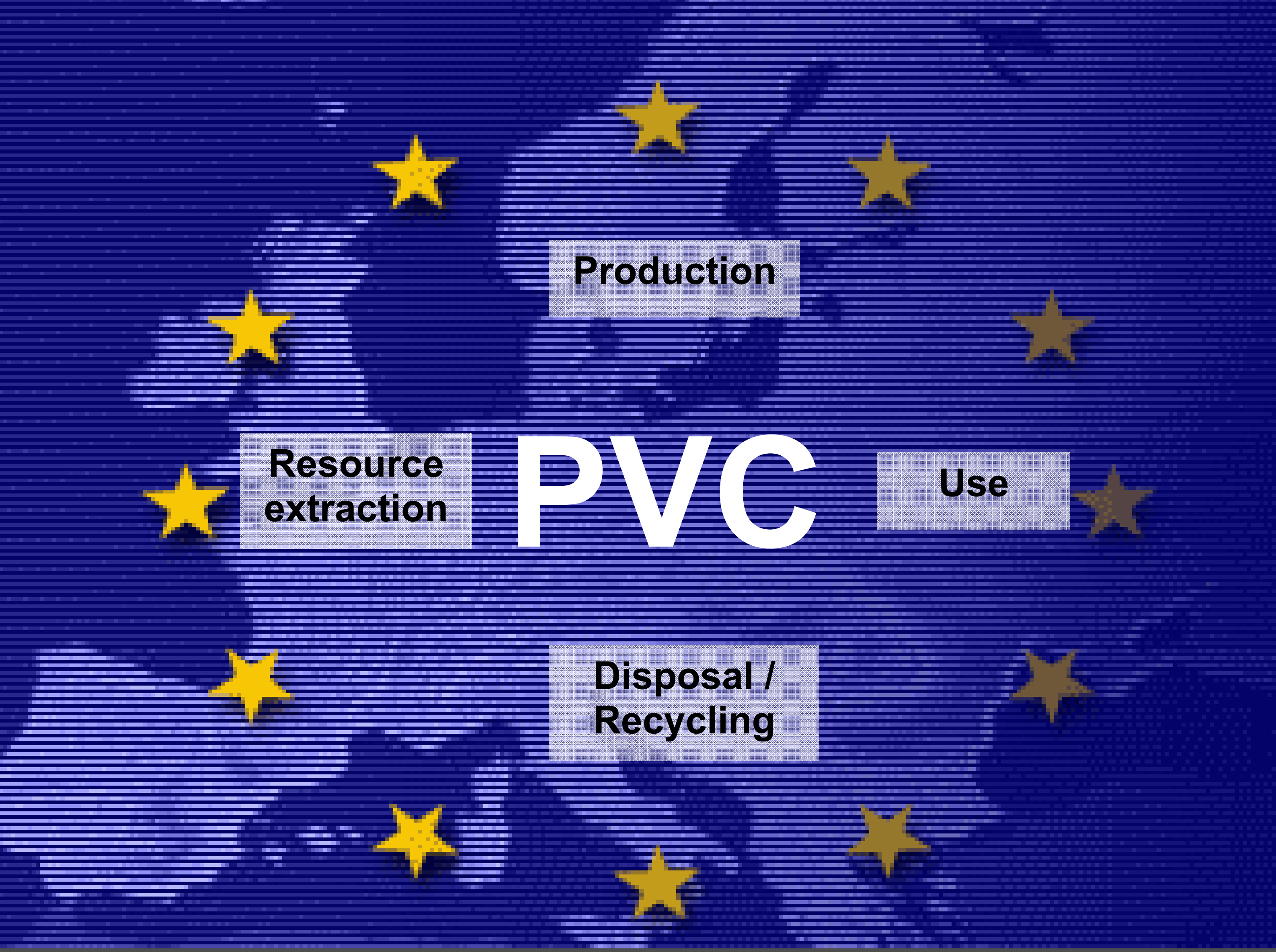

Extended Summary

Life Cycle Assessment of PVC and of principal competing materials

Commissioned by

European Commission

PE EUROPE GMBH Life Cycle Engineering

UNIVERSITÄT IKP STUTTGART

RANDA GROUP

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and of principal competing materials

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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 after 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 <u>all</u> 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

[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 case.