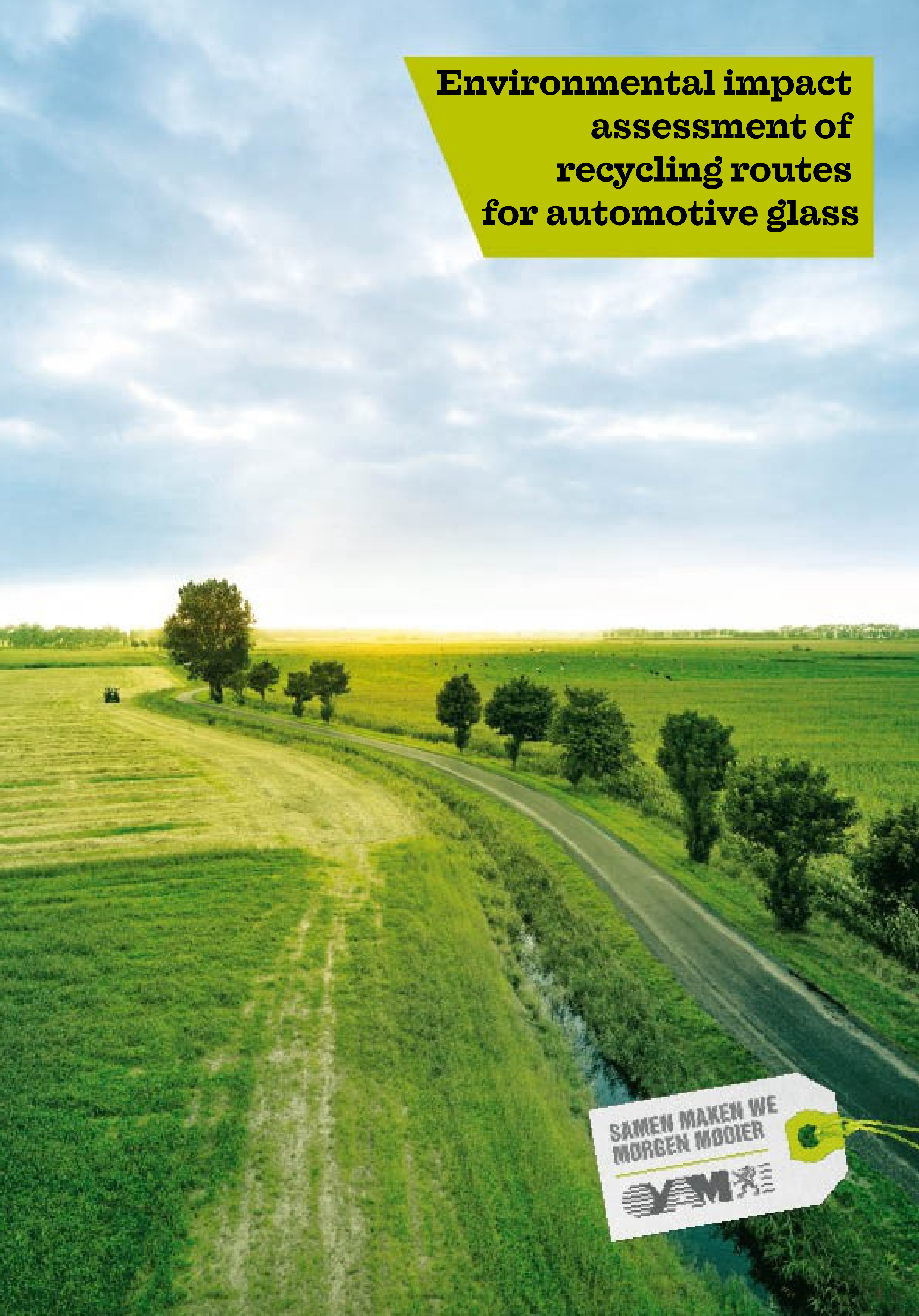
Environmental impact assessment of recycling routes for automotive glass



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Deze analyse vormt het tweede luik van een onderzoek naar de verwerking van glas uit ELV. De analyse van de milieu-impact toont aan dat de ontmanteling van glas uit ELV met recyclage in de glasindustrie en nuttige toepassing van de PVB in de plastic industrie milieuvoordelen heeft ten aanzien van de huidige situatie van shredding van het ELV met glas met recyclage van het glas in bouwtoepassingen. De milieuvoordelen van glasdemontage en recyclage zijn relatief klein, ook in het beste scenario. De belangrijkste milieu-impact is de klimaatverandering, veroorzaakt door CO_2 emissies. Verschillende scenario's werden onderzocht. Daarbij is gebleken dat transport een belangrijk aandeel heeft in de milieu-impact. Tegelijkertijd is gebleken dat de factoren om de impact van het transport te meten zeer moeilijk te bepalen zijn. Om de materiaalketen van glas uit ELV te sluiten moet een goed evenwicht gezocht worden tussen enerzijds meer demontage voor de milieuvoordelen en anderzijds het bijkomend transport daarvoor nodig dat milieunadelen oplevert. De studie gaat uit van de huidige organisatie en verwerkingsmogelijkheden.

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   Technical and economic assessment of recycling routes for automotive glass (OVAM studie uitgevoerd door Intertek RDC)
   Onderzoek verwerking van glas uit End-of-Life Vehicles: analyse van de wetgeving en praktijk in Europese landen, met focus op selectieve demontage

Inhoudstafel

1 Introduction

1.1 Description of the assignment

In the European Directive 2000/53/EC concerning end of life vehicles (ELV) targets are established for the reuse, recycling and recovery of ELV in Europe. By 2015, the reuse and recovery of ELV should increase to a minimum of 95% by an average weight per vehicle and year, while the reuse and recycling should increase to 85%. Annex I, subsection 4 of this Directive presents some treatment operations in order to promote recycling. One of those operations is the removal of glass. However, the Directive does not specify the way in which the glass should be removed, leaving room for the Member States to make their own interpretation of the Directive.

In the current recycling practice in Belgium, ELV are depolluted and shredded, without prior glass dismantling. A series of post shredder technologies (PST) separate the ferrous and non-ferrous fractions for material recycling. In this route, the glass ends up within the mineral rest fraction. An alternative route is the selective dismantling of ELV glass prior to shredding, followed by glass recycling. In former studies[1,2], selective dismantling is indicated as a possible way to significantly increase the environmental benefits of ELV recycling. However, dismantling costs were assumed to be high.

In this study, the environmental impacts and benefits of both recycling routes for automotive glass are compared, using life cycle assessment. The environmental results will be combined with the economic study that estimates the costs and revenues associated with glass recycling.

All relevant stakeholders were involved in the process: federations of vehicle producers, glass recycling industry, scrap and shredder industry, Belgian ELV management organisation, ELV dismantling companies, garages and glass industry.

1.2 Life Cycle Thinking methodology

One of the instruments to analyze the products or systems, is Life Cycle Thinking, with Life Cycle Assessment (LCA) as a specific tool to assess the environmental aspects. An LCA assesses the potential environmental impacts of a product, process or system over its complete life cycle (from cradle-to-grave). It is a scientifically-based methodology that is generally accepted by research organizations, industry and governments. An LCA consists of 4 phases (goal and scope, life cycle inventory, life cycle impact assessment and interpretation), as prescribed in ISO standards 14040[3] and 14044[4]. These 4 phases are not independent of each other.

LCAs do not represent a complete picture of the environmental impact of a system. They represent a picture of those aspects that can be quantified. Any judgments that are based on the interpretation of an LCA must bear in mind this limitation and, if necessary, obtain additional

1 Belconsulting, Recyclage van glas uit afgedankte voertuigen 24/05/2006 (studie uitgevoerd in opdracht van Febelauto, Coberec, Febiac)
2 OVAM, Gevaarlijke componenten in afgedankte voertuigen, D/2008/5024/76
3 ISO 14040, Environmental management - Life cycle assessment - Principles and framework, 2006
4 ISO 14044, Environmental management - Life cycle assessment - Requirements and guidelines, 2006

environmental information from other sources (hygienic aspects, risk assessment, etc.). The LCA-results are relative expressions and do not predict impacts on category endpoints, exceedence of thresholds, safety margins or risks.

In the context and the scope of the ELV glass study a so-called 'gate to grave study' is performed focusing on the treatment and recycling of ELV glass and its reapplication in future products. The original production of the glass and its use during the operation of the vehicle are excluded. The study starts at the point that the vehicle is considered End of Life, including all recycling processes, associated transports and input materials to come to a reusable resource material for a new product.

1.3 Reader's guide

The goal and scope definition of the LCA-study is presented in chapter 2 of this report. Chapter 3 describes the studied recycling routes and corresponding inventory data. In chapter 4, the environmental profile of both recycling routes is presented. In chapter 5 a scenario analysis is performed, that incorporates peripheral system changes induced by selected policy measures into the environmental impact assessment. And finally, chapter 6 enumerates the most important findings of the study and provides some guidelines for linkage of the environmental analysis to the economic analysis.

2 Goal and scope definition

In the first phase of an LCA, typically the intended use of the LCA (the goal) and the width and depth of the study (the scope) have to be clearly defined (ISO, 2006). The scope definition has to be consistent with the goal of the study. In the following paragraphs aspects that are agreed upon at the start of this study are shortly discussed .

2.1 Goal definition

2.1.1 Reasons for carrying out the LCA

In the context of their materials policy plan, with a focus on closing material loops, OVAM studies the EoL processing of glass in ELV. Two alternative processing routes exist: i) the current route of depolluting and shredding ELVs without prior glass dismantling and ii) the alternative route of selective dismantling of ELV glass prior to shredding, followed by glass recycling. With this environmental impact assessment study, OVAM wishes to get an insight into the environmental impacts of both processing routes.

So the objective of this LCA is to:

- identify the environmental hotspots in both alternative routes for glass recycling of ELVs;
- compare the environmental impacts of both routes according to different scenarios.

This analysis of the environmental impacts of different recycling routes for automotive glass follows an economical analysis. Since dismantling of the glass is time-consuming, costs are very important for the dismantling route.

2.1.2 Intended use of the results and the audience

Ultimately OVAM wishes to combine the results and conclusions of this environmental assessment with these of the economical analysis that estimates the costs and revenues associated with glass dismantling and recycling. This should allow OVAM to assess whether the costs are in balance with the environmental benefits (eco-efficient) and as such whether it is feasible to introduce this alternative route in Flanders.

2.2 Scope definition

2.2.1 Subject of the study

The study focuses on the environmental impacts of recycling routes for automotive glass from ELVs. Two different recycling routes are studied:

- Depollution and shredding (incl. PST) of ELV-glass, in which glass ends up in mineral rest fraction (current practice in Flanders);
- Depollution, selective dismantling of ELV glass prior to shredding, glass recycling (alternative route).

Different scenarios are defined, that combine both routes according to different assumptions. As a reference a Business-as-Usual scenario is defined, that reflects the current way of processing ELV glass in Flanders.

2.2.2 Function and functional unit

In an LCA-study, it is important to clearly define the functional unit. This is the reference basis all gathered data and as such environmental impacts refer to. Therefore, a functional unit must include a measurable parameter. It should include the function that the system under study fulfills and define the requirements the systems should meet. In a comparative study the functional unit also serves as the correct base for comparison.

To be in line with the cost-benefit study, it is decided in consultation with OVAM to perform an **attributional LCA**[5] to assess the environmental impacts of the different recycling routes and scenarios that are considered in this study. The functional unit is defined slightly different for the analysis of the routes and the scenario's. For assessing the environmental impact of both EoL routes for ELV glass, the functional unit is defined as "**the treatment of 1 kg glass in a depolluted ELV**". For comparing the EoL scenario's, the functional unit is defined as "**the treatment of an average ELV**".

To be able to focus in the attributional type of LCA specifically on the **glass flow**, and the impacts and credits associated herewith, **streamlining** is applied for both the analysis of the routes and the scenario's. Streamlining means that all parts of the system that are identical for the different alternatives, may be omitted from the (comparative) analysis. The EoL treatment of the ELV wreck is independent of the type of treatment of the windows, thus remains the same for the route where the glass is dismantled and treated separately as for the route where the glass goes into the shredder and PST together with the wreck. Therefore it is allowed to exclude the impacts and credits related to the treatment of the ELV-wreck from the LCA. When comparing the EoL scenario's, again streamlining of the ELV-wreck is applied, however in cases where the scenario has an effect on the transport or treatment of the wreck itself, the additional impact is taken into consideration. Although this approach might at some points seem similar to the methodology of a consequential LCA[6], the attributional methodology is still followed.

2.2.3 Product systems and system boundaries

The systems, which are studied in an LCA, have to be clearly defined and should be based on the life cycle thinking principle. Decisions have to be made regarding which life cycle stages, processes or releases to the environment can be omitted without compromising the results of the study. Any omissions should be clearly stated and justified in the light of the defined goal of the study.

In the context and the scope of this ELV glass study a so-called '**gate to grave study**' is performed focusing on the treatment and recycling of ELV glass and its reapplication in future products. The original production of the glass and its use during the operation of the vehicle are excluded. The study starts at the point that the vehicle is depolluted, including all recycling processes, associated transports and input materials to come to a reusable resource material for a new product. The process tree of all life cycle stages included in this study are presented and discussed further in this report.

As discussed in the previous paragraph, **streamlining** is applied for the treatment of the ELV wreck (without the glass). This study focuses on the impacts and credits related to the EoL treatment of the glass flow from the ELV and only includes additional impacts and credits due to

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5 An attributional LCA assesses the burdens associated with the life cycle of a product, process or system, at a specific point in time (typically the recent past).

6 A consequential LCA identifies the environmental consequences of a decision or a proposed change in a system under study (oriented to the future), which means that market and economic implications of a decision may have to be taken into account. This requires a deep insight in the system and market under study.

necessary changes in the transport and treatment of the ELV wreck imposed by the glass EoL treatment.

To clearly define the system boundaries, VITO proposes some basic principles:

- The *infrastructure* (production of capital goods like buildings, equipment and transport infrastructure) is not considered in this study. However, the use of these capital goods and the effects related to this are taken into account (e.g. emissions, waste related to the production process).
- *Accidental pollutions* are often difficult to distinguish from emissions that occur under normal conditions (accidental pollutions are not measured and reported separately) and are therefore not considered in this study.
- Environmental impacts caused by the *personnel of considered plants* are neglected, e.g. waste from the cafeteria and sanitary installations or accidental pollution caused by human mistakes, or environmental effects caused by commuter traffic. Heating of the plants is also neglected.

2.2.4 Types of impacts and methodology of impact assessment

The environmental impacts of both glass recycling routes are calculated and assessed according to the LCA-methodology. Different methods for impact assessment exist, which are widely recognized by experts worldwide. In consultation with OVAM it is decided to use the ReCiPe midpoint method as basic impact assessment method in this study. This method is recently developed and acknowledged as a scientifically founded methodology by LCA-experts. ReCiPe identifies the life cycle impact categories as summarized in Table 1.

For the purpose of estimating the relative importance of the different impact categories, the single score method (ReCipe Endpoint, Europe H.A) is used.

VITO uses the LCA software package “SimaPro 7.3.3” for performing the life cycle impact assessment (LCIA) and generating the environmental profiles.

Environmental impact categories	Unit midpoint
Climate change (Human health)	kg CO_2 eq.
Climate change (Ecosystem)	kg CO_2 eq.
Ozone depletion	kg CFC-11 eq.
Terrestrial acidification	kg SO_2 eq.
Freshwater eutrophication	kg P eq.
Marine eutrophication	kg N eq.
Human toxicity	kg 1,4-DB eq.
Photochemical oxidant formation	kg NMVOC
Particulate matter formation	kg PM10 eq.
Terrestrial ecotoxicity	kg 1,4-DB eq.
Freshwater ecotoxicity	kg 1,4-DB eq.
Marine ecotoxicity	kg 1,4-DB eq.
Ionizing radition	kg U^{235} eq.
Agricultural land occupation	m^2a
Urban land occupation	m^2a
Natural land transformation	m^2
Water depletion	m^3
Metal depletion	kg Fe eq.
Fossil depletion	kg oil eq.

Table 1: Environmental impact categories defined by the ReCiPe method

2.2.5 Data and data quality analysis

For all life cycle stages an input-output balance has to be made. Input data concern the consumption of energy and raw materials. Output data are emissions (to air, water and soil), waste and other (e.g. heat).The different data sources that are used should be stated. Efforts do not need to be put in the quantification of minor or negligible inputs and outputs that will not significantly change the overall results of the study. All assumptions made during the course of the whole project and the limitations of the LCA study are documented in the report.

The data inventory in this study is performed in close cooperation with all stakeholders. For each of the life cycle stages, the respective stakeholders are consulted and asked for data on input- and output flows. These specific data are used for all **foreground processes** (this means processes that directly take place under the stakeholders' responsibility, e.g. dismantling, shredding, glass recycling, glass production, etc.). This specific data are completed with data from literature, the economical cost-benefit study, and finally some own assumptions. These are clearly documented and discussed in this report.

VITO collected publicly available generic data for all **background processes** like for example the production of electricity, the production of glass, etc. The main life cycle inventory (LCI) source for this kind of background processes used in the study is the Ecoinvent database (Ecoinvent v2.2, 2010).

2.2.6 Sensitivity analyses

The results of an LCA depend on different factors. Sensitivity analyses assess the influence of the most relevant and most uncertain factors on the results of the study. The results of these sensitivity analyses are compared to the basic scenario. Sensitivity analyses do not make the basic data of a study more reliable, but allow assessing the effect of a change in inventory data on the results and conclusions of the study.

3 Process description and data inventory: General part

3.1 Introduction: data collection

During the data inventory phase of the LCA study, environmental data on the studied processes and products are collected. More specifically, all the input flows (materials, water, energy,…) and all the output flows (emissions, waste, …) of each studied process step have to be described and quantified. Life Cycle Inventory (LCI) collection is an iterative process. As data are collected and the system is better known, new data requirements or limitations may become apparent. This may require better or additional data to be collected or system boundaries to be refined

The data collection was done by VITO, in close collaboration with the stakeholders in the steering committee. During individual interviews and regular committee meetings, data were gathered and validated and expert estimations were consented for those aspects where no data were readily available. Additional data were collected in literature, while background data (e.g. on impacts of diesel combustion, electricity production, raw material mining,...) were taken from the Ecoinvent 2.0 database. Whenever available, data for the Belgian situation were taken (e.g. electricity mix). In most cases average data for Europe were used (RER-records), and in some cases country-specific data for Switzerland or Germany had to be used, due to lack of more appropriate data. All data records used are listed in the following sections.

After collection, the data are normalized to the functional unit '**the treatment of 1 kg of glass in a depolluted ELV'** and aggregated into the system model.

3.2 Automotive glass

3.2.1 Characteristics of automotive glass

The properties of automotive glass are discussed in detail in the economical cost-benefit study (OVAM, 2013)[7]. The following data are taken as a starting point for the environmental assessment. Glass from sunroofs and headlights are not considered in this study.

7 OVAM, 2013. Automotive glass – Part 1 – Technical and economical aspects

Window	Weight distribution	Average weight	Remarks
Windscreen	10-20 kg	13 kg	Laminated, containing 10% PVB[8]
All side windows	8-20 kg	13 kg	Not laminated
Rear window	3-10 kg	6 kg	Not laminated, containing heating wires
Total automotive glass	**20-40 kg**	**32 kg**	**Theoretical figure, does not account for losses due to accidents, spare part dismantling, etc.**
of which PVB	**1-2,5 kg**	**1,3 kg**	**Windscreen contains 10% PVB**
of which metal wiring	**negligible**		

***Table 2: Automotive glass: type and amount (OVAM, 2013)*[9]**

3.3 Treatment of End of life Vehicles

In 2011 about 170,000 ELV were treated in Belgium. Typically, the last owner of a vehicle delivers it at a garage or scrap dealer, who sends it further to an official depollution center for removal of hazardous parts (e.g. battery) and liquids (oils, fuel, cooling liquid,...).

3.3.1 Recycling routes for automotive glass

Currently, glass is not dismantled from ELV with the purpose of recycling (reuse as spare part does occur to a limited extent). The glass remains in the vehicle and is shredded together with the other materials at a shredder facility. In a post-shredder-technology (PST) line, different material fractions are separated, leaving a mineral rest fraction in which most glass particles end up, together with stones, concrete, porcelain, etc. This mineral fraction, when complying to the standards for material reuse, can be reapplied in the building industry. Reuse in the glass industry is currently not possible, both due to the presence of impurities and a too small particle size which hinder a further purification.

A possible alternative for the shredding route, is the selective dismantling of automotive glass prior to shredding. In this way, a relatively pure glass fraction is obtained, which can be processed by glass recyclers into high quality cullet that can be reused in the glass industry.

The environmental burdens associated with both recycling routes are related to energy and material requirements of the recycling processes themselves, transport movements in between treatment steps and the associated emissions and wastes that are produced. Environmental benefits can be found in the reapplication of the recycled materials: when material streams of sufficient quality are obtained, they can replace the use of primary materials in new production processes. Apart from this benefit, the use of cullet in glass production has the additional advantage of energy savings in the melting process.

In chapters 4 and 5 these 2 recycling routes are presented in detail, together with the data that were used to quantify the burdens and benefits for each process step.

8 CARE, 1999. Glass recycling, an automotive perspective.
9 OVAM, 2013. Automotive glass – Part 1 – Technical and economical aspects

3.4 Transport operations

Transport activities represent a wide range of environmental impacts, as they consume large quantities of fuel. Due to combustion emissions both in vehicle operation and in fuel production, transport is a major source of carbon dioxide, nitrogen oxide and hydrocarbons. In addition, the construction and operation of transport infrastructure (roads, bridges, canals...) and the production, maintenance and disposal of the vehicles themselves consume resources and cause additional, indirect environmental impacts (Ecoinvent report 14).

In the following paragraphs the different road transport modes are described that are considered in the first part of this study (staring from the ELV at the depollution center). In chapter 7 , some additional transport modes are introduced for the transport of ELV towards the depollution center.

As a detailed analysis of the transportation system of ELV treatment and glass recycling is very complex and goes beyond the scope of this study, several assumptions and estimations were made to characterize the different transport types and their associated environmental impact.

3.4.1 Scrap wagon and grapnel

The scrap wagon with grapnel is used for the transport of depolluted ELV from the depollution center to the shredder. The maximum truck load in case of waste transport is 12 ton for a single container and 2 times 10 ton for a truck with trailer (van Heede).

After depollution, the remaining ELV is transported to the shredder for final treatment and metal recovery. Whether or not the glass has been dismantled does not significantly change this transport stage. In some cases, the ELV carcases are pressed into flat 'pancakes' to allow for a more efficient transport.

Figure 1: Pressed ELV on a lorry (picture taken from http://cash4scrapcars.co.uk)

Figure 2: ELV crushed into cubes (picture taken from www.thescienceforum.com)

In the transport modeling, the following assumptions are made for this type of transport:

— only single container transports are considered
— an average container can harbor between 6 ELV (6 tonnes) and 12 ELV (12 tonnes, maximum container load) depending if pressing is done or not.
— an average load of 70% (8,4 ELV) is assumed, counting both pressed and unpressed ELV
— the return trip occurs with an empty wagon
— diesel consumption varies between 33 (empty) and 37 (full) liter/100 km
— all vehicles comply with the EURO 5 emission standard
— average distance between depollution center and shredder is discussed in 4.2.1.

3.4.2 Bulk truck

When the ELV is dismantled and/or shredded, the resulting material fractions are transported to their respective recyclers. From there, the recycled materials are transported to their users. This type of transport is typically done with a tipper or a walking floor lorry.

Figure 3: Tipper (picture taken from http://www.diytrade.com)

Figure 4: Walking-floor trailer (http://www.calrecycle.ca.gov)

In this study, the following assumptions are made for this type of transport:
— maximum load of 12 ton
— for the transport of dismantled automotive glass from the depollution centers to the glass recyclers, milk-round transports are assumed with an average load of 50% (6 tons)

- for the transport of other recycled fractions (recycled cullet, recycled PVB, shredded ELV,...), full transports (100%, 12 ton) are assumed
- the return trip occurs with an empty lorry
- diesel consumption varies between 33 (empty), 35 (50% load) and 37 (full) liter/100 km
- all vehicles comply with the EURO 5 emission standard
- average distances shredder/PST and recycler/producer is discussed further.

3.4.3 Inventory data

The following table presents the assumptions used in the environmental modeling:

Load		**Diesel consumption**	**Ecoinvent data record**	**Remark**
Scrap wagon with grapnel				
0%	0 tonne	0,330 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
70%	8,4 tonnes	0,358 l/km		Average load (8,4 ELV)
Bulk truck				
0%	0 tonnes	0,33 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
50%	6 tonnes	0,35 l/km		Milk-round, average load (6 tonnes)
100%	12 tonnes	0,37 l/km		Full load
* using Diesel, at regional storage, RER/U instead of CH/U				

Table 3: Life Cycle Inventory (LCI) of transport operations

The modeling of the transport operations only takes into account fuel use and associated emissions. The environmental impacts of vehicle production and road infrastructure are not taken into account.

4 Process description and data inventory: Route 1: Shredding

4.1 Route overview

Route 1 starts at the official depollution center, after ELV is depolluted. From there, the ELV including its windows (either intact or scattered within the ELV carcass) is sent to a shredder facility and PST. After PST the glass ends up in the remaining mineral fraction. The presence of glass in this mineral fraction has an important contribution to the compliance of this mineral fraction with the criteria for application as a building material (replacing primary sand).

The process steps are visualized in Figure 5 and described in more detail in the next sections.

The impacts related to the treatment of the ELV glass are isolated from the impacts related to the treatment of the rest of the ELV, which are assumed to be independent of the chosen route for the glass treatment. For this reason, these impacts are streamlined, and as such not included explicitly in the following assessment. All calculated impacts are thus specifically related to the glass treatment.

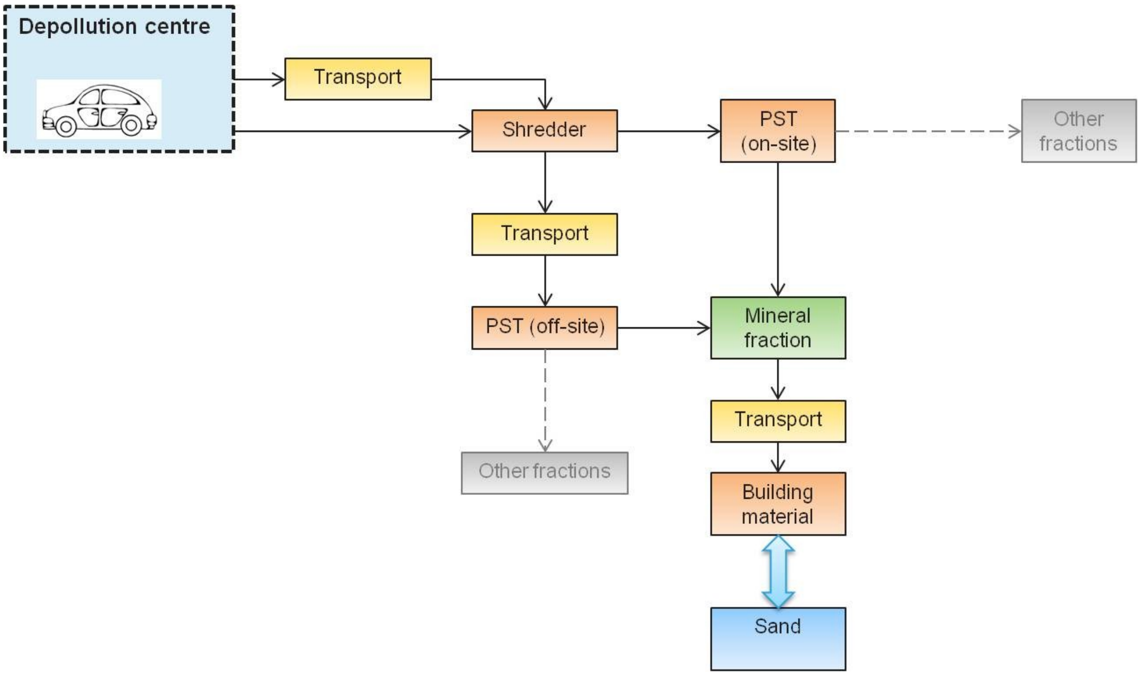

Figure 5: Process scheme shredding route

4.2 Shredder and Post-shredder technology (PST)

4.2.1 Process description

A depolluted vehicle is shredded in a hammer mill. A typical shredder batch contains about 20-30% ELV, the other inputs are washing machines and industrial or building scrap. A separation is made in 3 fractions:

— **Iron** is separated by a magnetic separation and sold to the steel industry.
— An aspiration removes the '**shredder light fraction**' (e.g. foam, textile,...).
— The remainder is called the '**shredder heavy fraction**' and consists of non-ferrous metals, glass, plastics, rubber, concrete and stones (e.g. from washing machines).

Both the light and the heavy fraction are treated further in the PST. The process is described schematically in Figure 6, based on data from the Belgian shredder company Galloo. Galloo receives the largest share of ELV in Flanders and operates a state-of-the-art PST installation.

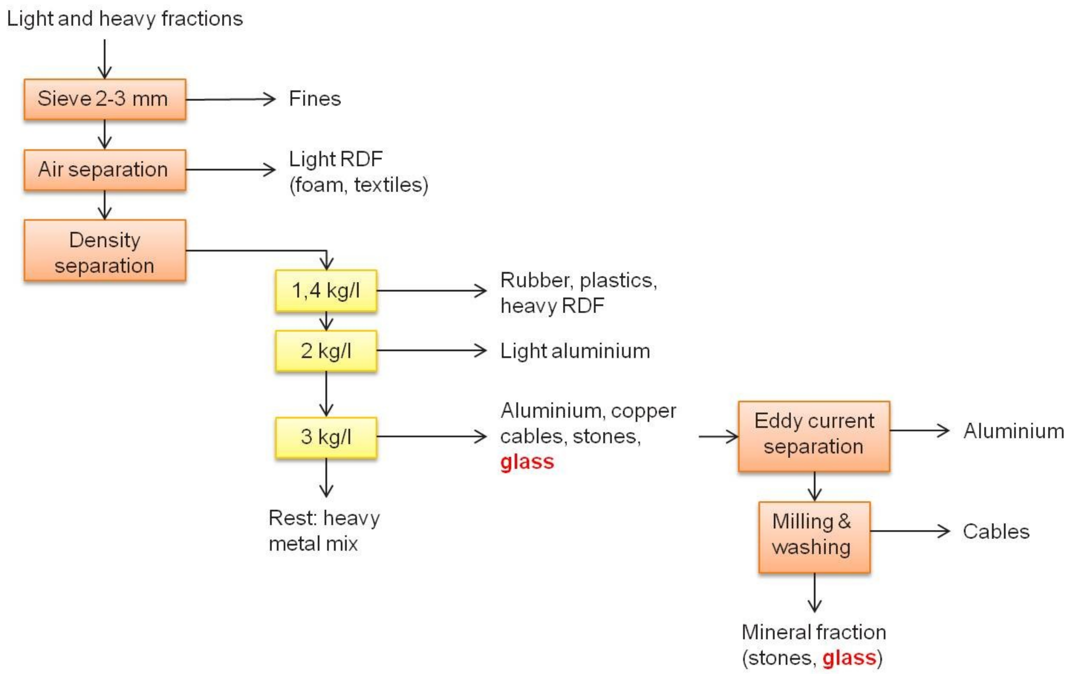

Figure 6: Steps within PST (source: Galloo)

As glass has a density between 2 and 2,5 it ends up in the aluminum fraction after density separation. This fraction is separated further and the glass, concrete and stones are finally recovered in a mineral fraction (about 25% glass), which is further described in paragraph 4.3.

In 2011 in Belgium, 44% of ELV are shredded at shredders without an own PST. Moreover, shredders that do have a PST often have various shredding sites, but only one site with PST. In those cases, the heavy fraction needs to be transported to a PST.

4.2.2 Inventory data

In this study, the following assumptions are made for shredding and PST:

— average distance between depollution center and shredder is 30 km
— 60% of ELV are depolluted at a center with an on-site shredder, 40% of ELV need further transport to a shredder after depollution

— 44% of ELV are shredded at shredders without an own PST
— 56% of ELV are shredded at shredders with a PST on-site
— average transport between shredder and off-site PST is estimated to be 50 km
— internal transport of input and output fractions on the recycling site or between shredder and its on-site PST (by forklift, dumper truck, tipper,...) is neglected
— transport of ELV from depollution centre to shredder is done by scrap wagon (70% loaded) (see 3.4.2)
— transport of shredded ELV between shredder and PST is done by bulk truck (100% loaded) (see 3.4.2)

After PST, 95% of the glass present in the ELV ends up in the mineral fraction, while 5% gets lost as impurities in other PST fractions (iron scrap, aluminum scrap, plastics)

Input	**Amount**	**Ecoinvent data record**	**Remark**
Electricity (shredder)	15,75 kWh/ton input[10]	Electricity, medium voltage, production BE, at grid/BE U	not allocated to glass
Electricity (PST)	1,75 kWh/ton input[10]	Electricity, medium voltage, production BE, at grid/BE U	allocated to glass on weight base
Transport by scrap wagon (70% loaded)	30 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport from depolluter to shredder
Transport by bulk truck (100% loaded)	29 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport from shredder to PST
Output	**Amount**	**Ecoinvent data record**	**Remark**
Glass in mineral fraction	95%	-	5% glass losses in PST
Waste	5%	Disposal, glass, 5% water, to inert material landfill/CH	Glass losses

Table 4: LCI Shredder and Post-Shredder Technology

4.3 Application of the mineral fraction

4.3.1 Process description

The glass fraction that can be recovered after PST is not accepted for glass recycling as current PST technologies to not achieve a sufficient purity. In addition, the size of glass pieces after PST is too small and this hinders the separation at the glass recycling plant.

Galloo has developed a PST process which allows to reuse the mineral rest fraction of the PST as a certified secondary building material. At the moment the total mineral fraction output is used as road basement on a landfill site, thus replacing virgin sand. Other application routes are

10 Lassesson H., 2008. Energy consumptions and CO2 emissions resulting from different handling strategies of glass from end-of-life vehicles. Master of Science Thesis. Chalmers University of Technology. Göteborg, Sweden.

investigated for the moment, although the yearly volume of mineral fraction from ELV treatment is relatively low (about 8000 tons).

4.3.2 Inventory data

In this study, the following assumptions are made for application of the mineral fraction:

Output	Amount	Ecoinvent data record	Remark
Route 1			
Sand	1 kg	Sand, at mine/CH U	Glass within the mineral fraction replaces the same amount (weight) of building sand
Transport to reuse site	-	-	Not considered as it replaces sand transport, which is assumed to be a similar amount.

Table 5: LCI Application of 1 kg of glass in the post-shredder mineral fraction

5 Process description and data inventory: Route 2: Dismantling

5.1 Route overview

Route 2 starts at the official depollution center, after ELV is depolluted. At this point the windows are dismantled. The dismantled glass is transferred to a glass recycling facility, where impurities (steel strips, rubber, plastics) are removed and glass cullet is produced meeting the quality requirements of the glass industry. Recycled cullet replaces raw materials for glass production and has an additional energy-saving effect. Windscreens contain PVB. During the glass recycling process, these foils are also separated from the glass fraction. The resulting PVB-rich output stream is sent to a dedicated PVB recycler for further purification and processing into reusable PVB flakes and pellets.

Some glass will remain in the ELV (edges, broken glass that fell on the floor or in the ELV) and end up at a shredder facility together with the ELV carcass.

The process steps are visualized in Figure 7 and described in more detail in the next sections.

As explained in paragraph 4.1, the impacts related to the treatment of the rest of the ELV (excluding the glass) are streamlined. All calculated impacts are thus specifically related to the glass treatment.

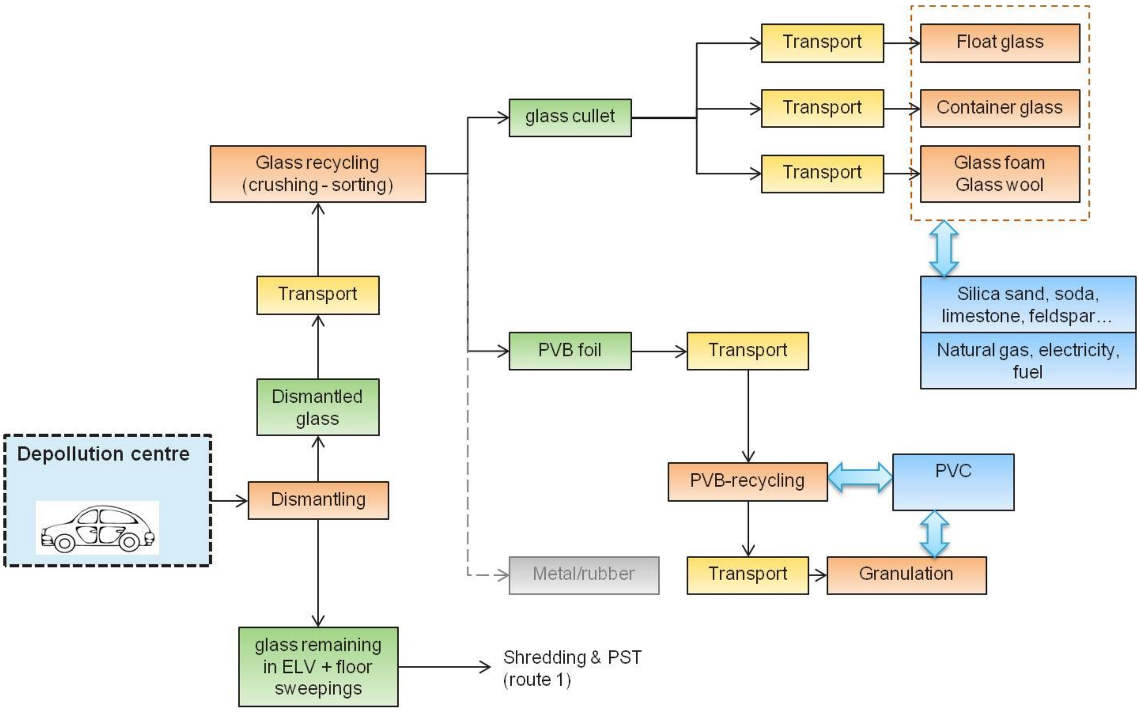

Figure 7: Process scheme dismantling route

5.2 Dismantling

5.2.1 Process description

An ELV was assumed to have a laminated windscreen, 4 side windows and 1 rear window. The windscreen is laminated (10% PVB). Different dismantling techniques exist and were described in the economical cost-benefit study (OVAM, 2013)[11]. These techniques differ slightly in their use of tools (electricity requirements) and their efficiency (glass losses between 0-20%). Depending on the chosen dismantling technique, some internal transport may be necessary to move the ELV outside or to a protected area. The different techniques with their estimated electricity requirements and efficiency are listed in Table 6.

Dismantling technique	% glass yield	Tools used (/kg glass)	Remark	Internal transport with forklift (/kg glass)
Windscreen				
1A. Breaking with metal bar	90-95%	-	-	0,005 kWh
1B. Breaking with a forklift	90-95%	0,015 kWh (forklift)	Tools: 8,8kW forklift, av. 1,5 minute dismantling, av. 15 kg windscreen per operation	0,005 kWh
1C. Sawing without vacuum cleaner	90-95%	0,006 kWh (saw)	2,5 kW saw, av. 2 minute dismantling, av. 15 kg windscreen per operation	0,005 kWh
1D. Sawing with vacuum cleaner	90-95%	0,006 kWh (saw)	2,5 kW saw, av. 2 minute dismantling, av. 15 kg windscreen per operation	-
1E. Cutting (metal wire with handles)	100,00%	-	-	-
1F. Cutting (Carglass tool)	100,00%	-	-	-
Side windows				
2A. Breaking with a sharp object	85-95%	-	-	0,005 kWh
2B. Cutting with a cutter	100,00%	-	-	-
2C&D. Unscrewing	100,00%	-	-	-
Rear window				
3A. Breaking with a sharp object	80-95%	-	-	0,005 kWh
3B. Cutting with a cutter	100,00%	-	-	-

Table 6: Dismantling techniques available (OVAM, 2013)

11 OVAM, 2013. Automotive glass – Part 1 – Technical and economical aspects

5.2.2 Inventory data

In this study, the following assumptions are made for dismantling of ELV glass:

— power consumption of dismantling is calculated as a worst case scenario: for each window, the power consumption of the most energy-intensive dismantling technique is used.

— the ELV needs to be transported by forklift to the dismantling place: a 8,8 kW forklift working for 1 minute for the transport of 1 ELV, containing 29,6 kg of glass (32 kg minus 7,5% glass loss due to accidents). This transport is allocated fully to the glass dismantling activity.

— average distance between depollution center and glass recycler is estimated at 130 km, as both recyclers are located in the east of Flanders and dismantled glass will have to be transported from depollution centers all over Flanders, with a maximum distance of about 200 km.

— glass that is left in the ELV after dismantling (efficiency losses or broken windows) is assumed to proceed to the shredder and end up in the mineral fraction, as described in chapter 4.

— transport of dismantled glass from depollution center to glass recycler is done by bulk truck in milk rounds (50% loaded) (see 3.4.2)

— Waste generated by glass dismantling is neglected.

Input	Amount	Ecoinvent data record	Remarks
Dismantling			
Electricity (tools) windscreen dismantling	0,015 kWh/kg	Electricity, medium voltage, production BE, at grid/BE U	Technique 1B is taken as worst case
Electricity (tools) rear window dismantling	0 kWh/kg	-	None of the techniques requires power tools
Electricity (tools) side windows dismantling	0 kWh/kg	-	None of the techniques requires power tools
Electricity (transport) for all windows	0,005 kWh/kg	Electricity, medium voltage, production BE, at grid/BE U	Internal transport of ELV to dismantling place
Transport			
Transport by bulk truck in milk-rounds (50% loaded)	130 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport of dismantled glass from depollution centre to glass recycler
Transport by scrap wagon (70% loaded)	30 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport of glass remaining in ELV from depollution centre to shredder
Output efficiency dismantled glass			
Windscreen	97%	-	(OVAM, 2013)[12]
Rear window	90%	-	(OVAM, 2013)
Side windows	85%	-	(OVAM, 2013)
Waste	neglected	-	Non-dismantled glass is added to remaining ELV for shredding

Table 7: LCI Dismantling ELV glass

12 OVAM, 2013. Automotive glass – Part 1 – Technical and economical aspects

5.3 Glass recycling

5.3.1 Process description

Incoming glass lots are visually inspected before there are accepted for recycling. The glass is stock-piled in open air. For laminated glass, the exposure to water and UV-light has the advantage that the glass breaks and the PVB foil loosens from the glass, facilitation crushing and separation afterwards.

The glass recycling process consists of 3 main steps:

- Preparatory step:
  - manual removal of large contaminants
  - removal of iron by magnetic separation
- Crushing and sorting:
  - crushing into glass particles of suitable size
  - removal of foils
  - removal of non-ferrous metals by eddy current separation
  - sieving
  - optical separation (laser technology) of CSP (ceramics, stones, porcelain)
- Quality control

Properly dismantled and uncontaminated glass is always accepted by the glass recyclers. In practice, laminated and non-laminated glass are treated together, so separated collection is not necessary. The dark glass zones along the window fringes (serigraphy) lowers the color quality of the glass cullet, but is no hindrance to recycling. The non-glass components of automotive glass, such as heating wires, PVB and small remaining fractions of rubber and metal do not hinder the glass recycling process. PVB is recovered in a separate fraction and sent to a PVB recycler.

About 5% of the glass is lost during the glass recycling process, mainly due to glass particles that stick to the PVB fragments. About 40% of the recovered PVB foil is not accepted for further recycling due to quality issues (e.g. colored PVB or PVB with a too high glass fraction) or insufficient recycling capacity (source: GRL, Maltha). However, as PVB recycling is a very young, upcoming industry, it is expected that within a short term additional production plants will come into operation (in Germany there are some recent initiatives) and that quality restrictions might be overcome by new technological developments (source: GRL).

Other minor material losses include impurities such as metals and rubber.

5.3.2 Inventory data

In this study, the following assumptions are made for glass recycling of dismantled ELV glass (from and validated by Maltha, GRL):

- properly dismantled glass is always accepted for glass recycling, no separate collection of window types (windscreen, rear window, side windows) is necessary
- electricity used for crushing and sorting is taken from the Belgian grid (although both Flemish glass recyclers have their own energy production based on renewable sources)
- internal transport of input and output fractions on the recycling site (by forklift or dumper truck) is neglected

— 5% of the glass in the input gets lost during the recycling process (mainly due to attachment to PVB, rubber). It is assumed that this fraction finally ends up at a landfill.
— about 60% of the PVB can be sent to PVB recycling, the remaining 40% is of insufficient quality due to coloring (e.g. dark green sunblock strips) or a too high glass content (> 10%) and is considered as waste. It is assumed that this inferior PVB is landfilled.
— a PVB containing output fraction is produced that is accepted for PVB recycling
— other waste generated by glass recycling is neglected
— distance between glass recyclers and PVB recycler is calculated as the average distance between both Flemish glass recyclers and the only Flemish PVB recycler.
— distance between glass recyclers and glass producers is calculated as the average distance between both Flemish glass recyclers and the glass producers (container glass, float glass, foam glass).
— Recycled glass and PVB containing fraction are transported by bulk truck (100% loaded) (see 3.4.2).

Input	**Amount**	**Ecoinvent data record**	**Remark**
Electricity	10 kWh/ton input	Electricity, medium voltage, production BE, at grid/BE U	Crushing and sorting
Transport by bulk truck (100% loaded)	Estimations and calculations in sections 5.5.2.3, 5.5.3.3 and 5.5.4.3		Transport of recycled cullet to glass production plant
Transport by bulk truck (100% loaded)	19 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport of PVB fraction to PVB recycling plant
Output	**Amount**	**Ecoinvent data record**	**Remark**
Recycled cullet	95% of glass input	-	5% glass loss during glass recycling process
PVB containing intermediate	60% of PVB input	-	40% PVB loss due to inferior quality (colored PVB, too high glass content) Intermediate fraction contains about 74% PVB, the rest is glass and other impurities (see 5.4)
Waste (glass)	5% of glass input	Disposal, glass, 0% water, to inert material landfill/CH	5% glass loss eventually ends up in landfill
Waste (PVB)	40% of PVB input	Disposal, inert waste, 5% water, to inert material landfill/CH	PVB loss due to inferior quality (colored PVB, too high glass content), not accepted by recycler
Waste (other)	Neglected/ not considered	-	Rubber, metal

Table 8: LCI Glass recycling

5.4 PVB recycling

5.4.1 Process description

Solutions A/S is a Danish based market leader in recycling post-consumer PVB from laminated glass. It receives a PVB-containing output stream from glass recycling and cleans it from glass and other contamination into clean PVB raw materials for the industry, e.g. flakes, pellets, powder and dispersion.

For the moment, recycled post-consumer PVB cannot be used again as PVB-film in laminated glass, mainly due to the required level of transparency. Numerous other industrial applications are possible. Shark Solutions is continuously developing new applications for the recycled PVB. Due to its extremely good adhesive abilities, recycled PVB is often used as adhesive promoter in printing inks, paints and lacquers and it also can be used for protection steel against corrosion. It adheres very well to many surfaces as steel, iron, zinc, aluminum and other light metals but also on glass, concrete, ceramics etc. The hotmelt adhesive can be used as known in laminated glass ”gluing”. PVB can be dissolved in several organic solvents - alcohols as ethanol, butanol and mixtures a.o. and other to form liquid solutions (http://www.shark-solutions.com).

5.4.2 Inventory data

In this study, the following assumptions are made for PVB recycling (source: Shark solutions):

— the PVB intermediate produced by the glass recyclers is always accepted for PVB recycling
— 25% of the PVB in the input gets lost during the recycling process
— waste (glass, small PVB particles, other waste) generated by PVB recycling is landfilled
— about 50% of recycled PVB undergoes an additional granulation process before reapplication, transport to granulation plant is done by bulk truck (100% loaded)(see 3.4.2).
— recycled PVB is used to replace the same amount (weight) of PVC (e.g. in carpet production)

Inputs	Amount	Ecoinvent data record	Remark
Electricity	confidential	Electricity, medium voltage, production BE, at grid/BE U	-
Water	confidential	Tap water, at user/RER U	-
Chalc	confidential	Limestone, milled, packed, at plant/CH U	-
Electricity (for granulation)	0,48 kWh/kg	Electricity, medium voltage, production BE, at grid/BE U (amount taken from USLCI record 'recycled post-consumer PET pellet/RNA')	for 50% of recycled PVB output
Transport by bulk truck (100% loaded)	2x 20 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport to granulation plant and back, both fully loaded
Outputs	**Amount**	**Ecoinvent data record**	**Remark**
Recycled PVB	1 kg	Polyvinylchloride, at regional storage/RER U	Avoided PVC production
Waste	confidential	Disposal, inert waste, 5% water, to inert material landfill/CH U	PVB of inferior quality, glass, other waste

Table 9: LCI PVB recycling

5.5 Glass production

5.5.1 Process description

5.5.1.1 Glass types

According to the BREF on Manufacture of Glass[13], which was adopted in March 2012, the glass industry consists of 8 sectors:

1 Container glass
2 Flat glass
3 Continuous filament glass fiber
4 Domestic glass
5 Special glass (without water glass)
6 Mineral wool (with two divisions, glass wool and stone wool)
7 High temperature insulation wools (excluding polycrystalline wool)
8 Frits

The scope of this study considers three types of glass, which are produced in Belgium and make use of cullet that may originate from recycled ELV glazing: container glass, flat glass and foam glass. Foam glass is a very specific glass application which differs from mainstream glass in some of the raw materials and techniques used. The current distribution of recycled cullet between these three applications is presented in figure 8.

13 BREF, 2012: available on http://eippcb.jrc.es/reference/gls.html

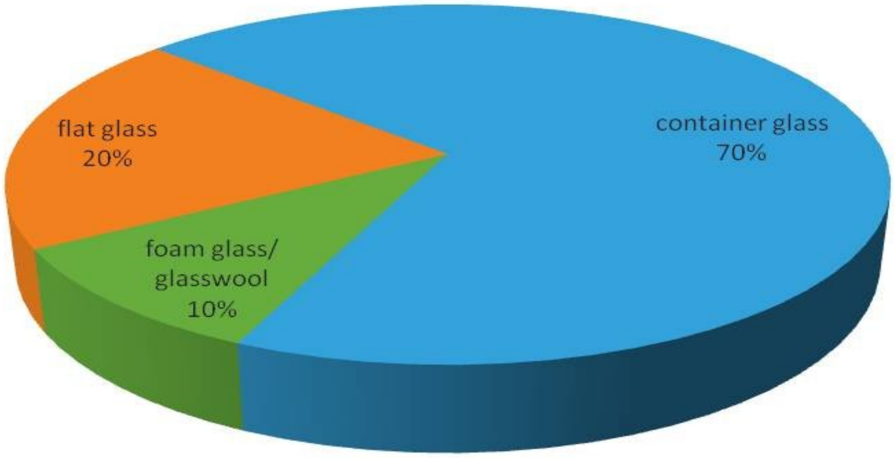

Figure 8: Current use of recycled cullet in the Belgian glass industry (source: glass recyclers Maltha, GRL)

In the following paragraphs, the glass production processes and specific characteristics of these 3 glass types are discussed. Recycled glass cullet has an important place in the production of new glass, providing several advantages. All technical information is based on the elaborate description of the glass industry in the BREF on Manufacture of Glass (2012).

5.5.1.2 Raw materials

The vast majority of industrially produced glasses have similar compositions and are collectively called soda-lime glasses. Soda-lime glass is used for bottles, jars, flacons, everyday tableware and window glass. A typical soda-lime glass composition consists of 71 – 75 % silicon dioxide (SiO_2, derived mainly from sand), 12 – 16 % sodium oxide (‘soda’ Na_2O from soda ash, Na_2CO_3), 10 – 15 % calcium oxide (CaO from limestone, $CaCO_3$) and low levels of other components aiming to give specific properties to the glass.

Sand (source of SiO2) is the most important raw material. As the melting point of sand is too high, a fluxing agent is needed to reduce the melting temperature. For this reason **soda ash (Na2CO3)** is typically used as main source of sodium oxide (Na2O), causing a release of carbon dioxide during melting. **Sodium sulphate** is added as a refining and oxidising agent and is a secondary source of sodium oxide, causing sulfur oxide emissions. Other metal oxides are added to the glass to reinforce the structural network. Calcium oxide (CaO) has this effect and is added to the glass as **calcium carbonate (CaCO3)** in the form of limestone or chalk. It can also be added as dolomite, which contains both calcium carbonate and magnesium carbonate (MgCO3). **Aluminium oxide (Al2O3)** is added to improve chemical resistance and to increase viscosity at lower temperatures. It is usually added as feldspar or alumina. An increasingly important raw material in glass making is **cullet** (broken glass). Both internal and external cullet can be used, as long as quality constraints are met.

5.5.1.3 Melting process

The central phase in the production of glass is the melting of the raw materials at high temperature to form a molten glass that serves as the base material for the further production process. The temperature necessary for melting the glass depends on the precise formulation, but is generally between 1250 and 1650 ºC. The batch material is continuously fed into the furnace and withdrawn in a molten condition.

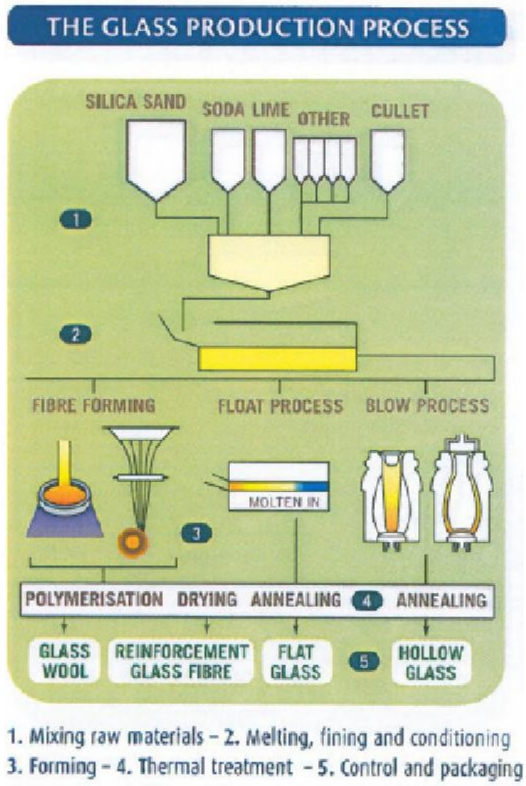

Figure 9: Glass production process (source: VGI)

Glass making is very energy-intensive. In general, the energy necessary for melting glass accounts for over 75 % of the total energy requirements of glass manufacture. The theoretical energy requirements for the melting of soda-lime glass from batch formulations without cullet recycling is 2,68 GJ/tonne. The calculation assumes all available heat is fully utilized and has three components:

— the heat of reaction to form the glass from the raw materials
— the heat required, enthalpy, to raise the glass temperature from 20 to about 1500 °C and
— the heat content of the gases (principally CO_2) released from the batch during melting.

The theoretical level only relate to the energy required to melt the glass formulations. The actual melting energy requirements experienced in the various sectors vary widely from about 3.3 to 7 GJ/tonne (Table 10). Additional energy will be required to refine, form and finish the glass, and for other ancillary services such as compressed air.

Sector	Furnace capacity	GJ/tonne melted glass (furnace energy consumption)	GJ/tonne finished product (total energy consumption)
Container glass (bottles and jars)	< 100 tonne/day	5,5 -7	< 7,7
Container glass (bottles and jars)	> 100 tonne/day	3,3-4,6	< 7,7
Flat glass	All capacities	5 - 7	< 8

Table 10: Energy consumption for glass melting (BREF, 2012)

The three main energy sources for glass making are natural gas, fuel oil and electricity. Combinations of these sources are also used. The choice of energy source determines the design of the furnace and is also an important factor affecting the environmental performance. Emissions of CO_2, SO_2 and NOx differ according to the energy source used.

5.5.1.4 Environmental issues

The majority of raw materials for the glass industry are naturally occurring minerals or inorganic substances. Most of the minerals used occur naturally in abundance and in general there are no major environmental issues associated with the provision of these materials.

The main environmental concerns for the glass industry as a whole are emissions to air and energy consumption. Upon melting, the raw materials decompose and release gases, particulates, as well as water vapor. In general, between 3 and 20 % of the batch weight may be emitted as gases. Emissions can vary greatly between sectors and between individual installations. The main factors are: inherent differences in the raw materials and products for each sector, the process selection (particularly the melter option), the process scale and the degree of abatement implemented. Where high levels of cullet are used, the figure will be at the lower end of this range.

Main pollutants from melting are:

— the products of fossil fuel combustion and the high-temperature oxidation of nitrogen in the combustion atmosphere (i.e. sulphur dioxide, carbon dioxide, and nitrogen oxides)

— particulate matter arising mainly from the volatilization and subsequent condensation of volatile batch materials

— gases emitted from the raw materials and melt during the melting processes, such as carbon dioxide, water vapor, and oxides of sulfur and nitrogen. The evolution of NO from the nitrates is essentially stoichiometric, i.e., all NO present in the nitrate is released in the furnace. Thus the amount of NO released depends on the nitrate content of the batch.[14]

5.5.1.5 Advantages of cullet use

Continued development within the sector has been the increased use of recycled glass (cullet).

The use of cullet has several environmental advantages: reduced energy requirements, reduced gaseous emissions, reduced raw material needs.

— The use of cullet can significantly **reduce energy consumption** as the endothermic chemical reactions associated with glass formation are already completed. As a general

14 EPA-453/R-94-037, Alternative Control Techniques Document NO Emissions from Glass Manufacturing, USEPA June 1994

rule, every 10 % increase in cullet usage results in an energy savings of 2 – 3 % in the melting process.

— Every 1 tonne of cullet replaces approximately 1.2 tonnes of **virgin raw material** in the batch formulation of most soda-lime-silica glasses.

— The melting of raw materials into glass emits gases from the glass matrix, which can account for between 3 and 20 % of the input mass. Because cullet has already been melted these **gas losses are reduced**. Moreover, its use helps to reduce the level of some of the volatile and reactive species, which contribute to dust formation, e.g. sodium chloride and batch sulphates. In addition, the reduction in fuel requirement due to the use of cullet, also reduces CO_2, NOx and SO_2 levels.

Type of glass	**Flat glass**	**Container glass**
Type of furnace	Float, regenerative, cross-fired	Regenerative, end-fired
Pull rate	600 tonnes/day	260 tonnes/day
Cullet use	25%	83%
Total energy consumption (GJ/tonne melted glass)	4,48 GJ/tonne	3,62 GJ/tonne

Table 11: Examples of energy consumption for the production of the most common industrial glass (BREF, 2012, table 3.7)

Economically spoken, the use of cullet generally results in significant cost savings as a result of the reduction in both energy and raw material requirements.

A distinction should be made between internal cullet (rejected glass from the production line) and external cullet (post-consumer glass from consumer or external industrial sources), which has a less well defined composition. Quality issues often limit the use of cullet in the batch formulation due to contamination. This is particularly the case for applications with high quality requirements. Especially the presence of ceramics, glass ceramics, metals, organic matter, etc. must be avoided or limited. Metallic impurities can cause serious refractory damage and shorten the furnace life. Metals, or metal droplets (particularly lead) accumulating at the refractory bottom of the melting furnace, will drill into the bottom material. In addition, metal contamination, the presence of lead crystal glass and reducing components in the cullet may cause defects in the glass. Ceramic inclusions will appear as ‘stones’ or knots, often with an opaque color, in the final product.

Contamination types	**Particle weight/size**	**Float (g/tonne)**	**Fiberglass (g/tonne)**	**Containers (g/tonne)**
Ferrous metals	> 0,5 g	None (2 if < 0,5 g)	65	50
Non-ferrous metals	> 0,1 g	None (0,5 if < 0,1 g)	24	20
Refractory materials	> 0,2 mm	None	250	20
Organic substances	> 2 g	None (45 if < 2 g)	120	3000

Table 12: Maximum permissible levels of the major contamination types usually found in cullet for float, containers and fiberglass (Glass for Europe, 2009)[15]

15 Glass for Europe, 2009. Brochure: Recycling end-of-life vehicle glazing

5.5.2 Container glass production

5.5.2.1 Process description

The container glass sector covers the production of glass packaging, i.e. bottles and jars.

Container glass is made from soda-lime glass. Where appropriate, coloring agents or other additives are added to the glass. The molten glass is formed into the products in a two-stage molding process. Firstly, the primary shape is formed in a first mold (blank mold) using compressed air (blow) or a metal plunger (press). Secondly, the primary shape is transferred into the final mold, where the shaping process is completed by blowing the container with compressed air to the shape of the final mold.

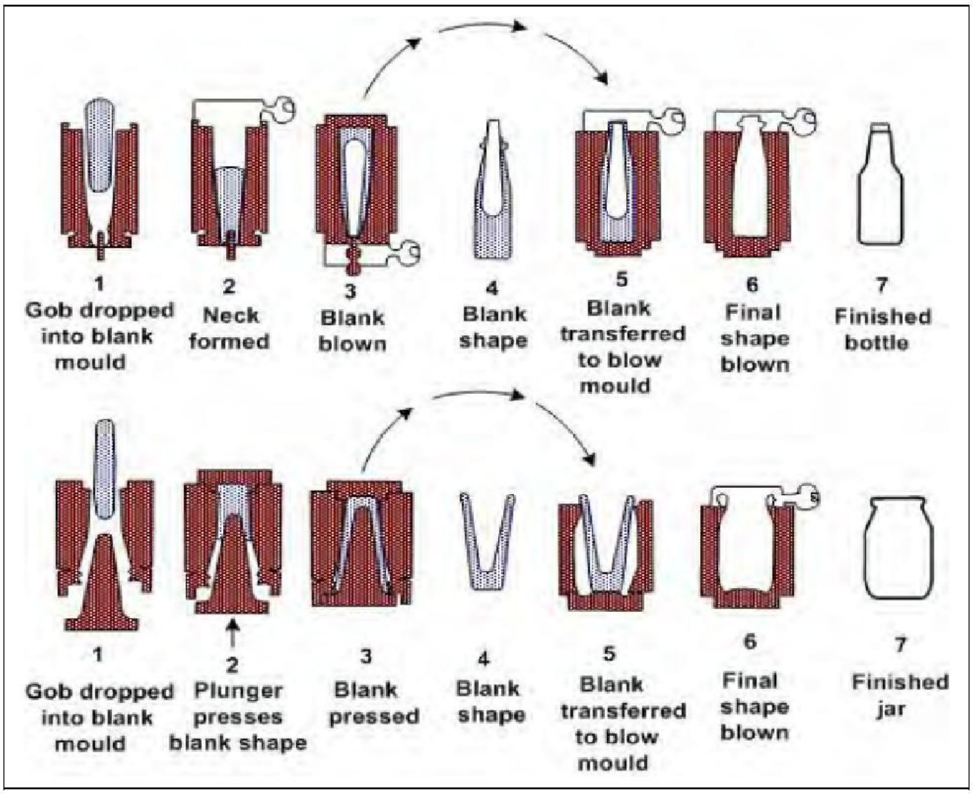

Figure 10: Container glass production (BREF, 2012, figure 2.5)

The largest inputs to the process are the silica-containing materials (sand and glass cullet) and the carbonates (soda ash, dolomite and limestone). Many container glass processes utilize a substantial level of glass cullet in the batch materials, with the EU sector average at approximately 50 %, made up of internal cullet and post-consumer cullet. Almost all processes will recycle their internal cullet which is usually around 10 % of the batch. The use of post-consumer cullet varies greatly (from 0 to >80 %, Table 13) and is limited in practice by the availability of cullet of suitable quality. For some colorless product types, post-consumer cullet may not be employed to a significant extent, due to colored glass impurities. In most cases, green glass is the least sensitive to such limitations and thus incorporates the highest cullet rates.

Cullet rate	Total cullet rate per furnace (% total cullet (intern+extern)/tonnes melted glass)		
	Mean	Min	Max
colorless	33	5	74
amber	49	15	81
green	72	30	96
other colors	55	20	85

Table 13: Statistical data on cullet use for the EU container glass furnaces, in relation to glass color, reported from the FEVE study in 2005 (BREF, 2012, table 3.12)

The type and size of the furnace, the energy source used and the amount of cullet used are important factors determining the melting energy consumption, as can be see in Figure 11. In this overview the energy consumption of all furnace types was corrected to a standard cullet use rate of 50% (EM50).

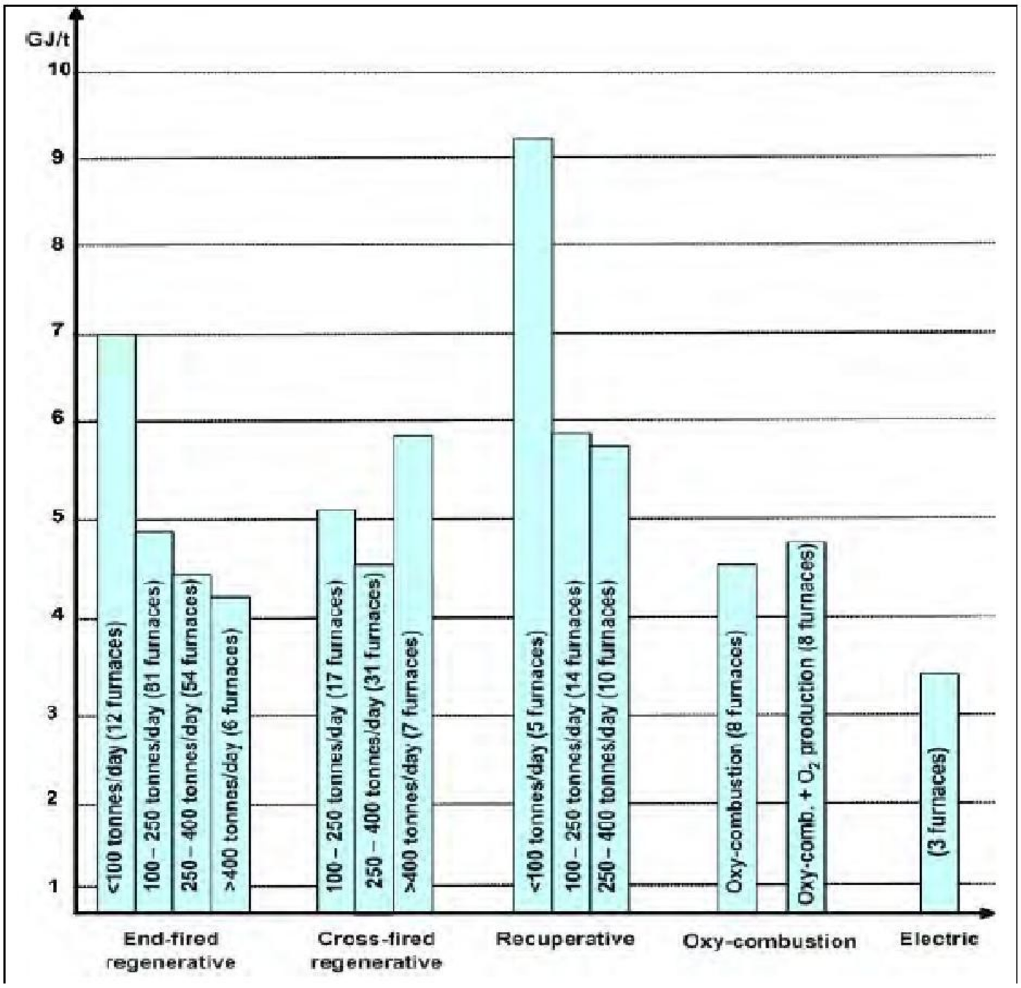

Figure 11: Mean energy consumption in glass container furnaces expressed in GJ/tonne melted glass and standardised to 50% cullet (2005) (BREF, 2012, figure 3.4)

In Belgium three container glass production plants are active. The Belgian plants use mainly furnaces based on natural gas (80%) and to a limited extent on electricity (20%) (data VGI, 2012).

Plant	Adress
Durobor	Rue Mademoiselle Hanicq 39, Soignies
MD Verre (Vidrala)	Rue des Ayettes 2, Ghlin
Gerresheimer	Rue Mandenne 19/20, Momignies

Table 14: Container glass production plants in Belgium

5.5.2.2 Cullet acceptance criteria

Acceptance criteria for cullet in container glass production are listen in Table 12.

An additional advantage of using recycled cullet originated from flat glass, such as automotive glass, is that it contains significantly lower lead concentrations than recycled container glass. Within the container glass recycling chain problems start to arise due to an increasing concentration of lead in recycled container glass. A dilution with cullet from flat glass helps to keep the lead levels in container glass below the European threshold value of 100 ppm (source: GRL).

5.5.2.3 Inventory data

In this study, the following assumptions are made for recycled automotive cullet use by the container glass industry:

— about 70% of cullet produced from automotive glass is used in container glass production
— the average distance from the glass recyclers to the container glass producers is calculated to be 169 km
— 80% of cullet transport for container glass production is done by road, 20% by boat (source: Maltha)

Input	Amount	Ecoinvent data record	Remark
Transport by bulk truck (100% loaded)	135 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	80%
Transport by boat (canal)	34 km	Operation, barge/RER U	20%

Table 15: LCI Transport of recycled cullet from glass recycler to container glass producer

The cullet use results in some important energy and raw material savings in the glass melting process. The following assumptions are made:

— glass melting for container glass production, without cullet use, uses 4,47 GJ/ton molten glass (calculated based on figures in table 3.7 from BREF)
— an additional use of 10% cullet generates an average saving in energy consumption for melting of 2,5%, which is 0,984 MJ/kg cullet used
— energy use in the Belgian container glass sector is based on 80% natural gas and 20% electricity (source: VGI)
— the use of 1 kg cullet saves 1,2 kg of raw materials. It is assumed that this saving is proportionally with the raw material composition in the production batch (as taken from EcoInvent record 'Packaging glass, white, at plant/RER U')
— the saving of raw materials also implies a saving in raw material transport to the production plant, estimated as 120 kgkm (transport of 1,2 kg over a distance of 100 km)
— a reduction of 0,18 kg of CO2 emission from the vitrification reaction, per kg cullet (GTS[16])

16 GTS, 2004. Carbon Trust/GTS study proves the benefits of using recycled glass. Available from: http://www.glass-ts.com/News/PressArchive/PressReleases6.html

Input	Amount	Ecoinvent data record	Remark
Electricity	0,1969 MJ	Electricity, medium voltage, production BE, at grid/BE U	20% of the energy input
Natural gas (burned)	0,7875 MJ	Natural gas, burned in industrial furnace low-NOx >100kW RER/U	80% of the energy input
Silica sand	0,6805 kg	Silica sand, at plant/DE U	57%
Dolomite	0,1446 kg	Dolomite, at plant/RER U	12%
Limestone	0,1139 kg	Limestone, milled, loose, at plant/CH U	9%
Feldspar	0,0620 kg	Feldspar, at plant/RER S	5%
Soda	0,1989 kg	Soda, powder, at plant/RER U	17%
Transport by bulk truck (100% loaded)	60 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport of raw materials, estimation
Transport by boat	60 km	Operation, barge/RER	Transport of silica sand, mainly by boat
Output	**Amount**	**Ecoinvent data record**	**Remark**
CO2 emissions	0,18 kg	Carbon dioxide, fossil	From vitrification reaction
Other emissions	-	-	Emissions, other than those from energy-related sources, are not considered due to lack of data

Table 16: LCI Savings by using 1 kg of cullet in container glass production

5.5.3 Flat glass

5.5.3.1 Process description

Flat glass is the second largest sector of the glass industry in the EU-27, representing around 29 % in 2007. The production of float glass generates 95 % of the flat glass output and is used principally in the building (75-85%) and automotive industries (15-25%). The majority of flat glass production is processed into other products, such as laminated windscreens, side and rear glazings, and sunroofs for the automotive industry and double or triple glazed units for the building industry. Demand for flat glass is particularly sensitive to economic cycles because it is heavily dependent on the building and automotive industries.

The basic principle of the float process is to pour the molten glass onto a bath of molten tin. Inside the float tank are several pairs of water-cooled rollers, that catch the glass sheet on both edges and draw it in length and width. The rate of glass flow and the rotation speeds of the rollers help to govern the thickness of the glass, typically from 1.5 to 19 mm. The edges of the glass ribbon that bear roller marks are cut off and recycled to the furnace as internal cullet.

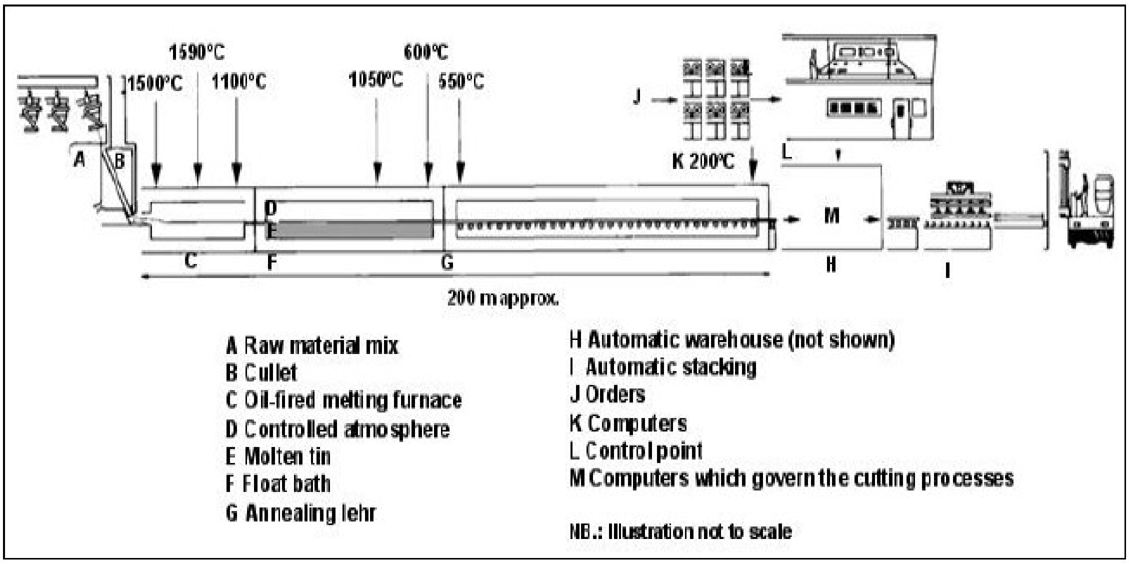

Figure 12: Float glass production process (source: BREF)

The largest inputs to the process are the materials containing silica (sand and glass cullet) and the carbonates (soda ash, dolomite and limestone). In typical float glass compositions, the oxides of silicon, sodium, calcium and magnesium account for around 98 % of the glass (SiO_2: 72.6 %, Na_2O: 13.6 %, CaO: 8.6 %, and MgO: 4.1 %).

Flat glass plants typically recycle all internal cullet directly into the furnace. Also, internal cullet coming from further transformation into laminated glass for building or automotive applications is also recycled in many cases. The total cullet introduced in the furnace is typically around 20 % but can range from 10 to 40 % for a float furnace, and to over 80 % for other types of flat glass. The amount of recycled cullet is generally limited by the availability of cullet of the correct quality and chemical compatibility. Slightly contaminated cullet can be used by manufacturers of other types of glass products.

In the flat glass sector, the greatest potential environmental emissions are emissions to air from the melting activities. Within the EU-27 installations, energy levels for melting are typically between 5.2 and 8.7 GJ/tonne of melted glass, mainly depending on the size and age of the installation, with an average value of 7.5 GJ/tonne of glass.

In Belgium five flat glass production plants are active. The Belgian plants use mainly furnaces based on fossil fuel (60%), natural gas (31%) and to a limited extent on electricity (8%) (data VGI, 2012).

Plant	Adress
AGC Glass Europe	Rue de la Glacerie 167, Moustier-sur-Sambre
AGC Glass Europe	Rue de Gosselies 60, Roux (Charleroi)
AGC Glass Europe	Voortstraat 27, Mol
Saint Gobain Glass Benelux	Rue des Glaces Nationales 169, Auvelais
Ducatt	Balendijk 161, Lommel

Table 17: Flat glass production plants in Belgium

5.5.3.2 Cullet acceptance criteria

Acceptance criteria for cullet in flat glass production are listed in Table 12.

5.5.3.3 Inventory data

In this study, the following assumptions are made for recycled automotive cullet use by the float glass industry:

- about 10% of cullet produced from automotive glass is used in flat glass production (float process is considered, as it delivers 95% of flat glass (BREF, 2012))
- the average distance from the glass recyclers to the container glass producers is calculated as to be 89 km
- 100% of cullet transport for container glass production is done by road (source: Maltha)

Input	Amount	Ecoinvent data record	Remark
Transport by bulk truck (100% loaded)	89 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	100%

Table 18: LCI Transport of recycled cullet from glass recycler to float glass producer

The cullet use results in some important energy and raw material savings in the glass melting process. The following assumptions are made:

- glass melting for float glass production, without cullet use, uses 6,90 GJ/ton molten glass (calculated based on figures in table 3.7 from BREF)
- an additional use of 10% cullet generates an average saving in energy consumption for melting of 2,5%, which is 1,486 MJ/kg cullet used
- energy use in the Belgian float glass sector is based on 60% heavy fuel oil, 32% natural gas and 8% electricity (InDUFed)
- the use of 1 kg cullet saves 1,2 kg of raw materials. It is assumed that this saving is proportionally with the raw material composition in the production batch (as taken from EcoInvent record 'Flat glass, uncoated, at plant/RER U')
- the saving of raw materials also implies a saving in raw material transport to the production plant, estimated as 120 kgkm (transport of 1,2 kg over a distance of 100 km)
- a reduction of 0,18 kg of CO_2 emission from the vitrification reaction, per kg cullet (GTS[17])

17 GTS, 2004. Carbon Trust/GTS study proves the benefits of using recycled glass. Available from: http://www.glass-ts.com/News/PressArchive/PressReleases6.html

Input	Amount	Ecoinvent data record	Remark
Electricity	0,1189 MJ	Electricity, medium voltage, production BE, at grid	8% of energy supply (VGI)
Natural gas (burned)	0,4844 MJ	Natural gas, burned in industrial furnace low-NOx >100kW RER/U	32% of energy supply (VGI)
Heavy fuel oil (burned)	0,9083 MJ	Heavy fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	60% of energy supply (VGI)
Silica sand	0,576 kg	Silica sand, at plant/DE U	48% of raw material input, according to Flat glass, uncoated, at plant/RER U
Limestone	0,396 kg	Limestone, milled, packed, at plant/CH U	33% of raw material input
Soda	0,229 kg	Soda, powder, at plant/RER U	19% of raw material input
Transport by bulk truck (100% loaded)	60 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport of raw materials, estimation
Transport by boat	60 km	Operation, barge/RER	Transport of silica sand, mainly by boat
Output	**Amount**	**Ecoinvent data record**	**Remark**
CO2 emissions	0,18 kg	Carbon dioxide, fossil	From vitrification reaction
Other emissions	-	-	Emissions, other than those from energy-related sources, are not considered due to lack of data

Table 19: LCI Savings by using 1 kg cullet in flat glass production

5.5.4 Foam glass

5.5.4.1 Process description

Cellular glass or Foamglas® is made by melting recycled glass cullet, sand, dolomite, chalc, feldspar, iron oxide, internal cullet (production waste) and some other raw materials in a furnace at a temperature of about 1250°C. The molten glass is cooled down and ground into a fine powder. The glass powder is mixed with internal production waste (trimmings,...) a small amount of carbon and poured into a mold. In a furnace at 850°C the carbon reacts with chemically bound oxygen within the glass matrix. This reaction produces CO2 and causes the glass to expand into a low-density foam structure, which has excellent insulation properties. Finally, the blocks are cut into the desired size and sold as insulation material in the building industry (website Foamglas).

In Belgium one foam glass production plant is active. It uses electric furnaces with a backup of natural gas. A material batch consists of about 20% internal cullet (production waste) and 30% external cullet, coming from glass recycling. In addition, 10% of internal cullet (production waste) is added after grinding. Main motivation for the use of cullet is the advantage of energy reduction. Recycled automotive glass is preferred for its very stable chemical composition, a factor that is very important for the foam formation process.

Plant	Adress
Pittsburgh Corning Foamglas	Albertkade 1, Tessenderlo

Table 20: Foam glass production plants in Belgium

5.5.4.2 Cullet acceptance criteria

Cullet use in foamglass production is limited by the chemical composition of the cullet. The concentration of earth metal oxides (Ca, Mg, Ba) in the production batch should about 5%, while external cullet typically contains about 12% of these oxides. In addition, contamination by elements such as Pb and As is strictly regulated. The color of the recycled cullet or the presence of small stones is not an issue. (data Pittsburgh Corning (Foamglas), 2013).

5.5.4.3 Inventory data

In this study, the following assumptions are made for recycled automotive cullet use by the foam glass industry:

- about 20% of cullet produced from automotive glass is used in foam glass production
- the average distance from the glass recyclers to the container glass producers is calculated as to be 25 km
- all road transport

Input	Amount	Ecoinvent data record	Remark
Transport by bulk truck (100% loaded)	25 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	100%
Transport by boat (canal)	-	Operation, barge/RER U	0%
Transport by train	-	Operation, freight train/BE U	0%

Table 21: LCI Transport of recycled cullet from glass recycler to foam glass producer

The cullet use results in some important energy and raw material savings in the glass melting process. The following assumptions are made:

- glass melting for float glass production, without cullet use, uses 3,5 GJ/ton molten glass (calculated based on figures from Pittsburgh Corning)
- an additional use of 10% cullet generates an average saving in energy consumption for melting of 2,5%
- energy use in the Belgian foam glass production (PC) is based mainly on electricity, with a backing of natural gas (PC)
- the use of 1 kg cullet saves 1,2 kg of raw materials. (Exact figures from PC)
- the saving of raw materials also implies a saving in raw material transport to the production plant, estimated as 120 kgkm (transport of 1,2 kg over a distance of 100 km)
- a reduction of 0,18 kg of CO2 emission from the vitrification reaction, per kg cullet (GTS[18])

18 GTS, 2004. Carbon Trust/GTS study proves the benefits of using recycled glass. Available from: http://www.glass-ts.com/News/PressArchive/PressReleases6.html

Input	Amount	Ecoinvent data record	Remark
Electricity	0,5343 MJ	Electricity, medium voltage, at grid/BE U	-
Natural gas (burned)	0,2234 MJ	Natural gas, burned in industrial furnace low-NOx >100kW/RER U	-
Silica sand	0,579 kg	Silica sand, at plant/DE U	-
Dolomite	0,206 kg	Dolomite, at plant/RER U	-
Feldspar	0,028 kg	Feldspar, at plant/RER S	-
Soda	0,187 kg	Soda, powder, at plant/RER U	-
Transport by bulk truck (100% loaded)	120 km	see Table 3: Life Cycle Inventory (LCI) of transport operations	Transport of raw materials, estimation
Output	**Amount**	**Ecoinvent data record**	**Remark**
CO2 emissions	0,18 kg	Carbon dioxide, fossil	From vitrification reaction
Other emissions	-	-	Emissions, other than those from energy-related sources, are not considered due to lack of data

Table 22: LCI Savings by using 1 kg of cullet in foam glass production

5.5.5 Glass wool

5.5.5.1 Process description

The mineral wool sector represents approximately 10% of the total output tonnage of the glass industry. The sector covers the production of glass wool and stone wool insulating materials, which are made of randomly interlaced masses of fibre, bound by a resin-based binder. The most important market for mineral wool is the building industry, which takes up to 70 % of output and is very dependent on the prevailing economic climate and on the regulatory framework.

Mineral wool manufacture consists of the following stages: raw material preparation, melting, fiberisation of the melt, binder application, product mat formation, curing, cooling, and finishing.

The basic raw materials for glass wool manufacture include sand, soda ash, dolomite, limestone, sodium sulphate, sodium nitrate, and minerals containing boron and alumina. Most processes also use internal process cullet as a raw material. External cullet, e.g. container glass and flat glass are also extensively used as a feedstock. One limiting factor in the use of cullet as a raw material is represented by glass-ceramics.

A stream of molten glass flows from the furnace and pours through a number (usually one to ten) of single orifice bushings into specially designed rotary centrifugal spinners. Primary fiberising takes place by means of centrifugal action of the rotating spinner with further attenuation by hot flame gases from a circular burner. This forms a veil of fibers with a range of lengths and diameters randomly interlaced. The veil passes through a ring of binder sprays that release a solution of phenolic resin-based binder and mineral oil onto the fibers to provide integrity, resilience, durability and handling quality to the finished product. The resin-coated fiber is drawn under suction onto a moving conveyor to form a mattress of fibers. This mattress passes through a gas-fired oven at approximately 250 °C, which dries the product and cures the binder. The product is then air-cooled and cut to size before packaging.

The chemical composition of mineral wool can vary widely, and is conventionally expressed in terms of the oxides of the elements it contains. It is difficult to identify a 'typical' batch composition for any of the main types of mineral wool, i.e. glass wool, stone wool or slag wool. The basic raw materials are selected and blended to give the final desired glass compositions. The percentage of each raw material in the batch can vary significantly, particularly where substantial amounts of recycled materials are used. Recycled cullet (soda-lime-silica flat and container glass) is extensively used as a sources of silicon dioxide for the production of glass wool (up to 90% cullet can be used).

Glass wool furnaces are predominantly air-gas-fired (usually with an electric boost), but with a substantial number of electrically-heated furnaces and a smaller number of oxy-gas-fired furnaces. Direct energy consumption for electrical melting is in the range of 2.7 to 5.5 GJ/tonne finished product. When a significant percentage of external cullet is used, this has a consequent high influence on the furnace energy consumption.

Plant	Adress
Knauf Insulation	Rue de Maestricht 95, Visé

Table 23: Glass wool production plants in Belgium

5.5.5.2 Inventory data

Glass wool is not considered in the environmental modeling due to incomplete data. However, as currently only a limited fraction (<10%) of the recycled cullet in Belgium is used in glass wool production, this has no significant impact on the results and conclusions of this study.

5.5.6 Fiberglass

5.5.6.1 Process description

Although glass wool and fiberglass are often mentioned in similar contexts, there is a difference between them.

Fiberglass is a composite polymer reinforced by extremely fine glass fibers. It is a light weight, extremely strong and robust material. Although the general production process is similar to glass wool, fiberglass fibers are different to the type used in glass wool, as they need to have surfaces that are almost entirely free of defects, in order to produce a strong structure.

Fiberglass is used in wind turbine blades, high end bicycles, kayaks and surfboards, body parts for automobiles, etc.

Acceptance criteria for cullet in fiberglass production are listen in Table 12. However, the Belgian fiberglass producer 3B does not make use of cullet in its process.

Plant	Adress
3B Fibreglas	Rue de Maestricht 67, Battice

Table 24: Fiberglass production plants in Belgium

5.5.6.2 Inventory data

Fiberglass is not considered in the environmental modeling as the Belgian fiberglass producer does not use cullet in his process.

6 Life Cycle Impact assessment

6.1 Introduction

The inventory process generates a long list of data, which may be difficult to interpret. Life cycle impact assessment (LCIA) is a tool to relate the large number of inventory values to a smaller number of environmental themes (environmental impact categories) so that the outcome of the assessment is more convenient. It is important to note that the inventory results generally do not include spatial, temporal, dose-response or threshold information. Therefore, impact assessment cannot and is not intended to identify or predict *actual* environmental impacts. Instead, the impact assessment predicts *potential* environmental damages (impacts) related to the system under study.

This chapter describes the approach, the methodology and the results of the life cycle impact assessment of **treatment of 1 kg of glass in a depolluted ELV**, for both recycling routes separately, starting at the ELV depollution center, until the reapplication of the recycled materials. In the next chapter 7 , both recycling routes will be combined into several recycling scenarios. There, the life cycle impacts will be calculated for the **treatment of the glass in an average ELV**.

6.2 LCIA methodology

The life cycle impact assessment (LCIA) phase of the LCA involves associating inventory data with specific environmental impacts and attempting to understand those impacts. The level of detail, the choice of impacts evaluated and the methodology depend on the goal and scope of the study. LCAs do not represent a complete picture of the environmental impact of a system. They represent a picture of those aspects that can be quantified. Any judgments that are based on the interpretation of LCI data must bear in mind this limitation and, if necessary, obtain additional environmental information from other sources (hygienic aspects, risk assessment, etc.). The LCIA results are relative expressions and do not predict impacts on category endpoints, exceeding of thresholds, safety margins or risks.

Various methods are in use to assess the environmental impacts of products and systems. For this study the environmental impact categories defined by the ReCiPe Midpoint (H) V1.07 method are considered, using the LCA software package SimaPro 7.3.3 [1]. We refer to Table 1 (paragraph 2.2.4) for the summary tables with all environmental impact categories and to paragraph 6.2.1 for a brief discussion of each impact category.

In discussing the results of the comparison the following rule-of-thumb is used to determine whether any difference is significant:

- 20% difference: for impact categories that have sufficient scientific basis e.g. fossil depletion and contribution to the greenhouse effect;
- 30% difference: for impact categories for which the methodology is not fully supported or which is incomplete e.g. human toxicity, ecotoxicity, acidification, and eutrophication.

Next paragraphs show and discuss the individual environmental profiles of the recycling routes for automotive glass. This allows getting a clear insight in those life cycle stages and processes that contribute the most to the environmental burden, from the gate to the grave.

During impact assessment, the input and output data of the inventory phase are aggregated into environmental impact categories. The use of raw materials, energy consumption, emissions and waste are converted into a contribution to environmental impact categories. The result of the impact assessment is a figure or table in which the environmental themes (environmental impact categories) are presented, describing the environmental profile of the selected functional unit.

The scope of this study focuses on different recycling routes for the ELV glass using the functional unit “the recycling of 1 kg of glass in a depolluted ELV”. It is assumed that the treatment of the rest of the ELV carcass (glass excluded) remains the same regardless of the choice of glass treatment. Therefor, the treatment of the ELV carcass is omitted from the analysis. This calculation approach is called **'streamlining'** and the result is a “**streamlined LCA**” which only shows the **glass-related environmental impacts**.

6.2.1 Impact categories

6.2.1.1 Climate change

Climate change is a measure of greenhouse gas emissions, such as CO_2 and methane. These emissions cause an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect. This environmental impact category is expressed in kg carbon dioxide (CO_2) equivalents, an indicator for the global warming potential of the greenhouse gas emissions.

6.2.1.2 Ozone depletion

Ozone layer depletion is a measure of a substance's ability to destroy stratospheric ozone, based on its atmospheric life time, stability, reactivity and content of elements that can attack ozone, such as chlorine and bromide. Stratospheric ozone depletion refers to the thinning of the stratospheric ozone layer as a result of anthropogenic emissions. This causes a greater fraction of solar UV-B radiation to reach the earth’s surface, with potentially harmful impacts on human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials. This environmental impact category is expressed as kg trichlorofluoromethane (CFC-11) equivalents.

6.2.1.3 Terrestrial acidification

Terrestrial acidification is a measure of emissions that cause acidifying effects to the environment. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials (buildings). The major acidifying pollutants are SO_2, NO_x and NH_x. This environmental impact category is expressed as kg sulphur dioxide (SO_2) equivalents, an indicator for the acidification potential of emissions.

6.2.1.4 Freshwater and marine eutrophication

Eutrophication covers all potential impacts of excessively high environmental levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In addition, high nutrient concentrations may also render surface waters unacceptable as a source of drinking water. In aquatic ecosystems increased biomass production may lead to a depressed oxygen level, because of the additional consumption of oxygen in biomass decomposition. This environmental impact category is expressed as kg phosphate (PO_4^{3-}) equivalents, an indicator for the eutrophication potential of emissions.

6.2.1.5 Human toxicity

Human toxicity covers a number of different effects, such as acute toxicity, irritation and corrosive effects, allergenic effects, irreversible damage and organ damage, carcinogenic effects, and neurotoxicity. This environmental impact category is expressed as kg 1,4-dichlorobenzene equivalents.

6.2.1.6 Photochemical oxidation

Photochemical oxidation is a measure of emissions of precursors that contributes to low level smog, produced by the reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) under the influence of UV-light. Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health and ecosystems and may also damage crops. This environmental impact category is expressed as kg ethene (C_2H_4) equivalents.

6.2.1.7 Particulate matter formation

Particulate matter is a mixture of particles of variable composition and size in the air. These particles are considered some of the main air pollutants that cause adverse health effects. The increased incidence of respiratory symptoms, cardiovascular and respiratory symptoms and early mortality are associated with them. Particulate matter formation is expressed as kg PM10 equivalents, the fraction of particles with an aerodynamic diameter of less than 10 microns.

6.2.1.8 Terrestrial, freshwater and marine ecotoxicity

These impact categories cover emissions to air, water or soil that (eventually) cause damage to terrestrial, freshwater or marine ecosystems, respectively. This is expressed in 1,4-dichlorobenzene equivalents.

6.2.1.9 Ionizing radiation

Ionizing radiation may cause damages to cells. The impact in this category is mostly related to electricity generation in nuclear power plants. Ionizing radiation is expressed in kg uranium-235 (U235) equivalents.

6.2.1.10 Agricultural land occupation

Occupation of an area for agriculture (crops, pasture, forest) over time can cause damage to ecosystems. This is expressed in square meters per year.

6.2.1.11 Urban land occupation

Occupation of an area for urban infrastructure (roads, buildings, landfills, ...) for a certain time can cause damage to ecosystems. This is expressed in square meters per year.

6.2.1.12 Natural land transformation

Natural land transformation (expressed in m^2) takes into account the land that is transformed from one state to the other, namely from land use type X to land use type Y. Land use type X and Y can be defined as natural land or non-natural land.

6.2.1.13 Water depletion

Desiccation (disruption of the water content and cycles of the aquifers) may be due to human activities. Water depletion is indicated as the amount of cubic meters of water used.

6.2.1.14 Metal depletion

Metal depletion is the decrease of availability of metals, due to the use beyond their rate of replacement. Metal depletion is expressed as kg Fe equivalents used.

6.2.1.15 Fossil depletion

Fossil resource depletion is the decrease of availability of the total reserve of potential functions of fossil fuel resources, due to the use beyond their rate of replacement. Fossil depletion is expressed as kg oil equivalents.

6.2.2 Illustration of real world impacts

In order to have a reference base, Table 25 and Table 26 indicate for each impact category:

- the amount of an everyday consumer product (typically contributing to this impact) that generates one unit of impact;
- the percentage of the production of an average car (VW Golf A4) that contributes one unit of impact to this category.

These illustrative values give guidance for interpreting the environmental profiles presented and discussed in the course of this report and allow to assess the importance of the contribution of the ELV glass treatment routes and scenario's.

Everyday consumption	Ecoinvent record used	Short description
1 km driving (average car)	Operation, passenger car/RER U	The operation of an average passenger car in Europe in the year 2005. Included are the consumption of fuel (diesel and petrol), direct airborne emissions of gaseous substances, particulates and heavy metals . Emissions comprise exhaust- and abrasions emissions to air, soil and water.
1 kg steel production	Steel, low-alloyed, at plant/RER U	Low-alloyed steel production. Mix of differently produced steels (both primary and secondary), representing the average of the World and European production mix, and hot rolling. Data relate to plants in the EU.
1 kg diesel production	Diesel, low-sulphur, at regional storage/RER U	Production of low-sulfur diesel (sulfur content < 50 ppm) and distribution at regional storage. Included are crude oil extraction, transport, refining and distribution of the product from the refinery to the final consumer (household, car, power plant, etc.). Estimation for the European situation.
1 kg biodiesel production	Rape methyl ester, production RER, at service station/CH U	Production of European rape methyl ester (RME) and distribution at service stations in Switzerland. Included are the production of rape seed, transport, oil extraction, esterification of oil, distribution from esterification plants in Europe (Germany, France, Austria, Italy, Czech Republic) to Switzerland, and distribution to the end user.
1 average car production	Passenger car/RER/I U	Production of a modern European car. The inventory values refer to the production of one Golf A4. Included are material, energy and water use and rail and road transport of materials. Plant infrastructure is also taken into account; addressing issues such as land use, building, road and parking construction.

Table 25: Reference Ecoinvent 2.0 records of everyday consumption items

Impact category	Unit	Comparison with everyday consumption	Comparison with production average car
Climate change	1 kg CO_2 eq.	4,2 km driving	0,02%
Ozone depletion	1E-07 kg CFC-11 eq.	1,3 kg steel production	0,04%
Terrestrial acidification	1E-02 kg SO_2 eq.	1,8 kg diesel production	0,04%
Freshwater eutrophication	1E-03 kg P eq.	1,5 kg biodiesel production	0,03%
Marine eutrophication	1E-04 kg N eq.	1,0 kg diesel production	0,01%
Human toxicity	1 kg 1,4-DB eq.	0,7 kg steel production	0,03%
Photochemical oxidation	1E-03 kg NMVOC	0,9 km driving	0,01%
Particulate matter formation	1E-03 kg PM10 eq.	3,8 km driving	0,01%
Terrestrial ecotoxicity	1E-04 kg 1,4-DB eq.	0,4 kg steel production	0,02%
Freshwater ecotoxicity	1E-02 kg 1,4-DB eq.	0,2 kg steel production	0,01%
Marine ecotoxicity	1E-02 kg 1,4-DB eq.	0,2 kg steel production	0,01%
Ionizing radiation	1E-01 kg U^{235} eq.	0,3 kg steel production	0,01%
Agricultural land occupation	1E-01 m²a	0,02 kg biodiesel production	0,10%
Urban land occupation	1E-02 m²a	0,1 kg biodiesel production	0,02%
Natural land transformation	1E-04 m²	0,2 kg biodiesel production	0,01%
Water depletion	1E-01 m³	8,4 kg biodiesel production	0,26%
Metal depletion	1E-01 kg Fe eq.	0,03 kg steel production	0,005%
Fossil depletion	1 kg oil eq.	0,8 kg diesel production	0,07%

Table 26: Illustration of 'real world impacts', as a reference for each impact category

6.3 Environmental profile of ELV glass recycling by shredding (route 1)

6.3.1 Results

Figure 13 presents the individual environmental profile for the treatment of 1 kg glass in an ELV, by shredding and PST, calculated with the ReCiPe impact assessment method. As all window types are treated in the same way in this process, there is no need to differentiate between different window types (windscreen, rear window, side windows), so the calculation is made for an 'average' kg of ELV glass.

The environmental profile shows the contribution of the various process steps in the life cycle, from the gate to the grave, per environmental impact category. Process steps that represent an environmental burden (e.g. energy use) are shown as a positive contribution to the overall environmental impact, while process steps that represent an environmental benefit (e.g. production of recycled materials that avoid primary material production) are represented as a negative contribution. For each impact category, the largest contribution (either positive or negative) of the recycling route is always set at 100% and the relative contributions of the various processing phases are visible.

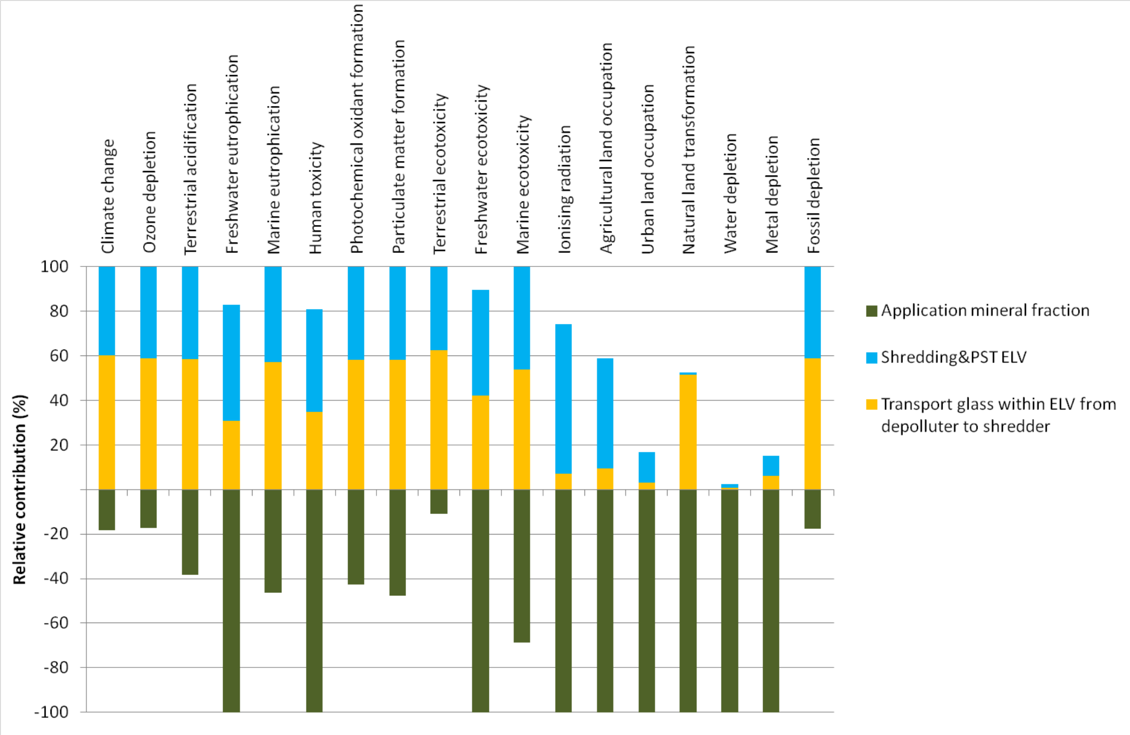

Figure 13: Environmental profile for the treatment of 1 kg ELV glass in route 1 (shredding & PST), per process stage

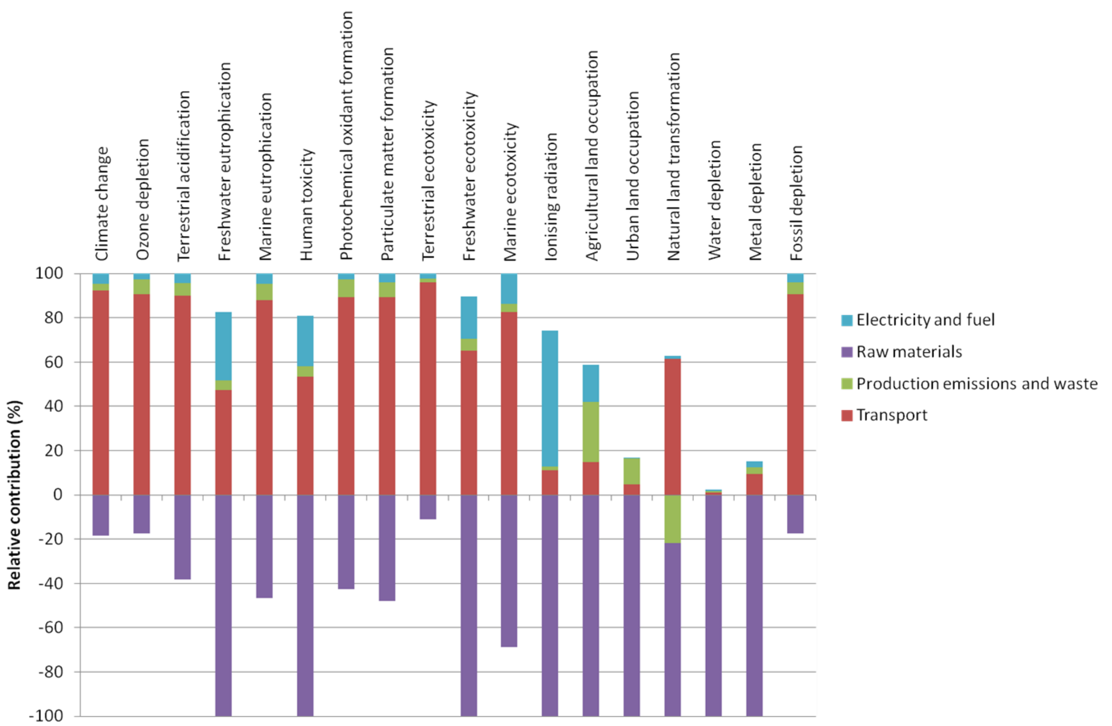

Figure 14: Environmental profile of the treatment of 1 kg ELV glass in route 1 (shredding & PST), per process type

Figure 14 shows a different representation of the same environmental profile as in Figure 13, but instead of showing the relative contributions of each process stage, a differentiation is made between 4 different impact-generating process input and output types: energy and fuel, raw materials, production emissions and waste and transport. For each process type, the net contribution to each impact category is visualized.

The numerical values of the total net environmental impact of route 1, per kg ELV glass treated, can be found in Table 27.

environmental impacts per kg recycled ELV glass		
Impact category	**Unit**	**Route 1**
Climate change	kg CO2 eq	0,010
Ozone depletion	kg CFC-11 eq	1,3E-09
Terrestrial acidification	kg SO2 eq	2,4E-05
Freshwater eutrophication	kg P eq	-1,1E-07
Marine eutrophication	kg N eq	9,5E-07
Human toxicity	kg 1,4-DB eq	-1,4E-04
Photochemical oxidant formation	kg NMVOC	2,8E-05
Particulate matter formation	kg PM10 eq	7,9E-06
Terrestrial ecotoxicity	kg 1,4-DB eq	2,1E-06
Freshwater ecotoxicity	kg 1,4-DB eq	-1,6E-06
Marine ecotoxicity	kg 1,4-DB eq	7,3E-06
Ionising radiation	kg U235 eq	-5,0E-04
Agricultural land occupation	m2a	-1,9E-05
Urban land occupation	m2a	-3,5E-04
Natural land transformation	m2	-3,4E-06
Water depletion	m3	-0,0013
Metal depletion	kg Fe eq	-3,7E-04
Fossil depletion	kg oil eq	0,0034

Table 27: Environmnetal impacts per kg recycled ELV glass by shredding (route 1)

6.3.2 Discussion

Figure 13 demonstrates that recycling of ELV glass, by shredding, PST and mineral fraction production, has a net environmental benefit in half of the impact categories, while causing a net environmental burden in the other categories. In short:

- The **environmental burdens** are mainly caused, to a more or less equal extent, by the transport between depollution center and shredder, and the shredding and PST processes.
- The **environmental benefits** are linked to the reapplication of the mineral fraction (which contains the glass) as a secondary building material, avoiding the mining of primary building sand.

From Figure 14, it can be understood that the main environmental burdens are actually related to **transports** within and across process stages: external transport from depollution center to shredder and internal transport between shredder and off-site PST. Transport burdens are due to diesel combustion emissions during operation and to the diesel production itself, while their relative importance changes between impact categories. The **electricity use** and **emissions (waste)** of the PST process itself contribute to a lesser extent and are typically due to emissions occuring during electricity production (ionising radiation, freshwater eutrofication) and its supply chain (extraction and production of oil and gas, contributing to human, freshwater and marine toxicity) and to the disposal of waste from the PST (5% glass is assumed not to end up in the mineral fraction) (agricultural and urban land occupation).

All environmental benefits are related to **raw material savings**, more specifically: avoided sand mining. For most impact categories, the impacts of sand mining are mainly due to diesel consumption of the excavation machines (>50% of contribution), and to a lesser extent to the use of electricity. The mine site and its surrounding infrastructure mainly poses environmental impacts in the categories on urban land occupation and transformation. Impacts in categories related to (eco)toxicity are mainly due to electricity consumption. All these impacts of sand mining are avoided when the recycled glass is reapplied as a building material.

6.3.3 Sensitivity analysis: landfilling of mineral fraction

When windows are shredded together with the ELV (as described in route 1), the glass ends up in a mineral fraction. However, a shredder installation only processes about 30% of ELV in an input batch. The rest of the input is mainly made up of industrial and building scrap and white goods, such as washing machines. These other waste streams contain a significant amount of concrete and stones, which after PST also are recovered in the mineral fraction. On average, the resulting mineral fraction contains about 25% glass and meets the Flemish criteria to be certified as a secondary building material.

However, the presence of the glass is important. If (e.g. due to a more intensive dismantling) the amount of glass that ends up in the mineral fraction would decrease significantly (< 20%), compliance to the Flemish criteria might no longer be possible and the total mineral fraction would have to be sent to landfill (source: Galloo).

As the scope of this study only includes the treatment of ELV glass, the concrete and stones that originate from a different source (washing machines) are not considered in the scope. This makes it impossible to allocate environmental burdens of the landfilling of non-ELV waste to the environmental impacts related to glass treatment. The inclusion of the landfilling option would require fundamental modeling changes (elaborate system expansion or full consequential modeling), that do not correspond with the original goal and scope of the study.

However, in order to provide a guiding figure on the environmental impacts of the landfilling of concrete, this landfilling process is modeled separately.

The following assumptions are made for the landfilling:

- the presence of a significant amount of glass (20-25%) is necessary for the use as secondary building material (compliance with conditions in the certificate)
- when insufficient glass is present (<20%), the full mineral fraction (80% concrete, 20% glass) has to be sent to landfill
- transport to the landfill site is not considered in the impact calculation
- the waste is assumed to be inert

Output	**Amount**	**Ecoinvent data record**	**Remark**
Mineral fraction to landfill	per ton	Disposal, concrete, 5% water, to inert material landfill/CH	-

Table 28: Inventory data for landfilling

The environmental impacts related to landfilling of concrete are listed in Table 29. All impacts represent environmental burdens, except for the impact category of 'natural land transformation'. This environmental 'benefit' is due to the assumption in Eco-Invent that landfill sites, after use, are transformed into natural woodlands. Of course, this assumption is questionable in a Belgian context.

Impact category	Unit	1 ton to landfill
Climate change	kg CO2 eq	2,6
Ozone depletion	kg CFC-11 eq	3,3E-07
Terrestrial acidification	kg SO2 eq	0,020
Freshwater eutrophication	kg P eq	1,3E-04
Marine eutrophication	kg N eq	0,0012
Human toxicity	kg 1,4-DB eq	0,15
Photochemical oxidant formation	kg NMVOC	0,034
Particulate matter formation	kg PM10 eq	0,010
Terrestrial ecotoxicity	kg 1,4-DB eq	2,4E-04
Freshwater ecotoxicity	kg 1,4-DB eq	0,0037
Marine ecotoxicity	kg 1,4-DB eq	0,0043
Ionising radiation	kg U235 eq	0,088
Agricultural land occupation	m2a	0,23
Urban land occupation	m2a	0,49
Natural land transformation	m2	-0,043
Water depletion	m3	0,0040
Metal depletion	kg Fe eq	0,069
Fossil depletion	kg oil eq	0,87

Table 29: Environmental impacts of landfilling mineral fraction

6.4 Environmental profile of ELV glass recycling by dismantling (route 2)

6.4.1 Results

Figure 19 presents the individual environmental profile for the treatment of 1 kg glass in an ELV, by dismantling, calculated with the ReCiPe impact assessment method. The contributions of the various process steps in the life cycle are represented in a similar way as in paragraph 6.3.1. For each impact category, the largest contribution (either positive or negative) of the glass recycling is always set at 100% and the relative contributions of the various processing phases are visible.

As there are differences in dismantling efficiencies (see Table 7) and composition (PVB-content) between different window types, a differentiation is made between the dismantling of a kg of windscreen (Figure 15), rear window (Figure 16) and side window (Figure 17).

In addition, the calculation is made for an 'average' kg of ELV glass (Figure 18 and Figure 19).

Numerical values of the net environmental impacts are presented in Table 30. All values are negative, representing an environmental benefit.

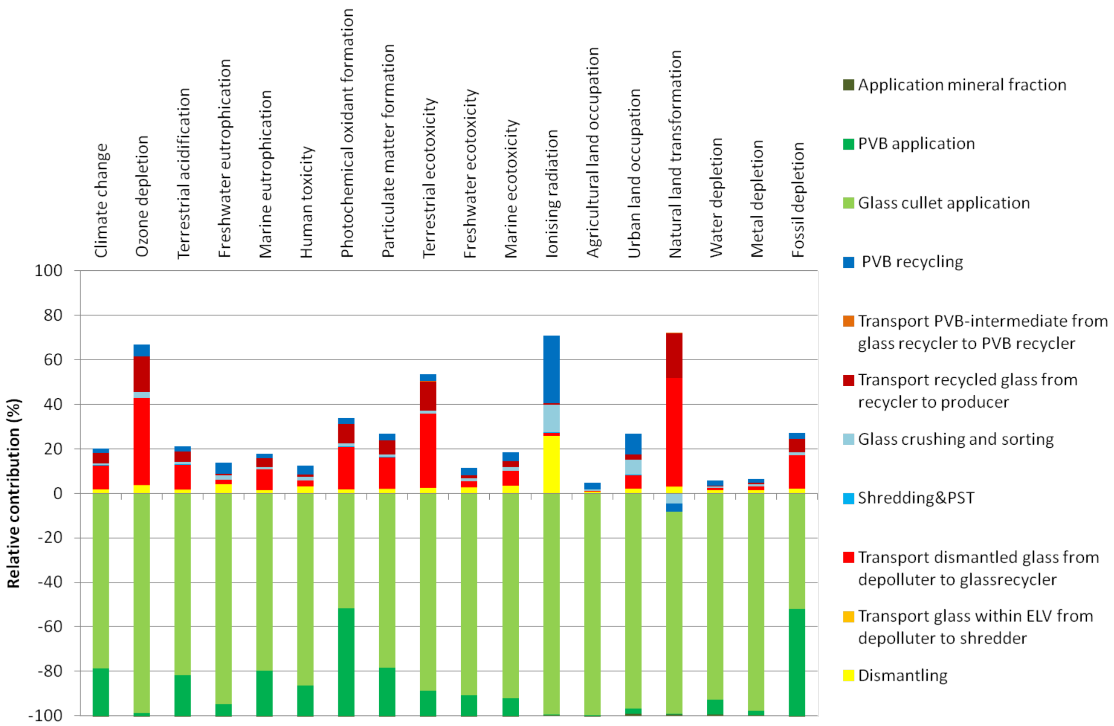

Figure 15: Environmental profile of the treatment of 1 kg of windscreen in route 2 (dismantling), per process stage

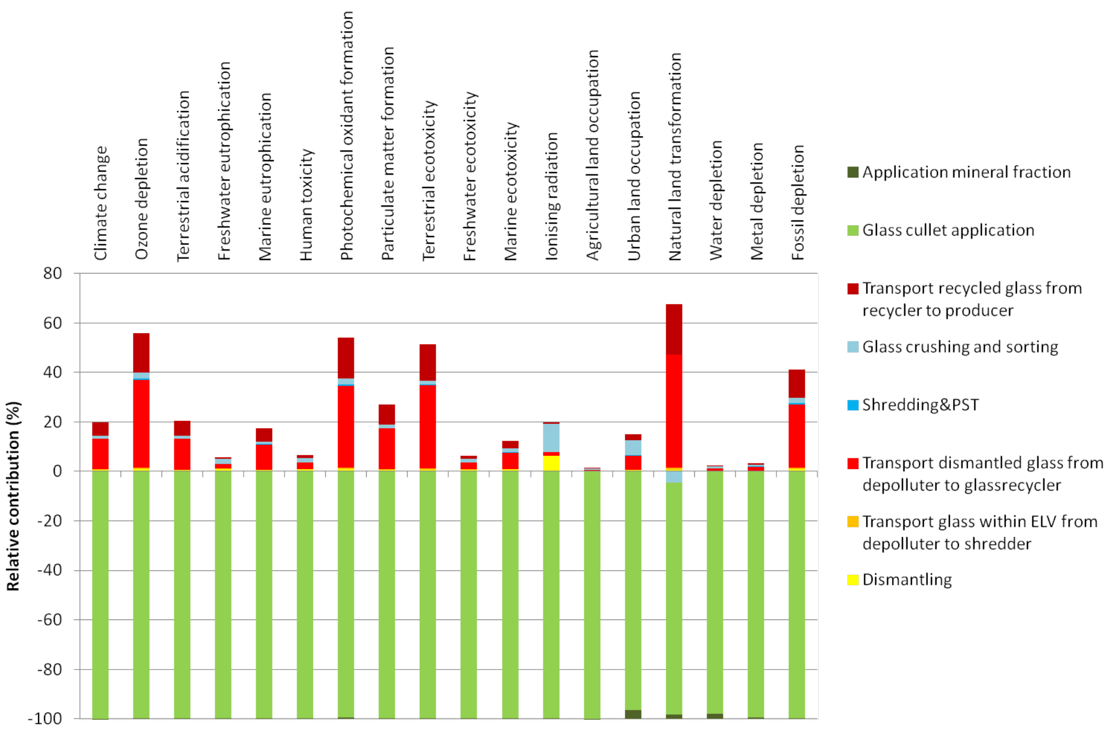

Figure 16: Environmental profile of the treatment of 1 kg of rear window in route 2 (dismantling), per process stage

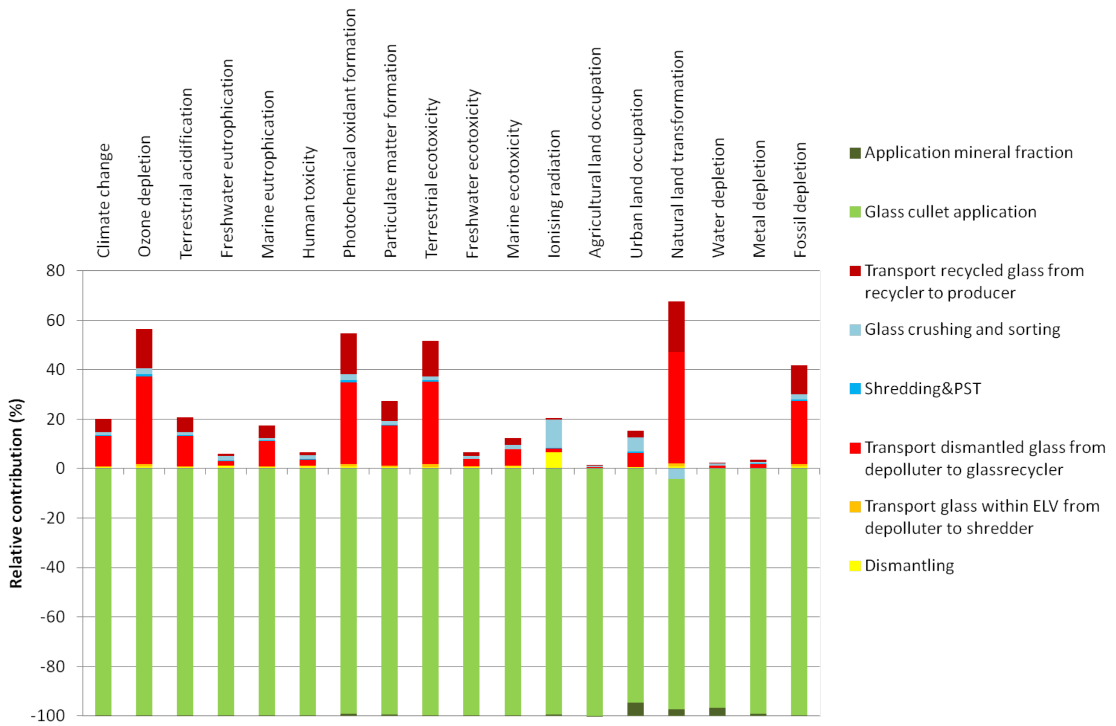

Figure 17: Environmental profile of the treatment of 1 kg of side window in route 2 (dismantling), per process stage

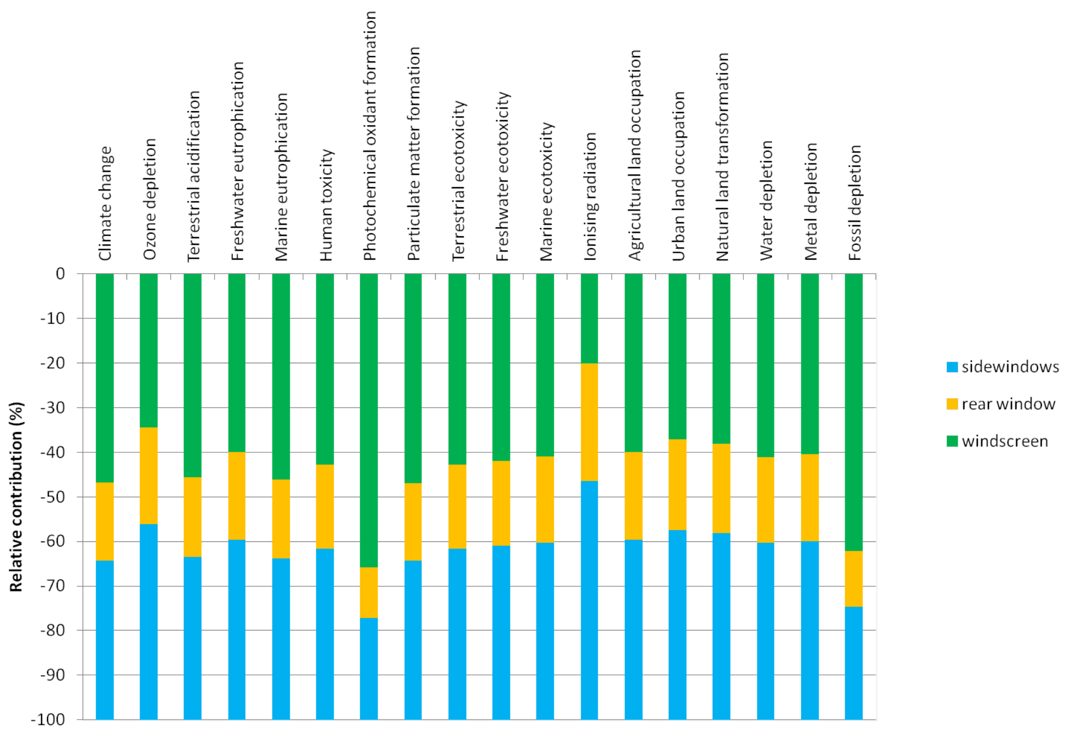

Figure 18: Environmental profile of the treatment of 1 kg of average ELV glass in route 2 (dismantling), contributions per window type

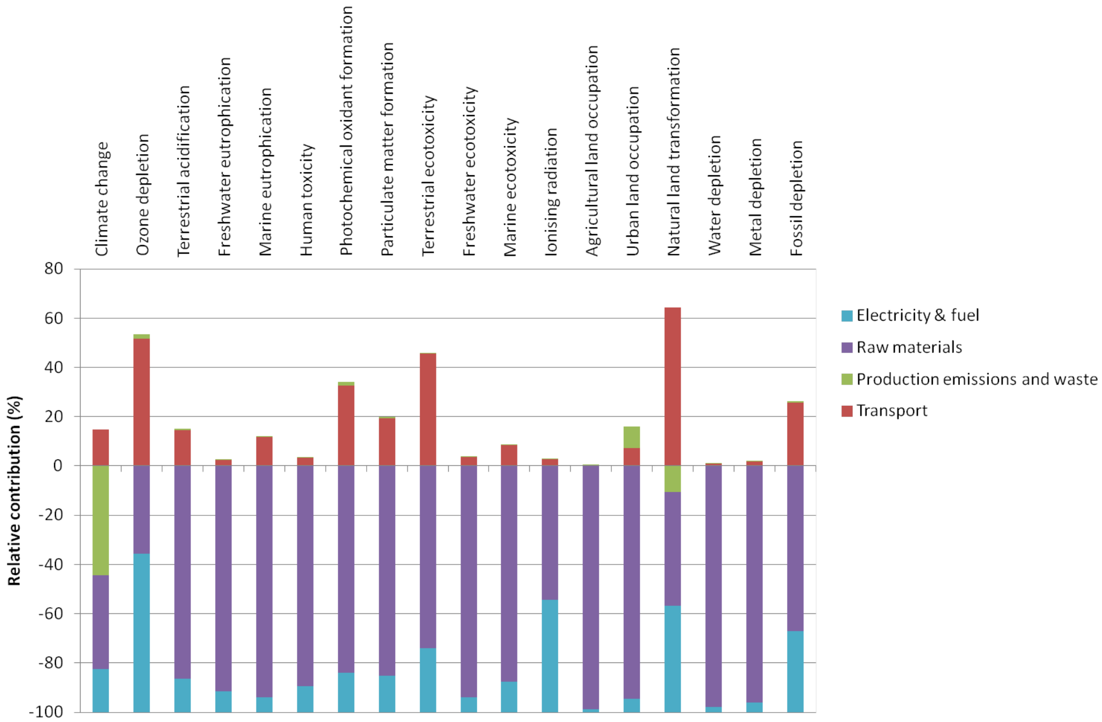

Figure 19: Environmental profile of the treatment of 1 kg of average ELV glass in route 2 (dismantling), contributions per process type

		environmental impacts per kg glass sent to dismantling			
Impact category	**Unit**	**Windscreen**	**Rear window**	**Side windows**	**Average ELVglass**
Climate change	kg CO2 eq	-0,33	-0,27	-0,25	-0,28
Ozone depletion	kg CFC-11 eq	-4,6E-09	-6,4E-09	-5,9E-09	-5,5E-09
Terrestrial acidification	kg SO2 eq	-9,5E-04	-8,1E-04	-7,6E-04	-8,5E-04
Freshwater eutrophication	kg P eq	-4,8E-05	-5,1E-05	-4,9E-05	-4,9E-05
Marine eutrophication	kg N eq	-5,5E-05	-4,6E-05	-4,3E-05	-4,8E-05
Human toxicity	kg 1,4-DB eq	-0,053	-0,050	-0,048	-0,050
Photochemical oxidant formation	kg NMVOC	-5,8E-04	-2,2E-04	-2,0E-04	-3,6E-04
Particulate matter formation	kg PM10 eq	-2,7E-04	-2,2E-04	-2,0E-04	-2,3E-04
Terrestrial ecotoxicity	kg 1,4-DB eq	-1,2E-05	-1,2E-05	-1,1E-05	-1,2E-05
Freshwater ecotoxicity	kg 1,4-DB eq	-0,0012	-0,0012	-0,0011	-0,0012
Marine ecotoxicity	kg 1,4-DB eq	-9,2E-04	-9,4E-04	-8,9E-04	-9,1E-04
Ionising radiation	kg U235 eq	-0,016	-0,044	-0,041	-0,031
Agricultural land occupation	m2a	-0,0093	-0,0099	-0,0094	-0,0094
Urban land occupation	m2a	-8,8E-04	-1,0E-03	-0,0010	-0,0010
Natural land transformation	m2	-1,3E-05	-1,4E-05	-1,4E-05	-1,3E-05
Water depletion	m3	-0,0064	-0,0065	-0,0062	-0,0063
Metal depletion	kg Fe eq	-0,0090	-0,0094	-0,0089	-0,0090
Fossil depletion	kg oil eq	-0,071	-0,031	-0,029	-0,046

Table 30: Environmental impacts of the treatment of 1 kg ELV glass in route 2 (dismantling), comparison

6.4.2 Discussion

From the previous Figure 15, Figure 16 and Figure 17 it is clear that recycling of ELV glass, by dismantling, cullet production and PVB recycling, has a significant net environmental benefit in all impact categories:

— The **environmental burdens** are mainly due the transports between process stages: transport of dismantled glass from depollution center to glass recycler and transport of recycled cullet from glass recycler to glass producer. The recycling stages (dismantling, shredding, glass crushing and PVB recycling) are of minor impact, and (as was discussed in the previous paragraph for the shredding process) also contain an important amount of internal transport.

— The **environmental benefits** are linked to the reapplication of the recycled materials. In the case of rear and side windows, practically all benefits are due to the production of glass cullet, which can be applied in the glass industry, thus replacing raw materials (mainly sand) and allowing energy savings. The glass fraction that cannot be dismantled in an efficient way (about 10-15% of the glass) ends up in a mineral fraction after shredding, but its contribution to the environmental benefits is negligible. In the case of windscreen dismantling, PVB recycling contributes between 10 and 50% to the environmental benefits, especially in the categories of fossil depletion and photochemical oxidant formation, related to avoided oil, gas and coal inputs for PVC production. The remaining benefits are related to cullet recycling. As only 3% of the glass is lost in dismantling, mineral fraction reapplication is insignificant for windscreens.

In Figure 18, the relative contributions of the different window types to the environmental benefits of the dismantling and recycling of an average kg of ELV-glass are presented. Windscreen and side window recycling each contribute for about 40% to the overall benefits, while rear window recycling contributes for about 20%. This distribution is similar to the weight distribution of the windows (13-13-6 kg). However, in the impact categories where PVB-recycling has a significant contribution (photochemical oxidant formation and fossil depletion), windscreen recycling represents over 60% of environmental benefits. On the contrary, in the category of ionising radiation, which is linked to electricity use, the benefit of windscreen recycling is much lower (about 20%), due to the significant electricity usage of the PVB recycling process and the windscreen dismantling techniques (see also Figure 15).

Figure 19 shows that the main environmental burdens are related to **transport**: mainly transport across process stages, and to a much lesser extent internal transport within process stages. Transport burdens are due to diesel combustion emissions during operation and to the diesel production itself, while their relative importance changes between impact categories. The **emissions** of the recycling process are of minor importance, while the (non-transport related) **energy use** of recycling operations is largely compensated by energy savings (gas, oil, electricity) due to cullet use in glass production (net benefit for electricity & fuel). For most impact categories energy savings make up between 10-20% of the environmental benefits of ELV glass dismantling. However, the most important benefits (about 80% in most categories) are related to raw material savings.

Overall, the most important **raw material savings** are due to avoided production of soda, silica sand (which are replaced by glass cullet) and PVC (which is replaced by recycled PVB). For most impact categories, the avoided production of soda is the main contribution to the environment benefit of recycling. Soda production uses a large quantity of heat (which the EcoInvent database assumes to be coal-based), while it requires a large input of sodium chloride. Mining, cleaning and drying of sodium chloride requires a lot of electricity.

One eye-catching detail is the result for the category 'climate change', where about half of the environmental benefit is due to **savings in production emissions**. This result relates to a saving in carbon dioxide process emissions in glass production, when using recycled cullet instead of virgin raw materials. As described in paragraph 5.5, the glass formation reaction causes an emission of chemically bound carbon dioxide. In the case of recycled cullet, glass formation has already taken place, eliminating this emission.

6.4.3 Sensitivity analysis: application of glass cullet

As described in paragraph 5.5 recycled automotive cullet can be applied in several different glass applications (float glass, container glass, …). Cullet use by the glass industry is market driven and highly dependent on the economical situation, so the relative distribution on cullet use among these different applications changes with the economy. As there are some differences in the melting process amongst these applications, the question arises whether the glass application distribution, has a significant influence on the overall environmental benefits achieved by cullet recyling. A sensitivity analysis is done on this issue, comparing the environmental impacts of dismantling and glass recycling (route 2) using extreme glass application distributions:

— all automotive cullet is reused in float glass production
— all automotive cullet is reused in container glass production
— all automotive cullet is reused in foamglass production
— the automotive cullet is distributed among the different applications in the same way as the current market for 'general' cullet (70% to container glass, 20% to float glass and 10% to other glass)

The results are shown in Figure 20 and Table 31.

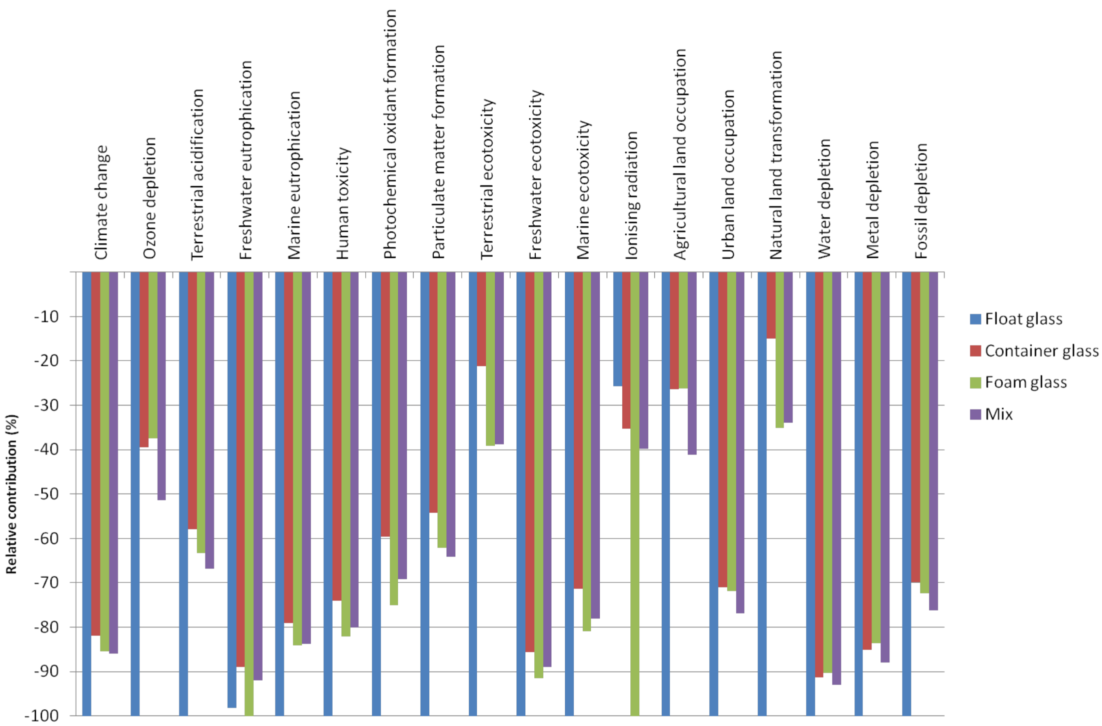

Figure 20: Influence of the glass application of recycled cullet on the environmental profile of route 2

	environmental impacts per kg recycled ELV glass				
Impact category	**Unit**	**Float glass**	**Container glass**	**Foam glass**	**Mix**
Climate change	kg CO2 eq	-0,33	-0,27	-0,28	**-0,28**
Ozone depletion	kg CFC-11 eq	-1,1E-08	-4,2E-09	-4,0E-09	**-5,5E-09**
Terrestrial acidification	kg SO2 eq	-0,0013	-7,4E-04	-8,0E-04	**-8,5E-04**
Freshwater eutrophication	kg P eq	-5,2E-05	-4,7E-05	-5,3E-05	**-4,9E-05**
Marine eutrophication	kg N eq	-5,8E-05	-4,6E-05	-4,9E-05	**-4,8E-05**
Human toxicity	kg 1,4-DB eq	-0,063	-0,046	-0,051	**-0,050**
Photochemical oxidant formation	kg NMVOC	-5,2E-04	-3,1E-04	-3,9E-04	**-3,6E-04**
Particulate matter formation	kg PM10 eq	-3,6E-04	-2,0E-04	-2,3E-04	**-2,3E-04**
Terrestrial ecotoxicity	kg 1,4-DB eq	-3,04E-05	-6,45E-06	-1,19E-05	**-1,18E-05**
Freshwater ecotoxicity	kg 1,4-DB eq	-0,0013	-0,0011	-0,0012	**-0,0012**
Marine ecotoxicity	kg 1,4-DB eq	-0,0012	-8,3E-04	-9,4E-04	**-9,1E-04**
Ionising radiation	kg U235 eq	-0,020	-0,028	-0,079	**-0,031**
Agricultural land occupation	m2a	-0,023	-0,0061	-0,0060	**-0,0094**
Urban land occupation	m2a	-0,0012	-8,9E-04	-9,0E-04	**-9,6E-04**
Natural land transformation	m2	-4,0E-05	-5,9E-06	-1,4E-05	**-1,3E-05**
Water depletion	m3	-0,0068	-0,0062	-0,0061	**-0,0063**
Metal depletion	kg Fe eq	-0,0102	-0,0087	-0,0086	**-0,0090**
Fossil depletion	kg oil eq	-0,060	-0,042	-0,044	**-0,046**

Table 31: Sensitivity analysis for the type of glass application in route 2

The result shows that reapplication of cullet in float glass production generates higher environmental benefits than the 2 other applications. This is due to the higher energy use in float glass melting and the relative higher percentage of soda in the raw material mix. Cullet use in container glass and foamglass productions yields similar environmental benefits for all impact categories except for ionizing radiation (which is due to the fact that the energy source in the case of foamglass is almost exclusively electricity). This study takes into account the current distribution in cullet reapplication, which is dominated by container glass production.

6.5 Conclusions

6.5.1 Comparison of both recycling routes

Figure 21 shows a comparison of the net environmental profiles of shredding (route 1) and dismantling (route 2) for an average kg of ELV glass. It can be seen that the shredding route has minor environmental impacts and benefits depending on the impact category, while dismantling in all categories has a much larger environmental benefit.

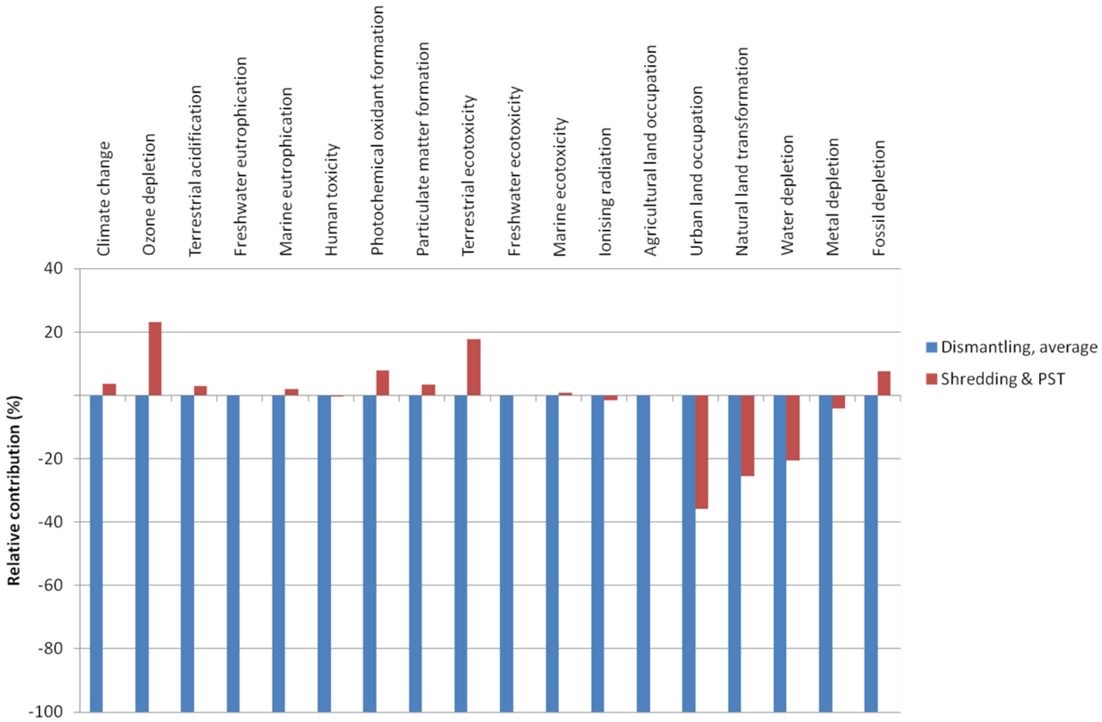

Figure 21: Comparison of the environmental profiles of route 1 & route 2, per ton of average ELV glass

		environmental impacts per ton recycled ELV glass	
Impact category	**Unit**	**Route 1: shredding**	**Route 2: dismantling**
Climate change	kg CO2 eq	10	-280
Ozone depletion	kg CFC-11 eq	1,3E-06	-5,5E-06
Terrestrial acidification	kg SO2 eq	0,024	-0,85
Freshwater eutrophication	kg P eq	-1,1E-04	-0,049
Marine eutrophication	kg N eq	9,5E-04	-0,048
Human toxicity	kg 1,4-DB eq	-0,14	-50
Photochemical oxidant formation	kg NMVOC	0,028	-0,36
Particulate matter formation	kg PM10 eq	0,0080	-0,23
Terrestrial ecotoxicity	kg 1,4-DB eq	0,0021	-0,012
Freshwater ecotoxicity	kg 1,4-DB eq	-0,0016	-1,2
Marine ecotoxicity	kg 1,4-DB eq	0,0070	-0,91
Ionising radiation	kg U235 eq	-0,50	-31
Agricultural land occupation	m2a	-0,019	-9,4
Urban land occupation	m2a	-0,35	-0,96
Natural land transformation	m2	-0,0034	-0,013
Water depletion	m3	-1,3	-6,3
Metal depletion	kg Fe eq	-0,37	-9,0
Fossil depletion	kg oil eq	3,4	-46

Table 32: Comparison of the environmental profiles of route 1 & 2, for the treatment of 1 tonne average ELV glass, in absolute values

Table 32 shows the numerical values of the impacts and should be read as follows: positive values represent a net environmental burden, while negative values represent a net benefit. For the impact category of 'climate change', this means that the recycling of 1 ton average ELV windows by shredding and PST yields a net emission (impact) of 10 kg CO_2 eq., while the dismantling and glass recycling of this ton ELV windows would yield a net reduction of 280 kg CO_2 eq.

6.5.2 Weighting of impact categories

Figure 22 and Table 33 show the environmental impacts of the treatment of 1 tonne average ELV glass as a single score (ReCipe Endpoint (H)/Europe H/A). The single score approach uses weighting factors in order to weigh the relative importance of each impact category and generates an 'overall' environmental impact, expressed in millipoints (mPt). The assumptions made in order to define the weighting factors are inherent to the method. As can be seen in the graph, the environmental impacts related to climate change (with effects both for ecosystems and for human health) and fossil depletion dominate the profiles. Note that the ReCiPe Endpoint method defines slightly different impact categories than the Midpoint method.

Please note that weighting is not supported by ISO because of the subjective character, particularly not in comparative assertions. In this study weighting is included to allow better interpretation. It is important to keep in mind the environmental profiles on an impact-category basis, as presented in the previous paragraph.

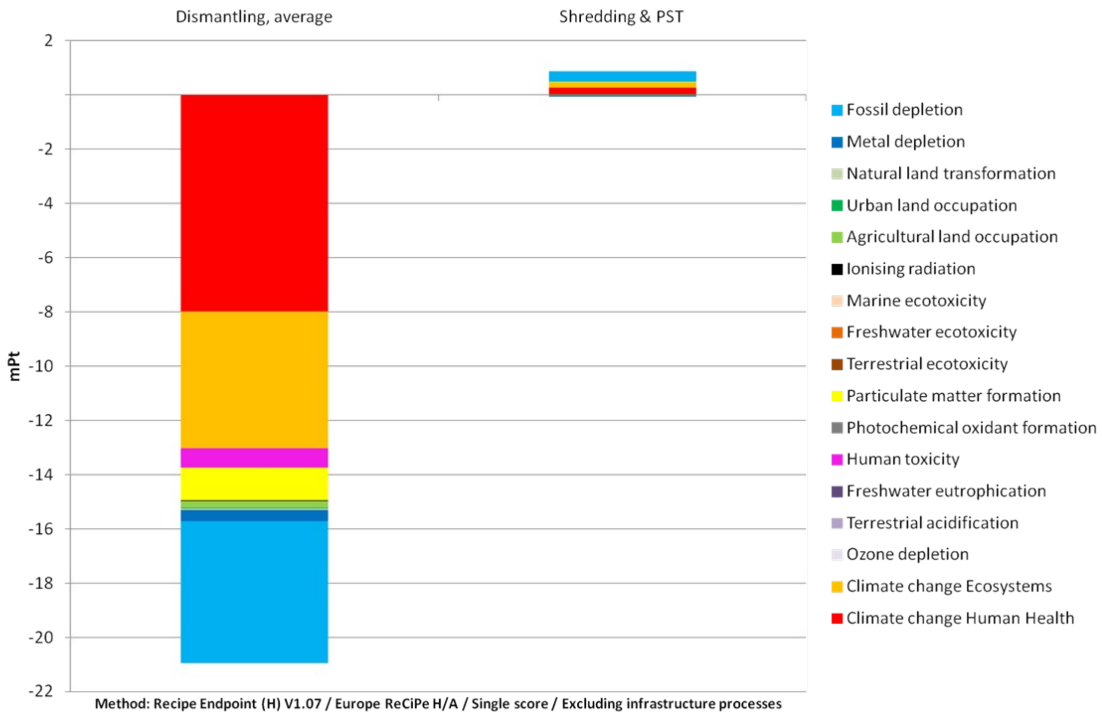

Figure 22: Single score impact of the treatment of 1 tonne average ELV glass (ReCiPe Endpoint (H)/ Europe H/A)

	environmental impacts per ton recycled ELV glass		
Impact category	**Unit**	**Route 1: shredding**	**Route 2: dismantling**
Total	mPt	0,81	-21
Climate change Human Health	mPt	0,28	-8,0
Climate change Ecosystems	mPt	0,18	-5,0
Ozone depletion	mPt	6,8E-05	-2,8E-04
Terrestrial acidification	mPt	3,1E-04	-0,011
Freshwater eutrophication	mPt	-1,1E-05	-0,0048
Human toxicity	mPt	-0,0020	-0,70
Photochemical oxidant formation	mPt	2,1E-05	-3,0E-04
Particulate matter formation	mPt	0,041	-1,2
Terrestrial ecotoxicity	mPt	7,0E-04	-0,0039
Freshwater ecotoxicity	mPt	-3,1E-06	-0,0022
Marine ecotoxicity	mPt	2,9E-06	-3,5E-04
Ionising radiation	mPt	-1,6E-04	-0,0098
Agricultural land occupation	mPt	-4,1E-04	-0,25
Urban land occupation	mPt	-0,016	-0,043
Natural land transformation	mPt	-0,019	-0,050
Metal depletion	mPt	-0,017	-0,42
Fossil depletion	mPt	0,36	-5,2

Table 33: Single score values for the treatment of 1 tonne of ELV glass, divided per impact category

6.5.3 Sensitivity analysis: transport operations (reduced fuel use)

In order to estimate the influence of the assumptions made for the transport operations, the environmental impacts of both treatment routes are recalculated, assuming a reduction in fuel use.

In this sensitivity analysis, the diesel consumption is assumed to vary between 20,4 (empty) and 31 (full) liter per 100 km, for both the scrap wagon (see 3.4.1) and the bulk truck (see 3.4.2). All other assumptions (load, distance, type of truck used) are unchanged. These fuel estimations are taken from the MIMOSA tool, which was designed by VITO to calculate emissions caused by road transportation, based on the COPERT 4-methodology (EMEP/CORINAIR, 2007[19], Ntziachristos and Samaras, 2010[20]) and finetuned to match the Belgian situation.

The following table presents the new assumptions used in the environmental modeling:

19 EMEP/CORINAIR. EMEP/CORINAIR Emission inventory Guidebook - 2007: Group 7 - Road transport. EEA. 5-12-2007. 1-11-2009.
20 Ntziachristos, Leonidas and Samaras, Zissis. EMEP/EEA emission inventory guidebook 2009, updated June 2010: Exhaust emissions from road transport. EMEP/CORINAIR. 2010. 5-3-2013.

Load		Diesel consumption	Ecoinvent data record	Remark
Scrap wagon with grapnel				
0%	0 tonne	0,204 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
70%	8,4 tonnes	0,28 l/km		Average load (8,4 ELV)
Bulk truck				
0%	0 tonnes	0,204 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
50%	6 tonnes	0,258 l/km		Milk-round, average load (6 tonnes)
100%	12 tonnes	0,31 l/km		Full load
* using Diesel, at regional storage, RER/U instead of CH/U				

Table 34: Life Cycle Inventory (LCI) of transport operations

Figure 23 and Table 35 show a comparison of the net environmental profiles of shredding (route 1) and dismantling (route 2) for an average kg of ELV glass, using these assumptions on different fuel consumption.

The overall conclusions are not changed by the reduction in fuel use. The dismantling route has an overall environmental benefit over the shredding route. The values of the environmental impacts are lower (or more negative) than in the reference simulation, indicating that the net environmental burdens are lower, while the net environmental benefits are higher than in the reference situation. As transport operations proved to be the major contribution to the environmental burdens, this result could be expected.

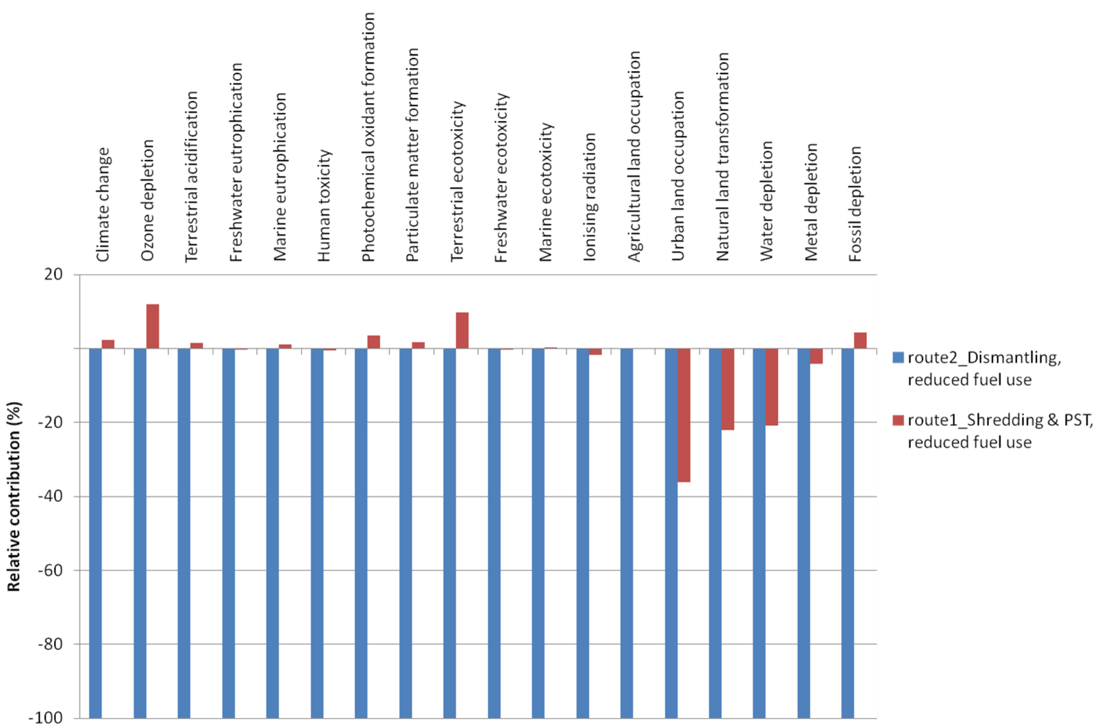

Figure 23: Sensitivity analysis transport operations (reduced fuel use)

		environmental impacts per ton recycled ELV glass	
Impact category	**Unit**	**Route 1: shredding**	**Route 2: dismantling**
Climate change	kg CO2 eq	7,0	-310
Ozone depletion	kg CFC-11 eq	9,1E-07	-7,6E-06
Terrestrial acidification	kg SO2 eq	0,014	-0,91
Freshwater eutrophication	kg P eq	-1,9E-04	-0,049
Marine eutrophication	kg N eq	5,3E-04	-0,051
Human toxicity	kg 1,4-DB eq	-0,25	-51
Photochemical oxidant formation	kg NMVOC	0,016	-0,45
Particulate matter formation	kg PM10 eq	4,2E-03	-0,26
Terrestrial ecotoxicity	kg 1,4-DB eq	1,5E-03	-0,015
Freshwater ecotoxicity	kg 1,4-DB eq	-4,4E-03	-1,2
Marine ecotoxicity	kg 1,4-DB eq	2,1E-03	-0,94
Ionising radiation	kg U235 eq	-0,56	-30,5
Agricultural land occupation	m2a	-0,020	-9,4
Urban land occupation	m2a	-0,35	-0,98
Natural land transformation	m2	-5,0E-03	-0,022
Water depletion	m3	-1,3	-6,3
Metal depletion	kg Fe eq	-0,38	-9,0
Fossil depletion	kg oil eq	2,4	-55

Table 35: Sensitivity analysis transport operations (reduced fuel use)

7 Scenario analysis

7.1 Introduction

In paragraphs 6.3 and 6.4 the environmental impacts were calculated for the treatment of 1 kg glass in an ELV, starting upon arrival of the ELV in a depollution center. While theoretically spoken, an average ELV contains about 32 kg glass, in practice this amount is significantly lower due to glass losses by accidents (about 7,5%). As a consequence, upon arrival in a depollution center, an ELV on average only contains 29,6 kg of glass (32kg*(1-0,075)). However, not all of this glass can be dismantled. Side and rear windows that are broken (e.g. as a consequence of transport) will be present as scattered glass fragments within the ELV and cannot be recovered. Intact windows and also broken laminated windows in principle can be dismantled.

In the scenario analysis in this chapter, the functional unit is expanded to the **treatment of an average ELV**, starting at the point where the last user brings in his ELV for waste treatment, e.g. the garage or scrap dealer. As in the previous chapter, it is assumed that the treatment of the ELV carcass (glass excluded) after depollution remains the same regardless of the choice of glass treatment (streamlining). The broadening of the scope of the scenarios to the point where the ELV is brought in, implies that the transport of the ELV to the depollution center has to be included in the calculations. However, as the purpose of the scenario analysis is to compare different policy scenarios, a similar streamlining approach can be applied for the transport to the depollution center: it is assumed that the transport to the depollution center remains the same between the different scenarios, regardless of the glass treatment after depollution (as is the case in scenarios 0 and 1). As a consequence, this approach implies that, if at some point the choice of glass treatment does have an influence on the treatment of the ELV carcass, these differences need to be corrected for in order to avoid double counting or disappearance of impacts. In those cases (scenario 2) a correction factor will be included in order to mainatin equivalence between the scenarios.

7.2 Transport of an ELV to a depollution center

7.2.1 Introduction

In practice, 2 main routes exist to transfer an ELV to an official depollution centre.

Official dealers of the large car brands work within the **EcoBonus system**: when a customer buys a new car, he receives a fee for bringing in his old vehicle for recycling. However, a list of conditions must fulfilled for an ELV to be eligible to receive an EcoBonus. In practice, most ELV that fall under the EcoBonus system are complete and still in a relatively good condition. The system, however, insists that all these vehicles are sent to recycling. In Belgium, EcoBonus vehicles are transferred to the large shredder facilities (Galloo, Cometsambre and BST) for depollution and further treatment. A very limited dismantling of spare parts for the second hand market can also take place at these facilities.

The alternative route for ELV to reach a depollution centre is less defined as multiple middle men can be involved. On average an ELV is sold and resold about 3 times before it reaches its final destination for treatment (source Febelauto-Federauto). Individual ELV are picked up at the end-user or garage. Municipalities often sell larger lots of abandoned or seized cars to scrap dealers or dismantlers. At present the majority of dismantling workshops are also certified as official depollution centre (source: DJ Autoparts).

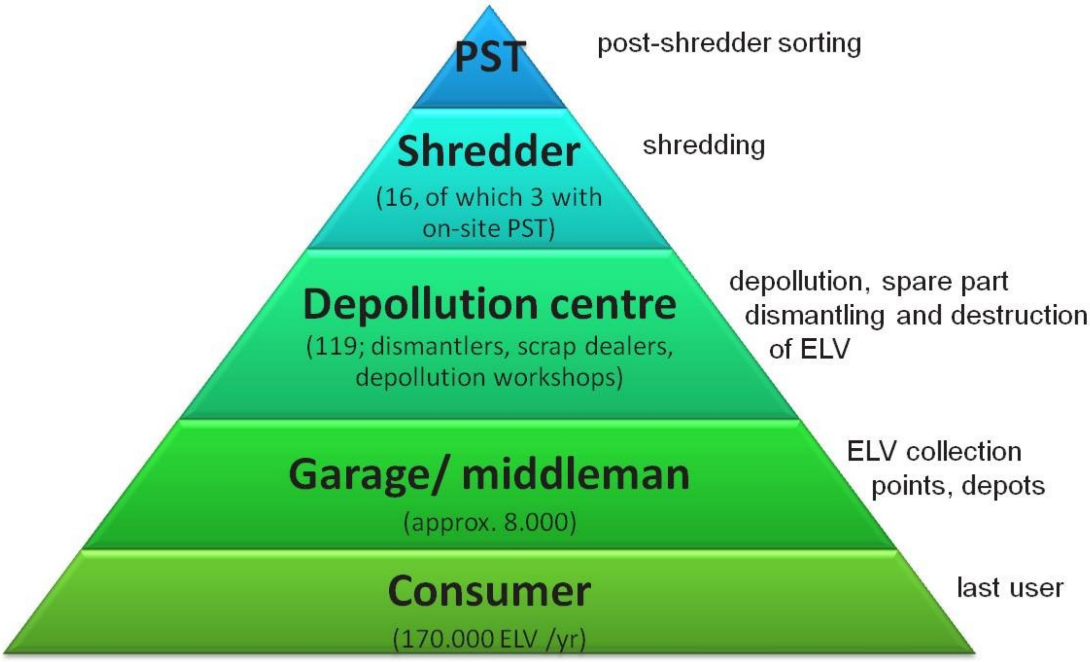

Figure 24: Different actors in ELV treatment

For the current study, the following general characteristics of ELV were taken into account:

- The average weight of an ELV is 1000 kg, of which 32 kg is glass (in the case that all windows are intact).
- 7,5% of the glass from ELV is missing, due to an accident (OVAM, 2013)
- dismantling of glass for the second hand market is not taken into account in the scenario analysis in order to maintain coherence with the cost-benefit study. However, in paragraph 7.6.3, a sensitivity analysis will be performed regarding spare part dismantling.

7.2.2 ELV transport by scrap wagon and grapnel (transport A)

According to Febelauto, 53% of ELV are manipulated with a grapnel upon transport from garage/middleman to the depollution center. The ELV are pilled into a container. The consequence of this type of transport is that all side windows and about 50% of rear windows are broken. Most of the glass particles will be scattered within the ELV carcass. The windscreen will stay in place due to the supporting PVB layer, although the glass sheets also will be damaged. 50% of rear windows are estimated to stay intact. Febelauto estimates that in 2011 about 53% of ELV were transported using a scrap wagon and grapnel.

Large garages will generally have enough ELV in stock to send fully loaded transports to a depollution center, while small garages will be served in 'milk rounds' (a scrap lorry that visits several workshops before it heads for the depollution center). The ELV cannot be pressed before depollution, but in practice a limited pressing up to 'half height' is done to increase the number of ELV that fit in the container.

The maximum truck load in case of waste transport is 12 ton for a single container and 2 times 10 ton for a truck with trailer (source: van Heede).

Figure 26: Scrap wagon with grapnel (picture taken from http://www.schroothandelwesleyt.be)

In the transport modeling, the following assumptions are made for this type of transport:
- only single container transports are considered (12 ton represents 100% load)
- an average container can harbor a maximum of 6 ELV (volume limitation) (6 tonnes, 50% load).
- an average load of 40% (4,8 ELV) is assumed, counting both full transports and milk rounds
- the return trip occurs with an empty wagon
- diesel consumption varies between 33 (empty) and 37 (full) liter/100 km
- all vehicles comply with the EURO 5 emission standard
- average distance between garage and depollution center is 45 km, taking into account an average of 3 movements before the ELV reaches its final destination (source: Febelauto-Federauto)

7.2.3 ELV transport by car transporter (transport B-B')

The ELV that are collected under the EcoBoni-system are transferred directly to one of the large shredders by means of a car transporter (also called a 'porte-huit'). This transport mode leaves the ELV glass intact. Febelauto estimates that in 2011 about 47% of ELV were transported using a car transporter. Large garages will generally have enough ELV in stock to send fully loaded transports to a depollution center, while small garages will be served in 'milk rounds' (a car transporter that visits several workshops before it heads for the depollution center).

However, it requires that the ELV is capable of driving onto the transporter. A typical car transporter has room for 8 vehicles, although some modern trucks can carry 9 or even more.

In this study, the following assumptions are made for this type of transport:
- a car transporter can carry a maximum load of 8 ELV (8 ton represents 100% load),
- as the EcoBoni system is used by the large brands, full transports (8 ELV) are assumed for the ELV that belong to this system (transport B)
- for non-EcoBoni transports by car transporter, milk rounds (50%, 4 ELV) are assumed (Transport B')
- the return trip occurs with an empty lorry
- diesel consumption varies between 33 (empty), 35 (50%) and 37 (full) liter/100 km

— all vehicles comply with the EURO 5 emission standard
— average distance between garage and shredder is 45 km (see 7.2.2).

Figure 27: Car-transporter (picture taken from http://www.schroothandelwesleyt.be)

7.2.4 ELV transport by towing lorry (transport C)

A third transport mode for ELV is a towing lorry (also called 'depanneuse'), which can carry one or two vehicles. This type of transport is more suitable for small garages and for ELV that are damaged by accidents or for some other reason cannot drive autonomously.

Figure 28: Towing truck (picture taken from http://www.schroothandelwesleyt.be)

In this study, the following assumptions are made for this type of transport:

— a towing lorry can carry 1 ELV
— the return trip occurs with an empty lorry
— diesel consumption varies between 10 (empty) and 12 (full) liter/100 km
— all vehicles comply with the EURO 5 emission standard
— average distance between garage and shredder is 45 km (see 7.2.2).

7.2.5 Inventory data

The following table presents the assumptions used in the environmental modeling:

Load		**Diesel consumption**	**Ecoinvent data record**	**Remark**
Transport A: Scrap wagon and grapnel				
0%	0 tonne	0,330 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
40%	4,8 tonnes	0,345 l/km		Average load (4,8 ELV)
Transport B: Car transporter (Eco-Boni-system)				
0%	0 tonnes	0,33 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
100%	8 tonnes	0,37 l/km		Full load (8 ELV)
Transport B': Car transporter (non-Eco-Boni)				
0%	0 tonnes	0,33 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
50%	4 tonnes	0,35 l/km		Milk-round, average load (4 ELV)
Transport C:Towing lorry				
0%	0 tonnes	0,10 l/km	Operation, lorry 3,5-16 t, EURO5, RER U*	Empty return trip
100%	1 tonne	0,12 l/km		1 ELV
* using Diesel, at regional storage, RER/U instead of CH/U				

Table 36: LCI transport operations between garage and depollution center

The modeling of the transport operations only takes into account fuel use and associated emissions. The environmental impacts of vehicle production and road infrastructure are not taken into account.

7.2.6 Environmental impacts of ELV transport to a depollution center

For each possible transport mode to transport an ELV to the depollution center, the associated environmental impacts are calculated, per ton transported, over 45 km. As 1 ELV weighs on average 1 ton, these values can also be read as impacts per transported ELV.

Table 37 shows that per transported tonne of ELV, the transport by full car transporters (transport B) has the lowest environmental impact. This can easily be understood, as car transporters under the Eco-Boni-system are assumed to be fully loaded (8 ELV) each time. When these car transporters are executing milk rounds, picking up individual ELV at several garages along the way, they are assumed to be 50% loaded (4 ELV) on average (transport B'). This load change results in an almost doubled environmental impact per transported ELV. This can be explained by the overall fuel consumption of the truck that decreases only slightly with a lighter load, while the empty return trip has to be divided over 4 ELV instead of 8 in the case of the Eco-Boni-system. The use of towing trucks (Transport C) has the highest environmental impact per transported kg ELV.

		per 1000 kg			
Impact category	**Unit**	**Transport A**	**Transport B**	**Transport B'**	**Transport C**
Climate change	kg CO2 eq	19,3	12,3	23,8	32,2
Ozone depletion	kg CFC-11 eq	2,40E-06	1,51E-06	2,94E-06	4,72E-06
Terrestrial acidification	kg SO2 eq	0,058	0,038	0,073	0,082
Freshwater eutrophication	kg P eq	0,00026	0,00032	0,00061	0,00071
Marine eutrophication	kg N eq	0,0026	0,0017	0,0033	0,0040
Human toxicity	kg 1,4-DB eq	0,38	0,43	0,83	1,1
Photochemical oxidant formation	kg NMVOC	0,072	0,047	0,090	0,12
Particulate matter formation	kg PM10 eq	0,022	0,015	0,028	0,038
Terrestrial ecotoxicity	kg 1,4-DB eq	0,0027	0,0024	0,0047	0,0083
Freshwater ecotoxicity	kg 1,4-DB eq	0,013	0,011	0,021	0,027
Marine ecotoxicity	kg 1,4-DB eq	0,024	0,021	0,040	0,069
Ionising radiation	kg U235 eq	0,20	0,23	0,44	0,59
Agricultural land occupation	m2a	0,0010	0,0071	0,014	0,018
Urban land occupation	m2a	0,00076	0,021	0,040	0,049
Natural land transformation	m2	3,64E-06	0,0061	0,012	0,011
Water depletion	m3	0,016	0,014	0,028	0,037
Metal depletion	kg Fe eq	0,00085	0,044	0,085	0,11
Fossil depletion	kg oil eq	6,3	4,0	7,7	10,1

Table 37: Environmental impacts of ELV transport from garage to depollution center (45 km), per ton

7.3 Scenario 0: Business-as-Usual (BAU)

7.3.1 Description

The Business-as-Usual scenario represents the current situation of ELV treatment. For the transport of ELV to a depollution center, two main transport modes are used:

— Transport A: Scrap wagon with grapnel
— Transport B: Car transporter, for the ELV belonging to the Eco-Boni system

In 2011, about 53% of ELV were transported using transport A and 47% using transport B. However, this distribution can change depending on the year.

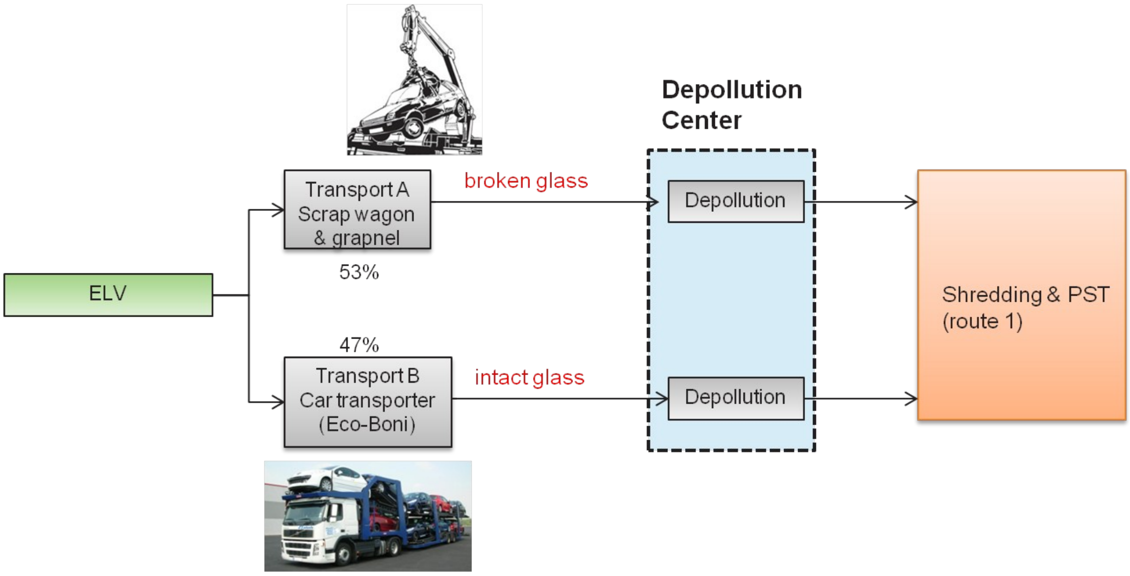

Figure 29: Scenario 0 (Business-as-Usual)

7.3.2 Environmental profile of scenario 0

As is shown in Figure 29, scenario 0 consists of 2 branches with a different transport mode. The amount of glass that reaches the depollution center is the same in both cases, however in branch A most of the glass is broken, while in branch B, the glass is intact. The treatment route for the ELV glass remains the same regardless of the windows being broken or intact. All glass is sent to the shredder, as described in chapter 4 .

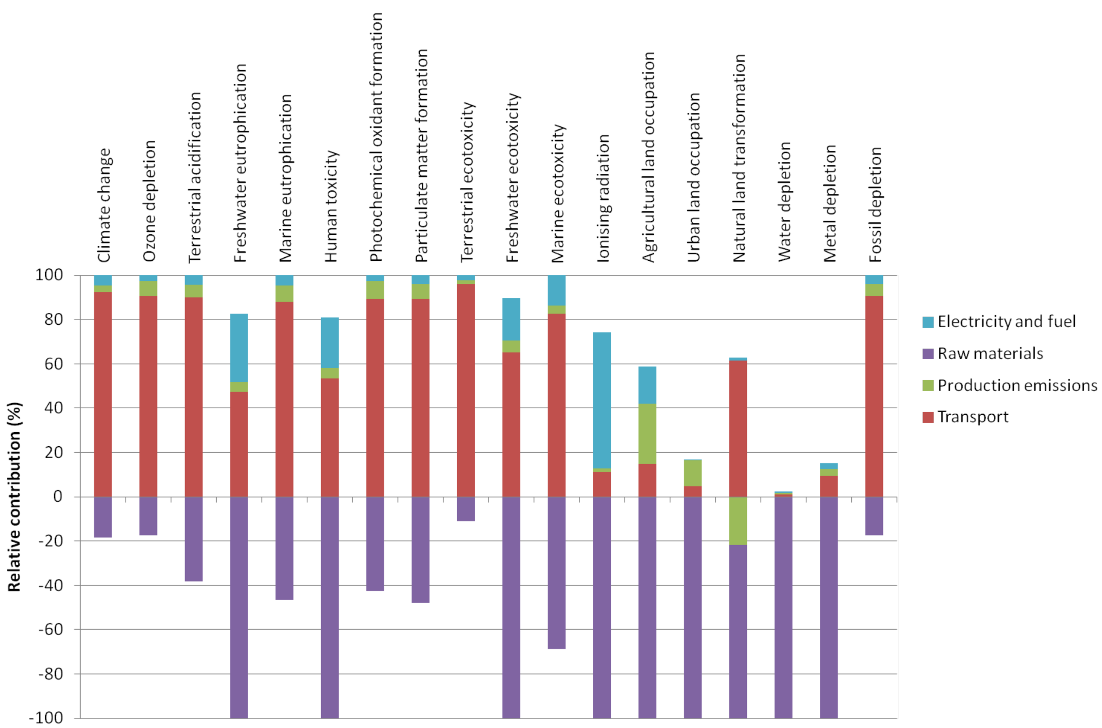

Figure 30: Environmental profile of scenario 0 (streamlined results)

Figure 30 shows the streamlined environmental profile of scenario 0. Due to the streamlining approach for the transport to the depollution center and the ELV carcass treatment, all impacts that are included in the calculations can be traced back to the impacts of recycling route 1 (see paragraph 6.3 for a detailed discussion) for 29,6 kg glass per ELV (32 kg, with a 7,5% reduction for glass loss due to accidents). Transport operations between depollution center and shredder and between shredder and PST are the main contributors to the environmental impact, while the avoidance of sand mining by the recycled mineral fraction generates an environmental benefit. The overall environmental profile shows a mixed result: the business-as-usual scenario generates a net environmental benefit in about half of the impact categories, while imposing a net environmental burden in the other half.

Numerical values of the (streamlined) environmental impacts per ELV are listed in Table 38. As explained in 7.1, the environmental impacts of the transport from garage to depollution center are omitted due to the streamlining approach.

Glass-related environmental impacts of scenario 0		
Impact category	**Unit**	**Scenario 0 (per ELV)**
Climate change	kg CO2 eq	**0,30**
Ozone depletion	kg CFC-11 eq	**3,8E-08**
Terrestrial acidification	kg SO2 eq	**7,1E-04**
Freshwater eutrophication	kg P eq	**-3,2E-06**
Marine eutrophication	kg N eq	**2,8E-05**
Human toxicity	kg 1,4-DB eq	**-0,0042**
Photochemical oxidant formation	kg NMVOC	**8,2E-04**
Particulate matter formation	kg PM10 eq	**2,3E-04**
Terrestrial ecotoxicity	kg 1,4-DB eq	**6,2E-05**
Freshwater ecotoxicity	kg 1,4-DB eq	**-4,9E-05**
Marine ecotoxicity	kg 1,4-DB eq	**2,2E-04**
Ionising radiation	kg U235 eq	**-0,015**
Agricultural land occupation	m2a	**-5,5E-04**
Urban land occupation	m2a	**-0,010**
Natural land transformation	m2	**-1,0E-04**
Water depletion	m3	**-0,039**
Metal depletion	kg Fe eq	**-0,011**
Fossil depletion	kg oil eq	**0,10**

Table 38: Glass-related environmental impacts of scenario 0 (Business-as-usual) for the treatment of an average ELV (streamlined results)

7.4 Scenario 1: Dismantling of ELV windows when possible

7.4.1 Description

In scenario 1 nothing changes to the transport of ELV to a depollution center:

- — Transport A: Scrap wagon with grapnel
- — Transport B: Car transporter, for the ELV belonging to the Eco-Boni system

However, all ELV glass that can be dismantled, will be dismantled for glass recycling:

- — All ELV that arrive with transport B have all windows intact (with a correction for the average glass losses due to accidents), so about 29,6 kg glass can be dismantled. Keeping in mind the dismantling efficiencies of the different windows (Table 7), this implies that about 26,9 kg of glass is recovered per ELV that arrives by transport B (of which 11,7 kg is windscreen, 10,2 kg is side window and 5,0 kg is rear window)
- — All ELV that arrive with transport A have most windows broken. The windscreens and 50% of rear windows (with a correction for glass losses due to accidents of 7,5%) are assumed

to stay intact (14,8 kg glass/ELV). Using their respective dismantling efficiencies from Table 7, this yields about 14,4 kg dismantled glass/ELV.

In 2011, about 53% of ELV were transported using transport A and 47% using transport B. The total amount of glass that enters the depollution center in a status that can be dismantled can thus be calculated as 21,8 kg, yielding about 20,2 kg of dismantled glass. Of course, this distribution can change depending on the year.

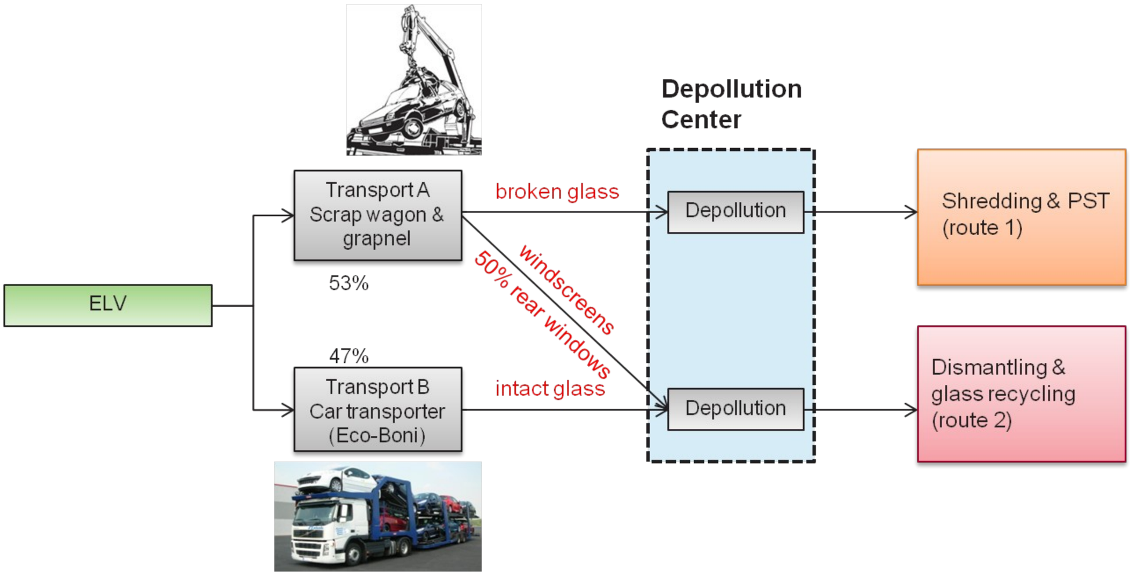

Figure 31: Scenario 1 (Dismantling of ELV windows when possible)

7.4.2 Environmental profile of scenario 1

As is shown in Figure 31, scenario 1 also consists of 2 branches, which are modeled separately in order to maintain transparency of the results. As explained in 7.1, the environmental impacts of the transport from garage to depollution center are omitted due to the streamlining approach. In order to calculate the glass-related impacts of the treatment of an average ELV within scenario 1, the two branches are combined.

Numerical values of the impacts per ELV in scenario 1 are listed in Table 41, for both branches separately (per ELV), and combined in scenario 1 following the 2011 distribution (53% of ELV by transport A, 47% of ELV by transport B).

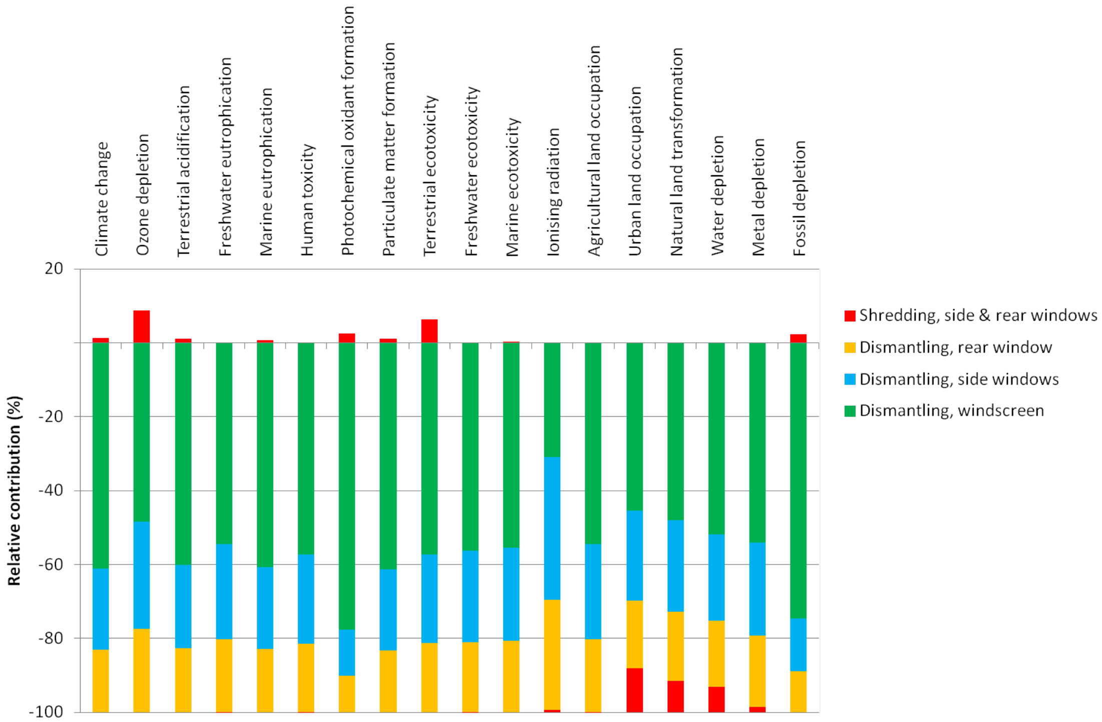

Figure 32: Environmental profile of scenario 1, per treatment route (streamlined results)

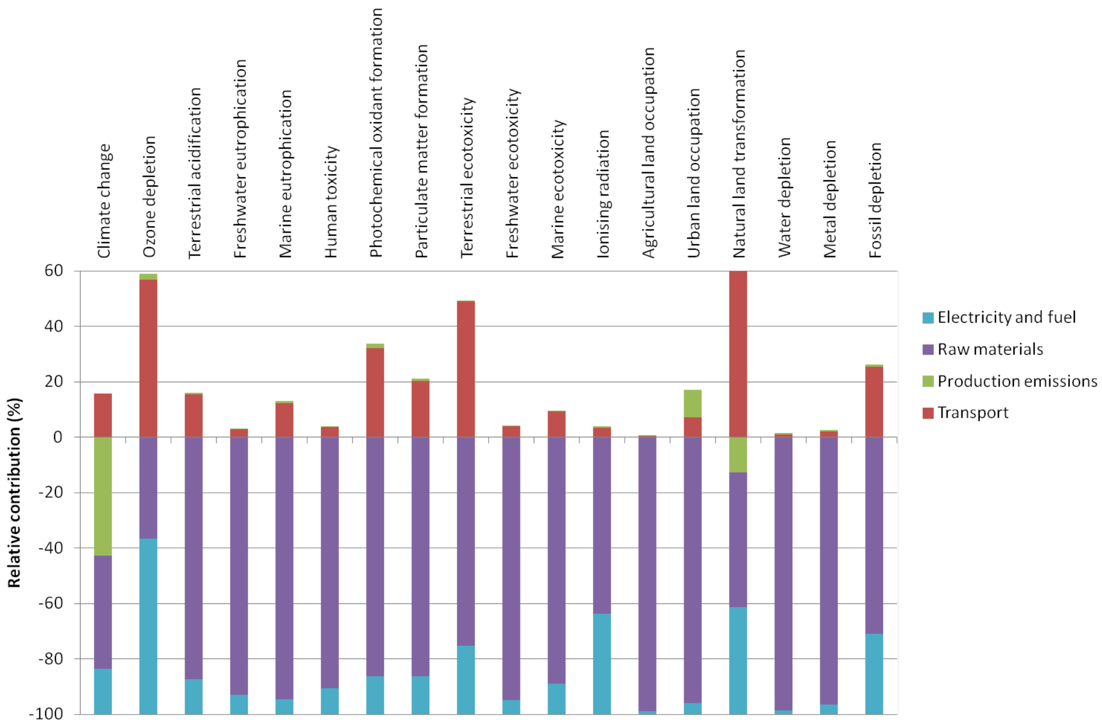

Figure 33: Environmental profile of scenario 1, per process type (streamlined results)

Figure 32 shows the streamlined environmental profile of scenario 1, with the respective contributions of the different treatment routes. In Figure 33, a differentiation is made between the different process types that contribute to the environmental burdens and benefits.

Transport operations are the main contributions to the environmental burdens, while the avoidance of primary minerals in glass (and PVC) production generates most of the environmental benefits, followed by avoided energy use. (see paragraph 6.4.2 for a more detailed discussion of the environmental benefits of the recycling of cullet and PVB.)

Numerical values of the (streamlined) environmental impacts per ELV are listed in Table 39. As explained in 7.1, the environmental impacts of the transport from garage to depollution center are omitted due to the streamlining approach.

		Glass-related environmental impacts of scenario 1		
Impact category	**Unit**	**Branch A (per ELV)**	**Branch B (per ELV)**	**Scenario 1 (per ELV)**
Climate change	kg CO2 eq	-4,5	-8,4	**-6,4**
Ozone depletion	kg CFC-11 eq	-5,4E-08	-1,6E-07	**-1,1E-07**
Terrestrial acidification	kg SO2 eq	-0,013	-0,025	**-0,019**
Freshwater eutrophication	kg P eq	-7,2E-04	-1,4E-03	**-1,1E-03**
Marine eutrophication	kg N eq	-7,7E-04	-1,4E-03	**-1,1E-03**
Human toxicity	kg 1,4-DB eq	-0,78	-1,5	**-1,1**
Photochemical oxidant formation	kg NMVOC	-0,0072	-0,011	**-0,0088**
Particulate matter formation	kg PM10 eq	-0,0037	-0,0069	**-0,0052**
Terrestrial ecotoxicity	kg 1,4-DB eq	-1,5E-04	-3,5E-04	**-2,4E-04**
Freshwater ecotoxicity	kg 1,4-DB eq	-0,018	-0,034	**-0,026**
Marine ecotoxicity	kg 1,4-DB eq	-0,014	-0,027	**-0,020**
Ionising radiation	kg U235 eq	-0,32	-0,93	**-0,60**
Agricultural land occupation	m2a	-0,14	-0,28	**-0,21**
Urban land occupation	m2a	-0,019	-0,028	**-0,023**
Natural land transformation	m2	-2,4E-04	-4,0E-04	**-3,2E-04**
Water depletion	m3	-0,11	-0,19	**-0,15**
Metal depletion	kg Fe eq	-0,14	-0,27	**-0,20**
Fossil depletion	kg oil eq	-0,88	-1,4	**-1,1**

Table 39: Glass-related environmental impacts of scenario 1 (Dismantling when possible) for the treatment of an average ELV

7.5 Scenario 2: Maximal dismantling of ELV windows

7.5.1 Description

In scenario 2 the transport of ELV to a depollution center partly changes:

— Transport B: Car transporter, for the ELV belonging to the Eco-Boni system remains the same as in the previous scenarios 0 and 1

— Transport A is no longer allowed for non-Eco-Boni ELV, as it breaks the ELV windows. This transport will be replaced by Transport B' (for ELV that are still able to drive onto a car transporter) and Transport C (for ELV that are unable to do so), in equal amounts (assumption).

As all windows will remain intact by these transport modes, all ELV glass can be dismantled for glass recycling, yielding 26,9 kg of dismantled glass per ELV.

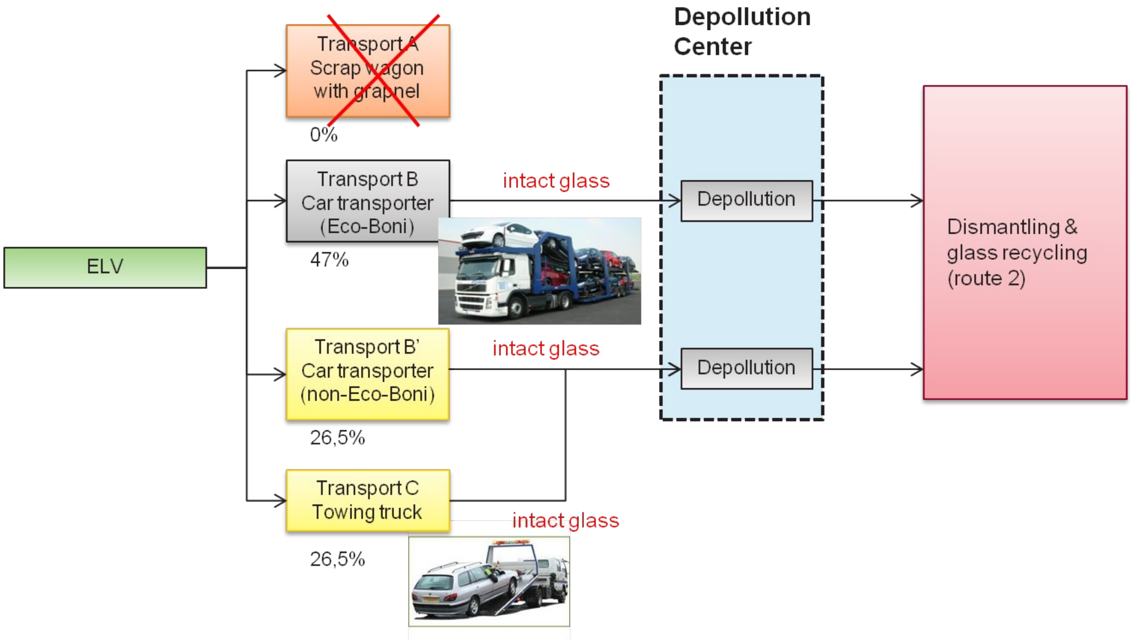

Figure 34: Scenario 2 (Maximal dismantling of ELV glass)

7.5.2 Environmental profile of scenario 2

As is shown in Figure 34, scenario 2 consists of 3 branches: B, B' and C. Although the transport modes towards the depollution center differ, the amount of glass that can be dismantled stays the same.

Branch B is identical to the branch B of scenario 1 (Figure 31). The two other branches are different, transport B' (car transporter non-Eco-Boni) and C (towing truck), both replacing transport A. Using the 2011 figures, scenario 2 implies that for about 53% of ELV a change in transport is required (from A towards B' and C) for the purpose of glass dismantling. This change in transport of ELV does not only influence the environmental impacts of ELV glass transport, but also changes the environmental impacts of the transport of the full ELV carcass. As in this study, a streamlined LCA approach is used in which the impacts of ELV carcass treatment were assumed to be constant between different scenarios, it is necessary to correct for this difference in order to maintain equivalence between the scenarios. Using the transport impacts calculated in Table 37, we calculate the correction per ton (or per ELV) as follows:

For transport B': $\text{Impact}_{(\text{Transport B'})}$ -$\text{Impact}_{(\text{Transport A})}$

For transport C: $\text{Impact}_{(\text{Transport C})}$ -$\text{Impact}_{(\text{Transport A})}$

This correction factor is multiplied by the contribution of each transport type (in scenario 2 the factor 0,5 is taken for both B' and C, as a 50/50 distribution is assumed), and by 0,53, as only in 53% of ELV a transport change is necessary. These corrected transport impacts are then added to the environmental impacts of the dismantling.

Numerical values of the impacts per ELV are listed in Table 40 for all three branches separately (per ELV). The overall impact of scenario 2 is calculated by combining these 3 branches using the 2011 ratio.

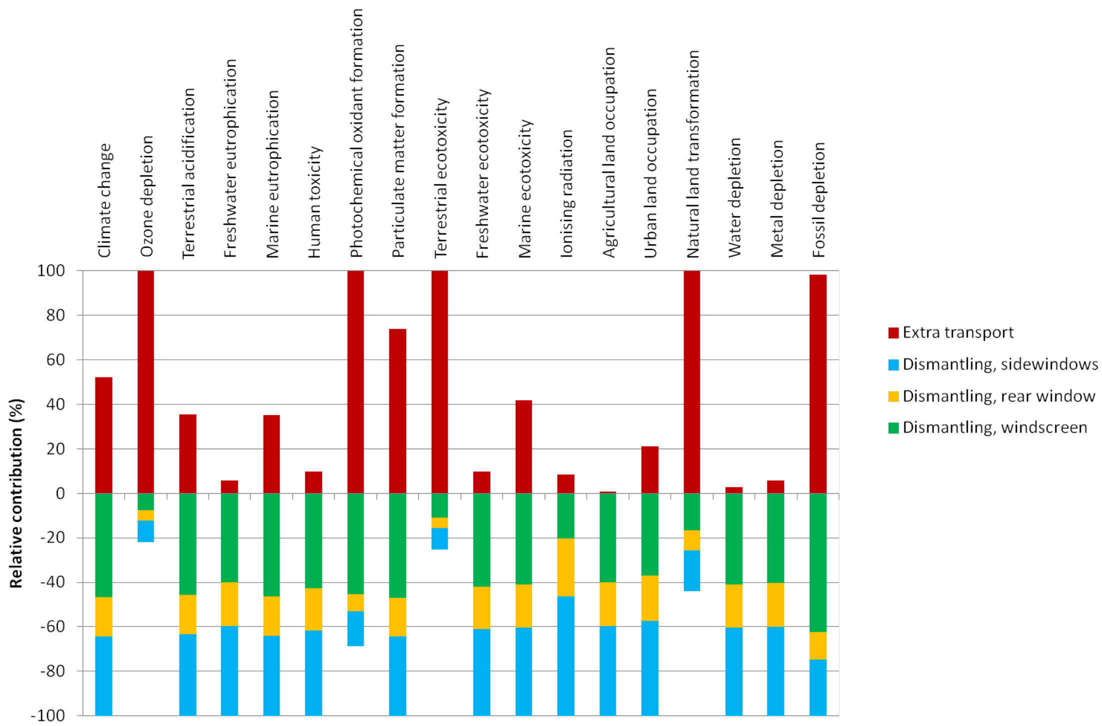

Figure 35: Environmental profile of scenario 2 (streamlined results)

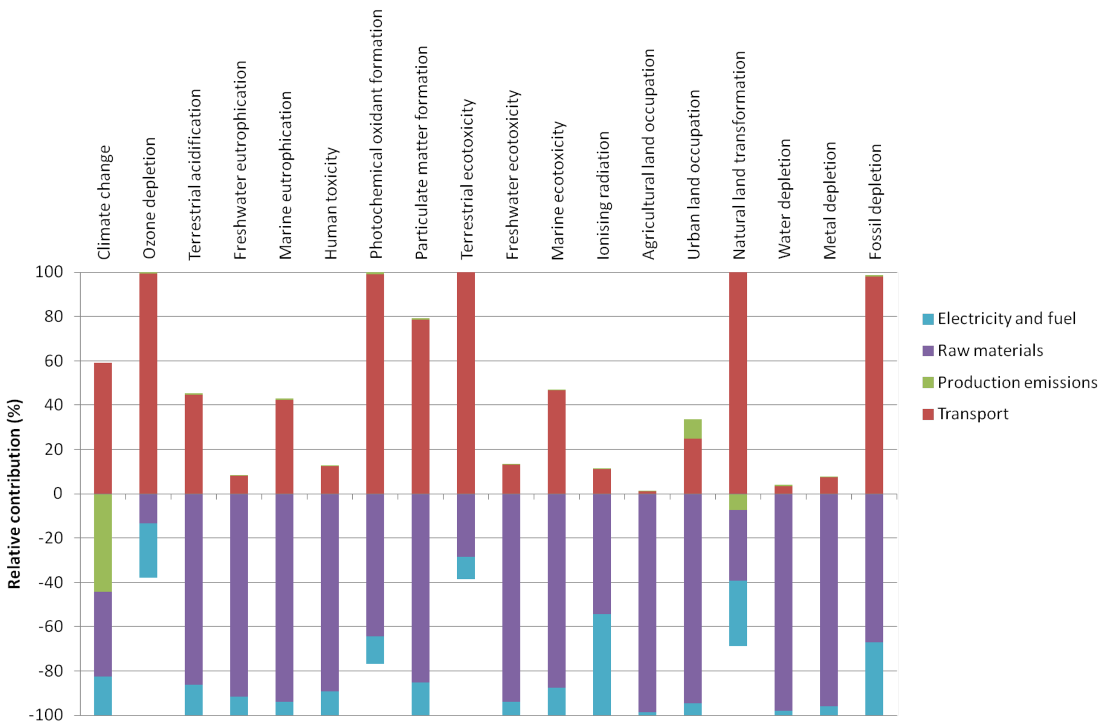

Figure 36: Environmental profile of scenario 2 (streamlined results)

Figure 35 shows the streamlined environmental profile of scenario 2. In Figure 36 a differentiation is made between the different process types that contribute to the environmental burdens and benefits.

Transport operations are the main contributors to the environmental burdens. Due to the significant transport efforts that are required prior to depollution, these transport burdens have increased considerably in comparison with scenario 1. The avoidance of primary minerals in glass (and PVC) production generates most of the environmental benefits, followed by avoided energy use. (see paragraph 6.4.2 for a more detailed discussion of the environmental benefits of the recycling of cullet and PVB.) The increased transport efforts in scenario 2 have a significant influence on the overall environmental impacts. The additional transport efforts represent an environmental burden that is larger than the environmental benefit of the additional glass recycling. For some impact categories, even a net environmental burden has arisen.

Numerical values of the (streamlined) environmental impacts per ELV are listed in Table 40.

		Glass-related environmental impacts of scenario 2			
Impact category	**Unit**	**Dismantling and glass recycling (route 2, per ELV)**	**Streamlining correction transport B' (per ELV)**	**Streamlining correction transport C (per ELV)**	**Scenario 2 (per ELV)**
Climate change	kg CO2 eq	-8,4	4,1	12	**-4,0**
Ozone depletion	kg CFC-11 eq	-1,6E-07	5,0E-07	2,3E-06	**5,8E-07**
Terrestrial acidification	kg SO2 eq	-0,025	0,013	0,021	**-0,016**
Freshwater eutrophication	kg P eq	-0,0014	1,1E-04	2,0E-04	**-0,0014**
Marine eutrophication	kg N eq	-0,0014	5,6E-04	0,0013	**-9,3E-04**
Human toxicity	kg 1,4-DB eq	-1,5	0,14	0,40	**-1,3**
Photochemical oxidant formation	kg NMVOC	-0,011	0,016	0,043	**0,0048**
Particulate matter formation	kg PM10 eq	-0,0069	0,0048	0,014	**-0,0018**
Terrestrial ecotoxicity	kg 1,4-DB eq	-3,5E-04	8,1E-04	0,0044	**0,0010**
Freshwater ecotoxicity	kg 1,4-DB eq	-0,034	0,0037	0,0092	**-0,031**
Marine ecotoxicity	kg 1,4-DB eq	-0,027	0,0069	0,035	**-0,016**
Ionising radiation	kg U235 eq	-0,93	0,076	0,22	**-0,85**
Agricultural land occupation	m2a	-0,28	0,0024	0,01	**-0,28**
Urban land occupation	m2a	-0,028	0,0069	0,016	**-0,022**
Natural land transformation	m2	-4,0E-04	0,0020	0,0014	**5,1E-04**
Water depletion	m3	-0,19	0,0048	0,014	**-0,18**
Metal depletion	kg Fe eq	-0,27	0,015	0,043	**-0,25**
Fossil depletion	kg oil eq	-1,4	1,3	3,7	**-0,025**

Table 40: Glass-related environmental impacts of scenario 2 (Maximal dismantling) for the treatment of an average ELV

7.6 Conclusions

7.6.1 Comparison of the studied scenarios

In Figure 37 the net results of the three studied scenarios are compared in order to see their relative differences. It is clear that the burdens and benefits related to scenario 0 (business-as-usual) are relatively small compared to scenarios 1 and 2. Scenario 1 generates environmental benefits on all impact categories, while the net result of scenario 2 is mixed: on some impact categories an additional environmental benefit can be established in comparison with scenario 1 (freshwater eutrophication and ecotoxicity, human toxicity, ionising radiation, agricultural land occupration and water and metal depletion). However, in other impact categories the benefits related to scenario 2 are significantly reduced by the additional transport requirements of the ELV carcass (climate change, particulate matter formation, fossil depletion) or transformed into net environmental burdens (ozone depletion, photochemical oxidant formation, terrestrial ecotoxicity, natural land transformation).

The numerical impact values of the three scenarios are summarized again in Table 41.

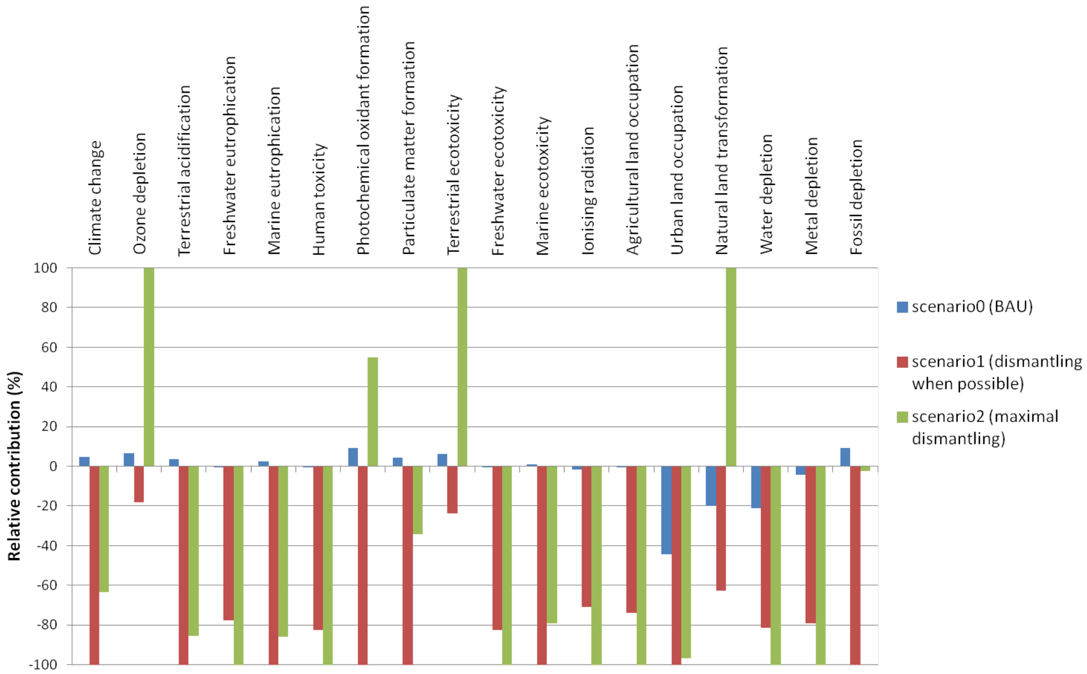

Figure 37: Comparison of the environmental impacts of the studied scenarios

		Scenario comparison		
Impact category	**Unit**	**Scenario 0 (per ELV)**	**Scenario 1 (per ELV)**	**Scenario 2 (per ELV)**
Climate change	kg CO2 eq	0,30	-6,4	-4,0
Ozone depletion	kg CFC-11 eq	3,8E-08	-1,1E-07	5,8E-07
Terrestrial acidification	kg SO2 eq	7,1E-04	-0,019	-0,016
Freshwater eutrophication	kg P eq	-3,2E-06	-1,1E-03	-0,0014
Marine eutrophication	kg N eq	2,8E-05	-1,1E-03	-9,3E-04
Human toxicity	kg 1,4-DB eq	-0,0042	-1,1	-1,3
Photochemical oxidant formation	kg NMVOC	8,2E-04	-0,0088	0,0048
Particulate matter formation	kg PM10 eq	2,3E-04	-0,0052	-0,0018
Terrestrial ecotoxicity	kg 1,4-DB eq	6,2E-05	-2,4E-04	1,0E-03
Freshwater ecotoxicity	kg 1,4-DB eq	-4,9E-05	-0,026	-0,031
Marine ecotoxicity	kg 1,4-DB eq	2,2E-04	-0,020	-0,016
Ionising radiation	kg U235 eq	-0,015	-0,60	-0,85
Agricultural land occupation	m2a	-5,5E-04	-0,21	-0,28
Urban land occupation	m2a	-0,010	-0,023	-0,022
Natural land transformation	m2	-1,0E-04	-3,2E-04	5,1E-04
Water depletion	m3	-0,039	-0,15	-0,18
Metal depletion	kg Fe eq	-0,011	-0,20	-0,25
Fossil depletion	kg oil eq	0,10	-1,1	-0,025

Table 41: Comparison of the environmental impacts of the studied scenarios

7.6.2 Weighting of impact categories

Figure 38 shows the environmental impacts of the different treatment scenarios for 1 average ELV as a single score (ReCipe Endpoint (H)/Europe H/A). The single score approach uses weighting factors in order to weigh the relative importance of each impact category and generates an 'overall' environmental impact, expressed in millipoints (mPt). The assumptions made in order to define the weighting factors are inherent to the method. As can be seen in the graph, the environmental impacts related to climate change (with effects both for ecosystems and for human health) and fossil depletion dominate the profiles.

Please note that weighting is not supported by ISO because of the subjective character, particularly not in comparative assertions. In this study weighting is included to allow better interpretation. It is important to keep in mind the environmental profiles on an impact-category basis, as presented in the previous paragraph.

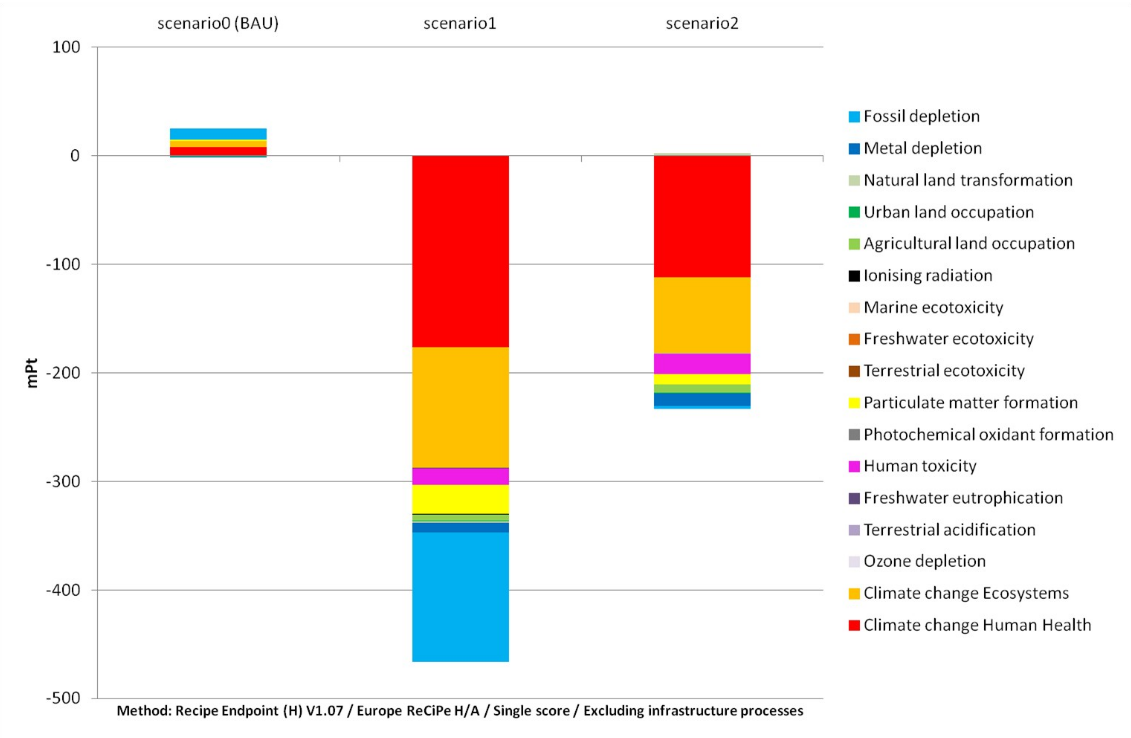

Figure 38: Single score impact of the treatment of 1 average ELV (ReCiPe Endpoint (H)/ Europe H/A)

		Scenario comparison (per ELV)		
Impact category	**Unit**	**Scenario 0**	**Scenario 1**	**Scenario 2**
Total	mPt	24	-467	-231
Climate change Human Health	mPt	8,3	-176	-112
Climate change Ecosystems	mPt	5,2	-111	-71
Ozone depletion	mPt	0,002	-0,005	0,03
Terrestrial acidification	mPt	0,009	-0,2	-0,2
Freshwater eutrophication	mPt	-0,0003	-0,1	-0,1
Human toxicity	mPt	-0,06	-15	-19
Photochemical oxidant formation	mPt	0,0006	-0,007	0,004
Particulate matter formation	mPt	1,2	-27	-9,3
Terrestrial ecotoxicity	mPt	0,02	-0,08	0,3
Freshwater ecotoxicity	mPt	-0,0001	-0,05	-0,06
Marine ecotoxicity	mPt	0,0001	-0,008	-0,006
Ionising radiation	mPt	-0,005	-0,2	-0,3
Agricultural land occupation	mPt	-0,01	-5,4	-7,3
Urban land occupation	mPt	-0,5	-1,1	-1,0
Natural land transformation	mPt	-0,6	-1,2	1,9
Metal depletion	mPt	-0,5	-9,3	-12
Fossil depletion	mPt	11	-119	-2,5

Table 42: Single score impact of the treatment of 1 average ELV (ReCiPe Endpoint (H)/ Europe H/A)

7.6.3 Sensitivity analysis: spare part dismantling

In the scenarios only glass losses due to accidents and dismantling inefficiencies were taken into account. However, in Belgium several dedicated workshops are active that dismantle parts and components (e.g. motor block) for the second hand market (or for export), while metals are recovered by scrap dealers. At present the majority of dismantling workshops are also certified as official depollution center. In the case of recent models, the ELV is almost fully dismantled for the spare part market, including windows (source: DJ Autoparts). Most reuse of windows takes place under the form of dismantling of complete doors. In 2012, about 41.000 ELV were dismantled in dedicated workshops in Belgium. It is estimated that 50% of the windows from the 41,000 ELV that are handled by dismantling workshops are removed for reuse, which represents 12% of all ELV glass (source: Febelauto).

A sensitivity analysis is performed with an additional glass loss of 12% prior to depollution. The results are presented in Figure 39 and Table 43. As may be expected, the environmental benefits in scenarios 1 and 2 are lower than the results in Table 42.

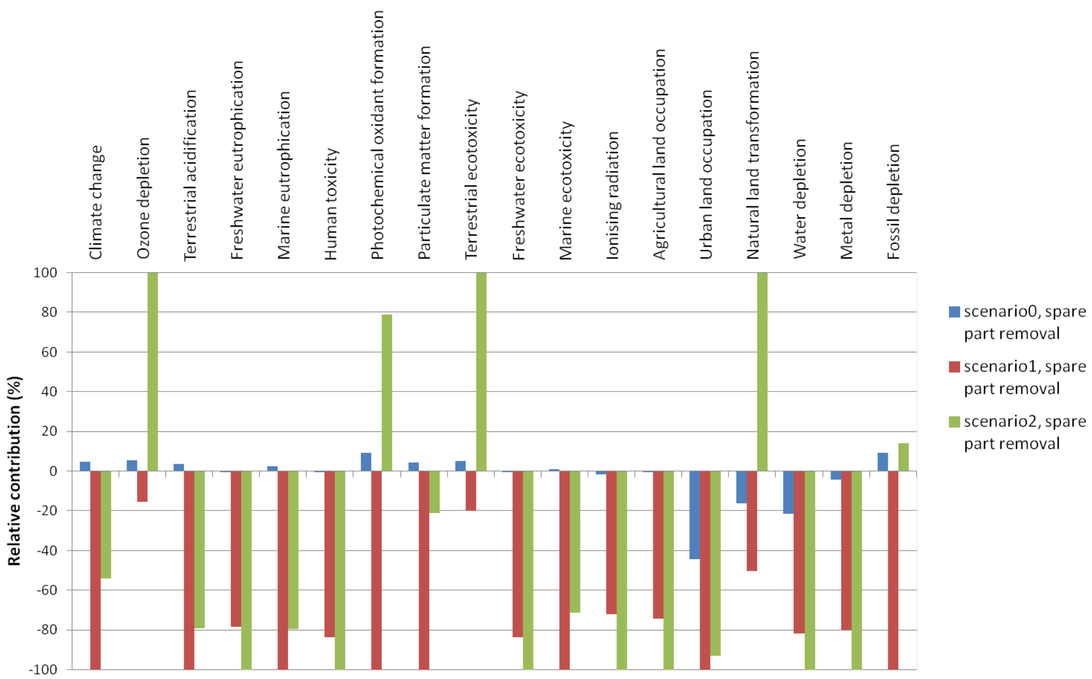

Figure 39: Sensitivity analysis spare part removal

		Scenario comparison		
Impact category	**Unit**	**Scenario 0 (per ELV)**	**Scenario 1 (per ELV)**	**Scenario 2 (per ELV)**
Climate change	kg CO2 eq	0,26	-5,6	-3,0
Ozone depletion	kg CFC-11 eq	3,4E-08	-9,3E-08	5,9E-07
Terrestrial acidification	kg SO2 eq	6,2E-04	-0,017	-0,013
Freshwater eutrophication	kg P eq	-2,8E-06	-9,4E-04	-0,0012
Marine eutrophication	kg N eq	2,5E-05	-0,0010	-7,6E-04
Human toxicity	kg 1,4-DB eq	-0,0037	-1,0	-1,2
Photochemical oxidant formation	kg NMVOC	7,3E-04	-0,0078	0,0061
Particulate matter formation	kg PM10 eq	2,1E-04	-0,0046	-0,0010
Terrestrial ecotoxicity	kg 1,4-DB eq	5,5E-05	-2,1E-04	1,1E-03
Freshwater ecotoxicity	kg 1,4-DB eq	-4,3E-05	-0,023	-0,027
Marine ecotoxicity	kg 1,4-DB eq	1,9E-04	-0,017	-0,012
Ionising radiation	kg U235 eq	-0,013	-0,53	-0,74
Agricultural land occupation	m2a	-4,8E-04	-0,18	-0,24
Urban land occupation	m2a	-0,0091	-0,020	-0,019
Natural land transformation	m2	-8,9E-05	-2,8E-04	5,5E-04
Water depletion	m3	-0,034	-0,13	-0,16
Metal depletion	kg Fe eq	-0,010	-0,18	-0,22
Fossil depletion	kg oil eq	0,088	-1,0	0,14

Table 43: Sensitivity for spare part removal

7.6.4 Sensitivity analysis: transport operations (reduced fuel use)

In order to estimate the influence of the assumptions made for the transport operations, the environmental impacts of both treatment routes are recalculated, assuming a reduction in fuel use.

In this sensitivity analysis, the diesel consumption is assumed to vary between 20,4 (empty) and 31 (full) liter per 100 km, for the scrap wagon (see 7.2.2) and the car transporter (see 7.2.3). To get the full picture on the influence of transport assumptions on the scenario analysis, the changes that are described in the sensitivity analysis in 6.5.3 are also included. The diesel consumption of the towing lorry, and all other assumptions (load, distance, type of truck used) are unchanged.

These fuel estimations are taken from the MIMOSA tool, which was designed by VITO to calculate emissions caused by road transportation, based on the COPERT 4-methodology (EMEP/CORINAIR, 2007[21], Ntziachristos and Samaras, 2010[22]) and finetuned to match the Belgian situation.

Load		**Diesel consumption**	**Ecoinvent data record**	**Remark**
Transport A: Scrap wagon and grapnel				
0%	0 tonne	0,204 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
40%	4,8 tonnes	0,247 l/km		Average load (4,8 ELV)
Transport B: Car transporter (Eco-Boni-system)				
0%	0 tonnes	0,204 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
100%	8 tonnes	0,31 l/km		Full load (8 ELV)
Transport B': Car transporter (non-Eco-Boni)				
0%	0 tonnes	0,204 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
50%	4 tonnes	0,258 l/km		Milk-round, average load (4 ELV)
Transport C:Towing lorry				
0%	0 tonnes	0,10 l/km	Operation, lorry 3,5-16 t, EURO5, RER U*	Empty return trip
100%	1 tonne	0,12 l/km		1 ELV
* using Diesel, at regional storage, RER/U instead of CH/U				

Table 44: LCI transport operations between garage and depollution center

The results are presented in Figure 40 and Table 45. As may be expected, the reduction in fuel use causes the environmental burdens in scenario 0 to become smaller, while the benefits in scenario 1 are larger in comparison with the results in Table 41. A more surprising result is the fact that the environmental benefits associated with scenario 2 are smaller in the case of reduced fuel use (-3,1 kg CO_2 eq. instead of 4,0 in the reference case). This counter-intuitive result is due to the fact that only the fuel use of the different truck types was reduced, while the fuel use of the towing lorry was kept unchanged. In scenario 2, 26,5% of ELV are transported by towing lorry (see Figure 34) instead of scrap truck. As the impact of the (avoided) scrap truck

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21 EMEP/CORINAIR. EMEP/CORINAIR Emission inventory Guidebook - 2007: Group 7 - Road transport. EEA. 5-12-2007. 1-11-2009.

22 Ntziachristos, Leonidas and Samaras, Zissis. EMEP/EEA emission inventory guidebook 2009, updated June 2010: Exhaust emissions from road transport. EMEP/CORINAIR. 2010. 5-3-2013.

transport is reduced while the impact of the towing lorry is not, this implies that the correction factor for branch C becomes larger, so the net environmental burden of the additional transport effort in scenario 2 increases. This explains why the overall net environmental benefit of scenario 2 is lower than in the reference situation (Table 41).

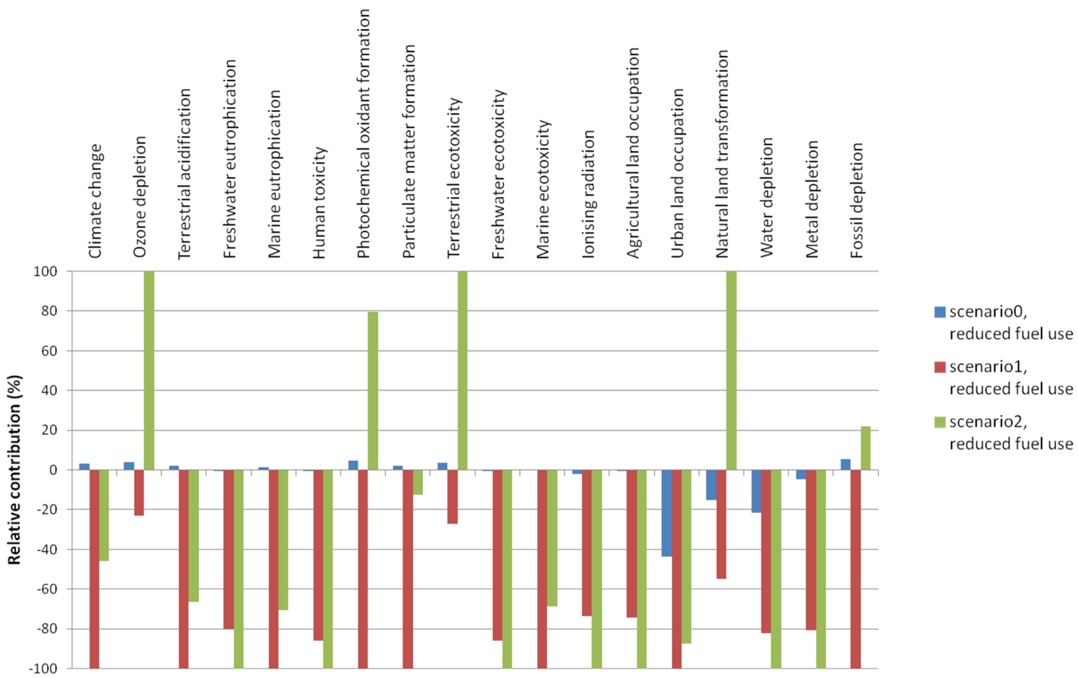

Figure 40: Sensitivity analysis transport operations (reduced fuel use)

		Scenario comparison		
Impact category	**Unit**	**Scenario 0**	**Scenario 1**	**Scenario 2**
Climate change	kg CO2 eq	0,21	-6,8	-3,1
Ozone depletion	kg CFC-11 eq	2,7E-08	-1,6E-07	6,9E-07
Terrestrial acidification	kg SO2 eq	4,3E-04	-0,020	-0,013
Freshwater eutrophication	kg P eq	-5,6E-06	-0,0011	-0,0013
Marine eutrophication	kg N eq	1,6E-05	-0,0011	-8,1E-04
Human toxicity	kg 1,4-DB eq	-0,0074	-1,1	-1,3
Photochemical oxidant formation	kg NMVOC	4,8E-04	-0,010	0,0083
Particulate matter formation	kg PM10 eq	1,3E-04	-0,0057	-7,2E-04
Terrestrial ecotoxicity	kg 1,4-DB eq	4,4E-05	-3,3E-04	0,0012
Freshwater ecotoxicity	kg 1,4-DB eq	-1,3E-04	-0,026	-0,030
Marine ecotoxicity	kg 1,4-DB eq	6,1E-05	-0,021	-0,014
Ionising radiation	kg U235 eq	-0,017	-0,61	-0,83
Agricultural land occupation	m2a	-6,0E-04	-0,21	-0,28
Urban land occupation	m2a	-0,010	-0,024	-0,021
Natural land transformation	m2	-1,5E-04	-5,3E-04	9,6E-04
Water depletion	m3	-0,039	-0,15	-0,18
Metal depletion	kg Fe eq	-0,011	-0,20	-0,25
Fossil depletion	kg oil eq	0,070	-1,2	0,27

Table 45: Sensitivity analysis transport operation (reduced fuel use)

7.6.5 Sensitivity analysis: pre-depollution transport operations (load)

In this sensitivity analysis, variations are made in the load of the trucks that transport the ELV from end user to the depollution center. Differences will only become visible in the results of scenario 2, as this transport phase is omitted from the calculations for scenarios 0 and 1 due to the streamlining approach.

It is assumed that a scrap wagon (see 7.2.2) on average harbours 3 ELV (instead of 4,8 in the reference situation), while the car transporter in the non-Eco-Boni system (see 7.2.3) on average transports 5,6 ELV (instead of 4). The load of a towing lorry (1 ELV), and all other assumptions (empty/full fuel use, distance, type of truck used) are unchanged.

Load		**Diesel consumption**	**Ecoinvent data record**	**Remark**
Transport A: Scrap wagon and grapnel				
0%	0 tonne	0,33 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
25%	3 tonnes	0,34 l/km		Average load (3 ELV)
Transport B: Car transporter (Eco-Boni-system)				
0%	0 tonnes	0,33 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
100%	8 tonnes	0,37 l/km		Full load (8 ELV)
Transport B': Car transporter (non-Eco-Boni)				
0%	0 tonnes	0,33 l/km	Operation, lorry 16-32 t, EURO5, RER U*	Empty return trip
70%	5,6 tonnes	0,358 l/km		Milk-round, average load (5,6 ELV)
Transport C:Towing lorry				
0%	0 tonnes	0,10 l/km	Operation, lorry 3,5-16 t, EURO5, RER U*	Empty return trip
100%	1 tonne	0,12 l/km		1 ELV
* using Diesel, at regional storage, RER/U instead of CH/U				

Table 46: LCI transport operations between garage and depollution center

The results are presented in Figure 41 and Table 47. The results for scenarios 0 and 1 remain unchanged due to streamlining. As may be expected, the environmental benefits of scenarios 2 are larger in comparison with the results in Table 42. For some impact categories they even become comparable to or significantly larger than the environmental benefits of scenario 1. This is due to the choice of load assumptions, that increase the environmental burden per ELV for scrap truck transport (lower average load), which is avoided in scenario 2, while it decreases the environmental burden per ELV for transport by car transporter (higher average load).

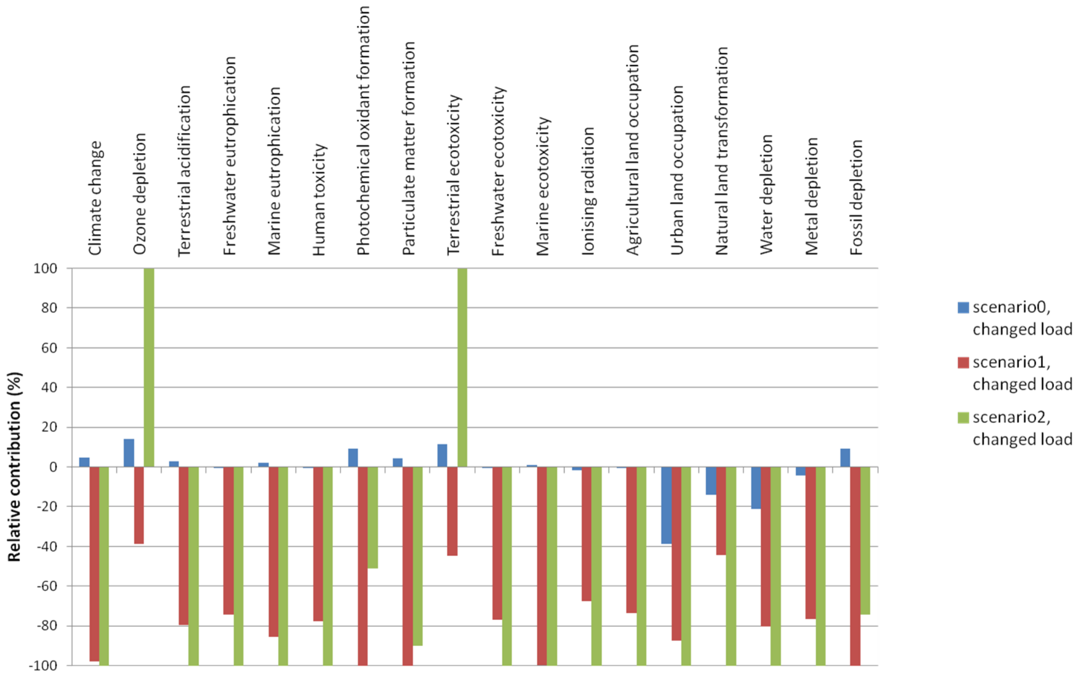

Figure 41: Sensitivity analysis pre-depollution transport operations (load)

		Scenario comparison (per ELV)		
Impact category	**Unit**	**Scenario 0**	**Scenario 1**	**Scenario 2**
Climate change	kg CO2 eq	0,30	-6,4	-6,5
Ozone depletion	kg CFC-11 eq	3,8E-08	-1,1E-07	2,7E-07
Terrestrial acidification	kg SO2 eq	7,1E-04	-0,019	-0,024
Freshwater eutrophication	kg P eq	-3,2E-06	-0,0011	-0,0014
Marine eutrophication	kg N eq	2,8E-05	-0,0011	-1,3E-03
Human toxicity	kg 1,4-DB eq	-0,0042	-1,1	-1,4
Photochemical oxidant formation	kg NMVOC	8,2E-04	-0,009	-0,0045
Particulate matter formation	kg PM10 eq	2,3E-04	-0,0052	-4,7E-03
Terrestrial ecotoxicity	kg 1,4-DB eq	6,2E-05	-2,4E-04	0,0005
Freshwater ecotoxicity	kg 1,4-DB eq	-4,9E-05	-0,026	-0,033
Marine ecotoxicity	kg 1,4-DB eq	2,2E-04	-0,020	-0,020
Ionising radiation	kg U235 eq	-0,015	-0,60	-0,89
Agricultural land occupation	m2a	-5,5E-04	-0,21	-0,28
Urban land occupation	m2a	-0,010	-0,023	-0,027
Natural land transformation	m2	-1,0E-04	-3,2E-04	-7,1E-04
Water depletion	m3	-0,039	-0,15	-0,18
Metal depletion	kg Fe eq	-0,011	-0,20	-0,26
Fossil depletion	kg oil eq	0,10	-1,1	-0,83

Table 47: Sensitivity analysis pre-depollution transport operations (load)

7.6.6 Sensitivity analysis: pre-depollution transport operations (type)

As a large part of the impacts of the first transport phase between end user and depollution center are related to the use of a towing truck (with a high fuel consumption per ELV transported), this last sensitivity analysis reduces the share of towing truck transport for non-Ecoboni ELV to 20% (instead of 50% in the reference situation), meaning that the remaining 80% are transported by car transporter (instead of 50%). All other factors (load, fuel use, distance) are unchanged in comparison with the original assumptions.

The results are presented in Figure 42 and Table 48. The results for scenarios 0 and 1 remain unchanged due to streamlining. As may be expected, the environmental benefits of scenario 2 are larger than in the reference situation (Table 42).

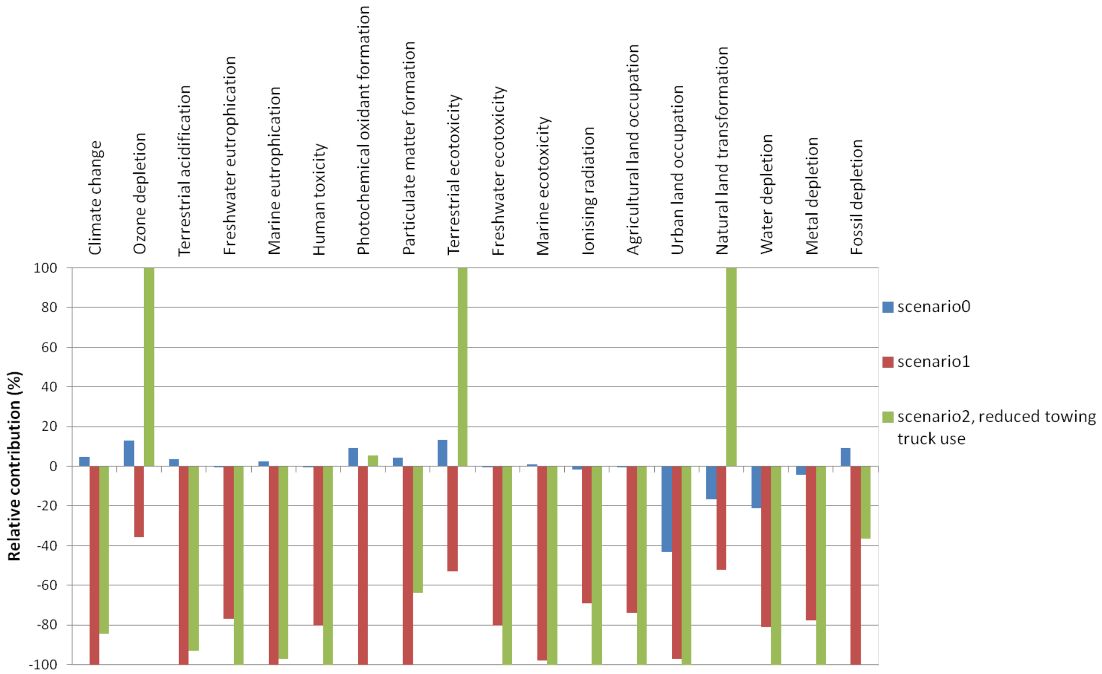

Figure 42: Sensitivity analysis pre-depollution transport operations (type)

		Scenario comparison (per ELV)		
Impact category	**Unit**	**Scenario 0**	**Scenario 1**	**Scenario 2**
Climate change	kg CO2 eq	0,30	-6,4	-5,4
Ozone depletion	kg CFC-11 eq	3,8E-08	-1,1E-07	2,9E-07
Terrestrial acidification	kg SO2 eq	7,1E-04	-0,019	-0,018
Freshwater eutrophication	kg P eq	-3,2E-06	-0,0011	-0,0014
Marine eutrophication	kg N eq	2,8E-05	-0,0011	-0,0011
Human toxicity	kg 1,4-DB eq	-0,0042	-1,1	-1,4
Photochemical oxidant formation	kg NMVOC	8,2E-04	-0,009	4,8E-04
Particulate matter formation	kg PM10 eq	2,3E-04	-0,0052	-0,0033
Terrestrial ecotoxicity	kg 1,4-DB eq	6,2E-05	-2,4E-04	4,6E-04
Freshwater ecotoxicity	kg 1,4-DB eq	-4,9E-05	-0,026	-0,032
Marine ecotoxicity	kg 1,4-DB eq	2,2E-04	-0,020	-0,020
Ionising radiation	kg U235 eq	-0,015	-0,60	-0,87
Agricultural land occupation	m2a	-5,5E-04	-0,21	-0,28
Urban land occupation	m2a	-0,010	-0,023	-0,024
Natural land transformation	m2	-1,0E-04	-3,2E-04	6,1E-04
Water depletion	m3	-0,039	-0,15	-0,18
Metal depletion	kg Fe eq	-0,011	-0,20	-0,26
Fossil depletion	kg oil eq	0,10	-1,1	-0,41

Table 48: Sensitivity analysis pre-depollution transport operations (type)

8 Conclusions

In this study it has been shown that the **dismantling of ELV glass** with recycling of the resulting cullet in the glass industry and recovery of the PVB in the plastics industry **has significant environmental benefits over the current practice of shredding**. By using cullet in glass production, primary materials (silica sand, soda, limestone, dolomite) and energy are saved, which yields higher environmental benefits than the avoiding of building sand by the production of a post-shredder mineral fraction.

The impacts of the recycling processes (shredding, PST, crushing,...) themselves are of minor influence, **it is the secondary application that dominates the environmental profile**. The glass industry accepts all recycled glass, as long as certain quality criteria are met. If future PST technology could be improved in such a way that a glass fraction can be separated that meets the requirements of the glass industry, the overall environmental profile of the shredding route could be improved significantly.

Despite the fact that dismantling of glass generates a net environmental benefit, even in the best case scenario (scenario 1) the **environmental benefits that can be expected from glass dismantling and recycling are relatively small**. The treatment of automotive glass according to scenario 1 yields the same average CO_2 reduction per ELV (6,4 kg) as a reduction in personal car use of 27 km (see Table 26). Furthermore, the total glass flow generated annually by ELVs is estimated to be about 5000 tonnes, which is also a limited quantity. Assuming that an average car drives about 15.600 km per year[23], the CO_2 reduction potential of treating 170000 ELV yearly according to scenario 1, equals the yearly CO_2 emissions of roughly 300 average personal cars (1100 tonnes CO_2).

From the single score results, it was concluded that **(avoided) climate change (caused by CO_2 emissions) is the most important environmental impact** of ELV glass recycling processes, followed by (avoided) depletion of fossil resources.

Transport operations contribute significantly to the environmental burdens of the recycling operations. At the same time, during this study, transport characteristics (type, average load, distances, fuel consumption per tonne transported) proved to be hardest to estimate. Several sensitivity analyses were performed. When only post-depollution center processes are considered, changes in transport assumptions have a relatively low influence on the overall result and glass dismantling (route 2) clearly is preferred over shredding (route 1) from an environmental point-of-view. About half of all Belgian ELV arrive in the depollution center with intact windows, while the other half of (damaged) ELV have at least some windows that could be dismantled. Dismantling of these windows would generate a clear net environmental benefit (scenario 1) in comparison with the current practice of shredding all ELV completely (scenario 0). However, for the damaged ELV, the transport operations between end-user and depollution center could be changed in order to keep the windows intact so that they can be fully dismantled. When the burdens generated by these additional transport efforts are accounted for in the analysis, the overall results can change significantly (scenario 2). Especially in this last scenario, changing assumptions about the transport characteristics (load, fuel use, type of transport, distance) have a large influence on the end result. So, if adjustments in transport modes are necessary to meet ambitious recycling goals, a detailed study on logistics of ELV treatment is necessary, in order to generate more reliable results. A careful balance should be made between the benefits of closing the glass loop for all ELV and the additional transport impacts that are generated by doing so, to avoid the shifting of burdens.

It is important to note that this study departed from the **current organizational and logistic situation** of ELV treatment in Belgium and assessed scenario's that took this situation as a prerequisite. Of course, a different organization scheme could be thought of to avoid additional transport requirements (e.g. dismantling of glass in the garage where the end consumer brings

23 http://www.mobimix.be/inhoud/2012/4/4/3046, figures for 2010

in his ELV, prior to the transport to a depollution center). However the investigation of the environmental impact of other organization schemes was not part of this study and is as such not included. In addition, changes as regulatory arrangements concerning ELV treatment (and glass treatment) could have significant effects on the ELV sector and its related markets, leading to considerable changes in the ELV treatment chain. These potential changes were not considered in this study.

Bijlage 1: Lijst van tabellen

Bijlage 2: Lijst van figuren

Afbeeldingenregister

Bijlage 3: Bibliografie

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