Environmental impact of Funerals. Life cycle assessments of activities after life.

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PREFACE

This thesis is the end product of my graduate research for the master programme of *Energy and Environmental Sciences* at the *Centre for Energy and Environmental Studies* (*IVEM*) at the *University of Groningen*. The research was performed in the form of an internship at *TNO*, in the department *Climate, Air & Sustainability* in Utrecht. The research project at TNO was commissioned by funeral organisation *Yarden*.

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To Cor, Ed, Karel, Swen & Eelco

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SUMMARY

This research investigates the environmental impact of funerals in the Netherlands. There are multiple reasons for this research. First of all, there is interest from civilians, the funeral sector and governmental authorities. Furthermore, there is a serious lack of scientific research on both the fundamental and the applied aspects of this topic.

The scope of this research includes all steps of the funeral cycle from death to decay, divided for simplicity reasons in a preliminary part, which includes all preparatory activities, and a final part, involving the final processes for body decomposition. Traditionally, the options for the final part are burial and cremation, but two new options are currently being developed with the claim to be more environmental friendly. One is resomation, which is based on alkali hydrolysis, and the other is cryomation, based on freeze drying.

By means of an extensive life cycle assessment (LCA), this research aims to investigate and compare all the steps in the funeral cycle on the magnitude and variability of their environmental effects, within economical, technical and ethical limits. Additional analyses are performed in order to obtain more and better insight in these effects. Given the fact that the environmental impact of funerals is up to now a poorly researched subject, some models needed to be developed especially for this research and input data from companies in the funeral sector were indispensable. It should be noted that for the new techniques, cryomation and resomation, only data was used directly from the company or from related internet websites. The results might be a little biased by these information sources.

The results show clearly that the highest environmental impact of the whole funeral lays in the preliminary part, as it scores three times or more higher than the final part options. Amongst the options for the final part, burial has the largest environmental impact, while the two new techniques have the lowest. Cremation scores somewhere in between. Emissions to air, especially fossil carbon dioxide, and resource consumption, mainly crude oil, are the most important environmental outputs of all funeral parts together. In the final part, transformation and occupation of land are also important resources, while nitrogen oxides and biogenic methane are other important emissions to air. Even if land use is left out of the analysis, because it is sometimes argued that it is not a real environmental effect, the conclusions stay the same.

After the life cycle assessments, sensitivity analyses are performed on the input, the processes, the models and the methods. The results show a surprising robustness. First, the range of the input data and assumptions has no influence on the conclusions. Next, a close look at the most dominant processes shows that only a small number of processes was of major importance, but the outcomes were not extremely sensitive for variations in most of these processes. The low net impact of cryomation and resomation is explained by the benefits of recycling of materials, which compensate for the high energy use of both new funeral options.

The applied models and methods supported the conclusions as well. The excel models turn out to be useful tools, as they lead to slightly higher impacts than with default processes. Furthermore, a comparison of the results with seven different life cycle assessment methods gives almost similar conclusions with each method and only differs on the details. This can be explained because of the large influence of energy use and the high burden of fossil carbon dioxide emissions, which provide a clear and consistent indication of the environmental impact of the funeral parts.

The relative value of the environmental impact of funerals however, scores low in all effect categories compared to the resource use and emissions of one year of life of an individual. Two major exceptions are energy use of all funeral parts and mercury emissions to air of cremation. The relative values compared to Dutch industry sectors are rather low, but this is not surprising because the funeral sector is rather small. Nevertheless, the reduction potential of funerals turns out to be very large. The preliminary part, burial part and cremation part show a reduction potential of about 50%.

The main conclusion of this research is that, even though the environmental impact of funerals on a national scale are not alarming, on the local scale there is an enormous reduction potential of their environmental impact, either by adapting traditional processes or by developing new techniques. In the preliminary part, a large reduction can be obtained by adaptations regarding the activities of the relatives of the deceased. For the final part, the funeral sector has high potential to decrease its

environmental impact by adopting the new techniques of cryomation and resomation. The high energy consumption is for a large part compensated by the benefits of material recycling.

This research provides new insights on the environmental effects of different processes in the funeral cycle, and provides input for the discussion on the environmental impact of funerals.

SAMENVATTING

Deze thesis onderzoekt de milieueffecten van een doorsnee Nederlandse uitvaart. Er zijn meerdere aanleidingen voor dit onderzoek. Allereerst is er interesse van burgers, de uitvaartbranche en de overheid. Daarnaast is er op dit moment een groot gebrek aan wetenschappelijk onderzoek naar zowel de fundamentele als de toegepaste aspecten van dit onderwerp.

De focus van dit onderzoek omvat alle onderdelen van de uitvaartcyclus van het moment van overlijden tot en met het vergaan van de stoffelijke overschotten. Voor de overzichtelijkheid is de cyclus opgedeeld in een voorafgaand deel ("preliminary part"), dat alle voorbereidende activiteiten van de uitvaart omvat, en een afsluitend deel ("final part"), waarbij de stoffelijke resten vergaan. Van oudsher zijn er twee mogelijkheden om de stoffelijke resten te laten vergaan, te weten begraven en cremeren. Op het moment worden er echter twee nieuwe technieken ontwikkeld, die claimen milieuvriendelijker te zijn dan de traditionele opties. *Resomeren* is gebaseerd op alkalische hydrolyse, terwijl *cryomeren* gebruik maakt van de vriesdroogtechniek.

Het doel van dit onderzoek is om de grootte en variatie van de milieueffecten van alle onderdelen van de uitvaart te analyseren, binnen realistische financiële, technische en ethische grenzen. Deze analyse is uitgevoerd door middel van een *levenscyclusanalyse* (LCA, "life cycle assessment"). Aanvullende analyses zijn gedaan om meer en beter inzicht in de milieueffecten te krijgen. Een aantal modellen moesten speciaal voor dit onderzoek ontworpen worden, omdat de milieueffecten van uitvaarten tot op heden nauwelijks onderzocht zijn. Input vanuit de uitvaartbranche was onmisbaar, omdat er weinig gegevens beschikbaar zijn in de gebruikelijke literatuur. Hierbij moet opgemerkt worden dat voor de nieuwe technieken, cryomeren en resomeren, alleen gegevens gebruikt zijn die door de bedrijven zelf werden aangeleverd, of die verkregen zijn met behulp van aan hun gelieerde websites. De resultaten zouden daardoor enigszins vertekend kunnen zijn.

Desalniettemin zijn de resultaten robuust. De resultaten laten duidelijk zien dat de grootste milieueffecten van de uitvaart veroorzaakt worden door het voorafgaande deel, dat drie keer of meer hoger scoort op de milieu-impact indicator dan de opties voor het afsluitende deel. Van alle opties voor het afsluitende deel heeft begraven het grootste milieueffect, terwijl de nieuwe technieken het laagst scoren. Cremeren zit daar ergens tussenin.

Kijkend naar de verschillende outputs van de gehele uitvaart, dan zijn er een paar categorieën die voor het grootste deel van de milieueffecten zorgen. Dat zijn emissies naar de lucht, waaronder vooral fossiele koolstofdioxide (CO_2), en het verbruik van hulpbronnen zoals ruwe olie. In het afsluitende deel spelen transformatie en occupatie van land ook een grote rol in het verbruik van hulpbronnen, evenals de emissie van stikstofoxiden (NO_x) en biogeen methaan (CH_4) naar de lucht. Zelfs wanneer landgebruik buiten de analyse gelaten wordt, omdat er soms geargumenteerd wordt dat landgebruik geen duidelijk milieueffect heeft, houden de conclusies stand.

Naast de levenscyclusanalyses is er gevoeligheidsanalyse uitgevoerd voor de input data, de processen, de modellen en de methodes. De bevindingen worden echter niet beïnvloed door de resultaten van deze analyse. Ten eerste heeft de variatie van de input data en de aannames geen grote invloed op de conclusies. Een nadere bestudering van de belangrijkste processen toonde verder aan dat slechts een klein aantal processen een grote invloed heeft op de resultaten. De resultaten zijn echter niet zeer gevoelig voor variaties in deze processen. Het kleine netto milieueffect van cryomeren en resomeren kan verklaard worden door de voordelen van het recyclen van metalen, die compenseren voor het hoge energieverbruik van beide nieuwe technieken.

Variatie in de gebruikte modellen en methoden tastte de conclusies evenmin aan. De Excelmodellen bleken nuttige instrumenten doordat ze net iets hogere en andere milieueffecten lieten zien dan bij het gebruik van standaardprocessen. De vergelijking van zeven verschillende methoden om levenscyclusanalyses mee uit te voeren, leverde vrijwel vergelijkbare resultaten op voor iedere methode. De resultaten verschilden voornamelijk in de details. Dit kan verklaard worden aan de hand van de belangrijkste factoren, namelijk energieverbruik en uitstoot van fossiele koolstofdioxide. Dit zijn duidelijke indicatoren waar veel onderzoek naar is gedaan en waar relatief duidelijke milieueffecten aan te koppelen zijn.

De score van de milieueffecten van een gemiddelde uitvaart valt echter nogal laag uit in vergelijking met de scores gerelateerd aan het hulpbronnenverbruik en de emissies in één jaar van het leven van een individu. Twee belangrijke uitzonderingen op deze bevinding zijn het energieverbruik

van de gehele uitvaart en de kwikemissies van crematies. Vergeleken met de milieueffecten van andere sectoren in het Nederlandse bedrijfsleven scoren uitvaarten ook vrij laag, hetgeen niet zeer verrassend is omdat de uitvaartsector vrij klein is. Desalniettemin blijken de mogelijkheden om de effecten te verlagen, juist heel groot. Zowel de milieueffecten van het voorafgaande deel als van begrafenissen en crematies kunnen met 50% worden gereduceerd.

De belangrijkste conclusie van dit onderzoek is dat de mogelijkheden zeer groot zijn om de milieueffecten van uitvaarten te verminderen op een lokale schaal, ondanks dat de omvang van de effecten op een nationale schaal niet zorgwekkend is. De effecten kunnen zowel verkleind worden door bestaande processen aan te passen, als door nieuwe technieken (verder) te ontwikkelen. In het voorafgaande deel van de uitvaart liggen de mogelijkheden vooral bij de nabestaanden, die hun activiteiten kunnen aanpassen. In het afsluitende deel is vooral een rol weggelegd voor de uitvaartsector, door nieuwe technieken als cryomeren en resomeren verder te ontwikkelen. De hoge energieconsumptie van deze technieken wordt grotendeels gecompenseerd door de voordelen van recycling die zij met zich meebrengen.

Dit onderzoek biedt nieuwe inzichten wat betreft de milieueffecten van verschillende onderdelen van de uitvaart, en verschaft input voor de discussie over de milieueffecten van uitvaarten in het algemeen.

1 INTRODUCTION

Humans have a large influence on the environment, even when they are not living any more. This happens both by actions and events preceding, during and following their funeral (Remmerswaal & Heuvel, 2005). The whole funeral life cycle consist of many steps with very different environmental effects. There is however a huge difference in contemplating the effects of burial and decomposition, or the preparatory activities like laying out and the farewell ceremony. In the former, the body of the deceased is the central subject, while the activities of the relatives are the main topic of the latter. Therefore, in this research the funeral cycle is split into a preliminary part and a final part, which will be separately investigated on their environmental consequences.

In the preliminary part, the relatives of the deceased undertake many actions. The main process steps are the laying out, the preparation of the fare well ceremony and the ceremony itself. Environmental effects that follow from these steps have to do with for example the production of the coffin, death announcements and flowers, the cooling of the body and the transport of relatives and guests to the ceremony.

Considering the final part, the Dutch law admits only four ways of body disposal: burial, cremation, the watery grave and donation of the body for scientific purposes (Wet op de lijkbezorging, 2010). The latter two occur rarely, they form only less than 1% (Monuta, 2010a). A small majority of the people is cremated nowadays in the Netherlands, the rest is buried (CBS, 2010; Landelijke Vereniging van Crematoria, 2010). Environmental problems that are often linked to burial are soil and groundwater pollution and long term occupation of land. Cremation on the other hand, costs energy and causes emissions of combustion gases, heavy metals like mercury and persistent organic pollutants (Mari & Domingo, 2010).

There have been scientific researches on only some small parts of the whole funeral subject. Three topics have been studied in more detail: the emissions of crematoria, the potential groundwater pollution of cemeteries and decomposition processes. The research on emissions focuses on air pollution by substances like particulate matter, metals and organic compounds (Elzenga, 1996; Santarsiero *et al.*, 2005). These researches however are sometimes hard to compare with contemporary Dutch cases, because emissions are highly dependent on the presence and type of the flue gas cleaning system, and because every country differs in its regulations for harmful materials. A special example is the use of formaldehyde as an embalming fluid, which is forbidden in large amounts in the Netherlands, while it is current practise in many other countries.

Besides the focus on emissions, some other researches investigated the energy costs and CO_2 emissions of cremations and other techniques (GHD, 2007; Welch & Swerdlow, 2009). Cemeteries are less regularly researched; this is illustrated by the fact that the article by Haaren from 1951 is still one of the most-cited sources about ground and drainage water pollution. Less well-known is the publication of Brinkmann *et al.* (1987), who concluded that cemeteries do not cause any form of water pollution. A more recent and voluminously research is presented in the more than 400 pages thick PhD thesis of Dent (2002). Nevertheless, there is still no consensus on whether cemeteries cause substantial pollution in the form of pathogens, organic compounds, chemicals and metals (Spongberg & Becks, 2000a and 2000b; Trick *et al.*, 2005). The same holds for the soil below and near cemeteries. Schraps (1972) showed a salinity plume near the graves, but that salinity diminished strongly with distance from the graves, which brought the overall effect almost to zero. Spongberg & Becks (2000a) expressed concerns about soil contamination based on their measurements. A related, though less discussed, topic is decomposition, of which the most important determinants and processes have been investigated (Iserson, 1994; Dent *et al.*, 2004).

Furthermore, little is publically known about the relative values of these steps in the funeral cycle. The final part options have barely been compared from an environmental point of view, nor have they been thoroughly compared to the preliminary part. The relative impact of funerals compared to other national environmental problems, or someone's lifetime influence on the environment, is also unknown. Two major examples of comparative researches are those from GHD in 2007 and Remmerswaal & Heuvel in 2005, and two minor examples are Welch & Swerdlow and Monaghan, both in 2009.

GHD performed a small comparative research between burial and cremation commissioned by the Centennial Park Cemetery Authority, a large burial and cremation company in Australia. GHD made an environmental risk assessment and a quick carbon footprint calculation for the specific location. It found that burial carried a higher environmental risk, while cremation scored higher in emissions of CO_2 equivalents. Both criteria were not combined in an analysis about the overall effect of burial or cremation on the environment. The critical reader finds some odd numbers, which make the report less reliable[1]. The report is published for private use and is not publically accessible.

Remmerswaal and Heuvel (2005) did perform a comparison, and in addition, they also involved the preliminary part and two new options for the final part, based on respectively alkali hydrolysis and lyophilisation or in other terms freeze drying. They performed a life cycle assessment of the preliminary part and the four final part options separately, which they compared on basis of energy use and on *Ecopoints* which indicate the sum of the environmental effects per option. Burial, cremation and hydrolysis scored about an equal amount of Ecopoints, while lyophilisation scored more than twice as high and the preliminary part scored almost four times higher. Although this research was more extensive and elaborate than the one of GHD, the research ignored some potential influential parts like the effects of flower production and ash dispersion, certain information[2] and legislation[3] is nowadays outdated, and moreover, the report was not publically published nor peer reviewed.

The research of Welch & Swerdlow (2009) was only a small, comparative research, elaborated by Isis Innovation Ltd and supported by Carbon Trust. This research compared cremation and cryomation on their CO_2 emissions. The conclusion was that both processes emitted about 50 kg of CO_2, but that cremation emitted another 100 kg for the body and the coffin, while cryomation did not have these additional emissions. However, they did not take into account what happens to the body and the coffin after the cryomation process. For example, if the remains are buried in the ground, still some CO_2 and CH_4 emissions can be expected. Last, Monaghan (2009) wrote a comparative article, analyzing the sustainability of burial, cremation, green burial and *promession*, an alternative form of cryomation. However, Monaghan used mainly unscientific and even promotional arguments, and therefore his opinion is not further discussed here.

There is another problem when researching the environmental effects of funerals, namely that the processes are barely researched and consequently absent in conventional databases in environmental research. That means that, specifically for this research, alternatives have to be searched or even fully developed.

Despite this lack of scientific research and fundamental knowledge, there is a wide and growing variety of options available to change environmental effects of funerals. Generally, two pathways can be followed. Either current products and processes can be adapted, or completely new concepts can be introduced in this market. Eco-coffins and green burials are examples of the first category, while alkali hydrolysis and freeze drying methods belong to the latter as potential replacements of burial and cremation. Various examples of the first category are already brought into practice on a small scale. For example there are only two green burial sites in The Netherlands (Monuta, 2010a).

The second category however, is still in the development stage. An example of alkali hydrolysis is *Resomation*. In the resomation process, the body is dissolved in a warm solution of potassium hydroxide, after which the environmentally harmful non-body metals can be separated and recycled, while the fluid is released to sewage and the remaining bone fragments are crushed until some powder remains. Resomation is already operational in a few countries and on a small scale for medical waste (Die Presse, 2010). The other new method is *Cryomation*. The principle of cryomation

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[1] For example, the report calculates that cremations cost 46.36 ton CO_2-equivalents per year (3000 cremations) and thus 0.01545 ton per cremation, but later presents a table which states that cremations cost 43.57 ton per year and 0.016 ton per cremation (which is not correct, dividing by 3000 gives 0.0145 ton). Meanwhile, several articles are published by others, which refer to the GHD research and speak of 0.16 ton CO_2-equivalents, which is a ten times higher value (e.g. Breuer *et al.*, 2008).

[2] At that time, the hydrolysis and freeze drying method were merely theoretical concepts, in contrast to the recent experiences.

[3] Two examples of outdated legislation are the possibility to undergo *thanatopraxie* (light embalming) or to be buried without a coffin, which were not allowed in the Netherlands until 2010 (Wet op de lijkbezorging, 2010).

includes that the body is put in a bath of liquid nitrogen and subsequently vacuum dried, which makes it become brittle and easily fall into pieces, so that again the harmful elements can be taken out and recycled. In contrast to resomation, there is not yet an all-in-one cryomation machine and the process is not legalized anywhere yet. Nonetheless, the company Cryomation Ltd claims that all sub processes have been tested and found to be working satisfactory (Crymation Ltd, 2010a).

However, very little is known about the impact of either these adaptations or innovations. Neither their absolute effects, nor their relative effects are commonly available in literature. It is hard to find publications about the effects of small or big changes of certain factors. Some fractional information is available on specific topics (e.g. Welch & Swerdlow, 2009), but integral and clarifying research is absent.

Meanwhile, both Dutch society and government are interested in these effects. The interest of certain citizens is illustrated by the appearance of several recent news paper articles (e.g. Snoeijen, 2009; Marijnissen, 2010; Olthuis, 2010). Furthermore, there was the launch of a complete website on "green funerals" in 1997, which is still operating and presenting news (Groene Uitvaart.nl, 2010a). The increase in "green" options throughout the funeral cycle -like FSC coffins, ecological coffee service and the funeral bus- throughout the last fifteen years, also indicate the interest of certain citizens (Monuta, 2010b). Yet this is not typically Dutch; in the period 1993-2008, 228 *natural burial grounds* were set up the UK (Thompson, 2008), compared to only two in the Netherlands (Jonkman & Veen, 2008).

The interference of the government dates from much longer ago and is visible in among others the existence of the Law on funerals since 1869 (Strijen, 2009) and in related decisions and directives (listed in Dijk & Mengen, 2002). Dijk & Mengen however mention that certain guidelines are not supervised at all and that it is not known for how far certain rules are truly followed, probably partly due to ethical reasons.

Consequently, the Dutch funeral branch is also interested in the environmental consequences of the activities that they execute and support. This is shown by the appearance of special editions of the sector's magazine, dedicated to the environment and to corporate social responsibility (Het Uitvaartwezen, 2009 and 2010) and after personal communication with Yarden, which is a large company in the sector (Yarden, 2010). Yarden is especially interested in the environmental comparison of the four already mentioned options for the final part, as the organisation is a guide and mediator for their members. In the development process however, they are not only facing ethical boundaries, but also economic and technical feasibility play a role.

Aim

Summarizing, there is a broad interest from society, government and business in the environmental effects of funeral practises, while there is a severe lack of scientific research on the topic. The aim of this research is therefore to investigate and compare all the steps in the funeral cycle on the magnitude and variability of their environmental effects, within the economical, technical and ethical limits.

Questions

The research aim and the given background lead to the following main research question:

What is the environmental impact of funerals, considering all the steps from death to decay, and how large is their variability and influence?

In order to answer the main question, it is divided into the next sub questions, addressing the environmental effects (sub question 1), the impact of the main determinants of the results (#2), the relative values of the results (#3) and the reduction potential (#4):

1) What are the environmental effects of different steps in the funeral cycle, and how do separate steps compare to each other?
2) Which factors are the main determinants of the effects, considering the inputs, processes, models and methods? How large is the variation and influence of these factors, and what does that mean for the interpretation of the results?
3) How large is the relative environmental impact of the funeral cycle, compared to the impact of the life of an individual and to the impact of industrial sectors?

4) To what extent can the environmental effects of funerals be reduced, within the technical, economical and ethical limits?

Report bookmaker

Before the sub questions will be answered, first the set-up of the research is explained and more background is provided. This is done in the next chapter, where the methodology and the chosen boundaries are explained, and in chapter 3, where the system and all its processes will be described in order to provide a solid background.

The sub questions are addressed in the subsequent chapters. The results of the standard scenarios that follow from sub question 1 are presented in chapter 4. A closer look to the results and its determinants, provoked by sub question 3, is explored in chapter 5. Chapter 6 discusses the relative values of the results, as a consequence of the third sub question. The reduction potential of the last sub question is answered in chapter 7. Conclusions and discussion items are presented in the two last chapters.

This report contains two appendices. The background of the applied LCA methods is presented in Appendix A. Appendix B shows the graphs of the other applied LCA methods, which are discussed in paragraph 5.4, for those readers who are interested in taking a closer look at the composition of these graphs.

2 METHODS AND BOUNDARIES

2.1 General approach and boundaries

The research aim asks for comparison of environmental effects over the course of a whole product cycle. The usual way to perform such comparisons is by means of a *Life Cycle Assessment* (LCA). This research comprises a LCA for the functional unit of the funeral of one adult person. The variability of the outcomes is studied into more detail by means of sensitivity, relative value and reduction potential analyses. The specific methods are explained in the next paragraphs.

The scope of this research is limited to expected environmental effects. This means that social or economical factors are regarded only in the second place and that, without losing respect for the subject, ethical questions are left out.

More specifically, the research limits itself to the average and standard, most common funerals as they take place at present or in the near future, in the Dutch situation. Although there are nowadays a lot of possibilities for organizing a funeral, varying from very sober to almost over the top extraordinary, the extremes are left out of the analyses. In comparing standard funeral methods, it is inconvenient to include all these options. Inclusion of many options would only diffuse the view and make it harder to draw general conclusions about the nature of the specific methods. Where the boundaries are exactly set in practice, is explained in the next chapter, the processes description.

The following paragraphs explain the specific methods that are applied in the LCA and the sensitivity, relative value and reduction potential analyses.

2.2 Life Cycle Assessment (LCA)

LCAs are applied to compare environmental impacts of provided products, which can mean both goods and services. In these analyses, the product is followed from "cradle to grave", starting with the required inputs and outputs of the design and production, followed by the use period and a certain end of life treatment. The aggregation of all the environmental effects, including extraction of resources and emissions to water, soil and atmosphere, is called the *Life Cycle Inventory* (LCI). This is the first main component of an LCA. The second component is the *Life Cycle Impact Assessment* (LCIA), in which the impacts are assessed (Rebitzer *et al.*, 2004). The LCI and LCIA will both be performed by means of the computer program *SimaPro 7*.

The input data for the research is in the first place retrieved from involved companies in the funeral sector by means of questionnaires, because very few literature data is available. The Dutch funeral organization Yarden, who was one of the initiators of this research, answered a part of the question and distributed the questionnaires to other companies in the funeral sector. Cryomation Ltd was addressed directly. Resomation Ltd does not participate in this research; their data is searched on the internet. Additional data for the life cycle assessments is searched in literature and requested to experts in the funeral and medical sector. In case no data or expert estimates are accessible, reasoned assumptions were made. The used figures and the underlying arguments are absent in this report. They are present in the special version of this report which is conserved at TNO.

Besides the limits that are set on the origin of the data, there is also a qualitative boundary, depending on how deep the life cycle will be investigated. Goedkoop *et al.* (2008) described three levels of life cycle assessment. First order analysis only involves production of materials and transport. Second order analysis includes all processes, except capital goods. Third order involves also the capital goods. Capital goods are included in the Ecoinvent database, and consequently this research follows the third order approach.

In SimaPro, the Life Cycle Inventory is built up of database records. Various types of databases are available which contain information about the inputs and outputs of certain processes. These so-called *libraries* exist in very general forms for all-round researchers, or may contain very specific data, for instance for a single industrial area. Primarily, this research will use the Ecoinvent database, as it is one of the most complete and actual ones, complemented by the methods and industry databases. Other available databases in SimaPro will only be used when there is a severe lack of other data. The Dutch Input/Output (DutchIO) database will be the most important one, as it is developed specifically for the Dutch situation, followed by IDEMAT which was developed in The Netherlands as well. DutchIO is however based on economic input data, meaning that the research is not any more based on pure numerical calculations. This is called a *hybrid* analysis. Guinée *et al.* (2001) advised to involve them as little as possible, so this will be applied only in essential cases.

Not all involved processes are present in the databases. The most deviating examples are grave rest, scattering of ashes and treatment of resomation fluid, which are all important processes in the whole funeral cycle. For these processes, it is hard to find a comparable alternative process, and therefore new ways are searched to model them. A waste model (explained by Eggels & Ven, 2000) and the waste water treatment model of Ecoinvent will be adapted to match better with the real processes. In section C.9 it is explained in detail how and why these models are altered.

Numerous methods are developed in the past to analyze the environmental impacts of products and services. A main difference in these methods is the level of impact assessment, which can be either on the basis of midpoint indicators, which orientate relatively more on problems, or endpoint indicators, which focus more on the damage of those problems (Goedkoop, Schryver & Oele, 2008). A major accompanying difficulty is how the different environmental impacts can be compared in an integrated manner. Several approaches have been developed throughout the years to tackle this problem. Values can be characterised by means of a monetisation approach, by assessing the distance to target levels or after panel surveys, in which people have given relative values of importance to certain subjects.

This research applies in the first place the Ecoindicator 99 method, which is an endpoint method that is characterised by panel input (Pennington *et al.*, 2004). It is an improved and widely appreciated version of Ecoindicator 95. An additional advantage of Ecoindicator 99 is that it gives the possibility to compare two products on the sum of their environmental effects, which is not possible with every method. The hierarchic perspective[4] with the average weighing set will be applied, as this is the most common method from a scientific point of view.

The second method used is CML 2000, which belongs to the monetisation method category. CML 2000 follows in principle the midpoint approach, and it has the additional possibility of performing shadow price analyses, either by attributing the costs for prevention of a certain effect, or by attributing the costs for the damage of that effect (Bruyn *et al.*, 2010). A small adaptation to this method is made, following the Declaration of Apeldoorn (Life Cycle Initiative, 2004). This declaration points at the disproportionally high impact of marine aquatic ecotoxicity (MAETP) with respect to metals, and recommends to set the characterisation factor of MAETP at zero for research where metals are important. In the funeral case, this is true for gold and therefore the recommendation will be followed.

Both methods will be used to compare the different funeral parts. If the two methods will lead to profoundly different results, a third method will be applied: ReCiPe. ReCiPe is developed as a combination of the best elements of Ecoindicator and CML; for more information, see Goedkoop *et al.* (2009). The endpoint version will be applied, amongst others because this method provides the possibility to obtain single scores as an aggregation of the environmental effects. The hierarchic version with average European weighting set will be used. ReCiPe also has a separate category for marine ecotoxicity, which will be set at zero as was done with CML.

Other available methods will be applied in the sensitivity analyses, as described in the next section. The Declaration of Apeldoorn is not applied to the other methods, as some do not use marine ecotoxicity at all, and some only present it in an aggregated form, namely as aquatic ecotoxicity. For all methods that are used in this research the normalization and characterization factors are added in Appendix A.

For all additional analyses, like the sensitivity, relative value and reduction potential analyses, ReCiPe will be used as well, because it gives the best average picture of the results, as it is somewhere in between Ecoindicator and CML.

After the LCA results, the inventory of outputs will be analyzed as well, being resource consumption and emissions to soil, air and water. First the most important outputs of the whole funeral will be examined, by checking which factors have the largest ReCiPe scores. Then, the five highest scores for each funeral part will be collected and added up per effect category, so that a

[4] For more information on the different perspectives and the Cultural Theory, see for example Goedkoop & Spriensma (2000).

ranking of the most prominent factors of environmental effects can be given. By means of this inventory analysis, it will also be tried to explain why the outputs are distributed in this way.

2.3 Sensitivity analysis

The sensitivity analysis of the main determinants of the results aims to show how reliable and variable the outcomes of the LCAs are. This analysis will be performed in several ways, considering both the inputs, processes, models and methods of the LCAs. The structure of the funeral model in SimaPro will not be discussed; all choices are explained and underpinned only in the special version of the report which is present at TNO.

First of all, the quality of the data will be analyzed. One might expect a Monte Carlo analysis for this, but this is not feasible because of the magnitude of the model. Therefore a minimum and a maximum scenario will be set up and compared to the standard LCA results, in order to give an indication of the uncertainty. These scenarios are designed by assessing all the data and assumptions on their realistic variation, thus not on their extreme possible values. The differences in the answers of the companies to the questionnaires are used as a measure for variation. Other measures are the report of Remmerswaal & Heuvel (2005) and, where appropriate, general information from the internet and rational assumptions.

For this analysis, only input data and assumptions are altered. The waste model, the structure of the analysis and the used ratios are left as they are; they are analyzed in the next section. Neither are standard, physical data, like body composition, changed.

Subsequently, the most influential processes for each funeral part will be contemplated in more detail. As "most influential", only the processes are considered which contribute 10% or more to the environmental score of that specific funeral part. Considering resomation, there are so many processes that contribute more than 10%, that only the processes contributing 50% or more will be shown. This is explained in more detail in section 5.2. The processes are assessed by varying them and subsequently analysing the changes in the outcomes.

After the analysis of the influence of the processes, quality of the system will be analyzed. This will be done by comparing the applied excel models with some alternatives and see how large their influence is. First, the waste model is analyzed. The influence of the waste model can be assessed in two ways, either by changing the model parameters, or by comparing the model outcomes with its alternatives. First, the parameters are changed, and the model is run a few times again. Three major parameters will be changed:

#1 The distribution of emissions to water and soil; this is reversed (thus towards 2% and 98% respectively).

#2 The emission factor of all elements is set at 100%; this means a large increase for most elements, which were previously only contributing a few percentages. Only for chloride and heavy metals this value means no big change.

#3 Gas production is increased to 50% instead of 5%.

The results from these changed scenarios are compared to the results from the standard LCAs. Secondly, the effects from the waste model are compared to alternative calculation methods. In this case, the most obvious alternatives are considering the body as "inert waste" or as "composting organic waste".

The third model analysis contemplates the effect of the waste water treatment model. Therefore the resomation life cycle results are compared to two other scenarios: one without any description of waste water treatment, and one with ordinary waste water treatment (class 3).

Last, the applied LCA methods will be analyzed. With every available LCA method at the research institute the LCA of the funeral parts will be performed, and the different outcomes will be compared. These outcomes will show both the influence of the preferred methods as well as the range in possible outcomes when taking another point of view. Besides Ecoindicator, CML and ReCiPe, the full set of methods which are available at TNO and which provide a single score outcome, will be applied: Ecological Scarcity, EDIP, EPS and Impact 2002+. Ecological Scarcity is based on the distance to target principle; the reference value is derived from environmental law or political targets (Frischknecht, Steiner & Jungbluth, 2009). This implies that the applied weighing factors are quite time and location specific. EDIP literally means *Environmental Design of Industrial Products* and is also a distance to target method, referring to political goals (Stranddorf, Hoffmann & Schmidt, 2005).

EPS stands for *Environmental Priorities in product design* and is explicitly developed as a clear tool for designers and not in principle for scientists. The method follows a monetary approach, namely the willingness to pay (Steen, 1999). The last applied method is Impact2002+, which follows a combined midpoint and damage approach (Jolliet *et al.*, 2003).

2.4 Relative values

The relative values of the LCA results can be compared to an infinite number of other values. This research will investigate the environmental impact of funerals on both an individual and a societal level. The reference for the individual level is resource consumption and emissions of an individual on a yearly basis. For the societal reference, the resource consumption and emissions of several industrial sectors, also on a yearly basis will be contemplated.

The impacts will be assessed from a pure environmental perspective, as well as with economic-environmental tools. The figures which are necessary for this comparison will be searched in literature, in the database of the Dutch Central Office for Statistics (CBS) and in the online dossiers of the Dutch *Compendium voor de Leefomgeving*, which contain “facts about environment, nature and planning”.

The comparison on individual level will be performed by placing the environmental effects of one funeral in the perspective of the environmental impact of the life of an individual on a yearly basis. The societal perspective will be investigated by comparing the total annual environmental effects of the funeral parts to those of other industries. It should be noted that the funeral parts are mainly contemplated from a consumer perspective and not from a business perspective. This is not only an important note for the application of the results, but also for comparing these results with other businesses, because overhead and infrastructure costs are left out of the analysis while other industries do not.

The environmental side of this analysis will focus on several environmental indicators, in order to give a multilateral view on all the funeral parts. Major Dutch environmental issues will be addressed, like energy use, together with the major factors which appeared in the results of the LCAs. The focus will be on emissions and resources; emissions to air, water and soil, and use of energy, water, land, and the most contributing resources.

An assessment of the *energy* and *CO_2 intensity* will form the economic related part of the analysis. The *energy intensity* is the energy use divided by the expenditures in the sector, while the *CO_2 intensity* is the amount of CO_2 emissions divided by the expenditures. These values will be compared to the energy intensity values of other individual activities and industrial sectors, which will be searched in literature. The rough average is that 1 euro spent in the Netherlands corresponds with about 8 MJ (CBS, 2010) and about 0.5 kg CO_2/€ (CBS, 2009). This analysis will show the height of the environmental *costs* of the different funeral parts.

2.5 Reduction potential

The estimation of the reduction potential can be seen as a special kind of analysis of the relative values: it investigates how flexible the results are, and to which extent they can be varied or optimized. However the minimisation of the environmental effects is a complex problem due to potential problem shifting. This research only involves a quick scan of the possibilities.

The first step, inventory of alternatives, is a laborious but relatively easy job. “Green” alternatives are available for almost all parts of the funeral cycle, as illustrated by Groene Uitvaart.nl (2010a). The next step is harder, because all alternatives should be checked on potential side-effects as a result of problem shifting. Probably some subjective decisions have to be taken here, as specific alternatives may have smaller effects for one environmental indicator, but more for the other. For all steps, the potential reduction of environmental effects will be expressed both in an absolute (points) and a relative (percentages) manner. Finally, the overall potential for environmental effect reduction per funeral part can be calculated.

3 PROCESS DESCRIPTION

3.1 Introduction: two parts

The funeral cycle can be split into two parts in order to gain better insights in the processes. The preliminary part consists of the activities of the relatives like the farewell ceremony and the transport, while in the final part the techniques applied to the body are the central item. Regardless of which specific final act is chosen, the preliminary part is considered approximately equal in all cases of this research.

The following paragraphs explain which activities are involved in each part. The preliminary part is explained further in the next paragraph. Paragraphs 3.3 to 3.5 deal respectively with the four different options for the final part, being burial, cremation, resomation and cryomation. The other two options in The Netherlands, the watery grave and donation of the body for scientific purposes, are not taken into account as they occur exceptionally (Monuta, 2010a). Nor are special cases like aboveground burial or burial caves described.

In addition, each paragraph explains which facts are common or expert knowledge, which assumptions have to be made and where the specific system boundaries were set.

3.2 Preliminary part

Dutch law requires that as soon as someone has died, a doctor or coroner should visit the body and give a declaration of death (Wet op de lijkbezorging, 2010, art. 3-7). In the following steps of the preliminary part, the body is laid out, and generally the death is announced and a farewell ceremony is prepared and held. Then the final part follows, finished with the termination. This is traditionally described as "condolences with coffee and cake", but nowadays a wide range of other drinks, like sodas and alcoholic consumptions, and foods, like sandwiches or snacks, is possible (Yarden, 2010). As the termination has nothing to do with the way the body is disposed, this part is analyzed as a separate process in the preliminary part. Transport is also considered separately, as it is not really part of the ceremony, nor of the final part.

The major preliminary steps can be divided into smaller steps, as shown in Figure 3.1 and further explained below.

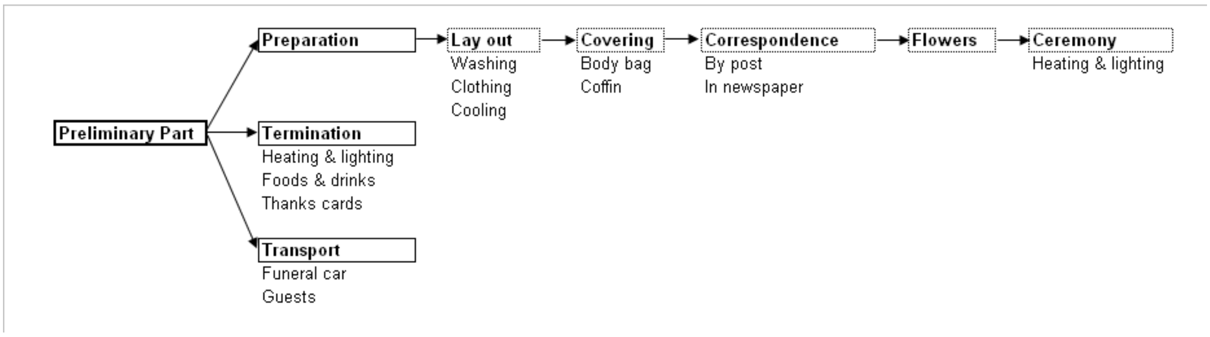

Figure 3.1 Schematic overview of the steps which are present in the preliminary part. The six major steps (lay out, correspondence, rituals, transport, farewell ceremony and termination) are presented in bold, with their smaller parts below them. A description is given in the paragraphs below.

The lay out starts by washing the body, but that is assumed to have negligible environmental influence and is therefore ignored here. Subsequently the body is clothed. Strictly spoken, clothing the body with non-degradable tissues like panties is not restricted by law, but employees in the funeral branch generally try to avoid them. Usually some personal care is given, possibly involving shaving and doing the hair of men, while for women it comprises care for not only the hair but also sometimes for the nails, make-up and jewellery (Protocol Overledenenzorg, 2010). The final step of the lay out is a matter of laying the body in an appropriate pose. However, as none of these activities consumes energy or resources that are not already present, like the clothing, it is not taken into account for the analysis.

Sometimes the deceased are enveloped in a body bag (Dijk & Mennen, 2002). The *Lijkomhulselbesluit* (1998) describes which body bags are allowed, and focuses on degradability.

However, a lot of body bags are imported from Belgium, where the rules are not that strict. As there is no control from the governmental institutions nor from the sector itself whether these rules are followed, it might be that a part of the body bags is not biologically degradable (Dijk & Mennen, 2002). However, as there is no reliable information on this topic, this criticism will be ignored.

There are two general ways to conserve the body until the day of the final act, cooling or embalming. Traditionally, the body is cooled by a cooling plate until the end of the farewell ceremony. The other option is embalming, which is a strong conservation process by which the blood is removed and replaced by 9 litres of embalming fluid which contain in total 180 grams of formaldehyde (Environment Agency, Science Group: Air, Land & Water 2004), is prohibited by the Dutch law because it disturbs quick and natural decomposition. A second problem of embalming is the required amount of formalin, which is a carcinogen for those who work with it (Hauptmann *et al.*, 2009) and a potential hazard of water pollution around cemeteries (Young *et al.*, 2002). However since 2010, a light form of embalming called *thanatopraxie* is allowed in the Netherlands (Wet op de lijkbezorging, 2010, art. 71). For thanatopraxie, a much smaller amount of formalin, a solution of 0.5%, is brought into the bloodstream, which only temporarily slows down the decomposition processes (Remkes, Donner & Ross-Van Dorp, 2006). As this is no common practice at the moment, only guesses can be made about the future market share and technical practises of thanatopraxie. Therefore, it is not taken into account for this research.

The body may be put in a coffin or only in a winding sheet, in combination with a platform (Besluit op de lijkbezorging, 1997). The *Lijkomhulselbesluit* (1998) gives rules for the fabrication of these coffins or sheets. Most coffins have some kind of grips, some coffins also have ornaments, which are here summarized as “grips and ornaments”. There is little information about the interior of the coffin. The *Lijkomhulselbesluit* defines which materials are allowed for the interior and the pillow, but there is no control and the national organisation of cemeteries (*Landelijke Organisatie voor Begraafplaatsen, LOB*) suggests they are poorly followed (Dijk & Mennen, 2002).

A lot of correspondence takes place before and after the funeral. Usually, death announcements are sent to a number of relatives, friends and acquaintances. Additionally, the first relatives often place a death announcement in one or more newspapers, often followed by some of other relatives, friends or acquaintances. After the funeral, the family often sends a thanks card. From a lifecycle perspective, these forms of correspondence do all not only involve natural resources to produce all the paper, but there is also a lot of transport involved to deliver the cards and news papers. Remmerswaal & Heuvel (2005) did not include any of this correspondence.

There is such a variety in applicable rituals (Uitvaart.nl, 2010b), that no standard funeral can be defined. Therefore we chose to focus only on the rituals which probably have the largest environmental impacts. Although funerals can involve music, art, natural elements, candles, and much more, this research only includes only one element, which is likely to have high environmental costs: flowers. About every funeral has a few or more flower bouquets and their influence is probably substantial, seen the fact that the production of flowers require a lot of land and fertilizers, and that the largest share of the flowers sold in the Netherlands come from abroad (Milieucentraal, 2010). Unfortunately, Remmerswaal & Heuvel (2005) also excluded the flowers from their analysis.

Remmerswaal & Heuvel did account for the transport towards the farewell ceremony, but not for the costs of the ceremony itself. The ceremony is held in a building which has to be heated or cooled and lighted and thus requires some electricity. During the ceremony, music or videos might be played, so some electricity is needed for that as well, but we assume that is marginal and can be ignored.

Prior to the funeral, two types of transport are required. First, the body has to be brought towards the funeral centre. This is usually done by car, although it can also be performed in alternative ways like by bike or by bus (Groene Uitvaart, 2010b). Next, almost always guests are coming to the funeral, which have to travel towards it and afterwards back home again, often by car.

After the final disposition of the body, people usually return to the funeral centre or to another meeting place, to express condolences to the family and to simply be together. For simplicity, we assume that this takes place in the funeral centre and that all guests go there. The funeral centre thus requires electricity for lighting and heating for about one hour. Traditionally, coffee, tea and cake are served, although currently almost everything is possible and usually beer and sodas are served additionally, as well as sandwiches and small snacks. This termination was also not included in the research of Remmerswaal & Heuvel (2005).

3.3 Final part: burial

During a burial, the body is placed in a covered grave in the ground. There are also some varieties of allowed aboveground burial, but they are not discussed here. The separate steps in standard burial are presented in Figure 3.2 below and described subsequently.

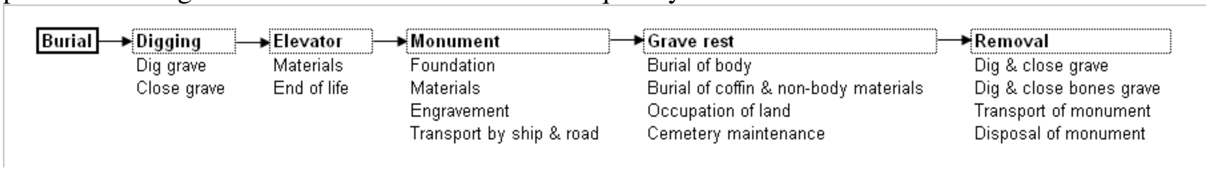

Figure 3.2 Schematic overview of the steps which are present in the burial part. A description is given in the paragraph below.

Prior to the burial, a grave is dug mechanically by a shovel. The depth of the grave is dependent on several factors, either protecting the environment or covering social aspects. For example, the law requires that any buried body should be at least 65 cm below surface and at least 30 cm above the average highest groundwater level. There may be buried maximally three people above each other in one grave, with a minimal distance between them of 30 cm (Besluit op de lijkbezorging, art. 5).

The coffin can be lowered into the grave with help of an elevator or by hand. Elevators are often of relatively simple mechanical or hydraulic design and made of aluminium or steel (Genius Loci, 2010). After descending of the coffin, the grave is filled again, mostly mechanically by the shovel – the few hands that the guests sometimes may throw up are no significant contribution.

Usually, the grave is not immediately covered by a grave monument, because the soil will sag for a certain period and because the relatives will not yet, in case of a sudden death, have a monument ready to be placed. A temporary monument can be placed (for example, see Va-de, 2010). Small as they are, they are ignored here, as did Remmerswaal & Heuvel (2005) as well.

After about four months, the grave monument is placed. 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. Remmerswaal & Heuvel (2005) assumed a weight of 115 kg, but a simple calculation leads to a higher estimation[5]. The stone usually undergoes some kind of treatment in the form of polishing and engraving. The stone also has to be transported over a long distance, as there is almost no rock production in The Netherlands. GHD (2007) did not include the headstone at all, but this short description already reveals that it probably has a substantial impact on the total effect of burial.

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 (Wet op de lijkbezorging, art. 28). The exact length of this period depends mostly on whether it is a general or a private grave. 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. About 90% of the graves are private graves, which are hired for initially twenty years and can be prolonged afterwards[6] (Dijk & Mennen, 2002).

The grave rest can be considered as a special kind of land filling, with decomposition processes that are determined by natural aspects of the land, management practises of the cemetery, funeral aspects of the interment and characteristics of the remains (Dent & Knight, 1998). The graveyard guardian however, will try to create conditions for optimal decomposition, because removal of only partly decomposed corpses after the grave rest period is undesirable (Dijk & Mennen, 2002).

[5] Suppose the stone is a covering plate of 120 x 250 cm and 5 cm = 0.15 m^3. If the stone is granite, which has a density of about 2.7 x 10^3 kg/m^3, the stone weighs about 400 kg.

[6] The Dutch association of graveyards (*Landelijke Organisatie van Begraafplaatsen, LOB*) estimates that there are about 50,000 graves in the Netherlands which can be called “eternal graves”. Due to changing laws, land owners, family situations and graveyard conditions, it is hard to predict the exactitude of this figure and the real implications for land use (Dijk & Mennen, 2002). Therefore these graves are ignored in this research.

Nevertheless, the process of saponification, by which a wax-like layer of adipocire is formed and the decomposition is almost stopped, takes place from time to time (Pagels, Fleische & Horn, 2003). Potential problems of cemeteries are contamination of the surrounding soil and water by viruses and bacteria, and local eutrophication due to mainly nitrogen and phosphorus release (Dent, 2002).

However, Dent (2002) concluded after more than seven years of research, that generally "earth burial is an ecologically sustainable activity". Therefore, and for simplicity, we will ignore the complications and consider the cemetery as a landfill site where the human body elements decompose naturally. A small difference that will be considered is the management of the site, which is clearly different for a cemetery than for a landfill. The cemetery is maintained by its guardian, meaning that he takes care of proper lighting, water availability, cleaning and often some gardening activities. Every cemetery differs in its design, but most graveyards have at least some kind of natural look.

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. In case that not fully decomposed human remains are found, they should be officially reburied. However graveyard owners try to avoid this situation for example by attending a longer rest period, among others for ethical reasons. All metals and plastics that are found at the moment of removal, like coffin ornaments and prostheses, are dumped as regular waste, as well as the grave monument (Yarden, 2010).

3.4 Final part: cremation

Cremation means the incineration of a corpse. The Dutch law commands that the cremation takes place in a crematorium, of which the specific requirements and tasks is given in the same law (Wet op de lijkbezorging, 2010, Chapter IV). The distinct steps that take place in the cremation part are shown in Figure 3.3 and explained subsequently.

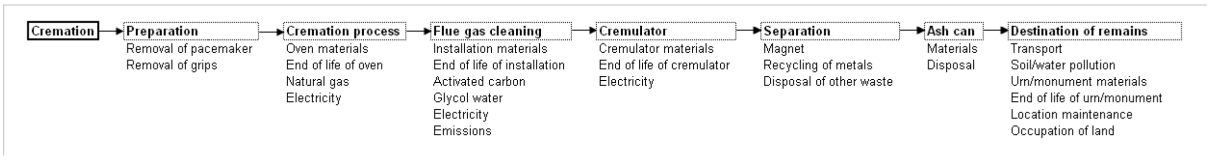

Figure 3.3 Schematic overview of the steps which are present in the cremation part. A description is given in the paragraph below.

Two actions that are undertaken prior to the actual cremation are removal of the pacemaker and removal of external metal elements of the coffin. The pacemaker, which is carried by about 0.1% of the population, should be removed because its battery has a high explosion risk in the oven (Protocol Overledenenzorg, 2010). The pacemaker is removed by a surgical operation. Large exterior prostheses like artificial legs are also removed on beforehand, while smaller and interior prostheses like artificial fingers and hips are left untouched (Klaver, 2010). The metal elements of the coffin, like grips and ornaments, are removed by a crematorium employee. These are collected with the rest of the metals that remain later in the process, as described further below.

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 gas. Ovens can weigh 13,000 to 25,000 kg all-in and they can treat 600 to more than 1800 cremations per year (DFW Europe, 2010). As warm start ovens form a majority, we will only focus on that specific system and its effects.

The actual cremation starts when the coffin is introduced to the oven. The cremation takes about 75 minutes in a warm starting oven and 150 minutes in the other ovens. During the cremation, the temperature rises up till 1100 ˚C, while at the end it lowers until 800 ˚C. The warm starting oven can immediately continue with the next cremation when the previous is finished (Palliatieve Zorg, 2006, after: Facultatieve Technologies). The whole cremation costs about 12.5 to 45 m^3 gas per cremation[7] (DFW Europe, 2010). Modern cremations are controlled by a computer system.

[7] GHD (2007) suggest that it costs 30 to 60 litres (dm^3) gas to cremate one person. Seen the fact that most other sources, amongst which the oven construction company DFW (DFW Europe, 2010) and the comparative

A by-product of the cremation is the flue gas (Appelman & Kok, 2005), which requires cleaning before it is released to air. The flue gas can be cleaned in several ways, of which an overview is given by Schenk, Mieog & Evers (2009). Remmerswaal & Heuvel (2005) considered a system with an *Amalgator*, which is a special catalyst type. However this Amalgator has received serious criticisms from the funeral sector (Willemse, 2010) and therefore this research considers a system with a ventilator and active coal injection. The hazardous components that are filtered from the gas are treated as special waste.

After the cremation there remains human ash and other remains. The human parts of those other remains are processed to ash in a cremulator and then added to the rest of the ashes. The last parts of the other remains are metals and plastics from prostheses and dental fillings (Remmerswaal & Heuvel, 2005). They are sorted out with a magnet and by hand (Klaver, 2010). The metals are collected and recycled by two specialized companies, Orthometals and Tjalling Wolthuis, respectively for ordinary metals and bullions (Morren, 2010).

The human ash is put in an ash can and kept for the legal term of one month in the crematorium. The subsequent ash destination options thereafter are numerous. The distribution of the most common options is shown in Figure 3.4. All the options can be reduced to two for this research, for the following reasons. What the family does with the ashes is officially unknown; the ashes might be kept in an urn, but is probably very often also scattered out without permission (Molenaar, Mennen & Kistenkas, 2009). However, very little can be said about the environmental effects of donation to the family. For medallions and art, only a small part of the ashes is used, so this is ignored as well. Conservation of the ash in an urn can be seen as a scattering process in the long run, because in the end the family will probably not keep the urn forever. An option that is not directly visible in this figure, is burial of the urn; however, in the long run, the ash still returns in the soil. Two main options thus remain: scattering over sea, or scattering on land.

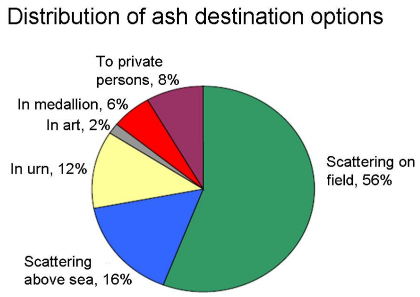

Figure 3.4 Destination of ashes, in percentages. Data are following from funeral organisation Yarden in 2000, reflecting about 16,000 ash destinations, which is about 30% of the total annual Dutch number of cremations. Source: Dijk & Mennen, 2002.

Scattering of the ashes above the sea can be done by ship or by plane, but Yarden (2010) estimates that most of it occurs by ship (95%). Sometimes the relatives join the trip, but the majority of the trips is for the crematoria (Aqua Omega, 2010). Dispersion on land can be done at an official straying field near the crematorium, which is usually intensively managed by mowing, at a special nature straying field, or at a non-registered location with permission of the land owner (Molenaar, Mennen & Kistenkas, 2009).

3.5 Final part: cryomation

Cryomation is the term for a corpse treatment which involves freeze drying. Other terms are *lyophilisation*, which just means freeze drying, or *promession*, following the name of the Swedish inventors, Promessa Organic Burial. Promession follows other process steps than cryomation and will therefore not considered here.

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research of Remmerswaal & Heuvel (2005), speak about tens of cubic meters, this again shows the lack of clarity of the GHD report.

At the moment, the cryomation process is not yet fully operative. Nevertheless, all steps have been tested. However, they have not been tested on humans yet, only on pig carcasses, and there does not yet exist an all-in cryomator. Another currently underdeveloped point is that standard cryomation reduces the body to one third of its original weight, but the inventors have developed an accelerated composting process which further reduces the remains by another 30%. Anyway, all steps in the cryomation part are more or less known, shown schematically in Figure 3.5 below and explained subsequently.

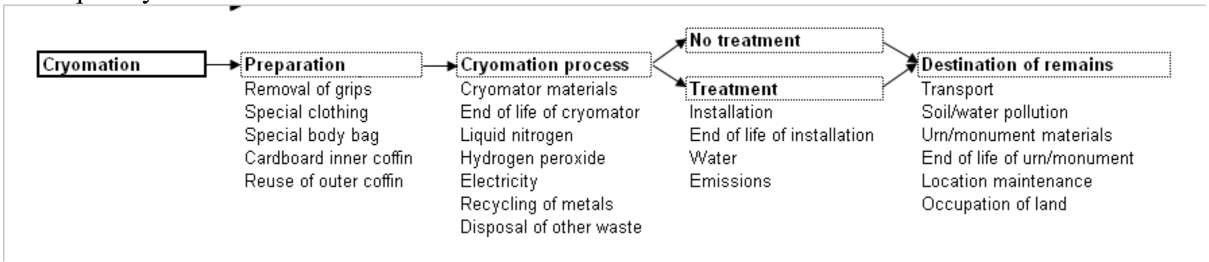

Figure 3.5 Schematic overview of the steps which are present in the cryomation part. A description is given in the paragraph below. Source: Cryomation Ltd, 2010c.

Prior to cryomation the body needs to be clothed in special clothing made of corn starch and leather. A special coffin is also required, which consists of an outer part which is reused and an inner part which enters the cryomator. Next, the body can be frozen by the undertaker, but this is not a necessary action.

The first step in cryomation is the automated weighing of the coffin, to control the required quantity of liquid nitrogen. After the liquid nitrogen is introduced to the coffin, the body in the coffin is allowed to rest until the core reaches the required temperature. From now on, the process is fully automated; there is no operator intervention until the dried remains are boxed.

The cryonic freezing makes the body very 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 which allows any non-organic material to be rejected. Ejected material is then cleaned of any tissue using high pressure liquid nitrogen, where after the tissue is returned to the process and any tramp material is collected for recycling or disposal. The sorted 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 sublimated.

At the end of the process the dried material is subjected to a treatment of gaseous hydrogen peroxide. This reduces the pathogen count by a factor 100,000. What remains, is about a third of the body and the coffin in the form of a beige, sterile odourless mix, no larger than pieces of 5mm.

These cryomated remains are then put into a biodegradable box and would need to be buried conventionally. An alternative option is that the remains are further processed by accelerated aerobic composting. This reduces the mass by a further 30% and it is safe to return to the relatives, either in an urn to be planted with a plant of choice, or in a (biodegradable) box for (woodland) burial, or to be strewn on a field or scattered at sea.

3.6 Final part: resomation

Resomation, called by other companies *Water Resolution*, *CycledBurial* or *Aquamation*, and or in technical terms *alkali hydrolysis*, is a way to dissolve the body in a basic solution. The total process, according to the producers, requires 450 litres of water (Matthews Cremation, 2010b) and costs 90 kWh for the whole cycle (Ecogeek, 2010). They state that it produces four times less CO_2 and that it is eight times more energy efficient than traditional cremation, but do not mention the exact figures (Biocremationinfo, 2010).

The different steps in the resomation part are shown in Figure 3.6 and explained in the subsequent paragraphs. The information of Resomation Ltd and its partners (Matthews Cremation, Biocremationinfo) will be followed mainly, because it is already operative in the USA. If necessary, additional information of Water Resolution will be used, as that company seems to follow the steps as

Resomation Ltd. The procedure of CycledBurial and Aquamation differs slightly from the other two[8] and is therefore left out here.

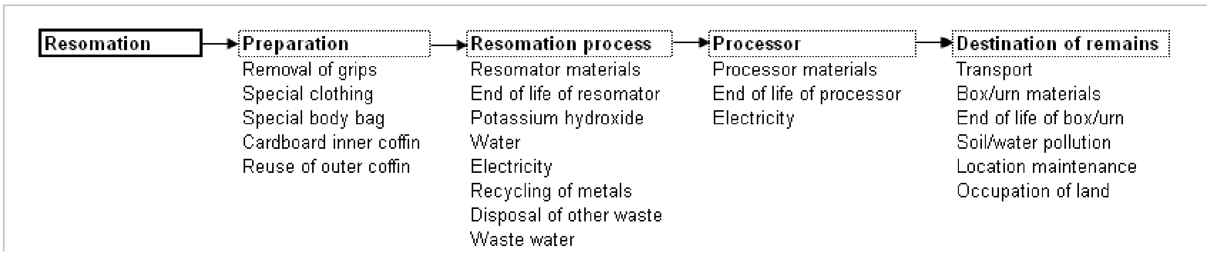

Figure 3.6 Schematic overview of the steps which are present in the resomation part. A description is given in the paragraph below. All information is taken from Resomation Ltd (2010), Water Resolution (2010), CycledLife (2010) and Remmerswaal & Heuvel (2005).

Before the resomation, the body should be clothed in tissues made of protein, being silk, wool or leather (Biocremationinfo, 2010). It is assumed that there are no additional transport costs for resomation, because it can take place in a crematorium according to Resomation Ltd. They state that the *resomator* has no additional requirements and it has similar dimensions as a cremation oven. In the starting phase of resomations in The Netherlands, some more travel might be required than for cremation or burial, because people from everywhere in the country might be interested, while only few machines are installed at that moment; this transition phase is left out of our analysis.

The resomation process starts by the separation of the body and the coffin. The coffin is reused for other bodies. The body is wrapped in a biodegradable bag and in a reusable metal bucket. It is then put in the resomator. A picture of the resomator is shown in Figure 3.7 below.

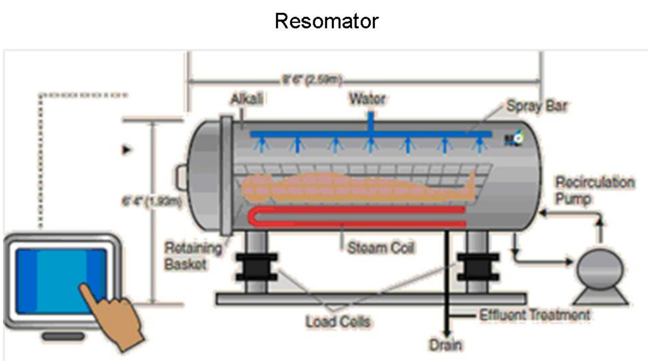

Figure 3.7 Technical drawing of a resomator. Source: Matthews Cremation (2010a), official supplier of Resomation Ltd in the USA.

Inside the resomator, load blocks determine the weight, after which the exactly needed amounts of water and lye are adapted. Several sources give different amounts of needed water, from 380 litres (WaterResolution, 2010) to 500 litres (Flossing & Kramer, 2009). As lye, KOH is named to be the best option (Biocremationinfo, 2010).

The inside of the resomator is heated up to about 150 to 185 ˚C by means of a gas heated steam, which flows through an internal coil (Matthews Cremation, 2010b). The pressure is kept at 5 bars to prevent the solution from boiling and for an optimal hydrolysis (Remmerswaal & Heuvel, 2005; Flossing & Kramer, 2009). A circulation pump takes care of continuous pumping. This takes place for about 2 to 3 hours.

Next, cold water is run through the coil in order to cool down the liquid. Provided that the process is completed, the resomator is drained. The solution that is drained contains salts, sugars, peptides and amino acids. According to Remmerswaal & Heuvel (2005), this solution weighs about

[8] Main differences are in the design of the vessel (vertical vs. horizontal, which has implications for among others water use and pump requirements) and temperature (low vs. high) (CycledLife, 2010). Similar quotes exist for Aquamation, but even fewer facts are available about that technique.

500 kg, has a pH of 10.3 to 12.9, a BOD of 70 g/L and a COD of 100 g/L. All inventors claim that the solution can be released straight on the sewage system without requiring further cleaning.

What remains in the resomator is rinsed with hot water of 90 ˚C. The remains are then dried and separated. Metals are recycled, prostheses can be reused (Biocremationinfo, 2010). The bones have become so fragile that they are easily crushed to a white powder in a processor (Remmerswaal & Heuvel, 2005; Matthews Cremation, 2010b).

The powder is put into a can, before it can go to its last destination: scattering on land or sea, conservation or burial in an urn or, as a new option, burial as compost (Ecogeek, 2010). It is not known whether the powder could be used in medallions or artwork, but these were already considered insignificant options in the previous section. For scattering, conservation and burial, roughly the same options are presented as for cremation ash. Another burial option is to bury the urn in a decomposable urn, which leads to an accelerated uptake in the ground. Concluding, scattering on land or scattering over sea are again the two main options, with burial as compost or in a decomposable urn, as a third.

4 RESULTS OF THE LIFE CYCLE ASSESSMENTS

4.1 Results with Ecoindicator

The results of the life cycle assessments of all different funeral parts are shown in Figure 4.1 below.

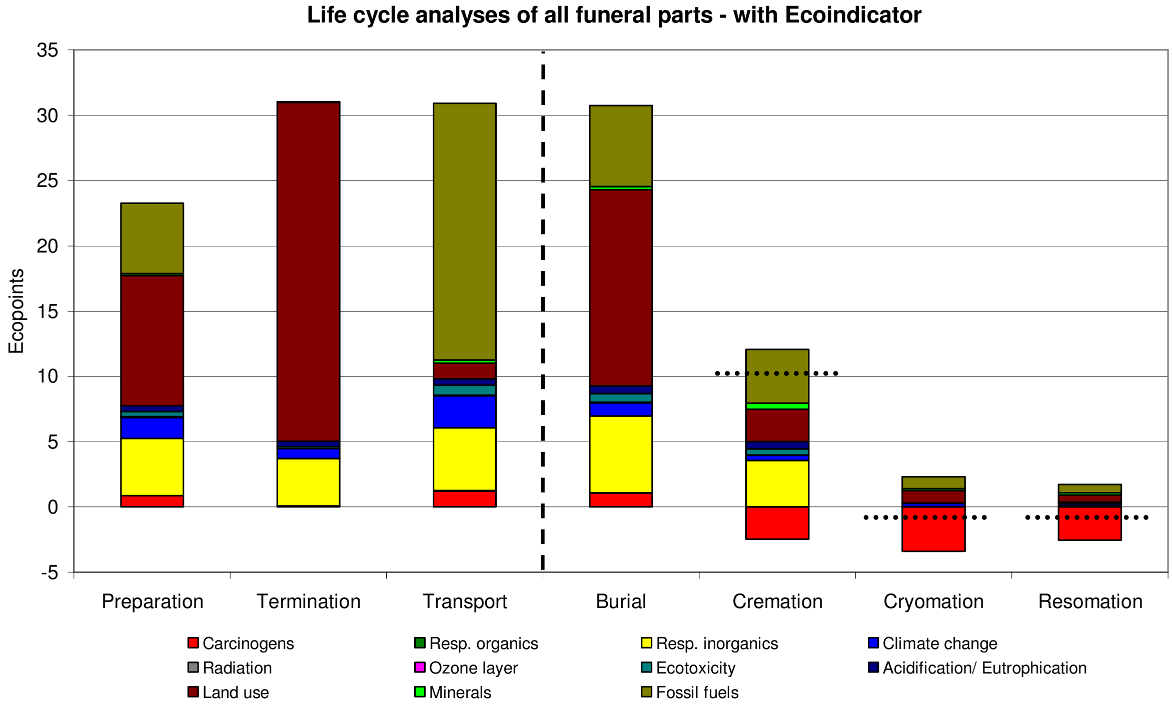

Figure 4.1 Results from the life cycle assessments of all different funeral parts, performed with the Ecoindicator99 method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options. Dotted lines indicate the height of the net result. Note that the points on the y-axis are Ecoindicator points, which means they are calculated in another way than and incomparable to the ReCiPe points of Figure 4.3.

From the first view, it is clear that all preliminary processes together carry by far the heaviest environmental burden of all the funeral parts. A quick analysis shows that this is mainly caused by the land use that is required for flowers, foods and drinks, and by the fossil fuel use for the funeral guests' and correspondence transport.

At the second place, with a three times smaller effect than the total preliminary part comes burial. Cremation, cryomation and resomation have also environmental scores, due to the recycling or reuse of metals. The net results are indicated with a dotted line in the graph. Cremation scores about three times lower than burial, even though its expected large gas consumption. It shows some similarities with burial because they both use one coffin per funeral, while the other techniques reuse the coffin several times.

Cryomation and resomation score the same, just below zero, although this is only a very small and probably insignificant negative value. Anyhow, the benefits from recycling and reuse are so big that they neutralize the high electricity needs from both processes. Especially the recycling of gold is beneficial for the reduction in environmental burdens. Strangely enough, one could consider cremation, cryomation and resomation as an extraordinary form of material recovery. Moreover, even without the recycling and reuse, both new techniques score much lower than cremation (factor three) and than burial or the preliminary part (even more than factor ten).

It should be mentioned that land use, which is largely present in some of the bars, is often discussed on its environmental impact and the indicators concerned. Nevertheless, even when ignoring the land use part of the bars, the main results remain the same.

Nevertheless, the graph below should be interpreted with some caution. This is further discussed in the next chapters. First, in the next paragraph, the results of the lifecycle analyses are also calculated with the CML method.

4.2 Results with CML

The life cycle assessment is performed with the CML method and the results are shown in Figure 4.2 below. The unit of the Y-axis is now in euros instead of points, as explained in section 2.2.

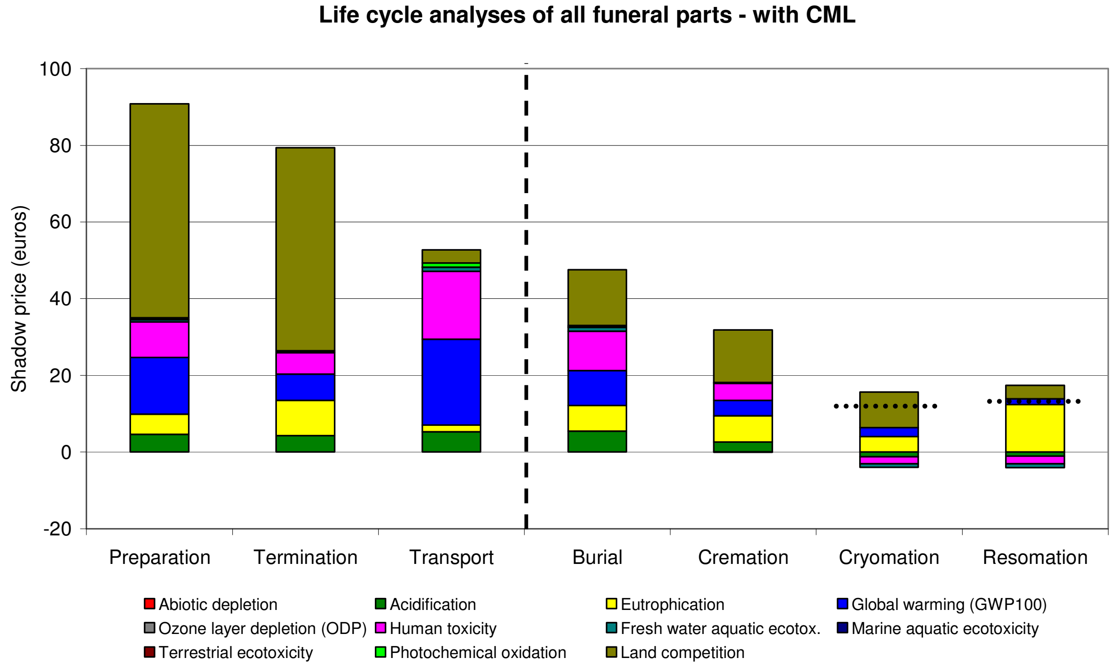

Figure 4.2 Results from the life cycle assessments of all different funeral parts, performed with the CML method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options. Dotted lines indicate the height of the net result.

Again, the preliminary part clearly scores the highest environmental effects. It scores high for the same reasons as in Ecoindicator, being the flowers, newspapers, foods, drinks, and transport. Transport scores much lower this time however; its global warming effect is rather low in comparison to the land competition effect of the other two preliminary parts.

The sequence of the other funeral parts is comparable with the Ecoindicator method. Burial scores second, however this time it is less influential than transport, though still about a quarter of the total preliminary effect. Cremation counts for much more than half, instead of a third, of burial. Resomation scores 1 euro higher than cryomation, both are about half of cremation.

Besides the expected land competition burden, burial has a surprisingly high global warming potential (GWP100), even though almost no fossil fuels are involved directly. This comes from amongst others from the cemetery maintenance, the transport of the monument and burial itself. The human toxicity of burial comes mainly from the natural stone of the monument.

The large eutrophication in resomation comes mainly from scattering of the ashes above the sea, even though it is only a minority option in this model (25%). This is surprising as well, seen the fact that scattering over sea is named by the government as the least environmental unfriendly option (Ministerie van VROM, 2004). The second reason why resomation has such a high eutrophying effect is that the waste water treatment involves waste incineration with long-term emissions to groundwater.

For CML the question could be raised again whether and how land competition should be taken into account. Leaving it out of the graph does not change the main conclusions, but does result in some new nuances. Cryomation suddenly has a score that is much lower than resomation; resomation lays exactly in between cryomation and cremation, differing about 8 euros with both others.

Again, it should be noted that these results should be treated with some reservations. The following chapters provide more information on this. However, as the results with Ecoindicator and

CML differ slightly, a third analysis is performed by means of ReCiPe. This is explained in the next paragraph.

4.3 Results with ReCiPe

Because the analyses with Ecoindicator and CML provided partially different conclusions, an analysis with the ReCiPe method is applied as well. ReCiPe is derived from both methods together and should therefore not be considered as another, totally different result, but more as a kind of combined result. The results are shown in Figure 4.3.

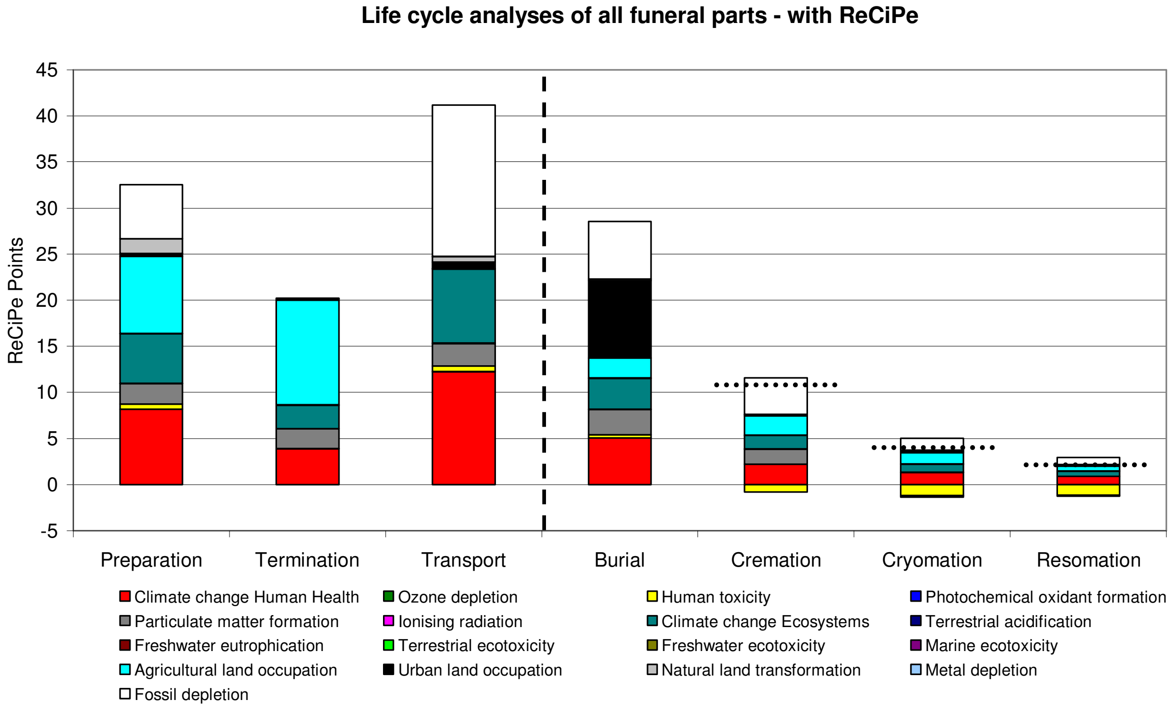

Figure 4.3 Results from the life cycle assessments of all different funeral parts, performed with the ReCiPe method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options. Dotted lines indicate the height of the net result. Note that the unit on the y-axis is ReCiPe points, which means they are calculated in another way and incomparable to the Ecopoints of Figure 4.1.

The first thing remains clear: the sum of the effects of the preliminary part's processes carries the highest environmental burden. The second place, with a third of the score of the preliminary part, is for burial, marked by an obvious burden of land use, but also a large burden of climate change human health, due to the greenhouse gas emissions from the grave rest. Cremation follows with only a third of the burial score. Cryomation scores a little bit higher now than resomation, both a few points above zero and two or three times lower than cremation.

Ignoring the land occupation or the land transformation has no effect on the main conclusions. The only major alteration is the order of magnitude of the burial effects compared to the others; cremation is more than half instead of only a third of the burial effect.

The results with ReCiPe seem rather comparable with CML and Ecoindicator. Nevertheless, the fault margins and relative values of these results require further analysis before hard conclusions can be made. The next chapters deal with these subjects.

4.4 Output inventory

Table 4.1 gives an overview of the twenty-one most prominent factors (all contributing ≥1%) of all funeral parts together, analyzed with ReCiPe. The ranking was calculated by setting the sum of the effects of all funeral parts together at a cut-off of 1%. Similar categories (like the several variations of occupation of land) were not summed up, because the inventory list is too long to check every category.

The selection of Table 4.1, reflects in most cases more than 90% of the environmental effects of the funeral parts[9]. The table shows that the large factors in the funeral sector come from emissions to air and from resources. Not shown in the table, is the fact that emissions to water only start appearing below a threshold of 1% (Manganese[10]), while emissions to soil start appearing below 0.1% (Phosphorus).

Fossil carbon dioxide emissions (27%) and crude oil use (11%) are the major substances that contribute to the environmental effects of funerals. Carbon dioxide is dominantly present in all funeral parts. Crude oil is mainly used for transport and is consequently present as an important player in all final techniques except cremation.

Table 4.1 Overview of the twenty-one substances (or: factors contributing 1% or more) that are most prominent in the effect of all funeral options together. The unit is ReCiPe points. "x" means absent or a an absolute value that is smaller than 0.1.

Nr	Substance	Compartment	Preliminary	Burial	Cremation	Cryomation	Resomation
1	Carbon dioxide, fossil	Air	27.0	7.0	2.0	1.8	1.0
2	Oil, crude, in ground	Resources	15.6	3.8	0.6	0.4	0.5
3	Occupation, arable, non-irrigated, diverse-intensive	Resources	14.7	x	x	x	x
4	Transformation, from forest, extensive	Resources	5.6	1.6	1.6	1.4	0.4
5	Carbon dioxide	Resources	8.3	x	1.1	x	x
6	Occupation, urban, green areas	Air	x	8.3	0.1	0.1	x
7	Gas, natural, in ground	Resources	3.6	0.9	2.5	0.2	x
8	Occupation, forest, intensive	Resources	4.4	x	X	0.3	0.3
9	Nitrogen oxides	Air	2.0	1.2	1.3	0.1	0.1
10	Coal, hard, unspecified, in ground	Resources	2.1	1.2	0.7	0.3	0.1
11	Occupation, forest, intensive, normal	Resources	0.7	1.2	1.2	0.8	x
12	Dinitrogen monoxide	Air	1.8	0.2	0.2	x	0.2
13	Methane, fossil	Air	0.9	0.4	0.3	0.1	0.1
14	Methane	Air	1.8	x	x	x	x
15	Coal, brown, in ground	Resources	0.9	0.2	0.1	0.3	0.2
16	Occupation, arable	Resources	x	0.8	0.8	x	0.1
17	Transformation, from tropical rain forest	Resources	1.4	x	x	0.1	0.1
18	Particulates, < 2.5 um	Air	0.6	0.5	0.2	0.1	0.1
19	Manganese	Water	0.5	0.1	-0.7	-0.9	-0.9
20	Transformation, to forest, intensive, normal	Resources	-0.9	-1.6	-1.5	-1.0	-0.1
21	Transformation, to forest, intensive	Resources	-4.6	x	x	-0.3	-0.3
22 to 395	**Other remaining processes**		**8%**	**8%**	**2%**	**-4%**	**-19%**

In Table 4.2 to Table 4.5 the inventories are analyzed per effect category for the final part options only. Each table shows the five elements that had the highest single score for a certain funeral part, rated from 5 (highest) to 1 (fifth). The scores for each substance were summed up, in order to give a ranking of the importance of the factors that influence the environmental effects of funerals.

The tables show slightly different outcomes between the different funeral methods, but most times there are only few important substances per effect category and only the order of importance differs per funeral part. The interpretation of these tables is discussed below per effect category.

[9] Resomation is an exception with only 81%, but this is partly due to the fact that resomation has a rather small net score. This net score is determined by larger positive and negative factors, which make the overall picture rather unclear when looking at percentages only.

[10] Manganese has a negative net value. If we only consider positive values, the first appearance of water emissions is with barium, at 0.044%.

When looking only at the environmental effects of resource use of the final parts in Table 4.2, oil is not the most but the second important; it is preceded by transformation of land from forest and followed by occupation of land as forest.

Table 4.2 Most prominent resources in the inventories of the different final funeral parts. The ranking is explained in the text above.

Substance	Burial	Cremation	Cryomation	Resomation	Sum
Transformation, from forest, extensive	3	4	5	4	**16**
Oil, crude, in ground	4		3	5	**12**
Occupation, forest, intensive, normal	1	3	4		**8**
Occupation, urban, green areas	5				**5**
Gas, natural, in ground		5			**5**
Coal, brown, in ground			2	2	**4**
Occupation, forest, intensive			1	3	**4**
Coal, hard, unspecified, in ground	2	1			**3**
Occupation, arable		2			**2**
Transformation, from tropical rain forest				1	**1**

Considering emissions to air in Table 4.3, fossil carbon dioxide is still the largest source of effects. Nitrogen oxides follow on the second place, while PM2.5 and fossil methane share the third place. Mercury, which was expected to be influential in air emissions, is only a minor player. A detailed look at the results shows that Mercury contributes less than 1% to cremation effects, probably because it is intensively filtered out of gas in the crematories and does not enter the air with the other methods[11].

Table 4.3 Most prominent emissions to air in the inventories of the different final funeral parts. The ranking is explained in the text above.

Substance	Burial	Cremation	Cryomation	Resomation	Sum
Carbon dioxide, fossil	5	5	5	5	**20**
Nitrogen oxides	4	4	1		**9**
Methane, biogenic			4	3	**7**
Particulates, < 2.5 um	1	1	3	1	**6**
Methane, fossil		2	2	2	**6**
Dinitrogen monoxide				4	**4**
Sulphur dioxide	3				**3**
Carbon dioxide		3			**3**
Methane, biogenic	2				**2**

Emissions to water in Table 4.4 are headed by phosphate and phosphorus, which are dominant in all funeral parts except burial. This fits with the findings of paragraph 4.2, which states that dispersion of human remains over sea might not be the most environmentally friendly option following the CML perspective. Barium is the third most influential factor for emissions to water.

Table 4.4 Most prominent emissions to water in the inventories of the different final funeral parts. The ranking is explained in the text above.

Substance	Burial	Cremation	Cryomation	Resomation	Sum
Phosphate	3	4	5	5	**15**
Phosphorus		5	3	4	**14**
Barium	2	3	4	3	**12**
Manganese	5				**5**
Arsenic, ion	4				**4**
Chlorine			2	1	**3**
Nickel, ion		2	1		**3**
Bromine		1		2	**3**
Selenium	1				**1**

[11] Mercury is also emitted in the preliminary part, but that is not because of the treatment of the dead body.

The last category, emissions to soil, shown in Table 4.5, is also headed by phosphorus. It is followed by the insecticide cypermethrin, and cadmium. However, as the previous sections already indicated that emissions to soil are only a minor effect category for funerals, these results will not be further discussed here.

Table 4.5 Most prominent emissions to soil in the inventories of the different final funeral parts. The ranking is explained in the text above.

Substance	Burial	Cremation	Cryomation	Resomation	Sum
Phosphorus	4	3	5	4	**16**
Cypermethrin	5	5	2	3	**15**
Cadmium	2	2	3	5	**12**
Aldicarb	3	4		1	**8**
Atrazine			4		**4**
Zinc				2	**2**
Barium	1				**1**
Diuron		1			**1**
Metolachlor			1		**1**

5 SENSITIVITY ANALYSIS

The sensitivity analysis of the main determinants of the results aims to show how reliable and variable the outcomes of the LCAs are. This analysis is performed in four ways, considering the inputs, processes, models and methods of the LCAs. The outcomes are presented and discussed in the next paragraphs.

5.1 Input data and assumptions

The results of this data quality analysis are illustrated in Figure 5.1. It shows large differences between the outcomes of the minimal and the maximal scenarios: up to a factor six. Especially the preliminary part contains large variations; this is for a large part caused by a variation in the number of funeral guests. Amongst the final parts, burial shows the largest variations. Nevertheless, all general trends stay the same in each scenario. The preliminary part carries by far the highest environmental burden of the funeral, burial is about half or a third of the total preliminary part, cremation scores half of burial, resomation has the lowest scores and cryomation is somewhere in between the latter.

The variations show that the exact outcomes are quite sensitive for the way the input is determined, being either from an abundant or a sober perspective. However, as the standard scenario seems to be about in the middle of the two perspectives and shows constant patterns, this means that the results can be compared if at least a consistent data perspective is chosen, at least for the preliminary part.

Considering the final part, the graph below shows that conclusions about burial are still valid, that cremation is probably higher than cryomation and certainly than resomation, and that a distinction between cryomation and resomation can hardly be made.

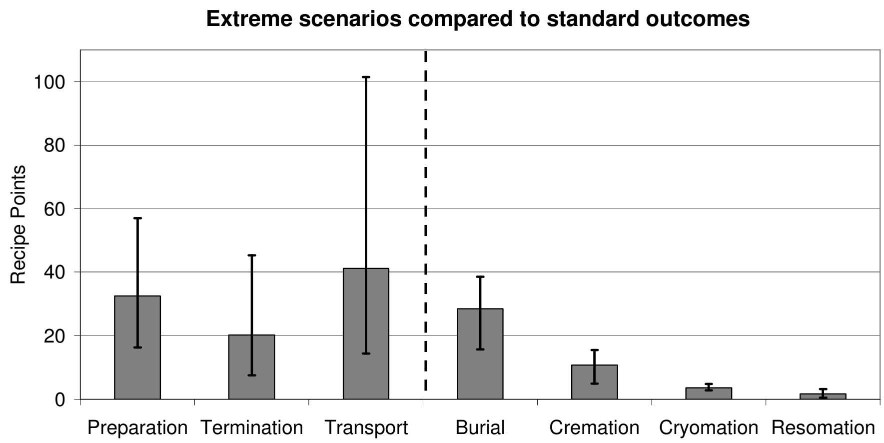

Figure 5.1 Illustration of the variability in the outcomes of the life cycle assessments; minimal and maximal outcomes are shown together with the outcomes of the standard analysis. Left from the dashed line, the preliminary parts are shown, right of it are the final part options.

A small additional analysis is performed on the effect of mercury in dental fillings, because it is such a widely discussed issue. A quick analysis shows that even a total abandonment of those types of fillings would decrease the cremation effect with only 1%, from 10.8 points to 10.7 points.

5.2 Processes

For each funeral part, it is determined which the most influential processes are and how large their effect is. The threshold for important processes is at least 10% with respect to the effects of that specific part. For the sake of clarity, the results are split up into two graphs, Figure 5.2 and Figure 5.3 below and discussed subsequently.

Figure 5.2 shows the major processes of the preliminary part. The newspaper advertisements are clearly the major player in the preparation, with about 50% influence. As only two advertisements are counted, this means that a single additional advertisement causes a 25% increase in effects for the preparation part. The van transport is partly also responsible for the newspaper transport, thus this increases the effect. Flowers are also quite influential; the 75 euro spending of flowers causes about a third of the total effect. Another bouquet of 25 Euros would cause then an increase in effect of 10%.

The termination is clearly divided in effects of food and of beverages; the effect of electricity use for heating and lighting is negligible. The food counts however about much heavier than the drinks, seen the fact that 25 euros are supposed to be spent on food, in comparison to 96 on drinks. The transport is, not surprisingly, mainly determined by passenger kilometres.

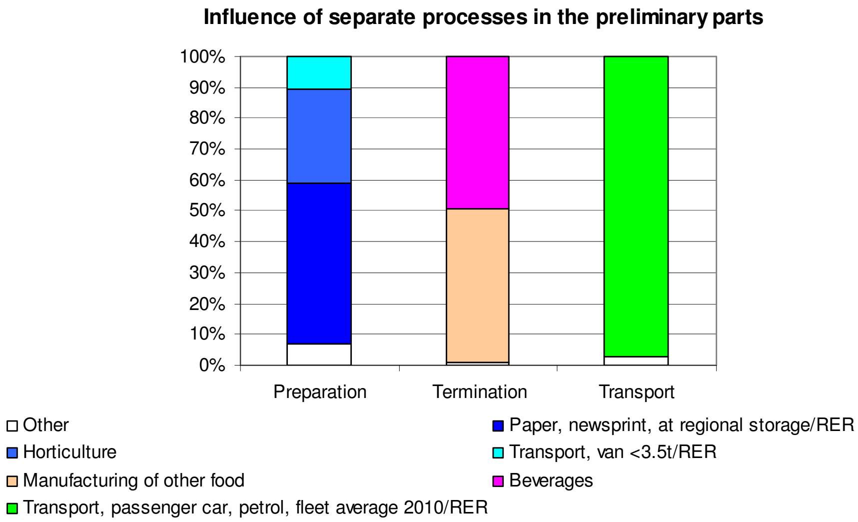

Figure 5.2 Influence of the separate processes that play a role in the preliminary funeral parts. Only the processes that contribute 10% or more are shown.

The most important processes of the final part are shown in Figure 5.3. Occupation of land dominates the total burial costs, by about 43%. An extension of the grave rest period with 5 years causes an increase of 1.3 point (about 5%) of the total burial effect. The natural stone plate contributes about 20%. A change of the stone weight of 50 kg would cause about the same effect, namely 1.5 point. Burial of the body is not visible in this graph, because it contributes even less than 2%.

Cremation is dominated by four processes, the flue gas cleaning emissions (20%), hard coal (two times 10%) and natural gas (10%). Flue gas cleaning emissions and natural gas consumption are the logical major contributors to total effects. Every 100 m^3 of flue gas that is emitted extra, cause 1% increase of the total cremation effect. Seen the fact that input sources showed already about 500 to 1000 m^3 of variation, there is a variation of 5 to 10% due to the flue gas emissions. Every cubic metre of natural gas use has the same effect and the same variation from the input sources. Last, hard coal originates from electricity for the cremation and for the coffin production, but these effects are smaller.

Cryomation also consists of four major contributing processes, but besides that, it has a large share of many smaller processes which play a role. Nevertheless, the fact that the passenger transport, which is used to pick up the cryomation ashes and bring them home or elsewhere, is one of the main contributors to the total cryomation effect, implies that the total effect is not very large. The same counts for the softwood, which is only applied for the small grave monument. Electricity use, liquid nitrogen production costs and soil or sea pollution by the cryomated remains are not visible in this graph, which means that their effect is rather small. (Avoided) disposal of sulfidic tailings weighs heavy, mainly as a consequence of gold recycling.

The resomation bar contains all processes which contribute 50% or more. Electricity is by far the most important process, counting for about half of all resomation effects together (350%). This electricity is used directly in the process, but also indirectly, for the production of potassium hydroxide and the waste water treatment. Every extra kilogram of potassium hydroxide cause about 0.15 point extra, which is not much compared to the other final parts, but which means about a 10% increase of the end score of resomation itself. Every 2.5 kWh of extra direct electricity has the same effect. An underestimation of the electricity costs with 10 kWh could then lead to 0.6 pt more environmental effects.

Natural gas, in two forms, is avoided by the reuse of metals. The avoidance of hard coal and disposal of sulfidic tailings was already discussed above and will not be considered in detail here. Again, pollution of soil or water are not visible at all, meaning that these processes only have a small contribution to the environmental effect of this funeral part.

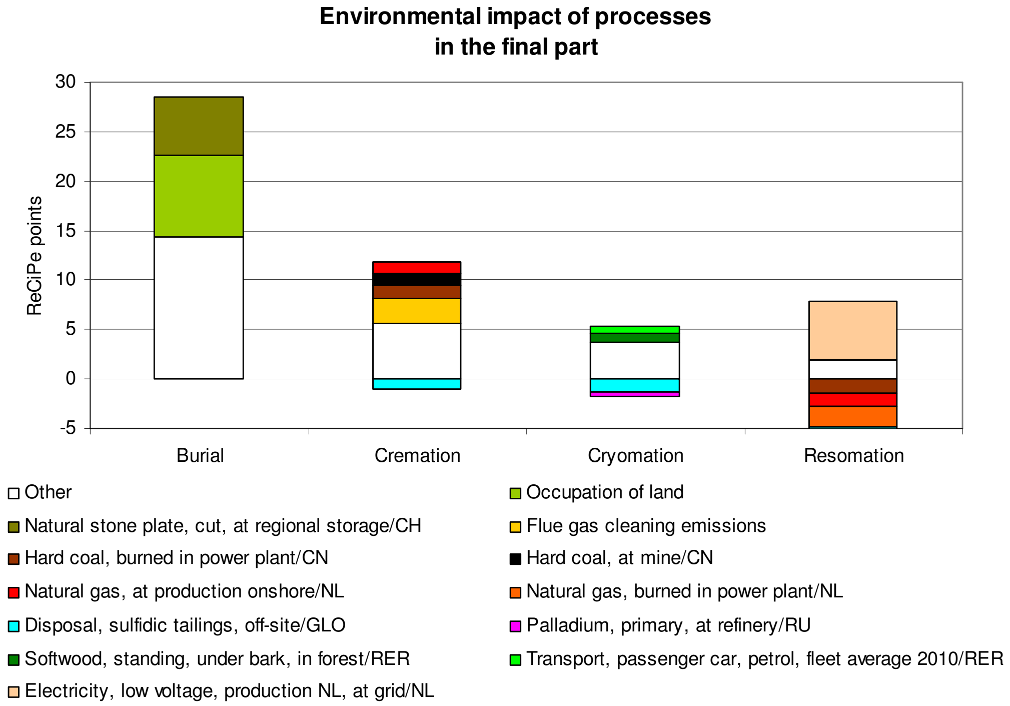

Figure 5.3 Influence of the separate processes that play a role in the final funeral parts. Only the processes that contribute 10% or more are shown, except for resomation, where all processes that contribute 50% or more of the net score are shown.

The high dominance of the negatively scoring processes in resomation raises questions about the way these negative values are obtained. Of almost all metals however, we know that they come from the coffin or from medical implants. A special case is gold: suppose that this amount originates only from dental fillings[12], and that these fillings will be replaced by other, "harmless" materials; what happens then? The result of this small experiment is presented in Figure 5.4.

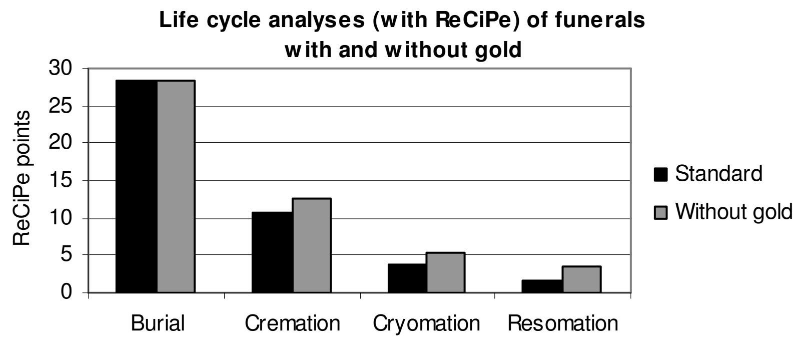

Figure 5.4 Results of life cycle assessments of funeral parts with ReCiPe, where the standard situation (black bars) includes gold recycling, and in the experimental situation (grey bars) gold is excluded from all calculations.

[12] Given the fact that amalgam fillings are present with about 1.5 gram per funeral, the 0.2 gram of gold is not unlikely to be merely dental fillings and not majorly jewelry.

Clearly, the exclusion of gold recycling causes a large increase of the cremation, cryomation and resomation effect. However, it does not cause a change of conclusions; cremation is still in between burial and cryomation. The only small change is that cryomation and resomation are less close to zero.

Nevertheless, the difference between burial and cremation in the ReCiPe graph was already quite large in the standard situation (Figure 4.3), which makes it no big surprise that the conclusions remain equal. The same holds for the Ecoindicator. For CML however, the situation is different. Figure 5.5 shows the situation with gold recycling and without any gold at all, and the conclusions do change this time: cremation and burial now differ only by a few euros.

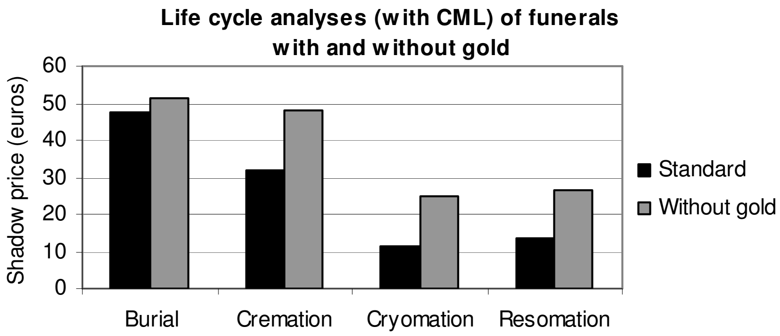

Figure 5.5 Results of life cycle assessments of funeral parts with CML, where the standard situation (black bars) includes gold recycling, and in the experimental situation (grey bars) gold is excluded from all calculations.

The analyses of Figure 5.4 and Figure 5.5 make two things clear. First of all, they show that the variation of different methods, even the methods that are selected on their specific qualities for this research, can lead to different conclusions. This item is further discussed in section 5.4. Secondly, these two figures reveal a major issue in the analysis of the results, namely that the presence or absence of gold in dental fillings can make a fundamental difference in the conclusions. A shift from fillings of gold towards another material, could lead to the conclusion that burial and cremation are equally harmful for the environment.

5.3 Excel models

First of all, the waste model is analyzed by changing three major parameters: the distribution of emissions to water and to soil (#1), the emission factors of the elements (#2) and the gas production (#3). The effects of these changes are determined for the burial part, and shown in Figure 5.6 below. Only an increase in gas production made a notable difference, namely five points increase. The other changes do not cause much difference. The changed distribution to water and soil has no visible effect. The (extreme) increase of emissions factors cause an increase of about ½ point.

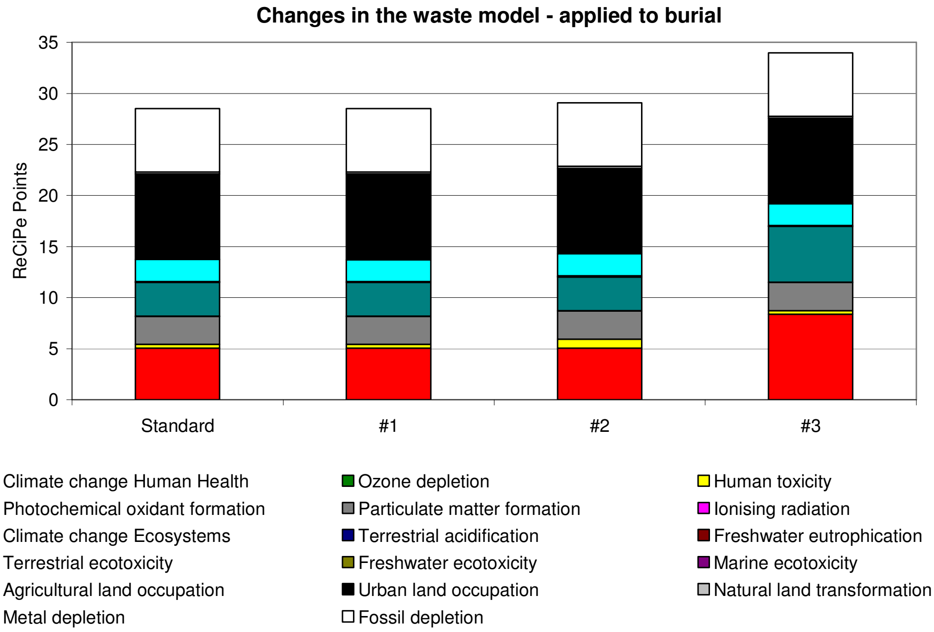

Figure 5.6 Analysis of the effect of changes in the main parameters of the waste model that was applied to burial: distribution of emissions to water and soil (#1), emission factor of the elements (#2), and gas production (#3), compared to the original calculation ("standard").

Secondly, the effects from the waste model are compared to alternative calculation methods. Both alternatives, considering the body as "inert waste" or as "composting organic waste", score about half point lower than with the standard waste model calculation, and are therefore not shown in a graph. This means that burial of a body causes only slightly more environmental effects than an ordinary landfill.

To assess the effect of the waste water model that was used for resomation, the resomation life cycle results are compared to two other scenarios: one without any and one with just ordinary waste water treatment. The comparison is shown in Figure 5.7. The effects between no waste water treatment and normal waste water treatment are marginal; they differ less than 0.1 point. The application of the waste water treatment model for the resomation fluid however, does show a remarkable difference of more than a half point. This fits the expectations that the difference in composition of resomation water and normal waste water requires more extensive treatment and has consequently a higher environmental impact.

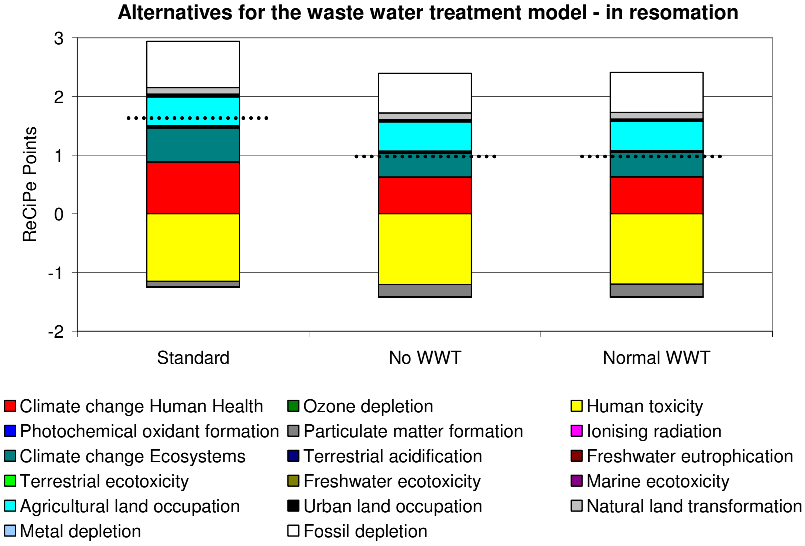

Figure 5.7 Comparison of the application of the waste water treatment (WWT) model and its alternatives, “no waste water treatment” and “normal waste water treatment”, shown for the resomation life cycle. Dotted lines indicate the height of the net result.

5.4 LCA methods

The lifecycle analyses are performed with four other methods in addition to the analyses of the previous chapter. The new results will not be discussed at a detailed level; our interest is in the relative scores of funeral parts with the different methods. These relative scores are presented in Figure 5.8 below. The results of each final part option are shown as percentages compared to burial (100%). The preliminary part is left out of the figure in order to get a better view on the comparison of the final parts. For your interest, the complete graphs are added in Appendix B.

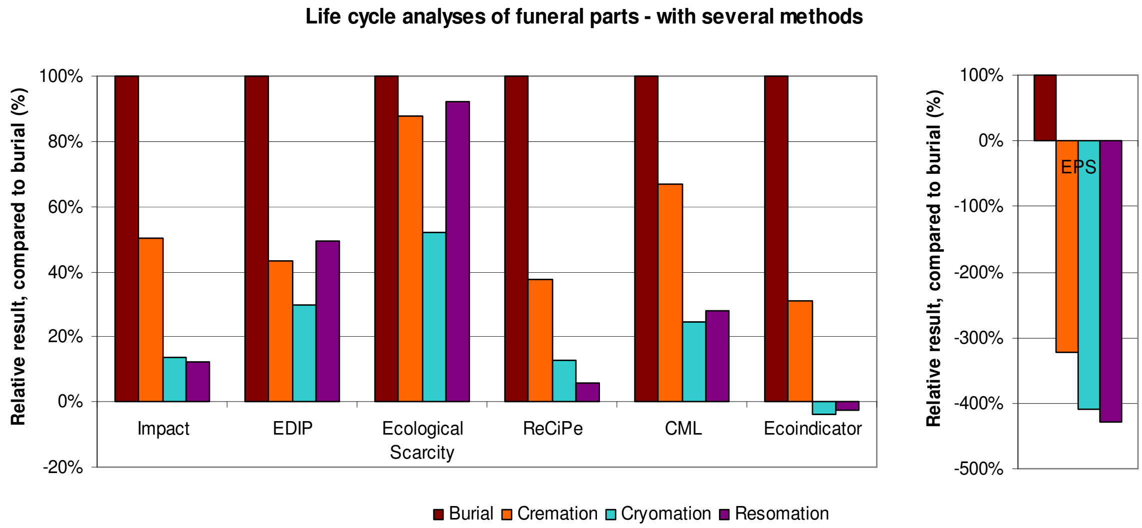

Figure 5.8 Relative results of life cycle assessments of the final funeral parts, examined with several methods. For each method, burial was taken as the reference value (100%) to which all other results were compared. EPS is shown separately because the range of its values differed too much from the others. Note that ReCiPe, CML and Ecoindicator were the preferred methods; the other four were applied in order to assess the differences. Negative percentages mean that the net score for those funeral parts were negative, which were most times caused by benefits from recycling.

The EPS graph is shown separately because it differs profoundly from the other graphs. In the EPS graph, large negative percentages are visible. This is a rather odd outcome, meaning that a funeral could be beneficial for the environment, as a rather unusual form of metal recovery. However, because of the negative outcomes, it will not be further discussed in the following text.

When comparing all the bars of chapter 4, Figure 5.8 and Appendix B, some major conclusions still hold and some minor ones do not. An explanation for this can be found by considering the output inventory analysis in section 4.4. The main contributors to environmental effects of all funeral parts are carbon dioxide emissions and crude oil use. Both subjects are extensively researched and represent actual topics of concern in environmental discussions. Therefore it is no surprise that the LCA results of Figure 5.8 are comparable in the headlines, but differ in the more specific topics.

The conclusion that withstands is that the whole preliminary part together scores the highest environmental effect. The graphs in Appendix B illustrate that transport is the major cause of these high effects. Amongst the final parts, the conclusion maintains that burial has the largest effects. However after that, the results differ. Sometimes cremation is the second highest (Ecoindicator, CML, ReCiPe, EPS and Impact), other times resomation is (EDIP & Ecological Scarcity). Cryomation is the lowest bar with EDIP, Ecological Scarcity, CML and Ecoindicator, although in most cases, the significance of the difference between resomation and cryomation might be doubted.

Cryomation and resomation always have the lowest scores. In all cases, except Ecological Scarcity and EDIP, they seem to be rather equal and differ only a few percent points. The difference between cremation and the new techniques showed some variation: sometimes it is only a few percent points and hardly significant; other times it is 25 percent points, which is likely to be significant. Burial and cremation always differ more than 15 percent points, except with Ecological Scarcity. Despite these variations, it should be noted that the three preferred methods provide all the same conclusions and are thus rather robust.

6 RELATIVE VALUES OF THE RESULTS

The results of the life cycle assessments do not stand alone. The relative values of these results are analysed in two ways, from an individual perspective and from a societal perspective. Both pure environmental and monetized environmental indicators are analyzed. The results of these analyses are presented in this chapter.

6.1 Individual level

First of all, the environmental effects of one funeral of an individual are compared to the other effects of that same individual. To provide the best insight in the results, the funeral LCA outcomes are compared to the annual environmental effects of the life of one individual. Note that this is thus not the comparison of a funeral to a whole life time.

Emissions to air

In Table 6.1 below, the annual Dutch emissions to air per person and the emissions per funeral part are given. SO_2 has a very high burden in several parts. The preliminary part and burial part emit 23 and 13 times more SO_2 respectively than an individual on a yearly basis. This is determined by the transport of funeral guests and cotton production in China; these cotton costs would also be expected with cremation, but there they are "compensated" by the benefits from recycling. This is of course a somewhat biased view of the net SO_2 balance. Methane and N_2O emissions are quite high in the preliminary part, mainly due to the foods and drinks at the termination.

In contrast, CO_2 emissions seems relatively unimportant. Even the preliminary part which includes the transport, compares to only 31% of the individual's contribution on a yearly basis. Unexpectedly, taking all percentages together, burial appears to be the highest air polluter amongst the final options.

Additionally, mercury emissions are contemplated. In the final part, it is evident why cryomation and resomation claim that they are more environmentally friendly than the traditional methods and why there is so much discussion about cremation emissions. Burial emissions of mercury mainly originate from zinc, cotton and natural stone production. For cremation, the major part of the mercury emissions comes, as expected, from the flue gas cleaning emissions, meaning the fraction that is not cleaned but just released to air. Even though the cleaning standards are rather high in the Netherlands, cremations thus still contribute to a large amount of the national mercury emissions. Nevertheless, it should be noted that the funeral transport emits even twice as much as the cremation.

Table 6.1 Funeral emissions to air, as a percentage of Dutch emissions to air per individual per year in 2009. Individual data were originally "total of households"; these data were therefore divided by 16 million (the Dutch population) to obtain individual data. Source: CBS, 2010. Mercury data from Emissieregistratie, 2010. Biogenic CO_2 was not taken into account. Negative emissions and values smaller than (rounded off) 1% were left blank. Values larger than 100% are marked grey.

	CO_2	N_2O	CH_4	NOx	SO_2	NH_3	PM_{10}	CO	NMVOC	Hg
Individual (kg/year)	2462	0.08	1.18	3.28	0.05	0.79	0.61	24.2	4.23	1.43 x 10^{-6}
Preliminary	31%	164%	202%	53%	2260%	46%	40%	22%	25%	1602%
Burial	6%	21%	84%	33%	1253%	5%		1%	4%	457%
Cremation	3%	14%	24%	36%	30%	5%		1%	1%	858%
Cryomation	2%	2%	32%	1%						
Resomation	1%	16%	8%	2%		4%				

Emissions to water

In Table 6.2 below, the annual Dutch emissions to water per person are given. Again, burial seems to be the largest polluter of the final methods. This might be due partly to the waste model, which was used most for burial and less for the other options, and which allocates the majority of the emissions of the human remains to the water and not to the soil. However, the recycling of metals causes negative counting of emissions for cremation, cryomation and resomation. Nevertheless, this does not mean that there are no emissions at all.

Resomation seems to contribute little to water emissions. This is not congruent with the expectations, because resomation produces a large amount of fluid with body derivates as a rest product. One could wonder if these emissions would be indeed that low in reality, but that is hard to predict without actual data.

One substance deserves special attention: nickel. It is emitted by all funeral parts in large amounts, up to seven times the annual individual emissions. These emissions are an effect of the production of stainless steel, which is indeed used by all funeral parts. An explanation might be that nickel emissions are usually not accounted to households, but to industry instead; however this is just a hypothesis.

Table 6.2 Funeral emissions to water, as a percentage of Dutch emissions to water per individual per year in 2008. Individual data were originally "total of households"; these data were therefore divided by 16 million (the Dutch population) to obtain individual data. Source: CBS, 2010. Negative emissions and values smaller than (rounded off) 1% were left blank. Values larger than 100% are marked grey.

	As	**Cd**	**Cr**	**Cu**	**Hg**	**Pb**	**Ni**	**Zn**	**P**	**N**
Individual (g/year)	0.23	0.05	0.21	9.9	0.02	3.87	0.51	12.0	813	4403
Preliminary	314%	541%	1410%	51%	50%	26%	753%	440%	4%	4%
Burial	144%	178%	262%	10%	54%	8%	386%	50%		
Cremation							568%		12%	
Cryomation							172%		2%	1%
Resomation							53%		15%	1%

Emissions to soil

In Table 6.3 below, the annual Dutch emissions to soil per person are given. The percentages, compared to the annual individual emissions, are rather low. One might expect that burial would cause more emissions. However, the applied waste model determines that only 2% of the waste would leach to soil (against 98% to water). Low emissions are therefore not surprising. Besides that, there are no extraordinary figures in the table.

Table 6.3 Funeral emissions to soil, as a percentage of Dutch emissions to soil per individual per year in 2009. Individual data were originally "total of households"; these data were therefore divided by 16 million (the Dutch population) to obtain individual data. Source: Emissieregistratie, 2010. Values of less than 1% are left blank. Phenanthrene is left out because it was not represented in the SimaPro inventory, arsenic and antimony because the contributions were all less than 1%.

	Cr	**Cu**	**Sr**	**Ba**
Individual (g/year)	3.79	6.44	1.45	5.96
Preliminary	9%	10%	2%	27%
Burial	5%		1%	7%
Cremation	3%			1%
Cryomation				1%
Resomation			3%	1%

Energy use

The energy demand of the separate funeral parts are shown in Figure 6.1 below. The energy costs per funeral part are dominated by the preliminary part, mainly because of the transport costs. Burial and cremation however have the highest energy costs compared to the other final parts. Furthermore, the energy demands per funeral part are compared to the energy consumption of an individual. This can be expressed in many ways, but here it was chosen to present it in the form of "days of electricity use of an individual". These analogies are also shown in Figure 6.1 below.

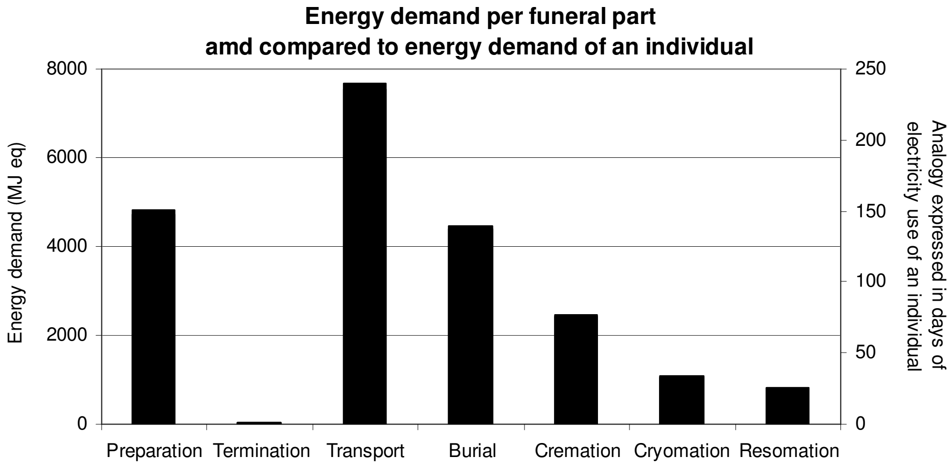

Figure 6.1 Energy demand of funerals, compared to the energy use of an individual, expressed in days of electricity use. Vringer (2005) stated that an individual uses 11.9 GJ per year for electricity, which means 33 MJ per individual per day.

The average costs of one funeral, calculated as if each final part was represented equally, and thus each representing 25% of the funerals, would be 15 GJ eq. This means that, from a lifetime perspective, a single funeral costs 1¼ year or 0.2% of the total individual energy budget[13].

Water use

The average Dutchman uses 46.5 m^3 of water per year (Compendium voor de Leefomgeving, 2010). This amount is compared with the water consumption per funeral part, illustrated by Figure 6.2. Only water from a lake, river or well in the ground, fresh water and water of unspecified natural origin are taken into account; salt water, water for turbine use and cooling water are neglected.

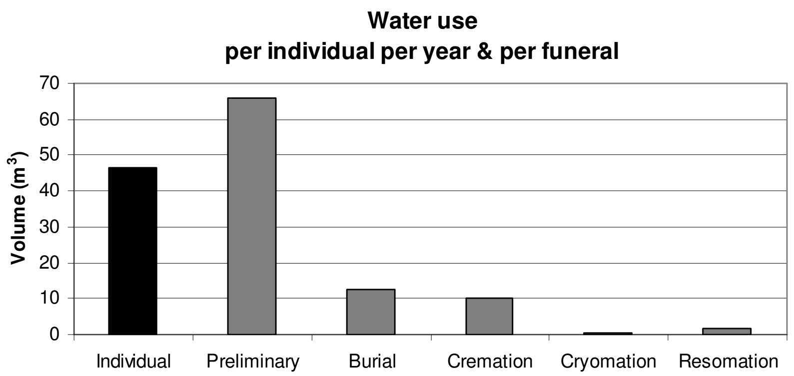

Figure 6.2 Water use of a Dutch individual on a yearly basis (m^3/year; black bar), compared to the water consumption per funeral part (m^3 per funeral; grey bars). Source for the individual bar: Compendium voor de Leefomgeving, 2010.

Since about 500 litres of water are needed for a single resomation, one might expect that resomation has the highest water use of all funeral parts. Figure 6.2 however, shows that all funeral parts, except cryomation, consume more water than a single resomation. The preliminary part alone consumes even more than the annual consumption of an individual, mainly caused by the foods and drinks of the termination and the flowers of the preparation. The reason that burial and cremation score higher than resomation, is mainly because of the high water consumption during the production of cotton for the coffin.

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[13] Following Vringer (2005), the individual energy use was 99 GJ per year (in 1990). On a lifetime of about 80 years, this is 7920 GJ. 15/7920 = 0.2%.

The small relative value of the resomation water can be shown in a second manner. Taking a bath requires about 100 litres of water; a resomation equals then 5 baths. Consider a person that takes a bath every once a week. If this person would be able to live 2 months longer, more water would be used than for a single resomation. Nevertheless, at a location or in a time period where water is scarce, resomation might be a point of discussion.

Land use

In Figure 6.3 the land use of the funeral parts is compared to the available surface for each Dutch inhabitant. The preliminary part needs about a quarter of the available space per person, burial needs 10%. Cremation and cryomation only need a few percents. Resomation is the most "sustainable" final option, as it requires less than 1% of the total available land surface.

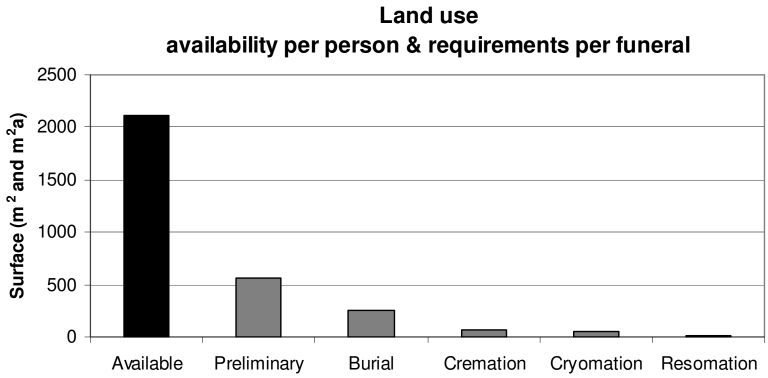

Figure 6.3 Land availability for a Dutch individual (m^2; black bar), compared to the land use requirements per funeral part (m^{2}a; grey bars). Source for the individual bar: CBS, 2010.

Resource use

As mentioned in section 4.4, besides occupation and transformation of land, crude oil, natural gas and hard coal are the most important resources for funerals. In figures Figure 6.4, Figure 6.5 and Figure 6.6, the resource consumption per funeral part is compared to the annual use of an individual.

Crude oil use is shown in Figure 6.4. It is no surprise that the preliminary part is a major consumer of crude oil, due to its high transport costs. The final parts are all smaller than the individual annual consumption of oil. The relatively high bar of burial, about a third of the annual consumption of an individual, comes mainly from the natural stone for the grave monument.

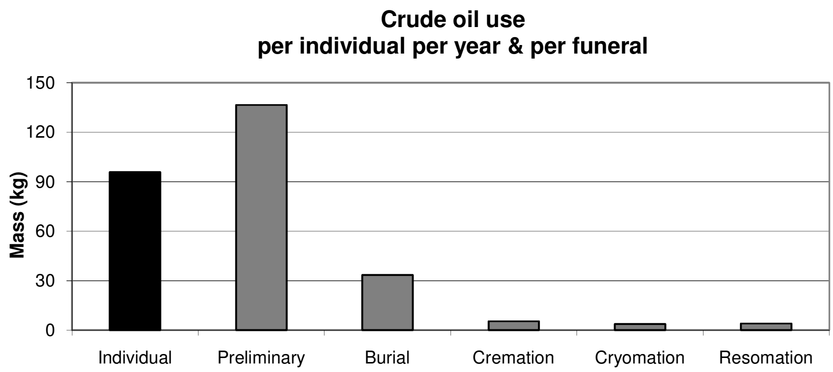

Figure 6.4 Comparison of crude oil use in the Netherlands: per individual per year (Vereniging Nederlandse Petroleum Industrie, 2011 after unspecified "CBS, 2009"; black bar) and per funeral part (grey bars).

The graph of the natural gas consumption, shown in Figure 6.5 below, shows that funerals do not really contribute to individual gas consumption, and, most surprising, even cremation does not.

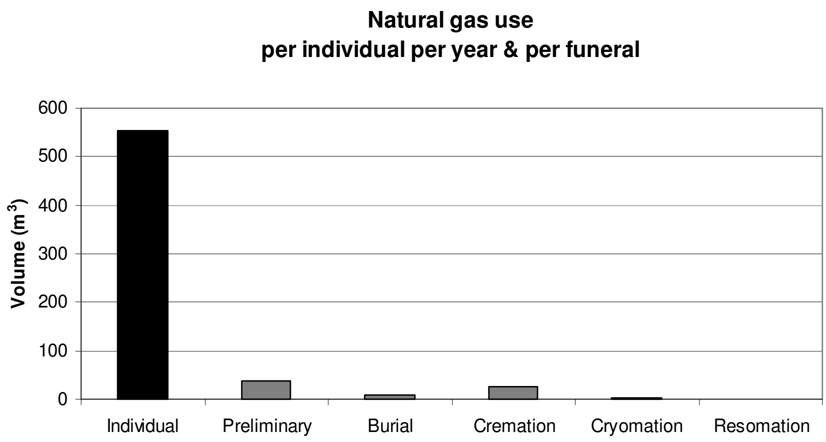

Figure 6.5 Comparison of natural gas use in the Netherlands: per individual per year (CBS, 2009 & 2010; black bar) and per funeral part (grey bars).

Hard coal use however, shown in Figure 6.6, scores much higher than annual consumption: up till 85 times per funeral part. This comes mainly from the low coal consumption for individuals in the Netherlands. Network analysis in SimaPro shows that the coal for the funeral parts is mainly coming from electricity production, while electricity is shown in the outcomes as a process and not as a resource. This means that the SimaPro hard coal amounts are incomparable to the individual amounts, but the funeral parts in the figure below can still be compared to each other.

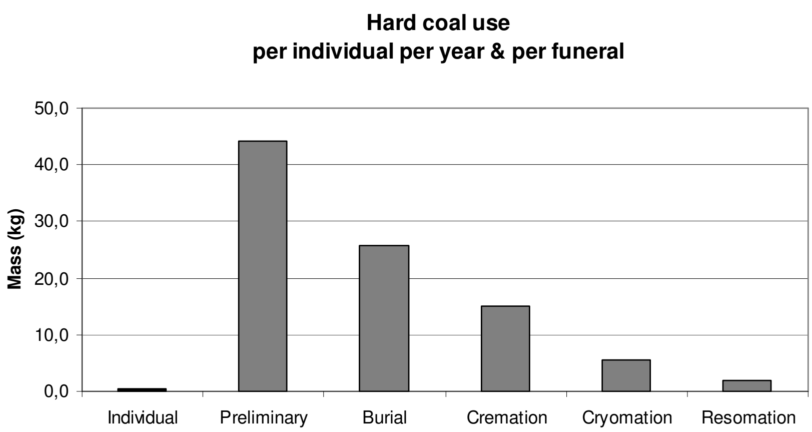

Figure 6.6 Comparison of hard coal use in the Netherlands: per individual per year (CBS, 2009 & 2010; black bar) and per funeral part (grey bars). Individual coal use is calculated without including the coal requirement for transport. This graph is not very accurate for comparing individual with funeral figures, as explained above. For comparing funeral figures amongst each other it is nevertheless very suitable.

CO_2 & energy intensity

The CO_2 and energy intensities of the different funeral parts are calculated with the results from the life cycle assessments and by means of funeral cost estimations. A difficult aspect is the expected costs for a cryomation or resomation in The Netherlands, because these techniques are not yet applied on a large scale and not at all in The Netherlands. The calculated intensities, which are shown in

Table **6.4**, should therefore be treated with some reserve.

Table 6.4 CO_2 and energy intensity of funeral parts. General data of costs from Uitvaart.nl, 2010c; Resomation data partly from Groovy Green, 2010; Cryomation data partly from Novak, 2010. Note that there exists no good prediction for the costs for resomation and cryomation in the Netherlands and that costs are highly variable per country. Average costs and intensities are calculated as the sum of the preliminary part and the average of the four final parts (each representing an equal share of 25%).

Funeral part	**Costs (€)**	**CO_2 intensity (kg CO_2/€)**	**Energy intensity (MJ/€)**
Preliminary part	€ 6000	0.13	2.09
Burial	€ 6500	0.02	0.69
Cremation	€ 1300	0.05	1.90
Cryomation	€ 700	0.06	1.53
Resomation	€ 550	0.04	1.49
Average funeral	**€ 8263**	**0.10**	**1.78**

The CO_2 intensities of the four final techniques are relatively close together; the preliminary part is a little higher. Table 6.5 shows the CO_2 intensities of several household categories. Compared to these intensities, funerals are only of minor importance. Even the lowest category, service, is five times higher than the average funeral CO_2 intensity.

Table 6.5 CO_2 intensity of household categories in 1992. Source: Munksgaard *et al.* (2000)

Category	**CO_2 intensity (kg CO_2/€)**
Food	1.28
Beverages and tobacco	1.19
Clothing	0.88
Household appliances, incl. operation	1.15
Health	0.75
Recreation & entertainment	0.91
Services	0.50
Transport	0.67
Average	**0.50**

The energy intensities differ more than the CO_2 intensities. Again, the preliminary part is rather high, as well as cremation. Cryomation and resomation are also rather high. Burial has, by far, the lowest energy intensity. Table 6.6 shows the energy intensities of several household categories. Again, funerals seem to be rather low in comparison to the household expenditures, although the differences are smaller now. An average funeral is half as intensive as the energy intensity of a house or of communication.

Table 6.6 Energy intensity of household categories in 1990. Source: Vringer, 2005.

Category	**Energy intensity (MJ/€)**
Food	12.3
Household effects	12.1
House	3.1
Clohing & footwear	5.9
Hygiene	9.0
Medical care	7.5
Education	9.2
Recreation	8.1
Communication	3.7
Transport	7.9
Average	**7.7**

6.2 Societal level

In this second part of the analysis of the relative values, some environmental effects of the funeral are compared to figures of other Dutch sectors. For all categories considered, the funeral figures are multiplied with the average number of deaths in the Netherlands (134,000 per year; CBS, 2010) in order to obtain figures for the sector as a whole.

Emissions to air

Emissions to air of the funeral parts are compared to the sector "Trade, services & government", which was one of the lowest emitting sectors (CBS, 2010). The results are presented in Figure 6.7 below. CO_2 emissions are left out because that bar was much higher than the other bars. Nevertheless, even the CO_2 bar shows the same pattern: the annual emissions are very small compared to the "trade, services & government" sector. Most other sectors score much higher than this sector, which means that the relative values of the funeral emissions are indeed quite low.

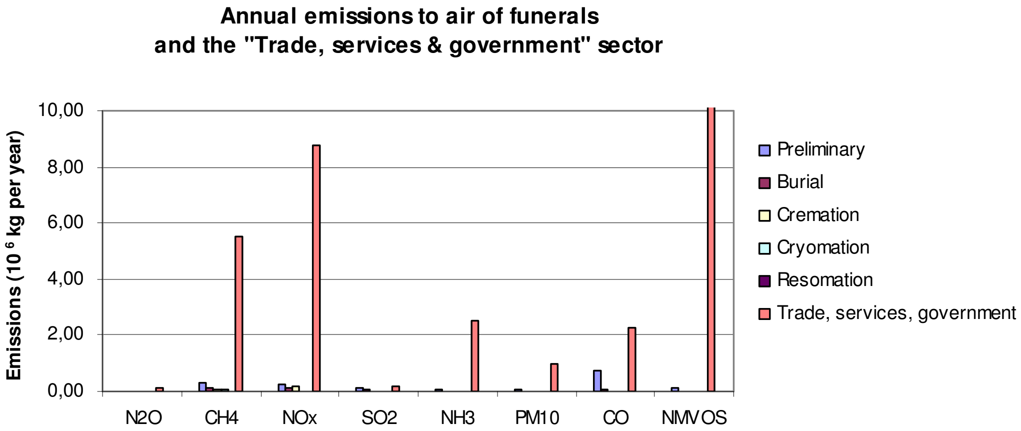

Figure 6.7 Annual emissions to air of funerals and the "Trade, services & government" sector in the Netherlands. Source of the "Trade, services & government" data: Emissieregistratie, 2010.

Emissions to water

The most important emission to water of the funeral parts is emission of phosphorus, as discussed in section 4.4. Therefore, only these emissions of the funeral parts are compared to other industrial sectors. The results are presented in Figure 6.8 below. Right away, it is clear that the funeral parts score quite low on phosphorus emissions. Nevertheless, cremation and resomation score higher than about five industrial sectors.

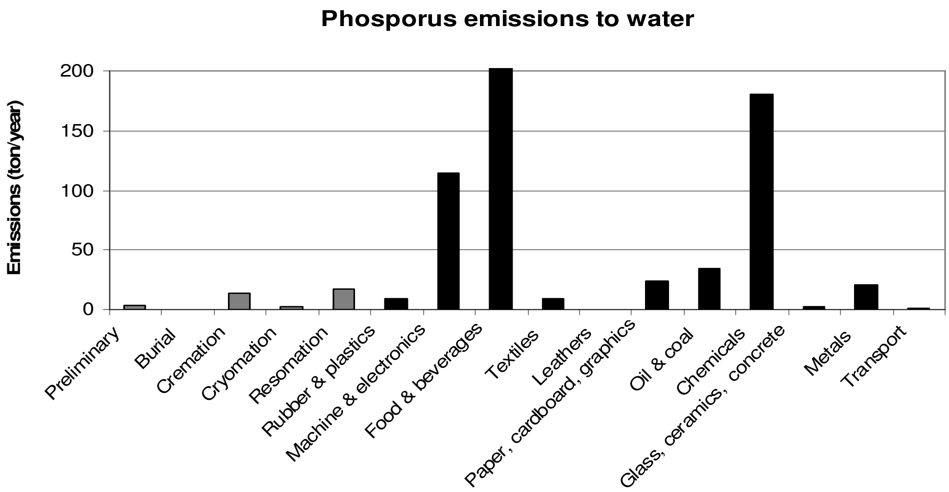

Figure 6.8 Annual emissions of phosphorus to water by funerals (grey bars) and by an overview of Dutch industrial sectors (black bars). Source of the industrial data: Emissieregistratie, 2010. The food & beverages bar is cut-off; its height is actually five times larger than the current axis, namely 1076 ton/year.

Emissions to soil

Phosphorus is also the most important emission to soil for all funeral parts. The comparison to other sources is shown in Figure 6.9 below. It is clear that all funeral parts are only minor contributors compared to agriculture. However, when leaving out agriculture a whole different picture emerges, shown in Figure 6.10. It is clear that all funeral parts have rather low emissions; only the preliminary part has emissions that are many times higher than waste removal.

The other two most influential substances, cypermethrin and cadmium, are also briefly considered. On cypermethrin however, no data was available for other Dutch sources. Cadmium emissions of funerals turn out to be tens to thousands times lower than other sectors.

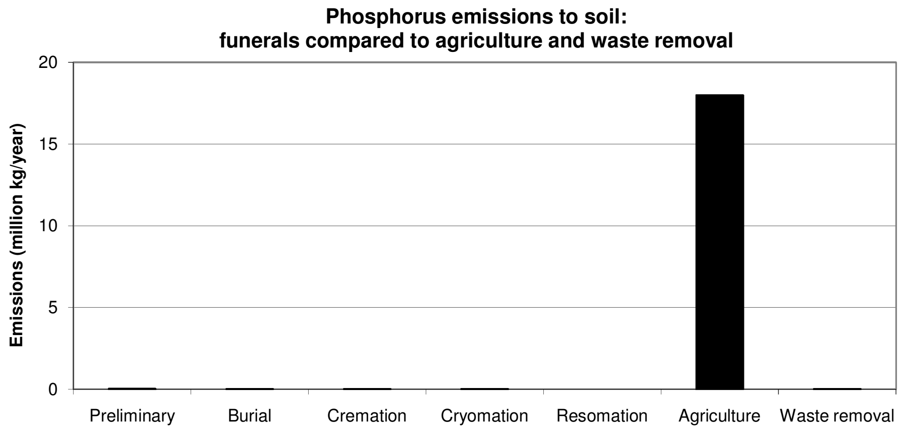

Figure 6.9 Phosphorus emissions to soil by different funeral parts (grey bars) and two other sources, agriculture and waste removal (black bars). Other sources from: Emissieregistratie, 2010.

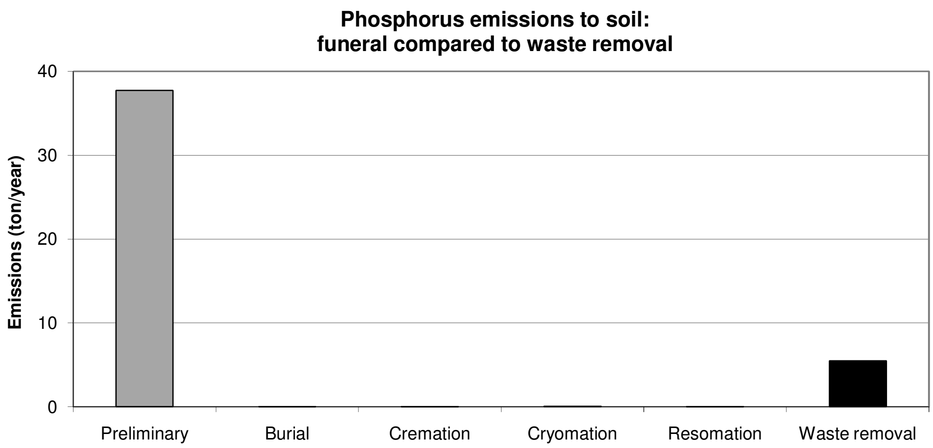

Figure 6.10 Phosphorus emissions to soil by different funeral parts (grey bars) and one other source, waste removal (black bar, from: Emissieregistratie, 2010). Same graph as Figure 6.9, but now without agriculture and another scale on the y-axis.

Energy use

The energy use of all funeral parts is compared to several Dutch industry sectors in Figure 6.11 below. The four largest energy consuming industries are left out of the picture. Nevertheless, it is clear that the funerals consume very little energy compared to the other sectors; only leather and wood products are comparable categories.

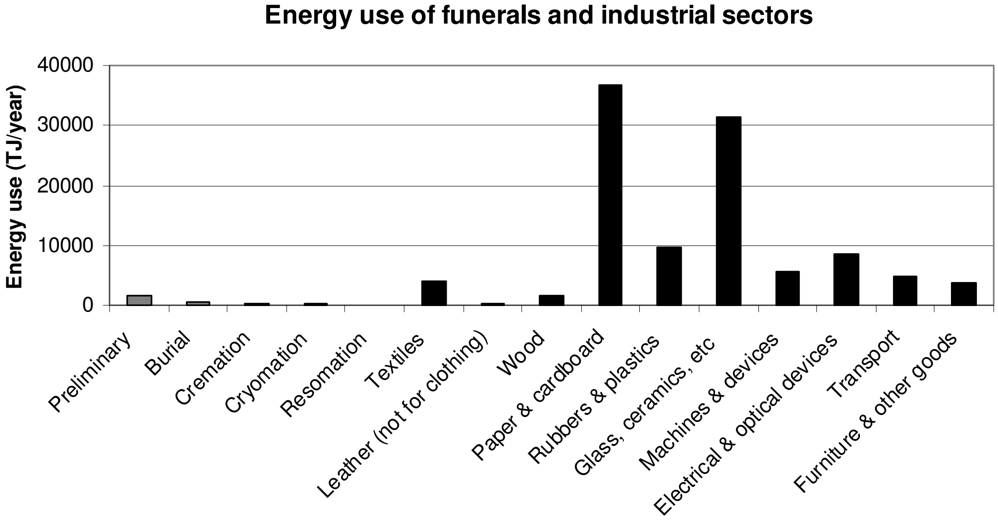

Figure 6.11 Energy use of different funeral parts, compared to industrial sectors in the Netherlands. Industrial data reflects the energy use (heat, light, power) of known values and amounts in 2006 (most recent data available). Source: CBS, 2010. Four categories were left out of the overview because they were enormously higher than the rest: chemicals, metals, food & beverages, and petroleum, coal & nuclear fuel.

Water use

The water use of all Dutch funerals is compared to the industries in Table 6.7 below. Only the winning of minerals, which is a small sector in the Netherlands, is comparable to the water use of the funeral parts. Besides that sector, none of the funeral parts, even not the preliminary part, comes close to the water use of other sectors.

Table 6.7 Calculated annual water use of the Dutch funeral sector, compared to water use of Dutch industrial sectors in 2007. Source of the industrial figures: Compendium voor de Leefomgeving, 2010. Salt and brakish water use is excluded.

Funeral part	**Water use (10^6 m^3/year)**	**Sector**	**Water use (10^6 m^3/year)**
Preliminary part	8.6	Minerals mining	2
Burial	1.1	Paper & cardboard	63
Cremation	1.1	Food & beverages	242
Cryomation	0.0	Chemicals	385
Resomation	0.1	Refineries	748
		Industry	1567
		Power plants	6209

Land use

In Table 6.8 land requirements per year for the funeral sector are presented together with the land use of all occupation types in the Netherlands. If we consider a time period of 30 years, burial needs as much space as there is available for recreation. For cremation, this surface is occupied only after 120 years, and cryomation and resomation need even more time.

Table 6.8 Calculated annual land use of the Dutch funeral sector, compared to land use per occupation types in the Netherlands, in 2006. Source for land occupation figures: Compendium voor de Leefomgeving, 2010.

Funeral part	Land use (km^2a/y)	Occupation type	Land use (km^2)
Preliminary part	75	Infrastructure	1366
Burial	35	Living	2684
Cremation	9	Working	1334
Cryomation	7	Recreation	1135
Resomation	2	Agriculture	26928
		Forest	4061
		Nature areas	1641
		Internal waters	2114
		Others	586

Resource use

The Dutch oil, gas and coal consumption for the whole country and for all funerals on a yearly basis, are shown in Table 6.9. The funeral consumption use is marginal; it is less than 0.1% of the total Dutch use. The oil use of the preliminary part has the largest share (0.07%). Most values in the final parts represent less than 0.01%.

Table 6.9 Consumption of resources by funeral parts compared to total Dutch use (in 2009), derived from CBS, 2010.

	Crude oil (10^6 kg/y)	Natural gas (10^6 m^3/y)	Hard coal (10^6 kg/y)
Preparation	18.3	5.1	5.9
Burial	4.5	1.2	3.4
Cremation	0.7	3.5	2.0
Cryomation	0.5	0.3	0.8
Resomation	0.5	0.0	0.3
Total Dutch use	26739	41683	13042

It would be interesting to look at the required amounts of liquid nitrogen and potassium hydroxide in comparison to national consumption levels. For example, if a quarter of all funerals would be a cryomation, 2½ million kilograms of liquid nitrogen would be needed annually in the Netherlands, which probably has certain influence on the production of liquid nitrogen. Unfortunately, the national data of liquid nitrogen and potassium hydroxide production are not available.

CO_2 & energy intensity

The CO_2 and energy intensities of the funeral parts are still the same as in

Table **6.4**. For CO_2 intensities, the overview article of Hetherington (1996) is used as comparison material. However, the outcome is rather simple: funeral's carbon intensities are about twice or more as low as the carbon intensities of other sectors. This means that relatively little carbon emitting sources, like energy consumption, are involved, or that the prices for funerals are relatively high. It should also be noted that the funeral sector has a lot of biogenic CO_2 emissions which are not counted for intensities.

The same conclusions hold for the energy intensity. Energy intensity of the Netherlands as a whole is about 8 MJ/€ (Anonymous, 2007). The funeral energy intensities are much lower. This means that either the energy use is relatively low, or the costs are relatively high, compared to other sectors.

For both comparisons, it would be interesting to compare these figures to several industrial sectors and study their differences in more detail.

7 REDUCTION POTENTIAL

In this optimization analysis, all processes in the funeral cycle are investigated on their potential to be carried out with a minimum of environmental effect. Resomation and cryomation are left out of the optimization analysis because there do not exist more or less environmentally friendly variations of them, which makes that there is nothing to analyse. There are several companies which offer comparable techniques as Resomation Ltd and Cryomation Ltd, namely respectively Water Resolution and CycledLife, and Promessa Organic AB and DeMaCo, but comparing these techniques requires a whole study on its own. It should be noted that the outcomes that are presented below, are very rough and maybe a bit too optimistic, but they provide a rough sketch of the possibilities.

7.1 Preliminary part

For the preliminary part, there exist a lot of alternatives which pretend to be "greener" or "more sustainable" than the traditional options. An overview is given in Table 7.1 below. One of those options is *thanatopraxie* or light embalming. For this temporary conservation technique the blood is replaced by a 0.5% formalin solution which contains also some methanol (1%), and eosin and sodium benzoate (which will be ignored here). The blood is released to the sewage grid and could not be exactly modelled in SimaPro, therefore ordinary waste water treatment is chosen; this is a very rough estimation, but it should suffice for this purpose.

Table 7.1 Quick scan of the available alternatives for the preliminary part of a funeral, from an environmental perspective, calculated with ReCiPe.

Step	Alternatives	Remarks	Reduction (points)	Reduction (%)
Cooling	Thanatopraxie	This might be a little too optimistic	1.7	2%
Correspondence	Less announcements in newspaper, only 1	Newspaper was a heavy burden; cards are left as they were	10.2	11%
Rituals	From own garden only		9.9	11%
Ceremony	Energy saving light bulbs were already taken into account. For heating we suggest that a 10% efficiency could be easily possible		0.0	0%
Transport	Guests come to funeral by bike & train instead of car.	Not everybody will be able to come by bus & train; suppose 90%: 5 km bike, 15 km train 10%: still 20 km by car	32.9	35%
Transport	Funeral bike instead of funeral car	There are also other alternatives (e.g. funeral carriage), but those are not easily modelled in simapro	1.05	1%
Termination	Electricity: idem as for ceremony		0.0	0%
Termination	Foods & beverages: Ecological/biological coffee etc.	Unfortunately there was no option to analyze or model this	n/a	n/a
Total reduction			**55.7**	**59%**

7.2 Burial

Considering burial, there is one major alternative to traditional burial. *Green burial* or *woodland burial* is the concept of burying humans in a natural area with as little negative influence on nature as possible, being "rather helpful than harmful". The burial sites often look as a nature area, without paths and artificial grave markers. The burial has to fulfil certain conditions, like a biodegradable coffin and clothes, and a shallow grave depth (Monaghan, 2009).

Green burial derives not only from direct environmental need, but also from a cultural movement (Breuer *et al.*, 2008). The concept emerged during the past decades in the United Kingdom, where are currently over 200 natural burial sites. In the Netherlands its market share is still quite small, with only two sites, but a similar trend might take place here as well (Jonkman & Veen 2008).

Despite the environmentally sound story, Molenaar, Mennen & Kistenkas (2009) already pointed out that green burial is not always the most environmentally friendly option. As a matter of fact, exogenous material is added to a nature area which is not always suitable for it. Burying can cause soil disturbance, eutrophication and acidification, which can be very harmful in certain nature areas. Therefore this subject is analyzed with some caution in this paragraph.

Besides green burial, there are some other alternatives to traditional burial. Both the green burial characteristics and the other options are shown in Table 7.2 below.

Table 7.2 Quick scan of the available alternatives for the burial part of a funeral, from an environmental perspective, calculated with ReCiPe.

Step	**Alternatives**	**Remarks**	**Reduction (points)**	**Reduction (%)**
Covering	No body bag		0.3	1%
Covering	There are many alternatives for coffins; a quick analysis showed that a cardboard coffin gave the largest reduction.	Bamboo could not be analyzed, but given the airplane costs, it is probably not the best option	2.4	8%
Elevator	No elevator	100% without elevator is not likely, we assume a 10% elevator use	0.0	0%
Monument	No monument; just use natural markers		9.3	33%
Rest period	Only biologically degradable clothing		0.0	0%
Rest period	No jewels	For simplicity, just assuming that all bullions were jewels	0.0	0%
Rest period	Natural burial: no maintenance	Natural burial requires more person kilometres, because there are not that many already; but assuming a future perspective with many of them	1.3	5%
Rest period	More people per graveyard	5 m^2 per grave instead of 10	4.2	15%
Removal	No removal	No removal means eternal land occupation, thus no option	n/a	n/a
Total reduction			**17.5**	**61%**

7.3 Cremation

As for burial, there is also an emerging market for scattering of ashes in nature areas; the Dutch national forest management even raised a special foundation for it (ANP, 2010). However, similar to natural burial, Molenaar, Mennen & Kistenkas (2009) raised some critical arguments to indicate that scattering in nature areas might be even more harmful than scattering the ashes at a special, controlled location. However, some aspects can be adopted from the natural burial or cremation concept, like the use of only biodegradable materials. These options, and other more environmentally friendly options, are shown in Table 7.3 below.

Table 7.3 Quick scan of the available alternatives for the cremation part of a funeral, from an environmental perspective, calculated with ReCiPe.

Step	Alternatives	Remarks	Reduction (points)	Reduction (%)
Covering	No body bag		0.3	3%
Covering	Particle board coffin with wooden grips	Cardboard & wool is discommended for safety reasons	0.73	7%
Cremation process	Use preheating heat for heating of the building or district heating (natural gas is deleted from the input record).	This kind of district heating happens already in Sweden. It is ethically acceptable because it is not the human remains that is used as heating fuel, but just the gas	2.7	25%
Flue gas cleaning	There are alternatives, e.g. cleaning with a catalyst.	Because of lack of exact data (questionnaire required) this option is not further investigated	n/a	n/a
Treatment of remains	Only scatter over sea (this option had the least environmental effects)	Scattering by hand instead of by boat might sound more environmental friendly, but disadvantages are: more car kilometres and a more densely concentrated dispersion of the ashes. This aspect is therefore ignored	0.79	7%
Total reduction			**4.5**	**41%**

7.4 Summarizing

A visual illustration of the effects of three optimizations is given in Figure 7.1 below. Summarizing, one can say that all traditional funeral methods, both in the preliminary as well as in the final part, could undergo a reduction in environmental effects of about 50%. The absolute gains are indisputably the largest in the preliminary part, where there is about 10 times more room for reduction than in the cremation part.

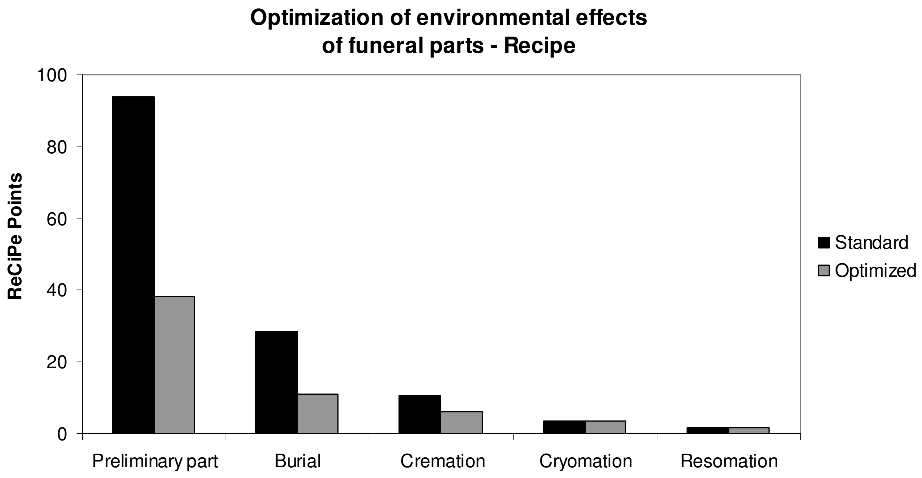

Figure 7.1 Visualisation of the effects of a quick scan optimization of the preliminary part, burial and cremation, in comparison to the non-optimized analysis results with ReCiPe (see chapter 4). Cryomation and resomation are shown without any reduction potential, as there is too little knowledge and they are supposed to have already as little effect on the environment as possible.

CONCLUSION

The aim of this research was to investigate and compare the different steps in the funeral cycle on the magnitude and variability of their environmental effects, within the economical, technical and ethical limits. The research provided the following answers to the sub questions; its main conclusion is presented below.

LCA results

First of all, the preliminary part was analyzed, which includes all processes undertaken by the relatives and excludes the final phase of decay. All phases of the preliminary part together, being the preparation, the termination and the transport, caused about three times higher environmental effects than burial and even more compared to the other final options.

Considering only the final parts, burial had the highest environmental effects with all three applied analysis methods. The cremation effects were about half of the burial effects. Resomation and cryomation had the lowest effects, twice or more times lower than cremation, but there was no significant difference between those two.

The analysis of the inventory of used resources and emitted substances showed that emissions to water and soil are not very important in the funeral processes, except for resomation. Most important were emissions of carbon dioxide and crude oil use. When looking only at the final funeral parts, crude oil was not the only most important resource, but also transformation and occupation of land. Emissions to air were still dominated by fossil carbon dioxide. Mercury, which was expected to have a large influence in cremation, contributed less than 1% to the total cremation effect.

Main determinant factors

The variation and influence of the outcomes were analyzed on four levels, being input data and assumption quality, underlying processes, applied models and LCA methods. The input analysis showed that in the preliminary part, it was rather important which type and size of funeral was chosen; clearly, an abundant and busy funeral has larger environmental effects than a sober and small one. Nevertheless, even with a sober funeral, the preliminary parts were still having a larger environmental impact than the highest calculated impact for the final methods. The analysis of input variation in the final parts did not lead to other conclusions than stated above.

The processes that formed the main causes of the environmental effects of the preliminary part were flowers and news paper announcements in the preparation phase, by foods and beverages in the termination phase and, for the largest part, by transport of funeral guests. Burial was mainly dominated by the grave monument and occupation of land and not by soil or water pollution. Gas use and flue gas emissions were the main contributors to the cremation effects. Cryomation was dominated by assisting processes like car transport, and not by primary processes like liquid nitrogen production. Electricity production and consumption was by far the most important process in resomation, both directly in the process as well as indirectly for the production of potassium hydroxide.

The applied waste and waste water models caused, exactly as expected, a slight increase of environmental effects, compared to the application of standard records. This was the preferred effect, and thus sustained the previous conclusions.

The methodology analysis showed that that with other methods, thus with other points of focus, the two main conclusions still hold, namely that the preliminary part is definitely more important for the environmental effect of funerals than the final parts, and that amongst the final parts, burial causes the highest effects. However, the sequence of the environmental scores of the other final parts was less consistent. The only remaining conclusion was that cryomation always had the lowest or second lowest environmental impact. Nevertheless, this analysis underlined that the conclusions of the three preferred methods were lying rather close together.

Relative values of the results

The outcomes of the analysis of the relative values showed that the environmental effects of funerals are rather small in comparison to the impact of the private life of an individual, and even less than the impact of industrial sectors, which is not surprising because the funeral sector is rather small. Even expected effects like high water use of resomation and high gas use of cremation, were not very high on a national scale. The only surprising outcomes were the high total energy requirements and the fact that mercury emissions were relatively high contributors compared to individual emissions, despite the advanced filter installations of crematoria. Following the inventory analysis, one might expect a high CO_2 intensity of the funeral parts, but even this seemed to be rather low. This is a consequence of relatively high prices of services compared to other products.

Reduction potential

The options for reduction of the environmental effects of funerals are numerous. A rough sketch showed that a reduction could be obtained for about 50% in the preliminary part, the burial part and the cremation part. The preliminary part would still form the highest burden of the funeral however. On the other side, it turns out that an optimized burial could cause about the same environmental effects as a non-optimized cremation. Compared to the new techniques, optimized cremation still seemed to have a slightly higher environmental impact, but the significance of this difference is small.

It should be noted that the relative reduction potential is the largest by optimization of the preliminary part, but from an absolute point of view, a change towards the new techniques creates a net environmental impact that is almost zero. These reduction potentials in both parts can be combined. The reduction potential of the preliminary part is mostly in the hands of the relatives, while the influence on the final options is largely determined by the funeral sector itself.

Main conclusion

This research shows that the preliminary part carries by far the highest environmental burden of the funeral. Amongst the final parts, burial has evidently the highest environmental effects and the new techniques, cryomation and resomation, have the lowest. The variation of the underlying inputs, processes and structures was large, but without a large relative effect on the outcomes. On a national scale the environmental impact of funerals is rather small. However, there is a large reduction potential up to 50% for the environmental effects of funerals.

The main conclusion of this research is that, even though the environmental impact of funerals on a national scale are not alarming, on the local scale there is a large reduction potential of their environmental impact, either by adapting traditional processes or by developing new techniques. In the preliminary part, a large reduction can be obtained by adaptations regarding the activities of the relatives of the deceased. For the final part, the funeral sector has high potential to decrease its environmental impact by adopting the new techniques of cryomation and resomation. The high energy consumption is for a large part compensated by the benefits of material recycling.

DISCUSSION

Reliability range

This research should not be used as an absolute measure of the effects, for example emissions of Aldicarb to soil as a consequence of cremation, because the results are highly dependent of the underlying data, structure and models which are suitable as an indicator, not as a measure. The results presented in this thesis provide a reliable indication of the magnitude and composition of environmental effects of funerals with an average size and type. Variations in inputs, processes, models and methods showed constant outcomes considering the main conclusions. Even despite certain disputable elements like the weighting of land use, the results were robust.

The conclusions with respect to resomation may be a little too optimistic, because official data was lacking and there was not an integral insight in the process. The presented results can be considered however as a good proxy and no substantial differences with reality are expected.

One major issue was however the recycling of gold, probably from dental fillings. A societal shift from golden fillings towards fillings of other materials, could lead to one fundamental change in the conclusions with respect to cremation, when considered with the monetization LCA method CML.

Decreased use of Mercury for dental fillings does not make such a big difference, but this is a bit misleading. It should be noted that the Mercury that is filtered or sorted out in the final part, goes to hazardous waste landfills where it has indeed no effect on the environment. As a consequence, the effect of Mercury seems rather low, but this solution is evidently not free of charges nor unlimited, even though it is not visible in this study.

Obviously, the use of average data has the same implication, namely that extremes can deviate from the general conclusions. For example, one cannot say that the transport always has the highest environmental burden of the whole funeral, as there exists an example of a funeral that was fully by bike (Hofstijl, 2010). Extremes are possible in many phases of the funeral, like sober and abundant ceremonies, few or many guests, short rest periods or long family graves, energy efficient or very old ovens, etcetera. Specific claims about such cases cannot be made based on this research.

Limitations of boundaries

The scope of this research is also a point of interest. The geographical boundaries were set at the Netherlands, and these results can only be extrapolated to other countries with a critical review of main inputs like preparatory habits, travelling distances, burial period and surface, cremation fuel and type of flue gas cleaning installation. Maybe one of the most important factors is the application of embalming, which was not taken into account for this research as it is forbidden in the Netherlands, but which is common practise in many other countries. Designing some geographical scenarios could be interesting however, among others:

- Specific burial and scattering location; what is the effect on water and soil at different locations?
- What is the role of climate on the environmental effect of funeral parts? Are there locations or climatic regions where a certain final technique could be preferred above the other? Cryomation might cost more energy and become less favourable in a warmer climate. Warmer situations might also change the conservation preferences towards less cooling, more embalming. Colder circumstances might be less feasible for burials because decomposition will be slower and digging harder.
- Embalming, clothing and covering habits differ from country to country; what happens if many Dutchmen want to be embalmed? Or if many want a body bag?

The time perspective was chosen as comparable to the current situation, with contemplation of cryomation and resomation as if they were current practice. However, future scenarios with the following elements could provide a rather different perspective on the results:

- *Population growth:* raises issues about land use, hygiene, high population density, pressure on resources, etcetera.
- *Climate change:* might change the funeral preferences as well, as indicated above.
- *Depletion of certain resources:* could cause problems or problem shifting for the resource intensive parts of the funeral, like grave monument and coffin.

- *Shortage of water:* might obviously cause a problem for resomation, but also changes the conditions for burial maintenance.
- *Shortage of fossil fuels:* would have a major influence on cremation practises, but also on resomation which has a high electricity use.
- *Technical developments:* it is possible that certain technical developments and innovations will change the environmental effects of funerals, for example regarding the energy and resource efficiency of ovens, cryomators and resomators. A current development is a decrease in the use of amalgam for dental fillings (Coenen, 1997). New filling types can have large consequences for the funeral sector, as already discussed above. Burial does not involve many technical processes, so the expectation is that the gap between burial and the other methods might only become larger. New and more prostheses might also change the preferences.
- *Public opinion:* has a high influence that is difficult to predict. Will people adopt the new techniques? How will people look towards energy or surface intensive options when those become scarce? Will people have the flexibility to accept the use of phosphate from human remains as a fertilizer? Or district heating with cremation rest heat?

Relation to other research

Environmental research on funerals exists in two forms, either specific or comparative. For the specific discussions, like on the groundwater pollution potential of cemeteries, measurement data are needed, which are not provided by this research. However this research did provide a qualitative contribution for the specific discussions, namely the remark that emissions to water and soil does not seem to be very important on the total picture, while most research on cemeteries focuses only on water and soil pollution.

Similarly, as a consequence of the focus on net output scores, it is also hard to compare for example emissions to air of this research with other articles that focus purely on directly measured or calculated emissions (e.g. Santarsiero *et al.*, 2005; Welch & Swerdlow, 2009; GHD, 2007). Nevertheless, this research was not meant to provide input for the specific discussions, thus that is in accordance with the expectations.

For the comparative side, there is only one complete other research investigation known, namely the one of Remmerswaal & Heuvel (2005). The differences are remarkable. Figure 0.1 below shows the main findings of Remmerswaal & Heuvel. Hydrolysis is based on the comparable principles as resomation. Note that their investigation did not involve cryomation, but the comparable though different process of promession, which they called lyofilisation. The inventors from Cryomation Ltd underscored that their technique is rather different. Nevertheless, some basic principles (use of liquid nitrogen, pulverization, metal recycling and short-term burial) are presented in both methods, and with some caution, the results can be compared.

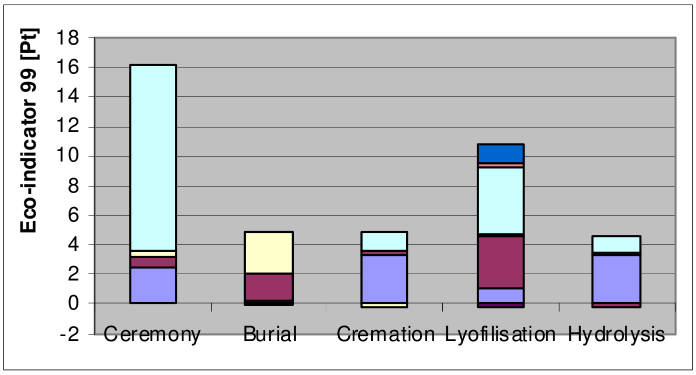

Figure 0.1 Results of the life cycle assessments for different funeral parts, performed by Remmerswaal & Heuvel (2005). Legend is absent. The lyofilisation process description is comparable to promession, which differs from cryomation, but is also a freeze drying technique. Hydrolysis is comparable to the resomation principles. The colours are *not* reflecting the effect categories; they refer to different processes and are thus not comparable!

Several items are surprising, when comparing these results with the general findings of this research and the results with the Ecoindicator (see section 4.1) in particular. Except the remark that the preliminary part has the highest environmental impact of the funeral, almost all other conclusions are different. Burial is not the final option with the highest environmental impact; that is lyofilisation, while cryomation appeared as one of the most environmentally friendly options in this research. Furthermore, there is almost no visible difference in the graph of Remmerswaal & Heuvel between burial, cremation and hydrolysis; they all score comparable, while this research showed large differences.

The order of magnitude is also rather different. A slight difference was expected, as this research was aiming to include many processes that Remmerswaal & Heuvel left out. However, comparing Figure 0.1 and Figure 4.1, results in more than a slight difference. While this research found an environmental burden of the preliminary part of more than 80 Ecopoints, Remmerswaal & Heuvel found only 16. Whereas in this research the lowest final part had -1 Ecopoints and the highest 31, Remmerswaal & Heuvel presented a range from 5 to 11 Ecopoints. In the current research, a difference of 6 points would hardly be significant. Unfortunately, there was almost no knowledge about the underlying assumptions, applied methods and fault margins of Remmerswaal & Heuvel. Therefore no conclusions can be made about the reliability of their results. Overall, it is clear that this research provides new insights on the environmental impact of funerals.

Two other, smaller comparative researches were GHD (2007) and Welch & Swerdlow (2009). GHD estimated the environmental risk of burial much higher than cremation, which is in accordance with the findings of this research. It also estimated more emissions of CO_2-equivalents with cremation than with burial, but this research showed in Figure 4.2 that the Global Warming Potential for cremation was lower than for burial.

Welch & Swerdlow (2009) compared cremation and cryomation on their CO_2 emissions and supported the claim that cryomation emits only a third (~50 kg) of the cremation CO_2 emissions (~150 kg). This research however, finds that, with inclusion of the benefits from recycling, cryomation emits about half (~40 kg) of the CO_2 emissions of cremation (70 kg). The conclusion of Welch & Swerdlow is thus true for as far as that the CO_2 emissions of cryomation are substantially lower than for cremation.

Summarizing, this research provides more and deeper background on the relative environmental impact of funerals than was available until now.

Suggestions for further research

A serious limitation in this research was the lack of field measurement data. Still, one of the most cited sources about soil and water pollution potentials of cemeteries is Haaren (1951), followed by Schraps (1972). The research of Boyd Dent (e.g., Dent, 2004) is voluminous and deserves more attention. In addition, some more field measurements for soil and water pollution both close to and further away from cemeteries would be interesting.

Furthermore, even though there are articles about crematorium emissions, there is often a limited number of repeated measurements which show high variations and make it hard to draw solid conclusions. Furthermore, the measurements are highly dependent on the applied type of flue gas cleaning installation, body weight, clothing and attributes in the coffin, and coffin composition, but those factors are often not registered, which again makes it difficult to use the data for reliable conclusions.

Considering the new techniques, it essential to know more about the exact composition of the remains and of the waste streams, like the liquid that is released to sewage in the resomation process. This could be achieved with relatively simple analyses.

Not only the input side of this research, but also the output side could be improved. The analysis of the relative values of this research gives an indication of the magnitude of the results, but more specific comparisons could be made. Without loosing respect for this subject, it might be useful to compare the funeral effects with waste treatment effects, in order to see where and how environmental effects could be reduced.

Another point of interest for further interpretation of the results was already indicated at the beginning of this chapter, namely the development of scenarios. Information about environmental impacts in different scenarios could be a useful tool for policy makers.

Implications for society

Even though this is a scientific research, some small notes have to be made on the societal implications of this research. First of all, this research makes clear that the relative impact of funerals on society is limited. Nevertheless, the research shows there is a large potential to reduce the impact.

In addition, this research provides input for the discussion on the pollution potential of funerals, which is particularly a comparison of burial and cremation and a call for "greener" funerals and funeral methods. This thesis shows that, although there are differences between the environmental impacts of the final parts, the largest environmental impact and the largest reduction potential lays in the preliminary part. This does not imply that the burial-versus-cremation discussion is moot, but this thesis adds some dimension to the whole discussion.

As said before, this research tried to analyze this complex and unusual problem from a scientific point of view, leaving out all social aspects whenever possible, without loosing respect for the ethical limits. Even though this thesis presents some interesting conclusions and consequently raises new questions, one could ask whether this topic merits further research. It could be argued that this is a topic of which we should only know the essentials -so to say: the life threatening effects- and thereafter, we should let it rest. On the other hand, this research also supports the statement that funerals are activities that are as normal as life itself, and therefore they are sustained by regulations, innovations and fundamental research, just as other activities.

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Useful websites

Background information

- www.uitvaart.nl
- www.groene-uitvaart.nl
- www.uitvaartmedia.com
- www.uitvaartinformatie.nl
- www.uitvaartinfotheek.nl

Companies

- Cryomation Ltd: www.cryomation.co.uk
- Promessa Organic Burial: www.promessa.se, www.promessa.org.uk
- Resomation Ltd: www.resomation.com, www.biocremationinfo.com
- Water Resolution: www.biosafeengineering.com/waterresolution
- Cycled Life: www.cycledlife.com
- Aquamation: www.aquamation.info
- Yarden: www.yarden.nl

APPENDIX A: CALCULATION FACTORS OF LCA METHODS

The tables in this appendix (Table A.1 to Table A.7) present the applied grouping, normalization and weighting factors of all the used LCA methods, as described in section 2.2 and 2.3.

Table A.1 Normalization and weighting factors with Ecoindicator99, v2.07, H/A.

Damage category	Normalization	Weighting
Human health	65.1	400
- Carcinogens		
- Respiratory organics		
- Respiratory inorganics		
- Climate change		
- Radiation		
- Ozone layer		
Ecosystem quality	1.95×10^{-4}	400
- Ecotoxicity*		
- Acidification/Eutrophication		
- Land use		
Resources	1.19×10^{-4}	200
- Minerals		
- Fossil fuels		

Ecotoxicity is multiplied by a factor 0.1 in PDFm^2yr/ PAF*m^2yr.

Table A.2 Normalization and weighting factors with CML 2 baseline 2000, shadowprice v2.05.

Effect category	Normalization	Weighting
Abiotic depletion	1	0
Acidification	1	4
Eutrophication	1	9
Global warming (GWP100)	1	0.05
Ozone layer depletion (ODP)	1	30
Human toxicity	1	0.09
Fresh water ecotoxicity	1	0.03
Marine aquatic ecotoxicity	0	0.0001
Terrestrial ecotoxicity	1	0.06
Photochemical oxidation	1	2
Land competition	1	0.201

Table A.3 Normalization and weighting factors with ReCiPe Endpoint v1.04, H/A.

Damage category	Normalization	Weighting
Human health	49.5	400
- Climate change Human health		
- Ozone depletion		
- Human toxicity		
- Photochemical oxidant formation		
- Particulate matter formation		
- Ionising radiation		
Ecosystems	5.72×10^{-3}	400
- Climate change Ecosystems		
- Terrestrial acidification		
- Freshwater eutrophication		
- Terrestrial ecotoxicity		
- Freshwater ecotoxicity		
- Marine ecotoxicity**		
- Agricultural land occupation		
- Urban land occupation		
- Natural land transformation		
Resources	3.27×10^{-5}	200
- Metal depletion		
- Fossil depletion		

**Marine ecotoxicity is multiplied by a factor 0 as explained in section 2.2.

Table A.4 Weighting factors with Ecological Scarcity 2006, v1.05.

Effect category	Weighting
Emissions into air	1
Emissions into surface water	1
Emissions into groundwater	1
Emissions into top soil	1
Energy resources	1
Natural resources	1
Deposited waste	1

Table A.5 Normalization and weighting factors with EDIP 2003, v1.02.

Effect category	Normalization	Weighting
Global warming 100a	1.15×10^{-4}	1.1
Ozone depletion	9.71	63
Ozone formation (vegetation)	7.14×10^{-6}	1.2
Ozone formation (human)	0.1	1.2
Acidification	4.55×10^{-4}	1.3
Terrestrial eutrophication	4.76×10^{-4}	1.2
Aquatic eutrophication EP(N)	0.0833	1.4
Aquatic eutrophication EP(P)	2.44	1
Human toxicity air	5.88×10^{-9}	1.1
Human toxicity water	0.0000169	1.3
Human toxicity soil	0.00323	1.2
Ecotoxicity water chronic	0	0
Ecotoxicity water acute	0	0
Ecotoxicity soil chronic	0	0
Hazardous waste	4.83×10^{-2}	1.1
Slags/ashes	2.86×10^{-3}	1.1
Bulk waste	7.41×10^{-4}	1.1
Radioactive waste	2.86×10^{1}	1.1
Resources (all)	0	0

Table A.6 Grouping and weighting factors with EPS 2000, v2.06.

Damage category	Factor	Weighting
Human health		1
- Life expectancy	85000	
- Severe morbidity	100000	
- Morbidity	10000	
- Severe nuisance	10000	
- Nuisance	100	
Ecosystem production capacity		1
- Crop growth capacity	0.15	
- Wood growth capacity	0.04	
- Fish and meat production	1	
- Soil acidification	0.01	
- Production capacity irrigation water	0.003	
- Production capacity drinking water	0.03	
Abiotic stock resource		1
- Depletion of reserves	1	
Biodiversity		1
- Species extinction	1.1×10^{11}	

Table A.7 Grouping, normalization and weighting factors with Impact2002+, v2.06.

Damage category	Factor	Normalization	Weighting
Human health		141	1
- Carcinogens	2.80×10^{-6}		
- Non-carcinogens	2.80×10^{-6}		
- Respiratory inorganics	7.00×10^{-4}		
- Ionizing radiation	2.10×10^{-10}		
- Ozone layer depletion	1.05×10^{-3}		
- Respiratory organics	2.13×10^{-6}		
Ecosystem quality		7.30×10^{-5}	1
- Aquatic ecotoxicity	5.20×10^{-5}		
- Terrestrial ecotoxicity	7.91×10^{-3}		
- Terrestrial acid/nutri	1.04		
- Land occupation	1.09		
Climate change		0.000101	1
- Global warming	1		
Resources		0.00000658	1
- Non-renewable energy	1		
- Mineral extraction	1		

APPENDIX B: RESULTS WITH OTHER METHODS

The following figures (Figure B.1 to Figure B.4) show the results of the lifecycle analyses which were performed additional to the prior analyses, in order to compare the outcomes of different methods. These methods and outcomes are discussed in paragraph 5.4.

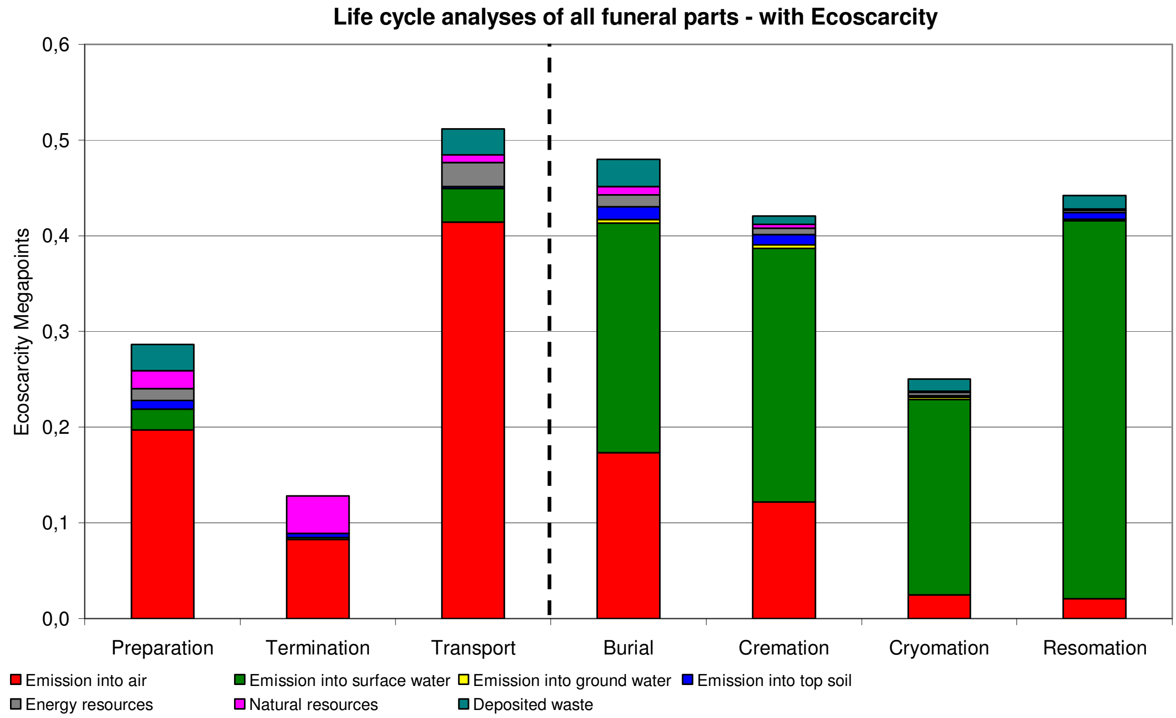

Figure B.1 Results from the life cycle assessments of all different funeral parts, performed with the Ecoscarcity method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options.

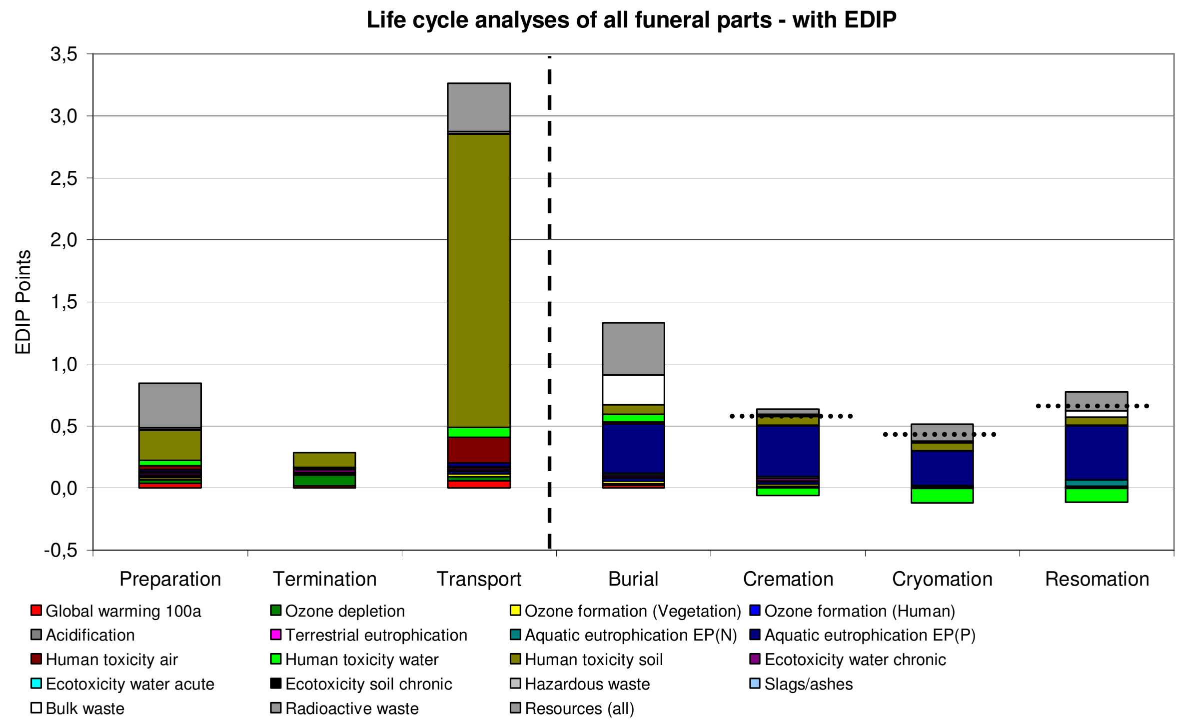

Figure B.2 Results from the life cycle assessments of all different funeral parts, performed with the EDIP method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options. Dotted lines indicate the height of the net result.

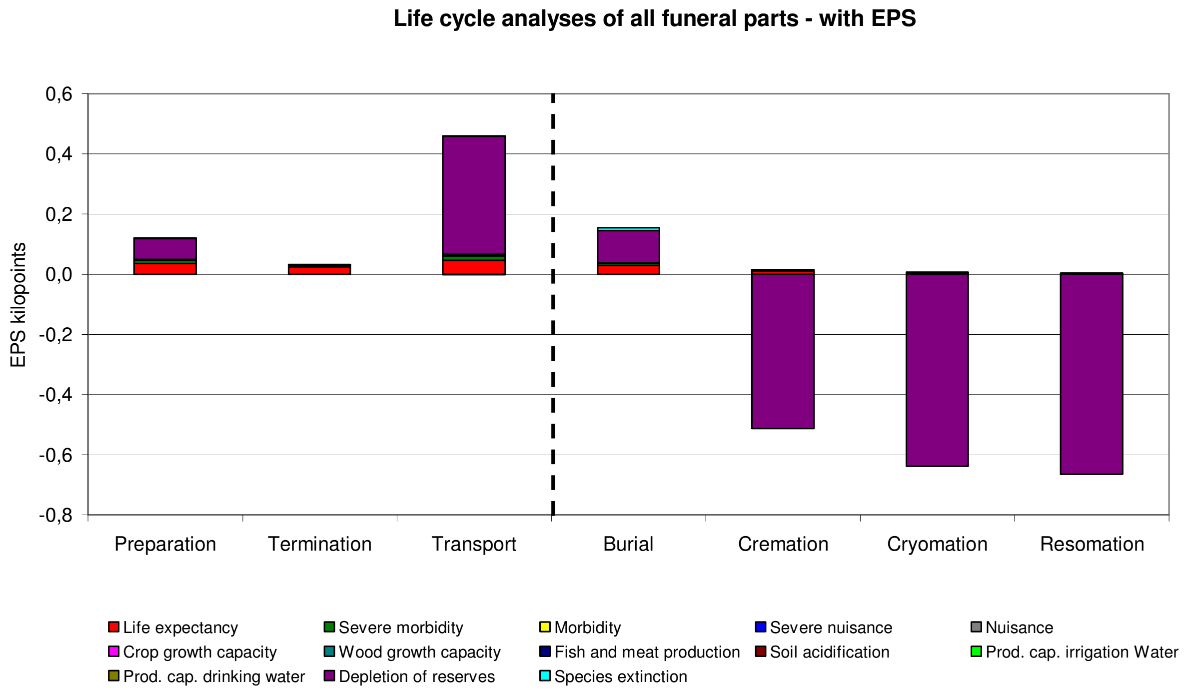

Figure B.3 Results from the life cycle assessments of all different funeral parts, performed with the EPS method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options. The last three funeral parts score negative overall. This is caused by the recycling, which is strongly counted for.

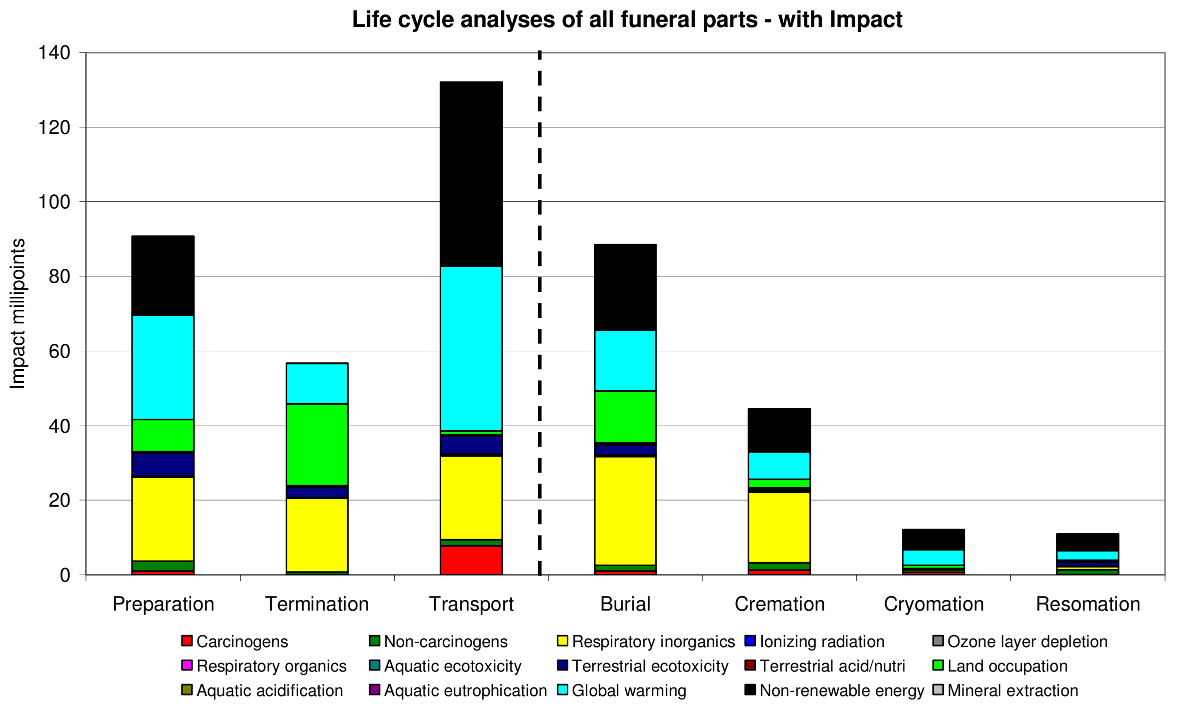

Figure B.4 Results from the life cycle assessments of all different funeral parts, performed with the Impact method. Left from the dashed line, the preliminary parts are shown, right of it are the final part options.