Urban Development
Princetonlaan 6
3584 CB Utrecht
P.O. Box 80015
3508 TA Utrecht
The Netherlands

www.tno.nl

T +31 88 866 42 56
F +31 88 866 44 75
infodesk@tno.nl

TNO report

TNO-060-UT-2011-001432

Environmental impact of different funeral technologies

Date	8 August 2011
Author(s)	E.E. Keijzer, MSc H.J.G. Kok, MSc
Number of pages	88 (excl. appendices)
Number of appendices	5 (A t/m E)
Sponsor	Yarden Holding BV Almere
Project number	034.24026

Summary

Yarden is a large and rapidly growing funeral organization in the Netherlands. The organization has nearly 1 million members. With 41 funeral homes, 22 crematoria and 7 cemeteries Yarden has a national distribution and coverage. Yarden wants to take account of environmental constraints and preferences. In this context Yarden follows new developments and invests in them. Yarden plans to introduce two new funeral techniques: cryomation and Resomation.

The Dutch law on funeral services provides in three destinations: burial, cremation or making available to science. To allow the two new funeral techniques an amendment to the law will be necessary. Before a proposal to amend the law will be set up, the Ministry of Interior Affairs will need a report with a solid foundation for the legalization of the new techniques.
As first step Yarden asked TNO to analyse the environmental impact (eco-footprint) of the 4 funeral techniques (burial, cremation, cryomation and resomation) through a Life Cycle Assessment (LCA). The Dutch version of this study has been peer reviewed and complies with the ISO standards on Life-Cycle Assessment [ISO, 2006].

For conducting the environmental study process data required for burial and cremation have been collected by Yarden itself. For these techniques, the average situation in the Netherlands and current state of the technology has been assumed. For the two new techniques, the process data were provided by Cryomation Ltd. and by Resomation Ltd. The new techniques have been considered as if these were already fully operational and integrated in the Dutch funeral sector.
The drafting of the eco-footprint is based on determining the environmental impact of a funeral based on a LCA according to the CML-LCA2 methodology. Under this method, the impacts of emissions on 11 different environmental impact categories are calculated in equivalents for an important substance in that category (impact unit).

The environmental impact for a funeral type is determined using the computational software tool SimaPro (version 7.2) and the Ecoinvent database (version 2.1). The Ecoinvent database contains environmentally relevant information for various types of processes and materials. The calculated results for each impact category has a different unit, so the differences between funeral types can in principle only be compared for each impact category separately.

Comparing the LCA results for the different environmental impact categories leads to following conclusions for the four funeral options:

- cryomation and resomation have the lowest environmental impact in all categories, except for eutrophication where resomation has the highest impact of all options;
- burial has the highest environmental impact in all the impact categories, except for eutrophication;
- consequently, cremation has in all categories an environmental impact that is somewhere in between the other options.

These results lead to the expectation that the total environmental impact of the funeral options is the highest for burial and the lowest for resomation or cryomation with cremation in between.

For a more quantitative statement about the overall environmental impact of four types of funeral the shadow price method is used. As the market environment is a virtual marketplace and the cost of the environment falls under the so-called external costs, the government must establish emission targets for the quality of the environment. The ‘shadow price’ for a specific impact category is the amount of money society is willing to pay for the reduction of these effect-causing emissions per unit of impact (for most impact categories, this unit is one kg of equivalent emission (eg. per kg SO2 equivalents for acidification).
The advantage of using shadow prices is that different environmental impacts can be expressed as (external) costs. Addition of the shadow costs for all the different environmental effects of a polluting activity (product or service) over its lifetime gives the total environmental costs of the activity (monetization of environmental impacts). In this way the environmental impact of a specific activity can be reduced by implementing cost-effective emission reduction measures at (other) activities that have the same reduction of environmental impacts as caused by the specific activity. Using this monetization method, alternative processes can be compared based on their total environmental costs over the life of the activity and, if relevant, per year.
This part of the study is outside the requirements of the ISO-standard, because weighting of impact categories is introduced.
The result of the calculations based on the shadow price method is shown in figure S1 for the four funeral options.

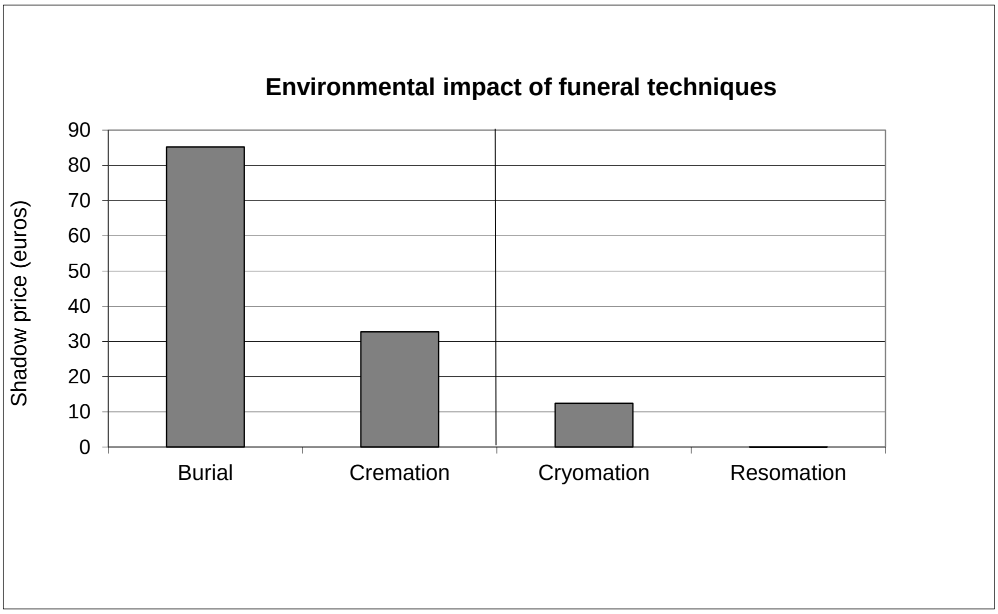

Figure S1 - Shadow costs for the existing funeral techniques burial and cremation and the new funeral techniques cryomation and resomation

The total impact (expressed as shadow price) for the four funeral techniques is between around 0 Euros per body for resomation and approximately 85 Euros per body for burial. Both other funeral options are in between: about 30 Euros for cremation and about 10 Euros for cryomation.

For burial, land use is the impact category with the largest contribution (52 Euros), followed by human toxicity (10 Euros) and global warming (9 Euros). Land use is also the largest impact category for cremation (14 Euros). Second contributor is eutrophication (7 Euros) and human toxicity (5 Euros). For cryomation, land use (10 Euros), eutrophication (4 Euros) and global warming (2 Euros) have a large contribution. The results for resomation are dominated by eutrophication (10 Euros) and the large negative values for human toxicity (-7 Euros) and global warming (-1.5 Euros).

Funeral options other than burial are largely determined by compensating effects from metal recycling, especially for cryomation and resomation. These funeral options offer better possibilities for recycling of valuable metallic remains, which would otherwise disappear with the remains, going into soil, water and air. For cryomation and resomation also small amounts of precious metals can be separated from the remains and recycled leading to bonuses compensating part of the environmental impact.

To get an indication of the (un)certainty of the results, sensitivity analyses have been carried out for the destination of the remains, composition of the waste water, use of utilities in the processes, type of cryomation burial monument, assumptions for metal recycling and the composition of the coffin.
Considering the results of all sensitivity analyses it can be concluded that the assumed variations in the processes do not change substantially the general conclusions according to the original impact calculations for the base scenario. It has become clear though that the coffin type is determining the extent of the difference in environmental impact between cremation on the one hand and the new techniques cryomation and resomation on the other. Furthermore the shadow costs for resomation, which are around zero in the base scenario after adding up the positive and negative environmental aspects, are very sensitive for the data used regarding recycling and the amounts of resources used.

The general conclusion on the environmental impact of the four funeral options is that the total environmental impact is highest for burial followed by cremation. The impact of cryomation and resomation is much lower than for burial and cremation. The impact of resomation is (probably) lowest of all funeral options.

With these results it should be realised that, independent of the applied technique, some funeral preparations take place (pre-phase) which also contribute to the environmental impact. These include the preparation of the body (including chilled exposition), sending the funeral cards and invitations, and the farewell ceremony itself (e.g. use auditorium, transport of guests and coffee). This pre-phase is not part of the study, but a preliminary calculation showed that the environmental impact of the pre-phase, expressed as shadow costs, is much larger than the four burial techniques themselves (about 220 Euro per pre-phase per body).

From this study it is concluded that further development and application of the new funeral technologies (cryomation and resomation) can lead to a reduction of the environmental impact of funeral services in the Netherlands. The environmental impact of energy use in these techniques is largely compensated by the benefits of recycling of scrap metals. For the current techniques the average Dutch situation is assumed. To which extent the ‘best practice’ is more environmentally friendly than the average and how much room for improvement is left, could be researched in a separate study. The ethical aspects of applying the various techniques are not considered in this study.

Contents

1 Introduction

Yarden is a large and rapidly growing funeral organization in the Netherlands. The organization has nearly 1 million members. With 41 funeral homes, 22 crematoria and 7 cemeteries Yarden has a national distribution and coverage. Yarden wants to take account of environmental constraints and preferences. In this context Yarden follows new developments and invests in them. Yarden plans to introduce two new funeral techniques: Cryomation and Resomation.

The Dutch law on funeral services provides in three destinations: Burial, cremation or making available to science. To allow the two new funeral techniques an amendment to the law will be necessary. Before a proposal to amend the law will be set up, the Ministry of Interior Affairs will need a report with a solid foundation for the legalization of the new techniques.

As a first step Yarden asked TNO to assess and analyse the environmental impact (eco-footprint) of the 4 funeral techniques (burial, cremation, cryomation and resomation). Social and economic aspects have not been considered in this report.

In this report the results of the environmental assessment of the 4 funeral types are presented.

Chapter 2 describes the exact goal and scope of this study.

In chapter 3, the method used for determination of the eco-footprint is elaborated. This is based on determining the environmental impact of the life cycle of the realization of a funeral technique based on a Life Cycle Assessment (LCA) according to the CML-LCA2 methodology.

Chapter 4 deals with the activities during the life cycle of the funeral techniques. Furthermore chapter 4 contains references to the data sources and discusses a number of key assumptions.

In Chapter 5 the results of the calculations are presented, analysed and discussed. For comparison of the total environmental impact of the funeral techniques the shadow price method is used.

In Chapter 6 the conclusions about the comparison of the environmental impact of the 4 funeral techniques are given.

2 Methodology

2.1 Goal

The goal of this study is to compare four different funeral techniques in terms of environmental impact during all phases of the realization of these techniques. This report is primarily made for the commissioner, Yarden. Yarden is planning to use the results of the comparison to investigate the opportunities to introduce two new funeral techniques in the Netherlands. Also, the commissioner wants to be able to use the report to support a proposal for law adjustment. Therefore the results of this research are presented in a form readable to both expert and layman.
Before this report is made public, the Dutch version of this report[1] has been reviewed according to the ISO 14040 and 14044 standards [ISO, 2006] regarding the following: methods, data, assumptions, interpretations, argumentation and overall transparency and consistency.
This review has been performed by:
- Harry van Ewijk (IVAM UvA)
- Bart Krutwagen (CE Delft)

For confidentiality reasons some underlying data are not included in this report. These data were yet available to the reviewers.

2.2 Scope

Functional unit
To enable a fair comparison of the four techniques, it is necessary to bring each of the alternatives under a common denominator. This is done by defining a so-called functional unit, which describes in an unambiguous, quantitative way the function the techniques fulfill.
The functional unit in this research is defined as the treatment of the mortal remains of one average deceased in the Netherlands.
The term ‘average deceased’ implies that averages have been taken for all variables, and that extremes were excluded. Examples of variables are: body weight, required coffin size, number of prostheses and teeth inlays. The exact composition of the average is included in Appendix C.

Product system
Distinction is made between the activities taking place from the moment of decease up to the ceremony (preparation phase) and the practice of one of the funeral techniques (realization phase). This research describes the realization phase.
In the preparation phase the relatives of the deceased undertake a number of actions. The most important being the preparation and (cooled) laying out of the deceased, the preparation of the farewell ceremony and the ceremony itself. Environmental effects that follow from these steps are related to, for example, the production of paper for the mourning cards and the emissions resulting from the transportation of the relatives and guests to the ceremony. All of these activities have been excluded from the scope of the study. Conversely, the production of the

---

[1] Keijzer, E. and H.J.G. Kok (2011). *Milieueffecten van verschillende uitvaarttechnieken.* TNO report TNO-060-UT-2011-01366-vs2, Utrecht: TNO.

coffin and transport of the remains (for example after cremation, to the final resting place) are included in the scope. The materials and processes involved are necessary for the realization phase and can be different among the funeral techniques.
The funeral techniques to be assessed are burial, cremation, cryomation and resomation. Figure 1 shows an outline of the most relevant process steps in the chain of activities for the four techniques. Chapter 4 describes the details in a systematic way.

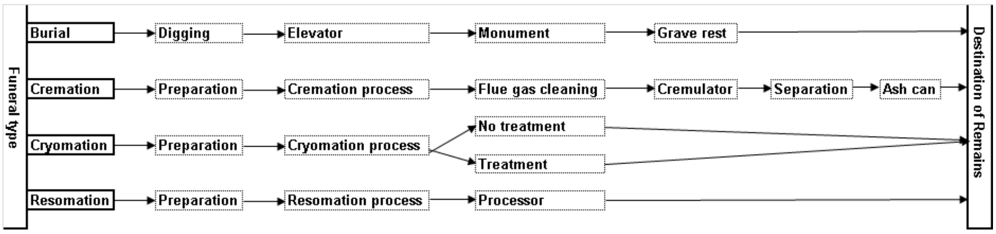

Figure 1 – System outline with process steps in the life cycle of the four funeral techniques

In all cases the subject of study is the funeral of an *average* deceased person in the Netherlands. Furthermore the average current situation is taken as a starting point, meaning that exotic materials or processes such as coffins of special materials or extremely energy efficient cremation ovens were not considered.

System boundaries
In the light of the goal to compare funeral techniques, the four systems are considered in a generic way. Studying the variations within one technique is not a goal by itself. Just the most common options within each funeral technique were included.
In chapter 4 and appendix C more detail is provided about the system boundaries per phase / process step and depth of study. In short, this research considers the funeral process that the deceased undergoes, not the activities preceding that. Not included are for example laying out of the deceased (cooled), the farewell ceremony and transportation of guests. Items that are included are all processes and materials that are directly related to the treatment of the deceased. For cremation those are e.g. the coffin, heating of the oven, transport of ashes to an ash scattering location and the recycling of implant metals.

In determining the environmental relevance of metals it is essential to discriminate between processes that take place in the life of the deceased and processes that are inextricably bound to the funeral. The manufacture of dentures and prostheses are outside the scope of this research, because it has not taken place for the funeral. Still recycling of these materials is inside the scope.
As a system, cremation, cryomation and resomation are well comparable, because in essence all three funeral options are machine based processes with inputs and outputs. The key parameters are common as well, such as energy consumption and soil contamination as a result of ash scattering. Burial is a completely different process: a number of preparatory steps are needed (see figure 1 and chapter 4) and the key parameters are different. To be able to make a fair comparison, the system analysis has been made as broad as possible, and all process steps have been considered in detail, where relevant.

For the system boundaries a so-called third order approach [Goedkoop et al., 2008] has been adopted, This means that not only materials (first order) and processes (second order) have been taken into account in the environmental impact calculations, but also the production and disposal of capital goods (third order processes). The structure of the used background database, Ecoinvent, is attuned to this approach. In effect, all necessary materials and processes that have any significance are inside the system boundaries of this study. This includes the material of the process equipment and the land occupied by the (collective) bone grave.

Allocation procedures

An important activity in making LCA-based environmental comparisons is allocation. Allocation is the procedure of attributing inputs and outputs to a certain process. Production processes may deliver multiple products, and a choice has to be made on which grounds the environmental impact associated with this process is divided over the outputs. In the background database in many cases allocation has already taken place; if applicable the outcome has been adopted in this study. In a number of specific cases and a generic one, an explication is justified. The specific allocation issues (e.g. how to attribute land use to multiple persons in a grave) are generally solved by using averages (in this example: land use per deceased = area occupied by the grave divided by the number of persons in the grave). Allocation procedures like this are discussed in appendix C.

A more general case is the allocation procedure for recycling. For funeral techniques, the recycling of metals has a large influence on the environmental impact. Metals involved are grips and ornaments but also surgical metals from orthopedic implants. Several methodologies can be followed to address recycling in LCAs. In the present study an environmental benefit or credit has been granted to ‘keeping metals in the loop’. To that end, the environmental impact of the original production is effectively given back after recycling. The underlying line of reasoning is that the amount of primary material the next user of the recycled material has to buy is less, because the material is kept in the loop. This form of compensation is done for a part of the amount of metal that is recycled: only for the extent to which primary material was used in the production of the metal. The average (primary and) secondary fraction is known for all metals, see appendix C. The environmental impact associated with the recycling of one kilogram of metal, has been calculated as follows:

*[1 – secondary fraction] * (environmental impact of the recycling process – environmental impact of the primary production process)*

On top of this fraction, a recycling process efficiency of 90% has been assumed, because some loss occurs in collection and processing. Furthermore the environmental impact of collection of the metals has been included.

The advantage of expressing recycling products as avoided products manufacture, is that an environmental benefit can be attributed to the recycling of metals. In this way the positive influence of the recycling step is clearly marked. Using other ways of allocating recycling, such as applying a ‘discount’ on the original metal production, the recycling benefits would be more difficult to identify in the results.

Life cycle impact assessment methodology and interpretation

The applied environmental impact assessment methodology, CML-LCA2 [Guinée et al., 2001], is described briefly in the next chapter. Appendix A contains a short description of each of the impact categories. The results are interpreted with the help of the shadow price methodology [Van Harmelen et al., 2007], which is also discussed in the next chapter as well as in appendix B.

Data requirements
The foreground data has largely been obtained from practice, i.e. from companies. This was preferred over literature data, because the little literature that is available on this subject is mostly outdated. Because this research is aimed at describing an average situation, foreground data from practice is considered suitable. Literature can be used as a reference though to check the quality and representativeness of the data provided. Specific assumptions are presented in appendix C, choices with respect to the underlying system can be found in chapter 4. For the background data, the Ecoinvent database has been used [Swiss Centre for Life Cycle Inventories, 2009].

Data quality requirements
The required quality for the data is described by the following aspects:

a) Time related coverage: this research aims at describing the current situation, the reference year is around 2010. Due to a lack of recent data, it is possible though that older sources have been consulted. For example the most complete and (still) most frequently cited source on the composition of the human body is the book by Forbes of 1987.
b) Geographical coverage: the research is aimed at describing the Dutch situation. For many background data no specific Dutch figures are available. In that case, Western European data have been used. Special attention has been paid to the emissions from cremation ovens (which are specific for the Netherlands due to filters required to meet the regulations).
c) Technology coverage: this study has been carried out as if the four funeral techniques were in the same stage of development, that is, the stage of development of the current techniques burial and cremation. Burial and cremation are thus considered in accordance with the 2010 technological state. The two new techniques are considered as if they were fully operational and integrated in the Dutch funeral sector. In this way, all four techniques are pulled to one level as much as possible. For clarity, the potential for further development of each of the four techniques has not been examined. A complicating factor in this is the fact that foreground data cannot be established with certainty: little knowledge has been derived from practice so far, the data from practice could be biased and the practice is still in development and has not been optimized yet. These complications give rise to overestimations as well as underestimations of the results. Therefore, in the interpretation of the results an additional error margin should be allowed for. An otherwise important consideration regarding technology coverage, is that for the two existing techniques the average Dutch situation has been assumed. Within the practice of the techniques burial and cremation there will be a bandwidth in the actual environmental impact. This bandwidth has not been examined. It is possible that the ranking of the four techniques in terms of environmental impact would change if the ‘best practice’ was assumed for burial or cremation, instead of the average.
d) Precision (variance): starting point is an average situation, as generic as possible, to enable a clear view with little ‘noise’. The current situation is taken as a reference, although this is difficult to put into practice, as indicated under c), and especially variation on a temporal scale is inevitable.

e) Completeness: no threshold value has been employed in terms of weight or weight contribution to determine whether input/output flows are taken into account in the calculations or not; this has been evaluated on a case-by-case basis, dependent on the expected contribution to the environmental impact. If a flow is small, difficult to quantify and is expected to have a small contribution to the total results, it has been left out of the calculations. This is done for e.g. the glass urn (which would make up for only a small percentage in the average urn). A flow that has been considered because of its relevance, is the mercury emission from crematoria.

f) Representativeness: the data used are suitable to the goal and scope of the current research.

g) Consistency: where possible, uniformity has been pursued in this research. The difference in maturity among the four techniques renders this impossible in some cases, as already explained at item c).

h) Reproducibility: the current report provides all necessary information[2] about the data used and actions taken to have insight in the basics of the research. For reproduction of the results of this research, TNO will need to be contacted because two calculation models[3] have been used that could not be elaborated in this report. Furthermore, for the sake of readability and comprehensiveness, the specific input data in the background database have been replaced by generic terms. When reproducing the calculations this might give rise to minor shifts.

i) Sources of the data: the foreground data have been derived from practice, i.e. from companies in the funeral service sector. The collected data have been checked by TNO and where necessary completed with literature data and information from TNO experts.

j) Uncertainty of the information: where possible, data have been cross-checked. Uncertainties have been clearly identified in chapter 5 and 6 and appendix C.

---

[2] Data for resomation are partially confidential, and are not included.

[3] Firstly, a waste treatment model by Eggels and Van der Ven, that has been tailored and used to estimate the emissions to soil and water resulting from burial and ash scattering over land; secondly, a waste water treatment model that is part of Ecoinvent, which has been used to model the treatment of waste water for resomation. See also: appendix C.

3 Methodology

3.1 Life Cycle Assessment as basis for comparing environmental impacts

Environmental impact of the different funeral types is mapped by performing Life Cycle Assessments (LCAs). An LCA is an analysis of all relevant environmental impacts throughout the lifecycle of a product or service, from the extraction of raw materials till the disposal after use. The method used complies with ISO 14040 and ISO 14044 [2].
At a funeral the environmental impacts occur throughout the lifecycle of the funeral. The life cycle of a funeral consists of the following phases:

- Extraction and production of the commodities, materials and/or products for non-natural components like the coffin, clothing, used equipment, etc.;
- Preparations for the operation of the intended treatment, such as grave digging, preheating of the cremation oven, etc.;
- Execution of the final treatment;
- Maintenance of grave (including gardening), furnace and other equipment;
- Drain and processing residues such as metal parts, ashes, polluted water etc.;
- Transport and other logistic operations between the various process steps or techniques.

The relevant processes in these phases are elaborated in chapter 4.

To carry out an LCA for a specific destination option, detailed information (including quantities) is needed on materials and energy use, operations (construction, maintenance and demolition), transport of materials and waste products, throughout the life cycle of the destination option. Based on a description of all phases of a funeral process TNO prepared a questionnaire. This has been done for the four funeral options. These questionnaires were filled in by Yarden for burial and cremation and by Cryomation Ltd. (cryomation technique) and by Resomation Ltd. (resomation process). These data have been checked where possible by TNO, and completed where necessary, by information from literature and from TNO experts. The specific data used for the calculations are aligned with Yarden. Yarden has no contractual collaboration with the named companies.

Based on specific data for various funeral possibilities of deceased persons, TNO calculated the environmental profiles for four funeral types using the CML-LCA2 methodology [1]. Under this method, the following environmental impact categories are considered [impact unit]:

- Abiotic depletion (ADP)	[kg Sb eq]
- Global warming (GWP)	[kg CO_2 eq]
- Ozone layer depletion (ODP)	[kg CFC11 eq]
- Human toxicity (HTP)	[kg 1,4-DCB eq]
- Fresh water aquatic ecotoxicity (FAETP)	[kg 1,4-DCB eq]
- Marine aquatic ecotoxicity (MAETP)	[kg 1,4-DCB eq]
- Terrestrial ecotoxicity (TETP)	[kg 1,4-DCB eq]
- Photochemical oxidation (POCP)	[kg C_2H_2 eq]

- Acidification (AP)	[kg SO_2 eq]
- Eutrophication (EP)	[kg PO_4^{3-} eq]
- Land competition (LC)	[m^2.year]

In Appendix A the different impact categories are briefly explained.

The values per impact category are calculated, not measured. The results do not by any means predict a future situation or the exceeding of norms, safety margins or risks; other analysis methods are available to assess that.

For each funeral type the environmental impact is determined using the computational model SimaPro version 7.2 [Pré Consultants, 2010] and the database Ecoinvent version 2.1 [Swiss Centre for Life Cycle Inventories, 2009]. As a result, the environmental impact obtained for the 11 impact categories is calculated and given in different reference units per category (usually in kilograms of a major pollutant in that impact category). This means that the result for each impact category has a different unit. Based on the results of SimaPro impacts of different funeral types can only be compared on the level of an impact category. In this way a clear picture of the 'total' environmental impact of the different funeral types is not possible. To be able to compare the ‘total’ environmental impact of the funeral types the shadow price method is used. This involves a weighting step, which is not within the requirements of the ISO 14040-14044 standards. Consequently, the weighted results in shadow prices are not in conformity with these ISO standards.

3.2 Total environmental impact based on shadow prices

The shadow price for a certain impact category is based on the costs of emission reduction measures to be taken in order to reach the present and near future environmental policy goals in The Netherlands for that category. A big advantage of shadow prices is that the sum of the monetary contributions of the individual impact categories can be used as indicator for expressing the size of the overall environmental impact. This makes the comparison of alternatives in a simple manner possible. More details about the shadow price method are given in Appendix B.
The shadow prices used for the different impact categories are included in Table 1.

Table 1 – Shadow prices of different impact categories

Environmental impact category	**Equivalent unit**	**Shadow price [€/eq. unit]**	**Source**
Abiotic depletion (ADP)	kg Sb eq	0	TNO*
Acidification (AP)	kg SO_2 eq	4	CE
Eutrophication (EP)	kg PO_4^{3-} eq	9	CE
Fresh water aquatic ecotoxicity (FAETP)	kg 1,4-DCB eq	0,03	TNO
Global warming (GWP)	kg CO_2 eq	0,05	CE
Human toxicity (HTP)	kg 1,4-DCB eq	0,09	TNO
Marine aquatic ecotoxicity (MAETP)	kg 1,4-DCB eq	0	TNO**
Ozone layer depletion (ODP)	kg CFC11 eq	30	CE
Photochemical oxidation (POCP)	kg C_2H_2 eq	2	CE
Terrestrial ecotoxicity (TETP)	kg 1,4-DCB eq	0,06	TNO
Land competition (LC)	m^2.year	0,201	NIBE

* The Netherlands has no policy to prevent depletion of abiotic resources (fossil fuels, metals, minerals), the authorities rely on the free market system which dictates a price increase as a result of scarcity. On this basis, it is assumed that the market price sufficiently represents depletion of resources, and that the marginal costs for abiotic resource depletion are 0 €/kg Sb-eq.

** The Declaration of Apeldoorn (2004) advices to leave out MAETP in assessments where metals play an important role. As the recycling of metals plays an important role in the results for the funeral techniques, MAETP is left out.

4 System description

This chapter contains descriptions of processes associated with the four funeral techniques, as well as the key assumptions regarding these processes. In chapter 2 the general system boundaries have been declared. This chapter elaborates upon the specific boundaries per funeral option. The first paragraph deals with the common characteristics among the four options, though.

4.1 General system characteristics

In this paragraph, properties that are common or relevant to more than one funeral technique, for instance the composition of the remains, are discussed.

4.1.1 Composition of the body and the remains

The composition of the human body, and hence the composition of the remainders after the funeral, are relevant to all four techniques and are therefore discussed separately in this paragraph. As a basis for the calculations, a research by Forbes (1987) was used that, despite being over twenty years old at this moment, is one of the most complete and most frequently referred researches in this field. A few missing elements / groups of substances were added: mercury (Slooff et al., 2004), PCBs (Axelrad et al., 2009) and PCDDs/PCDFs (background data for dioxins by WHO, 1998). Where values were unclear (for example below the detection limit) a worst case approach was followed (in this example the emission level was assumed to be on the detection limit).
A correction has been applied to all types of remains where the mass balance (usually expressed as mg/kg) was not complete (the sum of all components was less than 1.000.000 mg/kg). The correction was done in the following way:

[calculated dry weight (mg)] = [element concentration (mg/kg)] x 1.000.000 / [sum of element concentrations (mg)][4]*.*

The composition of cremation ashes shows some differences with the composition of the human body. Nevertheless it has been decided to use the analysis report of Smit (1996) as a basis for the calculations, because of the few sources of practical data for cremation ashes, this is the most complete one. For mercury an adaptation was made, because Smit added 2.47 grams of mercury before measurements to evaluate the effect, whereas on average only 1.5 grams is present (Molenaar et al., 2009).
The exact composition of the resomated remains was unknown. The resomated remains are mainly calcium phosphate (Ecogeek, 2010), or more specifically, hydroxyapatite ($Ca_5(PO_4)_3OH$). Furthermore it contains about 5% of carbonates and magnesium, fluoride, barium, strontium, sulphur, copper, zinc, manganese and silicon (see e.g. Mbuyi-Muamba et al., 1988) and lead. For uniformity we assume that the resomated remains contain half of the amounts of elements present in the body. This solution is far from ideal, but there are no grounds available to base a better assumption upon.

---

[4] The sum of the concentrations would in theory have to be 1.000.000 mg (1 kg = 1.000.000 mg). In practice this was not always the case, hence the correction.

The figures used in the calculations can be found in table 4 in appendix C.
Small differences among the calculation of the composition of the remains for each of the funeral techniques are a result of different standard body weights having been used in different literature sources (70 or 75 kg).

4.1.2 Non-human remains

The human body nowadays contains a range of non-human materials, such as prostheses, dental implants and pacemakers, but also breast implants and artificial heart valves. The “average” deceased would, as a consequence, have a range of materials, but by including all of these materials the results of the study would be clouded, where clarity was particularly one of the goals. Therefore just two categories of materials have been taken into account. The first is metals, because of a large (expected) and discriminating effect on the results and the availability of reliable, empirical data. The second is a set of dentures, worn by a large share of the deceased (CBS, 2003), and here employed as a proxy for non-metal, non-human materials.

Another subject for debate is the effect of medicine, such as palliatives and chemotherapeuticals in the human body. The latter are supposed to be removed quickly out of the body and are assumed to have no effect on any technique (Molenaar et al., 2009). Medicines in general do not appear to give rise to problems in funeral techniques. The websites of Cryomation and Resomation claim that all medical substances are neutralized in their respective processes. Medicines are assumed to decompose at the elevated temperatures of a cremation. Moreover, Molenaar et al. conclude that there is no necessity to regard medicines as chemical waste and that therefore there is no reason to take the presence of medicines into consideration in case of burial.

Table 5 in appendix C gives an overview of the figures used in this research. The first four items in the list (cobalt chrome, stainless steel, titanium and iron scrap) are components of the grips and ornaments of the coffin and surgical metals. The last four metals, the precious metals (gold, silver, platinum and palladium) are most probably teeth fillings and jewelry, and possibly partially surgical. The exact origin of these metals is not relevant to this study however, just the exact amounts, which have been made available by the recycling companies.

4.1.3 Body covering

For burial, cremation and cryomation, it is optional to cover the body with a body bag; this is done in approximately 22% of the cases (Hesselmans International, 2010). For resomation the use of a body bag is mandatory.

A coffin is mandatory in all cases, thus for all four techniques an equal, standardized coffin has been assumed in the calculations. The material composition of the coffin has been provided by Unigra. The three most frequently used types are:

- Particle board, 36 kg, market share of 80%
- Oak, 43 kg, market share of 14%
- Pinewood, 30 kg, market share of 6%.

In the calculations, the coffin assumed is an average of the three types (29 kg of particle board, 6 kg of oak and 2 kg of pinewood).

The lining of the coffin was based on data from Unigra, completed with an assumption for the pillow. Dijk & Mennen (2002) wrote that 85% of the coffins have

wooden grips. The weight was provided by Unigra. The average grips (metal / wood) have been calculated in a similar way to the average coffin.
For metal grips, an assumption has been made, because the weight was unknown. The assumed weight has been derived by taking half the weight of the steel that remains after the cremation (which is made up of surgical metals plus the grips that were removed in advance). The recycling company, Orthometals, provided the amount of zinc collected that was originating from the ornaments. On this basis the average amount of zinc ornaments per funeral could be estimated.

4.1.4 *Modelling burial of remains*

The burial of the body or of the remains after realization of a funeral technique, can be regarded as a disposal of an unusual type, as was illustrated by Dent & Knight (1998). In calculating the environmental impact of funerals, it is not sufficient to regard a graveyard as a normal disposal site. Therefore a landfill model (as illustrated in Eggels & Van der Ven (2000)) is adapted for the specific situation. The elementary composition of a human body can be entered in the model. The model then calculates the emissions to soil and water. A number of adaptations had to be made:

- Maintenance costs of the site in the form of diesel consumption, electricity use, flaring and gas motor have been set to zero. Maintenance has been addressed separately in the calculations.
- The gas production factor has been set to 5%. No data are available about the amount of gas production, but it is assumed to be low because of the buffering capacity of the soil and biological degradation in soil.
- Emission factors according to the landfill model were not changed (no specific information is available on the topic of graveyard emissions). It should be mentioned though that the emissions will most likely have a small effect on the total environmental impact, because biogenic emissions are disregarded in the calculation of the global warming potential.
- The cleaning factor has been set to zero as well, because this is irrelevant for a graveyard.
- Where possible, calculations were adapted or separately made to convert S into SO_4 or P into PO_4 and the other way round.
- Phosphate has been added, because this seems particularly relevant, for instance regarding eutrophication, but was missing in the landfill model. Information about distribution factors was not available, therefore figures for SO_4 have been used as a proxy.
- Dioxines (PCBs only) were added as well, and were attributed a k-value of 1%.
- COD-emissions to soil are not accounted for in the CML-LCA2 method, this has been disregarded.
- The Ecoinvent report on landfill sites (Doka, 2007), regards Ca, K, Mg, Na, Al and Si not harmful to the environment. It has been chosen to disregard these components in this analysis, even though these are present in the human body.
- *k-values*, which determine which fraction of each of the elements becomes available in soil or water, were missing. The factors described in Eggels & Van der Ven (2000) under the topic “Attribution model for landfilling of solid municipal waste” were used as an approximation. The other data were taken from a model for plastics waste that was available at TNO. This resulted in a set of *k-values*, which can be found in table 6 in appendix C.

4.1.5 *Recycling of metals*

The recycling of metals is relevant to several of the funeral techniques. The specific way that recycling of metals is dealt with in this research, has been elaborated in paragraph 2.2 under ‘Allocation procedures’. The specific data are recorded in table 7 of appendix C.

4.2 Burial

During a burial, the body is placed in a covered grave in the ground. There are some varieties of allowed above ground burial, but these are not assumed in this study. The separate steps in standard burial are presented in Figure 2 below and described subsequently. The data used in the calculations are presented in table 9 in appendix C.

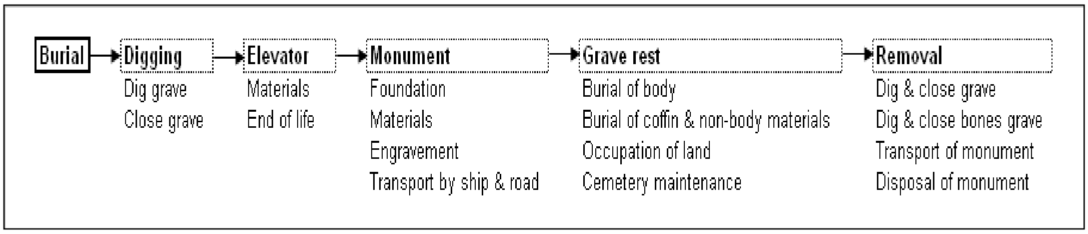

Figure 2 - Schematic overview of the burial process.

Prior to the burial, a grave is dug mechanically by a shovel. The depth of the grave is dependent on several factors and should be at least 65 cm below surface and at least 30 cm above the average highest groundwater level. Moreover there is a legal maximum number of deceased per grave. The depth varies widely. Genius Loci mentioned that as a guideline for a single grave, approximately 1 meter can be adhered, and for a double grave approximately 2 meter. Per person, approximately one meter of digging is required. The area of a grave is approximately 1.25 times 2.5 meter (Genius Loci, 2010). The coffin can be lowered into the grave with help of an elevator or by hand; in 95% of the cases, an elevator is used (Honor Piëteitstechniek, 2010). After descending of the coffin, the grave is filled again, mostly mechanically by the shovel.

Usually, the grave is not immediately covered by a final grave monument but first by a temporary monument (ignored in this study). After about four months, the final grave monument can be placed, which is actually done in 75% of the cases (LOB, 2010). Prior to the monument placement, a foundation of concrete is laid down. The grave monument itself may consist of all kinds of materials, but is usually made of stone (85%, LOB 2010). According to the LOB a stone usually covers about 70% of the grave, and when we assume a thickness of 5 cm, the weight of the stone can be approximated. The stone also has to be transported over a long distance, as there is almost no rock production in The Netherlands. The average transport distance is unknown, therefore as an average it is assumed that the stone has to be obtained from another continent over a distance of 5000 km by ship and another 200 km by truck within the Netherlands. The stone usually undergoes some kind of treatment in de form of polishing and engraving.

During the following period of rest, the body and the coffin can decompose undisturbed. The law requires a minimal period of rest for all types of graves for at

least 10 years. General graves are hired for ten years only and may be removed after this period by the graveyard owner. Usually this is done at a strategic moment for the graveyard owner, after more than the official ten years; we assume 15 years. About 90% of the graves are private graves, which are rented for initially twenty years and can be prolonged afterwards by ten years at a time (Dijk & Mennen, 2002). It has been assumed that these graves are maintained for 40 years, which was confirmed by the LOB. Accounting for the percentages the average grave rest is 37.5 years. The burial of human remains can be considered as a special kind of land filling, with decomposition processes that are determined by natural aspects of the land, management practices of the cemetery, funeral aspects of the interment and characteristics of the remains. Potential problems of cemeteries are contamination of the surrounding soil and water by viruses, bacteria and toxic substances such as the amalgam from teeth fillings, and local eutrophication due to mainly nitrogen and phosphorus release. Complicating in quantifying these potential problems is that they are normally of a local nature and that very little scientifically based information is available on this subject[5]. To avoid the associated uncertainties, the specific properties that discriminates a cemetery from a landfill site have been ignored in this study. The cemetery is considered as a special type of landfill site where the human body elements decompose naturally. The management of the cemetery is different from a landfill site and is taken into account (irrigation and some gardening activities).
To be able to calculate the maintenance requirement and land occupation per deceased, the average surface per buried individual needs to be known. It has been calculated by dividing the average area of a graveyard (13.200 m^2) by the average amount of buried people on a graveyard (1328; data from Steen & Pellenbarg, 2007). This includes the land use for the graves, the bone grave, green area and walks. The green area is assumed to amount to 25%, for simplicity reasons this is considered grass. To the question how much petrol is needed for the maintenance of a cemetery, the answers were varying from 66 (LOB) to 500 litres per cemetery per year (Groentotaal de Boer); as an average 300 litres is assumed.At some point after the rest period, the grave is emptied. This is usually done by means of a shovel and for several graves at once. The bones are reburied in a special bone grave. The metals and plastics that are still present, like coffin ornaments and prostheses, are not separated but buried along. The grave monument is disposed of as regular waste.

4.3 Cremation

Cremation is the incineration of a corpse in a crematorium. The subsequent steps in the cremation process are shown in Figure 3 and explained subsequently. The specific figures used in the calculations are listed in table 10 in appendix C.

---

[5] Illustrative for the lack of data is the fact that many of the publications after 2000 refer to a source of 1951 (Van Haaren, 1951). Dent (2002) wrote an exceptionally elaborate thesis about the subject, but is one of few. See: Van Haaren (1951), *Kerkhoven als bron van waterverontreiniging*, Water, 35 (16), pp167-172; and Dent (2002), *The hydrogeological context of cemetery operations and planning in Australia*, PhD Thesis, Sydney: University of Technology.

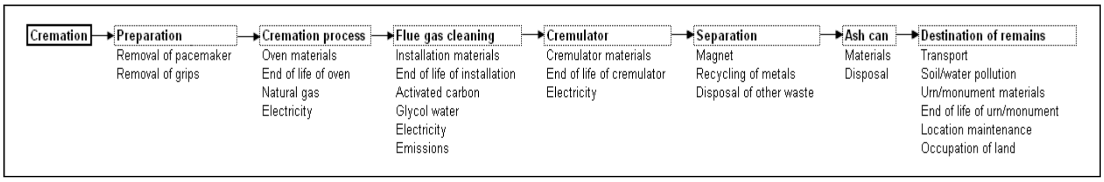

Figure 3 - Schematic overview of the cremation process.

Two actions that are undertaken prior to the actual cremation are removal of the pacemaker (high explosion risk of battery in the cremation oven) and removal of external metal elements of the coffin. Large exterior prostheses like artificial legs are also removed beforehand, while smaller and interior prostheses like artificial fingers and hips are left untouched. Removal of the pacemaker and of prostheses is not included (conversely, the treatment of the materials has been included, such as the recycling of metals; see hereafter). The metal elements of the coffin, like grips and ornaments, are removed and are collected and recycled.

There are two types of ovens used in the Netherlands: warm (70% of the total) and cold (30%) starting ovens. The warm starting oven is preheated up till 800 ˚C, the cold one till 400 ˚C. In the Dutch crematoria, both types are heated by natural gas. As warm start ovens form a majority the study is focused on the warm system and its effects. An oven consists mainly of stainless steel and electronic components, and has an average life span of approximately 25.000 cycles.

The actual cremation starts when the coffin is introduced to the oven. The cremation takes about 75 minutes in a warm starting oven. Modern cremations are controlled by a computer system. The provided numbers for average natural gas consumption per cremation varied from 15 up to 45 cubic metres. The average was about 25 m^3, which was endorsed by several informal sources on the internet. A by-product of the cremation is the flue gas, which requires cleaning before it is released to air. The flue gas can be cleaned in several ways and for this study a cleaning system with a ventilator, active coal injection and particulate filtration is chosen. The installation consists of stainless steel, copper and other materials. For simplicity reasons the latter category has been summarized as being PVC. The life span of the flue gas cleaning equipment is not known; it has been assumed to endure as long as the oven itself. Production of active coal has been modelled by TNO on the basis of production costs according to Lima et al. (2008) and a coal need of 1 kilogramme per kilogramme of active coal, in the absence of suitable literature data. The hazardous components that are filtered from the gas are treated as special waste. Due to the high concentrations of hazardous substances and the leachability of these, the waste is landfilled under special conditions. This way, leaching to the environment is (for the time being) strongly reduced. The remaining emissions after flue gas cleaning have been modelled on the basis of a report by Tauw (Tauw, 2006). The CO_2-emissions were calculated separately. Welch & Swerdlow (2009, after several sources) determined that the remains and the coffin together emit approximately 100 kilogrammes of CO_2 (the emission of CO_2 as a result of natural gas is not included). Here it is assumed, in accordance with the mass ratio, that one fourth is originating from the coffin, as ‘normal CO_2’, and three fourth is released from the body, as biogenic CO_2. The CO_2-emissions from gas have already been accounted for in the natural gas combustion.

After the cremation there remains human ash and other remains. It has been assumed that the separation of the remains does not require materials or energy, because this is done mainly by hand or with a magnet. The human parts of those

other remains are processed to ashes in a cremulator and added to the rest of the human ashes. The other parts are metals and plastics from prostheses and dental fillings. The metals are collected and recycled by two specialized companies.
The human ash is put in an ash can and kept for the legal term of one month in the crematorium. The ash destination options thereafter are numerous. The distribution of the most common options is shown in Figure 4. The three most common have been included in the calculations. The assumed ratio is 75% scattering over land, 20% over sea and 5% keeping in an urn.

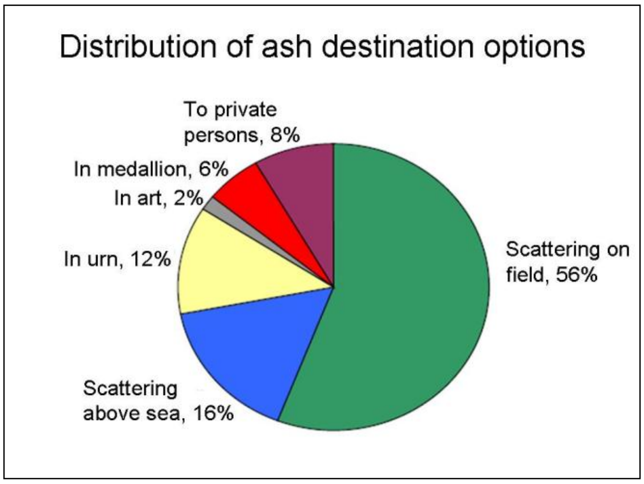

Figure 4 – Distribution ash destination options, in percentages. Source: annual figures of Yarden for the year 2000, published in [Dijk & Mennen, 2002].

Scattering over land is assumed to take place over a scattering field. Scattering in other places is allowed by law, but the land owner needs to give consent. The land use and associated maintenance costs per person were calculated on the basis of the number of remains that are scattered per field per year. Almost no data are available for this (Dijk & Mennen, 2002). The Dutch directive prescribes a maximum of 370 per hectare per year, if no additional precautions have been taken (Ministry of Housing, Spatial Planning and the Environment, 2004). Because every year new scatterings can take place on the same field, only one year's maintenance is attributed to each deceased. For the third option, keeping in an urn, it has been assumed that the urn is specially made and bought; the three most common types of urn have been included in the analysis. For simplicity reasons it has been assumed that the majority of the relatives choose to keep the urn at home, and not in a grave or a columbarium. It has been assumed that the ash is not kept for an indefinite period of time, but for a number of years (the duration is not relevant for the analysis) and that it finds its definitive resting place, be it by scattering, be it by disposal as household waste. Via all these routes, the ashes finally return to the soil[6]; for this, the same environmental impacts are assumed as for scattering over land.
For scattering over land as well as for keeping in an urn, the ash can needs to be collected in the crematorium and transported to a home or another final resting place. This is an additional transport need that is not necessary for burial. As a

---

[6] This is not the case if the ashes are scattered over sea after having been kept in a columbarium, but this possibility is neglected here because it would be a small fraction, given the share of scattering over sea.

consequence, it has to be included. As an assumption, two people collect the ashes and drive 12 kilometers on average[7].
For the calculations of scatterings over sea data from Aqua Omega have been used. The ashes are collected at crematoria. They drive 45.000 km annually to collect the ashes of 2.500 deceased. The personal car kilometres per deceased can then be calculated. Most scatterings occur by ship and are carried out without relatives present. Consequently, scatterings from an airplane or with many people present are disregarded. The ships leave port about every six weeks, which yields an average of 300 ash cans per trip. The ships sail 10 kilometers per trip. The influence of the ash on seawater is calculated by assuming that the cremation ash enters the ocean directly.

4.4 Cryomation

Cryomation is the process which involves freeze drying of a corpse and subsequent fragmentation. All cryomation steps have been tested on pigs by Cryomation Ltd., but the cryomation process is not yet in operation for human corpses and an all-in cryomator does not yet exist. For this study we have followed the information provided by Cryomation Ltd. The cryomator consists of stainless steel, plastic and electronic components. We have assumed a life span equal to that of a cremation oven. Furthermore, a cryomator would take approximately the same amount of space as a cremation oven, which means it could be situated in a crematorium without the necessity of a new building. In the calculations it has been assumed that the technology is on a level comparable to cremation, that the process runs smoothly and the figures provided by Cryomation Ltd are representative and that there are as much cryomation centres as there are currently crematoria.
The process steps of cryomation are shown in Figure 5 and are subsequently explained. The specific figures that are used in the calculations, are provided in table 11 in appendix C.

---

[7] This figure has been calculated by regarding the Netherlands as a raster of squares, with in the centre of every square a crematorium that serves the area in the square. The land area of the Netherlands is 41.528 km^2; with 67 crematoria the distance from the middle of a square to the edge is 12 km (0.5 * square root (41.528/67). Every location in the Netherlands is in theory closer than 12 km from a crematorium; some are closer, some are further away. The distribution in the Netherlands is obviously not as regular as assumed here (but the distribution of population isn't either); nevertheless this method suffices to give an indication of the average distance.

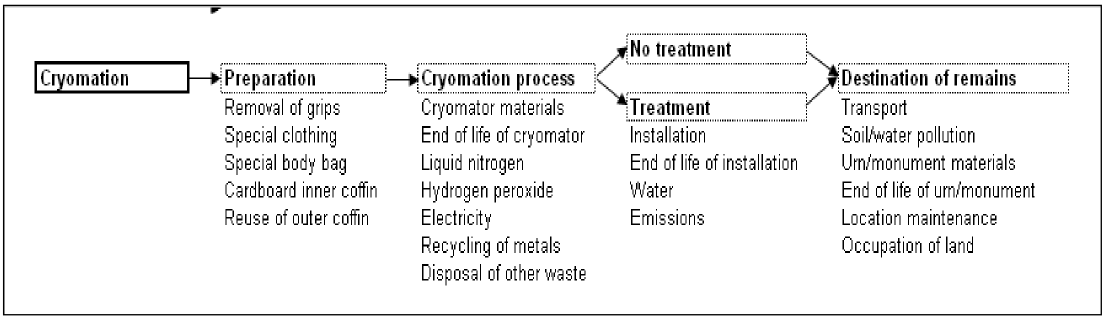

Figure 5 - Schematic overview of the cryomation process. Source: personal communication with Cryomation Ltd in 2010/2011.

Prior to cryomation the body needs to be clothed in special clothing made of corn starch and leather. A body covering is optional; the same percentage has been assumed as for burial and cremation. The body covering is made of mais starch. Two coffins are needed. The outer coffin is equal to the standard coffin, and can be reused. The inner coffin enters the cryomator. It has been assumed that the outer coffin is used 50 times, and then disposed of.
The first step in the cryomation process is the automated weighing of the coffin to control the required quantity of liquid nitrogen.
After the liquid nitrogen is introduced to the cryomator, the body in the coffin is allowed to rest until the core reaches the required low temperature. From now on, the process will be fully automated; there is no operator intervention until the dried remains are boxed. The cryogenic freezing makes the body brittle. The body is then subjected to a controlled pressure which reduces the body into smaller fractions. The remains then pass through a sensing field in which non-organic material is rejected. Rejected material is then cleaned and collected for recycling (metals) or disposal (dentures). The sorted organic remains are then passed through a second fragmentation process, a vibrating pin mill. This reduces the fraction to the required size for freeze drying. The size reduced remains are then treated in a vacuum chamber and frozen water is sublimated.
At the end of the process the dried material is subjected to a treatment of gaseous hydrogen peroxide to reduce the number of pathogens by a factor 100,000. What remains, is a beige sterile odourless mix of pieces smaller than 5 mm with weight of about a third of the weight of the body and the coffin.
Cryomation Ltd assumes that people who choose for cryomation, make that choice because they find it important to look after the environment, are therefore will want to make environmentally conscious decisions where it concerns the coffin after cryomation. Cryomation Ltd suggests a biodegradable box. It is assumed here to be a cardboard box, for this is a frequently mentioned option.

The cryomated remains can be buried in the biodegradable box in a conventional way. An alternative option is that the remains are further processed by accelerated aerobic composting. This reduces the mass by a further 30%. For this process a stainless steel installation is necessary, and water and microbes. The microbes have been disregarded in the calculations, but the (biogenic) CO_2 emitted has been taken into account.

After treatment the remains are returned to the relatives, either in a pot with a plant of choice (hence as compost), or in a box to be buried on a natural graveyard, or scattered over land or sea. The preference for each of the options as proposed by Cryomation Ltd has been adopted: 23% direct burial, 77% treatment with final destination 40% as compost, 14% burial, 20% scattering over land and 3% scattering over sea. For all options the calculations are equal to those for burial and cremation, such as the use of the modified landfill model to calculate emissions of burial. A small number of adaptations have been made regarding the calculation of effects in soil and water:

- The untreated remains in principle have exactly the same components as a human body, but the mercury content was corrected to the emission of 8.28 x 10^{-9} kg to water and 1.69 x 10^{-10} kg to soil
- For ‘burial as compost’ the same emissions have been assumed as for burial of untreated cryomation remains. Two things have been adjusted: 1) for emissions to soil, the subcompartment has been defined as ‘agricultural’, and 2) for each kilogramme of buried material, 1 kg of compost is accounted as avoided product.

The grave area (and as such the contribution to processes with an environmental impact such as maintenance) is smaller for cryomation than for a ‘normal’ burial. For untreated remains it has been assumed that twice as little space and maintenance is required in comparison to a regular burial; for the processed remains four times as little space and maintenance has been assumed. Moreover, only two years of grave rest is needed (instead of 37.5 years) and a wooded covering is assumed to be placed instead of a stone monument. As a result, no foundation is necessary. Scattering over land is different: because the remains have a volume five times as high, fewer scatterings can occur per hectare per year, and as a consequence five times as much maintenance is attributed to each deceased, compared to cremation.

4.5 Resomation

Resomation, or in technical terms *alkali hydrolysis*, is a patented way to dissolve the weak parts of a body in a basic solution. For this study the information and input data of Resomation Ltd and its partners (Matthews Cremation, Biocremationinfo) are used. Some of the data provided by Resomation are considered as confidential and are not included in this report. Just as for cryomation it has been assumed that resomation technology is developed up to a level comparable to cremation and that resomations can occur in a normal crematorium. The different steps in the resomation process are shown in Figure 6 and subsequently explained. The figures used in the calculations are shown in table 12 in appendix C.

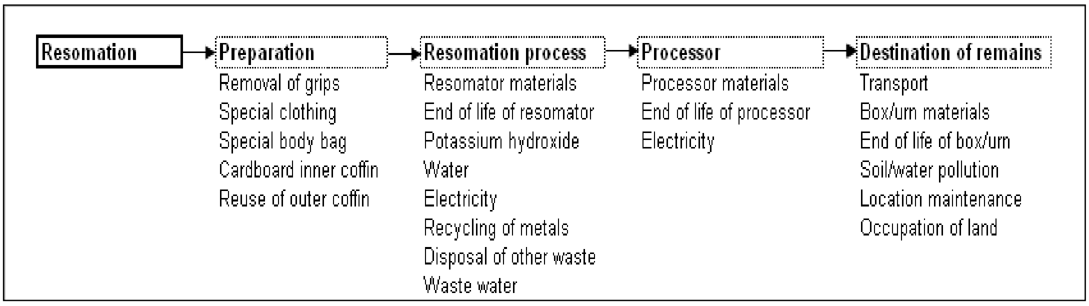

Figure 6 – Schematic overview of the resomation process. Source: personal communication with Resomation Ltd in 2010/2011.

Before the resomation process, the body should be clothed in tissues made of protein, being silk, wool or leather. Then, the process starts by the separation of the body and the coffin. The coffin can be reused, and just as for cryomation it was adopted that the reuse is 50 times on average. The body, wrapped in a biodegradable bag, is placed in a reusable bucket made of stainless steel. It is then put in the *resomator*, which has similar dimensions as a cremation oven. A drawing of the resomator is shown in Figure 7.

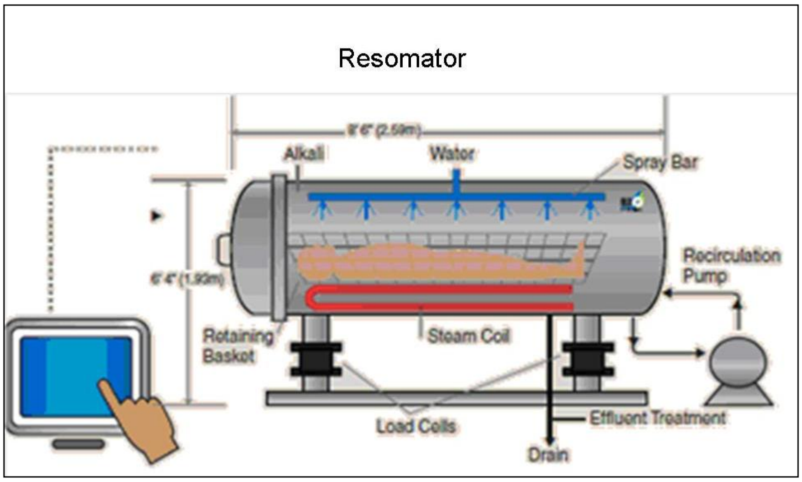

Figure 7 - Technical drawing of a resomator.

Inside the resomator, load blocks determine the weight, after which the exact pre-calculated volumes of water and lye are added. Sodium hydroxide is avoided due to gelling of the effluent at ambient to low temperatures; this gelling is avoided with KOH.

The inside of the resomator is heated up to about 180 ˚C by means of of an internal steam heated stainless coil fed by a gas run boiler system. The pressure is run at up to 10 bars to reach the required temperature and for an optimal hydrolysis. A circulation pump takes care of continuous pumping. The heat up and recirculation at 180 °C takes about 95 minutes.

Next, cold water is run through the coil in order to cool down the liquid to an acceptable level and the Resomator is drained. The solution that is drained contains salts, sugars, small peptides and amino acids. Resomation Ltd writes that the exiting pH will be between 10.5 -11.5 and have a COD/BOD of on average around 71,000/47,500 mg/L. Resomation Ltd claims that the drained fluid can be released on the sewage system without requiring further cleaning. During the calculation phase[8] of this study no exact information was available on the composition of this fluid. As a way round the composition of the waste water is modelled on the basis of the weight of the body, minus the parts of the resomation ash, dissolved in 310 litres of water. Subsequently this information was put into the calculation tool for municipal waste water treatment plant of Ecoinvent (Doka, 2002), which resulted in the emissions of the process. That is a quite course method to determine the environmental impact of the waste water treatment, so a sensitivity analysis on this topic has been added (see paragraph 5.2.3).

---

[8] In the completion phase of the research TNO received a water analysis report. The information in this report is considered in a sensitivity analysis.

What remains in the Resomator is immersed in water heated to 105˚C and held for 10 minutes before cooling and sending to drain. The remains are then removed, dried and separated. Metals from chirurgic, dental or jewel origin are recycled. According to Resomation Ltd, prostheses can be reused. In the calculations we assumed that 80% is reused. The bones have become so fragile that they are easily crushed to a white powder in a processor. For this processor the same figures have been used as for the cremulator.
The powder is put into a can for its last destination: scattering over land or sea, conservation or burial in an urn or, as a new option, burial as compost in a decomposable urn (accelerated uptake in the ground). At last, scattering over land or scattering over sea are again the two main destination options, with burial as compost as a third option. The calculations are based on an average, put together from the distribution of preference as proposed by Resomation Ltd: 25% scattering over land, 25% over sea and 50% burial as compost.

5 Results

In this chapter, the results of the LCA calculations are presented and the environmental impacts of the four funeral techniques are compared.
When interpreting the results, one should keep in mind the following:
For the two current techniques the average Dutch situation in 2010 is described. In reality there is a bandwidth, so the best practice could have a lower impact than shown in the results.
The two new techniques are approached as if these were already fully operational and integrated in the Dutch funeral sector. Limitations in terms of practical data bring about an additional error margin in the results.

5.1 Environmental impact of the four funeral techniques

5.1.1 The environmental impact per impact category

The environmental impact of the four funeral techniques is presented per impact category in Table 2. The higher the numbers, the higher the environmental impact. In a number of places a negative value occurs. This is a result of the way recycling impact is allocated; due to recycling, several techniques are accredited an 'avoided environmental impact', thereby reducing the environmental impact.

Table 2 – Environmental impact of the four funeral techniques per deceased.

Impact category	**Unit**	**Burial (average)**	**Cremation (average)**	**Cryomation**	**Resomation**
Abiotic depletion (ADP)	kg Sb eq	1,26	0,82	0,27	-0,11
Acidification (AP)	kg SO_2 eq	1,35	0,67	-0,32	-0,34
Eutrophication (EP)	kg PO_4^{3-} eq	0,75	0,76	0,45	1,08
Global warming (GWP)	kg CO_2 eq	180,3	79,9	47,2	-31,8
Ozone layer depletion (ODP)	kg CFC11 eq	1,84E-05	5,53E-06	3,21E-06	2,18E-06
Human toxicity (HTP)	kg 1,4-DCB eq	115	54	-18	-77
Fresh water aquatic ecotoxicity (FAETP)	kg 1,4-DCB eq	34,6	0,0	-31,5	-40,0
Terrestrial ecotoxicity (TETP)	kg 1,4-DCB eq	2,53	2,30	0,15	-0,58
Photochemical oxidation (POCP)	kg C_2H_2 eq	0,16	0,06	0,00	-0,01
Land competition (LC)	m^2.year	259,8	70,0	49,1	7,0

Table 2 makes clear that per deceased:

- Cryomation and resomation have the lowest environmental impact in all categories, except for eutrophication where resomation has the highest of all options;
- Burial has the highest environmental impact in all the impact categories, except for eutrophication;

- Consequently, cremation has in all categories an environmental impact that is somewhere in between the other options.

Per impact category there are usually a few processes that are together responsible for the large majority of the impact. These are hereafter discussed one by one.

Depletion of abiotic resources

The depletion of abiotic resources is mainly caused by burial and cremation. In the former case the effect is resulting from the stone and the cotton production for the coffin (for the cotton yarn as well as the weaving process). Cotton is used in the same way in the cremation route. For cremation, the other large contributor is the use of natural gas in the cremation oven. Furthermore, cremation, cryomation and resomation have in common that a large compensation occurs due to the recycling of metals.

Acidification

For acidification too the largest effect is in burial and cremation. The largest contributors for burial are the electricity production for the production of the cotton in the coffin, and the production and transport of the stone. For cremation again the cotton in the coffin plays a role, but the direct emissions are three times as important. Besides an equally large effect, but opposite or compensating, is resulting from the recycling of metals (avoided palladium mining). The negative values for cryomation and resomation are also caused by the avoided palladium mining due to recycling.

Eutrophication

For all techniques, eutrophication is an important factor. For burial this is for the larger part a direct result of burial. For the cryomation route, burial or scattering of the remains in or over the ground has the biggest overfertilizing impact. Scattering over sea and over land is important for cremation, as well as a compensating effect due to the recycling of metals (avoided gold mining). Resomation is dominated by the treatment of waste water, followed by the scattering of human remains in and over land and sea.

Climate change

Burial has the largest contribution to climate change, followed by cremation with half the contribution. The stone quarrying related to burial has the largest share, cotton production and related energy consumption is the second contributor. For cremation the effect is also related to cotton production, but to flue gas emissions as well. Furthermore a compensating effect is realized by metal recycling.

Ozone layer depletion

The depletion of the ozone layer is three to eight times stronger for burial than for any of the other techniques. More than half of this effect is caused by the grave monument: stone quarrying, transport and other smaller factors.

Human toxicity

Human toxicity is strongest for the burial route, two times smaller for cremation and also influential but negative for resomation. The cotton production and the steel grips for the coffin have a large share in the effect. For burial the grave monument adds to the impact. For cremation, the main contributor is steel production for coffin and machine (oven). This is however to a certain extent compensated by metal recycling (avoided gold mining). In resomation the machine has a smaller role and the main effect is brought about with metal recycling.

Freshwater aquatic ecotoxicity
This category is different than the others: the values for burial, cryomation and resomation are approximately equal, though positive for the first and negative for the latter two. The impact related to burial is mainly caused by the production of cotton. In the cryomation and resomation routes, recycling of gold gives a relevant avoided effect.

Terrestrial ecotoxicity
Burial and cremation both have high (and fairly equal) contributions to this theme. Once again, the production of cotton plays a large role in the effect.

Land competition
Land competition is not only high for burial as expected, but it is also rather high for cremation and cryomation. A large part of the land competition in burial and cremation originates from the coffin materials like particleboard, timber and cotton. Cryomation's land competition is mainly a result from the timber production for the memorial plaque when the cryomated remains are buried[9].

All impact categories together
The results presented above raise the expectation that the net environmental impact of the funeral techniques is the highest for burial and the lowest for resomation or cryomation. However, as the different impact categories are expressed in different units, it is not possible to add them up and to make quantitative statements about the total environmental impact of the different funeral techniques.

5.1.2 The total environmental impact, expressed in shadow prices

In this chapter the shadow price methodology is employed in order to calculate the total environmental impact of different options for funerals and to investigate which activities contribute largely to this total impact. This involves a weighting step, and as a consequence this part of the research does not comply to the ISO standards. The environmental impacts in all impact categories are calculated for all materials and processes of the funeral techniques. A complete overview of the results is given in Appendix D.

The total environmental impact in shadow price for the funeral techniques is shown graphically in Figure 8.

---

[9] The specific material choice for the grave monument in cryomation burial are further analyzed in paragraph 4.2.5.

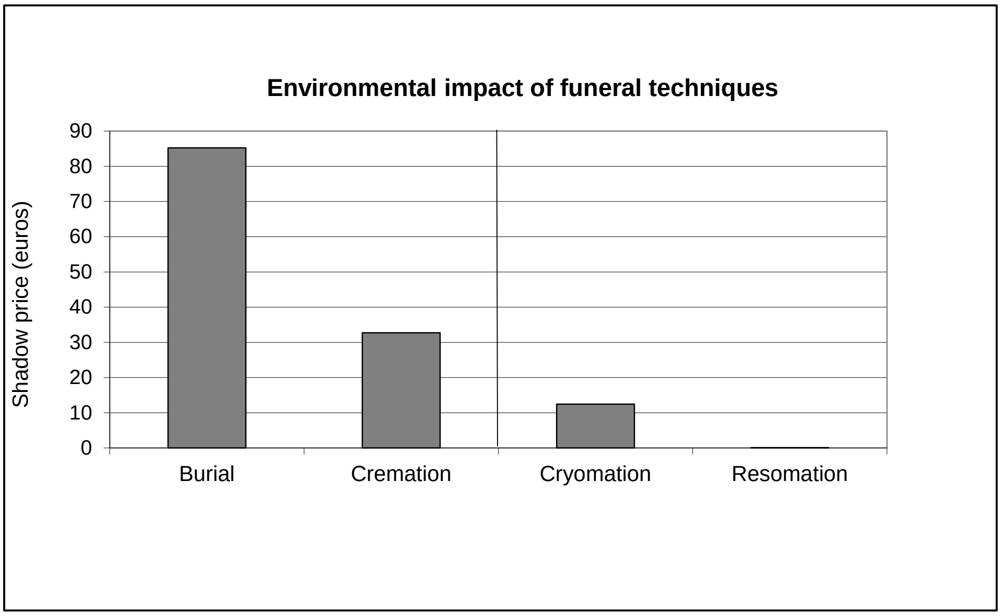

Figure 8 – Total environmental impact of funeral techniques.

The results make clear that the total environmental impact (as shadow price):

- of burial is the highest (more than 7 times higher than cryomation and even much more than resomation);
- of cremation is about a third of burial.

In Table 3 the environmental impact in terms of shadow prices for the funeral techniques is given per impact category.

Table 3 – Shadow prices per impact category for the four funeral techniques.

Impact category	**Shadow price per average deceased (euros)**			
	Burial (average)	**Cremation (average)**	**Cryo-mation**	**Reso-mation**
Abiotic depletion (ADP)*	0,00	0,00	0,00	0,00
Acidification (AP)	5,42	2,69	-1,27	-1,35
Eutrophication (EP)	6,76	6,84	4,01	9,71
Global warming (GWP)	9,01	4,00	2,36	-1,59
Ozone layer depletion (ODP)	<0.001	<0.001	<0.001	<0.001
Human toxicity (HTP)	10,31	4,85	-1,59	-6,92
Fresh water aquatic eco toxicity (FAETP)*	1,04	0,00	-0,95	-1,20
Terrestrial eco toxicity (TETP)	0,15	0,14	0,01	-0,03
Photochemical oxidation (POCP)	0,33	0,12	0,01	-0,02
Land competition (LC)	52,22	14,08	9,86	1,42
Total environmental impact (as shadow price)	***85***	***33***	***12***	***0***

*) The shadow price for abiotic depletion (ADP) is 0 euro per kilogramme, leading to a value of zero for each of the funeral techniques.
**) Marine aquatic ecotoxicity (MAETP) is left out, as remarked at table 1.

The results of Table 3 for the different impact categories are shown graphically in Figure 9.

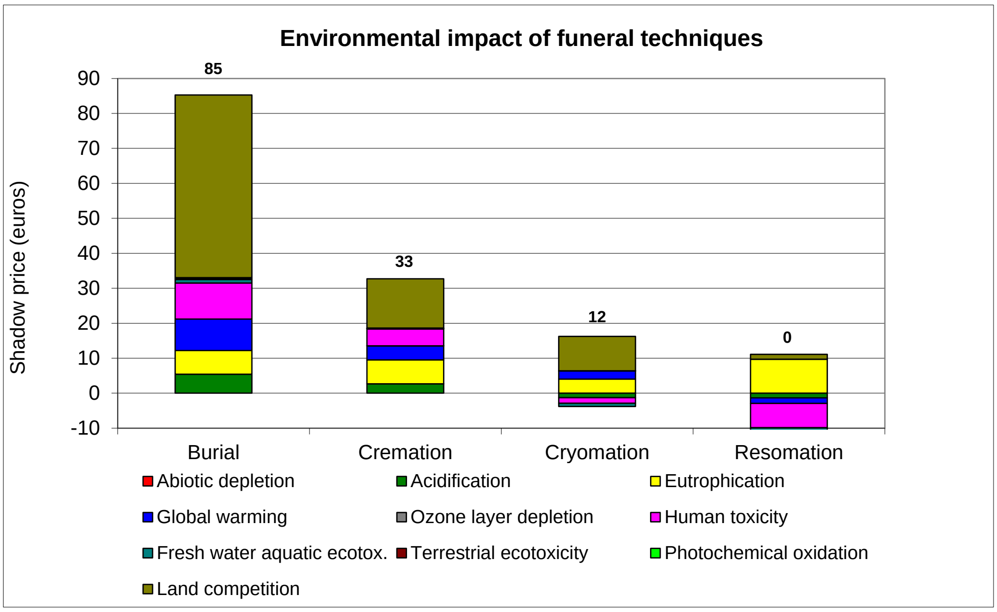

Figure 9 - Environmental impact, expressed in shadow prices, of four funeral techniques: burial, cremation, cryomation and resomation. The numbers above the bars in the figure represent the net shadow price

The priority in most important impact categories to the total impact is as follows (an asterisk* means that the contribution is negative):

- Burial: land competition, human toxicity, global warming, …
- Cremation: land competition, eutrophication, human toxicity, …
- Cryomation: land competition, eutrophication, global warming, …
- Resomation: eutrophication, human toxicity*, global warming, …

Notable is that, given the shadow price weighting method, for resomation the environmental impacts are in fact fully compensated by negative environmental impacts (environmental benefits). For cryomation compensation also occurs, but a net environmental impact remains. In paragraph 5.1.3 the contribution to the shadow price of each of the process steps is shown.

Land competition is the dominant theme for three of the four techniques. The weighting factor for land use is until now more under discussion than the weighting factors for other impact categories. Therefore another calculation was done where land competition effects were excluded. The result is included as Figure 10.

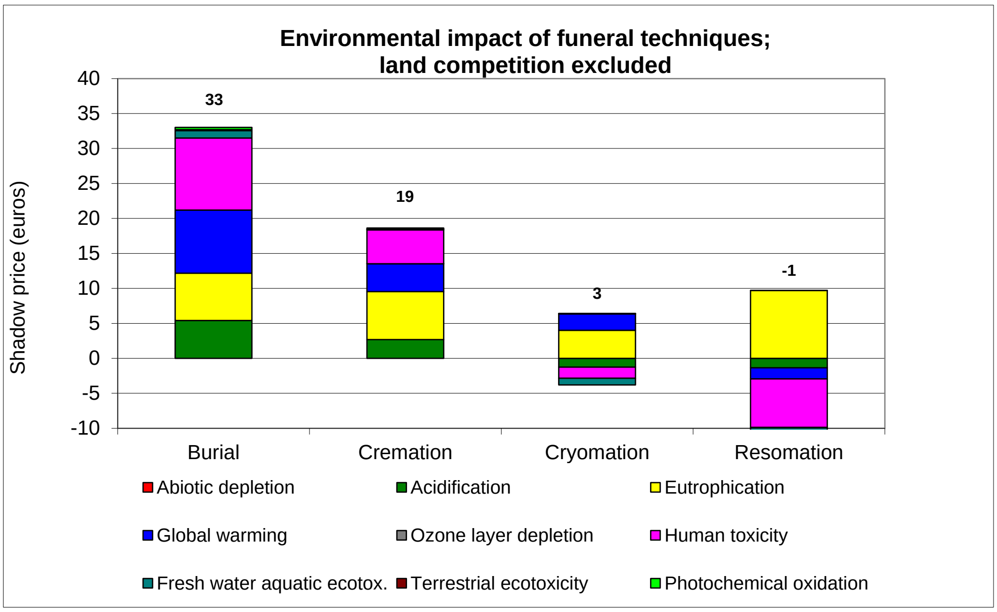

Figure 10 - Environmental impact without land competition, expressed in shadow prices, of four funeral techniques: burial, cremation, cryomation and resomation. The numbers above the bars in the figure represent the net shadow price.

All bars in Figure 10 are lower than the corresponding bars in Figure 9. Even so the conclusions regarding the relative order do not change: burial is still clearly the option with the highest impact, cryomation and resomation have the lowest impact and cremation sits somewhere in the middle. Notable is that resomation seems to have a higher shadow price than cryomation, but is eventually better because of the negative contribution of recycling (compensating environmental impact). This compensation leads even to a small net environmental benefit for resomation in case land competition is disregarded.

In general terms the differences in environmental impact among the techniques are more clearly drawn. With respect to burial, human toxicity and climate change appear to be the largest impacts. For the other three techniques the impact on eutrophication is clearly the most contributing.

5.1.3 *Environmental impact of the main process steps*

In the figures hereafter the contribution of each of the process steps to the environmental impact is analysed for the funeral techniques. The impacts of the different main steps, as have been described in chapter 4, are shown in Figure 11. The allocation of all smaller steps to these four main steps is explained in the caption.

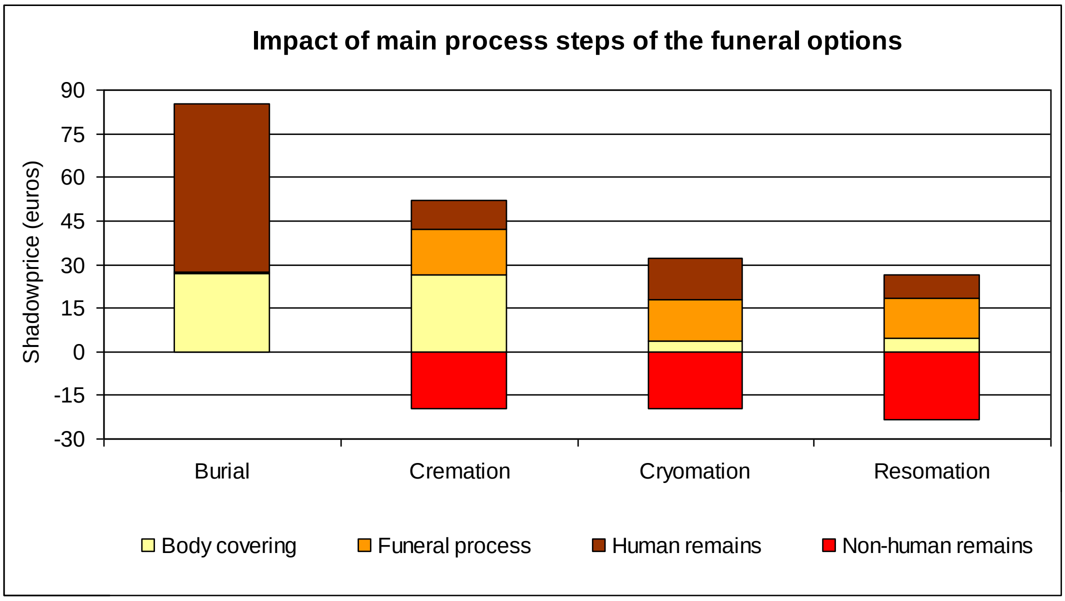

Figure 11 - Impact of main process steps of the funeral options.

Explanation to figure 11: “Body covering” includes body bag, coffin and, if relevant, special clothing. “Funeral process” includes preparatory activities like digging and elevator, processes themselves, direct emissions to air and water, machines, and utilities. “Human remains” includes grave rest period, monument, treatment of remains like ash processing, scattering, etcetera. “Non-human remains” includes metal recycling or reuse of all body related materials (coffin and machine disposal is accorded for in the previous categories) and disposal of dentures.

The burial bar is quite different from the other bars. “Funeral process” is not visible in the burial bar because only digging and elevator were allocated to this; the burial route has no mechanical processing step like the other funeral techniques. Nor is “non-human remains” visible, because the non-body materials are buried together with the human remains and are not treated (and thus not calculated) separately; the non-human remains are included in the bar of the “human remains”.
The other three options can be well compared among each other by means of Figure 11. “Body covering” shows the largest differences: high impact for burial and cremation, and low impact for cryomation and resomation, because the former use 1 coffin per deceased, while the latter reuse the coffin about 50 times. For cremation the coffin is decisive for the difference in impact with cryomation and resomation. “Funeral process” is almost equal for the three funeral techniques.

“Non-human remains” is only slightly different for each option, because in cremation and cryomation the non-body metals are only recycled, while in resomation some metal parts are reused instead of recycled[10]. Last, “human remains” shows some variation in the outcomes. These are further investigated in the sensitivity analyses of paragraph 5.2.2.

5.1.4 The environmental impact of the most relevant materials and processes

The contribution of the materials and processes in the cycle to the total environmental impact of the different funeral techniques are calculated separately. In order to make clear which contributors are the most important the total impact is expressed in terms of shadow price. The results are shown in Figure 12. Only the five most important contributors per funeral part are shown.

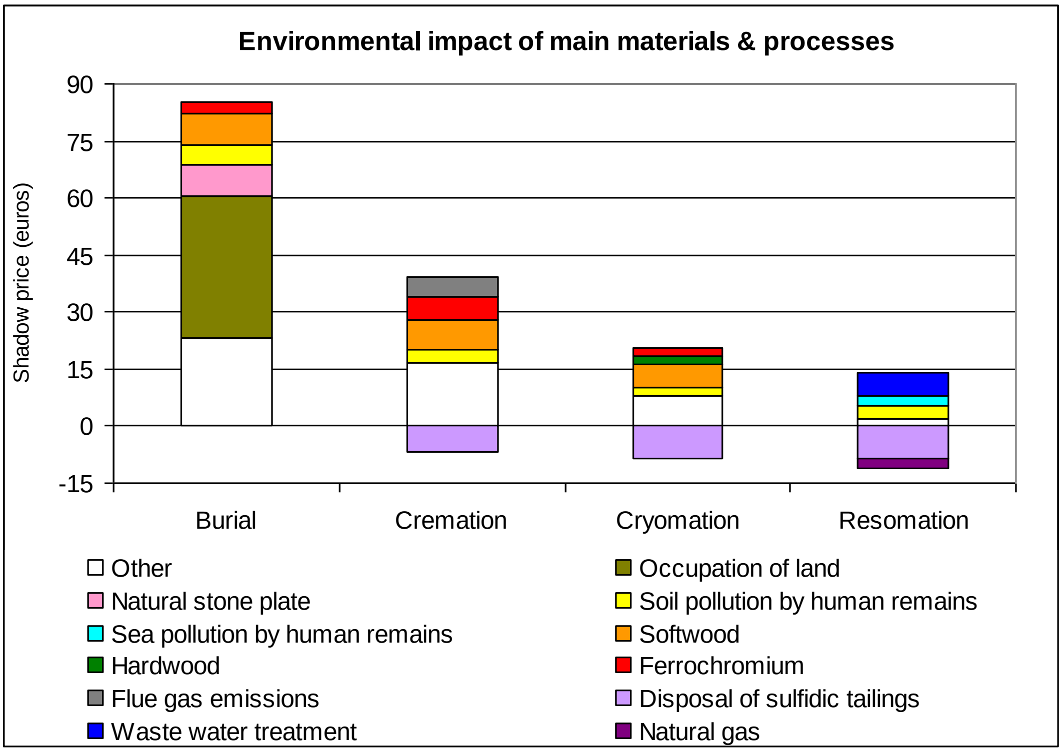

Figure 12 - Environmental impact in shadow prices of main materials and processes for the four funeral techniques (five most contributing factors are shown).

Figure 12 shows very different materials and processes. Four factors are visible in more than one funeral part:

- Soil pollution by human remains appears for all techniques. The impact seems to be by far highest for burial, but this is a bit misleading, because for burial, 100% of the deceased is buried, while for the other techniques it was assumed that only 75% or 80% was disposed to the earth in the form of burial as compost or scattering over land; the remaining part is scattered

---

[10] Resomation Ltd claims, among other things, that certain materials can be reused. It has been assumed to be correct, since there is an interest for Resomation Ltd to deliver reliable data. It has not been proven though that the quality of prostheses after resomation is of sufficient quality to be reused, and it is debatable whether these are going to be reused in reality. These questions cannot be answered within this research, and are considered part of the error margins of the study.

over sea. Partly due to this, the contribution to soil contamination is larger for burial than for the other techniques.

- Softwood is relevant in burial, cremation and cryomation. For the first two, this is caused by the part of the coffins that is made of softwood. For cryomation, it results mainly from the small wooden plaque that is applied as grave monument in the standard situation (see paragraph 5.2.5 for the sensitivity analysis on the specific material choice).
- Ferrochromium is also relevant in burial, cremation and cryomation, as an effect of stainless steel use for the coffin grips and the cryomator.
- Disposal of sulfidic tailings is a process in primary gold production. The environmental impact of this process is avoided as a result of the recycling of gold. This avoided environmental impact is visible as negative shadow prices for cremation, cryomation and resomation.

Generally, one can conclude from Figure 12 that the differences in environmental impact among the funeral techniques other than burial are strongly influenced by compensating effects from metal recycling. Cremation, cryomation and resomation offer better possibilities for recycling of valuable metallic remains than burial. Cryomation and resomation manage to separate the non-human remains more efficiently from the human remains than cremation does, and therefore the human ashes that remain afterwards are slightly cleaner in these funeral types. The environmental impact of burial is determined for about 50% by occupation of land.

5.2 Sensitivity analyses

5.2.1 Overview

By means of sensitivity analyses, the sensitivity of the results for variations in the input data can be analysed. Hereby, insight can be gained in the robustness and variation of the results. Sensitivity analyses can be performed on topics with uncertainties in the used methodology, applied choices or input data, or when large contributions determine the general picture or trends play a major role.

For this study, six sensitivity analyses were performed, on the following subjects:

1) Destination of remains;
   Cremation, cryomation and resomation have several options for the destination of the remains after the funeral process. In the calculations, each option was assigned a percentage. The question is how these percentages influence the results, and what the environmental effects of the destination of remains would be without this distribution. Composition of resomation waste water;
2) The composition of the waste water of resomation is not totally clear and there is little empirical information about it. For the calculations, major assumptions have been made on this topic. This sensitivity analysis investigates these assumptions.
3) Utilities of resomation and cryomation;
   The new techniques have barely been tested by external parties, and therefore the information that the companies provided for this research brings about some uncertainties. By means of varying the input data, this analyses checks how sensitive and dependent the results are for the input data.

4) Type of monument for cryomation burials.
   A large factor for cryomation seems to be the wooden plaquette that was placed on the grave of the buried remains, as shown in Figure 12. Cryomation Ltd called this material choice “the most likely”. This analysis investigates how large the influence is of this choice.
5) Recycling of metals
   Recycling of metals has a large influence on all results and therefore requires a sensitivity analysis. In this analysis, the fraction of primary metal that is recycled is varied.
6) Body coverage
   The environmental impact of cremation in comparison to the two new techniques is largely caused by the body coverage. In this sensitivity analysis, the effects of the potential variation in body coverage is compared to the average Dutch situation for cremation.

These sensitivity analyses are further discussed in the following sections. The last paragraph of this chapter discusses in short the other sensitivities which have not been quantitatively investigated.

5.2.2 Destination of remains

The final destination of the remains influences the total environmental impact of a funeral. For burial, the impacts are clear: the specific location of the cemetery highly influences the decomposition rate and the type of decomposition. For example, burial in peat soils causes more methane emissions, and consequently global warming, than burial in sand soils. It is unknown how large the environmental effects are in other circumstances.

The environmental effects of the destination of remains with the other techniques however, can be investigated in further detail. The general results have been calculated by assuming a certain distribution of the different destination options. This sensitivity analysis investigates the different options separately, thus without weighting.

The options have been analysed per technique. In the following paragraphs, Figure 12, Figure 13 and Figure 14 present the results of the comparison of the different destination options for cremation ashes, cryomated remains and resomated remains respectively (after removal of valuable metals).The description of these options is mentioned in chapter 4.

Destination of cremation ashes

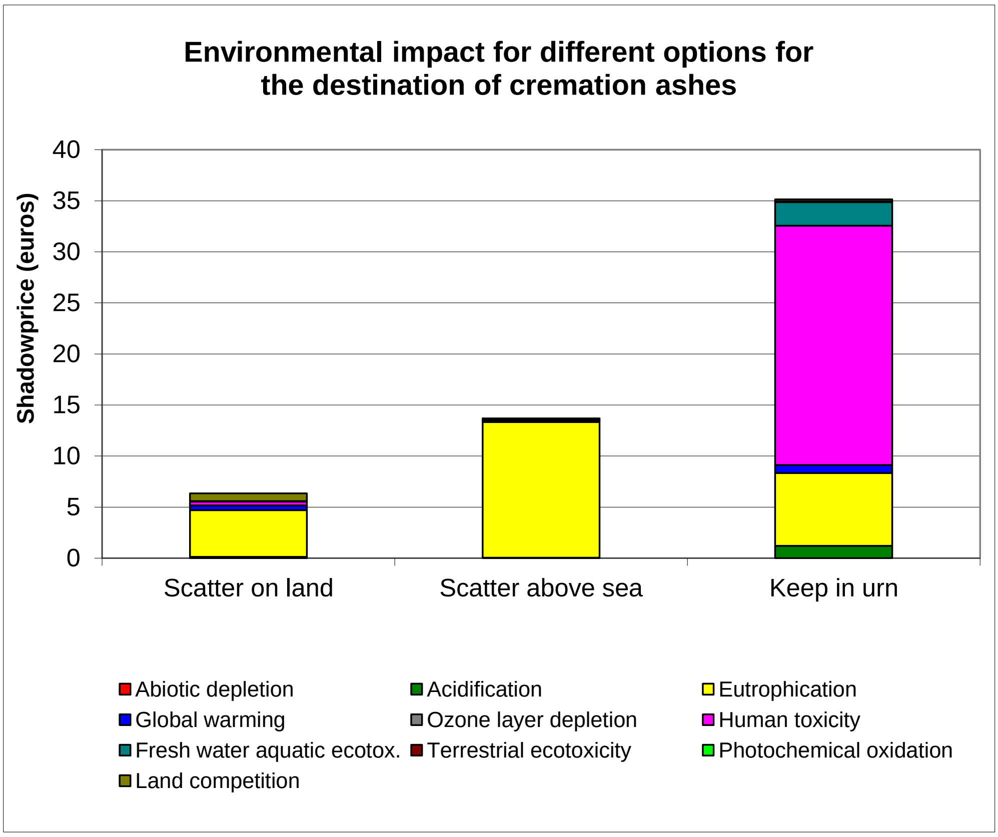

Figure 13 - Comparison of the environmental impact of different options for the destination of the cremated remains. The different options are already explained in chapter 4. In the standard situation, the assumed distribution was (from left to right): 75%, 20% and 5%. The total impact of the remains was 9.3 Euros.

The results indicate that scattering over sea is worse for the environment than scattering over land. Keeping the ashes in an urn for years has a high impact mainly caused by the production of brass, which has a high environmental impact (especially on human toxicity). In this research it was assumed that 80% of the urns are made of brass, because this fact was communicated by an urn producing company.
This material choice can be debated, but the question is then how large the influence is of the urn on the total effect. For the whole cremation lifecycle assessment, the specific material for the urn will probably not have a very large influence, because keeping in an urn is applied in only 5% of the cases.
In this case, the choice for brass determines 1.2 Euro[11] of the total cremation lifecycle costs. Choosing another material, with a smaller environmental impact than brass, would decrease the total cremation impact with up to about one Euro.

---

[11] This can be deducted from Figure 12. The difference between the urn and scattering over land is 35 – 6 = 29 euros. Given is the fact that 80% of the urns is made of messing and that 5% of all ashes is kept in an urn. Leaving out all brass urns, leads to the following calculation: €29 x 80% x 5% = 1.2 Euro.

Destination of cryomated remains

There are many options for the cryomated remains, as shown in Figure 13..

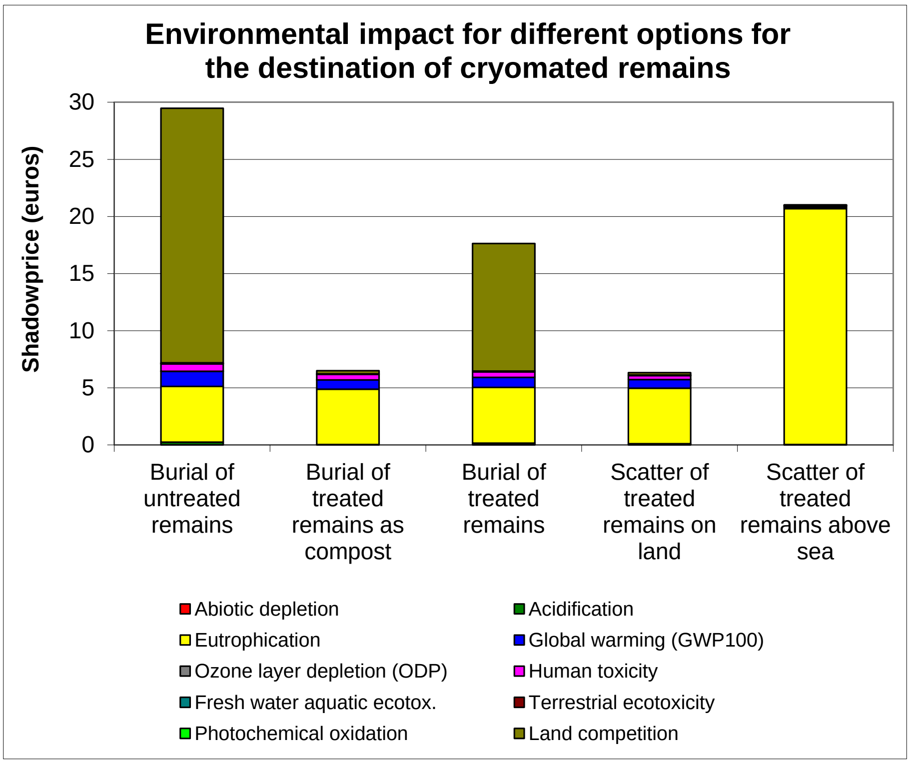

Figure 14 - Comparison of the environmental impact of different options for the destination of the cryomated remains. The different options are already explained in chapter 4. For the treated remains, the microbial treatment is taken into account as well. In the standard situation, the assumed distribution was (from left to right): 23%, 40%, 14%, 20% and 3%. The total impact of the remains was 13.9 Euros.

Direct burial of untreated and treated remains and scattering over sea, have a high environmental impact related to land competition. Burial of the treated remains as compost or scattering of the treated remains over land have the lowest impact (small contribution from land competition). A small advantage of burial as compost is that it avoids the production of artificial fertilizer. Without this advantage, it scores just as high as normal burial of treated remains. Scattering over land is thus again the option with the lowest environmental effect.

Keeping the cryomated remains in an urn is not considered, but the same reasoning can be followed as in the cremation paragraph. Keeping the remains in an urn causes a higher burden than scattering over land due to the urn production and disposal. If a fraction of all destinations of remains would be keeping them in an urn, than the total environmental impact of cryomation would probably be about one Euro higher (depending on the urn material and on which alternative would decreased in favour of keeping remains in an urn).

The results of the different options show that the total environmental effect of cryomation in the future is largely dependent on the choices that will be made for the last destination. These choices are hard to predict, which means that the results are sensitive on this point.

Destination of resomated remains

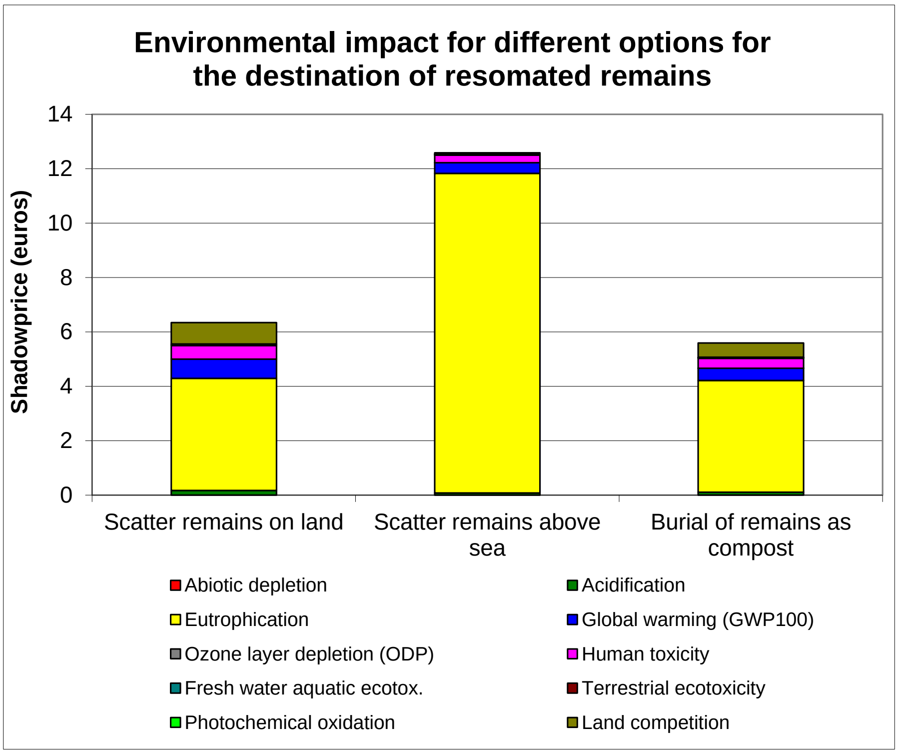

Figure 15 - Comparison of the environmental impact of different options for the destination of the resomated remains. The different options are already explained in chapter 4. In the standard situation, the assumed distribution was (from left to right): 25%, 25% and 50%. The total impact of the remains was 7.51 Euros.

For the resomated remains there are fewer options, but the results shown in Figure 14 lead to the same conclusions as for cryomated remains; scattering over sea has the highest impact, burial as compost or scattering over land have the lowest, with the note that burial as compost has also a compensation factor in the form of avoided fertilizer production and therefore has a slightly lower shadow price. Keeping the resomated remains in an urn is not considered, but this would have probably only a minor influence, as discussed in the previous paragraph. Altogether, the distribution of the options seems rather comparable to the cremation options. Therefore, variation of the results of the different options will probably not largely affect the overall results.

5.2.3 Composition of resomation waste water

The composition of the resomation waste water is a difficult factor to model, because in the first phase of the research there was no data available about the exact composition of the water. The composition of the body (according to, among others, Forbes (1987); shown in Appendix C) was used as a starting point, assuming that the bones (calcium phosphate) did not dissolve in the solution, and with them a certain amount of metals and minerals which are fixed to the bones. The question is however, which share of metals and minerals stays in the bones and thereby reaches the soil and water as a consequence of scattering or burial, and which amount goes to the regional waste water treatment plant. In the original

calculations, the metals and minerals were distributed equally among the remains and the water.
For this sensitivity analysis however, it was analysed what would happen in a worst case scenario, when all substances would be in the solution instead of in the bones. This was compared to the standard situation. Additionally, it was investigated how the picture would look like if the resomation waste water would not be specially treated at all, but just considered as ordinary household waste water. At last, a water analysis report carried out by Mr. Anderson of the Contaminated Land Assessment & Remediation Research Centre [6], commissioned by Resomation Ltd, was received and taken into account as a third option for this sensitivity analysis. The result of this analysis is shown in Figure 15.

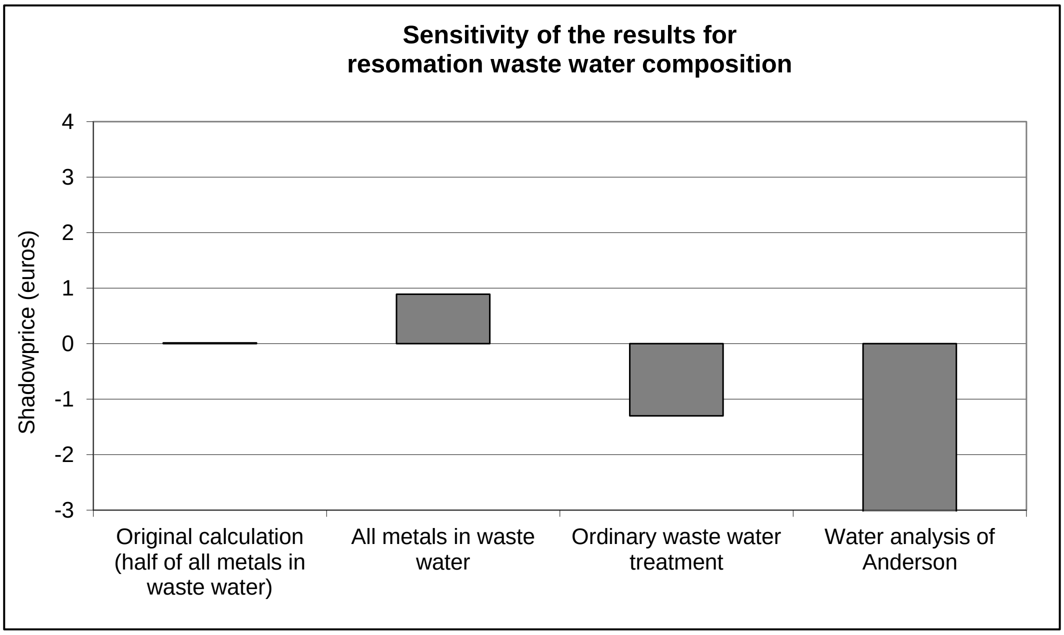

Figure 16 - Sensitivity analysis for the composition of the resomation waste water. The graph shows the effect of these analyses on the environmental impact of the complete resomation life cycle.

The left bar of Figure 15 shows the original calculation by which 50% of the metals of the human body were assigned to the waste water; the next bar shows the calculation with all metals in the waste water. These bars differ only about 1 Euro in absolute values, but it makes a difference between either or no environmental impact. This indicates that the exact allocation of the metals and minerals in the waste water are not relevant for the comparison of resomation with the other techniques, but that it does matter for conclusions about whether resomation does have an impact or not.
The third bar, calculated with ordinary waste water treatment, is 1 euro lower than the original calculation, and 2 Euros lower than the all-in calculation. This means that considering the resomation waste water as ordinary waste water might lead to an underestimation of the environmental effects.
However, the last bar, based on the water analysis of Anderson [Anderson, 2007], shows a whole different picture: this bar shows a negative shadow price for resomation and is thus the lowest bar of the graph. The fact that this bar is negative, is caused by the reycling of metals, which cause a compensation of the environmental effects. In this bar, the net effects are even negative.

Some notes should be taken into account before drawing conclusions about Figure 15. First, the water analysis of Anderson showed some discrepancies with the body composition analysis of Forbes (1987) that was used in the other scenarios. This illustrates the large fault margin of the outcomes due to assumptions on the water composition, and the danger of drawing conclusions too quickly. The other complication is that there is an incomplete insight in the mass balance of carbon in the resomation process and the different analyses, which is another major cause for the variation in the results.
The result of this sensitivity analysis is that because of discrepancies in body composition data the impact for resomation can be between about 1 euro and about -5 euros. On the basis of the hereby identified uncertainty, it cannot be concluded whether resomation has a net environmental burden, no environmental impact or a net environmental benefit. Yet resomation holds an advantage in terms of environmental impact compared to the other funeral techniques, irrespective of the waste water composition.

5.2.4 Utilities

Received data on use of utilities for the funeral techniques cryomation and resomation are expected to be not very accurate. Therefore a sensitivity analysis is done under the assumption that the use of utilities could be 50% higher than according to the data received for the different funeral options.

<u>Cryomation process</u>
Important utilities in cryomation are liquid nitrogen and electricity. The influence of these utilities was tested by increasing their use with 50%. The results of this sensitivity analysis are shown in Figure 17. The increase in both utilities results in a 35% higher impact.

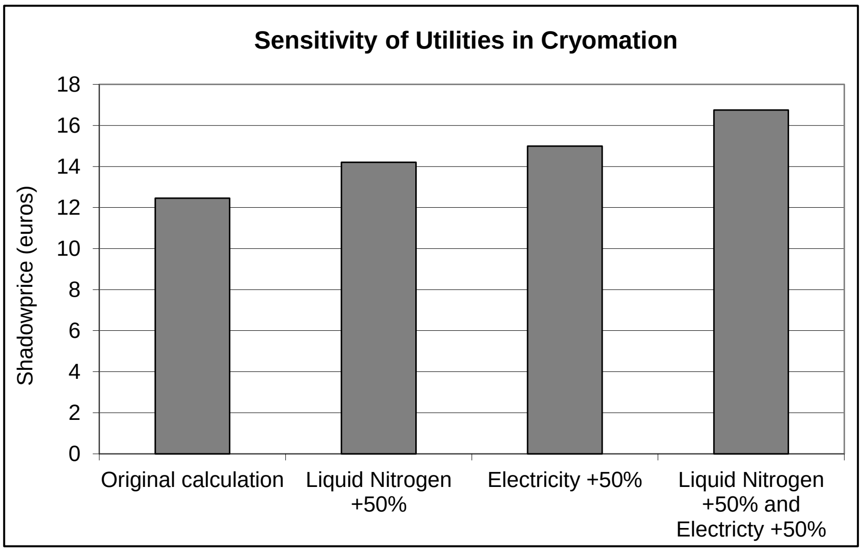

Figure 17 – Sensitivity of utilities in Cryomation.

Resomation process

For resomation, the same procedure was followed. The main utilities are potassium hydroxide, water, gas and electricity. Varying the amount of potassium hydroxide and water has two complications, namely that the concentration and the acidity of the waste water will change. Only the amount of the inputs is varied and not the composition of the waste water. The utilities potassium hydroxide, water, gas and electricity are raised by 50% in order to see their influence. The influence of their variation on the composition of the waste water is ignored.

The results are shown in Figure 18. If the use of potassium hydroxide is raised by 50% this results in an increase of the impact by more than 2 euros. This increase would cause the environmental impact of resomation to become almost as high as the impact of cryomation. Variations in water, gas and electricity use have minor influence on impact.

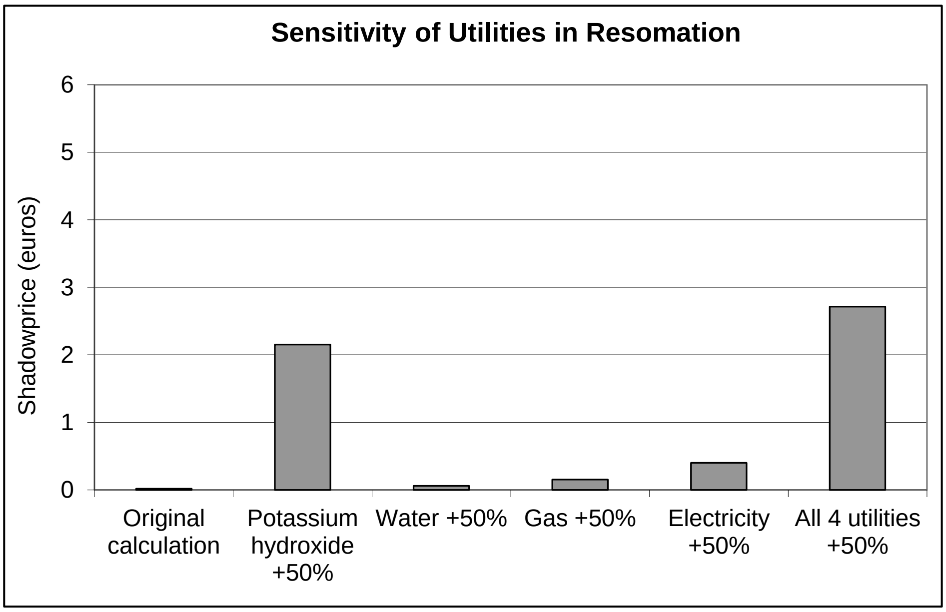

Figure 18 – Sensitivity of utilities in Resomation.

5.2.5 *Type of monument for cryomation burials*

The impact of softwood on the total environmental impact of cryomation seems rather high (see Figure 12), while this originates from a specific choice of material for grave monuments. An additional analysis was performed in order to see the effect of material choice. In this analysis, a stone monument was chosen instead of a wooden plaque. This was done for all variations for burial of the cryomated remains.

The environmental impact of this scenario of cryomation is lower than in the standard situation; the total shadow price of a cryomation is now 9 Euros, which means a reduction of about 3.5 Euros. This shows that the specific material choice does influence the net result of cryomation, but does not change the general conclusions about the environmental impact of the four funeral techniques.

5.2.6 *Metal recycling*

This sensitivity analysis investigated to what extent the results are influenced by variation in the benefits of recycling as a consequence of the choice for the percentage of primary metal in the production of metals. Note that the production

itself for chirurgic metals is not taken into account, but that the assumption of the ratio between primary and secondary material does influence the avoided environmental burden of recycling.
Figure 19 shows the net shadow prices for three scenarios: the original scenario in which the production of primary metal is avoided for a part of all the material, as shown in Table 7, furthermore a scenario with 0% avoided primary metal and a scenario with 100% avoided primary metal. The recycling efficiency of 90% is kept stable in all scenarios.

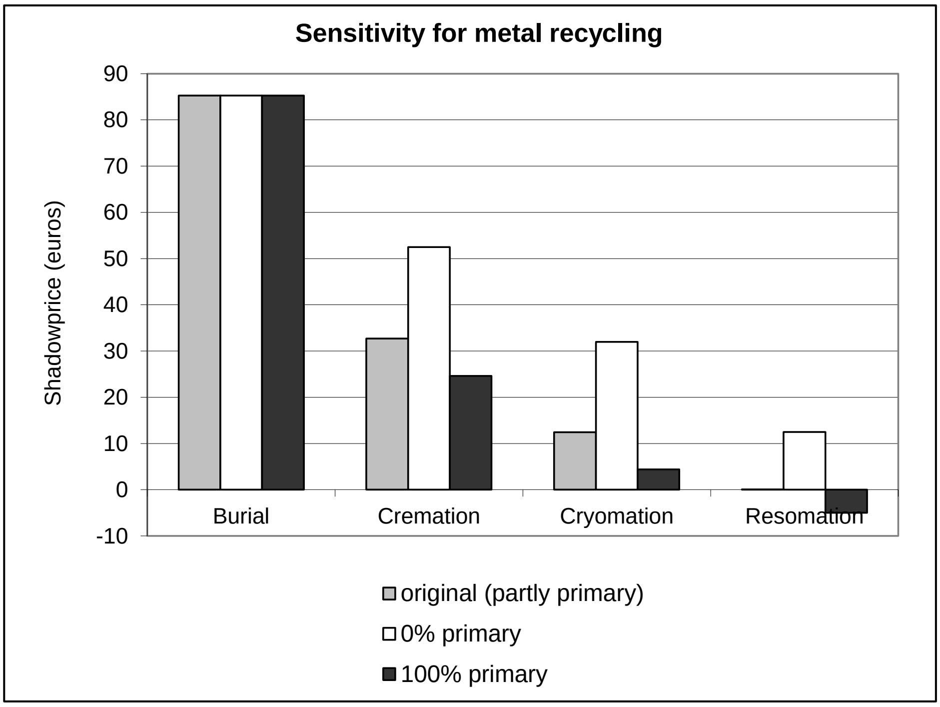

Figure 19 - Sensitivity analysis for the avoided environmental impact for the recycling of metals: shadow prices for the three funeral techniques in three scenarios. The following scenarios are considered: the original situation in which the production of primary metal is avoided after recycling for a part of the material, and situations in which respectively 0% and 100% primary metal is avoided. The burial bar does not change but slightly, because there is almost no metal recycling, except for marginal objects like the elevator

Figure 19 shows that metal recycling is a very influential factor; the difference between 0 and 100% avoided primary metals causes a difference in the final shadow price up to about 30 euros. However, this graph shows as well that the used recycling percentages do not change the major conclusions; burial still has the largest shadow price and resomation has the smallest one, in all scenarios.
In the scenario of 100% avoid primary production, the net environmental impact of resomation becomes negative. In other words, resomation then becomes beneficial for the environment. This requires however to be put into perspective; the shadow price is negative because the recycling of chirurgic metals is taken into account, but not the production.

5.2.7 *Body coverage*

The difference between cremation on the one hand, and cryomation and resomation on the other hand is mainly determined by the differences in environmental impact of the body coverage. In the average situation for cremation

the coffin is made of an average amount of particle board, oak timber and pine timber. The interior of the coffin determines almost half of the environmental impact of the coffin.
As a consequence of the choice for the coffin material, the environmental impact can vary about a factor 3 to 4. Oak timber is the least environmental friendly option and particle board is the most environmental friendly one. The production costs of the coffin play almost no role in cryomation and resomation due to reuse of the coffin. The additional environmental impact of cremation with respect to cryomation or resomation could be reduced with about 40% in comparison to the used average values. When reused timber is used for the coffin, this difference could become even a little larger. However, this does not change the main conclusion about the sequence of the for funeral techniques.

5.3 Other sensitivities

As already mentioned in paragraph 5.2, there are a lot of aspects which play a role in the sensitivity of the results. In this research, the most important aspects are discussed in the previous sections. Nevertheless there always remains range of subjects which might be interesting to investigate into further detail. These subjects are discussed shortly in this paragraph.

5.3.1 Methodology

In this research, the results have been presented both weighted and unweighted. Weighing however, directly involves subjectivity. A part of this subjectivity can be avoided by using several weighing methods, like ReCiPe and the Ecoindicator 99, and by comparing the results with the different methods. Such a sensitivity analysis has not been performed in this study, because the sequence of the four funeral techniques was the same for almost every impact category (see paragraph 5.1.1) and because it was clear from a preliminary research on this topic (Keijzer, 2011) that the specific method choice did not have decisive influence on the conclusions.
The used excel models, the waste model and the waste water treatment model, deserved some critical review as well. The waste water treatment model has been investigated in the previous paragraph. Following the same study of Keijzer (2011), there were indications that the applied choices in the waste model would not make a large difference, and therefore this topic has not been further investigated in this study.

5.3.2 Choices

In every study, numerous choices are made, but not each choice is important enough to be subjected to a sensitivity analysis. An important choice in this research was to choose for considering an “average situation” of all techniques and thereby placing them all at the same level in their development. In the future, when more knowledge is gained about the development of the techniques, a recalculation can be very useful. At this moment, very little is known about how the techniques might evolve.
Besides this system definition, many choices have been made with respect to material choice. Sensitivity analyses have been performed when these choices had clear influence on the results, like the wooden plaque for the cryomation grave. In the other cases, no additional analysis has been performed.

5.3.3 *Input*

The sensitivity of the inputs goes well with the previous section. When there were clear indications that certain input parameters had a large influence on the total, a large fault margin or much variation, additional attention was paid to this parameter. In most cases however, for example the variation in submitted values of gas use for cremations, it was possible to reason without further research why an average value would suffice. Additional sensitivity analyses were therefore not considered necessary.

5.3.4 *Large contributors which determine the general picture*

The largest contributors have been analyzed and given in, among others, Figure 12. For this subject, the same principle was followed as in the previous sections; in the first place these results have been analyzed theoretically and afterwards there was no more reason for sensitivity analyses except for the ones that had already been performed.

5.3.5 *Trends*

A last point of discussion is the sensitivity of the results for certain trends. Future developments that might have an influence on the results, are:

- Depletion of resources. For example, a scarcity of fossil fuels might cause the environmental impact of cremation to become worse than the other techniques.
- Water scarcity. The environmental impact of resomation could be altered if water would be a scarce resource.
- Climate change. A warmer climate can influence decomposition processes for the burial of human remains. Little is known on this topic.
- Metal recycling. Global metal recycling rates are expected to raise. As an effect of better cycle management and closed loops, the environmental impact of one kilogram of metal will become lower, because less metal will have to be produced from raw ore on total. As a consequence, the compensation value of recycling of chirurgic metals will become lower as well and cremation, cryomation and resomation will have fewer benefits than burial than they have in the original calculations.

Besides, there are some developments which might influence the results:

- Embalming. In the Netherlands, embalming is prohibited, but since 2011 a light form of embalming is admitted: thanatopraxie. It is not clear yet what influence thanatopraxie could have on the environmental impacts of the different funeral techniques.
- Change of dental filling types. The amount of mercury fillings is already decreasing and is replaced by other filling materials. The influence of this development on the calculated environmental effects is very small however. The crematorium emission rules are very strict in the Netherlands, and therefore almost no mercury enters the atmosphere because it is filtered out before release to air. The results of this study showed indeed that the contribution of mercury emissions is very low. Therefore it is not expected that changes of filling types will have large influences on the results.

6 Conclusions

From the comparison of LCA results for the different environmental impact categories for the four funeral techniques, it can be concluded that:

- cryomation and resomation have the lowest environmental impact in all categories, except for eutrophication where resomation has the highest impact of all options;
- the current average practice of burial has the highest environmental impact in all the impact categories, except for eutrophication;
- the current average practice of cremation has in all categories an environmental impact that is somewhere in between the other options.

These results lead to the expectation that the total environmental impact of the funeral techniques is the highest for burial and the lowest for resomation or cryomation with cremation in between.

Shadow prices are used for the impact in the different impact categories to calculate the total environmental impact of a funeral technique. The total impact (expressed as shadow price) for the four funeral techniques lays between about 3 Euro per body (resomation) and about 85 Euros per body (burial). Both other funeral techniques are in between: about 30 Euro for cremation and about 10 Euro for cryomation.

The environmental impact of burial is largely dominated by the effect of land competition. Funeral techniques other than burial are largely determined by compensating effects from metal recycling (especially for cryomation and resomation). These funeral techniques offer better possibilities for recycling of valuable metallic remains from the rest streams towards soil, water and air. For cryomation and resomation also small amounts of precious metals can be separated from the remains and recycled leading to bonuses compensating part of the environmental impact.

Important parameters for environmental impact are destination of the remains, composition of the waste water, use of utilities in the processes and the specific material choice for the cryomation grave monument. The coffin is decisive for the environmental disadvantage of cremation compared to cryomation and resomation. Several sensitivity analyses are performed on these parameters.

The analysis of the environmental impact of the destination of remains shows large differences between the techniques. The implication for the total resomation effect is not large, because an average distribution of the options can be chosen, comparable to cremation. The case for cryomation is slightly different, because the volume of the cryomated remains is much larger than for cremation, and therefore there are more options for the destination of the remains, and trends are harder to predict. The sensitivity analysis shows that the future environmental impact of cryomation is partly dependent on these trends.
The composition of the resomation waste water is a difficult factor to model, because of discrepancies in available data on the composition of the body and in what waste streams the dry substances are contained in the different processes. In the original calculations, the metals and minerals were distributed equally among

the remains and the water. The result of the sensitivity analysis is that the impact of resomation can be between about 1 Euro and about –5 Euros.
Increase of use of utilities (liquid nitrogen and electricity) with 50% leads for cryomation to an impact increase of about 30%. For resomation, an increase of the use of potassium hydroxide with 50% leads to almost doubling of the environmental impact.

The starting points and assumptions regarding recycling and the attributed environmental benefits for keeping metals in the loop, have a large influence on the absolute and relative differences in environmental impact among the four alternatives. Nevertheless the order of preference does not change. The choice of the material for the covering in the case of cremation determines to a large extent the amount of additional environmental impact of cremation compared to cryomation and resomation. Also in this case the order of preference does not change.

Taken together the results of all sensitivity analyses it can be concluded that the assumed variations in the processes do not change the general conclusions according to the original impact calculations.

The general conclusion regarding the environmental impact of the funeral technique for an average deceased in the Netherlands is that the total environmental impact is highest for burial followed by cremation. The impact of cryomation and resomation is much lower than for the average current situation for burial and cremation. The impact of resomation is (probably) lowest of all funeral techniques.

7 References

Anderson (2007). *Analysis of Alkaline Hydrolysis Sample.* CLARCC.

Appelman & Kok (2005). *Beoordeling van de milieu-effecten van het Amalgator kwikafvangsysteem voor crematoria.* Apeldoorn: TNO Bouw en Ondergrond.

Axelrad *et al.* (2009). PCB body burdens in US women of childbearing age 2001-2002: an evaluation of alternate summary metrics of NHANES data. *Environmental research, 1090,* pp368-378.

CBS (2003). Steeds minder mensen hebben een kunstgebit. *Webmagazine, 03-11-2003.* Retrieved from: www.cbs.nl/nl-NL/menu/themas/gezondheid-welzijn/publicaties/artikelen/archief/2003/2003-1308-wm.htm (last visited: 04-11-2010).

Dent & Knight (1998). Cemeteries: a special kind of landfill. The context of their sustainable management. *Conference of the International Association of Hydrogeologists: "Groundwater: Sustainable Solutions",* pp451-456. Melbourne, February 1998.

Dijk & Mennen (2002). *Lijkbezorging in Nederland. Evaluatie inspectierichtlijn, overzicht van de branche en inzicht in naleving van regelgeving.* Bilthoven: RIVM.

Doka (2007). *Life cycle inventories of waste treatment services. Ecoinvent report No. 13. Part III, Landfills – underground deposits – landfarming.* Dübendorf: Swiss Centre for Life Cycle Inventories.

Ecogeek (2010). *The greenest way to die: liquification*. Retrieved from: www.ecogeek.org/component/content/article/1529 (last visited: 29-11-2010).

Eggels & Ven (2000). *Background data for the building environment, a reference database. The VLCA database.* TNO-MEP R2000/130. Apeldoorn: TNO Institute of Environmental Sciences, Energy Research and Process Innovation.

Forbes (1987). *Human body composition: growth, aging, nutrition, and activity.* New York: Springer-Verlag.

Guinée, J.B. *et al.* (2001). LCA - An operational guide to the ISO-standards.

Goedkoop, de Schryver & Oele (2008). Introduction to LCA with SimaPro 7. Amersfoort: PRé Consultants.

ISO 14040 (2006). Environmental management – Life cycle assessment – Principles and framework en ISO 14044, 2006: Environmental management – Life cycle assessment – Requirements and guidelines.

Keijzer (2011). *Environmental impact of funerals. Life cycle assessments of activities after life.* Groningen: IVEM (master thesis).

Lima *et al.* (2008). Activated carbon from broiler litter: Process description and cost of production. *Biomass and bioenergy, 32,* pp568-572.

Mbuyi-Muamba *et al.* (1988). Biochemistry of bone. *Baillière's Clinical Rheumatology, 2 (1),* pp63-101.

Ministerie van VROM (2004). *Inspectierichtlijn Lijkbezorging. Handreiking voor de inrichting, technisch beheer en onderhoud van begraafplaatsen, crematoria en opbaargelegenheden. 3^{e} herziene druk*. VROM Inspectie.

Molenaar *et al*. (2009). *Terug naar de natuur. Mogelijke effecten en juridische aspecten t.a.v. natuurbegraven, asverstrooien en urnbijzetting in natuurgebieden*. Wageningen: Alterra.

Morren (2010). *Niet al het goud blinkt. Onderzoek naar edelmetalen en chirurgisch staal in crematieas bij Nederlandse en Duitse crematoria*. Landelijke Vereniging van Crematoria.

NCMS (2010). *Secondary smelting of non-ferrous metals. Impact, risks, and regulations.* Retrieved from: http://ecm.ncms.org/ERI/new/IRRsecsmelt.htm (last visited: 30-11-2010).

Pré Consultants (2010). SimaPro 7.2, http://www.pre.nl/simapro/

Slooff *et al.* (1994). *Basisdocument kwik*. Rapportnummer 710401023. Bilthoven: RIVM.

Smit (1996). *Massabalans en emissies van in Nederland toegepaste crematieprocessen.* TNO MEP R96/095. Apeldoorn: TNO Milieu, Energie en Procesinnovatie.

Steen & Pellenbarg (2007). Ruimte voor de dood. *De Begraafplaats, maart 2007.* Retrieved from: www.begraafplaats.nl/artikelen_db/224 (last visited: 03-11-2010).

Swiss Centre for Life Cycle Inventories (2009). Ecoinvent database v2.1. http://www.ecoinvent.org/database/

Tauw (2006). *Crematorium Leiden emissieonderzoek 2006*. R001-4444100RSA-sbk-V01-NL.

Welch & Swerdlow (2009). *Cryomation Limited - Carbon Trust Incubator - Due Diligence Report.* Oxford: Isis Innovation Limited.

WHO (1998). *Assessment of the health risk of dioxins: re-evaluation of the Tolerable Daily Intake (TDI). Executive summary.* WHO Consultation May 25-29 1998. Geneva: WHO European Centre for Environment and Health, International Programme on Chemical Safety.

8 Signature

Name and address of the principal

Yarden Holding bv
Att. Mr. J. Heskes
Transistorstraat 10
1322 CE Almere

Names and functions of the co-operators:

T.N. Ligthart, Dr.: LCA expert
M.E. Head, MSc.: LCA expert

Date upon which, or period in which the research took place

August 2010 – July 2011

Name and signature internal reviewer

R.N. van Gijlswijk, BSc

Signature:

H.J.G. Kok, MSc
Project leader

Release:

R.A.W. Albers, MPA
Research Manager

A Environmental impact categories

The environmental themes (environmental impact categories) used in this study are explained briefly below.

Depletion of abiotic raw materials (ADP)
Abiotic raw materials are natural raw materials that are regarded as lifeless, such as iron ore, crude oil and wind energy. The exhaustion of abiotic raw materials is one of the most discussed effect categories and as a consequence there are a large number of methods available that can be used to determine the contributions made to this category. Depletion of scarce raw materials is assessed according to the total stock of this substance (metal, mineral, energy carrier) in relation to the annual use. The depletion of abiotic raw materials is expressed in terms of antimony (Sb) equivalents.

Global Warming (GWP)
Climate change is defined as the effect of human emissions on the capacity of the atmosphere to absorb thermal radiation. This can in turn have negative effects on the stability of the ecosystem, public health and material prosperity. Greenhouse gases increase the capacity to absorb thermal radiation so that the temperature of the earth's surface increases, commonly termed the greenhouse effect. Greenhouse gases each have their own different Global Warming Potential and each separate emission can be converted to an equivalent quantity of carbon dioxide (CO_2) emission.

Depletion of the ozone layer (ODP)
The destruction of the ozone layer in the stratosphere by human emissions results in a greater part of the UV-B radiation from the sun reaching the earth’s surface, with possible harmful effects on public health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and biochemical compounds. The most important compounds that have impact on the ozone layer are chlorofluorohydrocarbons (CFKs) and halons. The capacity of compounds to have impact on the ozone layer is expressed in equivalents of the reference substance CFK-11.

Human, aquatic and terrestrial toxicity (HTP, FAETP, MAETP, TETP)
A multimedia distribution model, USES, developed by RIVM (National Institute for Public Health and the Environment) and developed further for use in LCA applications by the University of Amsterdam (Huijbregts, 2000) is used to determine the potential toxicity of a substance. How much of an initial emission can *potentially* eventually migrate to other environmental compartments is determined using substance-specific distribution factors. The calculated quantity of substance per environmental compartment is then divided by a factor derived from toxicology, such as the acceptable daily intake (ADI) or no-observed-effect concentration (NOEC), depending on the effect category and the substance group.
Human toxicity refers to the effects of toxic compounds in the environment on public health. Freshwater aquatic ecotoxicity and marine aquatic ecotoxicity refer to the effect of toxic compounds on freshwater aquatic ecosystems and marine aquatic ecosystems respectively. Terrestrial ecotoxicity refers to the effects of toxic compounds on terrestrial ecosystems. Human, aquatic and terrestrial ecotoxicity is expressed in equivalents of 1,4-dichlorobenzene.

Photochemical oxidant formation (POCP)
Photochemical oxidant formation is the formation of reactive chemical compounds, such as ozone, by the working of sunlight on certain primary polluting compounds in the atmosphere. These reactive compounds can be harmful to both health and crops. Photochemical oxidants can be formed in the troposphere under influence of ultraviolet light by the photochemical oxidation of volatile organic compounds (VOC) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx). The capacity for smog formation of compounds is determined using the compound C_2H_2 as reference.

Acidification (AP)
Acidifying compounds have a long series of effects on the soil, ground water, surface water, organisms and ecosystems. Acidification is caused by emissions of acidifying compounds to the atmosphere; the principle acidifying emissions are those of SO_2, NO_x and NH_3. The acidifying capacity of an emission is calculated in terms of SO_2 equivalents. Examples of the consequences of acidification include the decrease of forests, corrosion of building materials and the death of fish in Scandinavian lakes.

Eutrophication (EP)
Eutrophication includes all potential effects of excessively high levels of macronutrients, the most important of these being nitrogen (N) and phosphorus (P). Nutrient enrichment can cause undesirable shifts in the variety of species and increased biomass production in both aquatic and terrestrial ecosystems. High concentrations of nutrients can also make surface water unsuitable for use as drinking water. The increased biomass in aquatic ecosystems can lead to reduced oxygen levels, due to the extra oxygen used for degradation of the biomass. The total eutrophication effect of an emission is converted to equivalents of PO_4.

Land Competition (LC)
The environmental impact of land competition only relates to the use of the soil surface during a certain period of time and not to the effect on biodiversity or other impact on the ecosystem. The equivalent unity for land competition is: m2·year.

B Pricing the environment: the concept of shadow prices

Technological innovation often presents us with problem of weighting different environmental impacts, since new technologies are often performing better in many environmental aspects but not all. To what extent is a deterioration in one environmental theme counterbalanced by an improvement in another? One of the methods used to value environmental impacts, which is operationalized for a number of impact categories, is known as the shadow price method which uses the highest acceptable costs for mitigation measures as a valuation (Harmelen 2007; CE 2010). This is based upon the following principles.
Suppose, a demand for environmental quality or damage limitation exists on a virtual market for environmental quality, where the willingness to pay a high price will increase with the emission level of pollution. Also, a supply of emission mitigation measures is available that will cost more per unit of reduction at higher reduction levels. If this market existed, an equilibrium price would arise at the intersection of demand and supply. This is illustrated in the figure below.

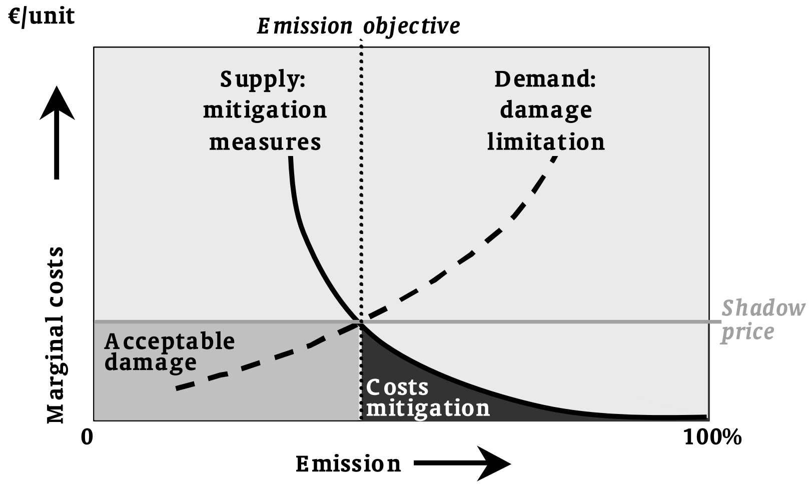

Figure 17 - In a virtual market, demand for environmental damage limitation and supply of emission mitigation by measures will result in an equilibrium price for environmental quality. If a government's emission objective will cross the equilibrium point, the shadow price is equal to the equilibrium price.

Since the environmental market is a virtual market and the costs of environment are so-called external costs, the government has to set an emission objective to improve the environmental quality. The price level at the crossing of the emission objective and the supply of emission mitigation is called the shadow price, being the highest acceptable price for the government to be paid by society for improving environmental quality. The shadow price is the extent to which total costs change as a result of a change in a limiting factor, in this case an emission objective.

The total environmental costs for society will be the costs of mitigation (the shaded area under the supply curve) plus the damage to the environment, being the remaining emissions multiplied with the price level that society is willing to pay (according to the demand curve). In market equilibrium this is the equilibrium price.

The government will aim its emission objective at the intersection of demand and supply since the virtual environment market is at this point in equilibrium according to society. Under the assumption that the government manages to design a policy of which the shadow price equals the equilibrium price, the shadow price multiplied with the remaining emissions indicate the environmental damage as perceived (and accepted) in society. This principle is used when applying the shadow price method.

The advantage of using shadow prices is that different environmental impacts are translated into (external) costs that can be compared with the internal production costs. Several sets of shadow prices have been assessed mainly for near future targets of well-documented Environmental Impact Categories (EIC) such as climate change, acidification, ozone depletion, tropospheric ozone formation and eutrophication, e.g. by ExternE (2005), NewExt (2009), HEATCO (2006), CE (2010), NIBE (2002) and van Harmelen (2003). The European Commission often requires Cost-Benefit Analyses of newly developed policy measures or scenarios, using this valuation of external effects.

If there is a need for monetization of impacts, the methodologies used for economic valuation that are distinguished are based on *avoidance costs* or *damage costs*. Traditionally, the policy debate on climate change has focused on the cost of emission mitigation, e.g. the cost of GHG emission reduction. Whereas the costs of emissions of local/regional pollutants may be based on *damage costs* as the impacts are mainly local or regional by nature, and the temporal extent may also be limited, the impacts of GHG emissions are global and long-lasting (up to hundreds of years).

The methodology denoted as ‘avoidance costs’ focuses on quantification of the *abatement costs* (instead of damage costs). Mitigation costs of GHG emissions use to be based on abatement costs, e.g. in the updated impact pathway approach or ExternE methodology, as a proxy for environmental cost (external cost) analysis. For the determination of damage costs a methodology was developed on behalf of the European Commission to quantify the *energy external costs* (ExternE). The research resulted in the development of a methodology called the *Impact Pathway Approach*. This approach to quantify environmental impacts is described in the ExternE research program (Externalities of Energy). Four main steps are distinguished:

- Emission: specification of the relevant technologies and pollutants.
- Dispersion: calculation of increased pollutant concentrations in all affected regions.
- Impact: using exposure-response functions for calculation of impacts cumulated exposures.
- Cost: valuation of impacts in monetary terms.

Therefore, the methodology denoted as ‘damage cost’ aims to quantify potential environmental impacts based on quantifiable damage costs incurred by humans, flora and fauna, buildings, etc. from emissions (to air, water, soil) that arise in case of a specific (power generation) technology. Whereas the ExternE methodology originally focused on GHG emissions, (local) air pollution and radio nuclides, recent extensions of the methodology address land use change, cultural heritage, impacts on building materials, biodiversity, visual impact, and noise.

Using ‘ExternE’ has the advantage that it draws on a relatively long history of quantification of external effects (from power generation). It is used as a corner stone for development of sustainable energy policies. Also, it enables the researcher to take into account long-term effects, e.g. the effects of GHG emissions. Limitations of the ExternE methodology relate to the geographical area considered, limitations with regard to dispersion and with regard to impact category.

References for appendix B

CE, Guidebook Shadow prices – weighting and valuation of emissions and environmental impacts (in Dutch: *Handboek schaduwprijzen – waardering en weging van emissies en milieueffecten)*. CE, Delft, the Netherlands, 2010, CE № 10.7788.25a.

CE, Handbook on estimation external costs in the transport sector, 2008

ExternE: *Externalities of Energy Methodology - 2005 Update*. Peter Bickel and Rainer Friedrich, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER) Universität Stuttgart, Germany, 2005.

Harmelen, A. K. v., T. N. Ligthart, S. M. H. v. Leeuwen, and R. N. v. Gijlswijk, 2007a, The price of toxicity, Methodology for the assessment of shadow prices for (eco-) toxicity and abiotic depletion, co-Efficiency in Industry and Science, Quantified Eco-Efficiency: p. 105-125.

HEATCO - Economic values for key impacts valued in the Stated Preference surveys, 2006.

Horssen, A.v., A. K. v. Harmelen, 2008. Monetization of Environmental Impacts in the RWS Catalogue Environmental Measures. TNO report 2008-U-R1325/B.

NEEDS: *New Energy Externalities Developments for Sustainability (NEEDS) - RS1a Deliverable № 6.1External costs from emerging electricity generation technologies.* Sixth Framework Programme, Project № 502687, March 24, 2009.

NewExt: New Elements for the Assessment of External Costs from Energy Technologies, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER) Universität Stuttgart, Germany, 2009.

C Specific input data for the LCA calculations

This appendix contains all numbers that have been used as an input to the LCA calculations. Table 4 and 5 show the human and non-human material composition respectively, for the average deceased. Table 6 provides a background for calculations with the landfill model. The figures that were used with respect to the recycling of metals are given in table 7. Table 8 deals with flue gas emissions. Finally table 9 up to 12 inclusive show the specific input data for the LCA calculations for each of the four funeral techniques.
Besides the sources mentioned in the tables, all other data presented in the tables have been derived from questionnaires returned to TNO by: Yarden, Cryomation Ltd, Resomation Ltd, Orthometals, Genius Loci, Groentotaal de Boer, Unigra B.V., Facultatieve Technologies, IFZW, De Gedenkgroep, SVT, LOB, Honor Piëteitstechniek, Hesselmans International, Funeral Products and Aqua Omega. Data of minor importance, such as the amount of clothing, were obtained through the internet. An explanation to the most important assumptions and the basis for these figures as well as the system description can be found in chapter 4.

Table 4 - Body and remains composition. Small differences are tolerated because several sources use different standard body weights: sometimes 70 kg, other times 75 kg. Note that the composition of the cremation ash shows some discrepancies with the body composition. Nevertheless, it is chosen to use the analysis report of Smit (1996) for the calculations, because it was one of the very few and the most complete cremation ash analysis reports.

Process part:	*Burial of body*	*Cremation ash*	*Untreated cryomated remains*	*Treated cryomated remains*	*Resomated remains*	*Resomated remains for sensivity analysis*
Source:	*Forbes (1987), Slooff* et al. *(2004) & Axelrad* et al. *(2009)*	*Smit (1996); (warm start oven; after cremulation; medians)*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & analysis by Anderson (2007)*
Unit:				*g dry weight*		
Al	0.06	35	0.000	0.060		
As	0	0.01	0.000	0.000		
Au	<0.01	0.44				
Ba	0.02	1.6	0.022	0.020		
Be	<0.0001					
Bo	<0.05					
Br	0.2		0.225	0.204		0.200
Cd	0.05	0.00	0.056	0.050		0.050
Co	<0.01	0.04				
Cr	<0.01					

Process part:	*Burial of body*	*Cremation ash*	*Untreated cryomated remains*	*Treated cryomated remains*	*Resomated remains*	*Resomated remains for sensivity analysis*
Source:	*Forbes (1987), Slooff* et al. *(2004) & Axelrad* et al. *(2009)*	*Smit (1996); (warm start oven; after cremulation; medians)*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & analysis by Anderson (2007)*
		0.40				
Cs	<0.01					
Cu	0.07	8.8	0.079	0.070	0.035	
Fe	4.2		4.7	4.2		3.5
I	0.01		0.011	0.010		0.010
Mn	0.01	7.3	0.011	0.010	0.005	0.010
Mo	<0.01	0.03				
Ni	0.01	1.8	0.011	0.010		0.010
Pb	0.12	0.06	0.135	0.120	0.120	0.120
Ra	<0.0001					
Sb	0	0.03	0.000	0.000		
Se	0	0.00	0.000	0.000		
Si	18		20	18	9.0	
Sn	<0.02	0.29				18
Sr	0.32		0.356	0.322	0.159	0.289
Te	0	0.00	0.000	0.000		
U	<0.0001					
V	0	0.20	0.000	0.000		
Zn	2.3	2.7	2.6	2.3	1.1	1.9
Hg	0.00041	0.0	0.000	0.000		0.00004
PCBs	0.000636		0.001	0.001		0.000636
C	16000		17965	8548		
Ca	1100		1235	1100	1100	1096
Cl	95	11	107	95	47	64
Fl	2.6	0.02	2.9	2.6	1.3	
H	1944		2183	1944	5.5	

Process part:	*Burial of body*	*Cremation ash*	*Untreated cryomated remains*	*Treated cryomated remains*	*Resomated remains*	*Resomated remains for sensivity analysis*
Source:	*Forbes (1987), Slooff* et al. *(2004) & Axelrad* et al. *(2009)*	*Smit (1996); (warm start oven; after cremulation; medians)*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & information from Cryomation*	*Calculation based on body composition & analysis by Anderson (2007)*
K	140		157	140	0.000	
Mg	19		21	19	9.5	18
N	1800	13	2021	1799	0.00	846
Na	100		112	100	50	0.552
O	2556		2869	2555	1144	
P	500	2910	561	500	500	471
Phosphates[12]		0.14				
S	140	7.2	157	140	70	98
Total (kg)	**24.4**	**3.0**	**27.4**	**17.0**	**2.9**	**2.6**

---

[12] As P_2O_5

Table 5 - Data for non-human remains present in or around the body. The explanation of the key assumptions this table is based upon, is given in paragraph 4.1.2.

Material	*Amount*	*Unit*	*Remark*
Cobaltchrome	0.533	kg	Orthometals (2010)
Stainless steel	0.867	kg	Orthometals (2010); part of this is from metal grips; assumption 50%
Titanium	0.800	kg	Orthometals (2010)
Iron scrap	1.333	kg	Orthometals (2010)
Zinc	0.467	kg	Orthometals (2010); Ornaments
Gold	0.283	g	Morren (2010)
Silver	0.124	g	Morren (2010)
Platinum	0.017	g	Morren (2010)
Palladium	0.101	g	Morren (2010)
Methylmethacrylate	36	g	Dentures (Veldhuis, 2010), worn by 50% of deceased (CBS 2003), thus 18 g per average deceased
Mercury	1.5	g	Dental fillings (Molenaar *et al.*, 2009)
Cotton	0.8	kg	Clothing; estimated figure based on internet research
Viscose	0.15	kg	Clothing; estimated figure based on internet research
Leather	0.36	m^2	Shoes: Remmerswaal & Heuvel (2005).; expressed as 1.5 kg if mass was needed (estimated figure based on internet research).

Table 6 – Distribution of substances in the landfill model that has been used to calculate environmental impact of burial of human remains. Further explanation is given in paragraph 4.1.4.

Element/substance	*k-value*	*Source*
Cl	96.55%	Eggels & Ven (2000)
SO_4	34.62%	Eggels & Ven (2000)
PO_4	34.62%	Copied from SO_4
As	0.17%	Eggels & Ven (2000)
Cd	0.05%	Eggels & Ven (2000)
Cr	0.08%	Eggels & Ven (2000)
Cu	0.14%	Eggels & Ven (2000)
Hg	0.50%	Eggels & Ven (2000)
Ni	0.12%	Eggels & Ven (2000)
Pb	0.05%	Eggels & Ven (2000)
Zn	0.02%	Eggels & Ven (2000)
Na	2.00%	Plastic waste model
Ba	0.00%	Plastic waste model
Fe	0.50%	Plastic waste model
Mn	0.00%	Plastic waste model
Sb	0.00%	Plastic waste model
Se	0.00%	Plastic waste model
Heavy metals	1%	Plastic waste model

Table 7 – Amounts of recycled materials. The following outputs and inputs were used in the recycling calculations. Further explanation about the methodology is given in paragraph 4.1.5.

Material	*Outputs/ avoided products*	*Amount (kg)*	*Inputs*	*Amount (kg)*	*Calculation / source*
Chrome	Chrome	0.72	Secondary nickel	0.8	Nickel inputs as a proxy. Recycling: 20% (NCMS, 2010)
Cobalt	Cobalt	0.612	Secondary nickel	0.68	Nickel inputs as a proxy. Recycling: 32% (NCMS, 2010)
Gold	Primary gold	0.639	Secondary gold	0.71	Recycling: 29% (NCMS, 2010)
Palladium	Palladium	0.639	Secondary palladium	0.71	Gold recycling data
Platinum	Platinum	0.756	Secondary platinum	0.84	Recycling: 16% (NMCS, 2010)
Silver	Silver	0.639	Secondary silver	0.71	Gold recycling data
Stainless steel	converter, chromium steel	0.567	electric, chromium steel	0.63	37% recycling as in Ecoinvent
Steel	Steel converter unalloyed	0.567	Steel electric low- and unalloyed	0.63	37% recycling as in Ecoinvent
Titanium	Titanium	0.61	Secondary aluminium	0.678	
Zinc	Primary zinc	0.657	Secondary lead	0.73	Secondary lead as a proxy; 27% recycling (NMCS, 2010)

Table 8 - Flue gas cleaning emissions (more information is provided in paragraph 4.3).

Emissions to air	*Amount*	*Unit*	*Remark*
CO_2, biogenic	30	g/m^3	Welch & Swerdlow (2009, after several sources) determined that the body and coffin together gave rise to a CO_2 emission of about 100 kg (excluding the CO_2-emission due to natural gas combustion). We have assumed that, in line with the mass ratio, one fourth is originating from the coffin (and as such 'normal' CO_2) and, as a consequence, three fourth from the body, as biogenic CO_2.
CO_2	10	g/m^3	From the coffin; gas is counted separately under 'natural gas'.
SO_2	32	mg/m^3	Facultatieve Technologies / Tauw (2006)
CO	19	mg/m^3	Facultatieve Technologies / Tauw (2006)
NO_x	410	mg/m^3	Facultatieve Technologies / Tauw (2006)
Dioxins (PCDD & PCDFs)	0.05	ng/m^3	Facultatieve Technologies / Tauw (2006)
Mercury	0.005	mg/m^3	Facultatieve Technologies / Tauw (2006)
Hydrocarbons	2	mg/m^3	Facultatieve Technologies / Tauw (2006)
Hydrogen chloride	5	mg/m^3	Facultatieve Technologies / Tauw (2006)

Table 9 - Inputs for the burial calculations.

Material/ Process	*Amount*	*Unit*	*Remark*
Body bag	**22%**		**Hesselmans International (2010)**
Cotton	0.490	kg	Unigra (2010); information limited to the qualification “biodegradable”. Assumption: cotton.
Coffin			
Particle board	28.8	kg	Unigra (2010): 36 kg, market share of 80%. Density: ~ 700 kg/m^3 (internet).
Oak timber	6.02	kg	Unigra (2010): 43 kg, market share of 14%. Density: ~ 780 kg/m^3 (internet).
Pine timber	1.8	kg	Unigra (2010): 30 kg, market share of 6%. Density: ~ 580 kg/m^3 (internet).
Sawdust	0.2	kg	Pillow, assumptions.
Cotton	1.8	kg	Interior of coffin. Unigra (2010).
Softwood	0.00134	m^3	Wooden grips; 1.1 kg (Unigra, 2010), 85% of all coffins (Dijk & Mennen, 2002).
Stainless steel	0.433	kg	Stainless steel grips; Orthometals (2010); 15% of all coffins (Dijk & Mennen, 2002). Assumption: 50% of the steel remaining after a funeral, is originating from grips.
Zinc	0.467	kg	Ornaments; Orthometals (2010).
Digging			
Excavation	6.25	m^3	Size of grave = 1.25*2.5*1 meters (Genius Loci, 2010); open and close, thus x2.
Elevator	**95%**		**Honor Piëteitstechniek (2010)**
Stainless steel	0.005	kg	50 kg of mainly stainless steel (internet); assumed to be used 10,000 times.
Recycling of steel	0.005	kg	Table 5 and 7.
Monument	**75%**		**LOB (2010)**
Natural stone plate	285	kg	Covering plate, covers 70% of grave (LOB, 2010) of 120 x 250 cm; assume 5 cm thick = 0.105 m^3.
Concrete	0.0335	m^3	Foundation of 80 kg (De Gedenkgroep, 2010)
Electricity	1	kWh	For engraving (Remmerswaal & Heuvel, 2005)
Transport, lorry	57	tkm	
Transport, ship	1420	tkm	
Grave rest			
Water	282	kg	Assumption: 10 m^3 per year.
Petrol[13]	6.1	kg	About 300 liter of 0.72 kg/l (internet).
Grass seed	0.466	kg	
Burial of body	24.5	kg	See Table 4 and Table 6.
Disposal of inert waste	4.17	kg	Burial of viscose clothing, normal metals, bullions and dentures
Disposal of organic waste	41.9	kg	Burial of coffin, pillow, body bag, cotton clothing, shoes, coffin interior and wooden

---

[13] Groentotaal de Boer suggested that the petrol is actually “Aspen”, a specific low-benzene and low-toluene and low-sulphur petrol, for which no data is available in Ecoinvent or other available databases; low sulphur petrol was used as an approximation.

Material/ Process	*Amount*	*Unit*	*Remark*
			grips.
Occupation of land	188	m^2a	10 m^2 per person divided by on average 2 persons per grave, multiplied by rest period.
Removal			
Excavation	6.25	m^3	Open & close grave
Excavation	40	m^3	Open & close bone grave, 20 liter volume (Genius Loci, 2010); no occupation of land is counted here because the calculation above included already the complete graveyard surface required per person
Transport, lorry	2.74	tkm	Removal of stone and foundation, transport for 10 km (assumption)
Disposal of inert waste	274	kg	Foundation + headstone

Table 10 - Inputs for the cremation calculations.

Material/ Process	*Amount*	*Unit*	*Remark*
Body bag	**22%**		**Same as for burial**
Coffin			**Same as for burial**
Preparation			
Recycling of stainless steel	0.433	kg	Metal grips: in contrast to burial, these are recycled. See table 5 and 7.
Recycling of zinc	0.467	kg	Ornaments: in contrast to burial, these are recycled. See table 5 and 7.
Cremation process			**Lifetime of oven: 25,000 cremations (Facultatieve Technologies, 2010)**
Stainless steel	0.12	kg	3000 kg (Facultatieve Technologies, 2010 and IFZW, 2010)
Electronic components	0.01	kg	250 kg (Facultatieve Technologies, 2010 and IFZW, 2010)
Bricks	0.4	kg	10,000 kg (Facultatieve Technologies, 2010)
Natural gas	879	MJ	25 m^3
Disposal of industrial devices	0.13	kg	Steel + electronic components
Disposal of inert waste	0.4	kg	Landfill of bricks
Electricity	30	kWh	IFZW (2010) and SVT (2010)
Flue gas cleaning			**Lifetime of installation = 25,000 times**
Water	0.08	kg	2000 liters (Facultatieve Technologies, 2010)
Ethylene glycol	0.022	kg	500 liters glycol (Facultatieve Technologies, 2010), density 1.11 kg/l
Stainless steel	0.416	kg	10400 kg (Facultatieve Technologies, 2010)
Copper	0.078	kg	1950 kg (Facultatieve Technologies, 2010)
PVC	0.026	kg	650 kg of other materials; for simplicity, this is just noted as PVC (Facultatieve Technologies, 2010)

Material/ Process	*Amount*	*Unit*	*Remark*
Active coal[14]	0.5	kg	(Facultatieve Technologies, 2010)
Flue gas cleaning emissions	2500	m^3	See Table 6: volume according to Appelman & Kok (2005)
Electricity	25	kWh	(Facultatieve Technologies, 2010 and IFZW, 2010)
Disposal of industrial devices	0.52	kg	
Cremulator			**Lifetime of cremulator = 25,000 times**
Stainless steel	0.011	kg	300 kg (DFW, 2010); assumption: 275 kg of steel and 25 kg of electronics
Electronic components	0.001	kg	See above
Electricity	1	kWh	IFWZ (2010) and SVT (2010)
Disposal of industrial devices	0.012	kg	300 kg (DFW, 2010)
Separation			
Recycling of metals			See Table 5
Disposal of inert waste	0.018	kg	For dentures
Ash can			
PVC	0.5	kg	According to Urnwinkel.nl (2010), usually PVC.
Disposal of inert waste	0.5	kg	
Scattering over land	**75%**		
Petrol	0.778	kg	400 litre per ha per year (figures as for graveyard)
Grass seed	0.135	kg	50 kg per ha per year (figures as for graveyard)
Occupation of land	2.7	m^2a	
Transport, passenger car	48	Pers. km	
Soil contamination by cremation ashes	3	kg	See Table 4 and Table 6
Scattering over sea	**20%**		
Transport, passenger car	18	Pers. km	Aqua Omega (2010)
Transport, ship	0.01	tkm	Aqua Omega (2010)

---

[14] Per kilogramme of producted active coal the following data have been used:

Material/ Process	*Amount*	*Unit*	*Remark*
Carbon	*1*	*kg*	Law of conservation of mass (more specific data unavailable)
Electricity	0.00319	MWh	For the production of 1,108,356 kg of active coal, 3532 MWh is required (Lima *et al.,* 2008)
Natural gas	0.0142	GJ	For the production of 1,108,356 kg of active coal, 15,693 GJ is required (Lima *et al.,* 2008)
Water	0.0325	ton	For the production of 1,108,356 kg of active coal, 36 kton is required (Lima *et al.,* 2008)

Material/ Process	*Amount*	*Unit*	*Remark*
Sea contamination by cremation ashes	3	kg	See Table 4
Keep in urn	**5%**		
Ceramics	0.25	kg	2.5 kg, 10% market share (Funeral Products, 2010)
Brass	2.4	kg	3 kg, 80% market share (Funeral Products, 2010)
Glass	0.25	kg	2.5 kg, 10% market share (Funeral Products, 2010)
Disposal of inert waste	2.9	kg	Urn, discarded after use
Soil contamination by cremation ashes	3	kg	See Table 4 and Table 6
Transport, passenger car	48	Pers. km	

Table 11 - Inputs for the cryomation calculations. Unless otherwise indicated, all data have been provided by Cryomation Ltd.

Material/ Process	*Amount*	*Unit*	*Remark*
Cryomation clothing			
Maize starch	0.760	kg	
Cryomation body bag	**22%**		
Maize starch	0.2	kg	
Cryomation coffin	**Amount**	**Unit**	**Origin/calculation**
Cardboard	3	kg	Inner coffin
Maize starch	0.450	kg	Lining + pillow
Outer coffin + grips: same as for burial	1/50	piece	Outer coffin, 1 needed for 50 deceased (assumption)
Disposal of inert waste	0.751	kg	Coffin + wooden grips, once disposed per 50 deceased
Recycling of zinc	0.00934	kg	Grips, see Table 7
Recycling of stainless steel	0.00867	kg	Grips, see Table 7
Cryomation process			**Lifetime of cryomator: 25,000 times**
Stainless steel	0.4	kg	10,000 kg
PVC	0.04	kg	Plastic parts of cryomator, 1000 kg
Electronic components	0.01	kg	Electronic parts of cryomator, 250 kg
Liquid nitrogen	80	kg	
Hydrogen peroxide	2.32	kg	
Water vapour	48	kg	
Cotton	0.02	kg	1 kg of cotton filters, replaced after 50 cryomations.
Disposal of industrial devices	0.45	kg	
Disposal of inert waste	0.018	kg	For dentures
Recycling of metals	all		See Table 5 and Table 7
Electricity	76	kWh	
Direct burial of untreated cryomated remains	**23%**		
Cardboard	1.19	kg	Dimensions: 0.5 x 0.7 x 0.7 meter.
Softwood	0.036	m^3	Wooden covering plate instead of natural stone; 0.9 x 2 m x 2 cm thick. No foundation needed.
Water	7.53	kg	
Petrol	0.163	kg	
Grass seed	0.0497	kg	
Transport, passenger car	48	Pers. km	
Excavation	3.24	m^3	
Disposal of compostable waste	1.19	kg	Burial of coffin
Record: burial of body	24.4	kg	See Table 4 and Table 6

Material/ Process	*Amount*	*Unit*	*Remark*
(adapted)			
Disposal of inert waste	18	kg	Disposal of covering plate
Occupation of land	10	m^2a	Max. 2 years needed
Treatment: accelerated decomposition	**77%**		
Stainless steel	0.0002	kg	Installation, 5000 times used
Water	3	kg	Microbes are ignored
CO_2 emissions (biogenic)	7.45	kg	Mineralisation by microbes
Recycling of stainless steel	0.0002	kg	Installation. See Table 7
Waste water treatment	0.003	m^3	
Burial of treated cryomated remains as compost	**40%**		
Ceramics	2	kg	Pot for plant
Horticulture	1	EUR	Plant
Burial of treated cryomated remains as compost	17	kg	See Table 4 and Table 6
Transport, passenger car	48	Pers. km	
Burial of treated cryomated remains	**14%**		
Cardboard	0.595	kg	
Softwood	0.018	kg	
Water	3.77	kg	
Petrol	0.0813	kg	
Grass seed	0.0248	kg	
Transport, passenger car	48	Pers. km	
Excavation	0.893	m^3	
Burial of treated cryomated remains	17	kg	See Table 4 and Table 6
Disposal of compostable waste	0.595	kg	For coffin
Occupation of land	5	m^2a	
Disposal of inert waste	12.6	kg	Disposal of wooden plaque
Scattering of treated cryomated remains on land	**20%**		
Petrol	0.156	kg	
Grass seed	0.027	kg	
Occupation of land	0.541	m^2a	
Transport, passenger car	48	Pers. km	
Burial of treated	17	kg	See Table 4 and Table 6

Material/ Process	*Amount*	*Unit*	*Remark*
cryomated remains			
Scattering of treated cryomated remains above sea	**3%**		
Transport, passenger car	18	Pers. km	
Transport, ship	0.01	tkm	
Sea contamination by cryomation ashes	17	kg	See Table 4 and Table 6

Table 12 - Inputs for the resomation calculations. Unless otherwise indicated, all data have been provided by Resomation Ltd.

Material/ Process	*Amount*	*Unit*	*Remark*
Resomation clothing			
Clothing	Confidential	kg	
Resomation body bag	**100%**		
Maize starch	Confidential	kg	
Modified starch	Confidential	kg	
Resomation coffin			
Stainless steel	Confidential	kg	
Coffin + grips: same as for burial	1/50	p	Outer coffin, 1 needed for 50 deceased
Disposal of inert waste	Confidential	kg	Coffin + wooden grips, once disposed per 50 deceased
Recycling of zinc	0.00934	kg	Grips; see Table 9
Recycling of stainless steel	0.00867	kg	Grips; see Table 9
Resomation process			
Stainless steel	Confidential	kg	
Polypropylene	Confidential	kg	
Copper	Confidential	kg	
Electronic components	Confidential	kg	
Disposal of industrial devices	Confidential	kg	
Electricity	Confidential	kWh	
Water	Confidential	litres	
Potassium hydroxide	Confidential	kg	
Natural gas	Confidential	m^3	
Resomation waste water treatment	Confidential	litres	
Normal waste water treatment	Confidential	litres	
Disposal of inert waste	Confidential	kg	For dentures
Recycling of gold	0.283	g	See Table 5 and Table 7
Recycling of silver	0.124	g	See Table 5 and Table 7
Recycling of palladium	0.017	g	See Table 5 and Table 7
Recycling of platinum	0.101	g	See Table 5 and Table 7

Material/ Process	*Amount*	*Unit*	*Remark*
Reuse of steel	0.433	kg	See Table 5 and Table 7. 1 kg of reuse is now denoted as 90% x 1 kg primary process avoided. Again a collection process is added, here for 100%.
Reuse of iron scrap	1.333	kg	Same as for stainless steel.
Reuse of cobaltchrome	0.533	kg	Same as for stainless steel.
Reuse of titanium	0.800	kg	Same as for stainless steel.
Processor			
Stainless steel	Confidential	kg	
Electronic components	Confidential	kg	
Electricity	Confidential	kWh	
Disposal of industrial devices	Confidential	kg	
Scattering over land	**25%**		
Ceramics	2	kg	Urn
Petrol	0.778	kg	
Grass seed	0.135	kg	
Occupation of land	2.7	m^2a	
Transport, passenger car	48	Pers.km	
Soil contamination by resomation ashes	3.14	kg	See Table 4 and Table 6
Disposal of inert waste	2	kg	Disposal of urn
Scattering over sea	**25%**		
Ceramics	2	kg	Urn
Transport, passenger car	18	Pers.km	
Transport, ship	0.01	tkm	
Sea contamination by resomation ashes	3.14	kg	See Table 4
Disposal of inert waste	2	kg	Disposal of urn
Burial as compost	**50%**		
Cardboard	0.595	kg	For coffin
Soil contamination by resomation ashes	3.14	kg	See Table 4 and Table 6
Disposal of compostable waste	0.595	kg	For coffin
Transport, passenger car	48	pers.km	

D Results expressed in shadow prices

In the following tables the results are presented for all steps in the funeral process, expressed in shadow prices. Table 13 shows the shadow prices for each of the impact categories, for the main process steps. Table 14 up to 17 inclusive show how the detailed process steps contribute to the shadow prices.

Table 13 – Environmental impact of four funeral techniques, expressed in shadow prices; detailed per impact category and per (main) process step. The impact categories are referred to by their abbreviation, see appendix A. Depletion of abiotic resources (ADP) is not included, because its shadow price is €0.

Process step	**AP**	**EP**	**GWP**	**ODP**	**HTP**	**FAETP**	**TETP**	**POCP**	**LC**
Burial									
Body bag	0.11	0.04	0.14	0.00	0.09	0.03	0.01	0.00	0.24
Coffin	2.17	0.75	3.18	0.00	5.54	0.84	0.12	0.08	13.44
Digging	0.10	0.05	0.17	0.00	0.20	0.00	0.00	0.01	0.00
Elevator	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Monument	2.68	0.99	4.33	0.00	3.91	0.14	0.02	0.19	0.24
Grave rest	0.19	4.86	0.89	0.00	0.25	0.01	0.00	0.03	38.20
Removal	0.17	0.08	0.31	0.00	0.29	0.01	0.00	0.02	0.09
Cremation									
Body bag	0.11	0.04	0.14	0.00	0.09	0.03	0.01	0.00	0.24
Coffin	2.17	0.75	3.18	0.00	5.54	0.84	0.12	0.08	13.44
Preparation	-0.03	-0.05	-0.04	0.00	-0.11	-0.02	0.00	0.00	0.00
Process	0.25	0.34	1.43	0.00	2.78	0.29	0.02	0.01	0.12
Flue gas cleaning	2.61	1.33	2.40	0.00	4.01	0.26	0.04	0.08	0.09
Treatment of remains	-2.42	4.43	-3.12	0.00	-7.46	-1.41	-0.05	-0.05	0.18
Cryomation									
Clothing	0.02	0.05	0.05	0.00	0.04	0.01	0.00	0.00	0.26
Body bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Coffin	0.05	0.06	0.12	0.00	0.18	0.02	0.00	0.00	2.61
Process	-1.45	-1.49	1.28	0.00	-2.30	-1.00	0.01	-0.03	0.02
Treatment of remains	0.12	5.38	0.91	0.00	0.49	0.03	0.00	0.03	6.96
Resomation									
Clothing	0.41	0.13	0.54	0.00	0.32	0.13	0.02	0.01	0.91
Body bag	0.01	0.02	0.03	0.00	0.02	0.00	0.00	0.00	0.12
Coffin	0.02	0.01	0.06	0.00	1.56	0.09	0.00	0.00	0.19
Process	-1.92	3.50	-2.73	0.00	-9.38	-1.47	-0.06	-0.05	-0.27
Treatment of remains	0.13	6.04	0.52	0.00	0.55	0.05	0.00	0.02	0.47

Table 14 – Shadow prices of detailed process steps in burial. In relevant cases it is indicated to which extent (in percentage) this process was accounted for in the calculations.

Process step	**Shadow price per deceased (€)**
Body bag (22%)	
Cotton	0.66
Coffin	
Coffin particleboard	4.16
Coffin oak	4.22
Coffin pine	1.70
Pillow	0.07
Lining	11.11
Wooden grips	0.73
Stainless steel	3.34
Zinc (ornaments)	0.80
Digging	
Excavation	0.53
Elevator (95%)	
Stainless steel	0.04
Recycling stainless steel	0.00
Monument (75%)	
Natural stone plate	8.05
Concrete	0.36
Electricity for engraving	0.05
Transport, lorry	1.55
Transport, ship	2.51
Grave rest	
Water	0.01
Petrol	0.69
Grass seed	0.63
Burial of body	5.41
Disposal of inert waste	0.01
Disposal of organic waste	0.00
Occupation of land	37.69
Removal	
Excavation, grave	0.53
Excavation, bone grave	0.00
Disposal of foundation & headstone	0.33
Transport, lorry	0.10

Table 15 – Shadow prices of detailed process steps in cremation. In relevant cases it is indicated to which extent (in percentage) this process was accounted for in the calculations.

Process step	**Shadow price per deceased (€)**
Body bag (22%)	
Cotton	0.66
Coffin	
Coffin particleboard	4.16
Coffin oak	4.22
Coffin pine	1.70
Pillow	0.07
Lining	11.11
Wooden grips	0.73
Stainless steel	3.34
Zinc (ornaments)	0.80
Preparation	
Recycling stainless steel	-0.22
Recycling zinc	-0.47
Process	
Natural gas	0.57
Stainless steel	0.92
Electronic components	1.67
Bricks	0.04
Disposal of industrial devices	0.03
Electricity	2.01
Disposal of inert waste	0.00
Flue gas cleaning	
Water	0.00
Ethylene glycol	0.00
Stainless steel	3.20
Copper	0.52
PVC	0.00
Activated carbon	0.19
Flue gas cleaning emissions	5.12
Electricity	1.67
Disposal of industrial devices	0.12
Treatment of remains	
Cremulator	0.32
Recycling steel	-0.02
Recycling stainless steel	0.22
Recycling cobalt	-0.26
Recycling chrome	-1.20
Recycling titanium	-5.72
Recycling gold	-10.07
Recycling silver	-0.02

Process step	Shadow price per deceased (€)
Recycling palladium	-2.16
Recycling platinum	-0.31
Disposal of dentures	0.00
Ash can	0.08
Scatter ash over land	4.76
Scatter ash over sea	2.74
Keep ash in urn	1.76

Table 16 – Shadow prices of detailed process steps in cryomation. In relevant cases it is indicated to which extent (in percentage) this process was accounted for in the calculations.

Process step	Shadow price per deceased (€)
Clothing	
Maize starch	0.43
Body bag (22%)	
Maize starch	0.02
Coffin	
Cardboard	2.50
Maize starch	0.25
Coffin particleboard	0.08
Coffin oak	0.08
Coffin pine	0.03
Stainless steel	0.07
Wooden grips	0.01
Zinc	0.02
Disposal of coffin	0.00
Recycling zinc	-0.01
Recycling stainless steel	0.00
Process	
Stainless steel	3.08
PVC	0.01
Electronic component	1.67
Liquid Nitrogen	3.51
Hydrogen peroxide	1.00
Cotton	0.12
Water vapour	0.00
Recycling gold (Au)	-10.07
Recycling silver (Ag)	-0.02
Recycling palladium (Pd)	-2.16
Recycling platinum (Pt)	-0.31
Recycling steel	-0.02

Process step	**Shadow price per deceased (€)**
Recycling stainless steel (Fe)	-0.22
Recycling cobalt (Co)	-0.26
Recycling chrome (Cr)	-1.20
Recycling titanium (Ti)	-5.72
Disposal of dentures	0.00
Electricity	5.09
Disposal of industrial devices	0.10
Treatment of remains	
Direct burial of untreated remains	6.78
Accelarated decomposition	0.00
Burial of treated remains as compost	2.60
Burial of treated remains	2.65
Scatter treated remains over land	1.26
Scatter treated remains over sea	0.63

Table 17 – Shadow prices of process steps in resomation. In relevant cases it is indicated to which extent (in percentage) this process was accounted for in the calculations.

Process step	**Shadow price per deceased (€)**
Clothing	
Cotton	2.47
Body bag	
Maize starch	0.17
Modified starch	0.04
Coffin	
Coffin particleboard	0.08
Coffin oak	0.08
Coffin pine	0.03
Stainless steel, grips	0.07
Wooden grips	0.01
Zinc	0.02
Stainless steel, frame	1.54
Disposal of coffin	0.00
Recycling zinc	-0.01
Recycling stainless steel, grips	0.00
Recycling stainless steel, frame	-0.10
Process	
Stainless steel	0.97
Polypropylene	0.00
Copper	0.00
Electronic component	1.67
Disposal of industrial devices	0.04

Process step	**Shadow price per deceased (€)**
Resomation process	11.43
Recycling gold	-10.07
Recycling silver	-0.02
Recycling palladium	-2.16
Recycling platinum	-0.31
Reuse steel	-0.21
Reuse cobaltchrome	-2.08
Reuse titanium	-8.64
Reuse stainless steel	3.00
Disposal of dentures	0.00
Treatment of remains	
Processor	0.26
Scatter remains over land	1.58
Scatter remains over sea	3.14
Burial of remains as compost	2.79

E Declaration of reviewers (in Dutch)

On the next page, the reviewers’ declaration on the Dutch report has been included.

Appendix E

ISO 9001 certified
research and consultancy on sustainability

IVAM

Plantage Muidergracht 14
P.O. Box 18180
1001 ZB Amsterdam
The Netherlands

tel +31 (0)20 525 5080
fax +31 (0)20 525 5850
www.ivam.uva.nl

Yarden Holding BV
t.a.v. de heer John Heskes
Postbus 10118
1301 AC ALMERE

Betreft: Review LCA studie “Milieueffecten van verschillende uitvaarttechnieken”

Amsterdam, 21 juli 2011

Geachte heer Heskes,

Het TNO rapport TNO-060-UT-2011-00819 “Milieueffecten van verschillende uitvaarttechnieken” is door Ir Bart Krutwagen (CE Delft) en Ir Harry van Ewijk (IVAM UvA BV) in drie ronden beoordeeld op basis van rapportversies van respectievelijk 6, 14 en 20 juli.
De correspondentie van de reviewers aan TNO, gedateerd 8 en 18 juli, met reacties daarop van 14 en 20 juli, is desgewenst beschikbaar bij IVAM en TNO.

De beschrijving van het onderwerp van de studie, inclusief de titel (oorspronkelijk: “Milieueffecten van verschillende uitvaartmogelijkheden”), en de vergelijkbaarheid van gemiddelde bestaande technieken enerzijds en nieuwe technieken anderzijds vormden de rode draad.

Opvallend misverstand was dat Cryomation Yarden Press Release 25 June 2010 suggereert dat er een samenwerkingsovereenkomst is tussen Cryomation Ltd en Yarden, terwijl dat niet meer blijkt te zijn dan een bevestiging van Cryomation dat zij ingaan op Yarden’s verzoek om informatie.

De review heeft geleid tot enkele inhoudelijke aanpassingen en andere presentatie, maar leidt niet tot een wezenlijk ander resultaat.

Het finale oordeel luidt dat het 20 juli rapport van de TNO studie “Milieueffecten van verschillende uitvaarttechnieken” voldoet aan de vereisten volgens NEN 14040/44 en goed LCA vakmanschap.

Sustainable Building
Chemical Risks
Cleaner Production
Chain Management
Quality of Life
Energy

Dat wil zeggen:

- De LCA is consistent met de methodische eisen uit de ISO14040/44.
- De methoden die gebruikt zijn om de LCA uit te voeren zijn uit wetenschappelijk en technisch oogpunt valide.
- De gebruikte gegevens zijn voldoende onderbouwd en zijn redelijk in relatie tot het doel van de studie.
- De interpretaties en de geïdentificeerde beperkingen weerspiegelen het doel van het onderzoek.
- Het rapport van het onderzoek is transparant en consistent.

De weging van individuele milieueffectcategorieën naar een ‘single score’ (schaduwprijzen), valt buiten de kritische beoordeling omdat weging geen deel uitmaakt van ISO 14040/44.

Hoogachtend,

Ir Harry van Ewijk