FINAL REPORT

Investigation of European life cycle assessment studies of pipes made of different materials for water supply and sewer systems – a critical comparison

Contracted by
TEPPFA, The European Plastic Pipe and Fitting Association

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Executive Summary

Life-cycle-assessment (LCA) has gained increasing importance in documenting and arguing ecological performance of products. The identification of environmentally weak and strong aspects of products through out its life cycle with LCA helps all involved actors, i.e. consumer, manufacturer or public sector to include ecological aspects in decisions. In that respect they are of essential help in product improving towards environmental friendliness in a very integral form. When LCA results are taken as basis for purchase decisions it is necessary to remark, that decisions should not be based on environmental performance only, except when the distance of one material to the others is significant and increasing or a threat for the environment or for neighbours can be assumed. Regularly decisions should be based on a balanced combination of economic, technical and environmental performance of the products, to avoid that some products gain a leading position in one aspect on account of environmental behaviour. Also for that purpose LCA can provide decisive and useful information.

In the field of plastic pipes several LCA studies have been published during the last ten years. This project should provide the members of TEPPFA with transparency about the result and the main conclusions in the single studies, as well as crucial differences in methodology, which are responsible for contrary statements. The final results were intended to be used for argumentation in promoting or defending plastic pipes.

For the investigation nine studies were examined and compared thoroughly. For PVC a general tendency to medium environmental characteristic can be seen. Three studies are excellent to argue for a midfield position of plastics ecological characteristics (Gastec, EMPA, Clausthal). Two studies more (Geberit, Nordiska) show good results for plastics but have another scope or in some respects not fully acceptable performance, so that the results were not recommended for argumentation. As plastic pipes seem to establish increasingly in the midfield, no distinct inferiority against other materials can be justified with existing LCA-studies.

Acknowledgement

We thank very much the European Plastic Pipe and Fitting Association TEPPFA and the chairman of the HSE group Mr. Speiser for contracting the study and hope that the results will contribute to better understanding and increasing use of LCA in plastic pipe industry. We are grateful to all members of the LCA project group for helpful comments and fruitful discussions in the meetings, which were essential for the success of our work. Our special thanks to Mr Gerhold Ratschmann for his ambitious organisation and his help in all respects, and to Mr. Georg Wuest for a lot of advises from his expertise in LCA of pipes.

1 Background

1.1 Life Cycle Assessment (LCA) in general

Life Cycle Assessments (LCA) of products (formerly also called eco-balances of products) consider environmental impacts during a product life cycle. The emissions into the air, the soil and the water are added up starting from the source of the raw material and ending up with the waste treatment, including the emissions from the energy production processes.

LCAs have been started years ago. At that time people thought, they would answer definitely the question “Which product is better: A, B or C?” Instead, we had to learn, that the results of an LCA fully depends on the goal of the study, the functional unit, the assumptions, the scope, the data and the valuation method.

The knowledge of how to perform reasonably an LCA has increased dramatically in the past years. A strong support today comes from the new ISO standards 14040 ff. concerning life cycle assessment. They are a guidance of how to perform an LCA in a generally accepted way maintaining full transparency. One could say: You may calculate everything, as long as it is done in a transparent way. To perform high quality LCAs you need skill, good data and time. And at the end it is often not easy to interpret the results.

LCAs quickly lead to misinterpretation, especially when inexperienced people just take the results, not considering the scope, the functional unit and the assumptions. In particular assumptions are often made on a national or even local basis. This may lead to contrary statements about the same subject.

On the other hand, LCAs are an important tool for the forming of an opinion, in spite of the fact, that LCAs never model all the environmental aspects of a product or product system.

Therefore it is important to have the knowledge about existing LCAs in the own field of activity in order to be able to argue or to act adequately and in time.

1.2 Scope of Teppfa

Several LCA studies of water supply, sewage and waste water pipes have been published, where single pipes or pipe systems of competitive materials are compared. Some results are in favour of plastic pipes, some do not show differences between the materials and some are in favour of non plastic pipes.

Therefore the members of Teppfa want to know all the studies, their statements, their scopes and assumptions and how to argue in case of an attack or a material discrimination, e.g. by public authorities. This will support TEPPFA to show their competence in the field of ecological aspects of plastic products.

2 Objectives of the project

From the goals stated above the following points could be specified as the scope of the contractor.

1. To get knowledge about the various water supply, sewage and waste water pipe LCAs, their goal, functional unit, scope, assumptions, limitations, strong and weak points
2. To know the main statements and whether they are in favour or to the disadvantage of plastic pipes
3. To know, how to argue in promoting or defending plastic pipes in the view of the LCA results
4. To summarise the conditions which favour the benefits of plastic pipes
5. To know, how plastic pipe producers might be attacked by competitors via the LCAs and how to behave in such cases
6. To learn more about LCAs and how to deal with them in the context of an association
7. To support Teppfa members to gather knowledge about LCAs and to use it in the marketing
8. To support Teppfa's image as a competent partner in the field of ecology

3 LCA Structure

Since some years, the LCA has become a promising instrument to evaluate a product of an industrial system from point of view of the ecological effects. A product LCA includes all environmental burdens caused during the product life *"from cradle to grave"*. Therefore, all activities from the extraction of raw material, processing, distribution and use of product, and finally disposal as waste or recycling as raw material should be considered.

The following four steps are the fundamental components of an LCA:

1. **Goal and scope definition**: Scoping is an activity that initiates an LCA, defining its purpose, boundaries and procedures. The scoping process links the goal of the LCA with the extent or scope of the study, i.e. the definition of what will or will not be included.
2. **Inventory analysis:** The inventory analysis identifies and quantifies all inputs and outputs associated with a product system including materials, energy and residuals. The data are recorded with data sheets and then allocated to and aggregated for the examined product. The result of the inventory analysis is the inventory table with data on environmental interventions.
3. **Impact assessment:** The life cycle impact assessment is the phase of a life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. It assists in the interpretation of inventory results in making these more understandable in their relationship to natural environment and human health. Impact Assessment according to ISO and SETAC consists of single steps during which the inventory results are expressed as a set of emission and resource impact indicators for selected impact categories in form of an environmental profile. An optional last step is the frequently Valuation called weighting across the impact categories, mainly based on values choices and not on scientific knowledge. The single methods differ in how far they are aggregating the results, some are starting with Valuation directly from the inventory results without a separated Impact Assessment. Highly aggregated results facilitate deriving decisions from them, but they lack transparency and information content, which is better provided by an environmental profile. The ISO-standard favours to derive the

conclusions from a profile in the interpretations phase as it is more transparent and can be better justified.

4. **Interpretation of results**: Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are combined together in line with the defined goal and scope. The findings of this interpretation may take the form of conclusions and recommendations to decision-makers, consistent with the goal and scope of the study.

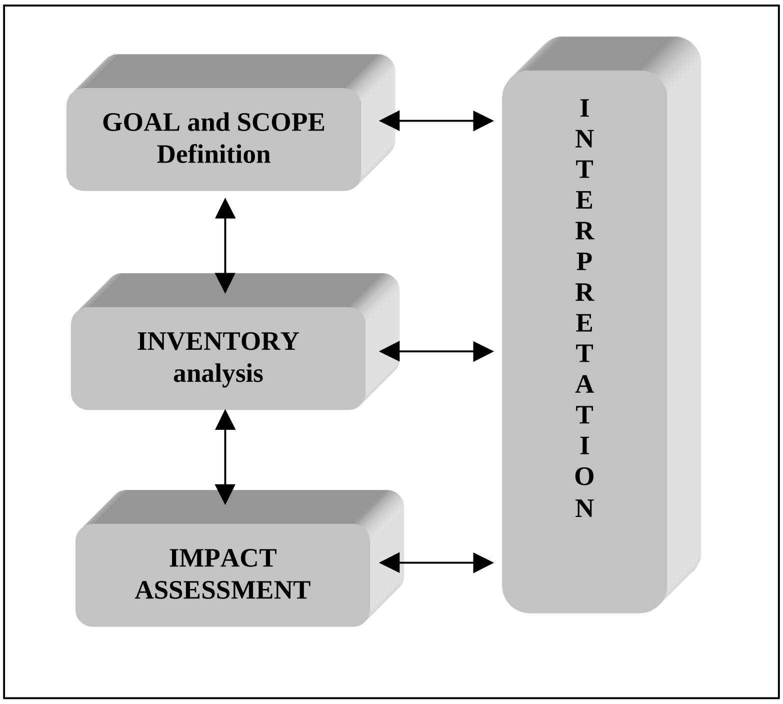

Figure 1 **General structure of environmental life cycle assessment**

3.1 Goal Definition and Scope

The investigated products in an industrial systems in the system boundary can be traced, if the goal of the study has been defined transparency and precisely. The Goal Definition and Scoping is the first phase of an LCA which makes the objective of the study clear. This component of LCA consists the following major activities:

1. defining the purpose of the study
2. specifying the boundary of the investigated system (Scooping)
3. defining the regional consideration
4. defining a functional unit as a base for comparison
5. determining the time horizon

6. defining the product group
7. specifying data quality goal
8. defining the responsible and beneficial body who undertake the application of the ultimate result

The analysis of an LCA is carried out for one or more products which are selected from the product group and meet the criteria of representatives. The final outcome of the goal definition has to be investigated for a particular purpose, based on the functional unit. The functional unit describes the main function performed by a product and indicates how much of this function is considered. It is the basis for comparison. Unfortunately additional functions of a product can sometimes not be included.

Under goal definition also the intended use of the LCA and the addressed user groups should be outlined.

The identification of the environmentally weak and strong aspects of the product through out its life cycle with LCA helps the involved actors, i.e. consumer, manufacturer or public sector to include ecological aspects in the decision. Hereby it is necessary to remark, that decisions should not be based on environmental performance only, except when the distance of one material to the others is significant and increasing or a threat for environment or neighbours can be assumed. Regularly decisions should be based on a balanced combination of economic, technical and environmental performance of the products, to avoid that products gain a leading position in one aspect on account of environmental behaviour. For that purpose LCA can provide decisive and useful information.

The second major factor to be defined under goal definition is the boundary of the investigated system. It defines and limits the width and the depth of the inventory data to be considered in Inventory Analysis.

LCAs are carried out based on the present and future impact of present day production and consumption of products. Hence, they should be targeted more on the present and future environmental impact, than on the impact that has already occurred. However, prior level of pollution are important when assessing the effect of the present condition. Therefore, in this first component, the time horizon of the assessment also been determined. This is of special importance for the choice of representative processes and related data.

3.2 Inventory Analysis

In the inventory section, the environmental burdens, i.e. emissions, waste and use of resources, of the life cycle are identified, quantified and calculated per functional unit. This part of LCA represents a detailed objective data based process of quantifying the inputs of raw materials and energy into a system and the outputs of solid, liquid and gaseous waste from the system through out the life cycle of a product, process or activity. Schematically, total Inventory consideration of an LCA is shown in Figure 2.

In the inventory three elements are distinguished:

- the definition of System and System Boundary
- the definition of Input / Output Data handling in Life Cycle Inventory
- the specification of all processes.

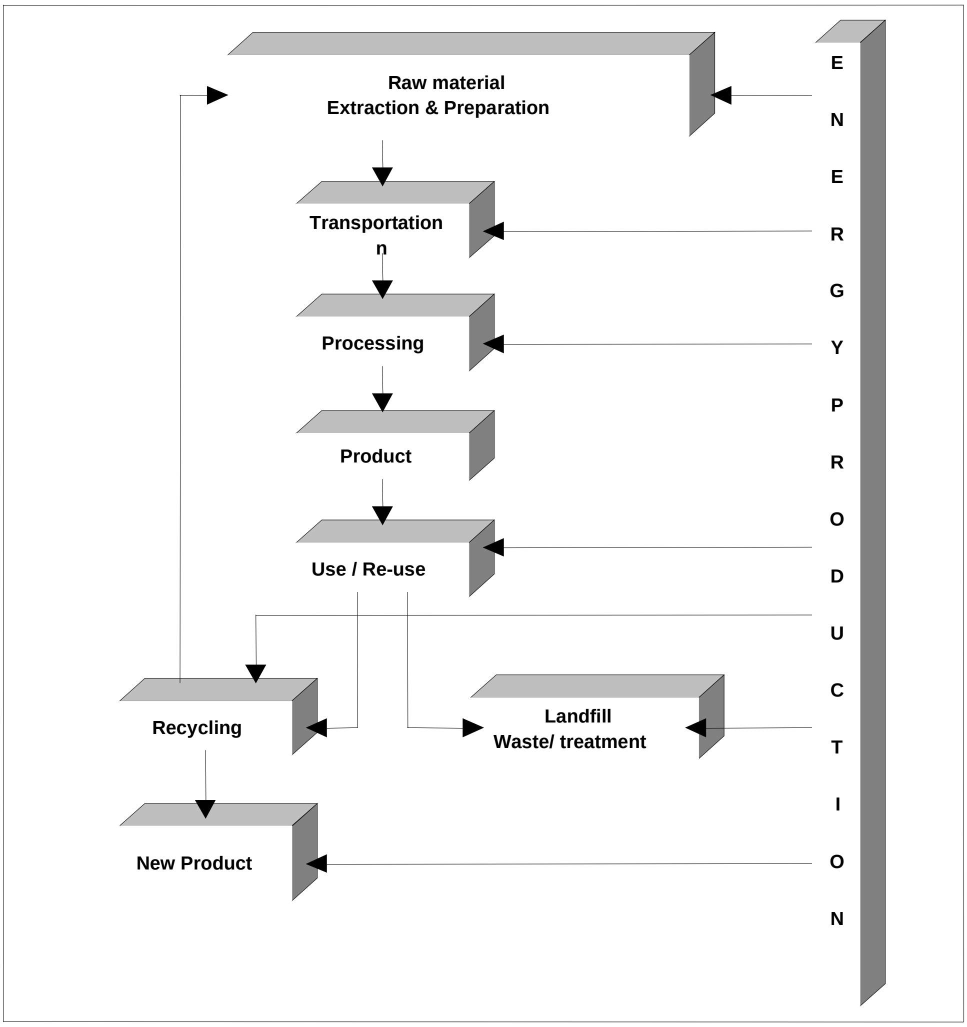

Figure 2: **Included steps of the production chain**

3.2.1 The Definition of System and System Boundary

To be in line with sustainability the results of LCA must refer to the use of renewable and non-renewable raw materials and energy resources which mean the distinction between solar and fossil fuels. Reuse and recycling processes should also be considered carefully. To meet this demand the system configuration and the boundaries as illustrated in Figure 3 used. Two boundaries are visible, one as a border between technosphere and nature and a second one between the respective process and the rest of technosphere. The inputs and outputs are counted at the one or the other boundary, which leads to two different quality levels.

The *first quality level* is the boundary between environment and technosphere and means environmental relevant flows. This concerns for example, air emission like particle, CO, CO_2, SO_2,...etc., water emission as well as solid waste cropping up during the entire life cycle. They become environmental pressures by passing the external environmental system boundary. But it means also that raw material will be calculated as extraction of environment only at the entrance to technosphere. All materials that have once been processed in industry are no longer considered as fresh material drawn from nature. There is also a possible way to reprocess materials, which were released to the environment by other processes in technosphere. They would then be subtracted from the streams of comparable quality passing the boundary in the reverse direction.

The *second quality level* can be assumed at the boundary of the regarded processes to the rest of the technosphere (processes in technosphere). This concerns material which comes from or goes to other processes. To be able to handle this case easily a material buffer can be assumed. Outgoing material which can be further used in other processes is assumed to go to that buffer, input material from other processes comes from it. Finally this material remains in technosphere and does not cross the environmental system boundary, therefore it is not considered as environmental pressure. This used material buffer plays a substantial role for handling of recycling- and reuse processes, which are essential ways to achieve sustainability.

Material recycling within the respective process chain is not counted directly as no boundary is passed, but it is implicitly included as it reduces the demand for fresh or processed raw material.

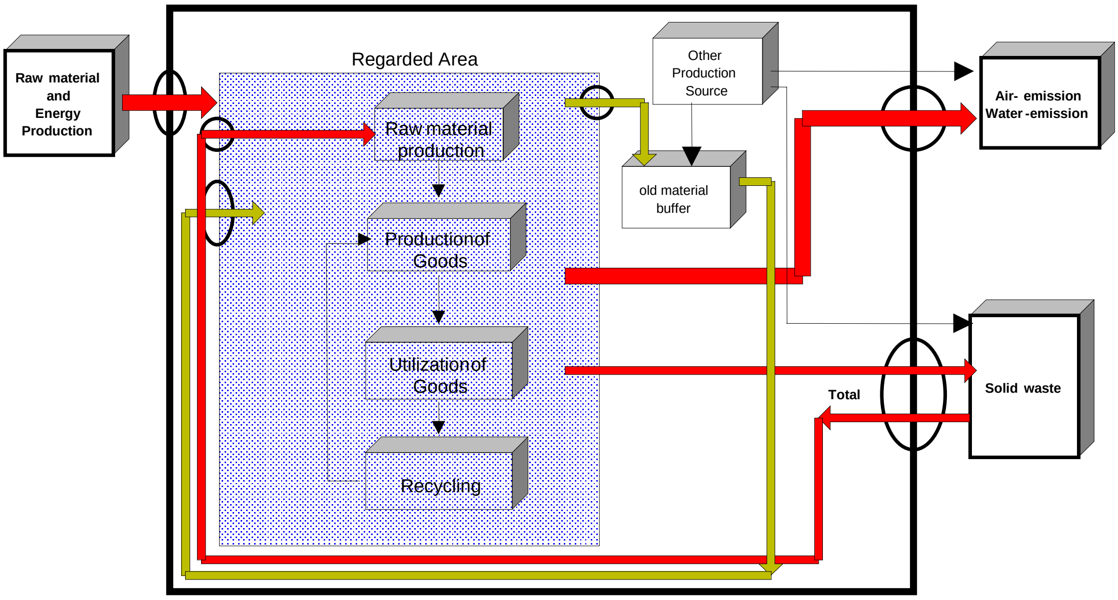

Figure 3 **Industrial System - Boundaries**

3.3 Impact Assessment - Valuation

The process of Impact Assessment is separated into different elements, each with a distinct procedure:

1.) Definition: In the definition, the particular impact categories, the effects and the indicators are chosen. This can thus be seen as a specification of the Goal and scope definition where the types of impacts the study will address shall be described.

2.) Classification: In the classification, the environmental interventions listed in the inventory table (i.e. the inputs and outputs through the studied system) are attributed to the selected impact categories.

3.) Characterisation: In the characterisation, the attributed interventions are modelled to express the burden as an indicator for the respective category. This modelling can be performed with weighting factors mainly based on scientific background. The result of category modelling is a loading or resource depletion profile

The next elements hereunder are steps on the way to aggregate the results further and are optional.

4.) Normalisation: Normalisation is the analysis of the relative contribution to the single impact categories through dividing the indicator result by a reference value. It may be helpful in providing information on the relative significance of the results.

5.) Valuation: Valuation means weighting across the impact categories to rank or aggregate the indicator results. This procedure is regularly based on values-choices as no science-based data exists. Some methods also start Valuation directly from Inventory data. The application of weighting methods should be consistent with the goal and scope and shall be fully transparent. Due to different values for the weighting different results can be reached from the same inventory. So it is recommendable to use several weighting methods to assess their influence on the results.

Some of the most frequently used valuation methods are described hereunder.

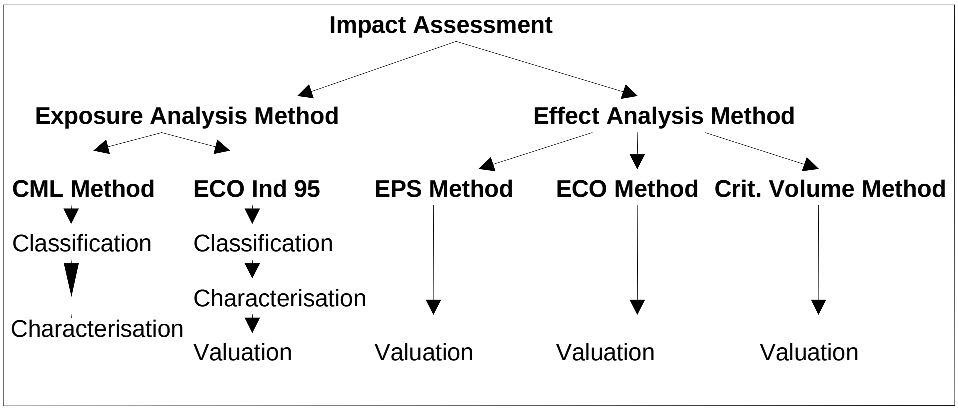

Figure 4 **Frequently used valuation methods**

3.3.1 CML Method for Impact Assessment

CML-method was introduced by Center of Environmental Research in Leiden,NL and is the most acknowledged method for Impact Assessment. This method is under continuous development in cooperation with the Society of Environmental Toxicology and Chemistry (SETAC) which tries to establish a uniform LCA method.

The impact assessment according to CML comprises all the steps described in 3.3. The pressures are aggregated in the following impact classes:

1. Resource depletion of energy carriers and raw material
2. Greenhouse effect – Global Warming Potential (GWP)
3. Depletion of stratospheric ozone - Ozone Depletion Potential (ODP)
4. Acidification Potential (AP)
5. Eutrophication Potential (NP)
6. Photochemical-oxidant formation (POCP)
7. Human-toxicology Potential (HTP)
8. Eco-toxicology Potential (ETP)
9. Land use

The inventory data is aggregated within the impact categories, the weighting is performed by equivalence factors based on physical or chemical properties. The environmental loads of the products or systems are grouped (sorted or classified) into selected environmental impact classes. Thereafter, by multiplying the measures of the relative equivalence with the pollutant load, the contribution of each pollutant to the impact class is calculated.

$$Effectscore_i = \sum_j Load_j \times Eqv_{ij}$$

The resulting environmental profile is the basis for the following interpretation.

3.3.2 ECO Indicator 95 Method

The ECO Indicator 95 Method method was developed by "Pre Consultants" in cooperation with CML, TNO, universities and companies. Basically, this method is a further extension of CML method. Therefore it bases on the Impact Assessment steps Classification and Characterisation and can be seen as a defined procedure for the steps Normalisation and Valuation.

As the results of the Impact Assessment steps Definition, Classification and Characterisation frequently do not lead to clear conclusions, the method focuses on the mutual weighting of the effects. The Normalisation step is based on the environmental effect of an average European in one year. This step reveals which effects are large and which small in relative terms, it does not say anything about the relative importance of the effects. So a small effect could very well be the most important one.

Very much consideration has been given to the weighting step, as it is of significant importance for the results. After thorough investigation the distance to target principle was chosen. This means an assumed correlation between the seriousness of an effect and the distance between the current and the target level, which is similar to the weighting scheme in Eco-scarcity method. But the target levels should be independent of politics and based on scientific information. To allow a consistent view as much as possible damage classes were established:

- ⇨ Fatalities as a consequence of environmental effects - accepted level 1 fatality per million inhabitants per year
- ⇨ Health problem as a consequence of environmental effects - hardly any smog
- ⇨ Ecosystem degradation - only 5 % degradation over several decades accepted

For the correlation between the damage and the effects a detailed study for Europe was carried out, from which weighting factors could be derived. The results show that highest priority must be given to abate substances causing ozone layer damage and to reduce pesticide use. Further items are acidifying and carcinogenic substances.

3.3.3 The Environmental Priority and Strategies in Product Design (EPS) Method

A third possible method is the Environmental Priority and Strategies in Product Design (EPS) method The EPS method was developed by the Swedish Environmental Research Institute together with the Swedish Federation of Industries and Volvo Car Corporation in 1991.

This method is a valuation method in which the basic principle is to describe impacts on the environment in terms of impacts to safe-guard subjects and value changes according to the willingness to pay to restore the nature to its normal status [Steen and Ryding 1992]. Under this method five safe-guard objects are valued. These are:

- Biodiversity
- Production
- Human health
- Resources, and
- Aesthetic values

The impact is valued in Environmental Load Units (ELU). One ELU corresponds to one European Currency Unit (ECU). Emission, use of resources, and other human activities are then valued according to their estimated contribution to the safe guard objects.

3.3.4 The Ecological scarcity (ECO) Method

The Ecological scarcity (ECO) method is a very popular approach of Valuation starting directly from the inventory data. The concept of ECO method for product assessment was introduced in a Swiss study [BUWAL 1990, updated 1998] and is widely exercised in companies.

The term eco-scarcity is used to express the fact that nature, in which the technology development is embedded, is of a limited size. The capacity of nature to absorb anthropogenous emission is limited, and its resources to supply materials and energies to technological development are limited.

In this method the level of environmental intervention (emissions or depletion) is expressed by an ecofactor. To obtain the total environmental impact, each product specific emission ($Load_j$) is multiplied by its corresponding ecofactor (substance and area specific), and added together as expressed below.

$$TI(ECO) = \sum_j (Ecofactor_j \times Load_j)$$

After having evaluated a number of algorithms, Braunschweig concluded that the hereunder mentioned algorithm, where the ecofactor is proportional to the scarcity, is preferable because of its simplicity and no requirement of arbitrary assumptions.

$$Ecofactor_j = \frac{Load_{j,total}}{Load_{j,criti.}} \times \frac{1}{Load_{j,criti.}} \times C$$

$Load_{j,total}$ = the current total level of anthropogenic emission or deposition of substances *j* within a certain area;

$Load_{j,criti}$ = the critical load(emission) of a substance *j* defined for a certain area;

C = a dimensionless number which is introduced in order to get manageable numbers Constant (10^{12}) .

The first quotient, $\frac{Load_{j,total}}{Load_{j,criti.}}$, expresses ecological scarcity, the second quotient, $\frac{1}{Load_{j,criti.}}$, is a standardising factor. It is necessary to compensate the second quotient to differentiate from the absolute levels of emissions. Otherwise, for example, 1g of CO_2 would get the same Ecofactor as 1g of CFC, if both of them are calculated based on the first quotient. This element of the equation therefore, allow to differentiate that the critical emission are evaluated according to the amount of $Load_{j,criti}$ .Critical loads can be defined either as ecological critical loads (sustainable Loads) or as politically maximum acceptable limits (political targets). Theoretically, two different sets of ecofactors can therefore be calculated, depending on the definition of the critical loads, but this is usually difficult in practice due to incomplete information. Given that different regions have different sensitivities to pollutants and different level of pollution, ecofactors are specific for the regions for which they are calculated.

3.3.5 The Critical Volume Method

One of the first evaluation methods which were applied to the ecological balancing was the Critical Volume method. It was applied the first time in 1984 in Switzerland on the project „ Ökobilanzen von Packstoffen".

The *Critical Volume* method aggregates data, which allows each emission in the air and water to be added up to one measure called critical volume.

$$V_{critj} = \frac{Emission\ m_j}{\mathrm{Im}ission\ C_j} \quad \frac{[mg/m - Pipe]}{[mg/m^3]}$$

$$TV_{crit.} = \sum V_{crit.\,i} \quad [\frac{m^3}{m - pipe}]$$

$TV_{crit.}$ is the amount of emission necessary to load each environmental media up to the imission boundary. The volume calculated for separate pollutants will be added to a total critical volume for air and water respectively. Because the volume always considers only one pollutant, the amount $TV_{crit.}$ presents only a pure numerical value. The calculated value does not refer to the reality. Therefore, it is false to believe that the cumulated emission of product Y with $TV_{crit.}$ indeed pollutes x-thousand m³ of air or water.

So the *critical Volume* has no direct relation to the reality but is an illustrative quantification of environmental pressure.

3.4 Interpretation – Improvement analysis

In the interpretation the results of all the steps should be summarised and conclusions derived. Hereby the results and effects of any sensitivity and uncertainty analyses should be included. Such analyses may have been performed as parts of earlier phases and elements. However, the conclusions in the interpretation phase should be of an encompassing nature. As a part of the interpretation phase, the information from all previous phases and elements, including qualitative information is compared with the goal of the study and conclusions are drawn on the environmental implications of the results. Recommendations to decisionsmaker may be formulated.

For more details see also chapter 4.1.11.

4 Analysis of the studies

Hereunder the role of the single aspects of the comparison of the studies and the points of special attention are described.

4.1.1 Functional unit

LCA´s for comparison of products should be based on the function of the respective products. The results of comparisons can vary remarkably, if products cannot provide the complete function. On the other hand additional functions, which will be provided by a product (especially aestethical facts) can hardly be regarded. Examples for that are aesthetic aspects or human health.

4.1.2 Boundaries

The chosen boundaries determine which of the ecological relevant processes are included in the analysis – more processes included along the life cycle will result normally in a higher ecological pressure of the product system. Excluding of processes along the life-cycle, as it is done in some studies will underestimate the overall impacts of the system.

4.1.2.1 Energy –Boundary

There are great differences in the calculation of emissions linked to energy consumption. In some cases the emissions from external energy supply are not included. This reduces the overall impacts associated with external energy use and, favours processes consuming external energy.

In some cases the feedstock energy (the energy content of the raw material) is not included, which can lead to a decisive advantage for products with high energy content of the raw materials like PVC or wood, discriminating products without or with less input of this type of raw materials.

4.1.2.2 Energymix for electrical energy

The share of the different types of energy production determines the environmental emissions linked with the consumed energy. There are crucial differences in the emissions behind energy supply in the european countries, so use of a national or EU-mix has effects on the results.

4.1.3 Life Time

The assumed life-time of the different pipe products vary a lot in the different studies. This has quite proportional effects on the results. A shorter life time leads to an equivalent higher impact per functional unit. The frequently used practise to exclude life-time in the investigation is an assumption of equal life time as well.

4.1.4 Regional situation

The assumed regional situation of the production site also has great effects on the results as the situation of energy supply, environmental standards and the transport distances vary for different countries. There is no effect on the comparison if european data are used for all materials. If special regional situations are taken, this might dominate the results, so that they reflect rather regional differences than materials differences, which are valid under that regional conditions only.

4.1.5 Production

All raw materials and the respective production processes shall be included. Moreover the processes involved in the final disposal of the product shall be regarded.

4.1.6 Transport

The transportation at all life stages of the product system shall be included. This concerns the upstream (raw material chain), the product distribution as well as the downstream processes (product disposal). If the ecological effects of transportion are not included, long-distance transportation is favoured.

4.1.7 Pipe Laying

Laying of the pipes is considered in most studies to be equal for all materials. In fact this ignores the differences in the wall thickness and the weight of the pipe. Moreover the required preparation of the ground surface differs between the pipes to some extent, but there is no agreement in that respect. Taking all that into account the equal assumption seems to be unjustified.

4.1.8 Use

The importance of the use phase depends on the respective product. Environmental relevant aspects of the use phase of pipes are:

- maintenance and cleaning
- failures, leakage, exfiltration and infiltration

Especially the second issue is dominated by lack of clear and concise data, so these effects are only qualitatively mentioned in the studies, mostly with sensitivity analyses.

4.1.9 Waste disposal

Ecological effects of the disposal of used products are strongly linked to the regional situation. The dominance of landfill or waste incineration in a country may lead to really different results. In some cases the waste disposal is not included, as pipes remain buried in ground, favouring products with high waste amounts or problems in waste treatment.

4.1.10 Sensitivity Analyses

Sensitivity analysis is any check of the effects of uncertain conditions on the results. It serves to estimate the magnitude of effects, where frequently assumptions are used to quantify effects.

4.1.11 Impact Assessment, Valuation

Impact Assessment is the grouping of pressures with similar affect in impact classes. The grouping uses (most scientifically derived) coefficients to relate the single components according to their effect. The results of impact assessments are values for the environmental pressure in each of the impact class leading to an environmental profile of the product.

Other methods focus on total aggregation of the single pressures listed in inventory to one (or some) index (indices). These methods use mainly factors of magnitude for the single pressures, which are created with complete different methods. Some are derived from expert panels, some come from willingness of public, some are tried to be based on physical background.

In fact, all the methods for Valuation have a considerable dominance of some pressures, which influences the results the more, the lower the number of dominant pressures and the more aggregated the results are. According to ISO 14040 no final aggregation to one index during Valuation is preferred.

4.2 List of analysed Studies

1. KIWA 1992: Milieu-effecten van leidingsystemen van asbestcement, PVC, gietijzer, staal en glasvezel versterkte kunststoffen, KIWA, Nieuwegein, October 1992

2. Clausthal 1995: Energieverbrauch und CO2-Emissionen bei der Herstellung und Entsorgung verschiedener Abwasserrohre (Steinzeug, Beton, Stahl, Gußeisen, PVC, PEHD), Jeschar, Specht, Steinbrück, Institut für Energieverfahrenstechnik und Brennstofftechnik, TU Clausthal, 1995

3. INTRON 1995: Levenscyclusanalyse van vergelijkbare buitenriolering (beton, gres, PVC), Institut voor Materiaal-en Millieu-onderzoek - INTRON, Holland 1995

4. FICU 96: Ökologischer Vergleich von Rohren aus verschiedenen Werkstoffen (Beton, Beton/PVC, Faserzement, GFK, Gußeisen, PVC, PEHD, Steinzeug), TU-Wien, Forschungsinstitut für Chemie und Umwelt, Juni 1996

5. Gastec 1996: Environmental Life Cycle Assessment of Gas Distribution Systems, Centrum voor Gastechnologoe (Gastec) and CML-S&P, The Netherlands, 1996

6. Nordiska 97: Miljovurdering af aflobsror i PVC, PE, PP og Beton, Nordiska Plaströrgruppen, August 1997

7. CHALMERS 1997: Chalmers, Technical Environmental Planning Report 1997, ”Life cycle assessment of wastewater systems”

8. GEBERIT 1998: Ökobilanz von Rohren zur Hausentwässerung, Geberit International AG, CH - 8645 Jona

9. EMPA 1998: Ökobilanz von Rohrleitungssystemen (PVC, PEHD, Gusseisen, Steinzeug), Eidgenössische Materialprüfungs- und Forschungsanstalt - EMPA, St.Gallen, März 1998

4.3 Aspects of comparison

At first, the contents of the studies are shown in a table for each study. The analysis of every study is described following the hereunder listed structure:

- General Information (Author, Title, year and way of publication, language, content...)
- Goaldefinition and Scope of the Study (Goal, Materials, Functional unit, Weight)
- Inventory analysis (Data, Boundaries, Life time, Regional situation, Not included flows, Transport, Pipe-laying, Use, Disposal, Sensitivity Analysis)
- Interpretation in the study (Inventory Results, impact assessment, Valuation)

The second step there is an overall judgement with gives answers to the following questions:

- Results of the study
- General review of the study
- Positive aspects for plastics
- Negative aspects for plastics
- Judgement, Recommendation

4.3.1 KIWA

Title: *"Milieu-effecten van leidingsystemen van asbestcement, PVC, gietijzer, staal en glasvezel versterkte kunststoffen"; KIWA, Nieuwegen; October 1992; Language: Dutch only, 112 pages*

Contractor: *VEWIN Association of Waternet operators in Netherlands*

Goal and Scope definition						
Goal	Comparison of different materials for sewer pipes commonly used in 1988 in Netherlands					
Material	Fibre cement	PVC	Cast iron	Steel	Glasfiber Polyester (GFP)	Glasfiber Epoxy (GFE)
Functional unit	100m sewer pipes, Diameter 100mm, pressure 1 MPa					
Weight [kg/m]	8,8	1,45	20,15	12,7	1,64	1,9
Inventory analysis						
Data	Mainly dutch sources					
Energy	Only the amount of energy in MJ is given					
Electr. Energymix	No details – generally Dutch situation mentioned					
Material Specifities	For all materials dutch data are used - not material specific					
Boundaries	General remark „Cradle to grave", but no clear information					
Life-time	Same lifetime taken for all materials					
Regional situation	Producer in Netherlands					
Not included flows	Not transparent					
Transportation	Not transparent					
Pipe-Laying	Qualitative description					
Use	Qualitative description					
Disposal	Qualitative description					
Sensitivity Analysis	No					
Interpretation of the results						
Inventory Results	Qualitative results, values only for energy					
Impact assessment	Classes for: Resource use, emissions to water, soil and air, Production of solid waste Energy use, Land use and Disruption of ecosystems					
Valuation	Results of Impact Assessment qualitatively documented					

4.3.1.1 Results of the study

Except for energy consumption, all results are presented in a qualitative manner

	F-cement	PVC	Cast iron	Steel	GfP	GfE
Resource consumption	--	--	---	--	--	--
Energy use (GJ/100m)	5,5	6,9	36	37	6,9	12
Pollution						
Extraction	---	--	-	-	--	--
Intermediates	---	---	---	---	---	---
Pipe production	---	-	-	-	--	-
Laying	--	-	-	-	-	-
Use	--	-	-	-	-	-
End of life	---	-	-	-	--	---

0 … renewable resources, no emissions
- … resource pool > 300 years, less emissions
--… resource pool 50-300 years, local emissions
---… resource pool < 50 years, permanent emissions

- Lowest energy consumption for Fibre cement, but high impact in all other aspects
- PVC is in second position from energy consumption, only raw material extraction and intermediates show notably high values
- Although cast iron and steel show highest energy consumption, only the values for intermediates are notable

4.3.1.2 General review of the study

4.3.1.2.1 Positives

- The Contractor seems to be neutral
- Generally the whole life cycle is included
- The study looks at important stages in the whole life cycle of each material
- Many different pipe materials (six) were analysed

4.3.1.2.2 Negatives

- There are no data tables so the results are not checkable
- The goal of the study was a comparison between the different materials but it results only a documentation of the weak points of each material. Only the energy consumption was quantitatively compared.
- Only one diameter is analysed
- The study does not comply with ISO 14040 due to the following points:

  No critical review,

  No sufficient transparency as no data tables are included

  No formal impact assessment

- Only dutch data are used
- Generally the study is rather old (1992) for LCA studies, the used data for the analysed materials are from the late eighties. Until the last years the production of every material has been improved so that study is not so interesting any longer.
- The great difference between the energy consumption of PVC pipes to Cast iron and Steel pipes (factor 5 !) is not explainable, as the qualitative assessment between these materials looks equal. Also the low energy consumption for fibre cement pipes is suprising when looking at the qualitative judgement.
- The weight of the Cast iron pipe is high by comparison with the PVC pipe (factor 14)

4.3.1.3 Positive aspects for plastics

- The study favours PVC, only the intermediates are documented as negative, but this is the same for all materials
- The energy use for PVC-pipes is with 6,9 GJ/100 m together with the GFP –pipe at the second place, only the Fibre cement pipe is lower with 5,5 GJ/100 m. The energy use for steel and cast iron is the highest (> 35 GJ/100 m). The big difference is not explainable – see General review
- The pipe production, pipe-laying, use and the end of life for PVC are seen as „less relevant“ for the environment.

4.3.1.4 Negative aspects for plastics

No discriminating aspects but it should be considered that:

- There are no data tables so the results are not checkable
- The goal of the study is only a documentation about the weak points of each material and no comparison between the different materials

4.3.1.5 Judgement – Recommendation

The study identifies important stages in the whole life cycle of each material. The chosen Goal of the study (comparison of different materials) is not arrived at, only the weak points of each material in the life cycle were investigated. The study is rather outdated, the data are not checkable and seem misleading in some cases so it is not a good basis for argumentation, although the results are favouring plastics.

4.3.2 Clausthal

Title: *"Umweltbeeinflussung bei der Herstellung und Entsorgung verschiedener Abwasserrohre"; Jeschar, Specht, Steinbrück; Institut für Energieverfahrenstechnik und Brennstofftechnik; TU Clausthal; 1995; Language: German, 31 pages*

Contractor: *European Association of vitrified clay pipe producers*

Goal definition and scope					
Goal	1. LCA for sewer pipes of different diameters (DN 100, DN 150, DN 300, DN 500) per m pipe 2. LCA for sewer pipes for a pipe system (length 55 m) in a hall (DN 100, DN 150)				
Material	PVC	PEHD	vitrified clay	concrete ferro/concrete	cast iron
Functional unit	1 m of a pipe system in a hall was considered				
Weight DN 100 [kg/m]	1,59	1,43	15	-	8,4
Inventory analysis					
Data	TU Berlin	TU Berlin	Europe – Industry data	German – Industry	∅ German Industry for cast iron production
Energy	German situation Efficiency electr. Energy = 32 % (public supply) Efficiency cogeneration (industry internal) = 80 %				
Electr. Energymix	ETH-data for Germany				
Material Specifities	25 % internal energy 75 % public energy supply	25 % internal energy 75 % public energy supply			> 90 % cast scrap
Boundaries	Cradle to grave, boundaries well documented				
Life-time	vitrified clay 100 years concrete/ferro concrete 60 years ferro concrete inc. corrosion resistant 80 years **only for sensitivity analysis** cast iron 60 years PVC, PEHD 50 years				
Regional Situation	European and Germany data Same expenditure for extraction in opencast mining for lime, clay, gravel				
Not included flows	• use • „production" of cast scrap				
Transport	Included				
Pipe-Laying	Not included				
Use	Not included				
Disposal	Combustion 50 % thermical 50 % waste	combustion 50 % thermical 50 % waste	100 % reuse as fire clay	after cleaning as street gravel	100 % reuse as cast scrap
Sensitivity analysis	Life time, relation to theoret. energy expenditure				
Interpretation of the results					
Inventory Data	The results of the inventory are listed for Waste Energy Emission in the atmosphere (CO_2, SO_2, NO_x, HF)				
Impact assessment	Not performed				
Valuation	Not performed				

4.3.2.1 Results of the study:

- For small diameters (DN 100, DN 150) lower energy consumption for PVC and vitrified clay pipes than for other materials
- With larger diameters (DN 300, DN 500) concrete has increasing advantages in energy
- By using the various life times in sensitivity analysis vitrified clay has the best results
- Increased recycling could reduce the environmental effects of PVC and cast iron

4.3.2.2 General review

4.3.2.2.1 Positives

- Generally the whole life cycle is included (except laying and use) the boundaries are well documented
- Many different pipe materials (five) and many different diameters were analysed
- Data quality for all materials is generally good, in the most cases german data - only for vitrified clay european data

4.3.2.2.2 Negatives

- No neutral contractor (European Association of vitrified clay pipes)
- No impact assessment method was performed. Only Inventory results for energy consumption, air emission (CO_2, SO_2, NO_x, SO_2, HF) and waste
- No external critical review was done
- Some assumptions are not fully transparent
- Cast iron pipes are analysed with 90 % cast scrap input – this seems high (in EMPA ~ 72 % cast scrap)
- The life-time for plastics is with 50 years shorter than the life-time for all other materials , that is not regular
- The recycling potential for Plastics after use is given with only 50 %, that seems too low.

4.3.2.3 Positive aspects for plastics

- CO_2-emissions of PVC and PEHD-pipes are lower than cast iron and vitrified clay
- The environmental effects for PVC are medium, despite some disfavouring assumptions
- Further potential to reduce the emissions for plastics pipes by increasing recycling

- Improvement potential by use of actualised APME data for PVC and PEHD ("*Eco Profiles of the European plastic industry, Report 6, Polyvinylchlorid, European Centre for Plastics in the environment, May1998"*)

4.3.2.4 Negative aspects for plastics

- The NOx Emissions for PVC and PEHD are at all diameters higher than the emissions of cast iron pipes
- Plastic decomposition was included
- The life time for PVC was assumed with only 50 years (vitrified clay 100, cast iron 60), nevertheless the energy consumption, CO2, SO2 and HF emissions of 1 m plastic pipe (included the sealing ring) with small diameters (DN 100 + DN 150) are lower than the emissions of cast iron-pipes
- Only a recycling potential after use for Plastics with 50 %
- Cast iron pipes are analysed with 90 % cast scrap input

4.3.2.5 Judgement, Recommendation

The study is respectable. Despite some discriminating assumptions, the position for plastics is in the midfield compared with the other materials. For this reason this study can be taken to argue against other pipes.

4.3.3 Intron

Title: "Levenscyclusanalyse van vergelijkbare buitenriolering"; Institut voor Materiaal-en Millieu-onderzoek – INTRON; Holland; 1995; Language: Dutch only, 30 pages

Contractor: VPB Woerden - Association of Concrete Producers

Goal and Scope definition					
Goal	Comparison of concrete pipe systems to different alternatives				
Material	Concrete	PVC kl.34 9,2-10,4 mm thickness	PVC kl.41 wallthickness: 7,7-8,7 mm	PVC 3 layers 21mm max	Vitrified clay
Functional unit	1. 1 km of rain water or waste water system with sealings and wells. (DN 300) 2. 1 m pipe incl. sealing ring (DN 300)				
Weight [kg/m]	72,5 kg/m	1,35 kg/m	2,24 kg/m		
Inventory analysis					
Data	Producer in Netherlands	APME for PVC, supplemented by Producer in Netherlands			Producer in Netherlands
Energy	Datasources not documented				
Electr. Energymix	Not documented				
Material Specifities	No special information about data sources				
Boundaries	Methodology according CML manual, Guinnee et al.				
Life-time	Economic lifetime: 40 years				
Regional Situation	Dutch				
Not included flows	Additives				
Transport	Included, but not documented how				
Pipe-Laying	In sensitivity analysis included				
Use	Cleaning every 5 years				
Disposal	Complete Recycling after use				
Sensitivity Analysis	Laying, Use (cleaning every 5 years)				
Interpretation of the results					
Inventory Data	Resources, Energy				
Impact assessment	CML-Method for • Resources • Energy • Global Warming Potential (GWP) • Acidification Potential (AP) • Photochemical Oxidant Formation (POCP) • Human Toxicity Potential (HTP) • Waste				
Valuation	Included, especially for concrete				

4.3.3.1 Results of the study:

- Concrete has the best results in all analysed impact classes.
- The laying of the pipes has significant importance for the impact classes POCP and Energy.

4.3.3.2 General review:

4.3.3.2.1 Positives

- A pipe system with 1 km length is analysed
- Methodology according CML manual, Guinnee et al
- Generally the whole life cycle is included

4.3.3.2.2 Negatives

- No neutral contractor (Association of Concrete Producers)
- Only one diameter is analysed (DN 300)
- No external critical review
- There are no data tables so the results are not checkable
- For clay and concrete is the location of the pipe production Netherlands was assumed. For PVC granulate European data are used. As the data tables are missing no detailed analysis is possible
- The energy demand for PVC is very high, we don't know exactly why because there is no detailed table of the used data
- Only parts of impact assessment method (CML-Resources, Energy, GWP, AP, HTP, POCP)
- For all materials recycling is only calculated as reduction of waste amounts, not regarded as material input
- Although the method is extensive, no representatives for europe is guaranteed

4.3.3.3 Positive aspects for plastics

- There are no aspects favouring plastics – all negatives points in the general review could be used for argumentation

4.3.3.4 Negative aspects for plastics

- There are no strong points for plastics
- PVC has the worst results of all analysed materials in all environmental classes, the results are influenced by the diameter DN 300 which favours concrete
- The laying and the use is included but the expenditure for all materials are assumed as equal to concrete, whereas plastics would have lower value
- The energy demand is very high - own calculation by means of the documented data sources leads to a maximum energy consumption of 88 MJ/m pipe. In the study the energy consumption is between 279-430 MJ/m. The difference is not explainable.

4.3.3.5 Judgement, Recommendation

The study is not fully transparent because data tables are missing. Calculation the energy use for PVC with given source leads to lower values, the differences is not explainable. At this moment the study is under actualisation, so the results might change in the future.

4.3.4 Ficu

Title: "Ökologischer Vergleich von Rohren aus verschiedenen Werkstoffen"; TU-Wien; Forschungsinstitut für Chemie und Umwelt; Juni 1996; Language: German only, 190 pages

Contractor: Local Government of Lower Austria

Goal and Scope definition							
Goal	1. LCA of drinking-water pipes for different diameters (DN 150 pressure 1 Mpa) 2. LCA of waste water pipes pipes for different diameters (DN 250 and DN 400)						
Material	Concrete	Concrete/ PVC	PVC	PEHD	Vitrified clay	Cast iron	Fibre-cement
Functional unit	1 m pipe						
Weight DN 250 [kg/m]	125	125-	6,6	7,2	51	38	24
Inventory analysis							
Data	• Representatives of all materials incorporated in a working group • Generally industry data from pipe-producers with market share in Lower Austria • PVC- and PEHD- granulate data from APME						
Energy	• Without feedstock energy • Generally regional situation of the producer regarded (especially for cast iron) • European data for PVC and PEHD incl. Precombustion						
Electr. Energymix	Regional situation (Austria or Europe (UCPTE)); Tyrol for cast iron						
Material Specifities	Austrian data		APME Data	APME data	Production in German	Energy mix Tyrol	Dutch data
Boundaries	Cradle to grave, without energy precombustion						
Life-time	Not included						
Regional Situation	Pipe producers representative for market in lower Austria						
Sensitivity analysis	Laying, Leakages, Distribution						
Not included flows	• Energy carrier production • Materials < 5 weight %						
Transport	Included, tapes of transport clearly documented						
Pipe-laying	As sensitivity analysis						
Use	Not included						
Disposal	• Different categories of recycling • Recycling also regarded at input (if relevant)						
Interpretation of the results							
Inventory Data	The results of the inventory were listed for • Waste • Energy • Emission in the Water and atmosphere						
Impact assessment	Selected classes of CML-Method • Global Warming Potential (GWP) • Photochemical Oxidant Formation (POCP) • Acidification Potential (AP) • Nutrification Potential (NP) • Human Toxicity Potential (HTP) Critical volumina						
Valuation	Included for all materials						

4.3.4.1 Results of the study

- No materials is to prefer against the others
- Cast iron pipes are in favour against plastics under the chosen condition
- The laying of the pipes is important to be analysed
- The leakage seems to be important for the results
- For PVC, PEHD, Concrete/PVC, Fibre cement and Concrete the raw material production dominates, pipe production plays a minor role
- Increased Recycling for PVC will reduce the environmental effects

4.3.4.2 General review

4.3.4.2.1 Positives

- The contractor is neutral
- Many different pipe materials (7) and different diameters (3) are analysed
- The whole life cycle is included
- The chosen impact assessment methods (CML, Critical volume) are generally acceptable, not all impact classes regarded
- The chosen goal (comparison of different Pipe producers representative for market in lower Austria) could be reached
- Data quality for the materials, except PVC and PEHD granulate, is still actual
- The importance of leakages and the laying is analysed in form of sensitivity analysis, but not considered material specifically

4.3.4.2.2 Negatives

- The energy carrier precombustion is not regarded
- There is no extern critical review
- The study is not representative for european (german) industry, as data are a mixture of regional and international data due to the market situation in lower Austria. For example the data for cast iron is from 1 Company in Tirol (Austria), for PVC, PEHD European data and for vitrified clay German data are used
- The regional view of the relevant pipe producers for Lower Austria leads to advantages for these materials (e.g. Cast Iron)

4.3.4.3 Positive aspects for plastics

- In the impact class global warming the emissions for plastics are in the same range as the emissions of cast iron and vitrified clay pipes, but lower than fibre cement

- There is a potential to reduce the emissions for plastics pipes by increasing the recycling input
- Improve in the position by use of new data for PVC and PEHD granulate ("*Eco Profiles of the European plastic industry, Report 6, Polyvinylchlorid, European Centre for Plastics in the environment, May1998"*)
- Looking at all products at international situation (for all materials international data with precombustion) might improve plastic results

4.3.4.4 Negative aspects for plastics

- Except Global warming potential (GWP) the values of plastics are worse than for the other materials at all diameters
- Due to the chosen data sources only for plastics (PVC granulate production) the emissions for precombustion are included
- Due to the Goal of the study (market situation of lower Austria) only one cast iron producer is analysed – this leads to advantages for cast iron pipes

4.3.4.5 Judgement, Recommendation

The study is acceptable but not fully in line with common method as no precombustion is included. Finally the results cannot be seen as representative for the materials but only valid for the regarded production chains (representative for the market in Lower Austria). The regional view of the pipes leads to advantages for these pipes especially cast iron pipes, which are under the chosen condition favoured.

4.3.5 Gastec

Title: “Environmental Life Cycle Assessment of Gas Distribution Systems”; Centrum voor Gastechnologoe (Gastec) and CML-S&P; The Netherlands; 1996; Language: English, 120 pages

Contractor: Dutch Centre of Gas Technology

Goaldefinition and Scope							
Goal	Environmental Life cycle Assessment of 2 Gas-supply Systems 1. 12,7 km Gas supply system (feeder system) 4 or 8 bar – **high pressure system** 2. 100 km Gas supply system (distribution system) 100 mbar – **low pressure system**						
Material	High pressure system				Low pressure system		
	Steel	PEHD 100	PEHD 80	PEX	Castr iron	PEHD 80	PVC
Functional unit	Pipe system (12,7 km and 100 km) for transport of 20.000.000 m3 Gas/a						
Weight [t/system]	207,9	77,7	124,3	77,1	1528	144	108
Inventory analysis							
Data	Dutch data preferred, otherwise ETH data						
Energy	Dutch data preferred, otherwise ETH data						
Electr. Energymix	Not documented, probably dutch data						
Material Specifities	20 % scrap – without environm. Effects	Dutch data	Dutch data	Dutch data manufact. in Sweden+ Germany	80 % scrap – without environm. effects	Dutch data	Dutch data
Boundaries	Cradle to grave, Source of scrap is not included						
Life-time	Generally 70 years, same for all materials, in sensitivity analysis 100 years for steel and cast iron assumed						
Regional Situation	Dutch						
Not included flows	No disposal						
Transport	Included						
Pipe-laying	Included						
Use	Included						
Disposal	Recycling after use is not included – pipes remain in the ground						
Sensitivity Analysis	• Gas leakage • Influences of the life spans • Changes in allocation factors • Boundaries – with and without recycling after use • Methodology – substance characterisation of unknown substances • The influences of auxiliaries • Dioxin appearance • Improvements for nodular irons • Data comparison PWMI:dutch data • Improvements of PEX						
Interpretation of the results							
Inventory Data	The effects were analysed after • Resource use • Energy use • Emission in air, water • Waste						
Impact assessment	CML Method • Ozone Depletion Potential (ODP)						

	• Global Warming Potential (GWP) • Photochemical Oxidant Formation (POCP) • Acidification Potential (AP) • Human Toxicity Potential (HTP) • Ecotoxicity Potential (ECA) • Nutrification Potential (NP) • Odour Threshold Limit (OTL) • Abiotic Depletion Potential (ADP)
Valuation	In detail included

4.3.5.1 Results of the study:

- For the high pressure system steel shows the highest values (with the exception of AP, ADP, ODP), followed by PE 80, the alternatives PE 100 and PEX has the lowest values.
- For the low pressure system cast iron has the highest (=worst) values, in distance followed by PE-80 and PVC. From these two materials PVC scores at best

Improvement analysis:

- Main option for improvement is the gas leakage.
- An improvement would be a decrease the system weight.
- An environmental improvement can be found by diminishing the use of pigments for plastics materials
- Pay attention to energy saving
- Produce pipe material close to the place where the pipes are applied

4.3.5.2 General review

4.3.5.2.1 Positives

- The contractor is neutral
- The whole life cycle is regarded
- The methodology is well documented but no data tables are included
- Dataquality for all materials is actual – in most cases ETH and dutch data
- The chosen impact assessment method is in compliance with ISO and very detailed documented
- External critical review is included
- Many sensitivity analyses were worked out (gasleakage, life span, data comparison,..)

4.3.5.2.2 Negatives

- The study represents only the situation in Netherlands

- The chosen functional unit is a distinct amount of transported gas per year through a given length, which reflects well the function of gas pipes
- Only one volume flow is analysed
- The sensitivity analyses shows that the chosen data for PVC and PE are higher than in other studies. For the other materials no comparison is worked out so the data quality could not be checked.

4.3.5.3 Positive aspects for plastics

- Plastics show the lowest environmental effects of the high and low pressure system
- The results of sensitivity analysis for a longer life time for steel and cast iron (100 instead of 70 years) are nevertheless better for PVC and PE than for steel and cast iron pipes
- Further environmental improvement is outlined by diminishing the use of pigments for plastics materials

4.3.5.4 Negative aspects for plastics

- The study represents the dutch situation. The used data don't seem to favour plastics, the effects on the other materials cannot be estimated
- In sensitivity analysis longer life time for steel and cast iron (100 years) than for plastics (70 years) was assumed.

4.3.5.5 Judgement, Recommendation

The study is conform to the commonly accepted method, actual and in compliance with ISO. But it represents only dutch gas pipes with special pressures. The functional unit is reasonable as based on the transport function of pipes.

The good results for plastics seem excellent for argumentation. Drawback is that the results are rather limited to gas pipes and focused on Netherlands.

4.3.6 Nordiska

Title: "Miljovurdering af aflobsror i PVC, PE, PP og Beton";
Nordiska Plaströrgruppen; August 1997; Language: English, 43 pages

Contractor: Nordic Plastic Pipe group

Goal and Scope definition								
Goal	Qualify the members of Nordiska Plastörgruppen to evaluate and commit qualified influences to other LCA, for this: Study of 2 gravity systems by comparing, one meter of sewage water pipes							
Material	Concrete D150	PVC D110	PP D110	PE D110	Concrete D250	PVC D250	PP D250	PE D250
Functional unit	System 1: One meter of pipe carrying the amount of sewage water equivalent to the capacity of a plastic pipe with inner diameter 104 mm over 50 years System 2: One meter of pipe carrying the amount of sewage water equivalent to the capacity of a plastic pipe with inner diameter 226 mm over 50 years							
Weight [kg/m] Diameter [mm] Length [m]	62,4 150 1,25	1,54 104 6	1,25 104 3	1,45 102 non rel.	116,7 250 1,5	4,78 226 6	3,65 226 6	10,7 222
Inventory analysis								
Data	Northern Europe							
Energy	Not documented							
Electr. Energy mix	Not documented							
Material Specifities	• same laying expenditure for all material • Concrete pipe (DN 150) in the DN 110 comparison							
Boundaries	ISO 14040, cradle to grave, Nordic guidelines, SETAC year 1995							
Life-time	50 years							
Regional Situation	Sewage pipes manufactured in the north and used in Denmark							
Not included flows	• fittings, wells, rainwater reservoirs • emissions of heavy metals and other toxic substances not included • data for extraction and refining of oil – for PVC, PE, PP • data for extraction of sand and gravel – for concrete							
Transport	Not transparent							
Pipe-laying	In relation with the pipe diameter but the same for all materials, time for excavation and refilling is proportional to filling material moved							
Use	Danish standard	Watertight	Watertight	Watertight	Danish standard	Watertight	Watertight	Watertight
Disposal	Pipes remain in the ground – no impact							
Sensitivity analyses	• Involvement of toxicity • Alternative stabilisers (substitution of lead in PVC) • Change of pipe diameter • Change of allocation in electricity production between heat and electricity • Norwegian production of electricity • Use of IVF method to study the working environment instead of the UMIP • Norwegian, swedish/finnish data for concrete production • Consequences of including sealing rings and wells in the analysis • Change of lifetime 50 to 80 years • concrete pipes supposed to be watertight • recycling: 50% recycling of used pipes • influence of impact assessment: CML-Method, Effect category (sweden long-term), EPS							
Interpretation of the results								
Inventory Data	In the summary the following results are documented as the most relevant ones • Energy							

	• Emission of CO_2, NOx, SO_2 in the atmosphere • Occupational diseases, occupational accidents *Results are shown in relation to the concrete pipe with + and -*
Impact assessment	• ECO-indicator 95 and UMIP (study of the working environment with a slightly modified method). Time horizon: 100 years • Working environment only included in production phase (not in the extraction of raw materials) *No figures are given*
Valuation	Included, but only qualitative

4.3.6.1 Results of the study:

- For system 1, PVC and PE are better or equal at all parameters, PP is better or equal at all parameters except SO2
- For system 2, PVC and PP are better or equal at all parameters except SO2 and energy. Only the smog parameters might favour concrete over PVC and PE in system 2. The PE pipe scores worse or equal except for diseases and accidents.

4.3.6.2 General review

4.3.6.2.1 Positives

- Many different materials are analysed
- A lot of sensitivity analyse was done

4.3.6.2.2 Negatives

- The contractor is the Nordic plastic pipe group
- Only qualitative analyses in form of + an – in relation to the concrete pipe is given
- Different diameters are compared because the function unit is defined with the transport capacity for plastics pipes of a defined diameter, so for concrete pipes larger diameters are necessary. Although the functional unit is correct, the use of plastic pipe as basis is not fair.
- Raw material chain not fully included (extraction and refining of oil are not considered)
- Only the materials which are common in Nordic states are considered
- No transparency because data tables are missing
- No critical review

4.3.6.3 Positive aspects for plastics

- PVC is in the most classes in favour against the others, but the extraction and refining of oil are not included and the functional unit is defined on the basis of plastic pipes
- Plastics would be improved if sealing rings and wells are included

4.3.6.4 Negative aspects for plastics

- There are no aspects discriminating plastics

4.3.6.5 Judgement, Recommendation

The study looks tendentious, the results favour plastic pipes clearly against concrete pipes, but this might be interpreted negatively as the method is questionable. The results are only in qualitative manner with no transparency, so the study should not be used to argue for plastic pipes.

If attacked because of tendentious results, the main focus on sensitivity, not on results can be argued.

4.3.7 Chalmers

Title:	"Life cycle assessment of wastewater systems"; Chalmers University of Technology; Göteborg; Sweden; 1997; Language: English, 147 pages
Contractor:	Swedish Environmental Protection Agency, Swedish Association of Water and sewage works and Swedish Association of Local Authorities

4.3.7.1 General review

This study consist of three parts, 2 studies with comparison of waste water treatment systems and 1 study with comparison of two sludge treatments

The goal of the study is lesser a comparison of pipes but more a comparison of different waste water and water treatment systems. PVC and PEHD pipes are also included in this systems comparison but not detailed analysed, only the raw material data from APME for PVC and PE plus the electrical use (4 MJ/kg pipe for each) were used for the calculation. No life cycle assessment and no comparison of different pipe materials was carried out.

4.3.7.2 Recommendation

As no detailed comparison of different pipe systems is presented in the study it cannot be used in our critical survey.

4.3.8 Geberit

Title: “Ökobilanz von Rohren zur Hausentwässerung”;
Geberit International AG; CH - 8645 Jona; 1998; Language: German, 36 pages

Contractor: Geberit International AG

Goal and Scope definition								
Goal	LCA for Pipes for soil and waste pipes for Product comparison and Discussion							
Material	Cast iron 100 % crude iron	Cast iron 100 % cast scrape	Fibre cement	PVC	Acrylnitril Butadien -Styrol-Pfropf-copolym. (ABS)	Poly-propylen (PP)	Poly-ethylen Geberit HDPE (PEHD)	Geberit Silent/db 20 (PE-S2)
Functional unit	1 m pipe, DN 100							
Weight [kg/m]	8,8	8,8	5,6	1,04	0,79	0,85	1,36	3,4
Inventory analysis								
Data	ETH 96	ETH 96	ETH 96 corrugated card board	Buwal 250 + ETH 96	High Impact Polystyrol (HIPS) instead of ABS	Buwal 250 + ETH 96	Buwal 250 + ETH 96	Buwal 250 + ETH 96
Energy	Seems from the amounts that Feedstock energy is included, but is not mentioned							
Electr. Energymix	generally UCPTE							
Material Specifities	high Energy for core pipe product.	high Energy for core pipe product.						
Boundaries	ISO 14040, cradle to grave							
Life-time	Not included, therefore the same for all materials							
Regional Situation	Europe, in some cases Switzerland							
Not included flows	• pipe-laying • use							
Transport	Included, except distribution of products							
Pipe-laying	Not included							
Use	Not included							
Disposal	100 % Recycl.	100 % Recycl.	100 % landfill.	100 % TVA as PVC	100 % TVA as PS	100 % TVA as PP	100 % TVA as PE	TVA and landfill.
Sensitivity Analysis	Not performed							
Interpretation of the results								
Inventory Data	The results of the inventory are listed for • Waste • Energy • Emission in the atmosphere • Emission in Water and ground							
Impact assessment	• Method of ecological scarcity (Buwal 297) • Eco-Indicator 95 • The significance of indirect (raw material production) and direct processes (pipe production) is shown for all Materials							
Valuation	Included in detail							

4.3.8.1 Results of the study:

- Plastic pipes and fibre cement pipes have lower impact on the environment than cast iron pipes. This result show the inventory data as well as the impact analysis

4.3.8.2 General review:

Positives

- Many different pipe materials are analysed
- The boundaries are well documented
- The whole life cycle is included, except distribution of products and use
- The data quality for plastics is good, it is comparable with other studies and representative for industry

Negatives

- The contractor is Geberit itself
- Only one diameter (DN 100) was analysed
- The data for fibre cement (corrugated card board) are maybe not of equivalent quality
- Data used for cast iron is not transparent – Data source is ETH 1996 as in EMPA, but the results for cast iron in EMPA are better
- The results for the cast iron pipe production are much higher (mainly SO2 and NOx emissions) than in other studies
- Only one process (core casting) assumed for cast iron production, this does not reflect the European situation
- The data tables show only a summary of the results no detailed information
- No external critical review
- Not all applied impact assessment methods are in compliance with ISO
- The chosen impact assessment methods are dominated by the emissions of SO2 and heavy metals, Materials with high emissions at this parameters (cast iron) have disadvantages.

4.3.8.3 Positive aspects for plastics

- Better results for plastics pipes than for cast iron pipes
- The data for cast iron are despite assumption of 100 % cast scrap very high
- Only one technology for cast iron pipe production (core-casting) is considered, this is probably not reflecting the european situation. The emissions of cast iron pipes along the whole life cycle result mainly from pipe production.

- The weight for plastic pipes (for example PVC in Geberit 1,04 kg/m pipe and 1,59 kg/m in Clausthal) is much lower than in other studies, so less material input is necessary. The reason for the difference between the weights is that the Clausthal study considers pipes outside the house whereas in the Geberit study soil and waste pipes (inside the house) were analysed.

4.3.8.4 Negative aspects for plastics

- There is a potential to reduce the emissions for plastic pipes by regarding of material recycling instead of 100 % incineration – this will reduce the resource Input and the emissions of burning

4.3.8.5 Judgement, Recommendation

The study is acceptable and generally actual, but the used data for cast iron pipes seem not to represented the average european situation (only one technology for the cast iron pipe production, ..). The high emissions for cast iron pipes influence not only the results for that material but also the comparison of the pipes. Before arguing for plastics with that study the real situation of cast iron pipe production in europe should be looked at. At this moment the study is under actualisation, so the results might change in the future.

4.3.9 EMPA

Title: "Ökobilanz von Rohrleitungssystemen"; Eidgenössische Materialprüfungs- und Forschungsanstalt – EMPA; St.Gallen; März 1998; Language: German, 130 pages

Contractor: Society of german chemical industry in cooperation with the plastic- and vitrified clay pipe association

Goal and Scope definition						
Goal	Eco balance for pipe systems, documented for drinking water network incl. house connections sewer network inc. lateral, both with ancillaries in small village					
Material	Drinking Water PEHD	Drinking Water PVC-U	Drinking Water Cast iron	Waste water PEHD	Waste water PVC-U	Waste water Vitrified clay
Functional unit	280 m of a DN 200 pipe system for drinking water supply and waste water					
Weight [kg/m]	13,3	11,1	30,2	7,8	7,6	19,9
Inventory analysis						
Data	Europe	Europe	Germany	Europe	Europe	Germany
Energy	Feedstock energy is included and separately documented					
Electr. Energymix	General UCPTE (ESU ETH 1994) different mix for each country, especially Germany					
Material Specifities	Not performed					
Boundaries	ISO 14040 , cradle to grave					
Life-time	Included in sensitivity analysis					
Regional Situation	One Housing area in Germany					
Not included flows	• Main-sewer • Materials < 5 weight %					
Transport	Included					
Pipe-laying	Included, Beyert 1995/EMPA					
Use	Not included					
Disposal	Pipes remain in the ground, no impact					
Sensitivity analysis	• PVC-U with 50 % Recyclate • Depth of Pipe-laying • Pipe-laying in ground water area • Life-time					
Interpretation of the results						
Inventory Data	The results of the inventory are listed for • Waste • Energy • Emission in the atmosphere • Emission in water and ground					
Impact assessment	Selected classes of CML-Method • Energy • Global Warming Potential (GWP) • Acidification Potential (AP) • Nutrification Potential (NP) • Waste					
Valuation	Detailed included, for the selected classes					

4.3.9.1 Results of the study:

- No material is to prefer against the others
- Raw material chain is important for most materials, especially material for the shafts
- For all drinking water pipes raw material chain dominates compared with pipe production
- The Global Warming Potential is very important for all materials especially cast iron
- More recycling can reduce the environmental effects of PVC

4.3.9.2 General review

4.3.9.2.1 Positives

- The contractor is neutral
- Complete pipe system (included, shafts, ...) is analysed
- The whole life cycle is included, the boundaries are well documented
- Data for all materials is actual – in most cases european data used, for cast iron and vitrified clay german situation
- Many sensitivity analysis (pipe laying, recycling,...) are done
- External critical review exercised

4.3.9.2.2 Negatives

- Only one diameter is analysed (DN 200)
- Only 5 classes of CML Method (Energy, Waste, GWP, AP, NP) are analysed
- The analysed pipe system is only a case study and so not representative for all pipe systems

4.3.9.3 Positive aspects for plastics

- The environmental effects for plastics are medium
- In the impact class global warming the emissions of plastic-pipes are lower than the emissions of cast iron and vitrified clay pipes
- There is a further potential to reduce the emissions for plastics pipes by increasing amounts of recycling material as input
- Significant potential to improve the results for plastics by use of new APME data ("*Eco Profiles of the European plastic industry, Report 6, Polyvinylchlorid, European Centre for Plastics in the environment, May1998")*

4.3.9.4 Negative aspects for plastics

- In the impact classes Eutrophication and Acidification the emissions for PVC and PEHD are higher than the emissions of cast iron and vitrified clay pipes

4.3.9.5 Judgement, Recommendation

The study is from a neutral institution with accepted and transparent methodology, mostly in compliance with ISO and generally actual for European pipe systems. The environmental effects of plastics are medium, so the study can be used to argue the midfield position of plastic pipes against other materials from ecological point of view.

The study is an example that the results are definitely influenced by the case, the assumed configuration of the pipe systems

5 Conclusion

The conclusion consists of three parts

- survey on the characteristics of the investigated studies and derived arguments
- comparative assessment of the studies for the given purpose
- cross comparison of the results of the analysed materials

5.1 Survey on the characteristics of the studies

The first part is performed with a table showing the characteristics of the single studies, in which the following essential aspects are briefly summarised for each study:

- Year of publication
- Language, number of pages
- Analysed materials
- Functional unit - pipe specification
- Results
- General review of the study
- Arguments pro plastics
- Arguments contra plastics and discriminating aspects
- Recommendation

Cross-comparison of the characteristics of the investigated studies

	KIWA	**Clausthal**	**Intron**	**FICU**	**EMPA**	**Geberit**	**Nordiska**	**Gastec**
Year of publication	1992	1995	1995	1996	1998	1998	1997	1996
Language	Dutch, 112 pages	German, 31 pages	Dutch, 30 pages	German, 190 pages	German, 130 pages	German, 36 pages	English, 43 pages	English, 120 pages
Contractor	VEWIN Association of Waternet operators in Netherlands	European Association of vitrified clay pipe producers	VPB Woerden - Association of Concrete Producers	Local Government of Lower Austria	Society of german chemical industry in cooperation with the plastic- and vitrified clay pipe association	Geberit	Nordic Plastic Pipe group	Dutch Centre of Gas Technology
Analysed Materials	• Fibre cement • PVC • Cast iron • Steel • Glasfiber Polyester • (GFP) • Glasfiber Epoxy (GFE)	• PVC • PEHD • vitrified clay • ferro/concrete • concrete • cast iron	• Concrete • PVC kl.34 • PVC kl.41 • PVC 3 layers • Vitrified clay	• Concrete • Concrete/PVC • PVC • PEHD • Vitrified clay • Cast iron • Fibre-cement	• PEHD • PVC-U • Cast iron • Vitrified clay	• Cast iron • Fibre cement • PVC • ABS-Pfropf-copolymer • PP • PEHD • Geberit Silent/db 20	• Concrete • PVC • PP • PE	• Steel • PEHD 100 • PEHD 80 • PEX • Cast iron • PVC
Analysed Pipes	Sewer pipes Length 100m, DIN 100mm, Press. 1 MPa	Sewer pipes DN 100, 150, 300, 500 per m Pipe system (55 m DN 100 and DN 150)	Rain water or waste water system (1 km length) DN 300	Drinking-water pipes pressure 1 Mpa, DN 150 Sewer pipes DN 250 and DN 400	Drinking and waste water pipe systems, for housing areas DN 200	1 m pipe for soil and waste DN 100	Sewage water pipes DN 110, 150	Gas pipes for high pressure (4 or 8 bar) and low pressure (100 mbar) systems

Cross-comparison of the characteristics of the investigated studies (cont.)

	KIWA	Clausthal	Intron	FICU	EMPA	Geberit	Nordiska	Gastec
Results	• PVC is in good position • Cast iron and steel show highest energy consumption	• For small diameters (DN 100, DN 150) advantages for PVC and vitrified clay • For larger diameters (DN 300, DN 500) concrete has advantages • By using different life times vitrified clay has the best results	• Concrete has the best results in all analysed impact classes • Pipe laying is important for POCP and Energy consumption	• No material is to prefer against the others • Laying and leakage can be important • For plastics the raw material production dominates	• No material is to prefer against the others • Raw material chain is important	• Plastic and fibre cement pipes are better than cast iron pipes	• Plastics are better or equal at all parameters against concrete, except SO2 • PE pipe scores worse or equal except for diseases and accidents	• For the high pressure system steel shows the highest values • For the low pressure system cast iron has the highest (=worst) values • Gas leakages are important emissions
General Review	• Only energy consumption quantitatively analysed • Important stages in the whole life cycle of each material identified • Goal (comparison) is not arrived • No data tables, the results are not checkable	• Contractor is not neutral • Data quality for all materials is good • No impact assessment • Some assumptions are not fully transparent	• Contractor is not neutral • No data tables • The results are not checkable • Energy demand for PVC is very high, reason not transparent • Only parts of impact assessment • not representative for european industry	• Contractor is neutral • Not representative for european industry • Goal (relevant pipe producers for Lower Austria) leads to advantages for Cast Iron	• The contractor is neutral • Complete pipe system is analysed (shafts included) • The whole life cycle is regarded, the boundaries are well documented • Many sensitivity analyses • The analysed pipe system represents only one case	• The contractor is Geberit himself • Cast iron data are not transparent • Only one process (core casting) for cast iron production • Only a summary table of the results • The chosen impact assessment methods are dominated by the emissions of SO2 and heavy metals	• Contractor is not neutral • Functional unit is defined on the basis of plastic pipes • Only qualitative analyses (+ and – in relation to concrete) • Raw material chain not fully included • No transparency because data tables are missing	• Neutral contractor • Accepted methodology, in compliance with ISO • Full impact assessment • Functional unit reflects function of gas pipes • Not representative for pipes in general • Focus on dutch situation

Cross-comparison of the characteristics of the investigated studies (cont.)

	KIWA	Clausthal	Intron	FICU	EMPA	Geberit	Nordiska	Gastec
Pro Plastics	• The study favours PVC • The energy use for PVC-pipes is together with the GFP–pipe at the second place	• For small diameters (DN 100, DN 150) advantages for PVC and vitrified clay • Lower CO2 emissions for plastics than for cast iron and vitrified clay pipes	• No positive aspects	• GWP is similar as cast iron and vitrified clay • Potential to reduce the emissions with more recycling • Reduction potential by use of new data for PVC granulate	• Emissions for Plastics are medium • At GWP plastics are better than cast iron and vitrified clay • Potential to reduce the emissions by more recycling • Potential to improve by use of new APME data	• Better results for plastic pipes than for cast iron • The weight for plastic pipes is much lower than in other studies, but the reason is documented • Potential to reduce the emissions by more recycling	• Plastics are in the most classes in favour against the others	• Plastics show the lowest environmental impacts for the high and low pressure system
Contra Plastics	• No discriminating aspects	• NOx emissions for plastics score highest • Decomposition was included • Life time for plastics only 50 years • Cast iron pipes 90 % cast scrap • For larger diameters (DN 300, DN 500) concrete has advantages • By using the various life times vitrified clay has the best results	• No strong points for plastics • Worst results for plastics in all classes • The energy demand is very high, this is not explainable	• Except GWP the values of plastics are worse than the others • Only for plastics precombustion is included • Only one cast iron producer	• At Eutro- and Acidification plastic pipes are worse than cast iron and vitrified clay	Results are rather positive	Positive results	• The used data don't seem to favour plastics • Longer life time for steel and cast iron

Cross-comparison of the characteristics of the investigated studies (cont.)

	KIWA	Clausthal	Intron	FICU	EMPA	Geberit	Nordiska	Gastec
Recommendation	The study identifies important stages in the life cycle. But no figures so data are not checkable, rather outdated	The study is respectable from methodology and data sources. Despite some discriminating assumptions, the position of plastics is in the midfield. For this reason this study can be taken to argue against other pipes.	The study is not fully transparent and not neutral. Calculation of the energy use for PVC with given source lead to lower values, the differences is not explainable. At this moment the study is under actualisation, so the results might change in the future.	The study is acceptable but not fully in line with common methodology as no precombustion is included. Finally the results cannot be seen as representative for the materials but are valid only for the regarded production chains (representative for the market in Lower Austrian).	The actual study is from a neutral institution, exercised with accepted and transparent methodology, mostly in compliance with ISO. The environmental effects of plastics are medium, so the study can be used to argue the midfield position of plastic pipes against other materials from ecological point of view.	The study is acceptable from methodology and actual, but the used data for cast iron pipes does not seem to represent the average European situation. Before arguing for plastics with that study the real situation of cast iron pipe production in Europe should be investigated. At this moment the study is under actualisation, so the results might change in the future.	The study looks tendentious, the results favour plastic pipes clearly against concrete pipes, but this might be interpreted negatively as the method is questionable. The results are given only in qualitative manner with no transparency, so the study should not be used to argue for plastic pipes.	The study is conform to the commonly accepted method, actual and in compliance with ISO. But it represents only Dutch gas pipes with special pressures. The functional unit is reasonable as based on the transport function of pipes. The good results for plastics seem excellent for argumentation. Drawback is that the results are rather limited to gas pipes and focused on Netherlands.

From that table the essential conclusions and the arguments pro and contra plastics were extracted and outlined hereunder. For each argumentation the studies from which it was derived are indicated in the brackets.

- The CO2 emissions and the "Global Warming" effects of plastic pipes are in good or in medium position in comparison with other materials (Geberit, EMPA, Clausthal; FICU, Gastec)
- Increased recycling offers a potential for further reduction of the emissions of plastic pipes (FICU, EMPA, Geberit)
- Use of actualised APME data would decrease the values for PVC (FICU, EMPA)
- Generally small diameters (DN 100, DN 150) show better results for plastic pipes than bigger diameters (Clasuthal, EMPA, Geberit)
- The impact classes "Nutrification" and "Acidification" show clear disadvantages for plastic pipes, they result from SO_2 and NO_x-emissions (FICU, EMPA, Clausthal) - only SO_2 emissions would decrease by use of actual data.
- The raw material production chain is the most important stage along the life cycle of plastic pipes (FICU, EMPA, Geberit)
- Pipe laying (FICU, KIWA, EMPA) and leakages (Geberit, FICU) have also significant importance along the whole life cycle for sewer pipes and gas pipes.

5.2 Comparative assessment of the studies

In the second part the performance of the single studies was assessed for the aspects listed below.

- Actuality of the study
- Contractor
- Methodology
- Analysed materials
- Data quality
- Regional aspects
- Results of plastics
- Impact assessment
- Recommendation

The assessment was done with a structured quality ranking method. For each aspect 1 to 5 points could be gained, one point for the worst case and 5 points for the best case. It was tried to find distinct quality steps as best as possible, which are explained in the table below.

	Gastec	EMPA	Clausthal	FICU	Geberit	Nordiska	KIWA	Intron
Actuality	5	5	3	3	5	3	1	3
Contractor	5	3	1	5	1	1	3	1
Analysed materials	3	3	5	5	5	3	5	1
Methodology	5	5	3	3	3	3	1	3
Data Quality	5	5	5	5	1	1	1	1
Regionality	3	5	5	1	3	1	1	1
Results for plastics	5	3	3	1	5	5	3	1
Impact assessment	5	3	3	3	3	1	1	3
Recommendation	5	5	5	3	1	1	1	1
sum	*41*	*37*	*33*	*29*	*27*	*19*	*17*	*15*

Summary of the characteristics of the single studies

Actuality:
1 before 1995
3 1995-1997
5 1998-

Contractor:
1 not neutral
3 seems neutral
5 neutral institution

Analysed materials:
1 1-3 different materials
3 3-5 different material
5 > 5 different materials

Methodology
1 important parts are missing
3 generally o.k., 1 m pipe
5 whole pipe system

Data Quality
1 not documented
3 good documented or actual
5 data good documented and actual

Regionality:
1 regional situation only valid for that region
3 regional focus but generally valid
5 situation in Europe for all materials

Results for plastics
1 bad results
3 medium results
5 good results

Impact assessment
1 only qualitative done
3 only parts of impact assessment
5 complete impact assessment

Recommendation
1 don't use it
3 some aspects to argument for plastics
5 very good to argument for plastics

As the table shows three studies are excellent to argue for plastics (Gastec, EMPA, Clausthal). The *Gastec* study has highest ranking for most of the aspects, only the aspect „Analysed materials“ (only gas-pipes) and the regionally (Dutch situation) shows some drawbacks. Due to its high compliance to ISO and the accepted methodology it can be seen as the source of highest magnitude to claim good results for plastic pipes (limited to gas pipes).

Also the *EMPA* study is a good basis for argumentation. The results for plastics are medium so the midfield position of plastics with other materials from ecological point of view can be argued. The *Clausthal* study shows also medium results for plastics despite of some discriminating assumptions for plastics. So this study can be taken as an illustration of the ecological midfield position of plastic pipes even under disfavouring conditions.

The FICU study has disadvantages for plastics as the framework of the study reflects the situation of the market in Lower Austria. This regional situation has a decisive influence on some materials so that the results cannot be seen as specific for the materials but specific for the products on Lower Austrian market.

Despite some positive scores for plastics, the other studies (Geberit, Nordiska, KIWA, Intron) are not recommended for argumentation for the following reasons:

- data quality is not transparent, moderate or insufficient (Nordiska, KIWA, Intron)
- impact assessment is only qualitative or insufficient (Nordiska, KIWA, Intron)
- important stages along the life cycle are not included (KIWA)
- or the contractor is not neutral (Geberit, Nordiska, Intron).

5.3 Qualitative cross comparison for the results of the analysed materials

As a complementary analysis the results of all materials which were investigated in the different studies are listed in a qualitative way, to summarise the differences in the statements for the materials. The assessment was done with a three level ranking method. The results for the materials in the studies were qualified from "+" to "+++", blanks indicate no investigation of the material in the respective study.

	KIWA	CLAUS-THAL	INTRON	FICU	EMPA	GEBERIT	NORDISKA	GASTEC
PVC	+++	++	+	+	++	++	+++	+++
PE		++		+	++	+++	+++	+++
PP						+++	+++	
PEX								+
ABS						+++		
GRP	++							
CAST IRON	+	++		+++	++	+		+
CONCRETE		+++	+++	+++			+	
CLAY		+++	++	++	++			
FIBRECEMENT	++			++		++		
STEEL	+							+

Qualitative cross check of the results of each material

+ bad results
++ medium results
+++ good results

As the table above shows the variation of the results of each material is mostly high. PVC shows good (in two studies) and bad results (also in two studies) as well – a general tendency to medium environmental characteristic can be seen. The same tendency can be stated for vitrified clay and cast iron. Rather bad results are visible for steel, only good results for PP, but this materials was analysed in only two studies, which are rather favouring plastics. Only the concrete pipe has a dominance of good results (3 studies) and only one with study bad results.

6 List of Abbreviation

AP	Acidification Potential
ADP	Abiotic Depletion Potential
BUWAL	Bundesamt für Umwelt, Wald und Landschaft
CML	Centre of Environmental Science in Leiden
ECO Method	Ecological Scarcity Method
EPS Method	Environmental Priority Strategies in Product Design Method
ETH Method	Environmental Theme Method
ECA	Ecotoxity Potential
GWP	Global Warming Potential
HTP	Human Toxicity Potential
LCA	Life Cycle Assessment
MAC	Maximum Imission concentration
NP	Nutrification Potential
OTL	Odour Threshold Limit
POCP	Photochemical Ozone Creation potential
R	Total Consumption of fossil raw material
RIVM	Dutch national Institute for Health and Environment
UCPTE	Union pour la co-ordination de la production de lelectricite
VMCI	Association of the Dutch Chemical Industry