation, electricity, capital goods and other ancillaries. • Pipes of different materials designed to transport 20 million m^3 of gas per year. • Lifespan (empirical): 70 years for plastic materials; 50 years for unmodified PVC; 70 years for steel and iron.	
Life Cycle Phases	• Production of raw materials, production of materials, production of components, construction of pipeline system, use of pipeline; and disposal. • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• For each household connection, an average 1 m network connection is required; 6 x 450 m is required for interconnecting transportation and distribution networks. Therefore, transportation networks are analysed based on a 12.7 km pipeline system. • In order to construct the distribution network, an average of 10 metre per household connection was assumed. Therefore, distribution networks are analysed based on a 100 km pipeline system. • Every alternative is equally fit for purpose or capable of fulfilling the same function.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• Allocations on three principles: economic service, economic materials and useful energy.	
Data requirements	• Spatial and temporal representativeness of data are stated. • The study notes that all environmental interventions modelled are assumed to originate equally around the world; no concentrations higher than the world average are included. • Precision level, completeness, consistency and reproducibility are not stated.	
Inventory	• Important topics of LCI model are discussed. • Sensitivity of inventory parameters (life span of the different materials, allocation factors and alternatively waste disposal processes) is qualitatively discussed but not analysed. • Database used: company specific data preferred, if not possible then available information taken from published literature and other research institutes (mainly from ETH database, 1993). • No actual measurements of possible air, water and soil emissions were carried out; data was supplied by specific companies and published data. • The authors highlight some gaps in data contained in databases regarding the following impact categories: aquatic toxicity (TBT emissions missing), abiotic depletion and ozone depletion.	
Impact Assessment	• The methodology of impact assessment is that proposed by Heijungs *et al.* (1992) and published by the CML (Leiden University). • The assessment methodology does not fully agree with ISO 14040. The study was performed before the publication of the standard.	
Environmental impacts included	• The included impact categories are appropriate to fulfil the goal. • Quantification of gas leakages during the use phase of pipeline systems.	
Weighting of environmental parameters	• Weighting not applied	
Overall ISO 14040 ff requirements	• As the study was carried out before the publication of ISO 14040 standards, methodology does not strictly follow all requirements.	

The study comes to the following key conclusions:

- In general, only small quantifiable differences were identified between the individual pipeline systems analysed. No system was found to score significantly worse or better on all environmental effect scores relative to other systems analysed.
- Regarding the high pressure transportation network, no significant difference between materials was found (steel 8 bar; polyethylene 100 - 8 bar; polyethylene 80 - 4 bar; crosslinked polyethylene – 8 bar).
- Regarding the distribution network, nodular iron showed the highest impact in all categories studied. This score was higher by a factor of 10 compared to PVC and polyethylene 80 pipes. The authors are sceptical about the result, which seems to be strongly affected by the value provided for energy consumption. As this value could not be obtained from industry specific data, and it seems to be highly dependent on the amount of virgin iron and re-melted scrap used, it was concluded that a closer investigation on the topic would be required.
- The gas leakage during the use phase leads to a significant increase in photochemical oxidant formation and global warming potential categories.

The study explains to manufacturers:

- The nodular iron pipeline system shows the highest impact pattern compared to PVC and polyethylene. Attention should be given to gas leakages from pipe systems.

The study explains to the users:

- The impacts of PVC and polyethylene pipeline systems differ very slightly; impacts are highest for the iron pipeline system.

The study explains to third parties:

- The nodular iron pipeline system results in the highest impact pattern when compared with the PVC and polyethylene pipeline systems.

Table 5-17 summarises the analysed impacts.

Table 5-17: Summary of the analysed impacts of IKP NL-12

IKP-NL-12	**Nodular Iron** **Gas distribution**	**PVC** **Gas distribution**	**PE** **Gas distribution**
Production and transportation processes	Highest score on aquatic ecotoxicity due to raw iron production, crude oil from refinery and transportation of crude oil by transoceanic tanker (mainly phenols and fats and oils).		
	CO_2 emitted during the production of raw iron is largely responsible for the score for global warming potential of the whole life cycle. This result is extremely sensitive, as indicated before, on energy values provided for this phase.		
	Highest score on acidification potential (SO_2 and NO_x emissions). The same arguments held for global warming potential are valid.	Lower scores on SO_2 and NO_x than for polyethylene. This is because PVC production requires less oil.	
	Highest score on abiotic depletion potential on zinc due to the use of a protective layer of metallic zinc sprayed on to the pipes.		
	Highest score on human toxicity air emissions due to SO_2 and NO_x emissions. Pb, As and Cd emissions caused by zinc processing.	Lower score on human toxicity air than polyethylene due to lower consumption of oil in material production.	
		Score on human toxicity soil emissions caused by the Hg emission from chlorine production	
	Highest score on nutrification potential due to NO_x emissions.		
	Highest score on odour threshold limit due to H_2S emissions.		
	Highest score on ozone depletion potential (halon-1301). This substance is emitted from transoceanic tanker transport and crude oil from refinery in the three materials assessed.	Tetra emission originated from chlorine production for VCM.	
Construction			
Use of the pipeline system	Contribution to photochemical oxidant formation along the whole life cycle dominantly determined by the gas leakages (methane, ethane, propane and butane) during the use phase.		
		Contribution to global warming potential mainly due to CH_4 emissions caused by gas leakages.	Contribution to global warming potential mainly due to CH_4 emissions caused by gas leakages.
Disposal	Highest score on human toxicity water emissions dominantly caused by residues from hard coal processing in landfill.	Lower values on human toxicity water emissions than PE due to lower energy requirements.	

Life cycle of waste water pipes from PVC, concrete and HD-PE (IKP NL-7)

Documentation sheet (IKP NL-7)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Controverses rondom chloor - overbrugbaar</td></tr>
<tr><td>Scope of investigation</td><td>Life cycle of waste water pipes made from PVC, concrete and HD-PE</td></tr>
<tr><td>Year of publication</td><td>2001</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>Other studies of 2000 are cited: ‘Economische en maatschappelijke beoordeling van PVC substitutie van rioolbuizen’ und ‘Milieubeoordeling Rioolbuizen’</td></tr>
<tr><td>Institution or Company</td><td>Stichting Natuur en Milieu;
(VNCI) Vereniging van de Nederlandse Chemische Industrie</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Michiel van Drunen, Jacob Bouwma, Marc Koene, Paulien de Jong, Arnold Tukker, Eric-Jan Tuininga</td></tr>
<tr><td>Availability/Publisher</td><td>Stichting Natuur en Milieu, Donkerstraat 17, 3511 KB Utrecht, Netherlands
VNCI, Vlietweg 16, Leidschendam, Postbus 443, 2260 AK Leidschendam, Netherlands</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>LCA, socio-economics, wastewater pipes</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Waste water pipes made from concrete, HD-PE</td></tr>
<tr><td>Reported data</td><td>LCA, Socio-economic</td></tr>
<tr><td>Short description of the study</td><td>Synopsis of environmental and socio-economic work done by the "steering group chlorine and alternatives" of the chemical industry in the Netherlands and environmental organisations.
Example: Waste water pipes made of PVC</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>100%</td><td>Specific/own/new data</td><td></td></tr>
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</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td>X</td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation</td></tr>
</table>

Systematic characterisation (IKP NL-7)[24]

Overall frame of study	*
ISO 14040 ff	
Code of practice	
other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	
Function analysed	wastewater system for flats
Functional unit	21 flats
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	not specified
System Expansion	
Substitution	Mass and energy credits for recycling of the used pipes. The credits are directly subtracted from the production of the materials. All materials are calculated with a share of 30% recycling material
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	X
Toxicity, eco	X
other:	X
Data quality	
time	not specified
geography	not specified
technology	not specified
Critical review performed	no
Evaluation	none
Normalisation	
Weighting	
other methods	

---

[24] the study is not an environmental assessment, but rather an economic and socio-economic study about the possible results of a complete substitution of PVC waste water pipes by pipes made of other materials

Critical Assessment (IKP NL-7)

Description of goals	• Identify possible impacts of a ban on PVC and the performance of alternatives	
Valuation of the goal	• The description of goals is not fully developed. Most of the goals deal with the socio-economic methodology that needs to be developed. The ecological part of the study has no goal definition of its own, but conclusions can be drawn considering the overall goals of the study	
Scope of study	• wastewater system for flats • system boundaries not described • The functional unit is not properly described	
Life cycle phases	• Production and end of life covered	
Level and cut-offs	• Full LCA with high degree of specific/own data	(X)
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	not documented
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• All materials are calculated with a share of 30% recycling material • No other information about assumptions	
Valuation of scope	• Both goal and scope are not described properly, so no evaluation can be given.	
Methodology	• no information about methodology, such as allocations. Mass and energy credits for recycling of the used pipes.	
Data requirements	• no data requirements set • data sources not specified	
Inventory	• no proper description of the technical system • no sensitivity analysis performed	
Impact Assessment	• used model not described,	
Environmental impacts included	• All commonly accepted impact categories included • No interpretation of the results given	
Weighting of environmental parameters	• no weighting performed • Interpretation of the results for the different recipients not fully developed	
Overall ISO 14040 ff requirements	• The ecological part of the study is obviously a short version (factsheet) of the original study. Important descriptions and information are missing. The **available document does not fulfil the ISO requirements.**	

Controverses rondom chloor – overbrugbar?, Stuurgroep Chloor en Alternativen (IKP-NL-7) and Milieubeoordeling Rioolbuizen, IVM/TNO (IKP-NL-11) based on the same study

Strictly speaking, this study is not an LCA study. Existing studies (environmental and socio-economic) are taken and analysed with the aim of developing a method for evaluation that includes all knowledge about the topic. The basis for the ecological part is a study performed by Van Drunen and Tukker 2000, of which NL 11 obviously is the abstract. **A full version of this study is not available**.

For further information see Table 5-16 on page 166.

Life cycle of sewage pipes (IPU 000.0001)

Documentation sheet (IPU 000.0001)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Miljøvurdering af afløbsrør i PVC, PE, PP og beton
(Environmental assessment of sewage pipes in PVC, PE, PP and concrete)</td></tr>
<tr><td>Scope of investigation</td><td>Sewage pipes.</td></tr>
<tr><td>Year of publication</td><td>1997</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1995</td></tr>
<tr><td>Institution or Company</td><td>DOR Århus A/S Management Konsulenter, Brendstrupgårdsvej 7, 8200 Århus N, Denmark</td></tr>
<tr><td>Contractor/ Address</td><td>Nordiska Plaströrgruppen, P.O.Box 105, S-101 22 Stockholm, Sweden</td></tr>
<tr><td>Authors</td><td>Kjærulff, Anders and Andersen, Anders</td></tr>
<tr><td>Availability/Publisher</td><td>Can be ordered from DOR or Nordiska Plaströrgruppen – addresses above</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, PE, PP, concrete, sewage pipes</td></tr>
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Qualitative/Quantitative</td><td>
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<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
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<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison done between four materials: PVC, PE, PP and concrete</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to allow the members within the organisation (not being experts within the field of LCA) to evaluate other life cycle initiatives. It focuses on explaining and illustrating the methods, assumptions and choices in an LCA. Some work has been put into getting data from the use phase – including working environment.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
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<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for **systematic characterisation**
</td></tr>
</table>

Systematic Characterisation (IPU 000.0001)

Overall frame of study	
ISO 14040 ff	X
Code of practice	X
other	Nordic guidelines on LCA
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Sewage pipes
Functional unit	One metre of pipe, 50 years
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	Pipes considered inert and left in ground
transportation	X
Allocation (mass/energy/price/exergy)	El/heat on exergy, material following APME reports
System Expansion	not performed
Substitution	not performed
Data categories described	
Primary energy consumption	
Air emissions	Referring to methodology
Water emissions	Referring to methodology
Waste categories	Referring to methodology
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	qualitatively in sensitivity analysis
Toxicity, eco	qualitatively in sensitivity analysis
other:	
Data quality	
time	1995
geography	Nordic countries
technology	not stated, probably average
Critical review performed	yes
Evaluation	
Normalisation	Ecoindicator and UMIP
Weighting	Ecoindicator and UMIP
other methods	

Critical Assessment (IPU 000.0001)

Goal description in short	• To qualify members of NPG (Nordic Plastic Pipe Group) to evaluate and commit qualified influences to other life cycle assessments. • Secondary:	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• Adequate system boundaries, including total life cycle. • To generalize instead of using specific location, the scope is sewage pipe without joints, connections etc. (evaluated in sensitivity analysis) • Two pipe systems each in four materials. - system 1: Draining water corresponding to capacity of plastic pipe, inner diameter 104mm - system 2: Draining water corresponding to capacity of plastic pipe, inner diameter 226mm - for system 1, concrete pipe are not produced in the relevant size, therefore the production of a larger size is used (i.e. overqualified for functional unit). • Duration: 50 years	
Life cycle phases	• All life cycle phases considered. • Specific focus on collecting data for use phase • Pipes stay in ground after use • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Danish Power Mix • Estimated that new sewage pipes of modern standards are maintenance-free. Based on discussions with Danish municipalities – assumption seems correct. • Waste scenarios analysed: Pipes left in ground after 50 years. Expected that toxic compounds are inert or strongly bound in material. Empiric literature suggests this is correct. • Assumptions done are clear and understandable, not having a great influence on the conclusions.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• Allocation by energy (basis is combined heat and power, CHP) • Allocation following APME source on materials.	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are discussed. • Critical review comments that the above is handled and discussed in the report.	
Inventory	• Important topics of LCI model are discussed. • Sensitivity of inventory parameters is discussed. • Database used: APME, ETH • Database from a Software System: EDIP • Gap in emissions of heavy metals in materials and production from PE and PP. • Gap in emissions of heavy metals from machinery in pipe placing/fitting.	
Impact Assessment	• EDIP and Eco-indicator • The methodology of assessment agrees with ISO 14042.	
Environmental impacts included	• The included impact categories are appropriate to fulfil the goal. • Toxicity categories only included in sensitivity analysis as emissions of heavy metals are not available for materials in PE and PP and from use of fuel in machinery when placing/fitting the pipes	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were met.	

The pipes in “system 1” are not directly comparable as the concrete pipe was not available in the correct (comparable) size. The conclusions are divided into three areas: scarce resources, pollution impacts and working environment. The following legend is applied:

= At the same level

> 5 - 20% better than

>> 20 - 50% better than

>>> more than 50% better than

The study comes to the following key conclusions:

Scarce resources (EDIP method)
System 1: concrete = PP = PE >>> PVC
System 2: concrete > PP >>> PE >> PVC

The reason PVC has the largest impacts is due to the use of lead as a stabilizer. But it should be kept in mind that PVC pipes have an almost proven lifetime of more than 50 years, due to their durability (stabilizers). This has an indirect but important effect on resource saving (e.g. less maintenance and renewal). Therefore, it is important that all alternatives (especially concrete) can provide this durability in practice.

Pollution-related impact categories (EDIP and ECO-indicator methods)
System 1: PVC = PP = PE >> concrete
System 2: PVC = PP > concrete > PE

Working environment (Modified EDIP method)
System 1: PVC = PP > (ns) PE >>> concrete
System 2: PVC = PP >>> PE >> (ns[25]) concrete

Two factors that were evaluated in the sensitivity analysis can influence the results significantly; the choice of impact method to assess the demand for resources and the use of zinc as a stabilizer system for PVC instead of lead. With this considered PVC is then determined to be the most advantageous material.

<u>The study explains to manufactures</u>:

- The use of lead as a stabilizer is significant in the environmental performance, in particular to the use of scarce resources.

<u>The study explains to users</u>:

- Factors not related to the type of pipe material are relevant to the environmental impacts: e.g. the handling of machinery, the planning of work, type of soil in which the pipe is laid, as well as the width of trench digging. Energy demands in operating these processes, and the respective emissions due to combustion processes, have the most influence on the environmental impacts.

Table 5-18 summarises the analysed impacts of the two different systems. System 1 is a draining water system corresponding to the capacity of plastic pipe with an inner diameter of 104mm.

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[25] (ns): not statistically significant

Table 5-18: **Summary of the analysed impacts of system 1 of IPU 0001**

IPU 0001	PVC	PE	PP	Concrete	Impact
Whole life cycle	Medium GWP	Medium GWP	Medium GWP	50% higher GWP than the three others	**GWP**
	Lowest generation of waste	Lowest generation of waste	Lowest generation of waste	Almost 5 times the waste than the other three	**Municipal waste**
	Lowest acidification	Lowest acidification	Lowest acidification	A little higher acidification than three others	**Acidification**
	Lowest summer smog	Second highest summer smog	Second lowest summer smog	Highest summer smog	**Summer smog**
	Lowest nutrient enrichment	Lowest nutrient enrichment	Lowest nutrient enrichment	Two times higher than the three others	**Nutrient enrichment**
Use	no maintenance needed	no maintenance needed	no maintenance needed	no maintenance needed	

Table 5-19 summarises the analysed impacts of the two different systems. System 2 is a draining water system corresponding to the capacity of plastic pipe with an inner diameter of 226mm.

Table 5-19: **Summary of the analysed impacts of system 2 of IPU 0001**

IPU 0001	PVC	PE	PP	Concrete	Impact
Whole life cycle	Lowest GWP	A little higher GWP PP and PVC	Lowest GWP	A little higher GWP than PE	**GWP**
	Lowest generation of waste	Lowest generation of waste	Lowest generation of waste	Almost 5 times the waste than the other three	**Municipal waste**
	Lowest acidification, but almost equal	Highest acidification, but almost equal	Second lowest acidification, but almost equal	Second highest acidification, but almost equal	**Acidification**
	Lowest summer smog, but almost equal between three lowest	Twice the summer smog of concrete	Second lowest summer smog, but almost equal between three lowest	Third lowest summer smog, but almost equal between three lowest	**Summer smog**
	Lowest nutrient enrichment	Lowest nutrient enrichment	Lowest nutrient enrichment	50% higher than the three others	**Nutrient enrichment**
Use	no maintenance needed	no maintenance needed	no maintenance needed	no maintenance needed	

Life cycle of sewage pipes (IPU 041.0032)

Documentation sheet (IPU 041.0032)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Afløbskomponenter af PVC, PP, HDPE og beton
(Sewage pipe components in PVC, PP, HDPE and concrete)</td></tr>
<tr><td>Scope of investigation</td><td>Sewage pipes</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>Nielsen, Charlotte Blak; Schaumann, Jette; Hvorslev, Steffen; Sejersen, Peter</td></tr>
<tr><td>Institution or Company</td><td>Danish EPA, Strandgade 29, DK-1401 København K, Denmark</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Nielsen, C. B., Schaumann, J., Hvorslev, S., Sejersen, P.</td></tr>
<tr><td>Availability/Publisher</td><td>Danish EPA website, www.mst.dk</td></tr>
<tr><td>ISBN</td><td></td></tr>
<tr><td>Keywords</td><td>Sewage pipes, PVC, PP, HDPE og concrete</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>PP, HDPE, beton</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Standard LCA. One conclusion is that cross-material comparisons are not possible from this study</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>100%</td><td>Specific/own/new data</td><td></td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
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Comment: Suggested for **systematic characterisation**
</td></tr>
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Systematic Characterisation (IPU 041.0032)

Overall frame of study	
ISO 14040 ff	
Code of practice	X
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	sewage components
Functional unit	1m of pipe for 100 years
System boundaries include:	
materials	X
energy	X
production	X
use	qualitatively due to lack of data
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	mass and energy
System Expansion	no
Substitution	no
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	
other:	Resources and waste
Data quality	
time	1997, and not more than 5 years old
geography	Denmark
technology	Danish average
Critical review performed	no
Evaluation	
Normalisation	no
Weighting	no
other methods	

Critical Assessment (IPU 041.0032)

Goal description in short	• To identify influential energy consumption and other environmental impacts in the life cycle of sewer components. • Data does not allow conclusions to made as to whether one material is preferable over another. The data can only point out advantages and disadvantages of one solution and indicate data shortages.	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• System boundaries for PVC and other materials are clear. • Functional unit is 1m of pipe and 1 well all with the same specifications. - small pipe: Concrete and PVC - medium pipe: Concrete and PVC - large pipe: Concrete and HDPE - small well: Concrete and PP/PVC combination - large well: Concrete and HDPE • Ecotoxicity not included.	
Life cycle phases	• Use phase excluded due to lack of data. It might still have significant impacts. • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	X
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Products deliver the same service in use phase • No need for maintenance in use • Assumed same handling for laying of pipes and wells in different materials • Precombustion of fuels in energy scenarios are not included due to lack of data.	
Valuation of scope	• The scope is somewhat appropriate to fulfil the goal. Human toxicity via air is included but no other toxicity categories.	
Methodology	• Allocation on mass and energy • Danish and European average power mix	
Data requirements	• Description and discussion of precision level, completeness, representativeness, consistency and reproducibility.	
Inventory	• General considerations on sensitivity and uncertainty of all important parameters. • Quantitative sensitivity analyses carried out important parameters when laying pipes. • Database used: APME • Database from a Software System: EDIP • Gaps of important impacts: Ecotoxicity is not included and human toxicity only via air.	
Impact Assessment	• EDIP • The methodology of assessment complies with ISO 14042. However, there is a lack of description of the excluded toxicity categories.	
Environmental impacts included	• Human toxicity via air is included but no other toxicity categories. No arguments presented for this exclusion. • All other impacts are included.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. No third party report is included. However, issues normally presented here are discussed, relevant stakeholders are involved in review group, but no comments herefrom are included.	

The study points out the most important life cycle stages, resource consumption categories etc. for the various components, but specifically states that the study can not and must not be used to conclude which materials are environmentally preferable over others.

The study, nevertheless, comes to some key conclusions:

- For small and medium sized pipes the laying of pipe is most influential, especially the digging and transport of materials to fill around pipes and wells. The important parameters are:
    - Degree of material reuse
    - Width and depth of digging
    - Distance to gravel pit and intermediate storage

The significance of the pipe laying process on impacts for smaller pipes may be explained by the relatively lower material consumption required compared to that of larger pipes, because there is only a small difference in the work required to dig and lay the pipes of different diameters.

- For large pipes and all well types the material stage is the most important.
    - For concrete pipes this is due to energy required for excavation of materials and energy required for producing cement.
    - For plastic pipes this is due to feedstock energy in the material and energy required for producing the polymer.
- Plastic pipes have not yet been in the ground for a full lifetime and thus their lifetime can only be estimated.
- It is advisable to reuse/recover material after use. However, no environmental burdens are expected if the old pipes are left in the ground.
- Significant data gaps still exist.

A comprehensive use phase and end-of-life modelling effort would be preferable, as the (real) lifetime of the pipes, as well as the quality of the material after the use phase, influences the environmental impact. A longer lifetime influences the results due to the lower need for production and installations of new pipes. The quality of the pipe (e.g. contamination) will affect the quality of the gainable secondary product.

The study explains to manufacturers (here considered to be the producers of pipes):

- No general comparison of materials is made.

The study explains to users (constructors of sewer systems):

- Very important are the processes involved when laying pipes, i.e. reuse of the soil and gravel, width of trench for pipes, and distance to gravel pit and disposal location for old gravel/soil etc.
- It is important to reuse or incinerate old pipe material.

The study explains to third parties: No considerations for third parties.

Table 5-20: Life cycle phases of IPU 0032 small and medium pipes

IPU 0032	PVC	PP	HDPE	Concrete
Production phase	Not primary relevant	Not primary relevant	Not primary relevant	Not primary relevant
Use phase	Digging, laying are important, durability advantages	Digging, laying are important	Digging, laying are important	Digging, laying are important, heavier
Recycling	Degree of reuse important, but quality aspects after 100 years of use are to be monitored.	Degree of reuse seems important, but PP from pipes seems not to be preferable PP for recycling (contamination)	Degree of reuse seems important, but PP from pipes seems not to be preferable PP for recycling (contamination)	Reuse questionable, as other sources of used concrete much easier to access.

Table 5-21: Life cycle phases of IPU 0032 large pipes

IPU 0032	PVC	PP	HDPE	Concrete
Production phase	Material production gains importance (feed stock energy increasing)	Material production gains importance (feed stock energy increasing)	Material production gains importance (feed stock energy increasing)	Cement production is increasing the importance
Use phase	See above	See above	See above	See above
Recycling	See above	See above	See above	See above

Life cycle of sewage pipes (IPU 000.0057)

Documentation sheet (IPU 000.0057)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Miljørigtig projektering af kloakfornyelse i Herning
(Environmentally correct handling of sewer renewal in Herning)</td></tr>
<tr><td>Scope of investigation</td><td>Renovation of sewer pipes</td></tr>
<tr><td>Year of publication</td><td>1997</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>Genanvendelsesrådet (spons); Nellemann, Nielsen & Rauschenberger A/S; Herning Kommune</td></tr>
<tr><td>Contractor/ Address</td><td>Danish EPA, Strandgade 29, DK-1401 København K, Denmark</td></tr>
<tr><td>Authors</td><td>Unknown</td></tr>
<tr><td>Availability/Publisher</td><td>On website www.mst.dk</td></tr>
<tr><td>ISBN</td><td>ISBN 87-7810-768-7</td></tr>
<tr><td>Keywords</td><td>Sewer pipes, sewer renovation</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th></th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparing concrete pipes, PVC pipes and PE lining</td></tr>
<tr><td>Reported data</td><td>LCA, LCC</td></tr>
<tr><td>Short description of the study</td><td>Environmental screening in connection with actual renovation of sewer pipe</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td>X</td><td>Profound</td><td></td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>100%</td><td>Specific/own/new data</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (IPU 000.0057)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	Selected environmental impacts
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Sewage components
Functional unit	Not specifically stated but is 50m of pipe
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	not described
System Expansion	not described
Substitution	not described
Data categories described	
Primary energy consumption	Described that secondary energy used in construction
Air emissions	Described
Water emissions	Described
Waste categories	Described
Impacts	
Global warming	Not used
Acidification	Not used
Nutrient enrichment	Not used
Tropospheric Ozone Formation	Not used
Stratospheric Ozone Depletion	Not used
Toxicity, human	Not used
Toxicity, eco	Not used
other:	working environment, resources, energy
Data quality	
time	Not stated
geography	Not stated, but Denmark
technology	Not stated, but average
Critical review performed	No
Evaluation	
Normalisation	Not performed
Weighting	Not performed
other methods	

Systematic Characterisation (IPU 000.0057)

Goal description in short	1. To participate in and test methods in practice described in "Håndbog i miljørigtig projektering" - in English "A Guide to Environmental Management in Project Design" 2. To illustrate selected environmental aspects on sewage-pipe renovation and to assess the possibility of including environmental demands in the selection of contractors.	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• Comparison of four methods for renovation of sewer pipes 1. Excavation and application of concrete pipes as combined sewer system 2. Excavation and application of PVC pipes as combined sewer system 3. No-dig rehabilitation by polyester stocking as combined sewer system 4. Excavation and application of concrete pipes as separate sewer system. System boundaries are clear. • Functional unit is described but vaguely quantified.	
Life cycle phases	• All life cycle stages included • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Energy consumption only as secondary energy, assuming higher consumption means higher impacts. No differentiation in fuel type	
Valuation of scope	• The scope is appropriate to fulfil the goal, both regarding methodological development and in selection parameters of contractors.	
Methodology	• No general considerations	
Data requirements	• No discussion of completeness, representativeness precision level, consistency and reproducibility.	
Inventory	• No general considerations on sensitivity and uncertainty. • Database used: Combination of industry information (Norsk Hydro and Danish pipe contractor) and databases (APME and Danish EPA reports) None. • Database from a Software System: Not used • Gaps in important impacts: - only energy consumption, resource consumption, working environment, and inconvenience to local citizens considered. - no toxicity parameters included	
Impact Assessment	• Not performed • The methodology of assessment does not agree with ISO 14042.	
Environmental impacts included	• No quantification of environmental impacts.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met.	

The study comes to the following key conclusions:

- It is environmentally advantageous to use no-dig solutions, as inconveniences the local community to a smaller degree and reduces energy consumption associated with manufacturing and pipe renovation.
- However, the dig up solution gives presents opportunity to perform other maintenance jobs at the same time.
- The concrete pipe consumes fewer resources in comparison to the supply horizon of the materials.
- The PVC pipe is lighter but requires the consumption of more scarce resources, hence, resulting in a higher weighted resource consumption indicator when compared with the concrete pipe.
- The concrete is recycled but with loss of material quality – PVC is not recycled to a high degree today but is potentially recyclable with only low loss of material quality.
- No conclusions can be reached based on the parameters included in the study.
- The study points out that no attempt is made to make generalisations based on the one location where the project takes place.

The study explains to manufacturers:

- It cannot be concluded which material is best based on the parameters included in the study.

The study explains to users:

- If users of pipes are citizens, then the study explains that no-dig solutions result in lower inconvenience to the local community.
- If users of pipes are contractors of sewage renovation then it is outlined that it is of utmost importance to reuse the soil from digging at the site.

The study explains to third parties:

- A guideline is given for parameters which can be used as selection criteria by contractors.

Table 5-22 summarises the analysed impacts of the two different systems.

Table 5-22: Summary of the analysed impacts of IPU 0057

IPU 0057	**PVC pipes**	**Concrete pipes**	**Impact**
Production phase	Higher due to lower resource base	Lower due to less consumption of scarce resources	resource consumption
	Higher	Lower	energy consumption
Laying of pipe	No documented differences	No documented differences	
Use phase	No active processes in use of pipe	No active processes in use of pipe	
Recycling	Lower degree of recycling but potentially a high degree of recycling with only little loss of material quality	High degree of recycling but with major loss of material quality (used in e.g. road construction)	material quality

Lifecycle Assessment of Pipeline Systems (IKP CH-5)

Documentation sheet (IKP CH-5)

<table>
<tr><td>Kind of report</td><td>Report</td></tr>
<tr><td>Title</td><td>Life Cycle Assessment of Pipeline Systems</td></tr>
<tr><td>Scope of investigation</td><td>Potable water supply and sewage disposal for a detached family house development</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1980 to 1994</td></tr>
<tr><td>Institution or Company</td><td>Eidgenössische Materialprüfungs- und Forschungsanstalt,
Überlandstr. 129, 8600 Dübendorf, Switzerland</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Eidgenössische Materialprüfungs- und Forschungsanstalt</td></tr>
<tr><td>Availability/Publisher</td><td>Eidgenössische Materialprüfungs- und Forschungsanstalt,
Überlandstr. 129, 8600 Dübendorf, Switzerland</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>production, building, drinking water, sewage disposal</td></tr>
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<tr><td>Comparison with alternatives</td><td>Comparison between HDPE, unplasticised PVC and cast iron for potable water supply and HDPE, unplasticised PVC and stoneware for sewage pipes.</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Extensive study about drinking-water supply and sewage disposal in a one-family house in an urban area with a focus on environmental impacts according to ISO 14040. Only the production phase is considered. Critical review was performed. The study in hand is only the summary report and includes only aggregated impact values. A detailed inventory analysis is not included. Weak-point analysis and evaluation with interpretation have been carried out.</td></tr>
<tr><td>Expert judgement</td><td>
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<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
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Comment: Suggested for **systematic characterisation**
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Systematic characterisation (IKP CH-5)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
Main technical systems properly described	X
Function analysed	potable water supply / sewage disposal
Functional unit	**1.** Construction of a potable water system for the potable water supply of a detached house development of 21 units **2.** Construction of the sewage system for the sewage disposal of a detached house development of 21 units
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	
recycling	
transportation	X
Allocation (mass/price/energy)	mass and energy
System expansion	
Substitution	
Data categories described	
Primary energy consumption	Sufficient
Air emissions	Sufficient
Water emissions	Sufficient
Waste categories	Sufficient
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	
Data quality	
time	1980 to 1995
geography	Europe (some data referred only to German conditions)
technology	average and specific
Critical review performed	X
Evaluation	
Normalisation	
Weighting	
Other methods	

Critical Assessment (IKP CH-5) part 1

Description of goals	• Life cycle assessment for installation of pipeline systems, using the potable water supply and sewage disposal in a detached family house development as a case study. • Materials for the potable water supply: HDPE, unplasticised PVC and cast iron. • Materials for the sewage pipes: HDPE, unplasticised PVC and stoneware. • Additional objectives were fixed: gaining experience within the scope of a cross-sector life cycle assessment project, providing an information basis and contributing to the development of standards.	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• Adequate system boundaries for the construction of the potable water supply system and the sewage system. Transportation is included. • The use and the disposal phases are not included. • The infrastructure (buildings, traffic roads, etc.) is not included in the assessment	
Life cycle phases	• Preliminary processes: provision of energy, materials production • Production of incidentals: hydrants, slides, control shafts, etc. • Transport. • Pipe laying work. • Disposal assessed separately.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• With respect to the installation of the pipeline systems, a model case example is assumed, i.e. professional and correct laying works. Possible damages (such as fractures or burst of pipes, corrosion, deformations, caving-in, defective seals, outlet blockages, damage to junctions or connection pieces) are not considered. • The study assumes that the building ground is free of specific anomalies and thus does not require special expenditure. • Assumptions regarding means of transport largely refer to truck transport. • Assumptions are clear and understandable, not having a great influence on the conclusions.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• Allocation inputs and outputs in the preliminary stages of polymer production were made on the basis of physical parameters (mass and energy) • Recycling material used to manufacture the construction components under review is included in the assessment together with the expenditure incurred for processing and, where available, the thermal value.	
Data requirements	• Quality of data is provided in terms of time-related and geographical data coverage, completeness and representativeness. • Data equivalence between different materials is assessed. Equivalence of data is achieved for plastic products and stoneware, but not for cast iron (individual data surveys and statistics for the cast iron industry could not be obtained).	
Inventory	• Important topics of the LCI model are discussed. • Data for provision of energy carriers from the study “Ökoinventare für Energiesysteme” (ESU-ETH 1994). Data on the provision and fuelling of thermal energy were also obtained from ESU-ETH 1994. • Data related to plastics manufacture are taken from the APME database and from surveys to the industry collected by EMPA. Multi-layer pipes made of unplasticised PVC are produced by using a 50% recycling share to which processing and associated transports are assigned. • Data for stoneware is obtained from bibliographic references and ESU-ETH 1994 data base. A share of 23.5% of broken pieces and recycling material are used as secondary raw material, i.e. processing and associated transports are taken into account. • Data-concerning cast iron production originates from EMPA databases and ESU-ETH and reflects German rather than European conditions. For the recycled portion (73%), only expenditure incurred through transport and processing of cast scrap is considered. • For sewage systems, data on HDPE, unplasticised PVC and stoneware was based on current, Europe-wide information. For potable water systems, data on cast iron reflected only German conditions, in comparison to data on plastics that referred to all of Europe. • The following sensitivity analyses are carried out on the basis of energy demand: impact on the allocation key on unplasticised multi-layer pipes with 50% recycling share; impact of pipe diameters; impact of a greater laying depth for the sewage system; impact of useful life; impact on setting up in groundwater holding soils. • The study takes into account the following new pipe developments in the sewage sector: unplasticised PVC ULTRA RIB pipes, unplasticised PVC multi-layer pipes with a 50% recycling share and thin-wall stoneware pipes. Data were only collected from a few plants. • No gaps of important impacts.	
Impact Assessment	• The determination of impact potential is based on the methodology developed by CML (1992), whereby a difference is made with a global or regional approach. • Deviations from ISO 14042 are not important.	

Critical Assessment (IKP CH-5) part 2

Environmental impacts included	•The included impact categories are appropriate to fulfil the goal. •The use of recycled material exerts a substantial effect on ecological impact and energy demand.
Weighting of environmental parameters	•
Overall ISO 14040 ff requirements	•The overall requirements of the ISO 14040 are met.

The study provides a comparison of the different manufacturing processes for materials used in the set up of potable water supply systems (HDPE, PVC and cast iron) and sewer systems (HDPE, PVC and stoneware). The use and disposal phase are not considered.

The choice of the functional unit (potable water supply system and sewage system for 21 detached houses) may influence the obtained results.

The assessment was based on an “abbreviated version” of the study. Therefore, some impacts could not be evaluated in detail.

The study comes to the following key conclusions:

- In HDPE and unplasticised PVC systems, eutrophic and acidifying emissions play a somewhat greater role in comparison to other materials (cast iron and stoneware).
- Using recycled material for the manufacture of plastic pipes provides considerable optimisation potential.
- A preference for individual materials cannot be justified based on the life cycle assessment results.

Sensitivity analysis carried out on pipe diameter showed a marked increase in energy demand of plastic pipes compared to that of cast iron and stoneware pipes. This may be related to the relatively lower firmness of plastics which, for static reasons, leads to a larger wall thickness.

It should be pointed out that the main objectives of this study were to carry out a case study in order to gain experience in LCA, to provide an information basis to support optimisation efforts in complex systems, to contribute to a more objective discussion on materials/product systems, and to contribute to the development of standards in relation to life cycle assessment methodology.

Table 5-23 summarises the analysed impacts of the different systems.

Table 5-23: Summary of the analysed impacts of IKP-CH-5

Impact categories	HDPE potable water pipes	Unplasticised PVC potable water pipes	Cast Iron potable water pipes
Energy demand	Highest energy demand per production step (approx. 130% of PVC and cast iron), dominantly consumed in the production step.		
Waste volumes		Largest amount of non-toxic chemicals (approx. double that	Largest amount of mineral wastes produced from iron

		of HDPE) and toxic waste (more than 10 times that of HDPE and 4 times that of cast iron). It should be taken into account that these categories were only considered in APME reports.	ore mining (the waste remains at the mining facility as inert material) Largest amount of slags generated primarily during the blast furnace process
Greenhouse effect			Highest greenhouse potential (approx. 1,5 times of PVC and HDPE)
Acidification potential		Highest acidification potential, approx. 35% more than HDPE (due to NOx and SOx emissions)	
Nutrification potential		Highest nutrification potential (approx. 80% more than cast iron and 25% more than HDPE) due to NOx emissions to air during plastic manufacturing.	
Impact categories	**HDPE sewage pipes**	**Unplasticised PVC sewage pipes**	**Stoneware sewage pipes**
Energy demand	Highest energy demand (approx. 14% more than PVC and stoneware)		
Waste volumes	Highest amount of non-toxic chemicals and toxic waste (only considered in APME reports).		
Greenhouse effect			Highest contribution to global warming potential (approx. 12% more than PVC). This is due to the release of CO_2 emissions in cement production.
Acidification potential		Highest acidification potential due to nitrogen oxide and sulphur oxide emissions, similar to water potable systems.	
Nutrification potential		Similar to water supply systems, highest nitrification potential due to nitrogen oxide emissions.	

Comparative LCA of PVC and zinc gutter systems (RANDA FR.001)

Documentation sheet (RANDA FR.001)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>ACV comparative de gouttières en PVC avec des gouttières en zinc.</td></tr>
<tr><td>Scope of investigation</td><td>Pipeline systems; comparative LCA of PVC and zinc; extraction, production and end-of-life steps</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1998</td></tr>
<tr><td>Institution or Company</td><td>Société ELF ATOCHEM</td></tr>
<tr><td>Contractor/ Address</td><td>ATOFINA
4-8, cours Michelet, La Défense 10, 92091 PARIS LA DEFENSE cedex FRANCE
phone: +33 1 49 00 80 80; fax: + 33 1 49 00 83 96</td></tr>
<tr><td>Authors</td><td>Équipe ACV of Elf Atochem</td></tr>
<tr><td>Availability/Publisher</td><td>Confidential (internal report), nevertheless this study has been provided to Randa by Forum PVC France with permission of Elf Atochem.</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>ACV, comparative, PVC, Zinc, pipes, building, Elf Atochem, virgin and recycled material.</td></tr>
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Qualitative/Quantitative</td><td>
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</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison between virgin PVC, 9% recycled PVC, virgin zinc and 40% recycled zinc.</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to compare the environmental impacts of materials used in a stormwater pipeline system (virgin PVC, 9% recycled PVC, virgin zinc and 40% recycled zinc). The study considers the stages from extraction of raw materials to final disposal after demolition; however the use phase is not included.</td></tr>
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<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
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Comment: Suggested for systematic characterisation.
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Systematic Characterisation (RANDA FR.001)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	
Aim of study	X
Target group of study	
Scope, description of	
Main technical systems properly described	X
Function analysed	stormwater pipes
Functional unit	A) stormwater pipeline made of 24.98 kg of virgin PVC versus stormwater pipeline made of 52.79 kg of virgin zinc B) stormwater pipeline made of 22.66 kg of virgin PVC + 2.32 kg of recycled PVC versus stormwater pipeline made of 31.67 kg of virgin zinc + 21.12 kg of recycled zinc
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	
recycling	X
transportation	
Allocation (mass/energy/price)	
System Expansion	
Substitution	
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	critical volume air and water[26]
Data quality	
time	Not reported for all data
geography	Europe
technology	Average
Critical review performed	no
Evaluation	
Normalisation	
Weighting	
other methods	

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[26] Critical volumes are calculated by dividing the flow (mg in the functional unit) by the maximum concentration of the substance according to current regulations.

Critical Assessment (RANDA FR.001)

Description of goals	• Comparison of zinc and PVC stormwater pipes.	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• System boundaries for PVC and zinc: do not include common phases for both materials (transport, installation, use and maintenance, decommissioning, collection of the recycled fraction, disposal, etc.), which are left out of the system boundaries. • Two options were studied. The use of 100% raw materials versus a mix of recycled and raw materials (for both PVC and zinc).	
Life cycle phases	• Extraction and disposal phases included • Use phase not included • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	X
Important assumptions	• The transport, installation, use and maintenance, dismantling and disposal are equivalent in all the alternatives that are accounted for. • Lifetime is assumed to be the same for all cases studied. • The non-recycled material is supposed to go to landfill. • The data regarding the technology of raw-zinc production are supposed to be those of the Boustead report. • The production of recycled zinc - supposed to be melted in order to obtain ingots • 1 kg of recycled PVC replaces 1 kg of raw PVC • For producing 1 kg of recycled PVC 1 KWh of electric energy is needed • Assumptions are clear and understandable. However, their influence on the conclusions should be further investigated.	
Valuation of scope	• The scope is not appropriate to fulfil the goal.	
Methodology	• No information on allocations.	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are not always stated.	
Inventory	• LCI model is not discussed, but simply mentioned. • Sensitivity of inventory parameters is <u>not</u> discussed. • Original data from industry used, along with data from recognized data bases and publications: APME, BUWAL, BOUSTEAD. • Common phases for materials compared are not included.	
Impact Assessment	• The methodology of assessment does not agree with ISO 14042. The study was performed before the publication of this standard.	
Environmental impacts included	• Limited number of impact categories included (Global warming, tropospheric ozone formation, eutrophication and acidification, critical volume approach).	
Weighting of environmental parameters	• Use of weighting methods not indicated.	
Overall ISO 14040 ff requirements	• There was not enough information to judge whether the overall requirements of the ISO 14040 ff were met.	

The study provided is a summary of the original extended document. Although all inventory data are supplied, there is a lack of information on data sources, assumptions made and system boundaries.

The study comes to the following key conclusions:

- PVC storm water pipes (containing 9.3% recycled material) are the preferred option over zinc pipes (containing 40% recycled material). This includes almost all impact categories except for water consumption for cooling. However, it should be noted that the use phase was not considered.
- For both materials, use of a mixture of recycled and virgin raw materials is preferable over using pipes made of 100% virgin material.

<u>The study explains to manufacturers:</u>

- Environmentally speaking, PVC (recycled or virgin) is the better option when compared with zinc pipes. The use of recycled materials is preferred over the use of 100% virgin material.

The study explains to users:

- The study does not consider the use phase and does not offer a lot of information to the user.

The study explains to third parties:

- PVC is, environmentally-speaking, preferable over zinc, even when using a mixture of virgin and recycled materials.

Table 5-24 summarises the analysed impacts of the two different systems.

Table 5-24: Summary of the analysed impacts of Randa FR.001

RANDA FR.001	**Zinc pipe (100%)**	**PVC pipe (100%)**	**Zinc (40% recycled)**	**PVC (9.3% recycled)**
Overall life cycle	For impacts in terms of consumption of natural resources and potential impacts (such as greenhouse effect and acidification) zinc ranges from 1.6 to almost 5 times more than PVC pipes (100%) in various categories. The largest differences are in air and water pollution (almost 5 times that of PVC).		There is less of a discrepancy between the impacts of recycled zinc and recycled PVC. Values for zinc range from 1.24 to almost 3.5 times the impacts of recycled PVC. The major differences are in the areas of water pollution (3.5x) and air pollution (3x).	
	Zinc consumes less water (0.8 m^3) than PVC (1.9 m^3).		Zinc consumes less water (0.5 m^3) than PVC (1.7 m^3). The consumption of cooling water is much larger for plastic production than metallurgy.	
	Zinc (100%) creates 357 kg of landfill waste in comparison to 2.6 kg by PVC (100%). This is mainly due to zinc extraction in the mine.		Recycled zinc pipes create 214 kg of landfill waste compared to 2.5 kg by recycled PVC. Recycling is considered the environmentally favourable option for both PVC and zinc.	

Summary for Pipes

The main materials used for pipe production are PVC, HDPE, PP, concrete, fibre-cement, clay, cast iron and stoneware. Zinc and ABS are also used but assessed only in one study.

The results on pipes are very heterogeneous. Some studies see advantages for concrete and fibre cement pipes, some report advantages for polymer pipes such as PVC and PE, some conclude that the material plays no role as long as cast iron is not chosen and some studies that analysed a variety of impacts report very individual advantages and disadvantages for the different materials.

The important parameters for pipes (also related to environmental impacts) are flexibility in shapes, durability, weight and leak-tightness.

The environmental impacts of the **pipe production** are dominated by the production of the specific materials.

There is no consistent conclusion made by the different studies regarding the **installation** of the pipes. Statements like “installation is not relevant” or “no statement possible” as well as “installation has significant influence on environmental impacts” are found.

We expect the laying and digging process for underground pipes to be very relevant. Therefore, smaller and lighter pipes are expected to have environmental advantages over the life cycle.

From our point of view the digging, laying and installation processes are not analysed sufficiently. However, for underground pipes relevance of these procedures does seem to be accounted for.

The assessment of gas distribution systems shows that gas leakage during the **use-phase** leads to a significant increase of the photochemical oxidant formation and global warming potential categories.

End of Life (EoL) related issues have been considered within the different studies in a variety of ways. EoL has been handled either by considering a certain percentage of recycled content within the material used for production, by energy recovery or by considering pipes as inert and therefore left in the ground. Even if EoL is handled in different ways the leading message is that recycling has a positive effect on the environmental impact and shows potential for improvement.

An enhanced use of recycling material may be especially interesting for pipes because optical requirements of the pipes are often low (as pipes are not often visible) and because coextrusion is a widespread technology allowing to get good surfaces by useing recycled material in a middle layer.

There is no consensus throughout the assessed studies as to which material is preferable for pipe applications when considering the **total life cycle**. Either the study came to the conclusion that there is no preferable material for the assessed application (sewage/wastewater, water supply, gas distribution) or there is no consensus among the studies.

Those studies that integrate the installation, maintenance and renovation, conclude quite similarly that the choice of material is of less importance. The properties of the pipes, which are defined in production by choosing e.g. material, diameter and technical properties, influence the environmental impacts significantly. That does not mean that the production of the materials is irrelevant.

The differences in results and interpretation are mainly due to differing **goal and scope** of the studies and the different ways of interpretation (CML, EDIP, Eco-indicator, on inventory level, single point). One study shows by applying different evaluation methods (CML, EDIP and Eco-Indicator) that the results are influenced by the applied method.

Most of the studies indicate a specific **lack of data** and are also based on different databases. Several studies use more than one database as source of data and among the studies, the functional unit and lifetime differs. **Consistency** of the data regarding time, place and appropriateness is not a priority.

Two different forms of **documentation** are typically used within LCA studies; either specifically documented for LCA experts (detailed on a unit process level) or more generally documented for decision makers (technical description of rolled up processes). Within the assessed studies either more general descriptions or none at all were found. Due to confidentiality issues, detailed documentation on a unit process level are often not possible within published LCA studies.

When conducting further studies it should be ensured that they are based on a consistent database.

No studies on ventilating pipes and cable channels have been found. Considering the production of the PVC version of these applications no significant difference to the assessed are expected but it is not possible to transfer the results because these applications have additional competing materials (e.g. aluminium, copper, etc.).

Further studies should be undertaken when new designs are within their development phase in order to integrate an environmental view point into the design process. The goal should be to consider the environmental impact as early as possible in the design to be able to reduce the environmental impact with minimal effort.

Further general studies on sewage (wastewater), water supply and gas distribution pipes should not be the primary focus. It would, however, be beneficial if a general study would be conducted within the same boundary conditions and functional unit on the basis of one consistent database considering the total life cycle.

5.1.5 Other Building/Construction

Product LCAs and application in construction industry (IKP D-9)

Documentation sheet (IKP D-9)

<table>
<tr><td>Kind of report</td><td>Research Project</td></tr>
<tr><td>Title</td><td>Produktökobilanzen und ihre Anwendungsmöglichkeiten im Baubereich</td></tr>
<tr><td>Scope of investigation</td><td>Product Life Cycle Assessments and their application in construction industry</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1990 to 1993</td></tr>
<tr><td>Institution or Company</td><td>Umweltbundesamt, Postfach 33 00 22, 14191 Berlin, Germany</td></tr>
<tr><td>Contractor/ Address</td><td>Umweltbundesamt, Postfach 33 00 22, 14191 Berlin, Germany</td></tr>
<tr><td>Authors</td><td>Prof. Dr. Walter Klöpffer, Dr. Ruth Wittassek, Dipl.-Ing. Alexander Rudolphi</td></tr>
<tr><td>Availability/Publisher</td><td>Umweltbundesamt, Postfach 33 00 22, 14191 Berlin, Germany</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>LCA, ecobalances, PVC, construction industry</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison of PVC products in construction industry with according products made of other materials</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The report is a summary of many studies about PVC products in the construction industry and equivalent products made of other materials. Part one describes the methodology used, with goal and scope definitions, functional units and data quality. Part two contains the inventory analyses, and part three describes scenarios and applications of LCA studies in an aim to compare selected components.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
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<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td>X</td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td>X</td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: The study summarises other LCA studies. This is not a pure LCA study as such, but deals with quantitative LCA impacts in a scientific way. Therefore a systematic characterisation is suggested.
</td></tr>
</table>

Systematic characterisation (IKP D-9)

Overall frame of study	
ISO 14040 ff	X
Code of practice	no
Other	no
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Building products
Functional unit	according to the specific function
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	as with the literature sources (e.g. BUWAL and APME)
System Expansion	as with the literature sources (e.g. BUWAL and APME)
Substitution	as with the literature sources (e.g. BUWAL and APME)
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	impacts are not calculated
Global warming	not specified
Acidification	not specified
Nutrient enrichment	not specified
Tropospheric Ozone Formation	not specified
Stratospheric Ozone Depletion	not specified
Toxicity, human	not specified
Toxicity, eco	not specified
other:	not specified
Data quality	
time	1990 to 1993
geography	Germany
technology	average
Critical review performed	X
Evaluation	
Normalisation	not specified
Weighting	not specified
other methods	not specified

Critical Assessment (IKP D-9)

Description of goals	• Ecological-material comparison of building materials. Therefore, the methodology of life cycle assessment is used to compare case studies of building materials as well as different raw-material sources for the building materials. The methodology is to be enhanced for the specific needs.	
Valuation of the goal	• The goal is sufficiently described.	
Scope of study	• Life cycle inventories of building materials with focus on production phase	
Life cycle phases	• Production phase, use phase and end of life	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Cut-off criteria: Materials with less than 10 % weight are not included • Main data sources are from literature and therefore the assumptions are adopted. • The use phase is not considered in the first step and it is specifically stated that the specific boundary conditions have to be considered in every application.	
Valuation of scope	• The scope is appropriate to fulfil the goal of providing a material database.	
Methodology	• Life cycle assessment focussing on specific needs.	
Data requirements	• The data requirements are stated in detail.	
Inventory	• Important topics of LCI model are discussed. • Sensitivity of inventory parameters is discussed. • Database used: BUWAL 1991, APME 1993/94 and manufacturer data. The study uses mainly literature data and from a combination of different sources. • Main inventories are covered. • The inventories are calculated for the supply chain of intermediate products for use in building industries	
Impact Assessment	• An impact assessment was not calculated.	
Environmental impacts included	• None	
Weighting of environmental parameters	• No weighting performed	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff are mainly met.	

The study comes to the following key conclusions:

- A structured cooperation between industry, science and public authorities is necessary in order to draw up meaningful ecoprofiles.
- The comparison of different materials is only possible with specific boundary conditions for special applications.
- Transparent and comprehensive documentation of the data is necessary to ensure further use of it.
- Flooring materials considered were PVC, polyolefin, linoleum and ceramic tiles. In terms of energy consumption and CO_2 emissions in the production phase, the favoured flooring material is linoleum.
- Window frame materials researched were wood, PVC and aluminium. The use phase, a relevant influencing factor of the life cycle, was not considered in detail in the study.
- Ecoprofiles for roofing materials couldn’t be established very well and the incomplete results can not be used in further studies.

<u>The study explains to manufacturers</u>:

- Different manufacturing routes with various raw material routes cause different environmental effects; hence detailed data for specific applications are necessary to get comparable results.

<u>The study explains to users</u>:

- The comparison of different materials is only reasonable with specified boundary conditions for specific applications.

The study explains to third parties:

- Results of life cycle assessment studies must be considered with regard to the background of the specific application.
- The whole life cycle must be considered. For example, in the case of window frames the use phase dominates. Results considering the production phase only often lead to false recommendations.

Table 5-14 summarises the analysed impacts of the two different systems.

Table 5-25: Summary of the analysed impacts of IKP D-9

IKP D-9	PVC window	Al window	Wood window	Impact
Life Cycle	1304 MJ/window	2719 MJ/window	866 MJ/window	Energy equivalent
	1,5 – 1,96 W/m^{2}K	2,0 – 2,8 W/m^{2}K	1,45 W/m^{2}K	Thermal transmission coefficient
	46 kg CO_2-eq.	126 kg CO_2-eq.	9 kg CO_2-eq.	Global Warming Potential

	PVC flooring	Polyolefin flooring	Linoleum flooring	Ceramic tiles	Impact
Life Cycle	200 MJ/ m^2	163 MJ/ m^2	146 MJ/ m^2	271 MJ/m^2	Energy equivalent

Important life cycle stages are not analysed in adequate detail (e.g. use phase of windows). The data cut-off criteria used for inclusion or exclusion of materials (10% of mass) is rough. The data bases used are based mainly on literature data; therefore many assumptions had to be made. Some important environmental impacts are not covered, like Photooxidant Creation Potential, which would affect the results significantly. Therefore, the results of this study can not be used to draw a comprehensive picture of the LCA impacts of building materials, but rather to sketch some related aspects of the topic.

Life Cycle Engineering of building materials and buildings (IKP D-41)

Documentation sheet (IKP D-41)

<table>
<tr><td>Kind of report</td><td>Book</td></tr>
<tr><td>Title</td><td>Ökologische Bilanzierung von Baustoffen und Gebäuden</td></tr>
<tr><td>Scope of investigation</td><td>Life Cycle Engineering of building materials and buildings</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>Institut für Kunststoffprüfung und Kunststoffkunde, Pfaffenwaldring 32, 73265 Stuttgart, Germany</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Peter Eyerer, Hans-Wolf Reinhardt, Johannes Kreißig, Julian Kümmel, Martin Baitz, Michael Betz, Volker Hutter, Konrad Saur, Hartmut Schöch</td></tr>
<tr><td>Availability/Publisher</td><td>Brinkhäuser Verlag Postfach 133 CH-4010 Basel, Switzerland</td></tr>
<tr><td>ISBN</td><td>3-7643-6207-3</td></tr>
<tr><td>Keywords</td><td>LCA, building materials, buildings, LCE</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>comparisons of various building materials (including PVC)</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The book is an extensive assimation of information on various building materials, their processing and their ecological aspects. Detailed inventory analyses and impact assessments are shown for many materials in different components. For all components, the customary materials are analysed and assessed.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>0%</td><td>Specific/own/new data</td><td>100%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td>X</td><td>Industry</td><td>X</td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td>X</td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic characterisation (IKP D-41)

Overall frame of study	
ISO 14040 ff	x
Code of practice	
Other	
Goal, description of	
Application/use of results	x
Aim of study	x
Target group of study	x
Scope, description of	
main technical systems properly described	x
Function analysed	various building materials in applications (including PVC windows)
Functional unit	various
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	stated in background studies
System Expansion	no
Substitution	not reported
Data categories described	
Primary energy consumption	X
Air emissions	not reported
Water emissions	not reported
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	not reported
Toxicity, eco	not reported
other:	
Data quality	
time	1996/97
geography	Germany
technology	average
Critical review performed	
Evaluation	
Normalisation	not reported
Weighting	not reported
other methods	

Critical Assessment (IKP D-41)

Description of goals	Consideration of environmental aspects – regarding the whole life cycle - for decision support in constructional engineering. Not just LCA of building materials, but of whole building. - Optimisation of building materials by analysis of the system (building) performance - Set-up of a consistent LCA database for building products - Identification of application fields of building materials - Weak-point analysis - Component optimisation - Decision support in the field of marketing - Optimisation of process technology - Product and quality control - Support of strategic decisions - Identification of potential changes of social and political general conditions	
Valuation of the goal	• The goal is sufficiently described.	
Scope of study	• Building materials and buildings as well as building components (e.g. PVC windows)	
Life cycle phases	• Whole life cycle	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Regarding the comparison of PVC and wooden windows: The forest is included within the system boundaries of the wooden windows. This means, CO_2 emissions (from the combustion or rotting of wood) are balanced against the amount of CO_2 which was fixed during growth (CO_2 absorption). This means wood is calculated CO_2-neutral over the life cycle.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• LCA according to DIN ISO 14040 ff	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are stated.	
Inventory	• Important topics of LCA are discussed. • Database used: GaBi • No gaps of important impacts.	
Impact Assessment	• The methodology of impact assessment is described. Impact categories cover DIN ISO 14042 except for Toxic potentials and noise pollution.	
Environmental impacts included	• Global warming potential • Acidification potential • Ozone depletion potential • Photochemical ozone creation potential • Eutrophication potential • Primary energy demand - Renewable (water, renewable primary products) - Not renewable • Waste categories	
Weighting of environmental parameters	• Not reported	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff are met.	

The study comes to the following key conclusions:

- No conclusions on the comparison of materials are made, but environmental impact results are given for all relevant building and construction products such as different mineral building materials within different wall constructions, wood components and constructions, different window systems (incl. PVC windows), heating systems, roofing components and floorings.
- Besides the production of the components mentioned above, the impacts of the construction phase and the use phase, and the potential of the recycling of building materials are also included.
- The results and impacts are presented for individual interpretation on inventory and impact category levels for production, transport, maintenance and recycling.
- There is an interrelation between specific components (e.g. PVC window or wood window) and the context of the whole building (e.g. chosen heating system) as well as the local situation (e.g. solar gains). Therefore, it is not adequate to solely calculate the impacts of component production.

- Due to the facts mentioned above, it is not sufficient to just add all impacts of the related materials within a building, if the goal is to get information about the environmental performance of the building as a whole. A methodological approach is needed to assess these effects correctly. The recommended approach is presented.
- An easy-to-use “Design-for–environment” (DFE) software tool based on the information of a professional LCA software tool was developed to make life cycle information easily accessible and interpretable for non-expert users with only a small loss of detailed information.
- Overall, the best potential environmental performance over the life cycle is gained when the quality of the components (e.g. walls, windows, heating system) is optimised with respect to the aimed duty, service or performance in the use phase. Most often these higher efforts in production are amortised through better environmental performance during the service life.

For specific conclusions on PVC windows see IKP D-6 on page 113.

Life cycle assessment of Polyvinyl Chloride and Alternatives (IPU 000.0015)

Documentation sheet (IPU 000.0015)

<table>
<tr><td>Kind of report</td><td>LCA report</td></tr>
<tr><td>Title</td><td>Life Cycle Assessment of Polyvinyl Chloride and Alternatives: Summary report for consultation</td></tr>
<tr><td>Scope of investigation</td><td>Collation trays, flooring, rainwater pipes, window profiles.</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>Unknown</td></tr>
<tr><td>Institution or Company</td><td>ENTEC UK Limited, 17 Angel Gate, City Road, London, EC1V 2SH, UK,
+44 (0) 20 7843 1400</td></tr>
<tr><td>Contractor/ Address</td><td>Chemicals and Biotechnology division of the Department of Environment, Transport and the Regions (DETR)</td></tr>
<tr><td>Authors</td><td>Unknown</td></tr>
<tr><td>Availability/Publisher</td><td>Company or contractor</td></tr>
<tr><td>ISBN</td><td></td></tr>
<tr><td>Keywords</td><td>Flooring, packaging, pipes, window profiles. PVC, PS, linoleum, aluminium, wood</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>LCA on collation trays (PVC or PS), flooring (PVC or linoleum), rainwater pipes (PVC or aluminium), window profiles (PVC or wood).</td></tr>
<tr><td>Reported data</td><td>LCA, Socio-economic</td></tr>
<tr><td>Short description of the study</td><td>Summary of full LCA to be commented by stakeholders.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>80%</td><td>Specific/own/new data</td><td>20%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic characterisation (IPU 000.0015)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Collation trays, commercial flooring, rainwater pipes and windows
Functional unit	(1) Weight of material for an 8 cavity collation tray (2) 1 m^2 of commercial floor for 20 y (3) 1 m of 68 mm diameter rainwater pipe for 25 years (4) Window profile 1.2 x 1.2 m for 30y
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	Mass
System Expansion	
Substitution	
Data categories described	
Primary energy consumption	Sufficient
Air emissions	No information on eco and human toxicity
Water emissions	No information on eco and human toxicity
Waste categories	No report of hazardous waste
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	
Toxicity, eco	
other:	non renewable resources, waste
Data quality	
time	1992 to 1999
geography	UK
technology	BAT and average
Critical review performed	X
Evaluation	
Normalisation	X
Weighting	
other methods	

Critical Assessment (IPU 000.0015)

Goal description in short	• The aim is to inform policy makers about the life cycle of PVC	
Valuation of the goal	• The aim of the study is clearly stated	
Scope of study	• Adequate system boundaries for PVC and other materials. • Inadequate inclusion of impact categories. Eco and human toxicity not included. • General cut-off of 3% mass unless data was available • Many smaller recycling scenarios excluded as unlikely. Seems fair decision. (1) Weight of material for an 8 cavity collation tray (2) 1 m^2 of commercial floor for 20 y (3) 1 m of 68 mm diameter rainwater pipe for 25 years (4) Window profile 1.2 x 1.2 m for 30 y; Window: 1.65 x 1.3 m, two casements	
Life cycle phases	• Use phase excluded for flooring due to lack of data and since assumed similarly for both materials • Otherwise all phases included • Conclusions can be drawn from the LCA stages included.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	X
Important assumptions	• UK Power Mix considered • All material is considered to be landfilled or recycled. No incineration or compost etc. • Release of compounds during accidents/fire is not included. • Waste scenarios analysed: landfill and recycling • Most assumptions are clear and understandable. • CO_2 credit for biomass uptake in material stage and only partly released in disposal at landfill. This difference is not further explained. It is probably all released at a one time and can be further degraded to methane (further increase in global warming).	
Valuation of scope	• The scope is NOT appropriate to fulfil the goal. Policy makers are not fully informed if significant impact categories (eco and human toxicity) are not revealed at least in sensitivity analysis. Macro-risk assessment is performed but results are reflected upon as being included in market price and thus not relevant.	
Methodology	• Mass allocations • Average power mix for UK	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are stated.	
Inventory	• Sensitivity carried out for important material assumptions and data substitutions • Sensitivity of important areas in life cycle not carried out – outside scope of study • Sensitivity analysis does not cover the exclusion of eco and human toxicity. • Database used: ETH, APME, BUWAL, • Database from a Software System: not stated • Gaps of important impacts: Ecotoxicity and human toxicity not included	
Impact Assessment	• The methodology of impact assessment is described. - IPCC for global warming - CML for acidification, ozone depletion and nutrient enrichment. - Ecobilan for resource use. - World Meteorological Organisation for ozone depletion. • The methodology of assessment is in conformity with ISO 14042.	
Environmental impacts included	• The included impact categories are not appropriate to fulfil the goal. Ecotoxicity and human toxicity are not included. A macro-risk assessment is performed after the LCA (covering human and ecotoxicity), but the results are mentioned as being reflected in the cost of production, and hence of no importance.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were met.	

The study comes to the following key conclusions:

<u>Collation (food) trays</u>:

The study underlines that this is only one type of packaging and no general statements on packaging should be drawn on the basis of the study.

The PVC product system performs marginally better, as the impacts are lower in most impact categories.

There are other possible alternative materials that would be interesting to compare.

Flooring:

The linoleum flooring shows a marginally better performance than PVC. It should be noted that the study only covers commercial flooring and may only prove indicative for domestic flooring.

Through a sensitivity analysis, various aspects within both products were found to effect or change the conclusions.

Rainwater pipes

The study does not include the full drainage system but only the pipe itself. However, it is not believed to change the results.

The difference in the two product systems is more significant than in the two product systems above. The PVC pipe performs better than the aluminium pipe. However, if the recycling of aluminium is increased the difference becomes less pronounced.

Window profiles:

A comparison of PVC window profiles with aluminium window profiles is also considered to be of interest but is not performed.

The difference between the wood and PVC window profiles is significant, as the wood profile performs better than the PVC profile. The parameters included in the sensitivity analysis did not change the result.

The study explains to manufacturers:

- Consider risks in production.

The study explains to users:

- There are more risks connected with the use of PVC, although the environmental profile under normal circumstances might prove favourable for PVC.

The study explains to third parties:

Policy makers should not only take into account environmental performance analysed by means of LCA. They should also consider aspects like the impact on employment in the PVC and alternative materials' industries, the actual availability of suitable alternative product materials, the willingness of individuals to pay for alternative products (if they are more expensive), and the perception of risks and performance from products themselves.

Table 5-26 summarises the analysed impacts of the different systems.

Table 5-26: Summary of the analysed impacts of IPU 0015

Collation trays	PS	PVC	Impacts
Total life cycle	Marginally higher global warming impact than PVC	Marginally lower global warming impact	**GWP**
	20% higher than PVC	Lower consumption of total primary energy	**Fossil Primary energy**
	Equal amounts	Equal amounts	**Municipal waste**
	no information	no information	**Hazardous waste**
	Marginally higher formation of photochemical ozone than PVC	Marginally lower than PS	**Photochemical ozone formation**
	Overall contribution to nutrient enrichment is low but marginally higher for PVV	Overall contribution to nutrient enrichment is low but marginally lower than PVC	**Nutrient enrichment**
	Approx. double the resource consumption of PVC	Approx half the impact of PS	**Consumption of non-renewable resources**
	Negligible	Negligible	**Ozone depletion**
Flooring	**PVC floor**	**Linoleum floor**	
Total life cycle	11% more than linoleum		**GWP**
		15% larger consumption than for PVC	**Total Primary energy**
	Equal amounts of waste	Equal amounts of waste	**Municipal waste**
	Relatively greater for PVC		**Acidification**
	Not stated	Not stated	**Hazardous waste**
		Linoleum performs relatively worse. Most emissions take place in rural areas.	**Photochemical ozone formation**
	Emissions are 100 times lower	Emissions are 100 times higher	**Nutrient enrichment**
	15% higher consumption		**Renewable resources**
	Negligible	Negligible	**Ozone depletion**
Rainwater pipe	**Aluminium pipe**	**PVC pipe**	
Total life cycle		approx 50% of Al pipe	**GWP**
	60% higher consumption than PVC		**Total primary energy**
	50% less waste		**Municipal waste**
		PVC pipe has 50% lower contributions	**Acidification**
	Not stated	Not stated	**Hazardous waste**
		PVC pipe has 50% lower contributions	**Photochemical ozone formation**
	Higher, but total impact is very low	PVC performs better,	**Nutrient enrichment**
		Consumption is similar with PVC performing slightly better	**Consumption of non-renewable resources**
	Negligible	Negligible	**Ozone depletion**
Windows	**PVC window profiles**	**Wood window profiles**	**Wood window**
	Marginally more emissions	Marginally less emissions	**GWP**
	Marginally more	Marginally less	**Total primary energy**
		43% less waste than PVC system	**Municipal waste**
Total life cycle		20% lower emissions	**Acidification**
	Not stated	Not stated	**Hazardous waste**
	Approx 50% as wood profiles		**Photochemical ozone formation**
		Wood has a factor of 40 higher impact	**Nutrient enrichment**
	Almost equal	Almost equal	**Consumption of non-renewable resources**
	Negligible	Negligible	**Ozone depletion**

The study aims to educate policy makers using the tool of LCA, but it fails to use the strength of LCA; providing an integral overview of the life cycle. Some relevant processes are left out (drainage and installation systems of pipes and the limitation of the considered use phase aspects of flooring for private use) which may affect the results and conclusions.

Summary other building/construction

The studies presented in this chapter focus on different applications and functional units. The outcomes of those applications already addressed in other chapters have been integrated into their respective chapter summaries.

Studies like IKP D-41 don't make comparisons; they rather provide basic information for the planning process. The cradle-to-gate[27] LCA information for the production of building products is necessary for the assessment of the total building but alone not sufficient for such an assessment. The best material has to be selected case-by-case.

There is not a specific gap within the field of construction products. However, if the database were more detailed, more planers could be encouraged to use it.

The integration of LCA information into the planning process requires representative information for all product groups[28]. Instruments of IPP like Environmental product declarations could help to provide such information.

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[27] Since the assessment is including all steps from ressource to the production, it is cradle-to-gate process chain

[28] knowing that the planning process needs to integrate economic and social aspects as well.

5.2 Toys / sports goods

Within this sector only the inflatable toys made from soft-PVC play a significant role. It accounts for approximately 3% of the total PVC mass stream; nevertheless, PVC is a major material within this application.

Due to the relatively low significance of PVC in this sector, no classic comparative LCA study could be identified. Rubber and polyester are the principal competing materials for PVC within this application.

Associated with the use of soft PVC is the use of plasticisers. Only one study with some relation to a life cycle viewpoint could be identified.

Table 5-27 shows an overview of the market share situation of the toys/sports goods sector.

Table 5-27: Overview of toys and sports-goods sector

Sector	PVC Application	principal competing materials (PCM)	share of used PVC mass	market share of PVC
toys/sports goods:				
	dolls, bath ducks, snorkels	polyolefins, wood	< 0.1%	small
	inflatable beach toys, balls, paddling pools	**rubber,** polyolefins	3%	major
	rubber boats, rafts	composites, PUR, **rubber**		
	building blocks, play figures	polystyrene, polyolefins	negl.	negl.
	camping/tents	**rubber,** TPE	< 0.5%	medium
	luggage	leather, cotton, **polyester,** ABS, PUR	1%	medium

Phthalates in Toys and Childcare Articles (RANDA EU.003)

Documentation sheet (RANDA EU.003)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>The Availability of Substitutes for Soft PVC Containing Phthalates in Certain Toys and Childcare Articles, Contract nº: ETD/99/502498</td></tr>
<tr><td>Scope of investigation</td><td>Phthalate plasticisers, toys, PVC, substitutes</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>2000</td></tr>
<tr><td>Institution or Company</td><td>Risk & Policy Analysts Limited (RPA), Farthing Green House, 1; Beccles Road, London, Norfolk, NR14 6LT, Tel: +44 1508 528465; Fax: +44 1508 520758
In association with: Research Institute for Toxicology, Utrecht University, PO Box 70.176, NL-3508, TD Utrecht, Netherlands. Tel: +31 302535400; Fax: +31 302535077</td></tr>
<tr><td>Contractor/ Commissioner</td><td>European Commission Directorate General Enterprise</td></tr>
<tr><td>Authors</td><td>M. Postle (RPA), C. Corden (RPA), M. van den Berg (RITOX), T. Sanderson (RITOX)</td></tr>
<tr><td>Availability/Publisher</td><td>Can be downloaded: http://europa.eu.int/comm/environment/waste/studies/pvc</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, toys and childcare articles, plasticiser, substitutes, EU market, risk to health</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td>X</td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison of PVC plasticizers: o-acetyltributyl citrate, benzoates, alkylsulphonic phenyl esters and possible adipates, polymerics, trimellitates, sebacates and azelates. Comparison of on other flexible plastics: PP, LPDE, chlorinated PE, metallocene PE, thermoplastic olefin, PP/EPDM, S-B-S block copolymer, S-EB-S Block copolymer, S-SB-S block copolymer, EVA, EEA, ionomer, polyester elastomer, polyester elastomer.</td></tr>
<tr><td>Reported data</td><td>Socio-economic, market information, other life cycle related data</td></tr>
<tr><td>Short description of the study</td><td>Provides an overview of the EU market, following restrictions on the use of phthalates in certain toys and childcare articles, to assess the risk to the health of children of possible substitute plasticisers and plastics and to consider the technical problems and economic implications of switching to substitute plasticisers and plastics. The study contains the following chapters: Production of Soft PVC and use of phthalates as plasticisers; Legislative context in EU Member States; The soft PVC toys market situation; Technical issues in substitution; Risk analysis and substitutes; and economic implications of substitution.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>X</td><td>Specific/own/new data</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
</table>
Comment: No LCA study, Life cycle related, issues comprehensively covered, scientific-based, suggested for **qualitative characterisation**
</td></tr>
</table>

RANDA EU.003

The purpose of the study was to assess the “availability of substitutes for soft PVC containing phthalates in certain toys and childcare articles.”

Table 5-28: Summary on technical suitability of flexible plastics as substitutes for plasticised PVC

Technical Suitability of Substitute Plasticisers		
Plasticiser Type	**Technical Suitability**	**Actual Use as a Substitute**
Citrates (ATBC)	I, II	I, II
Adipates (DEHA)	II (some)	Unknown
Benzoates	I (possibly), II (some)	II (probable)
Alkylsulphonic Phenyl Esters	I (possibly), II (some)	Possibly
Trimellitates	II (some)	Unknown
Polymerics	II (some)	Unknown
Key: I – products intended to be placed in the mouth II – other plasticised PVC toys and childcare articles (recreated from p. iii)		
Technical Suitability of Substitute Plasticisers		
Plasticiser Type	**Technical Suitability**	**Actual Use as a Substitute**
Polyethylene (various forms)	I, II (some)	I, II (some)
Ethylene Vinyl Acetate (EVA)	I, II (some)	I, II (some)
SBS Block Copolymers	I (possibly), II (some)	I (unknown), II (some)
Polyester Elastomers	II (some)	Unknown
Key: I – products intended to be placed in the mouth II – other plasticised PVC toys and childcare articles (recreated from p. iii)		

The tables provide a summary of the technical suitability of flexible plastics as substitutes for plasticised PVC. A risk assessment of each substitute is provided, along with an analysis of the economic implications of substitution.

The report concludes that generally, the use of substitute plastics appears to be less technically feasible than the use of substitute plasticisers. The economic implications for products intended to be mouthed by children under 3 years of age are relatively minor. However, other soft PVC toys and childcare articles constitute greater use and the economic implications for substitution, in terms of increased raw material costs alone, would be much higher.

Summary of toys/sports goods sector

No LCAs that consider applications of toys or sports goods could be identified.

The small number of life cycle related studies in this sector may be due to the comparably small mass streams of PVC in these applications.

Only in applications like inflatable beach toys, paddling pools and rubber boats/rafts are noticeable mass streams of PVC used.

The main competitor to PVC is rubber. Studies comparing the two are lacking, nevertheless some statements can be made. Nitrile rubber, styrene rubbers and polybutadiene rubbers demand more complex processing then PVC and, therefore, potentially result in higher impacts. Consequently, the use of those materials is not encouraged. Natural rubber may be an option as the resources used are based on renewable resources. But little is known about the impacts of natural rubber production in third world countries. The data quality regarding impacts of those production processes is not as detailed as those of the production processes of the chemical industry in industrialised countries. Furthermore, the material properties in the use phase play an important role (durability and lifetime, UV-stability). Therefore, rubber solutions need to be treated adequately with additives to provide comparable technical properties and lifetimes to those of PVC solutions.

Studies analysing applications of toys or sports goods should consider the behaviour and impacts of plasticisers and other additives of the competing materials in the production and use phases. Whether these additives play a major role in the life cycle, can only be answered on the basis of such studies conducted in the future.

Whereas it would be favourable to have more consistent comparison information on the principal competing materials within these applications, the lack of studies is not considered a major gap.

The possibility of improper use of toys exists. However, LCA is not the proper instrument to assess and quantify the health impacts of different materials, particularly of the plasticised PVC used in toys.

5.3 Consumer goods

Within the consumer goods sector, the mass of PVC used is not dominant. Artificial leather and office equipment play a certain role in terms of PVC use by mass. From a market share viewpoint, coatings, garden hoses, credit cards, shower curtains and tapes are significant consumers of PVC.Principal competitors of PVC in the consumer goods sector are various other polymers (e.g. PUR, polyester and polyolefins), leather and wood.

Table 5-29 shows an overview of the market-share situation of the consumer goods sector.

Table 5-29: Overview on the consumer goods sector

Sector	PVC Application	principal competing materials (PCM)	share of used PVC mass	market share of PVC
Consumer goods:				
Furniture	edge protection, furniture profiles	**wood,** ABS	1.5%	medium
	Coating	melamine paper, veneer, varnish (epoxy, acryl, alcyd, PUR)	0.5%	major
	garden hoses		1.5%	major
	garden furniture	wood, steel, aluminium, polyolefins, PA	negl.	negl.
Clothing	Wellingtons, ski boots	leather, PA, **EVA, rubber**	2%	medium
	soles/bottoms	**leather,** PUR		
	rain covers	cotton, **PUR,** polyester, PA (all coated)	< 0.5%	small
	fashion ware	wool, **polyester,** cotton, PA, silk, latex		
Office equipment	transparencies, trays, folders	**polyolefins,** PS, cardboard	2%	medium
	credit cards	PET, ABS	< 0.5%	major
Household goods	shower curtains	cotton, polyester	< 0.5%	major
	packaging-/electrical tapes	PET, PI, PP	1%	major
	Sealants	**silicones,** PUR, TPE	< 0.5%	medium

Few life cycle related studies have been published within the groups of furniture, clothing, office equipment and household goods. Only one comparative LCA on a consumer product application could be identified; an LCA of credit cards made of different materials.

Life cycle of plastic cards in credit card size (IPU 000.0052)

Documentation sheet (IPU 000.0052)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Substitution af PVC i plastkort
(Substitution of PVC in plastic cards)</td></tr>
<tr><td>Scope of investigation</td><td>Life cycle of plastic cards in credit-card size</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td></td></tr>
<tr><td>Institution or Company</td><td>DTI Miljø; S-Card A/S; ID-Kort A/S; SR Consult</td></tr>
<tr><td>Contractor/ Address</td><td>Danish EPA, Strandgade 29, DK-1401 København K, Denmark</td></tr>
<tr><td>Authors</td><td>Rasmussen, S., Pedersen, L. L., Møller, S., Mikkelsen, L. H.</td></tr>
<tr><td>Availability/Publisher</td><td>On website www.mst.dk</td></tr>
<tr><td>ISBN</td><td></td></tr>
<tr><td>Keywords</td><td>PVC, Plastic cards, credit cards</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>PET, ABS, PC</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Environmental, technical and economic screening of whether PVC in credit cards can be substituted by other materials</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td>X</td><td>Profound</td><td></td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>100%</td><td>Specific/own/new data</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (IPU 000.0052)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	hazard assessment
Goal, description of	
Application/use of results	x
Aim of study	x
Target group of study	x
Scope, description of	
main technical systems properly described	x
Function analysed	Credit card
Functional unit	Not stated
System boundaries include:	
materials	x
energy	x
production	x
use	
disposal	x
recycling	x
transportation	
Allocation (mass/energy/price/exergy)	no
System Expansion	no
Substitution	no
Data categories described	
Primary energy consumption	no
Air emissions	no
Water emissions	no
Waste categories	no
Impacts	
Global warming	no
Acidification	no
Nutrient enrichment	no
Tropospheric Ozone Formation	no
Stratospheric Ozone Depletion	no
Toxicity, human	Toxicity of selected chemicals
Toxicity, eco	Toxicity of selected chemicals
other:	waste
Data quality	
time	no
geography	no
technology	no
Critical review performed	no
Evaluation	
Normalisation	no
Weighting	no
other methods	no

Critical Assessment (IPU 000.0052)

Goal description in short	• Mapping of amounts of PVC used in credit cards in Denmark • Performance of an environmental screening of PVC, and selected alternatives, over the whole life cycle. • Performance of technical comparisons of the selected alternatives	
Valuation of the goal	• The goal of the study is clearly stated.	
Scope of study	• Comparison with PET, ABS and PC • System boundaries are clear. • Functional unit is not described	
Life cycle phases	• All life cycle stages included • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Energy consumption only as primary energy. No emissions. • All emissions given from EU TGD	
Valuation of scope	• The scope is appropriate to fulfil the goal. However, the goal is of little or no value, as it is only considered a rough check. Low criteria for goal → low quality of data → low value of result	
Methodology	• No general considerations • Only primary energy used	
Data requirements	• No discussion of completeness, representativeness precision level, consistency and reproducibility.	
Inventory	• No general considerations on sensitivity and uncertainty. • Database used: None. Selected LCAs for production data and EU TGD for emissions. • Database from a Software System: Not used • Gaps in important impacts	
Impact Assessment	• Not performed • The inherent toxicity, health aspects and physicochemical characteristics of selected chemicals are listed and emissions are calculated from EU TGD. This is used as a background for a qualitative comparison. • The methodology does not conform with ISO 14042.	
Environmental impacts included	• No quantification of impacts	
Weighting of environmental parameters	• -	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met. No third-party report, no impact assessment, etc.	

The study comes to the following key conclusions:

- Only environmental screening of the materials is performed. It concludes that all three alternatives are better when compared with PVC. However, the quality of the conclusion is questionable and should only be considered a screening.
- An economic screening of the materials was also performed and it showed that ABS and PET may be economically competitive with PVC[29].

<u>The study explains to manufacturers</u>:

- Consider a change of material for credit cards.

<u>The study explains to users</u>:

- There are possible alternatives to PVC which are economically feasible and better environmental performers.

<u>The study explains to third parties</u>:

---

[29] PVC cards are generally less expensive and ABS or PET may only suitable for specialised end use fuctions of cards due to this. The Polymer Institute (IKP) of the University of Stuttgart reported for PVC approx. 0,6 EUR/kg, for PET approx. 0,83 EUR/kg and for ABS approx. 1,22 EUR/kg (Calculated from information of "U.S. Imports History, Historical Summary 1996-2000", U.S. Department of Commerce, Economics and Statistics Administration, U.S. CENSUS BUREAU.

- There are possible alternatives to PVC which are economically feasible and better environmental performers.

Table 5-30 summarises the analysed impacts. It should be noted that no impact assessment is performed for the materials; only a screening is performed. The results are shown below. The conclusion that ABS and PET are advantageous in terms of environmental performance in the production phase is not concrete. ABS and PET are generally more complex and demanding in production and, therefore, potentially have more of an impact. According to our knowledge and according to information in publicly available LCA databases (e.g. GaBi 2003) and related professional information of industrial associations (e.g. APME 1990-2003), PVC does not have a higher environmental impact in production. Additives like plasticisers do not play a significant role in rigid applications. As no consistent data source was used for the study but rather different data sources from literature, it seems clear, that data of different quality and system boundaries was used for the comparison.

Table 5-30: Summary of the analysed impacts of IPU 0015

IPU 0052	**PET - energy**	**PET - environment**	**ABS - energy**	**ABS - environment**	**PC - energy**	**PC - environment**
Production	-	+	-	+	-	0
Manufacturing	0	0	0	0	0	0
Use phase	0	0	0	0	0	0
Disposal - recycling	?	0	?	0	?	0
Disposal - Incineration	+	+	+	+	+	+
Disposal - Landfill	0	0	0	0	0	0

IPU 0052	**PET - H&WE[30]**	**ABS - H&WE**	**PC - H&WE**
Production	+	+	0
Manufacturing	0	0	0
Use phase	0	0	0
Disposal - recycling	0	0	0
Disposal - Incineration	+	+	+
Disposal - Landfill	0	0	0

Legend
+: Better than PVC
-: Worse than PVC
0: No significant difference from PVC
?: Lack of knowledge

---

[30] H&WE = Health and working environment

Summary of the consumer goods sector

The existing study on credit cards does not enable overall conclusions to be made for the consumer goods sector from an LCA viewpoint. The products are simply not representative of the overall consumer goods sector.

Studies on clothing and furniture are lacking. The technical demands on the products and the type of use are completely different to the product discussed above. Hence, the results may differ significantly and can not be derivated.

Studies on clothing and furniture may be of importance due to some specific reasons. The products are subject to intensive use by the user. The user most often determines the life span based on fashion criteria. Besides disposal and recycling, an intensive reuse inside and outside of the EU is often the case (donation of used clothes, collection of used furniture). Therefore, recycling impacts may be of lower relevance.

5.4 Packaging

Within the packaging sector PVC plays a distinct role in food packs and blister packs. Despite PVCs minor role in the segment of bottles, quite a few comparative LCA studies of bottles have been carried out.

Table 5-31 provides an overview of the market share situation of the packaging sector.

Table 5-31: Overview on the packaging sector

Sector	**PVC Application**	**principal competing materials (PCM)**	**share of used PVC mass**	**market share of PVC**
packaging:				
container	bottles	**PET, glass,** polyolefins, ceramics	1.5%	small
	food packs	PET, aluminium, paper, **polystyrene, polyolefin,** PA	6.5%	medium
	shrink foils	**polyolefins,**		small
	blister packs	COC, **PP/COC/PP,** PE/PVDC, paper		Medium

PVC in the packaging sector is loosing importance, compared to durable PVC products (see also chapter **3.2.4**).

The principal competing materials are PET, glass and polyolefins.

LCA study in the field of packaging (IKP D-13)

Documentation sheet (IKP D-13)

<table>
<tr><td>Kind of report</td><td>Article</td></tr>
<tr><td>Title</td><td>Ökologische Bilanzierung von Verpackungsstoffen - Kunststoffe, Glas, Papier und Blech im Wettstreit</td></tr>
<tr><td>Scope of investigation</td><td>LCA studies done in the field of plastics</td></tr>
<tr><td>Year of publication</td><td>1991</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1980 to 1989</td></tr>
<tr><td>Institution or Company</td><td>Klöckner Pentaplast GmbH, Postfach 1165, 56401 Montabaur, Germany</td></tr>
<tr><td>Contractor/ Address</td><td>Werkstoffe in der Fertigung, Sonnenblumenring 35, 86407 Mering, Germany</td></tr>
<tr><td>Authors</td><td>Dr. Ing. Christian Kohlert</td></tr>
<tr><td>Availability/Publisher</td><td>Klöckner Pentaplast GmbH, Postfach 1165, 56401 Montabaur, Germany</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>Packaging, LCA</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>PP, PS, PE, glass, aluminium, cardboard, paper, steel sheet</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the article was to present different LCA studies performed in the field of packaging. Based on the results of these studies, this article showed that PVC has ecological advantages in comparison to other plastics (PP, PS, PE), glass, aluminium, cardboard, paper and steel sheet.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td>X</td><td>Scientific-like</td><td></td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>100%</td><td>Specific/own/new data</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for **systematic characterisation**
</td></tr>
</table>

Systematic characterisation (IKP D-13)

Overall frame of study	
ISO 14040 ff	too old
Code of practice	no
Other	LCA of packaging materials, literature comparison of former studies
Goal, description of	
Application/use of results	not specified
Aim of study	not specified
Target group of study	not specified
Scope, description of	
main technical systems properly described	no
Function analysed	packaging
Functional unit	1 kg packaging material
System boundaries include:	
materials	Included within the literature assessed
energy	Included within the literature assessed
production	Included within the literature assessed
use	Included within the literature assessed
disposal	Included within the literature assessed
recycling	Included within the literature assessed
transportation	Included within the literature assessed
Allocation (mass/energy/price/exergy)	not specified
System Expansion	not specified
Substitution	not specified
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	not specified
Acidification	not specified
Nutrient enrichment	not specified
Tropospheric Ozone Formation	not specified
Stratospheric Ozone Depletion	not specified
Toxicity, human	not specified
Toxicity, eco	not specified
other:	critical loads
Data quality	
time	1980 to 1990
geography	Europe
technology	average
Critical review performed	not specified
Evaluation	
Normalisation	not specified
Weighting	not specified
other methods	not specified

Critical Assessment (IKP D-13)

Description of goals	• Comparison of literature LCA data of plastics, glass, paper and tinplate as packaging materials	
Valuation of the goal	• The goal is not explicitly described; the respective goals of the different studies must be taken from literature sources.	
Scope of study	• The scope is not explicitly described; the respective scopes of the different studies must be taken from the literature sources.	
Life cycle phases	• Single life cycle phases are not described, the published results are aggregated and refer to the whole life cycle as defined in the literature sources	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	X
Important assumptions	• Assumptions of the literature sources are adopted but not separately reported. • Results of different literature sources are compared and therefore it is assumed that the boundary conditions, scope of the studies, cut-off criteria and others are comparable.	
Valuation of scope	• The scope is not explicitly described and therefore cannot be valuated.	
Methodology	• method of critical loads for impact assessment • method of Thalmann (1985) for evaluation	
Data requirements	• No explanation of data requirements is stated.	
Inventory	• Aggregated inventory data for the entire life cycle is listed for selected emissions to air and water • Data source: BUWAL 1990 • No further information about boundary conditions, sensitivity analyses or data restrictions is given.	
Impact Assessment	• Aggregated impact data for the entire life cycle is listed for selected categories (energy equivalents, critical loads to air and water, landfill volume) • Data source: BUWAL 1990 • No further information about boundary conditions, sensitivity analyses or data restrictions are given	
Environmental impacts included	• energy equivalents, critical loads to air and water, landfill volume	
Weighting of environmental parameters	• evaluation method of Thalmann (1985) • other methods are used in the literature sources, but not reported in this article	
Overall ISO 14040 ff requirements	• ISO 14040 ff. requirements are not met	

The study comes to the following key conclusions:

- The ecological profile of plastics as packaging material is better than that of glass, aluminium and tinplate.
- Within the group of plastics, PVC is favourable because of its oxygen barrier quality and its low migration tendencies. Furthermore, PVC has advantages in the environmental categories of primary energy demand, emissions to air and landfill volume, compared to other plastics.
- Ecological assessment is an essential tool for strategic future development for packaging producers and users.

<u>The study explains to manufacturers</u>:

- PVC is a suitable packaging material.
- Packaging made of plastics is ecologically favourable compared to glass, aluminium, tinplate and composite materials.

<u>The study explains to users</u>:

- For non-returnable packaging, plastic packaging is environmentally better than glass, aluminium or tinplate.

The study explains to third parties:

- PVC is the preferable material for use in packaging applications.

The study is a rough screening based on a comparison of literature LCA data for plastics, glass, paper and metals as packaging materials. The study was an achievement at that time, although data from different sources was used for the comparison. Information from LCA databases and studies was lacking. The use phase is not sufficiently covered and the data is quite old (1980-1989). Therefore, we would not judge the study as representative for today's circumstances.

Table 5-32: Summary of the analysed impacts of IKP D-13

IKP D-13	**Sheet metal**	**Combined glass, sheet metal and PP**	**PP**
Coffee cream packaging (170g)	Medium energy equivalent, medium critical air volume and medium landfill volume, highest critical water volume in comparison.	Highest energy equivalent, highest critical air volume and highest landfill volume, low critical water volume in comparison.	Low energy equivalent, low critical air volume, low landfill volume, low critical water volume in comparison.

IKP D-13	**PVC**	**Paperboard**
Folded box (1,0 litre)	In comparison to paperboard, lower energy equivalent, little lower critical water volume and lower landfill volume. Little higher critical air volume.	In comparison to PVC, higher energy equivalent, little higher critical water volume and higher landfill volume. Little lower critical air volume.

IKP D-13	**PS/PVC packaging with Al lid**	**Glass packaging with sheet metal lid**
Jam packaging (450g)	In comparison to glass packaging with sheet metal lid, lower energy equivalent, lower critical air volume, higher critical water volume and lower landfill volume.	In comparison to PS/PVC packaging with Al lid, higher energy equivalent, higher critical air volume, lower critical water volume and higher landfill volume.

IKP D-13	**PVC**	**PE/Al**	**Paperboard/Al/PS**	**PP**
Margarine cup (500g)	Low energy equivalent, medium low critical air volume, medium high critical water volume and medium low landfill volume in the performed comparison.	High energy equivalent, medium high critical air volume, medium low critical water volume and high landfill volume in the performed comparison.	Medium low energy equivalent, high critical air volume, high critical water volume and medium high landfill volume in the performed comparison.	Low energy equivalent, low critical air volume, low critical water volume and low landfill volume in the performed comparison.

The table explains results of the article (following BUWAL 1990), the stated weights are packaging and content for one unit, stated volume is the packaging volume. The results are aggregated over the life cycle and boundary conditions are not stated. Single life cycle phases are not presented.

Packages made of glass, PVC, PS and PP over the life cycle (IKP D-15)

Documentation sheet (IKP D-15)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Umweltauswirkungen von Verpackungen aus Kunststoff und Glas</td></tr>
<tr><td>Scope of investigation</td><td>Packages made of glass, PVC, PS and PP during extraction and processing of raw material, production and disposal/recycling</td></tr>
<tr><td>Year of publication</td><td>1988</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1985</td></tr>
<tr><td>Institution or Company</td><td>TU-Berlin (Straße des 17. Juni 135, D-10623 Berlin, Germany), Technischer Umweltschutz Berlin</td></tr>
<tr><td>Contractor/ Address</td><td>EF-Verlag für Energie- und Umwelttechnik GmbH, Berlin, Germany</td></tr>
<tr><td>Authors</td><td>Dr. Karl J. Thomé-Kozmiensky, Marina Franke</td></tr>
<tr><td>Availability/Publisher</td><td>EF-Verlag für Energie- und Umwelttechnik GmbH, Berlin, Germany</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>Packaging, LCA, glass, PVC, PS, PP</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td></td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>glass, PVC, PP, PS</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to analyse the environmental effects: raw-material requirement, waste products, energy and water requirement, gas and dust emissions of one thousand 250 ml packs. It presents favourable results for plastics and negative results for glass.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>90%</td><td>Specific/own/new data</td><td>10%</td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic assessment.
</td></tr>
</table>

Systematic characterisation (IKP D-15)

Overall frame of study	
ISO 14040 ff	Too old
Code of practice	no
Other	Environmental effects of plastic and glass packaging
Goal, description of	
Application/use of results	not specified
Aim of study	not specified
Target group of study	not specified
Scope, description of	
main technical systems properly described	X
Function analysed	packaging
Functional unit	1000 units of 250 ml packaging
System boundaries include:	
materials	X
energy	X
production	X
use	not specified
disposal	X
recycling	X
transportation	not specified
Allocation (mass/energy/price/exergy)	not specified
System Expansion	not specified
Substitution	not specified
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	no specific aggregation to impact categories
Global warming	not specified
Acidification	not specified
Nutrient enrichment	not specified
Tropospheric Ozone Formation	not specified
Stratospheric Ozone Depletion	not specified
Toxicity, human	not specified
Toxicity, eco	not specified
other:	not specified
Data quality	
time	1985
geography	Germany
technology	average
Critical review performed	not specified
Evaluation	
Normalisation	not specified
Weighting	not specified
other methods	not specified

Critical Assessment (IKP D-15)

Description of goals	• Comparison of environmental effects of plastics and glass as packaging materials	
Valuation of the goal	• The goal is briefly described.	
Scope of study	• Life cycle of a packaging system including raw material extraction, processing, production and recycling/disposal • Not included: distribution and use phase	
Life cycle phases	• Raw-material extraction • Processing • Production • Recycling/disposal	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• Made assumptions are not explicitly reported.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• A short general methodology description is given, but no necessary details are reported • Environmental effects to soil include raw material demand, disposal and qualitative comments to other effects • Environmental effects to water include amount of fresh water and waste water. Specific substances of content are differentiated. Biochemical and chemical oxygen demand are also included. • Emissions to air include gaseous emissions and dust. • Energy demand is differentiated to electrical and thermal energy	
Data requirements	• No explanation of data requirements is stated.	
Inventory	• Inventory data for the packaging parts (cup and lid) are listed for selected inputs and emissions to air and water. • No further information about boundary conditions, sensitivity analyses or data restrictions is given.	
Impact Assessment	• The methodology of impact assessment is not exactly described. The step from inventory data to impact categories is not reported.	
Environmental impacts included	• Raw-material requirement, waste products, energy requirement, water requirement, gaseous emissions and dust emissions	
Weighting of environmental parameters	• No weighting is performed.	
Overall ISO 14040 ff requirements	• ISO 14040 ff. requirements are not met.	

The study comes to the following key conclusions:

- The ecological profile of plastics is better than that of competing materials.
- The ecological profiles of different plastic types are almost equivalent.
- The manufacture of glass packaging results in high environmental impacts.

The study explains to manufacturers:

- There are different environmental effects of the cup and lid (made of different materials) of a packaging system.

The study explains to users:

- Plastic packaging systems (cup and lid made of plastic) are environmentally better than mixed packaging systems with plastic or glass cup and metal lid.

The study explains to third parties:

- Glass packaging is unsuitable for non-returnable packaging.

The conclusions are drawn based on the functional unit of 1000 units of 250 ml packaging for the whole life cycle of the packaging. The study was published in 1988, long before the first LCA standardisation documents. The life cycle approach is correctly chosen, but the environmental impacts are chosen “randomly”. The inventory data is partly reported in detail but, for interpretation reasons, emissions are summed up and compared. This method is not adequate for current LCA comparisons. Therefore, we would not judge the study as representative of current circumstances.

Table 5-33: Summary of the analysed impacts of IKP D-15

IKP D-15	PVC cup PVC lid	PS cup aluminium lid	PP cup PVC lid	Glass cup tin foil lid
Raw material demand [kg]	11,27	15,93	13,09	231,21
Waste products [kg]	7,88	9,77	8,69	58,64
Energy demand [MJ]	450	564	458	1791
Water demand [m3]	0,28	1,42	0,25	1,81
Waste water ingredients [g]	≈ 170	≈ 210	≈ 140	≈ 44000
Gaseous emissions [g]	≈ 1150	≈ 1200	≈ 1100	≈ 2550
Dust emissions [g]	41,36	35,61	51,99	237,27

The functional unit of the comparison is 1000 units of average 250 ml packages in a life cycle view, excluding use phase.

LCA of packaging materials (IKP CH-16a+16b)

Documentation sheet (IKP CH-16a+16b)

<table>
<tr><td>Kind of report</td><td>Book</td></tr>
<tr><td>Title</td><td>Ökoinventare für Verpackungen Band 1 und 2</td></tr>
<tr><td>Scope of investigation</td><td>LCA of packaging materials</td></tr>
<tr><td>Year of publication</td><td>1996</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1978 to 1983</td></tr>
<tr><td>Institution or Company</td><td>Institut für Verfahrens- und Kältetechnik (IVUK) ETH Zürich;
EMPA St. Gallen</td></tr>
<tr><td>Contractor/ Address</td><td>BUWAL, Bundesamt für Umwelt, Wald und Landschaft, 3003 Bern, Switzerland</td></tr>
<tr><td>Authors</td><td>Dr. Kurt Haberstatter, IVUK ETH Zürich;Dr. Ivo Fecker, EMPA St. Gallen; Silvio Dall'Acqua, Dr. Matthias Fawer, Frieder Fallscheer, Ruth Förster, Christiane Maillefer, Martin Ménard, Laurent Reusser, Claudia Som, Ueli Stahel, Peter Zimmermann</td></tr>
<tr><td>Availability/Publisher</td><td>BUWAL, Bundesamt für Umwelt, Walt und Landschaft, 3003 Bern, Switzerland</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>Packaging materials, LCI, production, end of life</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td></td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Alu, glass, PE, PP, PS, PET, paper, cardboard, steel</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>One of the most extensive life cycle studies on packaging materials, their production and end of life. The different materials are compared on a kg basis.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>40%</td><td>Specific/own/new data</td><td>60%</td></tr>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic characterisation (IKP CH-16a+16b)

Overall frame of study	
ISO 14040 ff	too old
Code of practice	no
Other	LCI of packaging materials production
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	production of packaging materials
Functional unit	1000 kg material
System boundaries include:	
materials	X
energy	X
production	X
use	not specified
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	not specified
System Expansion	not specified
Substitution	not specified
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	not specified
Acidification	not specified
Nutrient enrichment	not specified
Tropospheric Ozone Formation	not specified
Stratospheric Ozone Depletion	not specified
Toxicity, human	not specified
Toxicity, eco	not specified
other:	not specified
Data quality	
time	1990 to 1995
geography	Switzerland
technology	average
Critical review performed	
Evaluation	no evaluation
Normalisation	No
Weighting	No
other methods	No

Critical Assessment (IKP CH-16a+16b)

Description of goals	• Perform inventory data of the production of relevant materials for packaging systems	
Valuation of the goal	• The goal is sufficiently described.	
Scope of study	• The scope of the study is production and recycling. • The entire process chain from raw-material extraction over processing and transportation to production of preliminary products (the last step to end products is missed) is included. • Energy-supply chains are also considered in detail (part II) • The end-of-life processes are included in the second part of the study • The use phase of products is not included	
Life cycle phases	• Raw-material extraction and processing • Production of preliminary products • End of life	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• No important assumptions made	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• The used methodology is described in detail.	
Data requirements	• Data requirements are reported. • If possible data quality indicators were acquired	
Inventory	• Detailed inventory data is calculated. • The reporting is very transparent and comprehensible. • The collected data is used to perform an extensive database (BUWAL 1996).	
Impact Assessment	• no impact assessment performed	
Environmental impacts included	• no impacts included	
Weighting of environmental parameters	• no weighting included	
Overall ISO 14040 ff requirements	• Requirements of ISO 14041 are generally fulfilled.	

The following points can be drawn from this study:

- The study does not intend to provide conclusions, but to provide LCI data for production processes of materials used in packaging systems.
- A material comparison is not performed.

<u>The study explains to manufacturers</u>:

- The study gives a comprehensive database with detailed LCI information about different production processes to manufacturers of packaging systems as well as manufacturers of other products using the same preliminary products. Specific environmental profiles can be calculated by using and combining the performed processes with specific data from manufacturers.

<u>The study provides users with</u>:

- detailed insights in the methodology of life cycle assessment and the possibility to understand how ecological profiles are performed;
- detailed LCI data for materials and specific processes in the packaging sector.

<u>The study explains to third parties</u>:

- Besides the manufacturers of packaging materials, public authorities, NGOs, research institutes and consultants can use the data as a basis for further specific studies. The study explains the life cycle assessment methodology used, and the steps necessary to gather significant data.

A direct comparison of materials is not performed. The reference unit in the material production phase is 1000 kg for each material. The study provides inventory information of material production processes so that it can be used as a basis of further specific studies. To get comparable functional units for specific packaging applications, data on material processing, shaping, use phase and end-of-life information have to be combined.

Despite the fact that this study does not directly compare different packaging materials, the data and information provided can be used to model specific packaging systems and for comparison studies on a LCA level.

Table 5-34: Summary of the analysis of IKP CH-16a+16b

IKP CH-16a+16b	PVC	Other materials
Production phase	10 PVC producers are listed with different production routes (suspension, emulsion, block). An average PVC production is deduced from this information.	Production processes for aluminium, glass, plastics (PE, PP, PS, PET and different additives), paper, board and steel are performed with average European data background.
	Eco-profile with material resources, energy resources, emissions to air and emissions to water is performed for PVC powder.	Eco-profile with material resources, energy resources, emissions to air and emissions to water is performed for the materials mentioned.
	An average calendering process for PVC is available.	Different specific material processing information for the materials are available.
Use phase	For the use phase general processes for distribution and bottle washing are performed (not PVC specific).	For the use phase general processes for distribution and bottle washing are performed.
End-of-life phase	Waste treatment process scenarios for PVC are performed for Situation in Switzerland 1995 100 % waste incineration 100 % disposal	Specific waste treatment processes for materials are performed with background of situation in Switzerland 1995. Additionally, some scenarios are included.

Comparative LCA in bottling of mineral water (RANDA SP.004)

Documentation Sheet (RANDA SP.004)

<table>
<tr><td>Kind of report</td><td>Project for Master in Environmental Engineering and Modelling</td></tr>
<tr><td>Title</td><td>Ecobalance Comparativo de Diferentes Materiales Empleados en el Envasado de Agua Mineral</td></tr>
<tr><td>Scope of investigation</td><td>Comparative ecobalance of different materials used in the bottling of mineral water</td></tr>
<tr><td>Year of publication</td><td>1993</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1988 to 1991</td></tr>
<tr><td>Institution or Company</td><td>Universitat Politècnica de Catalunya, Institut de Tecnologia i Modelització Ambiental</td></tr>
<tr><td>Contractor/ Address</td><td>Barcelona</td></tr>
<tr><td>Authors</td><td>Daniel Arcarons Alibés</td></tr>
<tr><td>Availability/Publisher</td><td>It can be ordered from the Universitat Politècnica de Catalunya (ETSEIB), Department of Enginyeria Química, Dr. Margarita González.</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>Bottled water, ecobalance</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th></th><th>Use phase</th><th>X</th><th>End of life</th><th></th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>glass, PVC, PET, LDPE</td></tr>
<tr><td>Reported data</td><td></td></tr>
<tr><td>Short description of the study</td><td>This document is a masters project in engineering and environmental modelling. It compares the ecoprofiles of different materials used in the bottling water. However, because it was carried out before ISO 14000 was introduced, the study does not follow the ISO standard. The study is very thorough and includes crude oil extraction, electricity production, transportation, production, use, recycling, incineration etc. It should be noted that the Spanish market share of PVC for bottled water has considerably changed since 1993.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td></td><td>Specific/own/new data</td><td>X</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td>X</td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic characterisation (RANDA SP.004)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	X
Goal, description of	
Application/use of results	
Aim of study	X
Target group of study	
Scope, description of	
Main technical systems properly described	X
Function analysed	PVC/ PET /LDPE and glass bottle
Functional unit	1 litre of bottled water
System boundaries include:	
materials	X
energy	X
production	
use	
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price)	Mass and energy
System expansion	
Substitution	
Data categories described	
Primary energy consumption	X
Air emissions	X (transport: some air emissions are missing)
Water emissions	X
Waste categories	X
Impacts	
Global warming	
Acidification	
Nutrient enrichment	
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	critical volume approach
Data quality	
time	1977 to 1991
geography	Spain/Europe/United States
technology	not reported
Critical review performed	
Evaluation	
Normalisation	
Weighting	
other methods	

Critical Assessment (RANDA SP.004)

Description of goals	• To define the meaning and aim of an “ecobalance” and an “environmental profile”. • To point out the quantifiable and unquantifiable impacts of the production system and the limitations of ecobalances. • To establish criteria of impact addition. • To apply the proposed methodology for ecobalances in order to compare the impacts of different packaging options for mineral water and to point out the critical phases of the life cycle.	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• Adequate system boundaries for the different materials: entire life cycle, transportation, electricity and other energy sources. • Bottles of different materials (glass, PVC, PET and LDPE).	
Life cycle phases	• Extraction of raw materials; plastic granules/glass production; production of bottles; end of life. • Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	•
	• Screening LCA with high degree of specific/own data	•
	• Screening LCA with high degree of generic/literature data	• X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	• X
	• Major cut-offs/incompleteness which are likely to affect conclusion	•
Important assumptions	• Plastic materials are not recycled. • The plastic industry produces heat by co-generation. The reduction of impacts due to co-generation is not considered in this study.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• No information on allocation.	
Data requirements	• Spatial and temporal representativeness are not stated. • Precision level, completeness, consistency and reproducibility are not stated.	
Inventory	• Important topics of LCI model are not discussed. • Glass packaging: data on production (raw materials, emissions, consumption) correspond to the situation in Switzerland. Data was extrapolated taking into account the recycling rate in Spain. • Plastic packaging: data on production were obtained from BUWAL database. • Sensitivity of some inventory parameters, i.e. changes in the production process, energy model, waste treatment, number of bottle reuse are discussed or analysed. • Databases used: BUWAL, 1990; Franklin, 1989; industry data, etc. • The results present a limited number of chemicals emitted. • The impacts of washing are not taken into account for reused glass bottles.	
Impact Assessment	• Impact assessment methodology is that of the Critical Volume. • The assessment methodology does not agree with ISO 14042. The study was performed before the publication of the standard.	
Environmental impacts included	• The included impact categories are not broad enough to fulfil the goal. • Glass (with and without reuse) PVC, LDPE and PET.	
Weighting of environmental parameters	• Not performed.	
Overall ISO 14040 ff requirements	• The overall requirements of ISO 14040 ff were not met, as the study was carried out before the publication of this series of standards.	

The study comes to the following key conclusions:

- PVC has good environmental properties as a packaging material (i.e. high energy efficiency, low consumption of raw materials). However, large amounts of water effluent are produced over its life cycle.
- LDPE produces the lowest emissions (to water and air); however, its energy and raw material consumption is higher than that of PVC. The impacts due to energy consumption could be decreased by increasing the rate of LDPE incineration.
- PET does not seem to be a good packaging material due to its high energy consumption and production of water effluent (much more than LDPE).
- Single-use glass is the packaging material with the highest environmental impacts due to its high *weight/volume of liquid contained* ratio. However, by increasing the number of reuses, the environmental impacts decrease significantly and among all packaging studied, reusable glass bottles are the best from an environmental point of view (i.e. high energy efficiency, low occupation in landfill).

The study explains to manufacturers:

- The impacts of LDPE, due mainly to high energy consumption, could be reduced by selecting a waste treatment method including a high percentage of incineration with energy recovery.

The study explains to users:

- For reusable applications, glass bottles are preferred, followed by PVC and LDPE bottles. For single-use applications, glass bottles and PET bottles should be avoided.

The study explains to third parties:

- Of the reviewed options, reusable glass bottles are the best packaging option from an environmental standpoint.

Table 5-35: Summary of the analysed impacts of RANDA SP.004

Life cycle phases	Glass Bottled mineral water	PVC Bottled mineral water	HDPE Bottled mineral water	PET Bottled mineral water
Production	Consumption of energy decreases with a higher recycling rate. Important amount of air emissions due to energy consumption (NO_x, SO_2, HCl, HF and Pb).		Emissions generated in the pre-combustion of co-products with high heating value were assumed to be negative. In the case of HDPE, emissions from the production phase were negative.	
Disposal		Incineration was irrelevant when assuming the incineration rate for municipal waste products (6%). However, if a higher incineration rate (80%) is considered, critical volume of air emissions almost triples.		Highest amount of critical volume of occupied landfill due to the “shape factor”.
Recycling	When considering higher recycling rates all critical volumes are considerably reduced, including the critical volume of air emissions.			
Transport	Transport operations have a low contribution to global environmental impacts. Distances considered are quite short.	Transport operations have a low contribution to global environmental impacts. Distances considered are quite short.	Transport operations have a low contribution to global environmental impacts. Distances considered are quite short.	Transport operations have a low contribution to global environmental impacts. Distances considered are quite short.
Life cycle	Lowest critical volume of water emissions, energy demand, landfill and raw materials consumption. Highest critical volume of air emissions.			

End of life of selective collection of PVC/PET bottles (RANDA FR.004)

Documentation sheet (RANDA FR.004)

<table>
<tr><td>Kind of report</td><td>Executive summary of a study</td></tr>
<tr><td>Title</td><td>Bilan environnemental de la collecte sélective des bouteilles PVC et PET en vue de leur recyclage.</td></tr>
<tr><td>Scope of investigation</td><td>End of life, selective collection of PVC/PET bottles, LCA methodology, Paris. Energy recovery, recycling.</td></tr>
<tr><td>Year of publication</td><td>1996</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1994</td></tr>
<tr><td>Institution or Company</td><td>Société ECOBILAN</td></tr>
<tr><td>Contractor/ Address</td><td>City Council of Paris (France)</td></tr>
<tr><td>Authors</td><td>Société ECOBILAN</td></tr>
<tr><td>Availability/Publisher</td><td>ECOBILAN</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>Selective waste collection, PVC, PET, bottles, recycling, energy recovery, incineration.</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th></th><th>Use phase</th><th></th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td></td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Comparison between two end-of-life alternatives for plastic bottles, but not between PVC and PET.</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to evaluate, in a quantitative and objective way, the benefits of implementing a selective collection of PVC/PET bottles in Paris. The study uses LCA to compare the proposal of a recycling alternative with the present situation (100% incineration). Three different organisations collaborated in the critical review.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td>X</td><td>Profound</td><td></td></tr>
<tr><td>Selected/limited impacts</td><td>X</td><td>Main/high variety of impacts</td><td></td></tr>
<tr><td>Generic data/literature data</td><td>80%</td><td>Specific/own/new data</td><td>20%</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for **systematic characterisation.**
</td></tr>
</table>

Systematic Characterisation (RANDA FR.004)

Overall frame of study	
ISO 14040 ff	
Code of practice	
Other	Experimental French Standard on LCA X30-300 (1994)
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
Main technical systems properly described	X
Function analysed	Elimination of 1 t of municipal solid waste; production of a certain amount of energy (which can be calculated as the energy obtained through incineration of 1 t of MSW); production of a certain amount of PVC and PET (calculated as the material obtained through the recycling of PVC and PET bottles selectively collected from 1 t of MSW).
Functional unit	1 t of municipal solid waste
System boundaries include:	
materials	X
energy	X
production	
use	
disposal	
recycling	X
incineration with energy recovery	X
transportation	X
Allocation (mass/energy/price)	
System expansion	X
Substitution	
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	exhaustion of non-renewable resources
Data quality	
time	1990 to 1994
geography	Paris
technology	specific (except for data from BUWAL data base)
Critical review performed	X
Evaluation	
Normalisation	
Weighting	
other methods	

Critical Assessment (RANDA FR.004)

Description of goals	•To provide the City of Paris (France) with a systematic method to evaluate, in an objective and quantitative way, environmental impacts of the selective collection of PVC and PET bottles for their further recycling. •Comparison of two alternatives of MSW management: selective collection of PVC and PET bottles to be recycled and incineration with energy recovery of the rest of waste versus 100% incineration with energy recovery (current situation).	
Valuation of the goal	•The goal is sufficiently and clearly described.	
Scope of study	•Adequate system boundaries. Transportation and maintenance included. •Systems described for specific conditions of Paris	
Life cycle phases	•Life cycle phases included: selective collection (door-to-door system for MSW and selective collection of PVC and PET bottles in special containers. Cleaning and maintenance of containers included, as well as transport operations; incineration with energy recovery; separation of PVC and PET bottles; PVC recycling; and PET recycling. •Conclusions can be drawn from the included LCA stages.	
Level and cut-offs	•Full LCA with high degree of specific/own data	•X
	•Screening LCA with high degree of specific/own data	•
	•Screening LCA with high degree of generic/literature data	•
	•Minor cut-offs/incompleteness which are not likely to affect conclusion	•X
	•Major cut-offs/incompleteness which are likely to affect conclusion	•
Important assumptions	•Waste scenarios analysed assume conditions specific for Paris in 1993 and 1994. •It is assumed that conditions of incineration in Paris are not modified as a result of the establishment of the selective collection of PVC and PET. •The traditional production of energy (system expansion) is assumed to be generated through the use of 75% coal and 25% heavy fuel oil. •The 3 organizations that carried out the critical review disagreed with some of the assumptions made on the basis of waste management in Paris.	
Valuation of scope	•The scope is appropriate to fulfil the goal.	
Methodology	•Study carried out using the experimental norm X30-300, as well as Ecobilan methodology. Ecobilan methodology follows SETAC "Code of Practice" (1993).	
Data requirements	•Specification of data requirements is not provided in the executive summary	
Inventory	•Sensitivity of inventory parameters is not discussed. •Waste management technology data (collection, selection, recycling and incineration) were obtained from specific processes from France and Germany. •Data on energy from data base BUWAL. •No gaps of important impacts.	
Impact Assessment	•The methodology of impact assessment is not specified in the executive summary.	
Environmental impacts included	•The included impact categories are appropriate to fulfil the goal. •Emissions of HCl are not quantified in the study. •Environmental impacts included: renewable and non-renewable resources, eutrophication, greenhouse effect and atmospheric acidification.	
Weighting of environmental parameters	•No weighting performed	
Overall ISO 14040 ff requirements	•The overall requirements of the ISO 14040 ff were not met, as this standard was not published at that time.	

The available study is an executive summary of an extended document. Therefore, a detailed assessment of the inventory and impact assessment could not be carried out.

The summary comes to the following key conclusions:

- Most of the environmental impacts are due to the establishment of a selective collection system, whereas recycling of PVC and PET bottles have a contribution of less than 10% of the total.
- Comparison between both alternatives indicates that certain flows are diminished when recycling of PVC and PET bottles is considered (such as suspended matter in water), while others are increased (i.e. emission of CO_2).
- For decision-making on waste management scenarios, environmental impacts should be arranged in order of importance depending on specific decision criteria such as geographical coverage or amount of flows.

Packaging waste management: PET, PVC, HDPE, LDPE, Incineration or recycling alternatives. (RANDA FR.006)

Documentation sheet (RANDA FR.006)

Kind of report	Study
Title	Eco-balances for policy-making in the domain of packaging and packaging waste.
Scope of investigation	Packaging waste management, PET, PVC, HDPE, LDPE, LCA methodology. Comparison of Incineration and recycling alternatives for different types of packaging.
Year of publication	1997
Ref. year(s) of assessment	January 1996 to May 1997
Institution or Company	RDC-Environment and Coopers & Lybrand
Contractor/ Address	Commision Européenne (Direction générale de l'environnement) Centre d'information (BU-9 0/11), B-1049 Bruxelles, Belgium Fax +32 (2) 299 61 98, e-mail: env-pubs@cec.eu.int
Authors	RDC-Environnement
Availability/Publisher	European Commission (publication services).
ISBN	No
Keywords	PET, PVC, LDPE, HDPE, incineration, recycling, packaging material

Life cycle phases Qualitative/Quantitative	**Production phase**		**Use phase**		**End of life**	**X**
	Qualitative		Qualitative		Qualitative	
	Quantitative		Quantitative		Quantitative	X

Comparison with alternatives	Comparison of different scenarios based on the type of packaging material and waste treatment.
Reported data	LCA
Short description of the study	The objective of the study is to compare different waste management scenarios for industrial and household packaging, based on LCA methodology, to assist in the definition of European public policy. Energetic valuation (incineration) is compared to material valuation (recycling). Plastic recycling is preferred over incineration, in terms of environmental impacts, in cases where substitution of recycled material for raw materials is high. However, where the recycled-material substitution index is low, incineration is preferred.

Expert judgement				
	Brochure-like		Scientific-like	X
	Overall/screening		Profound	X
	Selected/limited impacts		Main/high variety of impacts	X
	Generic data/literature data	30%	Specific/own/new data	70%

Comments related to further assessment	**Initiator**		**LCA**	
		Industry		PVC/competitor material
		Academia		part of PVC compound
	X	Government		material PVC/comp. comparison
		NGO	**X**	PVC/competitor application
				application PVC/comp. comparison
				Other than LCA

Systematic Characterisation (RANDA FR.006)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	VUB, SETAC, CML
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
Main technical systems properly described	X
Function analysed	packaging and management of packaging waste
Functional unit	1 kg/1 litre/1m^3 of packaging material
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price)	
System Expansion	X
Substitution	
Data categories described	
Primary energy consumption	sufficient
Air emissions	sufficient
Water emissions	sufficient
Waste categories	sufficient
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	
other:	Waste production, energy resource consumption, other resource consumption (global and local impacts are distinguished)
Data quality	
time	1992 to 1996
geography	European Union
technology	average/specific
Critical review performed	
Evaluation	
Normalisation	X
Weighting	
other methods	

Critical Assessment (RANDA FR.006)

Description of goals	• The aim of the study was to "*evaluate the potential of 'state-of-the-art' techniques such as eco-balances and life cycle assessments (LCA) for policy-making purposes and in particular to establish a global hierarchy on packaging and packaging waste*". • For this purpose 5 different studies were carried out. Comparison of recycling and disposal options for different materials, including PVC, PET, LDPE, HDPE, glass, paper/board, aluminium, and steel.	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• Adequate system boundaries are included, along with an "optimistic-pessimistic range" for understanding possible variations in environmental impacts. • Primary, secondary and tertiary packaging included for household and industrial waste streams. • Study considers the European context and was carried out between January 1996 and May 1997.	
Life cycle phases	• Life phases considered for material recycling and energy recovery: primary (virgin) production, transportation in and between phases, recycling (selective collection, packaging production starting from recycled material, recycling operation), energy recovery (MSW collection, incineration). • Life phases considered for reuse system: primary (virgin) production of all materials, transportation in and between phases, packaging production for primary, secondary and tertiary packaging, caps and labels, distribution, reuse (washing and filling), recycling (selective collection, recycling, transportation), energy recovery (MSW collection, incineration, post-incineration recycling) • Conclusions can be drawn from the LCA stages considered.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• For recycling a "close loop" approach is assumed: the amount of recycled material can replace virgin material. • All LCA studies carried out are comparative. Therefore, common phases to the two alternatives of management such as the use stage are not considered.	
Valuation of scope	• The scope is appropriate to fulfil the goal.	
Methodology	• Detailed information of system expansion used to define the system boundaries. • Comparison of waste management alternatives was done by using, in each case, two sets of parameters: one set of optimistic values for selected parameters and one set of pessimistic values for selected parameters.	
Data requirements	• Precision level, completeness, representativeness, consistency and reproducibility are stated in the introduction.	
Inventory	• Important topics of LCI model are discussed. • 1992 to 1996 • Databases used: BUWAL; APME; IDEMAT; FEFCO; CEPI (Confederation of European and Paper Industries) and confidential data from RDC, IPU and Coopers & Lybrand confidential databases • Some data sources are referred to confidential studies and, subsequently, not properly described. • Application of regional parameters for two Member States (Portugal, Germany) was made on 3 case studies. • Data gathered from the European situation.	
Impact Assessment	• The methodology is sufficiently described and includes references. • Global and local impacts are distinguished. • Classification factors taken from the CML method (1992) except for the input-related category depletion of resources.	
Environmental impacts included	• The included impact categories are appropriate to fulfil the goal. • Depletion of abiotic/biotic resources, global warming, acidification, nutrient enrichment, ozone formation and depletion, human and ecotoxicity and waste. • Global and local impacts are distinguished.	
Weighting of environmental parameters	• Normalisation performed: normalisation factors concern the whole world except for waste where it concerns the European Union (only the 12 members before 1996). • No weighting.	
Overall ISO 14040 ff requirements	• The overall requirements of the ISO 14040 ff were not met because this standard was under development in 1997. Draft of ISO 14040 was followed. For impacts not considered in the Draft, specific choices were made based on SETAC "Code of Practice", CML methodology and VUB method[31].	

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[31] The VUB method refers to the study 'Waste Management – Life Cycle Analysis of Packaging' by VUB-VITO-BPI for the European Commission DG Xi/A/4, 1994.

The waste management hierarchy, in particular material recycling versus energy recovery (incineration) options, and reusable versus non-reusable packaging alternatives is analysed within this study.

Following the hierarchy, 5 scenarios were defined including material recycling and incineration with energy recovery for 6 materials and two waste streams: (i) household waste (PET, PVC, LDPE, HDPE, beverage cartons, aluminium, steel, glass and paper/board); (ii) industrial waste (LDPE, HDPE and cardboard); (iii) compares beverage packaging systems (primary, secondary and tertiary); (iv) compares industrial packaging systems (cardboard boxes are considered for non-reuse option and HDPE crates for reuse option); (v) compares tertiary industrial packaging (non-reusable and reusable wooden pallets are compared).

The study comes to the following key conclusions:

- Technological, material, logistic, market, and regional or local conditions determine to a large extent which of the options (reuse, recycling or recovery) is preferred from the perspective of a high level of environmental protection. The study refers to this as “conditional preference.”
- In terms of environmental impacts, recycling is preferred over incineration/energy recovery with a “conditional” preference for plastic recycling.
- For large-volume-content packaging, reusable PET is the lowest impact option for both the optimistic and the pessimistic scenarios for all impacts except for municipal solid waste, acidification, mining waste and radioactive waste; in all scenarios differences, between options are relatively small.
- For small-volume-content beverage containers, cartons were identified as the “conditional” lowest impact option for the optimistic scenario for all impacts except for hazardous waste, municipal solid waste and mining waste; reusable glass and non-reusable PET are also identified as relatively low impact options for the optimistic scenario for all impacts except for acidification and radioactive waste.
- Detailed analysis should be carried out to better identify realistic sets of conditions that lead to a clearer preference for one system or another.
- Additional conclusions on policy-making and development of LCA methodology are provided.

The study explains to manufacturers:

- Efforts should be made to reduce the overall amount of packaging waste produced. Producers should take waste management concerns into account at all stages of the product life cycle.

The study explains to users:

- When considering the full range of optimistic and pessimistic results, including those produced by different secondary and tertiary packaging, a clear preference or absolute “lowest impact option” is never found.

The study explains to third parties:

- Life cycle assessment using the general approach in this study can facilitate transparent decision-making in the domain of packaging waste. The evaluation of environmental results for specific materials often demonstrates a preference for material recycling over incineration.

Additional conclusions on policy-making and development of LCA methodology are provided.

Table 5-36: Summary of the analysed impacts of RANDA FR.006

RANDA FR.006	**Glass**	**Aluminium and Steel**	**Plastics (PET, PVC, LDPE, HDPE)**	**Paper and Board**	**Wood**
Recycling and Incineration	Shows clear preference for material recycling over incineration in both optimistic and pessimistic scenarios.	Aluminium and steel show preference for recycling.	Show no clear preference, but in most categories a conditional preference for recycling is found for all plastics. Especially with respect to energy resource depletion, greenhouse effect and waste categories (except radioactive waste for the 4 plastics and acid emissions for LDPE and HDPE in the pessimistic case). For PVC, however, the contribution to hazardous waste is very high, thus recycling should be encouraged in all cases.	Shows no clear preference. Study notes that due to the high-energy content of paper, incineration with energy recovery seems to be an acceptable alternative management option.	For reuse versus non-reuse wooden pallets, reuse wooden pallets identified as conditional lowest impact option.
Reuse and non-reused systems	For large-content packaging, reusable glass is a relatively low impact option for the optimistic scenario, in particular, for municipal solid waste (reuse glass).		For the large-content packaging, reusable PET is the lowest impact option for all categories except for municipal solid waste, acidification, mining waste and radioactive waste.	For large-content packaging, the use of non-reuse beverage cartons is a relatively low impact option for the optimistic scenario, in particular for acidification.	
	For small-content packaging, reusable glass is a relatively low impact option for the optimistic scenario for all impacts except for acidification and radioactive waste.		For small-content packaging, non-reuse waste is a relatively low impact option for the optimistic scenario for all impacts except for acidification and radioactive waste.	For small-content packaging, beverage cartons were identified as the conditional lowest impact option for the optimistic scenario for all categories except for hazardous waste, municipal solid waste and mining waste.	

PVC, packaging, environmental, health, Spain (RANDA SP.002)

Documentation sheet (RANDA SP.002)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Estudio técnico sobre el policloruro de vinilo (PVC) como material de envasado</td></tr>
<tr><td>Scope of investigation</td><td>PVC, packaging, environmental, health, Spain, production, use, EoL</td></tr>
<tr><td>Year of publication</td><td>1998</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1996</td></tr>
<tr><td>Institution or Company</td><td>Comité de expertos sobre PVC (Committee of experts on PVC)</td></tr>
<tr><td>Contractor/ Address</td><td>MIMAM - Ministerio de Medio Ambiente (Spanish Ministry of Environment), Departamento de Calidad Ambiental</td></tr>
<tr><td>Authors</td><td>J. M. Barrales-Rienda, E. Blount, O. Castillo, A. Cid, S. Díaz, R. Fernández, L. Fontanet, M. D. Hernando, J. J. López, J. Mora, L. F. Núñez, T. Oberhuber, C. Polo, D. Romano, M. P. Santamaría</td></tr>
<tr><td>Availability/Publisher</td><td>It can be ordered from the Spanish Ministry of Environment.</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, production, use, waste management, environmental, health, packaging</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternative</td><td>No comparison with PVC alternatives</td></tr>
<tr><td>Reported data</td><td>Socio-economic, market information, other life cycle related data</td></tr>
<tr><td>Short description of the study</td><td>The study was commissioned in accordance with Final Disposition of Law 11/1997 on packaging. The scope of the Commission of Experts was the evaluation of PVC as a packaging material, by taking into account its effects on human health and environment caused by production, transformation, use and post-consumption. The study includes the following chapters: A) Production process of EDC, VCM and PVC: technical description and evaluation of environmental/health effects. B) Formulation and production of PVC products: technical description and evaluation of environmental/health effects. C) Use of PVC as packaging material (food, sanitary): legislation, review of studies on environmental/health effects. D) Post-consume of PVC: waste management in Spain, mechanical and chemical recycling, incineration, landfill. The study contains a complete and updated review of studies on environmental/health/ production/waste management data of PVC.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>X</td><td>Specific/own/new data</td><td></td></tr>
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</td></tr>
<tr><td>Comments</td><td></td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
</table>
Comment: No LCA study, but socio economic information, suggested for qualitative characterisation
</td></tr>
</table>

This study was carried out by an “Expert Committee” assigned by the Spanish Ministry of Environment, with the aim of evaluating PVC as a packaging material with respect to the environmental and health impacts of its manufacture, transformation, use and disposal.

The Committee comprised of:

- researchers from University/Research and Technology Centres;
- delegates from trade unions;
- technical staff from the Ministry of Health and Consumption, the Ministry of Industry and Energy, and the Ministry of Agriculture, Fisheries and Food;
- delegates from NGOs;
- a delegate from the Spanish Association of Consumers;
- a delegate from the Spanish Association of Plastic Manufacturers; and
- a delegate from the Spanish Federation of Business Organisations.

The study consists of an extended compilation of environmental and health impacts of PVC as packaging material during its life cycle and includes detailed references. However, members of the Committee could not reach a common position on the conclusions. Four separate sets of conclusions were formulated:

- from researchers, government, manufacturers and business organisation delegates;
- from NGOs and union delegates;
- from trade-union delegates; and
- from NGOs.

This is a practical and real example of how different participants involved in the life cycle of a product can reach different conclusions from the same information basis.

Summary for the packaging sector

In 1998, PVC had a share of approx. 5% of the 12,000,000 t of total plastic material used in the packaging sector in Western Europe [VKE 1999]. Furthermore, considering that besides plastics (approx. 13% [DSD 2002]), materials like wood, glass, metals, paper and cardboard are used as well, the relevance of PVC from this point of view seems to be very small (approx. 0,6% mass of the total materials used). Nevertheless, as shown before, approx. 6.5% of PVC is used in the packaging sector. These facts further underline the relevance of the other materials within this sector.

The materials used for packaging that are covered by the assessed studies are PVC, glass, PP, PE, PET, PS, aluminium, paper, cardboard and steel. When selecting the packaging material, technical questions usually lead to a certain material. What kind of product is packaged? What kind of protection (provided by the packaging) is needed? How and how far is it transported and will the package be returned, recycled or disposed?

From an **LCA viewpoint** the weight, to be precise, the mass ratio packaging/good plays a key role over the life cycle as lighter packaging directly influences the weight of transported goods and therefore the transport impacts etc. Considering simply the different densities of the packaging material, the potential advantage of plastics becomes clear. But of course there are other points besides weight to consider like the ability of to be recycled, where glass and aluminium are traditionally strong.

The studies which cover the **total life cycle** conclude that plastic as packaging material for non-reusable applications is favourable but there is no consensus as to which plastic is preferable. Each material has individual strengths and weaknesses. There is consensus throughout the studies that for single-use applications glass is the worst material. But when assessing reusable applications, the disadvantages of glass decrease. Even if one study determines reusable glass as the best solution there is no unanimous position on this.

End of Life is covered with different levels of detail in the studies. From an LCA viewpoint, landfill is not a preferable option for any of the discussed packaging materials. It is also stated within one study that material recycling is preferable over incineration and reusable systems are preferable over non-reusable systems. Another study points out that the environmental impacts of the collection system can not be neglected.

Most of the assessed studies do not fulfil the ISO requirements, which is mainly due to the fact that they were conducted prior to the publishing of the standard.Consequently, the studies don’t represent the state-of-the-art; any further studies would be beneficial. Of particular interest would be those that cover the total life cycle of the system with focus on End of Life options and sustainability (e.g. closed material cycles) because there has been a technical development/improvement within End of Life treatment recently. If further studies are tol be conducted, it is important that they are conducted within defined boundary conditions and on the basis of one consistent database.

LCA studies are most beneficial if they are conducted within the development phase of new systems or technologies. This ensures that environmental issues are considered early enough so that any possible design or technology changes that would reduce environmental impact are feasible.

Some examples of technological improvements or experiences gained by LCA studies conducted that would justify further studies are:

- Technological improvements have occurred within modern municipal waste incineration plants (with energy and material recovery) like the state-of-the-art plants in Germany (e.g. Hamburg) where the co-combustion of PVC is not considered a problem anymore. Emissions like HCl and dioxins are suppressed by the respective technologies and electricity and steam as well as HCl or salts for industrial use are recovered. This leads to considerable credits over the life cycle if the recovered products are used further and potentially substitute “virgin” energy and materials.
- From an LCA point of view, PVC shows the obvious disadvantages within a mixed waste fraction in the packaging sector. If mixed packaging waste contains PVC, the usability of the waste is limited. The waste cannot be used in certain applications, e.g. the thermal recovery as a fuel substitute in cement kilns[32]. This reduces the potential to save the virgin primary energy carrier. Therefore, sorting plastic waste is, technically-speaking, environmentally preferable before the recycling takes place. This leads to a potentially better quality secondary material, which consequently has more possibilities to substitute the virgin material, which would then be accounted for by the life cycle. However, additional sorting does not seem to be economic yet.

Nevertheless – as stated above - the treatment of the mixed waste together with municipal waste in the municipal waste incineration (under lower efficiency due to enhanced fluegas treatment) is no longer a technical or environmental problem as long as up-to-date technology is applied.

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[32] The treatment of mixed plastics from the packaging sector in thermal recovery / cement kilns is limited not only by presence of PVC, but also because of other unwanted elements like nitrogen, sulphur, which are not to be allocated to PVC products.

5.5 Transport

Within the transport sector, material choice plays a very important role. The properties of the materials influence design, safety, weight, environmental impact and costs. Light-weight constructions are a key issue in this sector. From a LCA point of view, the weight of the part (and therefore, its related fuel consumption in the use phase), the material production efforts required to produce the part and the recyclability of these materials all play an important role. The performance of the materials in the coating processes for exterior body-parts e.g. doors and fenders (or bumpers) influences the LCA results significantly. Table 5-37 shows an overview of market share.

Table 5-37: Overview of the transport sector

Sector	**PVC Application**	**principal competing materials (PCM)**	**share of used PVC mass**	**market share of PVC**
Transport:				
Cars and trucks	plastisol (sealing, underbody protection)	polymer bitumen, PB rubber, SMA, Zn	2.5%	major
	Parts	**PP-GF, PP/EPDM, PP**, PB, PBT, PC/ABS, SMC, PC, PA	1%	small
	Tarpaulins	acrylics, PUR (all coated)	0.5%	major
	dashboard	**PP,** PP/EPDM, leather, **PUR**	1.5%	medium
	artificial leather	PUR, leather, cotton, wool, polyester		major
	cable harness	PE-X, TPU	1%	major
Yachting	foams, fenders, etc.	wood, PUR	< 0.5%	major
Trains	seat covering	PUR, **polyester**	< 0.5%	small

Only one (extensive and very detailed) publicly available LCA study from the automobile sector (covering a comparison for underbody protection on application level) could be identified.

Perspectives of an environmentally and socially sound development of materials (EX DE-01)

Documentation sheet (EX DE-01)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Perspektiven für eine umwelt- und sozialverträgliche Werkstoffentwicklung in der Automobilindustrie unter Einbeziehung der Zulieferer- und Verweterbetriebe</td></tr>
<tr><td>Scope of investigation</td><td>Comparison of three different systems of underbody protection of an automobile in production, use and recycling.</td></tr>
<tr><td>Year of publication</td><td>1996</td></tr>
<tr><td>Ref. year of assessment</td><td>1990 to 1994</td></tr>
<tr><td>Institution or Company</td><td>Sozialforschungsstelle Dortmund, Rheindammstr. 199, 44139 Dortmund, Germany</td></tr>
<tr><td>Contractor/ Address</td><td>See above</td></tr>
<tr><td>Authors</td><td>Ammon, U.; Becke G.; Peter, G.</td></tr>
<tr><td>Availability/Publisher</td><td>Sozialforschungsstelle Dortmund</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>Environment, automobile, supplier, end-of life , Plastisol, underbody protection</td></tr>
<tr><td>Life cycle-Phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td>X</td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>PVC-Plastisol, SMA-Plastisol, PVC-zinc combination, SMA-zinc combination</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>Technical analysis with a separate, very detailed LCI report. The systems are technically described in detail. The whole energy- and material-supply chain is described and quantitative facts are given. The systems are analysed along their individual supply chains. All relevant sub-chains (intermediates, auxiliaries) are described. The important modules are quantified on a unit process level. The use phase is characterised by kilometres driven and the consumption-reduction rule. The end-of-life phase is qualitatively characterised by potential recycling possibilities.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure like</td><td></td><td>Scientific like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/Literature data</td><td>10%</td><td>Specific/own/ new data</td><td>90%</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td>X</td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic Characterisation (EX DE-01)

Overall frame of study	
ISO 14040 ff	(X)
Code of practice	X
other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	underbody protection of a car
Functional unit	1 underbody protection (of a mid size car) in 4 versions
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	X
Allocation (mass/energy/price/exergy)	different (documented in study)
System Expansion	no
Substitution	no
Data categories described	
Primary Energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X qualitative
Stratospheric Ozone Depletion	
Toxicity, human	X qualitative
Toxicity, eco	X qualitative
other:	
Data quality	
time	mostly primary data collection
geography	Germany
technology	data of actual technology used
Critical review performed	Review within institutes in project
Evaluation	
Normalisation	no
Weighting	no
other methods	No, all impacts displayed and discussed

Critical Assessment (EX DE-01)

Goal description in short	• Primary goal of the study was to analyse the four individual value creation chains and identify individual optimisation potentials. It was clearly stated that there was no primary aim to find a "winner". The participants in the project (most of the key companies in the chain and academic institutions of the respective fields) understood that most benefits can be obtained from the individual identification and optimisation of existing weakpoints.	
Valuation of the goal	• The goal definition is clearly stated and the goal of the study can easily be understood.	
Scope of study	• Analysis of four different underbody protections PVC-Plastisol, SMA-Plastisol, PVC-zinc combination, SMA-zinc combination • Geographical scope is Germany. Economical scope is the value creation chains with all important sub-chains. • Functional unit clearly described.	
Life cycle phases	• All life cycle stages included. • Conclusions can be drawn from the included LCA stages • End-of-Life stage is mostly qualitative discussed (very less quantitative data given). Due to the long use phase of the cars, definite recycling or disposal pathways could hardly be defined, but rather assumed.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which MAY affect conclusion	
Important assumptions	• Plastisol production exclusively calculated for German boundary conditions • DINP production could only be estimated (stoichiometry) as primary industry data was not available. • Any of the chosen allocation is verbally discussed and important ones are analysed by a sensitivity analysis. • Consumption reduction rule 0.003235 l/(100km*kg) • Example car 1,280kg; 9.2l/100km	
Valuation of scope	• The scope is appropriately chosen (all important industries of the main chain are in the project group) to fulfil the goal.	
Methodology	• Swiss UBS "Umweltbelastungspunkte" and Norwegian Ecofactors chosen and compared. • Very detailed LCI[33] information (LCI information possibly confidential) • Detailed LCIA[34] on many impacts (see above) as well • Easily understandable and well-documented. • Proposal for project specific valuation and interpretation of environmental results presented.	
Data requirements	• Discussion of completeness, representativeness precision level, consistency and reproducibility. The sensitivity of data was analysed and discussed.	
Inventory	• GaBi 2.0 database for background data • Primary collected industry data for foreground data	
Impact Assessment	• Performed on several different impacts (see systematic characterisation). Photochemical oxidant formation could not be assessed properly as impact models and characterisation values were missing. Due to the huge uncertainty within toxicity potentials, those were only discussed qualitatively.	
Environmental impacts included	• Primary-energy use, global warming potential, acidification, nutrification, toxicity (qualitatively)	
Weighting of environmental parameters	• A sensitivity analysis between the different weighting schemes (Swiss and Norwegian) was carried out. It can be recognised that the overall (absolute) values are of course differing. But the relative difference of the versions does not change significantly. This means that the kind of weighting influences the absolute amount of weighted impact, but has less influence on the interpretation of the optimisation potentials within the individual chains as well as less influence on the interpretation comparing the options.	
Overall ISO 14040 ff requirements	• The study was undertaken while the standards were still in development. The study was orientated on the "Code of practice" and the organisations of some authors of study were partly integrated into the standardisation process as delegates. Since the development of the standards itself was partly influenced by the "Code of practise", it can be stated that overall requirements of the ISO 14040 ff are met.	

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[33] LCI = Life cycle inventory

[34] LCIA = Life Cycle Impact Assessment

The study comes to the following key conclusions:

- The most promising potentials for the environmentally and socially sound development of materials within the automotive industry lie in the optimisation of the different production chains. Any of the four underbody protection versions has its specific advantages and disadvantages.
- From an objective point of view, a “winner” can not be identified.
- PVC shows tendencies to have less impact during the production phase than SMA, but due to a higher weight (within this particular design of this car component) it has some higher impacts in the use phase (fuel consumption).
- The use phase dominates the life cycle impacts for this application; therefore, the optimisation of the design of the part – to reduce its weight - is identified as the preferable approach.

<u>The study explains to manufacturers</u>:

- Environmental qualification, science practices and material (design) innovation of the companies and branches along the value creation chain offer promising improvement potential. Possible environmental and social effects of ecological-technical developments need an early commitment from all participants, as steady environmental improvement in the long run can only be achieved if the ecological and social impacts over the whole value chain are considered.

<u>The study explains to users</u>:

- Nothing in particular, as the user of a car has doesn’t have any possibility to influence the environmental performance of the underbody protection during use. The only (interesting and trivial) messages for users may be that the weight of car parts directly influences the consumption and that overall life cycle impacts are heavily influenced by the use phase and therefore (besides the weight of the car), by the behaviour of the driver.

<u>The study explains to third parties:</u>

- Highest environmental optimisation potentials in the automotive industry may be connected to the improvement of existing concepts over the life cycle, or to the development of innovative concepts of car parts, which consider the life cycle in the earliest stages of the part development. Synergistic effects of different materials used in combination, may offer additional environmental optimisation potentials, if the recirculation of the materials into the value creation chain is possible.

Summary of the transport sector

Many studies have been carried out to compare the use of PVC with other materials, such as other plastics and metals (among various other materials) within the transport sector, in specific applications. It is known that studies comparing different sealings, underbody protection, body parts, tarpaulins, dashboards, (artificial) leather parts, cable harnesses, foams, fenders and seat covers have been undertaken.

However, in contrast to other sectors, most of these studies are not published. LCA studies in the transport sector are often used for internal decision support and are considered a competitive advantage by companies. Many studies are financed or even carried out by the companies themselves, which explains why, in contrast to studies commissioned by public authorities or governmental bodies, the results are not usually published.

Today, ecological decision making (in the context of technically innovative and economically feasible product development) within the transport sector and especially within the automobile sector, is of ever growing importance. This is occurring more commonly during research and development phases by assessing future technologies or new product ideas, rather than on a retrospective basis. The automotive industry is continually working on further developments using these types of analysis, because new technical questions arise and new aspects of optimisations are integrated into the product development process based on life cycle information. Furthermore, the goal of future work includes the preparation and integration of process-chain information directly into the development and design phase of the product, before the product moves into production [UWS 2002]. At the beginning of the 1990s, the automotive industry played an important role in developing application orientated LCA methods and databases and consequently, has used LCA since that time, but nevertheless, due to the above mentioned facts, little public information is available.

Due to the existing EU directive on end-of-life of vehicles, and to the traditional drive for light weight concepts in the automotive industry, the efforts to perform analysis of concepts using different materials are ongoing. An area of conflict seems to be between light weight plastics and the established recycling systems of metals. This situation pinpoints that material choices should be made in the context of the system, rather than independent of the application. The automotive industry is an enthusiastic defender of this basic principle.

PVC in the automotive sector is not used in simple products and parts (the underbody protection can be understood as a stressed part of the car, as it is exposed to mechanical, thermal and chemical impacts). Within the automotive industry, PVC is mostly used to provide specific technical properties which may be difficult to achieve with other (cheaper) materials.

Therefore, individual comparisons with the possible alternatives on a case-by-case basis are needed. This is done in many automobile companies with different intensity.

The automotive sector is (one of) the leading sector(s) in LCA, having integrated the concept of LCA into their daily work flow for many years now. Besides leading to environmental optimisations, LCA has proven to be beneficial economically as well. New products and alternatives have often been analysed and optimised during development, rather than retrospectively, after market launch.

The single publicly available LCA study on an application comparison of underbody protection does not justify any general material preference conclusions.

Therefore, considering that the information exists but is confidential, it is concluded that a huge gap exists regarding the *public* availability of PVC information for automotive applications.

We see two different points where important gaps exist relative to the public availability of information on PVC comparisons to competing materials; first, related to in-door applications (dashboards etc.), but even more so to end-of-life questions, due to the take back regulations (End of Life Vehicle directive). Comparisons of different treatment and recycling options, based on product environmental performance in the production and use phases, can provide valuable answers to industry, users and policy makers.

5.6 Electric and electronic equipment

In the electric and electronic-equipment sector, one application dominates the mass share of total PVC, as well as the market share within this application: cables.

Nevertheless, few LCA studies have been undertaken to compare the application of different cable insulation materials.

Table 5-38 shows an overview of the market-share situation of the electric and electronic equipment sector.

Principal competing materials are polyolefins, polycarbonate, ABS and PC.

Table 5-38: Overview of the electric and electronic sector

Sector	PVC Application	principal competing materials (PCM)	share of used PVC mass	market share of PVC
electric and electronic equipment:				
	cables	**PE, PEX**, rubber, TPE, PP	11%	major
	casings	**ABS, PC, PS**, polyolefin (all with FR), metals	0.5%	small
	cable ducts	Polyolefins		major

Environmentally Sound Product Development of Cable (IPU 000.0014)

Documentation sheet (IPU 000.0014)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Environmentally Sound Product Development of Installation Cable</td></tr>
<tr><td>Scope of investigation</td><td>Installation cable</td></tr>
<tr><td>Year of publication</td><td>1995</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>Unknown</td></tr>
<tr><td>Institution or Company</td><td>CIT Ekologik, Chalmers Industriteknik, Chalmers Teknikpark, SE-412 88 Göteborg, Sweden</td></tr>
<tr><td>Contractor/ Address</td><td></td></tr>
<tr><td>Authors</td><td>Rydberg, T.; Sjöström, K.; Karlson, L.; Larsson, P.; Videsson, A.; Hanssen, O. J.</td></tr>
<tr><td>Availability/Publisher</td><td>CIT Ekologik, Chalmers Industriteknik, Chalmers Teknikpark, SE-412 88 Göteborg, Sweden</td></tr>
<tr><td>ISBN</td><td></td></tr>
<tr><td>Keywords</td><td>Installation cable, PVC</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><td>Production phase</td><td>X</td><td>Use phase</td><td></td><td>End of life</td><td></td></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td></td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Not directly, but concluding comparison to alternatives done</td></tr>
<tr><td>Reported data</td><td>LCA, LCC</td></tr>
<tr><td>Short description of the study</td><td>Combining LCA, LCC and QFD (Quality Function Deployment – to assess customer requirements) to give product improvement potentials.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td>X</td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>(X)</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for systematic characterisation
</td></tr>
</table>

Systematic characterisation (IPU 000.0014)

Overall frame of study	
ISO 14040 ff	
Code of practice	x
Other	
Goal, description of	
Application/use of results	x
Aim of study	x
Target group of study	x
Scope, description of	
main technical systems properly described	(x)
Function analysed	Installation cable
Functional unit	1 km of cable
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	assumed deposited
transportation	X
Allocation (mass/energy/price/exergy)	not described
System Expansion	not described
Substitution	not described
Data categories described	
Primary energy consumption	not described
Air emissions	not described
Water emissions	not described
Waste categories	not described
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	X
Toxicity, human	X
Toxicity, eco	X
other:	Resources
Data quality	
time	not stated
geography	Sweden
technology	not stated
Critical review performed	(meetings with working group)
Evaluation	
Normalisation	X
Weighting	X
other methods	

Critical Assessment (IPU 000.0014)

Goal description in short	• To make an LCA as a reference for product improvements	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• System boundaries are not thoroughly described. • Duration unknown	
Life cycle phases	• Conclusions can be drawn on the basis of the included life cycle stages.	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	
	• Major cut-offs/incompleteness which are likely to affect conclusion	X
Important assumptions	• Swedish average electricity • Cable assumed land filled as the recycling companies contacted did not receive the cable.	
Valuation of scope	• The scope is too vaguely described to act as reference product as it is not possible to see, if other materials/products/systems are comparable.	
Methodology	• Allocation not mentioned	
Data requirements	• No discussion of precision level, completeness, representativeness, consistency and reproducibility are stated.	
Inventory	• No discussions on LCI model. • Sensitivity of inventory parameters are not discussed, only scenario analyses. • Database used for generic data: APME, PWMI, Neste Oxo AB. • Database from a Software System: LCAIT	
Impact Assessment	• Impact assessment is carried out via three different methods; - EPS - Ecological Scarcity - Environmental Theme Method (CML). • Methodologies of assessment do agree with ISO 14042.	
Environmental impacts included	• Only selected results are presented. • The included impact categories are appropriate to fulfil the goal of the comparative assessment of flooring materials, especially since one solution scores lowest or almost lowest in all methods.	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• Work is carried out according to “SETAC Code of Practice”	

The study comes to the following key conclusions:

- The highest environmental impact is the use of copper.
- The highest environmental improvement potentials are:
    - Making sure copper is recycled, which will reduce the demand for primary copper, and thereby, reduce the environmental effects from production of primary copper.
    - Changing to a hidden cable system. This will reduce the consumption of materials and their associated effects. Furthermore, the critical customer requirements of discrete design, resistance to dirt, and resistance to colour degradation are improved. A good economy in this is also reported.
- Shifting from PVC to other materials for cable insulation provides no environmental gain.
- Lead used as stabiliser should be avoided. However, this conclusion on environmental preference depends on the impact assessment method used.

The study explains to manufacturers:

- Ensuring the reuse of copper improves environmental performance.

The study explains to users:

- Request hidden cables.

The study explains to third parties:

- Whether reuse is feasible depends on the logistics of the recovery system. Shifting from PVC to PE does not improve environmental performance.

A detailed discussion is not provided, but the general conclusions seem adequate.

Table 5-39: Summary of the analysed impacts of IPU 0014

IPU 0014	PVC	PE	Impacts
Total life cycle	Better performance		Resource use
		Better performance	Acidification
		Better performance	Toxicity

Summary of the electric and electronic sector

The limited number of LCA comparisons of cable materials may be due to a limited number of comparable alternatives to PVC. Polyolefin based cable systems exist, but the material choice is strongly influenced by technical requirements (e.g. mechanical properties of the material) and economic boundaries. In some cable applications (e.g. certain high voltage applications) PVC can simply not be used due to technical reasons and in the other applications PVC seems be very dominant.

Durability, temperature and fire resistance together with flexibility are technical aspects, which competing materials would have to fulfill as well.

Due to the use of copper and aluminium, cable waste has a high economic value. Therefore, cables are often recycled. The collection of this material fraction is done separately from other waste. This is advantageous and enables various recycling possibilities.

The recovery of PVC from cable waste has proven uncritical by a comparative LCA of four recovery technologies related to landfilling (see study EX EU-01 on page 278 under sector overlapping studies). This study was commissioned by Vinyl2010[35], conducted by a neutral consultancy, supported by the respective companies and assisted by the Danish EPA. A critical review was performed by another independent external organisation from Switzerland, which specialises in LCAs of wood products, and therefore, represents a potentially opposing viewpoint. The study was positively reviewed. Specific and new data was collected on-site and analysed. Therefore, the project is representative of current situations regarding the potentials and impacts of PVC recycling.

Polyethylene, polypropylene and rubber cables have to be treated with flame retardants such as halogens in order to provide required fire resistance. PEX (crosslinked polyethylene) turns out to have disadvantages related to durability and is more expensive. Current alternatives are not expected to offer environmental advantages over PVC from a LCA viewpoint.

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[35] Vinyl2010 is a non-profile organisation representing the whole European PVC industry

5.7 Medical applications

Within the medical applications sector PVC plays a major role in terms of market share, whereas the absolute mass stream of PVC used within this sector is small.

LCA does currently not play a major role within the optimisation of medical applications[36]. Therefore neither public LCA studies on the comparison of PVC with alternatives nor public LCA studies on medical application made from PVC, could be considered[37].

Table 5-40: Overview of the medical sector

Sector	PVC Application	principal competing materials (PCM)	share of used PVC mass	market share of PVC
medical applications:				
	blood and infusion bags and medical devices	**multilayer polyolefins,** glass	0.5%	major
	gloves	**rubber,** PU		

Within the medical sector, we see a large potential for optimisation using LCA approaches. Relevant information gaps, therefore, still exist today. Due to the specific requirements of medical products, the use and end-of-life phases may be the most important. Even when the use phase of the disposable products is short, the technical and hygienic demands are of utmost importance (e.g. due to the need to be sterile and safe). The end-of-life phase is important due to the fact that the products are disposable. The chosen functional unit should take these factors into consideration. Therefore, LCAs within the medical sector based on the specific medical goal (improvement of the health of humans) are recommended for environmental optimisation.

5.8 Agricultural applications

PVC in the agricultural sector is found in foils and greenhouse sheets. The market share, as well as the mass stream of PVC, in these applications is negligible. No LCA studies could be identified related to PVC applications in this sector.

Table 5-41: Overview of the agricultural sector

Sector	PVC Application	principal competing materials (PCM)	share of used PVC mass	market share of PVC
agriculture:				
	green houses sheets	polyethylene, glass, PMMA	negl.	negl.
	Foils	**polyolefines**	< 0.5%	small

---

[36] Only one study could be identified analysing infusion bags amongst other products (see IKP AT-1, Annex A2.2). The information could only be gathered as comprehensive slide presentation, without publication date, reference year, information on data origin or literature links. Surprisingly many products in many different applications are analysed. The quality requirement could not be checked.

[37] According to information of industry associations (EVCM) further LCA's have been executed by industry, but are not public. If this sector is to be investigated, collaboration with the industry sector should therefore be ensured to avoid double work.

We do not see any relevance within this sector and therefore, no relevant gaps.

5.9 Sector-overlapping studies

In this section, LCA studies which do not relate to a specific sector or application are listed. Nevertheless, the studies were considered important enough to be systematically or qualitatively characterised.

The studies mainly consider end-of-life methods of disposal or recycling, which may apply to various sectors. Where, conclusions are drawn on specific applications, this information is also taken into account in the respective summaries of the specific sectors.

PVC end-of-life, incineration, municipal solid waste, hazardous industrial waste, clinical waste, (RANDA EU.001)

Documentation sheet (RANDA EU.001)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>The influence of PVC on the quantity and hazardousness of flue gas residues from incineration, Contract number: B4-3040/98/000101/MAR/E3</td></tr>
<tr><td>Scope of investigation</td><td>PVC end-of-life, incineration, municipal solid waste, hazardous industrial waste, clinical waste, European Union</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1999</td></tr>
<tr><td>Institution or Company</td><td>Bertin Technologies, Pôle Environment et Genie des Procedes, Centre de Tarnos</td></tr>
<tr><td>Contractor / Address</td><td>European Commission Directorate General Environment</td></tr>
<tr><td>Authors</td><td>Bernard Jacquinot, Ole Hjelmar, Jürgen Vehlow</td></tr>
<tr><td>Availability/Publisher</td><td>Can be downloaded from EC PVC homepage:
http://europa.eu.int/comm/environment/waste/studies/pvc</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, incineration, municipal solid waste, hospital waste, chlorine</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th></th><th>Use phase</th><th></th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td></td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>No comparison with PVC competing materials</td></tr>
<tr><td>Reported data</td><td>Life cycle related data</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to identify the influence of PVC on the quantity and hazardousness of flue gas residues from incineration. This comprises: the identification of PVC influence regarding quantity and hazardousness of flue gas residues from incineration in practice and in theory; the distinction between dry, semi-dry and wet gas treatment systems; and the identification of the potential environmental and health effects caused by waste water, sludge and solid flue gas residues resulting from incineration of PVC.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>X</td><td>Specific/own/new data</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. Comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
</table>
Comment: No LCA study, life cycle related, issues comprehensively covered, scientific-based, suggested for qualitative characterisation.
</td></tr>
</table>

The study is aimed at identifying the influence of PVC on the quantity and hazardousness of flue gas residues from incineration. This includes:

- The identification of PVC effects on the quantity and hazardousness of flue gas residues from incineration, in practice and in theory.
- The distinction between dry, semi-dry and wet gas treatment systems.
- The identification of the potential environmental and health effects caused by waste water, sludge and solid flue gas residues resulting from PVC incineration.
- Estimation of the costs for PVC incineration, including the environmental costs.

In order to meet the objectives mentioned above, the study includes the following parallel or successive steps:

- *Step 1:* The incineration processes and associated gas-treatment systems utilised in the EU are described.
- *Step 2*: The variety of PVC products and the ways these are incinerated after being mixed with other types of waste are described.
- *Step 3*: The influence of PVC on the combustion step and therefore, the distribution of chlorine and other pollutants (heavy metals and trace elements) in the solid and gas phases are described.
- *Step 4*: The influence of PVC on the quantity of gas-treatment residues is evaluated.
- *Step 5*: The influence of PVC on the composition of the gas-treatment residues (Fly Ash and Neutralisation Products) or liquid effluents from the different gas-treatment systems in relation to the possible neutralisation agents is evaluated.
- *Step 6*: The cost of PVC incineration is quantified.
- *Step 7:* A synthesis table, which summarises the effect of PVC on the quantity and composition of the residues from the gas treatment, is created.

Theoretical calculations and experimental data from different European industrial incineration plants were used to complement the literature survey. The following plants were selected for this purpose:

- *Dry GTS Process*: Würzburg (Germany); Novergie and Pontivy (France); Nordforbraending (Denmark) and Reggio Emilia (Italy)
- *Semi-dry GTS Process*: Würzburg (Germany); SELCHP (United Kingdom); Amager-Forbraending (Denmark); Toulon and Carrières (France); and Beveren (Belgium).
- *Wet GTS Process*: Alkmaar (Netherlands), Bamberg (Germany); Vestforbraending (Denmark); Spittelau (Austria); and Antwerpen (Belgium).
- *Clinical Waste Incinerator – Dry GTS Process*: CW Incinerator (Belgium)

The following conclusions are drawn:

End-of-life PVC, when dealt with by incineration, ends up mainly in municipal waste incinerators, as hazardous waste incinerators and cement kilns do not treat PVC rich wastes. PVC is also present in hospital waste which is incinerated.

Due to the wide range of uses of PVC, there is a correspondingly wide range of performance properties required. Therefore, a wide range of PVC formulations exist. The content of pure PVC (resin) within the various formulations varies from 44% to 93%.

The influence of PVC on the composition of the MSW input fraction is mainly related to the chlorine content of the waste to be incinerated: PVC is responsible for 38 to 66% of the chlorine content of the MSW. The PVC influence on lead content in the MSW input fraction is assumed to be less than 1% and the influence of cadmium around 10%.

The presence of PVC in MSW has a direct effect on the quantity of chlorine in the raw gas and, therefore, on the corresponding gas treatment required. The higher chlorine content in the gas requires an additional neutralisation-agent and therefore affects the quantity of residues or effluents generated by the different gas-treatment systems (dry, semi-dry and wet).

LCA of PVC in windows, pipes, packaging films and cables (IKP D-3)

Documentation sheet (IKP D-3)

<table>
<tr><td>Kind of report</td><td>Report</td></tr>
<tr><td>Title</td><td>PVC und Nachhaltigkeit - Systemstabilität als Maßstab, ausgewählte Produktsysteme im Vergleich/ PVC in Selected Product Systems - A contribution to the sustainability discussion</td></tr>
<tr><td>Scope of investigation</td><td>LCA of PVC in windows, pipes, packaging films and cables</td></tr>
<tr><td>Year of publication</td><td>1999</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1992 to 1998</td></tr>
<tr><td>Institution or Company</td><td>PROGNOS-AG, Missionsstr. 62, CH-4012 Basel, Switzerland</td></tr>
<tr><td>Contractor/ Address</td><td>Steuerungsgruppe zum 'Dialogprojekt PVC und Nachhaltigkeit' und Arbeitsgemeinschaft PVC und Umwelt e. V., Am Hofgarten 1 - 2, 53113 Bonn, Germany</td></tr>
<tr><td>Authors</td><td>Plinke, Eckhard; Wolff, H.; Meckel, H.; Schüssler, R.</td></tr>
<tr><td>Availability/Publisher</td><td>Steuerungsgruppe zum 'Dialogprojekt PVC und Nachhaltigkeit' und Arbeitsgemeinschaft PVC und Umwelt e. V. or Publisher: Deutscher Instituts-Verlag, Gustav-Heinemann-Ufer 84 - 88, 50968 Köln, Germany</td></tr>
<tr><td>ISBN</td><td>3-602-14485-2</td></tr>
<tr><td>Keywords</td><td>PVC, sustainable development, windows, pipes, packaging, cables</td></tr>
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Qualitative/Quantitative</td><td>
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<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>Windows: PVC, aluminium, wood/ Pipes: PVC, HDPE, vitrified clay, cast iron/ Packaging: PVC, PP, PS, PET/ Cables: PVC; PE</td></tr>
<tr><td>Reported data</td><td>LCA / market information</td></tr>
<tr><td>Short description of the study</td><td>The study analyses four main products: windows, pipes, packaging and cables in PVC and respective competing materials. The final result is presented in a 'sustainable portfolio' which gathers the results of environmental, economical and social sustainability indicators. Inventory data is not presented and the database is based on different studies.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td></td><td>Academia</td><td>X</td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td>X</td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
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Comment: Suggested for systematic characterisation
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Systematic characterisation (IKP D-3)

Overall frame of study	not specified
ISO 14040 ff	
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Windows, pipes, packaging and cables
Functional unit	Windows: 1.65 x 1.3 m Pipes: DN 200, DN 150 Packaging: Film 0.25 mm thick Cable: Cable sheathing compound
System boundaries include:	
materials	X
energy	X
production	X
use	X
disposal	X
recycling	X
transportation	
Allocation (mass/energy/price/exergy)	not specified
System Expansion	not specified
Substitution	not specified
Data categories described	not described
Primary energy consumption	
Air emissions	
Water emissions	
Waste categories	
Impacts	
Global warming	X
Acidification	
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	X
Toxicity, eco	X
other:	
Data quality	
time	
geography	Europe
technology	
Critical review performed	no
Evaluation	
Normalisation	
Weighting	
other methods	sustainability indicators

Qualitative characterisation IKP D-3:

The study comes to the following conclusions:

- Window frames: PVC window frames have more favourable prospects (lower ecological, economical and social risks) in the short (5-7 years) and medium (up to 20 years) terms, i.e. fewer risks than the alternatives: wooden and aluminium window frames. The PVC window frame is the cheapest and has thereby been able to greatly increase its market share. At the same time, the social risks (lower impact on employment) and the ecological risks are limited or slight.
- Pipes: PVC pipes for drinking water and wastewater have more favourable prospects in the short term than the alternatives made of vitrified clay or cast iron, but not in comparison to HDPE pipes. In the medium term, the prospects for both plastic pipes (PVC and

HDPE) are more favourable. Due to possible improvements in design, measures for saving materials and – to a limited extent – for recycling, a reduction of the risks can be achieved (in particular in the ecological sphere and in energy consumption).

- Packaging films: In the short and medium terms, PVC is competitive in price (approx. the same as PP) and further emission reduction measures are possible in order to reduce the ecological disadvantages (toxic and ecotoxic emissions that are usually already subject to statutory regulations and standards). In the medium to long term PP films have the more favourable prospects.
- Cables: PVC prospects in the shorter and medium term are favourable. The decisive factor is the much lower price compared to cables made of polyolefins (PE). In the medium and long term the prospects for PVC cables are unfavourable. When compared to PE, PVC has clear ecological disadvantages.

The study further concludes that the sustainability of products (or materials) can not be seen as an absolute, it is always a ‘relative contribution to the sustainability of the entire system’ in comparison to other, alternative products.

This study was not recommended for a critical assessment as many of the results presented in it were based on studies already assessed in this chapter. A highlight of this study was the simple, practical and transparent presentation of the results in a portfolio, considering the risks as well as the time period. Nevertheless, although it involves ecological, economical and social indicators, it should be noted that the uncertainties present in each indicator are also present in the presentation. Future estimations should be carefully analysed before they can be used to make final decisions, given that the uncertainty of data tend to be higher for future estimates.

PVC and additives: behaviour in landfill (RANDA EU.002)

Documentation sheet (RANDA EU.002)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>The behaviour of PVC in landfill</td></tr>
<tr><td>Scope of investigation</td><td>PVC and additives: behaviour in landfill (end of life), European Union</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1999</td></tr>
<tr><td>Institution or Company</td><td>ARGUS in association with University Rostock-Prof. Spillmann, Carl Bro a/s and Sigma Plan S.A.</td></tr>
<tr><td>Contractor/ Address</td><td>European Commission DGXI.E.3</td></tr>
<tr><td>Authors</td><td>ARGUS (Germany), Prof. Spillmann (University of Rostock, Germany), Carl Bro (Denmark), Sigma Plan (Greece)</td></tr>
<tr><td>Availability/Publisher</td><td>Can be downloaded from EC PVC homepage: http://europa.eu.int/comm/environment/waste/studies/PVC</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, landfill, additives, analysis, environmental impacts</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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<tr><th>Production phase</th><th></th><th>Use phase</th><th></th><th>End of life</th><th>X</th></tr>
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</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>No comparison with PVC alternatives</td></tr>
<tr><td>Reported data</td><td>Other life cycle related data</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to provide a survey of existing analyses and research regarding the behaviour of PVC in landfills and to evaluate the environmental impact of PVC waste after final disposal in landfills. Furthermore, to perform practical analysis under simulated landfill conditions and estimate the quantities of PVC landfilled and the cost of landfilling PVC waste, including environmental costs.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>X</td><td>Specific/own/new data</td><td>X</td></tr>
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</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
</table>
Comment: No LCA study, Life cycle related, issues comprehensively covered, scientific based, suggested for **qualitative characterisation.**
</td></tr>
</table>

RANDA EU.002

In recently published studies on environmental impacts of PVC, particular attention is given to the behaviour of PVC in landfills. Consequently, this study provides useful information.

The study contains:

- general information on PVC applications, on the most commonly used additives, and to what extent these additives are used in PVC products;
- data on the increase of PVC waste and the amount of landfilled PVC in the EU;
- description of the relevant landfill processes;
- results of a literature survey on environmental impacts of PVC in landfills; and
- results of a practical analysis of the environmental impact of PVC in landfills, taking into consideration the emissions and additional costs resulting from the landfilling of PVC.

In the simulation studies, plasticised and rigid PVC was incubated in lysimeters under aerobic thermophilic (up to 80ºC[38]), anaerobic thermophilic (60ºC) and alternating aerobic-anaerobic conditions. The samples were also incubated in a biological waste-treatment plant under aerobic conditions. Specific processes, including microbiological attack on PVC materials and the leaching behaviour, were examined. The main results are as follows:

- Phthalates are released from PVC material under landfill and under soil buried conditions.
- DEHP was detected in the condensate of gaseous emissions from lysimeters with and without the presence of incubated PVC.
- Fingerprint analysis from gaseous emissions from lysimeters indicates differences between those with incubated PVC and blank control.
- Microbial growth was observed in plasticised PVC.
- Mechanical properties of plasticized and rigid PVC samples, investigated through ductility tests, changed during incubation conditions.
- Molecular weight distribution of the PVC polymer of a thin flexible packaging foil changed under thermophilic aerobic conditions.

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[38] Remark: During the project is was discussed whether the simulation trials were run at unusual high temperatures (80 deg C), but no clarification concerning the conclusions could be drawn.

Long-term behaviour of PVC products and their additives under landfill conditions (EX DE-02)

Documentation sheet (EX DE-02)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Long-term behaviour of PVC products and their additives under landfill conditions</td></tr>
<tr><td>Scope of investigation</td><td>PVC and additives: behaviour in landfill (end of life)</td></tr>
<tr><td>Year of publication</td><td>2001</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1999/2000</td></tr>
<tr><td>Institution or Company</td><td>Technische Universität Hamburg, Technologie GmbH (TuTech) Integrated Management.</td></tr>
<tr><td>Contractor/ Address</td><td>European Commission DGXI.E.3</td></tr>
<tr><td>Authors</td><td>Mersiowsky, Ivo</td></tr>
<tr><td>Availability/Publisher</td><td>Technische Universität Hamburg, Technologie GmbH (TuTech) Integrated Management</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>PVC, additives, landfill behaviour</td></tr>
<tr><td>Life cycle phases
Qualitative/Quantitative</td><td>
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<tr><td>Production phase</td><td></td><td>Use phase</td><td></td><td>End of life</td><td>X</td></tr>
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<tr><td>Quantitative</td><td></td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>No comparison with PVC alternatives</td></tr>
<tr><td>Reported data</td><td>Other life cycle related data</td></tr>
<tr><td>Short description of the study</td><td>The long-term behaviour of various PVC products was investigated in laboratory-scale landfill simulation assays. These assays were operated at conditions which reflect the expected behaviour of average sanitary landfills. In order to make a long-term assessment feasible, characteristic landfill processes (leaching and biodegradation) were enhanced. Leachate and gas were monitored, and PVC samples were analysed.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
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<tr><td>Generic data/literature data</td><td>X</td><td>Specific/own/new data</td><td>X</td></tr>
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<tr><td>Comments related to further assessment</td><td>
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<tr><td>Initiator</td><td></td><td>LCA</td><td></td></tr>
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<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
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<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
</table>
Comment: No LCA study, life cycle related, issues comprehensively covered, scientific based, suggested for qualitative characterisation.</td></tr>
</table>

The study concludes the following on plasticisers:

Findings of phthalates in leachate were significantly lower than expected (from laboratory release and dissolution tests). While phthalates and their degradation products may occur temporarily in landfill leachate, complete microbial removal is possible. Possible losses of plasticisers are not expected to continue indefinitely.

The study concludes the following on stabilisers:

The detection of organotin components in landfill leachate required highly sensitive analytical methods. Nonetheless, organotin compounds were hardly detected in leachate under regular landfill conditions. However, findings increased at elevated temperatures. Heavy metals like lead (Pb) and zinc (Zn) are abundant in landfill leachate, originating from a wide range of sources in municipal solid waste other than just PVC. Usually detection of heavy metals cannot be attributed specifically to PVC, since concentrations in the leachate do not differ, regardless of the presence of PVC products. The noticeable release of lead from the PVC cable occurred (apparently) in conjunction with the loss of the plasticiser DINP. Nonetheless, the differences in concentrations of lead in the leachate were still found to be minor. Conversely, cable formulations without DINP, containing only DIDP plasticiser, as is usually the case, are reasonably expected to show even less or no detectable release of lead. Zinc from the PVC flooring and lead from the PVC pipe were barely noticeable and transient. Both may be explained by superficial wash-off. Taking into account the elevated amounts of PVC products incubated, in comparison to their statistical abundance in landfilled waste, it is apparent that PVC products do not have a detectable influence on leachate quality with regard to heavy metal concentrations.

The study further concludes:

A degradation of the PVC polymer was not observed. Vinyl chloride in landfill gas does not originate from PVC products, but from volatile chlorinated carbons, such as perchloroethylene. Plasticisers differ considerably in their behaviour: some leach, depending both on their compatibility with the polymer matrix and their anaerobic biodegradability. Due to microbial transformation, the concentrations in the leachate are, however, not correlated with the losses. Phthalates and their degradation products may occur transiently at low concentrations. In contrast to this, the release of stabilisers appears to be attributable to leaching from the surface. Concentrations in leachate can usually not be distinguished from background concentrations. Any losses of additives tend to increase at elevated temperatures. The behaviour of the PVC polymer matrix changes completely upon glass transition. The contribution of PVC products to the inventory of heavy metals in municipal solid waste is low. However, PVC products do constitute a major sources of phthalic and organotin compounds. Findings of both phthalic and organotin compounds cannot solely be ascribed to post-consumer PVC products in landfilled waste. Therefore, other waste components must be taken into consideration, particularly dispersed pollutants conveyed by sewage sludge.

Despite the fact that landfilling is neither a ‘forward-looking’ nor a sustainable end-of-life option for most of the existing products and materials, additional impacts due to additional PVC waste being landfilled is assumed to be less relevant in terms of LCA impacts.

PVC Recovery Options - Environmental and Economic Analysis (EX EU-01)

Documentation sheet (EX EU-01)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>PVC Recovery Options - Environmental and Economic System Analysis</td></tr>
<tr><td>Scope of investigation</td><td>Analysis of four new technologies for the recycling of PVC cable waste with reference landfill</td></tr>
<tr><td>Year of publication</td><td>2003</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>2002</td></tr>
<tr><td>Institution or Company</td><td>PE Europe GmbH, Reutlingen University, Tu Tech Hamburg</td></tr>
<tr><td>Contractor/ Address</td><td>VINYL 2010</td></tr>
<tr><td>Authors</td><td>Johannes Kreißig, Martin Baitz, Jochen Schmid, Peter Kleine-Möllhoff, Dr. Ivo Mersiowsky () Mersiowsky, I.</td></tr>
<tr><td>Availability/Publisher</td><td>VINYL 2010</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>PVC, cables, recycling options, thermal, chemical, mechanical</td></tr>
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</td></tr>
<tr><td>Comparison with alternatives</td><td>No comparison with PVC alternatives, comparison of technologies to recycle PVC</td></tr>
<tr><td>Reported data</td><td>LCA data</td></tr>
<tr><td>Short description of the study</td><td>Four different recycling options are compared. The municipal waste incineration in the MVR Hamburg facility in Germany with the recovered products electricity, heat, HCl, and metal(s). The feedstock recycling with the Watech process of RGS90 A/S in Denmark. It uses pyrolysis followed by purification and extraction steps. The recovered products are CaCl2, coke, pyrolysis oil (condensate) and metal(s). The feedstock recycling process of Stigsnæs Industrimiljø A.S. in Denmark is a hydrolysis followed by post-heating (pyrolysis) of the dechlorinated solid fraction. The recovered products are NaCl, hydrocarbon (CnHm) fractions, solid residue for the production of sandblasting material, and metal(s). The mechanical recycling with the Vinyl-loop process developed by Solvay S.A. uses solvents and is based on selective dissolution, separation and precipitation of the PVC compound. The recovered products are PVC compounds and metal(s). Landfilling is used as a reference.</td></tr>
<tr><td>Expert judgement</td><td>
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<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td></td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td></td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: LCA study, issues comprehensively covered, scientific based, suggested for **qualitative characterisation.**</td></tr>
</table>

Systematic characterisation (EX EU-01)

Overall frame of study	
ISO 14040 ff	X
Code of practice	
Other	
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	Recycling of cable insulation
Functional unit	1 t of cable insulation from dismantling
System boundaries include: (for the recycling processes)	
materials	X
energy	X
production	
use	
disposal	X
recycling	X
transportation	
Allocation (mass/energy/price/exergy)	Various in auxillary material, specified
System Expansion	yes
Substitution	no
Data categories described	
Primary energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	X
Impacts	
Global warming	X
Acidification	X
Nutrient enrichment	X
Tropospheric Ozone Formation	X
Stratospheric Ozone Depletion	
Toxicity, human	X
Toxicity, eco	X
other:	Specific emissions reported
Data quality	
time	2002
geography	Europe (IT, DE, DK)
technology	Primary data collection at sites
Critical review performed	yes
Evaluation	
Normalisation	no
Weighting	no
other methods	

Critical Assessment (EX EU-01)

Goal description in short	• Investigation of different end of life treatment options and identification of optimisation potentials for PVC-rich waste with respect to LCA and economic criteria,.	
Valuation of the goal	• The goal is sufficiently and clearly described.	
Scope of study	• System boundaries are clearly described. • Duration 2002	
Life cycle phases	• Conclusions can be drawn on life cycle stage of end of life.	
Level and cut-offs	• Full LCA with high degree of specific/own data	X
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which are likely to affect conclusion	
Important assumptions	• No transport from dismantler to recycling plant considered	
Valuation of scope	• The scope is chosen and documented well for the goal of the study	
Methodology	• The common method of system expansion[39] is used to compare the technologies and the different products from PVC recycling.	
Data requirements	• Data requirements were checked and reviewed	
Inventory	• Model based on extensive LCI model (key figures discussed). • Sensitivity of inventory parameters is discussed, as well as scenario analyses. • Database used for generic data: GaBi Database. • Primary data collected	
Impact Assessment	• Impact assessment is carried out via CML Method. • Methodologies of assessment agree with ISO 14042.	
Environmental impacts included	• Variety of impacts considered	
Weighting of environmental parameters	-	
Overall ISO 14040 ff requirements	• External critical review performed (see summary below). Work is carried out according to series of standards ISO 14040ff.	

The results of the environmental and economic system analysis from this study are only valid for mixed cable waste with the described composition and for the specific conditions of the investigated recovery plants. The environmental assessment was conducted according to the applicable ISO 14040 ff standards. Differences in national environmental policies may also effect the conclusions from this study.

In general, the following conclusions can be drawn:

1. When considering recovery options for an integrated waste management concept, an eco-efficiency approach provides valuable insights in the environmental and the economic aspects of the investigated processes.

2. Compared with the referenced landfilling option, all of the investigated recovery options have a positive effect on the demand of primary energy, due to the recovery of either energy or materials. The Vinyloop mechanical recycling process shows the best performance in this respect, followed by the Watech and Stigsnæs feedstock recycling processes, on a similar level, and with the MVR incineration process in third place.

3. In addition to this criterion, the results for the other impact categories – global warming potential (GWP) and acidification potential (AP) – as well as the management of substance flows (lead and dioxin) also need to be considered. For example, the Watech and Stigsnæs processes are the only ones allowing for the separation and recovery of lead.

4. The management of the polymer, as a resource, plays a decisive role for the environmental assessment. In landfills, the carbon content of the waste product is “stored”, although

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[39] System expansion is a method, which makes it possible to compare systems with different products as output in a transparent way. Both systems under study are enlarged on a theoretical basis by the respective missing product output of the other process to ensure an adequate comparison.

a long-term fixation is uncertain. Furthermore, landfilling incurs long-term risks and liabilities, which cannot be represented in the Eco-efficiency diagram. In Europe, landfilling of plastic waste does not represent a long-term disposal option from a legal point of view. Incineration processes such as MVR, use the embodied energy of the polymer, while recycling processes such as Vinyloop, Watech, and Stigsnæs recover the material itself or its feedstock energy.

5. When taking the economic dimension (gate fees) into consideration, the Vinyloop process is shown to be competitive with landfilling, while all other recovery options entail higher costs – MVR, Stigsnæs and Watech in order of increasing gate fees – mainly because of their low revenues for the recovered products.

The results of the environmental and economic system analysis from this study are only valid for mixed cable waste with the described composition and for the specific conditions of the investigated recovery plants. Differences in national environmental policies may also effect the conclusions from this study. The task for the decision-makers to arrive at an evaluation of the eco-efficiency profile of each recovery option under consideration remains. The final evaluation will have to be based upon the system boundaries, conditions and specific demands of the technology, but will also need to take local and regional aspects into consideration.

The results of the external critical review can be summarised as follows:

- the methods used to carry out the LCA are consistent with the series of ISO 14040 ff standards;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study; and
- structure and content of the study report complies with the requirements stipulated in ISO 14040, chap. 6 (i.e. the study report is transparent and consistent).

Environmental, technical and economical aspects of mechanical PVC recycling (RANDA EU.005)

Documentation sheet (RANDA EU.005)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Mechanical Recycling of PVC Wastes
(BA-3040/98/000821/MAR/E3)</td></tr>
<tr><td>Scope of investigation</td><td>PVC, environmental, technical and economic aspects of mechanical recycling</td></tr>
<tr><td>Year of publication</td><td>2000</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1999</td></tr>
<tr><td>Institution or Company</td><td>Prognos in co-operation with
• Plastic Consult (Italy)
• COWI (Denmark)</td></tr>
<tr><td>Contractor/ Address (commissioner)</td><td>European Commission DG XI</td></tr>
<tr><td>Authors</td><td>Eckhard Plinke (Prognos), Niklaus Wenk (Prognos), Gunther Wolff (Prognos), Diana Castiglione (Plastic Consult), Mogens Palmark (COWI)</td></tr>
<tr><td>Availability/Publisher</td><td>Can be downloaded: http://europa.eu.int/comm/environment/waste/studies/pvc</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, mechanical recycling, waste management</td></tr>
<tr><td>Life cycle phases Qualitative/Quantitative</td><td>
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<tr><th>Production phase</th><th>X</th><th>Use phase</th><th>X</th><th>End of life</th><th>X</th></tr>
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</td></tr>
<tr><td>Comparison with alternatives</td><td>No comparison between PVC alternatives</td></tr>
<tr><td>Reported data</td><td>Other than LCA</td></tr>
<tr><td>Short description of the study</td><td>The objective of the study was to assess the environmental, technical and economic aspects of mechanical PVC recycling and the evaluation of measures for improvements. In detail, the objective includes the following aspects: a) Quantitative and qualitative assessment of existing PVC waste recycling systems; b) Identification of environmental, technical and economic problems involved in the recycling of PVC wastes; c) Analysis of the impact of the presence of PVC on the recycling of other plastics; d) Identification of Community and national measures to improve the recycling of PVC wastes.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure-like</td><td></td><td>Scientific-like</td><td>X</td></tr>
<tr><td>Overall/screening</td><td></td><td>Profound</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/literature data</td><td>X</td><td>Specific/own/new data</td><td>X</td></tr>
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<tr><td></td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
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<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
</table>
Comment: No LCA study, suggested for **qualitative characterisation**
</td></tr>
</table>

The goal of the study was to assess the environmental, technical and economic aspects of the mechanical recycling of PVC and included the evaluation of measures for improvements. The specific objectives included:

- Quantitative and qualitative assessment of existing PVC waste-recycling systems;
- Identification of environmental, technical and economic problems involved in the recycling of PVC wastes;
- Analysis of the impact of the presence of PVC on the recycling of other plastics;
- Identification of community and national measures to improve the recycling of PVC wastes.

A major part of the information was obtained from interviews based on a standard questionnaire. The interviews were carried out on two levels:

- Interviews and discussions with the related European associations ECVM (European Council of Vinyl Manufacturers) and EuPC (European Association of Plastics Converters) which provided the basic data on present and future PVC waste and recycled PVC quantities.
- Interviews with the PVC industry, PVC and plastics converters, recycling organizations and recycling companies in the different member states.

It is worth mentioning that **the study summarises and analyses the results of existing life cycle studies on the environmental advantages of mechanical recycling of PVC products**.

The following conclusions were drawn:

- The estimated total PVC waste arising in the EU is about 4.1 million tons per year (PVC compounds). The current PVC compound consumption of 7.4 million tons per year. The majority of the long-life products produced in the past are still in use and do not yet contribute to wastes. However, with more and more of the “old products” reaching the end of their lifetimes, in the coming years PVC waste will increase significantly.
- The recycling of pre-consumer wastes is dominant today, as it is economically profitable and is thus carried out under “free market conditions”. At present, more than 80% of this waste (about 420,000 tons) is recycled.
- However, the majority of PVC post-consumer waste is currently landfilled. The recycling of post-consumer wastes is currently limited; the quality of recycled PVC is not equivalent to virgin PVC in most cases. The total recycled quantity is about 100,000 tons in the EU, thus representing a recycling rate of less than 3%.
- By 2020, PVC waste is expected to reach about 7.2 million tons per year in the EU, 80% more than today. PVC post-consumer waste will increase to 6.2 million tons and PVC pre-consumer waste will increase to 0.9 million tons. Increasing the recycling rate would mean that PVC recycling must grow at an even higher rate.

PVC, chemical recycling (RANDA EU.006)

Documentation sheet (RANDA EU.006)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>Chemical Recycling of Plastics Waste (PVC and other resins)</td></tr>
<tr><td>Scope of investigation</td><td>PVC, chemical recycling</td></tr>
<tr><td>Year of publication</td><td>1999</td></tr>
<tr><td>Ref. year(s) of assessment</td><td>1999</td></tr>
<tr><td>Institution or Company</td><td>TNO Institute of Strategy, Technology and Policy</td></tr>
<tr><td>Contractor/ Commissioner</td><td>European Commission, DG III</td></tr>
<tr><td>Authors</td><td>Dr. A. Tukker (TNO-STB) , Ing. H. De Groot (TNO Industrial Research)
Ir. L. Simons (TNO-STB), Ir. S. Wiegersma (TNO Industrial Research)</td></tr>
<tr><td>Availability/Publisher</td><td>Can be downloaded from EC PVC homepage:
http://europa.eu.int/comm/environment/waste/studies/pvc</td></tr>
<tr><td>ISBN</td><td>No</td></tr>
<tr><td>Keywords</td><td>PVC, chemical recycling, incineration, landfill, waste management</td></tr>
<tr><td>Life cycle phases
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<tr><td>Production phase</td><td>X</td><td>Use phase</td><td>X</td><td>End of life</td><td>X</td></tr>
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<tr><td>Reported data</td><td>LCA related</td></tr>
<tr><td>Short description of the study</td><td>The objectives of the study were: a) to make an inventory of all research programmes, pilot projects and commercial plants the chemical recycling of plastics; b) to evaluate the technical issues related to the chemical recycling of plastics; c) to evaluate the possible future scenarios in the field of chemical recycling, including a forecast of probable industrial investments (member state by member state); d) to describe the effects on the environment and the risks, analysing costs and benefits, and making a comparative assessment of the environmental, economical and technical aspects of the various technologies for chemical recycling, mechanical recycling, and incineration for chemical recycling, mechanical recycling, and incineration with energy recovery for PVC and mixed plastics containing PVC.</td></tr>
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<tr><td></td><td></td><td>X</td><td>Other than LCA</td></tr>
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Comment: No LCA, but suggested for qualitative characterisation</td></tr>
</table>

RANDA EU.006

This study was carried out by TNO with DG III (Industry) as the primary client. The overall aim was "to analyse the role that chemical recycling may have in a future European system for PVC waste management."

Objectives included:

- Creation of a list of current research programmes, pilot projects and commercial plants involved in chemical recycling of plastics;
- Evaluation of technical issues related to the chemical recycling of plastics;
- Evaluation of possible future scenarios in the field of chemical recycling, including a forecast of possible industrial investment;
- A description of environmental effects and risks, analysis of costs and benefits, and a comparative assessment of the environmental, economic and technical aspects of technologies for chemical recycling, mechanical recycling and incineration with energy recovery for PVC and mixed plastics containing PVC.

Chapter 2 reviews viable initiatives for chemical recycling and summarises the main competing technologies: cement kilns, MSWIs (several flue gas cleaning options), mechanical recycling and landfilling. Brief descriptions of various chemical-recycling processes for plastic wastes and some alternatives are given, including a description of the process, acceptance criteria for the input material, resource needs and emissions, and processing costs. Reference is made to some existing LCAs of chemical recycling processes (pp.11, 21, 23, 38). *Appendix D* provides a comprehensive gross list of initiatives on chemical recycling that have taken place in the last 5 years.

Chapter 3 reviews sources of PVC waste and the collection structures needed before chemical treatment can be carried out, as well as associated costs.

Chapter 4 provides a mainly qualitative comparison of chemical recycling and alternative technologies for mixed plastic waste (MPW) and PVC-rich waste. This chapter also refers to some existing LCAs of chemical recycling technologies for MPW (p.54, 55). It concludes that for PVC-rich waste, direct mechanical recycling, if possible, is probably the preferred option in environmental terms; particularly with regard to recycling high-quality products. MPW, landfill and MSWIs scored relatively low in environmental terms.

Chapter 5 provides scenarios for chemical recycling along with a discussion of the amount of plastics available for chemical recycling. The future of chemical recycling of PVC is also addressed.

Types of data included:
Appendix A: Post-user plastic waste generation by country and end-user sector; theoretical availability for chemical recycling of MPW per end-use sector; and calculation of the market percentage for chemical recycling by sector.
Appendix B: Waste supply scenarios for PVC waste.
Appendix C: List of organisations contacted.
Appendix D: Gross list of initiatives for feedstock recycling.

5.10 LCA related PVC studies beyond the European Union

Japan

In Japan, the following five studies on PVC are publicly available. To our knowledge (after discussions with Japanese colleagues) PVC is not especially present in the environmental debate. The Japanese efforts aim at a general reduction of waste masses. The development of recycling methods and recycling strategies are core activities. Among these strategies a mix of mechanical, chemical and thermal recycling including the recovery of the halogens (from flame retardants) in building materials and electronics seems to be the most effective approach. Furthermore, the development and assessment of new biodegradable polymers over the life cycle is more a focus of Japanese activities.

1. Plastic-Waste Management Institute (http://www.pwmi.or.jp)
Original name:

石油化学製品の LCI データ調査報告書

This was a research project of LCI data of petrochemicals. In short, this project provides data for Japanese LCA users (not necessarily public). It was one of the biggest projects of the “national project of LCI data collection” in Japan, supported by chemical companies from 1995 to 1999. It was financed by the Ministry of Economy, Trade and Industry and the final report was published July 1999. It includes LCI data for LDPE, HDPE, PP, EPS, PVC, PS, and B-PET. The aim of this project is to catch up with the work APME is doing in Europe. The project coordinator was Ryosuke Aoki from Mitsubishi Chemical. The aimed result was to provide average datasets for plastic materials.

2. Plastic Waste Management Institute (http://www.pwmi.or.jp)
Original name:

平成 10 年度□廃棄物燃料化事業普及基盤整備調査報告書

（廃プラスチックの処理・処分に関する LCI 分析）

This project is also an LCI analysis. Its scope is waste plastic treatment and disposal. This report mainly consists of questionnaires sent to municipal waste treatment plants. It was initiated by the Ministry of Economy, Trade and Industry and the final report was published in March 1999. The project coordinator was also Ryosuke Aoki from Mitsubishi Chemical.

3. **Plastic Waste Management Institute** (http://www.pwmi.or.jp)

Original name:

プラスチック廃棄物の処理・処分に関する LCA 調査研究報告書

The study calls itself an “LCA investment report” of waste plastic treatment and disposal. This expression is neither standardised nor defined by known literature. It is unclear why this name was chosen. It can be taken as a follow up of report 2. This second study was conducted because report 2 could not collect all necessary data, as it was undertaken before the Japanese plastic recycling regulations were executed. Therefore, report 2 could not evaluate the LCA methodology. In contrast to the above mentioned project the basket method[40] was used. This report was published in March 2001. Chief member of the commission was Masanori Ishikawa, an assistant professor at Tokyo University of Fisheries. Chief Examiner was Tatsuo Hattori of the Tosoh Corporation.

4. **Plastic Waste Management Institute** (http://www.pwmi.or.jp)

Original name:

廃プラスチック処理・処分システムの LCA 手法による検討報告書

The report can be taken as a further follow-up to reports 2 and 3. The study is called “Examination of systems of waste plastic treatment and disposal with the LCA method.” The study deals with mechanical/material, chemical and thermal recycling using the basket method, based on LCI data. This report was published in March 2002. Chief Examiner was Katsujiro Ozawa of Dainippon Ink and Chemicals.

5. **Vinyl Environmental Council** (http://www.vec.gr.jp/lca/index.htm)

This council is organizing the LCA activities of 12 PVC resin producers and monomer companies. Four studies related to Vinyl products and LCA were undertaken, but whether reports will be publicly available is still unknown.

The studies are essentially LCIs of the production phase of PVC products (mainly pipes and products for agriculture use) and also provide material recycling information.

Summary

All of the above-mentioned reports are only available in Japanese.

For the Japanese situation, it can be concluded in general that PVC is not a particular focus in environmental discussions. The efforts concentrate on the possible recycling pathway options.

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[40] Method applied to enable environmental comparisons of processes which yield different amounts and types of products (comparable goal to that of system expansion)

From an LCA point of view, Japan is still behind Europe - based on the number of studies conducted and published. But the government has made a clear commitment to support and push the environmental research activities related to LCA and process chain analysis over the whole life cycle, as one key point of sustainability.

The above mentioned studies were undertaken in Japan, and only information about the existence and procedure of the projects is published. No detailed results or any other valuable information or interpretation was made available for external use.

North America

Compared to Europe there is little publicly available information on this subject in North America. The number of LCA studies undertaken in the US and Canada is quite small in comparison to the EU. To our knowledge the North American car industry has undertaken a number of studies, but the results of those studies are considered confidential and have therefore, not been published. This is comparable to the situation in the European car industry, which has also conducted many internal LCA studies. In contrast to the European Union, fewer studies have been financed or initiated by government or governmental bodies. In other branches (like building and construction or packaging) very few studies have been published so far. Generally, PVC is not considered a special environmental problem in the US and Canada. The problems and possible potentials of environmental optimisation are discussed in the same context as those of other materials. Waste reduction plays a less significant role in North America, because there seems to be less public pressure to reduce the mass streams to dump sites than in Europe and Japan.

The most comprehensive public study on PVC as a packaging material is a study conducted by the Tellus Institute in Boston, prepared for the Council of State Governments and the U.S. Environmental Protection Agency.

6. CSG/Tellus Packaging Study

The study was published in May 1992. It was sponsored by many associations related to the packaging and waste sector, by city and state councils as well as by some chemical and consumer products companies.

The Tellus study was a milestone at that time and was the only publicly available study related to PVC products within North America.

Assessing the impacts of production and disposal of packaging and public policy measures to alter its mix (EX US-01)

Documentation sheet (EX US-01)

<table>
<tr><td>Kind of report</td><td>Study</td></tr>
<tr><td>Title</td><td>CSG / Tellus Packaging Study</td></tr>
<tr><td>Scope of investigation</td><td>Assessing the impacts of production and disposal of different packaging materials.</td></tr>
<tr><td>Year of publication</td><td>1992</td></tr>
<tr><td>Ref. year of assessment</td><td>1974 - 1991</td></tr>
<tr><td>Institution or Company</td><td>Tellus Institute, 11 Arlington Street, Boston, MA 02116</td></tr>
<tr><td>Contractor/ Address</td><td>The Council of State Governments, Iron Works Pike, P.O. Box 11910, Lexington
U.S. Environmental Protection Agency, New Jersey Department of Environmental Protection and Energy</td></tr>
<tr><td>Authors</td><td>not listed</td></tr>
<tr><td>Availability/Publisher</td><td>The Council of State Governments</td></tr>
<tr><td>ISBN</td><td>-</td></tr>
<tr><td>Keywords</td><td>Environment, packaging, packaging materials, costs, LCA, monetisation of environmental and health effects</td></tr>
<tr><td>Life cycle-Phases
Qualitative/Quantitative</td><td>
<table>
<tr><th>Production phase</th><th>X</th><th>Use phase</th><th></th><th>End of life</th><th>X</th></tr>
<tr><td>Qualitative</td><td></td><td>Qualitative</td><td></td><td>Qualitative</td><td></td></tr>
<tr><td>Quantitative</td><td>X</td><td>Quantitative</td><td></td><td>Quantitative</td><td>X</td></tr>
</table>
</td></tr>
<tr><td>Comparison with alternatives</td><td>aluminium, glass, steel, kraft paper, kraft paperboard, boxboard, linerboard, corrugating medium, HDPE, LDPE, PP, PET, PS, PVC
recycled linerboard, boxboard and corrugating medium, recycled aluminium, recycled glass, and recycled steel are also considered</td></tr>
<tr><td>Reported data</td><td>LCA</td></tr>
<tr><td>Short description of the study</td><td>The goal of the study was to create a comprehensive framework and database for different packaging materials concerning the environmental effects during their life cycle. The evaluation of the different materials was realised by the monetisation of the impacts. The outcome of the study should serve as a foundation for policy measures altering the mix of packaging materials.</td></tr>
<tr><td>Expert judgement</td><td>
<table>
<tr><td>Brochure like</td><td></td><td>Scientific like</td><td>X</td></tr>
<tr><td>Selected/limited impacts</td><td></td><td>Main/high variety of impacts</td><td>X</td></tr>
<tr><td>Generic data/Literature data</td><td>100%</td><td>Specific/own/ new data</td><td></td></tr>
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</td></tr>
<tr><td>Comments related to further assessment</td><td>
<table>
<tr><th>Initiator</th><th></th><th>LCA</th><th></th></tr>
<tr><td></td><td>Industry</td><td></td><td>PVC/competitor material</td></tr>
<tr><td>X</td><td>Academia</td><td></td><td>part of PVC compound</td></tr>
<tr><td>X</td><td>Government</td><td></td><td>material PVC/comp. comparison</td></tr>
<tr><td></td><td>NGO</td><td></td><td>PVC/competitor application</td></tr>
<tr><td></td><td></td><td>X</td><td>application PVC/comp. comparison</td></tr>
<tr><td></td><td></td><td></td><td>Other than LCA</td></tr>
</table>
Comment: Suggested for **systematic characterisation**
</td></tr>
</table>

Systematic Characterisation (EX US-01)

Overall frame of study	
ISO 14040 ff	
Code of practice	
other	X
Goal, description of	
Application/use of results	X
Aim of study	X
Target group of study	X
Scope, description of	
main technical systems properly described	X
Function analysed	different packaging materials, different packaging products
Functional unit	1 ton of packaging material, 1 unit of final packaging product (within case studies)
System boundaries include:	
materials	X
energy	X
production	X
use	
disposal	X
recycling	X
transportation	
Allocation (mass/energy/price/exergy)	mass
System Expansion	
Substitution	
Data categories described	
Primary Energy consumption	X
Air emissions	X
Water emissions	X
Waste categories	
Impacts	
Global warming	
Acidification	
Nutrient enrichment	
Tropospheric Ozone Formation	
Stratospheric Ozone Depletion	
Toxicity, human	
Toxicity, eco	
other:	
Data quality	
time	used data should be public, thus should be available for everybody. As result the data is partly out-of-date (1974 – 1991).
geography	U.S.A.
technology	the considered technologies are state-of-the-art, but e.g. the respective emission data are based on older studies.
Critical review performed	
Evaluation	
Normalisation	no
Weighting	no
other methods	monetisation of environmental and health effects

Critical Assessment (EX US-01)

Goal description in short	• Modelling of the production of 14 different packaging materials • Modelling of the disposal of these packaging materials • Using only PUBLICLY accessible data • Thus creating a comprehensive and comprehensible database for future assessments • Creating a method to evaluate the environmental and health impacts of the production and disposal of the packaging materials (monetisation) • Comparison of the package material alternatives on a per ton basis and on a per package basis to provide public policy with aggregated information	
Valuation of the goal	• The goal definition is clearly stated and the goal of the study can easily be understood	
Scope of study	• Steel (primary and recycled), aluminium (primary and recycled), glass (primary and recycled), 5 types of paper and paperboard (primary and thereof three also recycled), 6 types of plastic (only primary, no sufficient data concerning recycling) • Adequate system boundaries • Functional unit clearly described	
Life cycle phases	• Production phase and end-of-life of the packaging materials are included • Use phase is not included since this phase has no relevance • Production of recycled materials are also included	
Level and cut-offs	• Full LCA with high degree of specific/own data	
	• Screening LCA with high degree of specific/own data	
	• Screening LCA with high degree of generic/literature data	X
	• Minor cut-offs/incompleteness which are not likely to affect conclusion	X
	• Major cut-offs/incompleteness which MAY affect conclusion	
Important assumptions	• Ranking of health effects of emissions according to a newly developed method • Monetisation of the impacts according to a newly developed method, monetary valuation of environmental effects by determining the price the society is willing to pay for pollution controls • Forming and filling of the packages and transportation are excluded • Not considered quantitatively: solid industrial waste, no sufficient data available • Recycling of plastics is not considered due to the lack of data	
Valuation of scope	• The scope is appropriate chosen to fulfil the goals	
Methodology	• Within the study, the ranking and evaluation of impacts are newly developed. The methodology is clear and fully discussed • No credits for recycling, no charges for depletion of non-renewable resources • System and boundaries are fully discussed and well documented	
Data requirements	• The used data sources are public accessible and well documented • Emissions data partly out-of-date	
Inventory	• Extensive description of the technical systems, but no specific data was gathered • Literature data	
Impact Assessment	• Each emission is "priced" according to the defined method. The total costs of the packaging materials comprise the environmental costs of the production and the economic and environmental costs of the disposal.	
Environmental impacts included	• Commonly used air and water emissions included	
Weighting of environmental parameters	• No normalisation • No weighting	
Overall ISO 14040 ff requirements	• The study was undertaken while the standards weren't available.	

The aim of the study is to support (environmental related) packaging policy with scientific information. In the goal and scope of the study, it is mentioned that the life cycle view is mandatory to compare alternatives on an "objective basis". However, it is stated that only material production (rather than the complete packaging production) is compared, due to the lack of consistent data. Therefore, the hypothesis was used that the material is the main impact. Only publicly available data was used[41]. The environmental impact of the production is partly reported in inventory data. The overall (environmental) results are reported in cost figures; environmental (cost) impacts of material production, conventional (monetary) cost of disposal and environmental cost of disposal. The environmental results of the production stage do not show a clear tendency. In some categories like "emission of suspended particulates" and

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[41] Taking into consideration that this study was undertaken over 10 years ago, the LCA related database was probably very weak.

"biological oxygen demand" PVC performs as one of the best, whereas in energy demand and SO_2 emissions its performance is only average. Unsurprisingly, in the category of "VOC emissions" PVC is one of the worst, as crude oil (with related VOC emissions in the refining steps) is used for the production of plastics.

The study comes to the following key conclusions:

- Results on a per-ton basis: PVC has by far the highest costs, followed by primary aluminium and PET. Glass has the lowest impacts.
- The environmental impacts of disposal have the lowest effect (about 1 % of total impacts). Environmental impacts of production of the packaging materials are larger than (combined monetary and environmental) disposal impacts except for glass and corrugating medium. For PVC and aluminium, disposal impacts are less than 10 % of the total, whereas for all remaining impacts are at least 23 % of the total. In other words, the differences in disposal phase impacts between the various materials are less when compared to the differences in the production phase impacts.
- The highest production costs generally reflect only a few key pollutants. For example, for PVC the high impacts are due to the emissions of vinyl chloride monomer (VCM).
- The results for the recycled materials considered (like aluminium and glass, but not polymers) are influenced by the amount of secondary material used. If more secondary material is used in the production of new packaging material, the impacts decrease. Therefore, the production impacts of aluminium, boxboard and linerboard and glass (incl. the recycled material) are significantly lower. For steel packaging (mostly cans), no significant share of material is recycled (as it is considered to end up in the dump site); therefore, the impacts are nearly the same compared to primary production.
- Results were cross-checked with a view on the per-package basis: Case studies are performed for the packaging of soft drinks, juice, fast food hamburgers, microwave dinners, and hardware like screws and nails.

The study explains to manufactures:

- Certain packaging materials result in high costs (external and internal) according to the developed methodology, and some materials result in lower costs. Therefore, the production costs are not included because they are reflected within the price. The external environmental costs of e.g. PVC are much higher than for glass considering the per-ton results. The study puts the industry in the position to evaluate the total costs (including the "priced" pollutants) for specific packages. Furthermore, the study explains that it is important to reduce the weight of packages and to enforce the recycling of the materials.

Whereas the conclusions related to the weight and the recycling rate are still valid today, the conclusions related to the environmental impacts of the different materials are questionable. The data is, in part, nearly 30 years old and represents the impacts of old production technologies. Furthermore, the precision of assessment for the environmental impacts based on costs is questionable. With hindsight, it can be stated that the methodology (and thus the comparability) of this study is outdated. The available database was thin and sources diverse. Nevertheless, it was a milestone – at least for North American circumstances.

The study explains to users:

- Packaging accounts for a bulk of the solid waste stream. Additionally, the production and disposal of packaging material causes significant emissions which are responsible for hazards related to environment and health. Thus, it is necessary to find out on a scientific basis which packaging materials cause high or low impacts to create a basis for the analysis of specific packages.

The study explains to third parties:

- The outcomes of the study should be the scientific foundation for future packaging policy. The study enables policy makers to classify the different packaging materials according to their costs related to pollutants within the production phase and end-of-life phase.

The overall conclusions are split into two categories: “non-beverage packaging” and “beverage packaging”.

For the non-beverage packages the following is concluded (citation):
“While it is not appropriate to draw sweeping or definitive conclusions from this limited set of case studies, we (the Tellus Institute) can suggest the tentative implications emerging from our result. For the non-beverage packaging options we examined, PVC packages have much higher impacts than alternative materials; among other the lightest-weight package, per unit of delivered end product, is generally the lowest impact product. Technologies and designs that allow lower package weights will achieve lower total impacts; weight reduction will often be more important than changes in types of material.”

For the beverage packages the following is concluded (citation):
“For the beverage options, a number of common materials, including glass, steel, virgin aluminium and PET had broadly similar impacts per ounce of beverage. Another set of materials had lower impacts per ounce, including recycled aluminium, HDPE, paperboard cartons and aseptic packages. Here the choice of material appears significant, as well as the potential of weight reduction.”

According to current LCA related quality standards, considering only the material production phase and omitting the packaging production steps is not acceptable. Furthermore, the conversion from environmental impacts into costs may result in unnecessary uncertainties.

7. CSG/Tellus Packaging Study (update)

In 1994, an update of the Tellus Institute Packaging Study was conducted. Primarily, the Impact Assessment Method was newly defined. The authors were Brian Zuckerman and Frank Ackerman from the Tellus Institute, and the sponsors were again the Council of State Governments, New Jersey Department of Environmental Protection and Energy, and the US EPA.

8. Vinyl Products Life Cycle Assessment

The “ChemSystems” reports document selected inputs and outputs of chemical processes. Within this framework, Chem Systems, Inc. in Tarrytown, New York published in March 1992 information about Vinyl Products. No comparison is undertaken and no emissions are reported. These reports aim primarily at supporting the choice of adequate technical dimensions of planned processes or plants.

9. LCA of the production of a PVC compound

A consultancy firm carried out the study “LCA of the production of a PVC compound“ in August 1995. The Sponsor was the Geon Company Cleveland, Ohio. There are no indications that suggest this study is publicly available. The title does not indicate any comparison.

10. LCI of a PVC Part: Analysis of Manufacturing and End-of-life Options

The same holds true for a study called “LCI of a PVC Part: Analysis of Manufacturing and End-of-life Options” from May 1995. The sponsor was IBM Corporation. The title indicates more of an inventory collection than a comparison.

11. Canadian Raw Materials database (http://crmd.uwaterloo.ca/)

There is data on North American PVC production available on the Canadian Raw Materials database. There is no comparative information within this database. The database only stores environmental (LCI) information about the production of various materials.

Summary

From an LCA standpoint, North America is behind Europe concerning the amount of studies undertaken and published. Only one study was of value within this context was available from the whole of North America: The Tellus Study from 1992.

The following conclusions are clear:

- the technologies and designs to reduce the weight of the packaging offer a large environmental optimisation potential; and
- the choice of material is (at least for non-beverage packaging) less relevant.

5.11 The bandwidth of life cycle related opinions of PVC

This section discusses the specific summaries of the individual studies and sectors of sections 5.1 through to 5.10 and includes general opinions about the life cycle of PVC that are (probably) more commonly recognised in public discussion. The mirroring of these opinions within this report is done in contrast to the specific summaries of the analysed LCA studies, knowing that "overall" valuations of products and alternatives for decision support purposes within LCA need to be carried out on the basis of specific life cycle considerations of applications per sector.

Life cycle related opinions may cover a wide interpretation range, depending on the goal and interest of the related stakeholder. Therefore, this section aims not to conclude overall findings of the studies within this report, but rather to allow the use of the findings of sections 5.1 through to 5.10 to be used in public discussions in a balanced way.

Two opposing viewpoints of directly involved stakeholders - from industry and from an NGO - as well as two viewpoints from indirectly involved stakeholders - from an expert panel of political stakeholders and from a LCA consultant - are reflected.

Firstly the opinion of "Greenpeace", a campaigning non-profit organisation that uses creative confrontation to expose global environmental problems is cited[42]:

Globally, over 50% of PVC manufactured is used in construction, in products such as pipelines, wiring, siding, flooring and wallpaper. As a building material PVC is cheap, easy to install and easy to replace. PVC is replacing 'traditional' building materials such as wood, concrete and clay in many areas. Although it appears to be the ideal building material, PVC has high environmental and human health costs that its manufacturers fail to tell consumers. From its manufacture to its disposal, PVC emits toxic compounds. During the manufacture of the building block ingredients of PVC (such as vinyl chloride monomer) dioxin and other persistent pollutants are emitted into the air, water and land, which present both acute and chronic health hazards. During use, PVC products can leach toxic additives, for example flooring can release softeners called phthalates. When PVC reaches the end of its useful life, it can be either landfilled, where it leaches toxic additives or incinerated, again emitting dioxin and heavy metals. When PVC burns in accidental fires, hydrogen chloride gas and dioxin are formed.

Secondly the opinion of "Vinyl2010", a non-profit organisation representing the whole European PVC industry is cited[43]:

"A sustainable society needs products that make best use of natural resources and provide long, cost-efficient usage and have low environmental impact. PVC already meets many of these requirements. Vinyl 2010 is adding to its strong sustainability profile by lessening the impact on the natural world. Our activities cover all parts of the PVC life cycle from production

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[42] Citations taken from the internet: http://archive.greenpeace.org/toxics/pvcdatabase/bad.html

[43] Citations taken from the internet: http://www.vinyl2010.org/ProgressReport2003/progressreport2003.htm

and additives, to usage and waste collection, recycling initiatives and efficient energy recovery technologies. PVC is extremely durable in use and difficult to break down. This is one of product's greatest strengths from a sustainability perspective. PVC pipes, window frames and cables – which account for about half of all PVC applications – have a lifetime of 30 years or more. Strong and leak proof, PVC piping systems help reduce drinking water losses and sewage pollution – even in contaminated soils that would corrode many other materials. Worldwide, as much as 30% of domestic fresh water supply is estimated to be lost because of old and inadequate pipes. Lightweight, insulating, durable PVC products help save energy in a variety of domestic, industrial and transport applications."

Concerning PVC in general the German Council of Environmental Advisors (Sachverständigenrat für Umweltfragen des deutschen Bundestages, SRU) [SRU 1998] summarised in 1998:

"The advisory board of experts for environmental questions recognised the ongoing development in production and waste disposal engineering related to the environmental impact of PVC. Therefore the environmental impact related to PVC cannot be used as independent argument for a regulative intervention within the chlorine chemistry anymore. Today, the PVC-related health and environmental risks – in comparison to substitutes such as PET, PP and others – cannot be seen as that serious that would justify a ban or wide restrictions.

To foster recycling, takeback regulations should be introduced for large volume products of PVC such as pipes or roof sheets. However, such a takeback regulation must then be applied to products from alternative plastics as well.

To foster recycling of PVC wastes the board of experts does not recommend the implementation of recycling ratios or other interferences besides mechanisms of the market-economy, since it does not see serious environmental reasons, which would argue against the incineration of PVC wastes.

A theoretical alternative to the material recycling is the chemical recycling of PVC waste. Also the possibilities of the recovery of chlorine and its reuse within the PVC production should be optimised."

After consideration of the information gathered within this project, as well as the experience gained since 1991 from performing several different life cycle related analyses of PVC products for different stakeholders from industry and governmental bodies, the LCA consultant PE Europe GmbH summarises:

PVC does not play an especially significant role as a material, from a LCA viewpoint. It has individual environmental advantages and disadvantages, as do other polymers, metals or renewable materials. Therefore, (from a LCA viewpoint) there seems to be no reason why PVC should be treated differently than other materials.

During the production of PVC (intermediates, additives, monomer and polymer) environmental impacts occur (see chapter 4 for details). Considering a broad range of internationally accepted environmental impact potentials (like global warming, abiotic resource depletion, primary energy consumption, acidification, nutrification, stratospheric ozone depletion, tropospheric ozone creation, photochemical oxidant creation, toxicological potentials) and comparing PVC with various other polymer materials on a mass basis (like PE, PP, PS, PA, PB, PET, ABS, PEI, PPS, PPE, POM, PMMA, PEX, PEG, PBT, NR, MA, NBR, SBR, EPDM), PVC does not show any general disadvantageous tendencies in the material production phase[44]. Knowing that a meaningful comparison of products has to be conducted on an application level rather than on a sole material and mass basis (see chapter 1 and 3 for details), it can nevertheless be stated that PVC tends to result in a lower abiotic resource depletion potential and in lower primary energy consumption compared to most of the materials mentioned above. The potential toxicological impacts of PVC production tend to be lower on aquatic and terrestrial ecosystems and higher on humans when compared with the impacts associated with the production of various other polymers (listed above).

For all other impact potentials, the results are very diverse (depending on the impact and the compared polymer, PVC has between 200% more and 400% less potential impacts) therefore no general trends can be identified.

The calculation of toxicity potentials within LCAs is still a current scientific challenge, as the actual toxicity is strongly dependent on local circumstances and specific cases. Commonly used, accepted models to calculate toxicity potentials exist, but the uncertainties throughout a process chain containing several hundred processes remains high. Therefore, the toxicity potentials within LCA are rather useful to check general differences in potential toxicological impacts. If indicators suggest that a general difference in a toxicological impact potential exists in a certain process in the process-chain of the life cycle, other tools like Risk Assessment may be used to analyse the situation on a more local level.

These general indications are not identified for PVC. PVC tends to have potentially more toxicological impacts in the intermediates production processes compared to other polymers, but potentially uses less energy in production and synthesis and therefore, tends to cause less toxicological impacts in the energy production processes.

The better, or the more realistic, the life cycle is modelled, the more important it is to identify the most significant parameters in the life cycle of products and the less important single parameters become. Material choice is often discussed as it is a parameter that is easily understood. However, material choice is often simply one parameter among many other interdependent parameters.

Therefore, in our opinion it is most effective to further optimise the life cycle of PVC products and its competing materials separately, than to give preference to a certain material due to life cycle arguments. The optimised materials can then be used – perhaps even synergistically– to take further steps towards more innovative and sustainable products.

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[44] There are specific weaknesses and strength associated with the production of all polymers.

6 Socio-Economic Costs and Benefits

In this chapter studies on the socio-economic aspects of PVC production use and disposal and studies that compare PVC with alternative materials will be discussed.

The chapter starts with a short historical account of the development of PVC and the PVC industry. The account illustrates the actions that initiated PVC and PVC industry development, and the industry's rapid development in the 1950s and 1960s. Furthermore, the historical account indicates how the technical, societal and environmental agendas related to PVC developed and influenced innovation and technology diffusion agendas of the PVC industry. It then illustrates how the current development and societal discussions of PVC, and the diversity in these - as demonstrated in the reviewed studies - are shaped by the variety in interests and conditions, on which these discussions are held.

As the chapter continues, studies that address more specific aspects of PVC production, use and disposal are acknowledged. These studies have been identified by the partners responsible for the overall study and have been supplemented with studies from additional searches in databases, literature and the Internet. Studies that partly or solely deal with the socio-economic aspects were selected.

6.1 Introduction

PVC is a material with the potential for a large number of applications and this has led to enormous increases in production and use, particularly since the 1950s. Industrial production was established in the 1930s, as a result of inventions in the 19th and beginning of the 20th century. The first synthesis of a vinyl chloride monomer was carried out by Regnault in 1835 (Hansen and Serin, 1989; AEA Technology, 2000). In 1872 rigid PVC was polymerised by Baumann in the laboratory but there was no futher progress made for its use in practice (Hansen and Serin, 1989).

Findings significant for the industrial use of PVC are identified by Hansen and Serin (1989); two patents were taken out by the Russian Ostromislensky on the use of sunlight or the dissolvents benzene and carbonsulfide, in the production process. Hansen and Serin (1989) also refer to the Chemische Fabrik Griesheim Elektrons' patent on the production of vinyl chloride by adding hydrochloric acid to acetylene and to a number of other patents that make it possible to use PVC in the production of industrial products.

According to Hansen and Serin (1989), plastics were still primarily visualised as a substitute for the production of combs, buttons and film. However, the production process could not be scaled up satisfactorily. Griesheim therefore gave up the patent in 1926. This spurred innovation, especially in the US and in Germany, and a number of different modifications took place in the 10 years that followed, paving the road for the commercialisation of PVC in Germany in 1938 and, according to Hansen and Serin (1989), in the US not long after.

Hansen and Serin (1989) recognise the innovative activities in plasticisers as one of the most significant stages for the establishment of PVC as one of the large volume plastics. These activities were carried out by Semon for Goodrich between 1927 and 1933 and plasticisers have since been a strongly contributing factor to the now extensive use of PVC.

A second contributing factor was the establishment of PVC as a material with specific superior advantages, not just as a less expensive substitute for certain fancy goods. These applications were, among others, within the building sector (particularly in floor coating), cable insulation and uses within the chemical industry. The use of PVC for packaging started in the 1940s and 1950s (Hansen and Serin, 1989).

A third factor contributing to the rapid diffusion of PVC was, according to literature, the Second World War, due to the shortage of certain competing materials.

The industrial development largely increased in the 1950s and 1960s when it appeared that a number of PVC's traits were particularly valuable in certain applications. The production and use of PVC has increased ever since, and even today the development and increased use of PVC can, to a large extent, be explained by its technical properties as well as its economic advantages over other materials.

Alongside the large increases in production and use, PVC began to be suspected to be the cause of a number of problems in occupational health, and health in general, as well as problems in the local and global environment. Suspicions were raised in medical and scientific literature and by NGOs and trade unions.

In 1949, a Russian survey was published reporting that 15 PVC workers out of a group of 48 were suffering from hepatitis (Nørretranders, 1980). In the years that followed, several surveys reported different symptoms, including various liver problems among workers in the PVC industry (Nørretranders, 1980). In 1973, 3 workers at the American PVC producer B.F. Goodrich had died from a rare kind of cancer of the liver; Angiosarcoma. A conference by The New York Science Academy reported that statistics world-wide showed incidents of this form of cancer to be very high among PVC workers (Annals of the New York Academy of Sciences, 1975). . Earlier studies, as well as studies initiated after the findings at Goodrich, were also presented. A mortality study of VCM-workers in the United Kingdom in 1940-1974, published in 1988 in the Scandinavian Journal of Work Environmental Health, further underlined concern about occupational health at the time.

This led to the setting of public regulatory measures and standards in many countries, and to the implementation of improved technologies in industry that reduced worker exposure to vinyl chloride.

Since the 1980s, concerns for broader environmental consequences have been the focus of public debate. Many of these concerns were raised by parties not normally considered as drivers of innovation: NGOs, citizen groups, concerned scientists and regulatory authorities. Converters and retailers have subsequently been concerned about consumer demands and wishes, and about potential legal regulation that could influence their sales.

Studies and assessments of PVC's environmental consequences have been undertaken, and a number of national and EU policies have been introduced to address the environmental concerns. Whereas environmental problems had earlier been defined in relation to the more local environment and to the location of PVC plants, a much broader definition of the problems has now been made, including CO_2 emissions, ozone depletion, energy use, ecotoxicity etc. Many of these studies are dealt with in the preceding chapters.

Most recently, the concerns over the potential health impacts of the hormone disrupting effects of phthalates have been highlighted, an effect suspected both in the use and in the disposal of PVC. The connection between additives and occupational health and safety problems has long been known, and a number of studies that address these concerns can be found e.g. in Miljøstyrelsen (1999), Jensen et al. (1989). In the study 'Asthma and allergic rhinitis due to sensitization to phtalic anhydrid' in Journal of Allergy, Kern (1938) also points to an early awareness of work health problems with the additives.

Phthalates as a work health problem also appears in scientific journals from the 1970s, (among others Milkov L.E., M.V. Aldyreva and T.B. Popova (1973) 'Health status of workers exposed to phthalate plasticizers in the manufacture of artificial leather and films based on PVC resins, in Environmental Health Perspective,1973'). The phthalates also became an occupational health and safety problem in occupational health courses at The Danish Technical Highschool (now Danish Technical University) from the mid and late 1970s (Broberg, 1999).

Whereas the occupational health impacts led to technical and social innovations that would reduce exposure, the environmental impacts gave rise to discussions of substitution. The emphasis on substitution is also found in many of the initiatives that demonstrate the environmental advantages of PVC compared to alternative materials.

Concurrent with the debate on its environmental consequences, the production and use of PVC has increased. However, the rates of production have decreased in Europe. In certain developing countries the growth rates increase at a greater rate than the respective GNP. Continued growth in Europe (especially in Eastern Europe) and in third world countries is however expected by, among others, Warmington (2002) and the EU Panorama Industry (1997). Third world countries are expected to increase their PVC use with increasing per capita incomes. The expected growth rates in PVC consumption in both Eastern Europe and third world countries are reflected in the establishment of production facilities (Warmington, 2002). The per capita use of PVC in Europe is a good deal lower than in the United States, which by some is regarded as an indication of further European market potentials (Warmington, 2002).

Environmental concerns are, however, increasingly apparent in the debate on development, and studies that attempt to calculate negative environmental externalities in monetary values have recently started appearing. But as shown below, socio-economic aspects also include analyses of user, industry and national economic consequences, while also considering employment.

6.2 Socio-economic studies

Socio-economic studies of PVC have had a number of backgrounds and departure points. This diversity means that the studies do not constitute a field in which comparison within a certain scheme between the studies can be made meaningfully. Instead, an attempt to list different departure points and different foci, and a discussion of the kind of results they may reach, is made.

Relatively few studies that included socio-economic aspects were identified. Compared to the large number of technical analyses of the environmental aspects and LCAs of PVC, the role of socio-economic aspects seems to have played a very modest role. In most cases, studies of the socio-economic consequences are 'add-ons' to the environmental assessments, not socio-economic studies in themselves.

A possible explanation for this may be the large productivity advantages of PVC, advantages which have been the primary drivers for PVC development, and which have not been questioned. The environmental concerns raised (particularly in the 1980s and 1990s) have however pointed to environmental consequences and negative externalities and the costs of these. From 1990, even more studies address the cost of environmental consequences and the cost of reducing these consequences.

The socio-economic aspects of PVC appear primarily in reports: in consultancy reports and background reports. These mostly have the environmental aspects as their main focus, and are mainly industry/sector accounts. Only a few national/governmental reports were identified.

The main departure points in the studies that include societal, social and economic aspects of PVC production, use and disposal can be divided in the following categories;

- the role of the PVC industry with regard to employment, industry structure, turnover, exports and imports etc.
- sustainability in relation to PVC production and PVC compared to alternative materials (primarily analyses at the company or product level).
- analyses of the economic and social conditions for PVC disposal.

In addition, some socio-economic studies include studies of the industrial, historical and political conditions for development and innovation. A study by Høyer and Jørgensen (1995) is one example; tentative considerations are made in others. However, studies which analyse the role of the industrial and institutional structure for innovation and development at a European level were not identified.

6.2.1 On structure and employment in the PVC industry

A number of studies concentrate on the PVC industry itself and its development and role in the economy. These accounts of the PVC industry *per se* emphasise the ‘stable’ industrial structure as a basis for techno-economic development.

The PVC industry is characterised in these accounts by traditional industry statistics, such as industry structure (number of companies, number of suppliers, number of customers (converters)), turnover, the market for PVC, location of producers, employment, exports and imports etc.

These studies aim to give a picture of the role that the industry and the PVC supply chain play in the national, European and world economy. Furthermore, they give an overview of how the development of the industry could be and an impression of how different developments may influence the industry structure, as well as how industry may influence techno-economic development.

The studies have further contributed to the industry’s own strategic considerations with regard to production development, location and markets. A number of internal consultancy reports have given their view on potential developments in the light of production capacity, financial situations etc., but these have not been included here.

These types of accounts are found, for example, in EU reports and in industry accounts of the industrial development, and in a few national studies (German and Danish), which point to the potential societal conditions and consequences of PVC industry development.

Some of the figures from these studies are given below. Here they are primarily taken from the EU Green Paper (2000).

The total of 21,000 companies includes PVC producers, producers of stabilizers, producers of plasticisers, and PVC transformers. The PVC industry estimates (European Commission, 2000) that the structure in the industry in 1999 is as follows:

Table 6-1: Structure of the PVC industry

	PVC polymer production (EU and Norway)	**Stabiliser production**	**Plasticiser production**	**PVC transformation**
Number of companies	10	11	20	21,000
Number of production plants	52 (in 10 countries)	22		
Production volume, in tonnes	5,500,000 (1998)	160,000	1,000,000	
Turnover, mio. €		380		
Employment	10,000	5,000	6,500	508,500[45]

Source: EU Commission, 2000, p.6-7.

Warmington (2002), acknowledges 11 leading European PVC producers in 2001, one more than given in the Green Paper, which according to the PVC industry is due to the integration of central European producers. The 11 producers are shown in the table below, in which production capacity is also given. According to Warmington (2002), production by the Chemical Market Associates, Inc. (CMAI) is estimated to be 87% of capacity in 2000.

Table 6-2: PVC producers and capacities

	EVC	**Solvin**	**Atofina**	**Vinnolit**	**Norsk Hydro**	**LVM**
Production capacity, 1000 tonnes per year	1400	1300	880	650	580	440
	Shin-Etsu	**Vestolit**	**Aiscondel**	**Anwil**	**BorsodChem**	
Production capacity, 1000 tonnes per year	390	350	350	300	290	

The total production capacity of these amounts can be calculated as 6930 thousand tonnes per year; using the production estimate of 87%. The production in 2001 was 6029 thousand tonnes.

The PVC industry is located in 10 EU countries and in Norway, with 52 plants in 40 regions. This means that every plant has on average approx. 200 employees employed in PVC production.

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[45] Calculated as the estimated employment in the PVC industry of 530,000 (ECVM) minus the employment in the polymer, stabiliser, and plasticizer industries. EU Commission (2000) states that 90% of these companies have less than 100 employees.

According to the EU, 90% of the 21,000 PVC converters are estimated to have less than 100 employees in 2000.. According to the EuPC, the European plastic converter industry has more small plastic converters than Japan and the US.

PVC applications and use in Europe are divided differently by different authors (PVC, Informationsrådet, Warmington (2002), with reference to Norsk Hydro, EU (2000)). According to the EU (2000, p.4), the application and use of PVC in Europe was distributed as in the table below, with building as the main application of PVC.

Table 6-3: Main use categories of PVC in Europe (1999)

Use/application	Percentage	Average life-time (years)
Building	57	10 to 50
Packaging	9	1
Furniture	1	17
Other household appliances	18	11
Electric/electronic	7	21
Automotive	7	12
Other	1	2 to 10

Source: EU, 2000, p. 4.

Other sources also give building as the largest area for PVC application, responsible for more than 50% of applications. Within the building sector, pipes and fittings are quoted as the largest area of PVC application, with 27% (ECVM, 2003).

The above description of the PVC industry is at a very general level. It appears from the figure of 21,000 PVC converters that the industry covers a wide range of fields in which very different conditions apply, environmentally and socio-economically.

The 21,000 plastic converters have different competitive, innovative, educational and regional constraints. Competitors include other plastics, alternative materials and alternative products. Innovative activities may take place within a company, within the PVC producing industry, within other industrial sectors or in public institutions. Education may also be organised very differently. Finally, with regard to regional constraints, different regions may have very different employment, economic and environmental conditions that all influence their assessment of the PVC converting industry. In addition, the different converters are confronted with different national and market conditions.

The overall description of the PVC industry provides a basis for further analysis of the effects of different policies, or a basis for policy making. But at the same time, the diversity in the PVC converting industry, both for making environmental as well as socio-economic analyses and policies should be acknowledged. However, only small and regionally very limited studies analyse socio-economic consequences.

6.2.2 Economic, environmental and socio-economic sustainability studies.

Studies within this group all relate in some way or another, to an environmental agenda. The way the sustainable agenda is reflected differs, however. Whereas some studies separate the three sustainability concepts – the environmental, the social and the economic – other studies take their departure point in attempts to economically value the environmental aspects.

The Prognos study (1999) was made explicitly on the background of environmental considerations. Though environmental concerns were the foundation, the aim from the start was to discuss PVC in relation to the broader sustainability concept, with inclusion of the economic and societal dimensions.

Prognos (1999) is cited by many, for various reasons. The study was written on the basis of discussions from 1996 and onwards between 'environmental experts from science and politics, from NGOs, the media and industry, who had agreed to an intensive dialogue about PVC' (Prognos, 1999). The study was financed by the Arbeitsgemeinschaft PVC und Umwelt e.V, and was published in 1999.

Prognos (1999) assesses the production and use of PVC in relation to competing materials for applications such as pipes, windows, cables and packaging films, for all of which alternative materials exist. In the study, social and economic sustainability, and how it can be analysed, is discussed. As referred to in the summary and conclusions of Prognos (1999), the sustainability concept – including ecology, economy and society – 'to date had mostly been discussed from an overall economic and social perspective, and not from an industry or product perspective'.

Prognos (1999) also refers to the difficulties in using the economic and social sustainability indicators drawn up by the international working group of the Commission on Sustainable Development. These are, according to Prognos (1999), directed towards assessing the economic development at an even more general level, namely of whole regions or countries, and not to providing clues to the product-specific assessment of potential risks to 'sustainable development' (freely from Prognos, 1999, p.87).

The economic sustainability indicators estimated in Prognos (1999) are, in the short term;

- cost fluctuations
- dependency on foreign trade
- system price

and in the long term;

- disposal costs
- consumption of energy resources
- labour cost share
- innovation dynamism

For the analysis of 'social sustainability' Prognos (1999) refers to some of the same difficulties of definition as for the analysis of economic sustainability. The social sustainability indicators from the EU Statistics Office (1997, p.80), are related to '**development of a society overall**' and are referred to as not significant to the assessment of individual products and their constituent materials. Indicators of social sustainability stability, often used in the development of social consensus, are referred to as poverty, injustice, education level and prosperity, which may be ignored in assessments of the many individual products.

The social sustainability indicators estimated in Prognos (1999) are in the short term;

- industrial accidents

- skill levels
- pay load ration

and in the long term;

- ethical standards in import/export
- susceptibility to political intervention
- industrial diseases

on which the PVC products are compared with competing materials.

The Prognos study from 1999, underlines the importance of including short, medium and long term sustainability in the analysis, recognising that the increasing uncertainty of consequences in the long term should be taken into account. It further remarks that the positioning of PVC products in relation to sustainability is very dependent on the purpose for which PVC is used. And also, it is ‘excused’ that the environmental, economic and social sustainability are treated separately, while acknowledging that the three are interdependent (p.15).

In its conclusion, the Prognos study underlines that when sustainability is assessed, economy, society and the environment should be seen as parts of an overall system, not as opposite poles that have to be counterbalanced. (The economic consequences of exceeding the environmental limits are mentioned as an example).

It is further emphasised that sustainability assessment must include both short and long term considerations. In the study, PVC comes out as favourable in the short term e.g. for windows, whereas it comes out unfavourable in the long term for many of the other analysed products because it is based on non-renewable resources. In the conclusion, it is stated that innovation, developments and new knowledge will potentially change this.

Lastly, Prognos (1999) states the need for additional data if more specific analyses of the social and economic aspects are to be made, data which should be provided for example by the companies and the sectors.

Prognos (1999) does not comment on the potential economic costs of the negative environmental consequences nor on the distribution. It also fails to mention the economic and social distribution of both narrow and broader impacts on health i.e. the differences in impacts for inhabitants within areas of PVC production and waste disposal/incineration compared to those who live outside these areas.

As suggested in several of the more general studies, more specific studies have been carried out for a number of products/applications. A number of studies compare the use of different materials for the same products, primarily within the building and construction sector. In these studies, economic arguments are included as a factor in the decision making.

Among the socio-economic studies that focus more directly on comparing competing materials for specific productions or uses, are studies carried out at the PVC producing company Vinnolit by Spindler (1999, 2001), GUA (2002) for the Austrian PVC industry, the Danish Ministry of Environment, Miljøstyrelsen (1990, 132-134) and Entec (2000). The specific product assessments in Prognos (1999), mentioned above, can also be found in this category.

Spindler (1999, 2001), on the basis of Vinnolit's production, compares PVC products with products from alternative materials. The comparison is made using LCA studies, and then supplemented with a cost analysis. PVC windows are compared with aluminium and wooden windows based on a number of factors – CO2, human toxicology, eco-toxicology, nutrification, acidification, ozone formation, waste and total energy.

The costs are based on Prognos (1999) and E. Topritzhofer (1994). The externalised costs are largely not identified, that is, a number of the concerns raised in relation to PVC as well as the other window systems are not included in the cost balances.

In the cost analysis by Spindler (1999, 2001), PVC products are found to have the lowest price over their lifetime. The difference in price relative to wooden and aluminium windows is then suggested to be used for reducing the additional environmental costs of PVC – which has been done by producing an improved PVC window (Spindler, 2001).

It is acknowledged that the monetary valuation of the ecological impacts varies by a large factor – from between 15 to 40 times, and that 'the methodology for monetarising ecological impacts still needs to be greatly improved' (Spindler, 2001). The ecological consequences included have all been monetarised, and none of them are found to be 'unacceptable'.

The studies concentrate on the short term assessment of competing materials in relation to the specific LCA. Consequently, they do not include potentially longer term resource restrictions, employment, trade balance or other effects, for either material. Neither do they include longer term effects on innovative activity and broader societal consequences such as employment and resource availability.

In GUA (2002), the sustainability of PVC flooring is compared with alternatives. For both PVC and the alternatives, a high and a low quality product are analysed, indicating that the product quality is decisive for the results of the LCA[46].

In the calculations, the internal costs are supplemented with external costs of a number of emissions, for both PVC and the alternative(s). The prevention costs (vermeidungskosten), were used for calculating the monetary value of the emissions.

Environmental costs in production, use and disposal are found to be larger for PVC than for alternative materials, but are found to constitute a relatively small part of the product costs, and especially so if the alternative product has high labour costs. A number of emission costs are not monetarised, including phthalates and chlorine air and water emissions, emissions which have been part of the PVC-related concerns.

The Entec, 2000 study (DEFRA, 2003), has been commissioned by the UK Department for Environment, Food and Rural Affairs, to help inform policy development regarding PVC. Entec, 2000, assesses PVC packaging versus PS packaging, PVC flooring versus linoleum flooring, PVC pipes versus aluminium pipes and PVC windows versus wooden windows.

An LCA is supplemented with an 'economic' LCA, which calculates the total social costs of the products. These are divided into internal and external costs. Internal costs are calculated as the production costs, represented by the list price, the method used also by the Danish Environmental Protection Agency (1990) and Spindler (1999), which assumes that the market mechanism works. Also included in the Entec study's internal price are road transport costs,

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[46] A conclusion, stemming from the efforts to compare different qualities of the products, is that the longer the product lifetime of similar products, the smaller the environmental effect and the role of the material

landfill costs and the cost of recycling. The calculated external costs, which they define as the societal costs of producing, using and disposing of PVC include;

1) the impacts of air emissions on health, crops, buildings and materials and global warming and

2) the impact of road transport on road safety and the probability of accidents.

However, the eco- and human toxic effects of lead and cadmium and phthalates are not considered, neither in use, nor in disposal. Depletion of non-renewable resources is not considered either, thus the study refrains from assessments of some of the potentially long term consequences.

This means that some of the major concerns of NGOs and the critical researchers are omitted because ‘lack of scientific consensus and quantitative evidence of these impacts means that these cannot be treated in a project of this type in any way which is not qualitative’.

In the Entec study, PVC products come out favourable in all cases except for packaging, where the social costs of PS packaging are lower than for PVC packaging.

The studies by the Danish EPA are from 1990 and are therefore earlier than the studies mentioned above. These studies of alternatives to PVC for building and construction, for packaging, and for office articles and health uses (Miljøstyrelsen (1990), 132, 133, and 134), refer to more general economic consequences of a possible substitution.

Description and general consideration of some of the relevant aspects were made with regard to;

- user economy
- company economy
- societal economy.

The reports are written as a result of the Government’s wish to address the environmental and toxic uncertainties of PVC, and thus have a very different point of departure than the studies mentioned above. The acknowledgement of the uncertainty of the data for assessing the negative consequences has led to a focus on the technical possibilities for substituting PVC, whereas the above mentioned studies either omitted these effects or refrained from economically valuing them. A potential use of PVC was consequently considered where PVC was regarded as technically superior or where the existing alternative was regarded as prohibitively expensive. Both the costs of substitution of PVC with alternatives, as well as the costs of continued use of PVC are calculated. It is then discussed whether the users, the companies and society will be willing to pay for substitution and if they are willing to pay for keeping PVC (Miljøstyrelsen, PVC i byggeri og anlæg, 1990).

Very general considerations are made on

- the consumers’ demand for PVC/non-PVC products
- the potential change of production equipment in the individual companies and on structural changes since companies within other sectors take over production

It is stated that the societal analysis will have to further analyse specific PVC substitution projects with regard to

- the environmental benefits from substitution
- substitution costs for specific uses and
- expected substitution costs resulting from the technological product and process developments

A later study from the Danish EPA (Jørgensen and Høyer, 1995), also demonstrates the technical possibilities for substituting PVC with other materials. The study points to the structural and institutional prerequisites needed for substitution to take place and for the development of alternatives on the basis of initiatives in Danish industry and policy, amongst others. It demonstrates, following conclusions from the 1990 studies, that bar a few exceptions, PVC can be substituted at no or very little cost. It also points to the stimulation of demand for alternatives as important for substitution.

Of the referred studies, Prognos (1999) and Spindler (2001) request improved methods for monetarising the environmental consequences. In addition, the Danish EPA studies (Miljøstyrelsen 1990, 133) and Entec (2000) refer to insufficient data for the conducting of the analyses; data which do not exist, data with very large uncertainties and data that exist but have not been collected/published.

But as opposed to the Prognos (1999), Spindler, (1999, 2001) and Entec (2000), the studies from the Danish EPA regard the potential environmental externalities as potentially more negative than externalities from substitutes and value the negative environmental externalities higher in economic terms than the other studies. This difference in valuation of the environmental consequences and uncertainties has thus led to the different conclusions in the referred studies, and where Prognos (1999) suggests a long time planning of the use of PVC within different areas, primarily from a resource perspective, and Spindler (1999) advocates environmental improvements of PVC products, the studies from the Danish EPA demonstrate the techno-economic possibilities for a substantial substitution and out-phasing of PVC, and point only to very specific applications of PVC that haven't had substitutes developed for them.

6.2.3 PVC waste studies

A group of studies concentrates on the environmental and economic costs of different ways of dealing with PVC waste and on specific waste systems. AEA (2000) and Craighill and Powell (1996) comment that the reason for looking at waste separately is not quite justified – LCA, and the related cost calculations, include the disposal phase therefore the waste studies are thus just the last step in the LCA. *But* the focus on the waste phase can be explained by the more prominent role of negative environmental consequences in this phase, as well as the discussion of how the disposal and environmental costs are to be allocated. Furthermore, it raises more explicit questions regarding the economic and environmental efficiency of different social waste disposal systems.

AEA (2000) builds on a number of other studies, also concentrating on PVC waste, and focuses on different strategies for the treatment of PVC from pre- and post consumer use.

The studies do not explicitly compare competing or alternative materials, but could provide important contributions to life cycle analyses and economic life cycle analyses. The studies can therefore be used in assessments of future policy for PVC and for comparing PVC waste management with the management of the waste from competing materials, as well as for assessments of the waste strategy for the existing amount of PVC.

The AEA study had the objective to ‘assess the economic implications of diverting PVC waste away from incineration’ (AEA, 2000, p.2). The study covered 21 European countries. Concerns related to incineration are ‘to include the possible formation of traces of toxic chlorinated organic compounds, the impacts of PVC in the waste stream on the requirements for reagents to control emissions of hydrogen chloride (a major combustion product), and its impacts on other releases and discharges from incinerators.’

Three scenarios for reducing PVC incineration before 2020 are evaluated. The environmental burdens and the PVC waste management cost changes are identified and the extent to which recycling can consume the PVC waste diverted from incineration is analysed i.e. if some waste streams or PVC applications tend to contribute more to reduction and which support systems stimulate recycling.

The study concludes that there are benefits of diverting PVC away from incineration, a conclusion underlined by the high weighting of air pollution stated. Recycling is determined to be better than landfilling, but it is also acknowledged that not all PVC can be recycled.

Furthermore, it is noted that the landfilling of PVC comes out positive, because the leaching of additives such as phthalates is weighted as a less serious environmental problem than emissions from incineration.

In studies from CSERGE, social behaviour is considered in relation to different waste collection and recycling schemes. The environmental benefits of different schemes seem to be very dependent on the social context – that is, both the system and the way it is used. Craighill and Powell (1996) more explicitly compare PVC recycling with the recycling of other materials.

As with Entec (2000), the study focuses on gaseous emissions and on road casualties, rather than the different ways of disposing of PVC. A kerbside scheme combined with recycling and a kerbside collection scheme with disposal was compared. The study distinguishes between materials, not products, and calculates the external costs in £/ton. Recycling comes out with the least external societal costs, apart from for PVC, where landfill is found to be economically favourable over recycling. This conclusion is, according to the Danish EPA, a consequence of the high weighting of CO_2 emissions.

Further, Craighill and Powell (1996) regard the long-term availability of resources for PVC production to be reflected in the internal costs of PVC (as also assumed in Entec (2000)). But as stated in Prognos (2000), this might not be a realistic assumption and the role of recycling and higher prices for recycled material is, therefore, not regarded.

6.3 Summary on Socio-Economic Costs and Benefits

The studies identified either included or focussed solely on the socio-economic aspects. Conflicting socio-economic aims have characterised the socio-economic studies/considerations; whereas LCAs have an aim of reducing environmental impact, the socio-economic studies have a mixture of employment, national budget, employment, competitive and environmental considerations. A common scheme for comparison is, as mentioned above, thus meaningless to establish.

Despite the different foci, the studies have all been conducted with consideration of the long term concerns and debate of the health and environmental consequences of PVC production, use and disposal. The studies referred to are both industry and government initiated. NGO studies have not been included. These were not identified as containing socio-economic aspects, but are mentioned to have, nevertheless, been very important for raising the concerns and debate, to which many of the studies are a reaction.

The industry initiated studies often demonstrate the economic advantages of PVC. A conclusion particularly based on high labour costs due to higher employment in alternatives. Prognos (1999), however, points to the long term economic consequences of decreasing access to resources for PVC production and thus increasing prices.

Important environmental and health concerns with regard to PVC have been excluded from a number of the economic (and environmental) assessments and thus these concerns have not been internalised. The reason for not including these environmental and health concerns is the uncertainty of the consequent environmental impacts and economic valuation. This exclusion contributes to the fact that PVC comes out as economically advantageous. In addition, it should be noted that the studies tend to look at rather ideal situations for PVC-production, use and disposal, with a focus on Northern European countries, which assume relatively controlled and strict regulation.

Studies with a point of departure in an agenda aiming at reducing health and environmental consequences by reducing and substituting PVC, are mainly represented by the German and Danish studies in this report; Hendriks et al. (1996), however, refers to more studies with this focus. These studies, from 1990 and onward, point to the technical and economical possibilities of substituting PVC with alternatives for most uses, and suggest a number of policies to increase development of alternatives as well as to increase the use of already existing alternatives.

These studies have focussed on the socio-economic conditions for both development and change, and thus also include considerations on the role of industry structure and institutional conditions for development of both PVC and alternatives. Policies that include regulation, development activities and demand stimulation are suggested.

Waste studies have formed a special group of studies. PVC waste will continue be produced for a long time, with many of the large uses of PVC having a lifetime of up to 50 years. Whether a substitution strategy is followed through or not, PVC waste has to be disposed of. Critical for the conclusion of the studies that focus on the weighting of different disposal systems, is the weighting of the analysed health and environmental consequences of the different disposals.

This difference in approach – a defence of PVC contrasting investigations into the socio-economic possibilities for reduction and change – therefore becomes an important distinction in the policy making efforts.

More data and more transparency in both data collection and in the uncertainties regarding these data, may contribute to both the debate on PVC and the debate on alternatives. But data will still be uncertain, and much of it will be politically negotiated and changeable, as some of the uncertainties (or certainties) and political priorities change.

It is thus important to acknowledge that parties with different interests value both environmental and economic benefits and costs differently, and that it may be a hanging matter to try and hide these differences in a weighted end-result with very little transparency. Innovations were spurred by the different parties' conflicting emphases on specific aspects of production, conversion and use, as indicated in some cases, and demonstrated in others.

Finally, it should be stressed once more that the studies with inclusion of socio-economic aspects were all made on the background of Northern European production, use and disposal conditions. The perceived relatively high environmental protection, and rather high labour costs in these countries thus influence the productivity calculation for PVC and the alternatives, as well as their environmental costs.

6.4 References for Chapter 6

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7 Significant gaps

The following chapter discusses existing information gaps based on the reviewed studies that compare PVC containing systems with systems containing competing materials. The significance of these information gaps is discussed in terms of:

- the potential for optimisation that could result from information provided by a comparison study,
- the dependence of the PVC system studied on interrelated factors (that may hamper a free material or system choice), and
- the importance that the optimisation would have with respect to the overall market.

7.1 Building and construction

The building and construction sector is the most important for PVC applications, based on the large mass share of PVC used in building products. As a result, many PVC LCA studies focus on building products. These studies are distributed over various product groups, hence, the separation of the building sector into product groups for discussion in this section.

Windows

Studies that took a systems-view approach and that considered the important parameters came to similar conclusions (see section 5.1.1). **For PVC window applications, no significant information gaps were identified**. The production of the various chemical components of PVC material for window applications are analysed and impacts and important parameters associated with their production are identified. The interdependence of the window's environmental performance with important use phase parameters (e.g. heating system/heating energy losses, orientation of windows and the influence of maintenance) are stated. The studies compare PVC with competing materials in window applications; therefore, **no significant information gaps exist for the principal competing constructions either**. Some studies are reviewed and are of a high quality. The behaviour of the various constructions using different material compositions are thoroughly analysed and their associated life cycle impacts are well known.

From a life cycle perspective, there are no indications for immediate action in the window application area, as it has been well covered over the past several years. Consequently, no immediate optimisation potential is expected from further comparison studies of different window systems.

Based on previous work, the life cycle knowledge gained in this application area will soon be available in software tools, such as planning software.

The studies available analyse specific window applications. Representative window applications have been chosen. The LCAs of these window applications provide valuable information, but are not parameterised. Therefore, the adaptation of technical boundary conditions (that may influence the environmental impact) is difficult. The maintenance of existing data and information on a certain level is important (further details follow in chapter 1).

Cladding

A few studies exist for claddings. Despite this, we see **no significant information gaps that would call for immediate action**. Many producers of claddings are also producers of window frames; therefore, the window market is the key-market. Due to the relationship between claddings and window frames, life cycle conclusions for claddings can partially be deduced from studies on window frames, as some of their production steps, use phase behaviour, and recycling steps are comparable. Life cycle impacts of claddings are therefore known and no significant differences are expected between claddings made of different materials. No immediate optimisation potential is expected.

Shutters

No comparative studies are publicly available, and **information gaps in comparative LCAs exist**. The material choice for shutters is often related to windows, as more and more ”integrated systems” combining window- and shutter-systems are emerging. Isolated assessments (ignoring the influence of the windows) could be inappropriate and would possibly lead to a “virtual” optimisation potential, which is not useful.

Due to current fashion trends, flexible metal-shutters are on the market. Comparisons of this new system with the traditional systems would be useful. But due to the limited PVC market relevance of this application, and due to the limited degree of freedom in choosing systems independent of the window, these **measures are not considered “important**”.

Sheets/conduits/rails/skirts

No comparative studies are publicly available for these applications. Hence, **there are information gaps in comparative LCAs**. In general, there are no studies available comparing indoor equipment made of PVC systems and competing material systems. Several different polymer systems are available (e.g. ABS, PS, SB, PP, PMMA and PC), but these alternative polymer systems have to be treated with flame-retardants. In some applications the use of metals is possible (e.g. rails). The choice may depend on price, as there may be significant cost differences between the material systems. **Overall, we expect no extreme differences between various material systems in LCA comparisons** as the differences in the production of the materials are known, and all materials must comply with the same safety standards. The use phase is of minor relevance because the user has only limited access to the systems, the systems do not further consume energy, and the systems require little servicing.

Flooring

Many flooring studies are publicly available; nevertheless, significant information gaps exist. The **gaps are not related to PVC flooring,** as PVC systems are analysed quite well. The gaps are related to some of the competing material systems; however, **no information gaps exist for wood flooring systems**. Sufficient information is available for both PVC and wood. A few comparative LCA studies have been undertaken for linoleum and rubber flooring systems, but there are few studies for carpet, which makes up approximately 50% of the market. But the PVC segment in the flooring market is only competing with carpet in a few applications. Nevertheless, due to the fact that flooring is a subject concerning every building in Europe, **a large optimisation potential exists**.

Due to the relevance of the use phase in flooring systems, maintenance must be included in an assessment. It is important to identify relevant use phase parameters which need to be included, such as electricity consumption due to vacuum cleaning for carpeting systems.

LCA may not be the appropriate tool to measure the effects of indoor air quality; nevertheless, indoor air quality is an issue that should be taken into consideration.

Roofing

No major information gaps were identified in the production of PVC or bituminous roofing. The production of competitor systems, like EPDM, has not yet been analysed. **A comparison of the competing systems may offer important new insights**. It is expected that a classical trade-off situation will arise. For example, EPDM-systems are more expensive but tend to have a longer lifetime compared to PVC-systems, whereas a PVC system tends to be easier in repair.

In the study reviewed only average lifetimes are considered. This parameter significantly influences the overall performance of roofing systems. Therefore, lifetime should not be included as just an average and constant parameter, but should rather be subject to modelling and sensitivity analysis.

Roofing system performance (from an economic and environmental perspective) is also linked to the system design, as it influences the system lifetime. Consequently, design parameters have to be considered in a flexible way.

Installation of the system is also a factor in overall performance. During the roof laying process, tight edge work is especially important, as it influences the roof lifetime. We suggest that new studies investigate the durability of the compared systems in various use phase situations.

Pipes

Many studies use the LCA framework to assess different pipe systems. Many different materials are compared on the system level, and the installation and maintenance stages are included. Studies that took a systems-view approach and that considered the important parameters, came to similar conclusions (see section 5.1.4). For sewage pipe applications, further material comparisons for pipe systems are not expected to lead to new conclusions, therefore, **no significant gaps can be identified for sewage pipes**. Pipe durability and pipe laying efforts are the most dominant parameters. **Information gaps exist for potable water systems**. There are currently no available studies comparing stainless steel, copper, galvanised steel, PEX and PEX/Aluminium with PVC drinking water installations. Due to the wide range of potable water pipe applications, a significant optimisation potential may arise, given that the best performing system (for each representative application) is identified for different installation situations.

7.2 Toys/sports goods

LCA may not to be the most appropriate tool for analysing the potential risks of using different materials in toys. LCA is able to provide information on environmental impacts of the different materials related to the production phase, intended use phase, and end-of-life phase. The use phase of toys is of particular importance. For toys, there is a concern related to their unintended use and the related potential risks (due to e.g. ingestion or chewing). The main topics in the discussion of toys (e.g. plasticiser in PVC or coating of wood) are direct cause-and-effect relationships. Most of the existing LCAs specify potential impacts or hazards. The applicable cause-and-effect relationship parameters within impact assessment are being developed. Some approaches exist, but due to the large uncertainties associated with the modelling of cause-and-effect relationship parameters within LCA, those impacts are far from being of practical use.

As LCA is not the most appropriate tool to analyse the major problems in this application, we do not suggest performing LCA studies in this sector. These problems would be better analysed using different tools, such as risk assessment.

7.3 Consumer goods

There are few comparative LCA studies available for consumer goods. **Information gaps exist for consumer goods in general**. To better specify the information gaps, consumer goods are sub-divided into products with a short lifetime and products with a long lifetime.

Consumer goods with a short lifetime include products like office equipment, household goods and clothing. **The possible optimisation potential in comparing different systems of short lifetime consumer goods is expected to be small**, with the exception of clothing. For non-electrical applications of household goods and office equipment the difference in their environmental impact is mainly due to the production of different materials used (which is well known). The use phase is relatively short and undemanding, and the end-of-life phase is a relatively small contributor to environmental impacts. Hence, no relevant optimisation potential is expected for short life-time consumer goods. The next step must be the improvement of the end of life options in general.

A more promising optimisation potential exists for clothing, possibly due to the lack of existing studies. The mass flows in the fashion sector are large and unpredictable. PVC does not currently play a major role in this market; however, it could in the future, as the market is continually changing. Therefore, a comparison of the life cycle of different clothing materials is of interest, as the impact of future tendencies can be estimated (e.g. durability vs. fast changing fashion trend, cleaning and drying behaviour, reuse, end-of-life) and the optimisation potentials of traditional clothing and the future potential of new materials could be quantified.

No studies are available on long lifetime consumer goods. Long lifetime consumer goods in this context are mostly furniture systems. Most often the durability (or the failure of the system) is dependent on a single component of the furniture (e.g. fittings, edge veneer, hinges). Therefore, the assessments of PVC-systems and its competitors have to be done on a system level. The environmental relevance is dependent on the lifetime of the whole system. The duration of the “sensitive” parts depends on use phase requirements and on the behaviour of the user. The most promising environmental optimisation potentials are possibly in the production of high quality furniture, with a long use phase duration. Within the use phase possible maintenance effects should not be neglected. But as furniture is a static system during use (in the sense that it is non-moving and does not require energy), the influence is small. Hence, better quality furniture may result in a higher environmental impact during production, but this may pay off quickly over a long, undemanding use phase. **We see great potential within this area.** Nevertheless, it should be kept in mind that furniture is highly influenced by the so called “life style”.

7.4 Packaging

Many studies were undertaken within the packaging sector. No gaps have been identified. The impact of various packaging materials are known and discussed. There are various options available for the treatment of packaging waste. The choice of packaging material is dependent on the demands of product protection and presentation. **From a LCA perspective, we see no further demand for information** related to the comparison of different packaging material systems.

7.5 Transport

Within the transport sector, which includes automobiles, **a lot of studies related to PVC and competing material systems have been undertaken, but most are not publicly available.** This is due to confidentiality issues and other factors as discussed in section 5.5. For example, the automotive sector carries out LCA comparisons on a case-by-case basis, in-house for research and development and in close relation to production. Consequently, the results are considered a competitive advantage.

The chances of closing this information gap are remote. The themes which are analysed within the automotive industry are very complex and advanced. Assessments have been carried out for years and huge (internal) databases have been compiled. Public studies, therefore, only make sense if the companies are participating and providing their own data. The drive to do so will most likely be very small because the companies may not learn too much, as they have extensive knowledge themselves. Furthermore, material choice and selection within the automotive industry has been a central point of optimisation since the 1970s. Therefore, “easy-to-get” potentials that are not already employed are not likely be found after 30 years of optimisations. Some companies in the automotive industry have been active in terms of LCAs for 15 years, hence, much is known about materials and systems comparisons and today’s activities focus on “forecasting” environmental impacts prior to the production of the parts and systems.

In contrast, another information gap within the transport sector exists which has **promising optimisation potentials: the public transportation sector.** There are no PVC-competitor studies presently available. Large optimisation potentials could arise if system level comparisons lead to optimised solutions for seats, seat covers and transparent panels within public transportation vehicles like buses and trains. The selection of these materials is largely independent of other parts of the vehicles, and the optimisation potentials due to weight-reductions and the reduction of maintenance during the service life could be highly significant. An economic side effect could include public authorities saving money, due to potential fuel and maintenance cost savings. In addition, public authorities would also benefit, as many citizens would use the “optimised” system daily. However, the PVC flow in these applications is not very large (see chapter 3.2.4).

7.6 Electronic and electrical applications

In the electrical and electronic equipment sector, PVC plays a predominant role in cable applications. Nevertheless**, very few studies are available**.

PVC cable simply seems to have **no significant competitors** in many of its cable applications. A comparison on different application levels (low-voltage, hair-wire) with respect to the different technical demands may be of importance. It is unknown whether there are significant differences in environmental performance between the different cable systems within the various applications. The potential environmental effect is large, as the market volume of PVC in this sector is high. Nevertheless, in many applications costs will continue to drive the material decision. **A potentially relevant information gap exists within this application.**

7.7 Medical applications

No comparative studies have been undertaken within medical applications to compare PVC systems with possible competitor systems. Medical applications are a major PVC application, therefore, it is considered a significant information gap; the optimisation potential is expected to be high. Available LCA studies have not covered topics related to issues such as quality, sterilisation, recycling and waste treatment of medical applications. Considering the amount of waste produced in hospitals from medical applications and the fact that environmental optimisation in medical applications has thus far played only a minor role, **the potential of comparative studies in this sector is expected to be high.**

7.8 Agriculture

Within the agricultural sector no comparative studies have been undertaken, **but no significant information gaps exist.** There is a wide choice of materials and material choice is largely independent of other parameters. The environmental performance depends mostly on material production and recycling (material inventories and possible recycling processes are known). The use phase is not relevant. Therefore, the significance is low. Furthermore, the mass streams and market share of PVC in this sector are negligible. A **low optimisation potential is expected**.

7.9 Recommendations and possible further steps

In this section recommendations related to **LCA** are given. A structured procedure is outlined, which can further contribute to the identification and realisation of environmental optimisation potentials over the whole life cycle of the various product systems. Current information gaps should eventually be filled, and the knowledge gained thereby should be used directly and effectively with the information identified within this project, to provide transparent decision support. Double work should be avoided. A corresponding outline is provided for guidance.

Future LCA studies that either

- fill existing gaps in a certain sector; or

- support decision making in politics

should follow some basic rules:

- The **same "Goal and Scope"** should be carefully stated and described, as foreseen in ISO 14040 ff. If studies are used for comparisons, a comparable Goal and Scope needs to be defined (see chapter **1** for details).
- The subject under study (such as PVC systems in comparison to competitor systems) should be **compared on an application level**, to allow easy identification of interdependent phases (see chapter **3** for details).
- The **most influencing parameters** (e.g. technical parameters like mechanical or chemical properties or processing parameters), **impacts** (mostly environmental) and **effects** (all others) over the life cycle **have to be considered** and interdependent factors have to be addressed (see chapters **4** and **5** for examples, details and conclusions).
- A **consistent background database** (with specific up-to-date data for energy, transport, and upstream processes covering all important regional and technical differences) is mandatory. Otherwise, differences within the systems will be down to the differences in the data used.

Compliance with ISO standards is mandatory.

To use the LCA information effectively, it is of the utmost importance to analyse further studies by their **parameters**, rather than to undertake a number of different studies on many different systems in numerous application situations. If the important parameters of a system are identified as a basis for modelling, the model can be updated relatively easily (and at little cost), keeping the environmental information of products and materials up-to-date. This would avoid a lot of double work as the model would only need an update at certain process steps and all boundary conditions, which are maintained, could still be used.

In contrast to parameterised, flexible models (that are easily updated and maintained), it is less useful, even ineffective, to undertake "static" studies, which may describe certain average life cycle effects, but can not be applied when a (potentially important) detail of the life cycle changes (e.g. the electricity grid or an organic synthesis).

Further steps and studies should be undertaken and organized by sector. Besides the automotive sector (which acts internally, as discussed), the **building sector** is also considerably active in this field and significant environmental optimisation potential exists over the life cycle of its product systems.

The first step would be the definition of representative systems within the "building and construction" sector (to specify a goal)[49]. Representative systems could include the following: Window frames and shutters, outer walls, inner walls, heating systems, roofing, flooring, doors, and ceilings. Goal and scope definition is important as this sector is highly complex and common rules cannot be applied to the different kinds of activities without proper differentiation, e.g. for activities ranging from new construction to renovations and from small family houses to business buildings.

The **existing representative information** (presented in this study) can be used. The **missing representative information** should be obtained.

Generalisations may be possible at later stages if representative systems for each sector or for each application can be identified (generalisations are only valid if the behaviour of the influencing parameters is known and - as mentioned before - the goal and scope of the available information is adequate).

Next, the **important life cycle parameters** have to be identified. This is a very important step as the number of parameters sometimes influences the flexibility of the model. Hence, the more parameters identified, the better the model can adapt to an altered situation and the easier and faster the model can represent changes or developments in certain parts of the life cycle. **These "flexible" parameters** include, for example:

- Different electricity grid mixes or various national grids
- Shares of import streams of resources and fuels
- Transport distances
- Efficiencies of chemical processes or oil refining processes
- Ore grades in metal ores
- Water content of renewable resources
- Fuel or electricity consumption of use phase processes
- Sizes of systems (e.g. different window sizes)
- Maintenance frequencies
- Duration of use
- Recycling quotes and recycling pathways

The life cycle of the compared systems should then be set-up (within the more technical Life Cycle Inventory, LCI) to include the dominant identified parameters. Life cycle **modelling is not limited to linear input-output relationships**. Even logic functions and time effects can be integrated into today's LCI modelling. These techniques already exist in some LCA databases (e.g. GaBi 2003), but is not a public domain. This kind of modelling has the advantage that the information can be used in a flexible manner and can be adapted easily according to new questions and situations.

For the building sector, this life cycle information should be set up for a broad field of applications. Many people would benefit from this assimilated information, for instance in the integration of LCA based systems into planning tools.

Technically, this is feasible and is already carried out in some companies and research organisations. Life cycle information, with the respective parameterised information, can be used in planning tools directly to generate general indicators like "environmentally preferable or environmentally questionable" very quickly, and considers the whole life cycle. Within a planning or development phase, a designer is informed about the environmental performance of his material or application choice. No extra work is necessary since the information is stored and provided from background software systems.

Within decision making, such a tool would allow easy identification of any promising potentials of new materials or applications since the model can be adapted to represent various scenarios. The important parameters are identified and accessible.

All quantified LCA related information gathered as results of projects commissioned by the European Commission (in addition to the print version of the final reports), could be stored centrally and published on the Internet allowing interested parties to access it. Decision-making (e.g. related to material choices) in the Commission as well as outside it, can be supported more easily if the information were to be stored centrally.

Within **other sectors,** this concept essentially works the same. Consistent information has to be gathered (as outlined in this study) and information gaps must be filled. LCA should play an important role in identifying important parameters over the life cycle of the product systems.

Parameterised, flexible models should be set up as an LCI structure, to allow easy scenario calculations, parameter variations, and sensitivity analyses. By applying these methods, the significance of **material choices becomes quantifiable,** different solutions and scenarios become easily assessable, and effects of substitutions become more transparent.

In the long term, after a representative set of situations have been analysed, **guidelines can be developed**. These guidelines would be valuable for:

- newcomers to environmental related design within companies;
- customers buying products, as it would help them to understand the interdependencies more easily and better prepare them to make decisions between products; and
- politicians, as decision support for forming regulations or legislation.

LCA is an ideal tool for analysing systems in decision support. Existing standards – if applied properly – make it a transparent and consistent tool with reproducible results. However, LCA should be used to analyse the potential environmental benefits of a policy decision rather than to be used solely as a system for justification.

The breadth of consequences and the importance of decisions can, thereby, be sufficiently evaluated. Using existing life cycle tools together with the appropriate information or databases, in most cases, can effectively support an environmentally related political decision making process from a product related life cycle viewpoint.

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8 Further Sources

ISO 14040	ISO 14040:1998: Environmental Management - Life Cycle Assessment - Principles and Framework
ISO 14041	ISO 14041:1998: Environmental management — Life cycle assessment - Goal and scope definition and inventory analysis
ISO 14042	ISO 14042:2000: Environmental management — Life cycle assessment - Life cycle impact assessment
ISO 14043	ISO 14042:2000: Environmental management — Life cycle assessment - Life cycle interpretation
ISO 14049	Technical Report ISO/TR 14049 Environmental management – Life cycle assessment – Examples of application of ISO 14041 to goal and scope definition and inventory analysis (ISO/TR 14049: 2000(E))
ECVM 2003	De Grève, J.-P. : PVC market in Europe and EU PVC Horizontal Initiative - Present status and perspectives, European Council of Vinyl Manufacturers 2003.
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DSD 2002	Löschau, M.: Verwertung von Verkaufsverpackungen: Duales System Deutschland, Institut für Technischen Umweltschutz, Fachgebiet Abfallwirtschaft, TU Berlin, 2002.
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GABI 2003	GaBi 4: Software and Databases for Life Cycle Analyses, IKP, University of Stuttgart and PE Europe GmbH, Leinfelden-Echterdingen, April 2003.“
APME 1990-2003	Boustead, I.: ECO-PROFILES of the European plastics industry, commissioned by the Association of the Plastics Manufacturer in Europe, 1990-2003.

Annex A

The Annex A contains chapters A1 “Contacted organisations”, chapter A2 “Documentation/Systematic characterisation of LCAs”, and chapter A3 “Documentation sheets of non-LCA studies”.

For easier document handling, Annex A is stored in a separate document.