VOLKSWAGEN AG

Executive Summary
Life Cycle Assessment of End-of-Life Vehicle Treatment

Comparison of the VW-SiCon process and the dismantling of plastic components followed by mechanical recycling

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1 Summary

1.1 Motivation for and background to the study

The EU End-of-Life Vehicles Directive (2000/53/EC) [EU End-of-Life Vehicles Directive 2000] contains statutory specifications for the recovery and recycling quotas of end-of-life vehicles that must be satisfied as from 2006 resp. 2015.

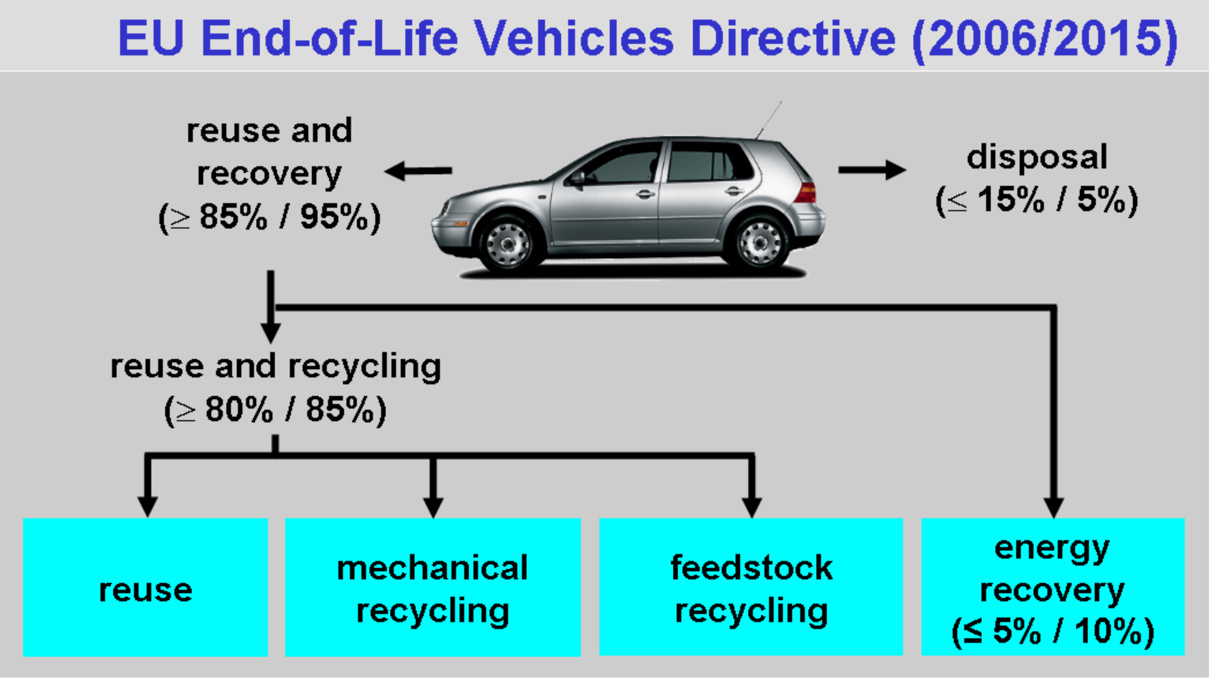

Figure 1-1: Specifications of the EU End-of-Life Vehicles Directive (2000/53/EC)

Figure 1-1 shows that as from 2006 resp. 2015 at least 85% resp. 95% of the average weight of an end-of-life vehicle must be recovered whilst the remaining materials may be disposed of. The vast majority of the total recovery quota is taken up by reuse and recycling (80% resp. 85% of the average weight per vehicle) whilst the proportion of energy recovery in the total recovery quota is restricted to a maximum of 5 resp 10% of the average weight per vehicle.

The current situation of end-of-life vehicle treatment is shown in Figure 1-2.

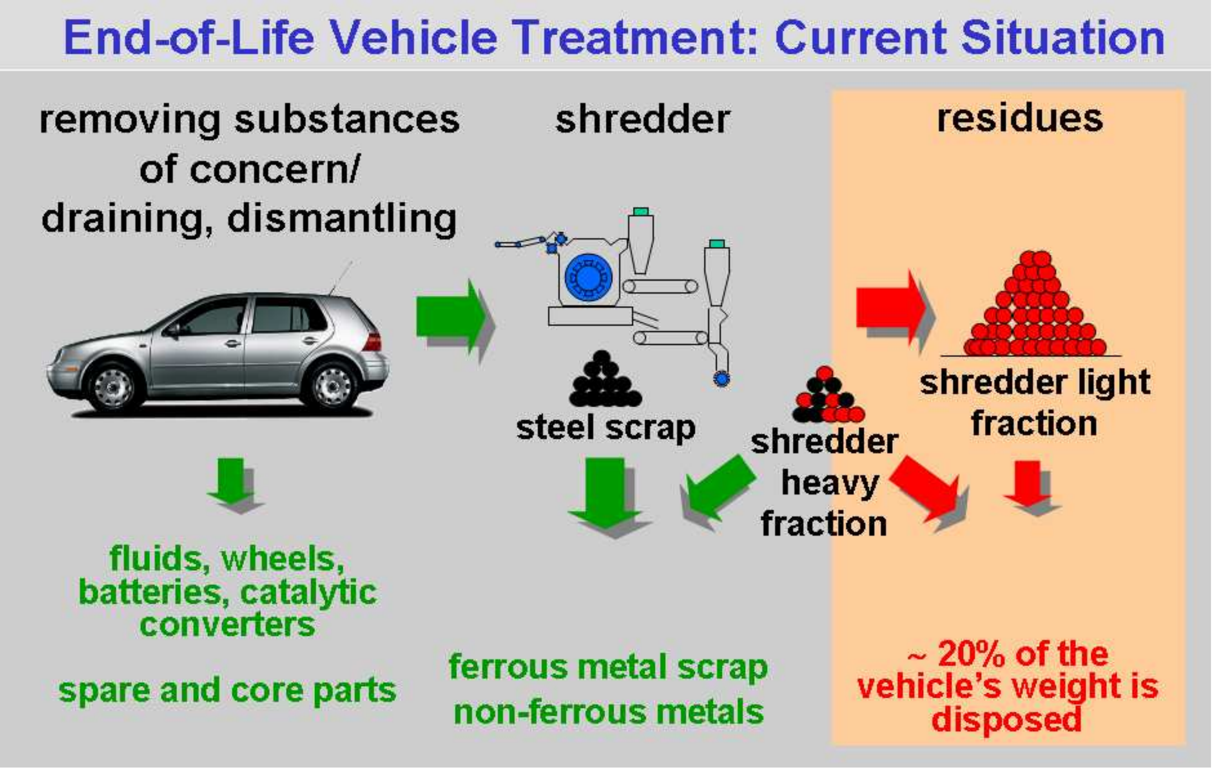

Figure 1-2: Current situation in end-of-life vehicle (ELV) treatment

The current situation of end-of-life vehicle recycling can be described as follows:

The first step is to drain the fluids and remove substances of concern from the end-of-life vehicle. Spare and core parts are removed if this is economically viable for the operator.

After pre-treatment the remaining body is fed into a shredder in which the majority of the iron content is recovered in the form of shredder scrap.

A second material flow, the shredder heavy fraction which contains the majority of non-ferrous metals, is fed into special plants for further processing.

The residue from this stage of the process is the non-metallic content of the heavy fraction, which together with the third material flow from the shredder (the shredder light fraction) constitutes the shredder residues.

These shredder residues (approx. 20% of the average weight per vehicle) currently undergo very little treatment and are mostly placed in landfill sites. This means that to achieve the required quotas for end-of-life vehicles, the majority of the material included in the shredder residues have to be recovered[1].

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[1] The fact that mechanical and feedstock recycling processes form the focus of this study is due to the high recycling and low energy recovery quotas for ELVs set out in the EU End-of-Life Vehicles Directive. Other studies [VDA-VKE 2004; LIRECAR 2004] have shown that the differences between the environmental profiles of mechanical, feedstock or energy recovery processes are small.

Shredder residues consist of plastics, rubber, glass, rust, lacquer particles, textile fibres, seat foam and small quantities of metal.

In principle the recycling quota required in future for an end-of-life vehicle can be achieved by two methods:

1. Separation of individual material flows from the shredder residues and specific treatment of these material flows mainly for subsequent feedstock recycling,
2. Removal of components before the shredder process and subsequent mechanical recycling.

1.2 Goal of the study

This study compares the environmental profiles of two different recycling methods for end-of-life vehicles:

a. The VW-SiCon process based mainly on feedstock recycling of material fractions that are specifically separated from the shredder residues of end-of-life vehicles after the shredder process.
b. The dismantling of plastic components from end-of-life vehicles followed by mechanical recycling.

Both of these options are suitable for achieving required quotas for end-of-life vehicles even in 2015.

The reason that dismantling was selected for comparison with the VW-SiCon process is that dismantling followed by mechanical recycling is often regarded as a particularly beneficial process in ecological terms. Nevertheless other studies also show that mechanical recycling does not offer any general environmental benefits compared to other processes [VDA-VKE 2004].

It should also be noted that the end-of-life phase of a vehicle plays a minor role in its complete life cycle [LIRECAR 2004].

This study is a comparative life cycle assessment in the sense of DIN EN ISO 14040ff [DIN 2000]. The results of the study have been reviewed by an external independent reviewer. The assumptions and data on which the study is based were supplied by plant operators and associations that monitored the project in the form of an advisory group.

1.3 End-of-life vehicle recycling processes covered by the study

The ***VW-SiCon process*** is a technology that was developed jointly by Volkswagen AG and SiCon GmbH with other technology partners over the past few years.

The VW-SiCon process is based on the principle of generating material flows from end-of-life vehicles by specific treatment and refinement of shredder residues, so that the gained materials can be used in existing plants as secondary raw materials substituting primary raw materials. The generated materials must therefore satisfy the quality standards imposed by the operators of such plants. Requirements that relate to the process as well as to the product and emissions of the operators' plants must be satisfied. Another premise in the development of the VW-SiCon process was that the generated materials should only be used in processes for which an adequately large market capacity exists. Concerning the produced fractions deriving from shredder residues such as shredder granulate, shredder fibres and shredder sand these capacities are sufficiently high.

Currently there are several VW-SiCon treatment plants under construction or being planned in European countries. The average treatment capacity of a VW-SiCon plant for shredder residues is approximately 100,000 tonnes per annum. In view of the annual shredder residues generated in Germany of approx. 450,000 tonnes (figure for 2003), this means that four to five VW-SiCon treatment plants will be required. Of this total quantity, however, only approximately 200,000 tonnes (figure for 2003) were generated by shredder residues from end-of-life vehicles. These quantities will not be treated separately, however, since on the one hand end-of-life vehicles are not shredded separately, and on the other hand the VW-SiCon process can - and should - also be used for shredder residues from other end-of-life goods (white goods, light mixed scrap, etc.).

To achieve these aims, potential plant operators and customers for produced VW-SiCon fractions were included in the development of the process at an early stage. This ensures that the requirements of the plant operators relating to the materials introduced into their processes are satisfied with respect to their chemical and physical properties. In parallel to the process development life-cycle assessment studies were performed in order to compare the environmental profile of different technologies. This approach, especially the constructive dialogue with technology partners along the added-value chain can be regarded as an important building block for successful life cycle management.

The VW-SiCon process has been proved successfully in several large scale tests. For example, the complete treatment and recovery chain was tested involving 700 end-of-life vehicles based on a standard market mix. Materials from the shredder residues were treated and then used successfully in the various plants.

The VW-SiCon fractions investigated in this study are:

- Shredder granulate (refined) is a plastic fraction with a low chlorine and metal content, that can be used as a reducing agent in blast furnaces as a substitute for heavy oil.
- A plastic fraction with a high PVC-content can be used to produce PVC in the Vinyloop process developed by Solvay.
- Shredder fibres (refined) are a mixture of textile fibres and seat foam, which can be used in sewage sludge dewatering as a dewatering agent instead of coal dust.
- Shredder sand (refined) consists of glass, fine iron particles, rust, fine copper wires, dust containing lead and zinc and lacquer particles. Glass, rust and lacquer particles can be used as slag builder in non-ferrous metallurgy as well as reducing agents (ferrous metals). Fine iron particles can also be used as reducing agents. Copper wires, lead and zinc dust are introduced back in the metallurgic cycle.
- Further ferrous and non-ferrous metals are recovered from the shredder residues.

The second process investigated in this study is the ***dismantling*** of plastic components from end-of-life vehicles followed by mechanical recycling. In order to achieve the recycling quotas plastic components are removed to an extent that the dismantled plastic fractions plus metal fractions from the shredder sum up to 85% of the average weight per vehicle. The remaining 10% quota is achieved by energy recovery from the remaining shredder residues.

As far as the collection of dismantled plastics is concerned, it should be noted that in practice only large, heavy components are collected separately whilst smaller and lighter components are collected in a mixed fraction. Therefore the following assumptions were made concerning the dismantling of plastic components and their subsequent mechanical recycling:

1. Components above 500 g will be separated into single type materials and supplied for mechanical recycling.
2. Components whose weight is below this threshold of 500 g will be collected in a mixed fraction.

For separated single type materials it has been assumed that the recycled plastic material can substitute the equivalent new product on a 1:1 ratio. The mixed plastic fraction was used to substitute concrete. The environmental expenditures for the cleaning of the dismantled components, the removal of metal parts and the separation of various plastic fractions from composite components were neglected so that the additional environmental burdens from the mechanical recycling of plastics are higher in practice than those described in this study. Therefore the mechanical recycling process described in this study constitutes a best case scenario.

1.4 Scope and functional unit

The functional unit is a reference end-of-life vehicle for recycling/recovery in 2015. This reference end-of-life vehicle is defined by a representative end-of-life vehicle mix in 2015 (various equipment packages and derivatives of the VW Golf 4 and the VW Golf 5). Since the VW Golf is one of the best-selling vehicles in Europe, the reference end-of-life vehicle used for the study may be regarded as a characteristic end-of-life vehicle in 2015. The recycling quotas that will come into force in 2015 (95% recovery, at least 85% recycling) were used as the target for the studied recycling processes. The scope of the study is given in Figure 1-3.

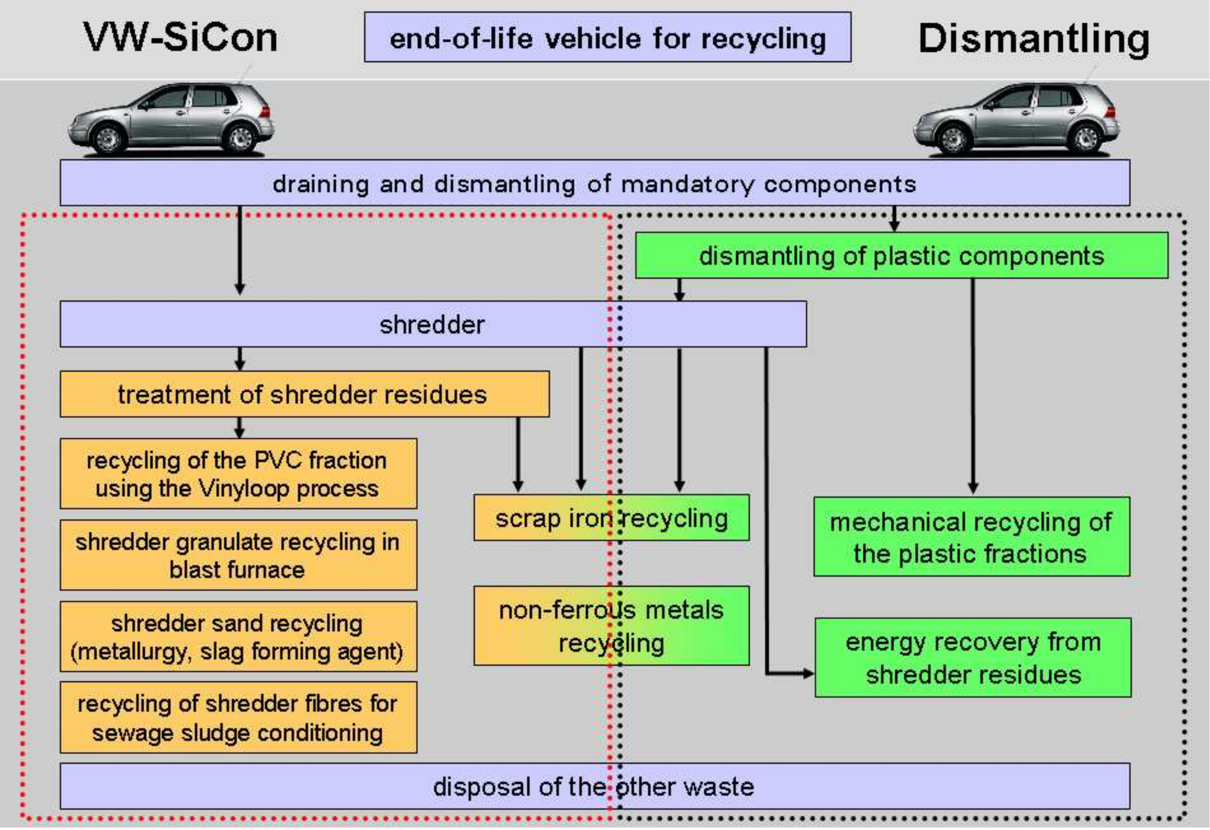

Figure 1-3: **Scope for the life cycle assessment comparison**

1.5 Sensitivity analyses

Different sensitivity analyses were conducted to study how the results of the life cycle assessment change if the model assumptions are varied. The following questions were discussed:

1. How do the LCA results change concerning the market capacities for the dismantled plastic materials? In this case other applications have to be taken into account, e.g. the production of pavement slabs (substitution as concrete). This subject was analysed by ***varying the substitution rate of recycled plastic materials into new plastic products***.
2. Which effect could be expected resulting from a modification of the amount of plastics collected in single type materials to substitute virgin material? By ***considering plastic components down to a weight of 100 g*** (instead of 500 g) this issue was investigated.
3. To what amount do the LCA results depend on transport distances of the produced materials? This matter was dealt with by ***varying the transport distances***.
4. How do the results change depending on a different material composition of the end-of-life vehicle? To give answers to this question ***different material compositions of end-of-life vehicles were investigated***.

1.6 Environmental aspects included in the study

The life cycle inventory (LCI) contains all the material flows drawn from the environment (on the input side) or discarded into the environment (on the output side). The subsequent phase referred to as life cycle impact assessment comprises the assignment of the calculated emissions to environmental impact categories. This proceeding is supported by a scientifically approved method. The following categories were investigated in this study:

The ***Global Warming Potential*** (GWP) is characterised by the effect of substances contributing to the warming of the Earth's atmosphere. Related substances are for example carbon dioxide, methane and nitrous oxide.

The ***Acidification Potential*** (AP) is defined by the emission of substances into the environment leading to a decrease of pH-value, e.g. nitrogen oxides and sulphur oxides.

The ***Photochemical Ozone Creation Potential*** (POCP) describes the formation of photo oxidants (ground level ozone, etc.) originating from hydrocarbons and nitrogen oxides being affected by sunlight.

The ***Eutrophication Potential*** (EP) refers to the emission of substances into the environment resulting in over-fertilisation. Eutrophicating substances are for example nitrates, phosphates and ammonium salts.

This life cycle assessment study does not contain any consideration of toxic environmental impacts. Current models regarding toxicity associated to life cycle assessment are controversial and not being scientifically approved so far [Apeldoorn 2004].

Additionally, the Ozone Creation Potential was not investigated because of lacking relevant contributions.

1.7 Results

A comparison of the two environmental profiles (VW-SiCon process and dismantling of plastic components) is shown in Figure 1-4.

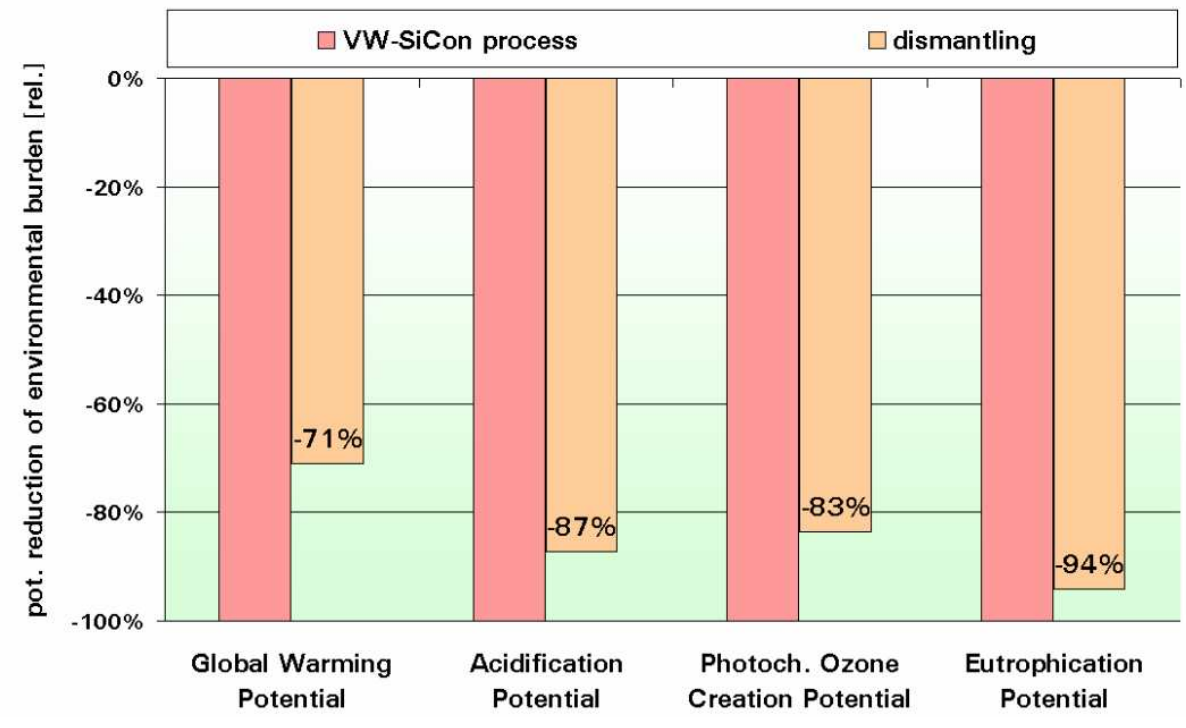

Figure 1-4: Comparative life cycle assessment of the VW-SiCon process and the dismantling of plastic components

In Figure 1-4 the potential savings of environmental burden are compared to each other in a relative scale. The reduction of environmental burden resulting from the VW-SiCon process is set as 100%. Both scenarios show a potential reduction of environmental burden. All impact categories show a better environmental performance of the VW-SiCon process. Depending on the respective category the difference makes up 6 to 29% between the two scenarios. By varying specific model parameters the stability of the results was investigated. In the following sections the results of the mentioned sensitivity analyses are shown.

Influence of the substitution ratio of recycled plastic materials into new plastic products (dismantling scenario)

The environmental advantage of the VW-SiCon process is enlarged by additional 14 to 32% (depending on the category) regarding a different substitution ratio of recycled plastic materials into new plastic products. Taking into account market capacities and quality standards a 1:1 substitution ratio concerning new materials has to be replaced by an approach considering other applications as well (e.g. the production of pavement slabs). For this purpose 80% of the dismantled plastic material was used as a substitute for concrete whereas 20% was accounted to substitute virgin material as shown in Figure 1-5.

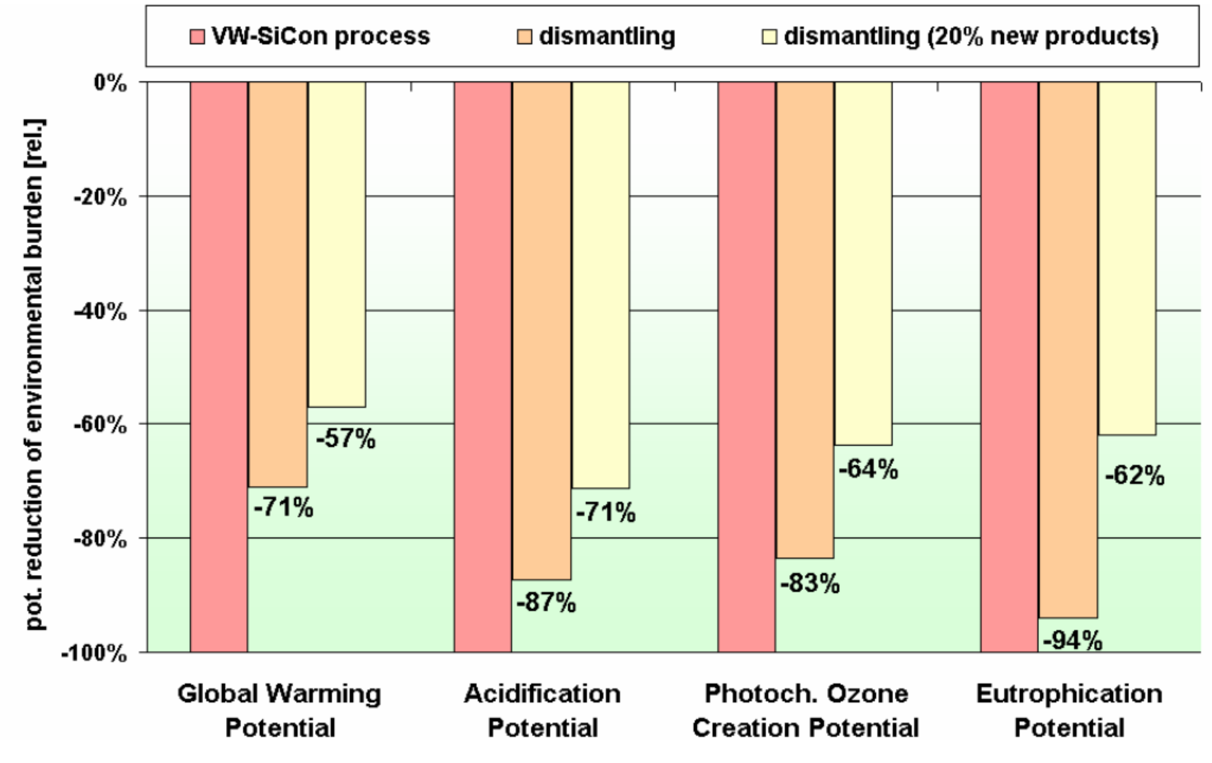

Figure 1-5: **Comparison of the influence of the substitution ratio of recycled plastic materials into new plastic products (dismantling scenario)**

Influence of the amount of plastics separated into single type materials (dismantling scenario)

Figure 1-6 shows the results of a sensitivity analysis examining an increase in the volume of the amount of plastics separated into single type materials. In both dismantling scenarios the total amount of dismantled polymers is the same. The only difference is the amount of separated single type materials, which is considered down to a weight of 100 g (instead of 500 g). The difference between the environmental profiles is relatively small. In conclusion, an increase in the time-consuming separation of single type materials leads only to a small additional environmental benefit.

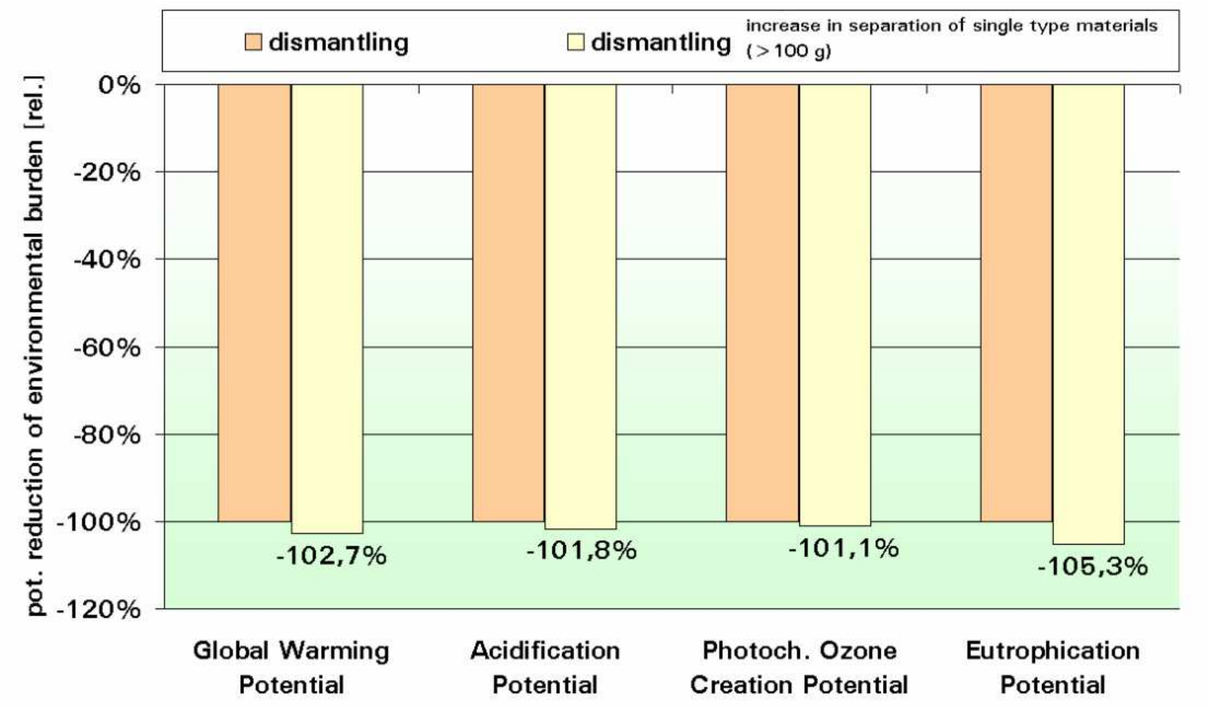

Figure 1-6: Influence of the amount of plastics separated into single type materials (dismantling scenario)

Influence of transport distances

A multiplication of the assumed transport distances by a factor of five causes only a small reduction of environmental savings regarding the VW-SiCon process as well as the dismantling scenario.

As shown in Figure 1-7 the advantages of the VW-SiCon scenario in comparison to the dismantling persist in all categories besides Eutrophication even if only the VW-SiCon transport distances are increased by a factor of five.

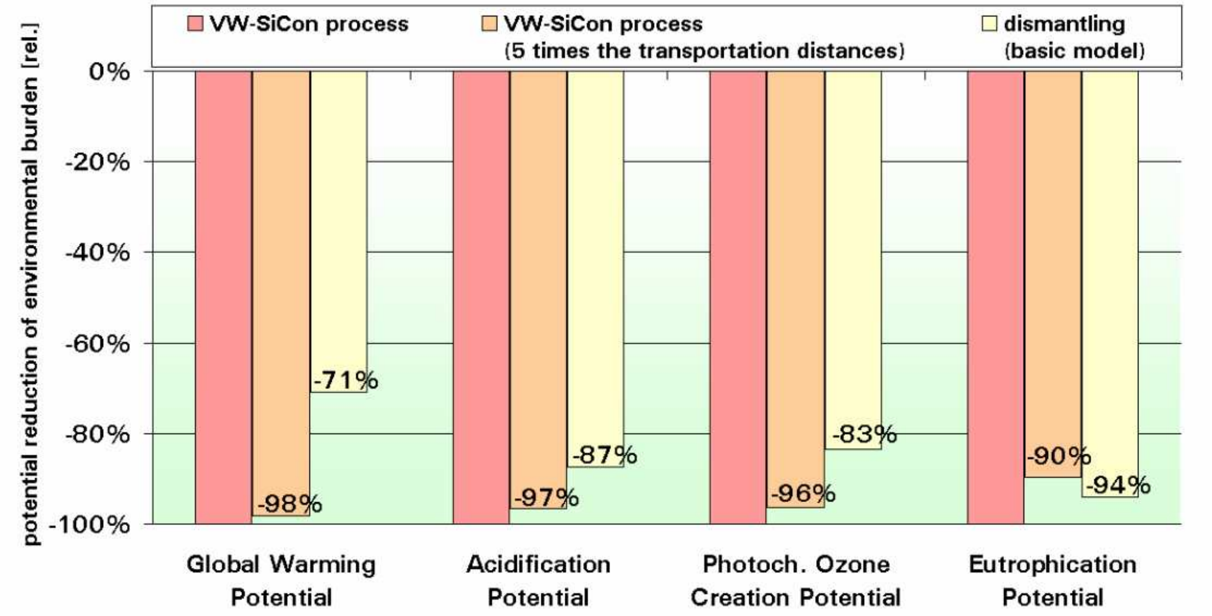

Figure 1-7: **Influence of transport distances (VW-SiCon scenario)**

Influence of the material composition of the end-of-life vehicle (VW-SiCon scenario)

By increasing the amount of plastic materials as well as of light and non-ferrous metals installed in a vehicle the reduction of environmental burden rises when applying the VW-SiCon process. In Figure 1-8 this development is shown by comparing the LCA results of the Volkswagen Passat (1995), Sharan (1996), Polo (2000) and Bora (2000) to the reference end-of-life vehicle (various equipment packages and derivatives of the VW Golf 4 and the VW Golf 5) which is set as 100%. Future end-of-life vehicles tend to lead to an even better environmental profile referring to the VW-SiCon process.

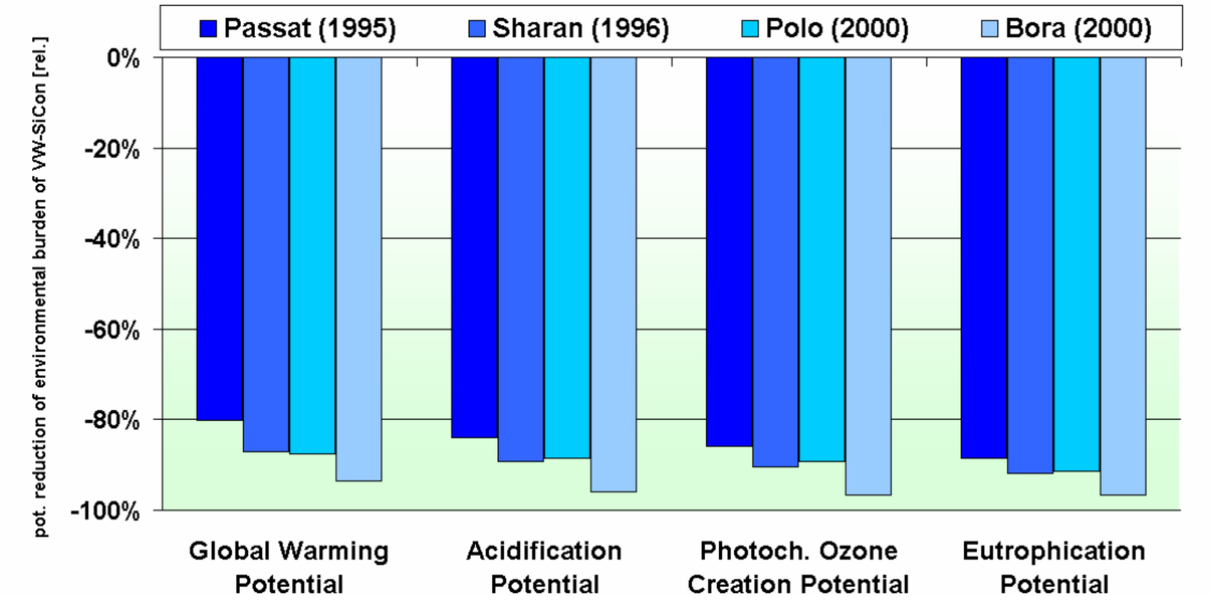

Figure 1-8: **Influence of the material composition of end-of-life vehicle-vehicles (VW-SiCon scenario)**

The results of this study can be summarized as follows:

- The VW-SiCon process is a market-oriented concept offering solutions to achieve the future recycling/recovery quotas.
- The VW-SiCon fractions take into account market capacities as well as existing industrial applications.
- The VW-SiCon process turns out to be a better solution concerning the environment in comparison to a dismantling scenario with subsequent mechanical recycling. Regarding Global Warming, Acidification, Photochemical Ozone Creation and Eutrophication Potential the advantages are in a range of 6 and 29%.
- Even when model parameters are varied the environmental advantage of the VW-SiCon process remains stable.

2 Bibliography

[Apeldoorn 2004] “Declaration of Apeldoorn”; 15th April 2004; http://www.uneptie.org/pc/sustain/reports/lcini/Declaration%20of%20Apeldoorn_final.pdf

[DIN 2000] DIN EN ISO 14040 – 14043; „Deutsches Institut für Normung e.V. Berlin“, 1997-2000

[EU End-of-Life Vehicles Directive 2000] Directive 2000/53/EC of the European Parliament and the Council from 18th September 2000

[LIRECAR 2004] Schmidt, W.P.; Dahlquist, E.; Finkbeiner, M.; Krinke, S.; Lazzari, S.; Oschmann, D.; Pichon, S.; Thiel, C.; Int. J. LCA 9 (6) 2004, 405-416

[VDA-VKE 2004] Nürrenbach, T; Dr. Goldhan, G.; Woköck, A.: „Fraunhofer Institut für Verfahrenstechnik und Verpackung“; „Verwertung von Kunststoffbauteilen aus Altautos – Analyse der Umwelteffekte nach dem LCA-Prinzip und ökonomische Analyse“; study by order from VKE and VDA-FAT. www.vda.de / www.vke.de