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Life Cycle Assessment (LCA) – Recycling of CFC – and HC – containing refrigerator equipment

Summary

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– Summary –

Summary

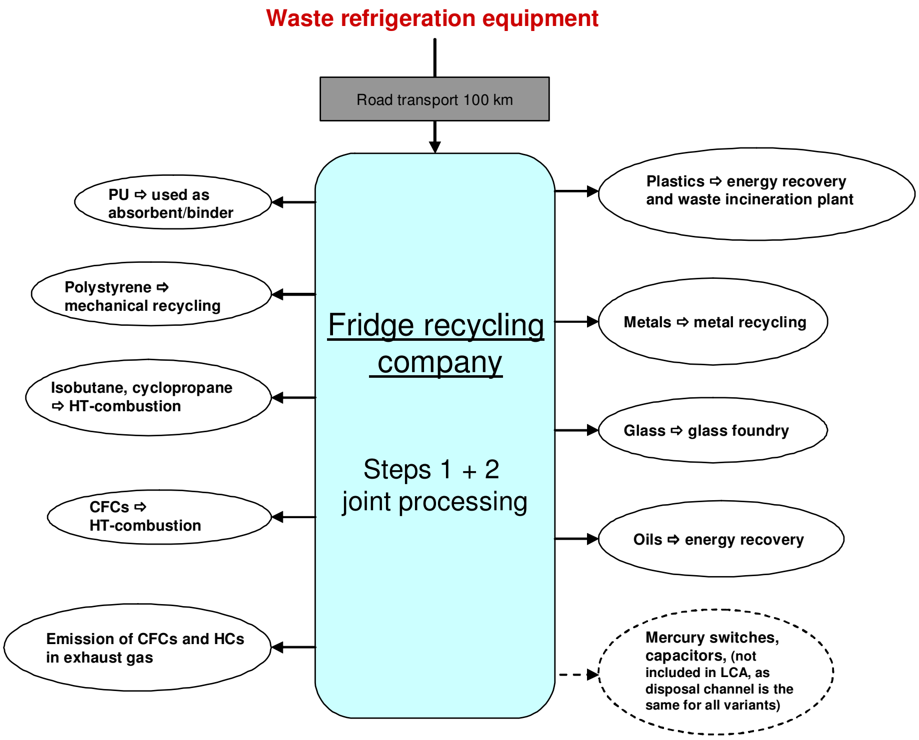
1.1 Background and subject of study

This life cycle assessment (LCA) was commissioned by the RAL Quality Assurance Association for the Demanufacture of Refrigeration Equipment. Its objective is to make an ecological comparison of the different disposal channels for waste domestic refrigeration appliances containing CFCs and hydrocarbons that could arise from potential changes to the WEEE Directive. The study was carried out in accordance with ISO 14040 and 14044. It also includes a critical review by Mr Giegrich of the Institute for Energy and Environmental Research (*Institut für Energie- und Umweltforschung*) in Heidelberg. Assistance was also provided by Dr Keri of the Austrian Ministry of Agriculture, Forestry, Environment and Water Management (*Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft*), Mr Schmit of the Luxembourg State Environmental Agency (*Umweltamt*) and Mr Hornberger and Ms Janusz-Renault of the Fraunhofer Institute for Manufacturing Engineering and Automation (*Fraunhofer-Institut für Produktionstechnik und Automatisierung*).

1.2 Description of processing variants

1.2.1 Variant 1: Joint processing

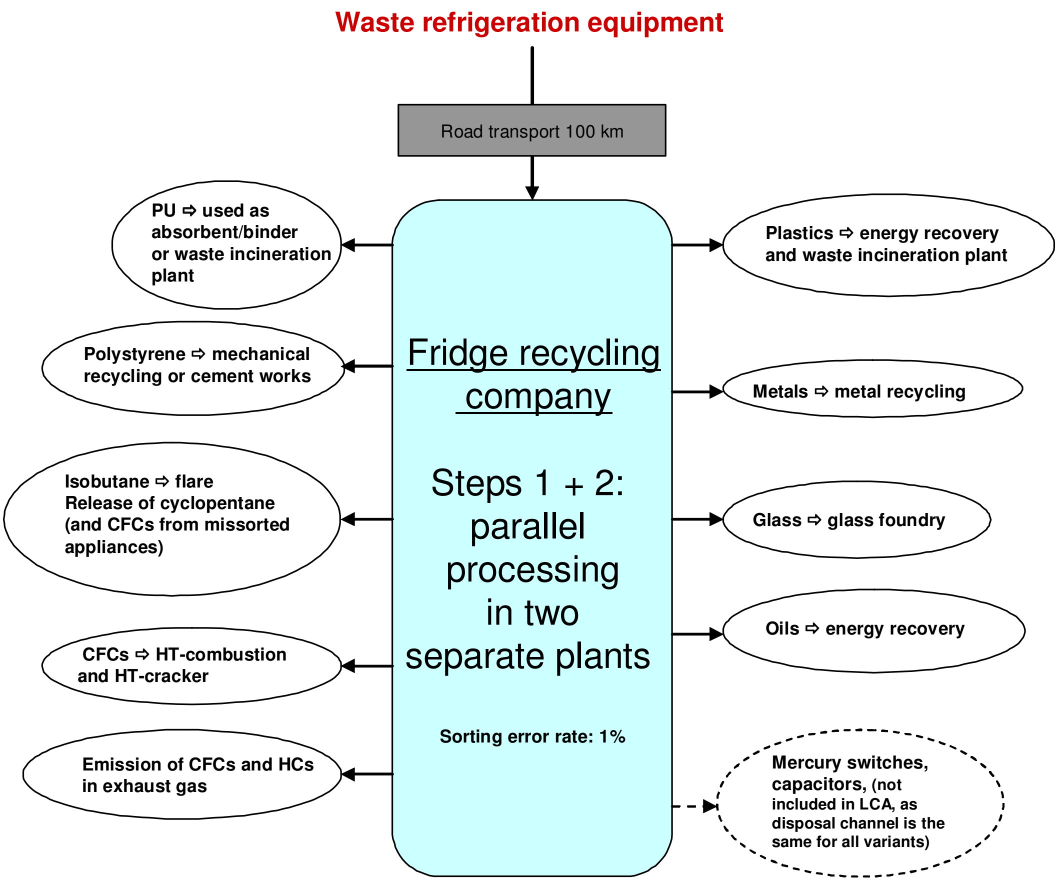
Material flows for joint processing are shown in the following figure:



In variant 1, the waste refrigeration appliances are all treated at the premises of the fridge recycling company. This involves the simultaneous treatment of waste appliances containing hydrocarbons (HCs) and those containing chlorofluorocarbons (CFCs) in a single plant. The resulting polyurethane powder is reused as an absorbent (chemical and oil binder). The highly purified polystyrene fraction is mechanically recycled. Metals are sent for metal recycling. Less pure plastic fractions go to waste incinerator plants or for incineration in cement works.

1.2.2 Variant 2: parallel processing

Material flows in parallel processing are shown in the following figure:

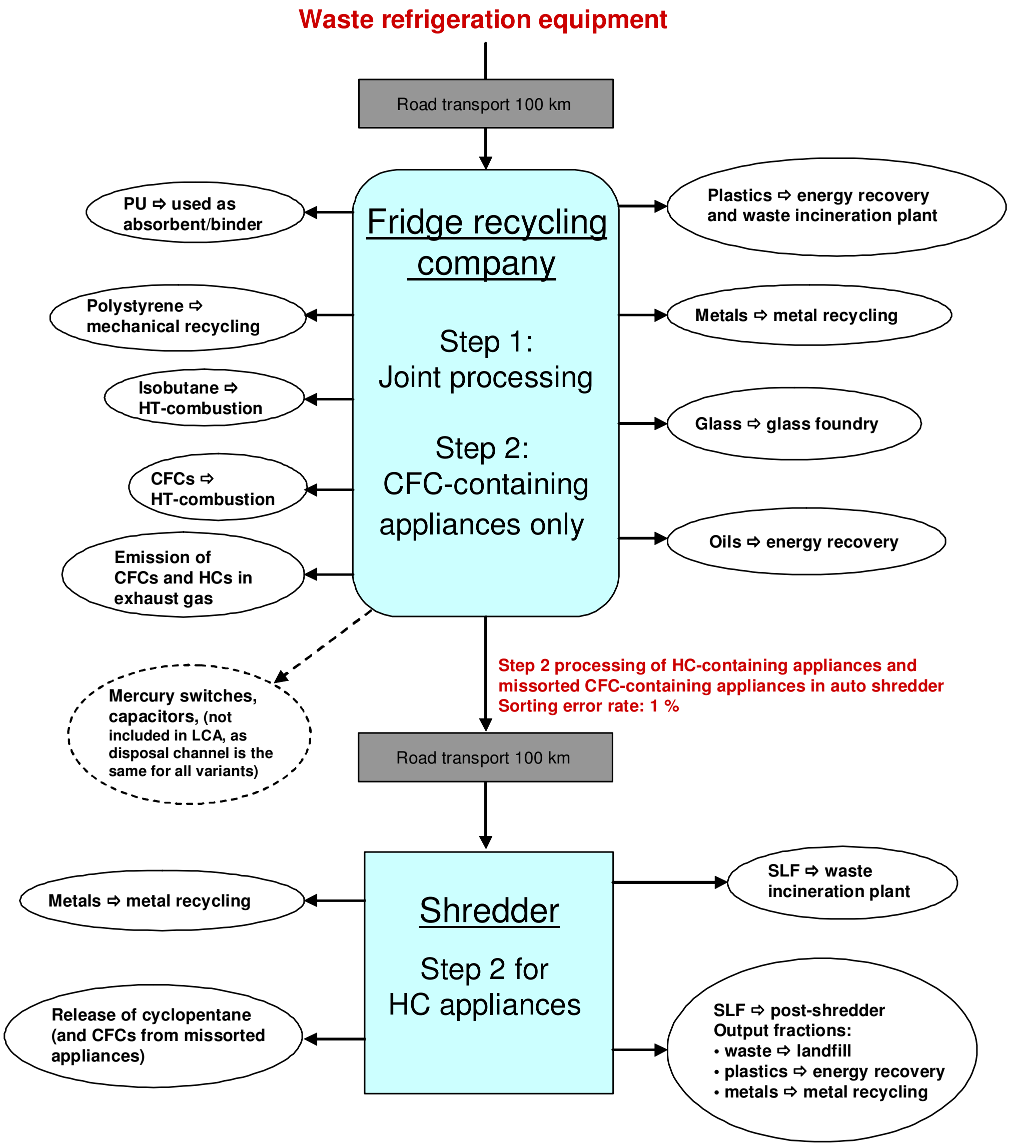


In this variant, the waste refrigeration appliances are all treated at the premises of the fridge recycling company. The HC-containing and CFC-containing appliances are processed in separate plants (no batch operation). The CFC line operates essentially as in variant 1 (joint processing).

The computational model assumes that the cyclopentane that is outgassed and collected during the crushing or shredding process (30 % of the total quantity in the foam) is subsequently released. The polyurethane flakes and chunks are subsequently incinerated. The model also assumes that 1 % of CFC-containing appliances are missorted and thus processed together with the hydrocarbon units.

1.2.3 Variant 3: Step 2 processing of HC-containing appliances in an auto shredder

Material flows in variant 3 are shown in the following figure:

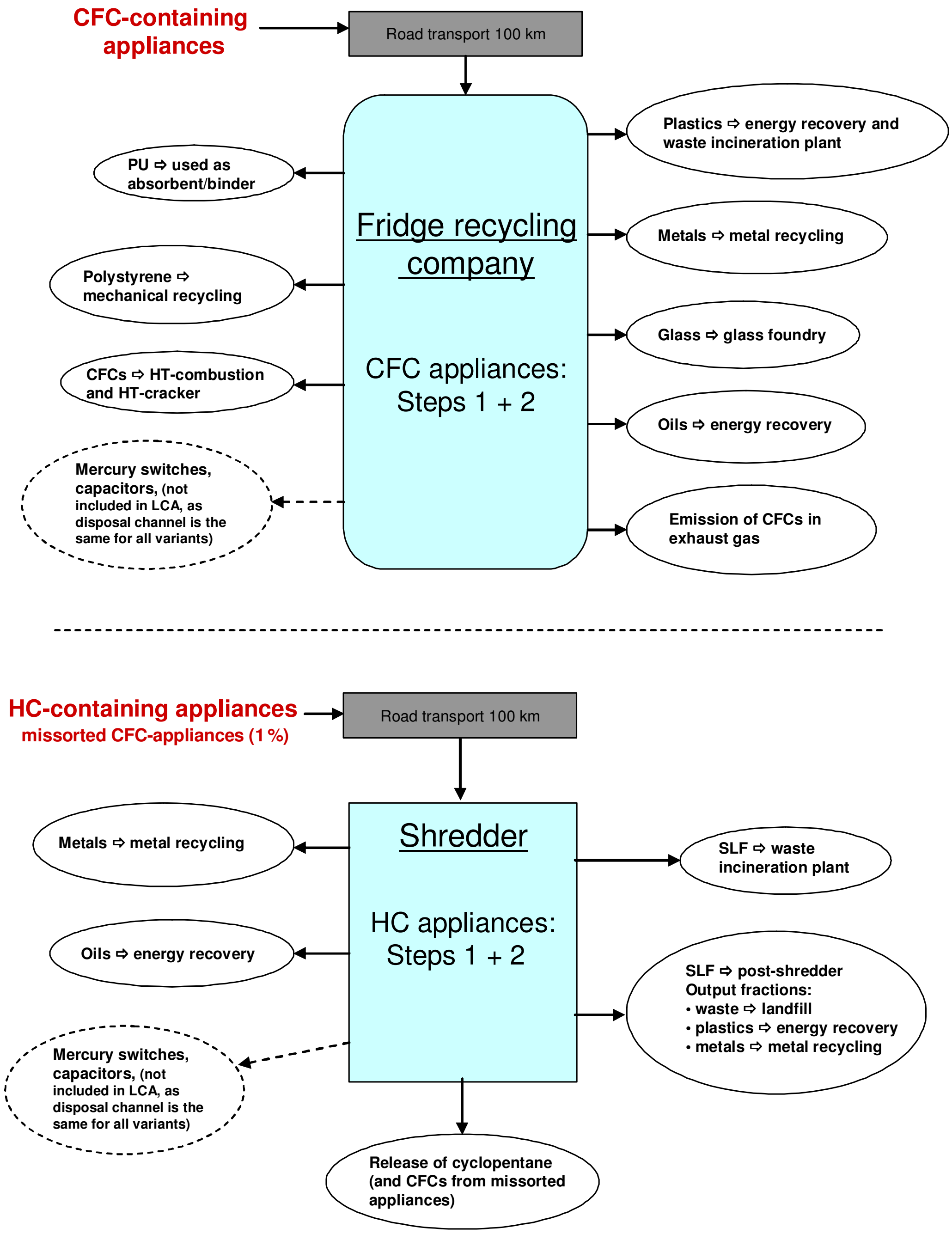


Variant 3 assumes that step 1 processing is carried out at the premises of the fridge recycling company with HC-containing and CFC-containing appliances being processed jointly to a high environmental standard. Apart from those incorrectly sorted appliances, the CFC-containing units are then treated at the premises of the fridge recycling company as in variant 1.

The HC-containing appliances and the missorted CFC-containing appliances (assumed sorting error: 1 %) are transported to a car shredder facility for disposal. Fine shredding of the appliances results in the release of 70 % of the cyclopentane, or 70 % of the R11 in the case of the missorted CFC-containing appliances. Subsequent treatment occurs in the post-shredder equipment and incinerator.

1.2.4 Variant 4: Step 1 and step 2 processing of HC-containing appliances in auto shredder

Material flows in variant 4 are shown in the following figure:



Variant 4 assumes that HC-containing and CFC-containing appliances are sorted at the collection point, for example a public waste-collection depot. Apart from the missorted appliances, the CFC-containing appliances are treated at the premises of the fridge recycling company to a high environmental standard.

The HC-containing devices and the missorted CFC-containing appliances are treated in an auto shredder as in variant 3.

1.3 Sorting errors

The number of missorted CFC-appliances that end up in the hydrocarbon line by mistake has a significant influence on the results of the life cycle assessment. The error rate depends on many factors. In order picking, error rates are typically between 0.1 and 3 %. However in fridge recycling, there are three additional factors that have an important effect on sorting errors: the lack of labelling of many refrigerator appliances (estimated at 20–30 %), the lack of feedback to the sorter when an appliance has been incorrectly sorted, and potential problems with the recycling plant (e.g. explosion protection) if too many HC-containing are erroneously sorted into the CFC-appliance line. This suggests that the error rates in sorting refrigeration appliances are considerably higher than in order picking. The authors therefore estimate that a sorting error rate of 1 % represents a realistic lower limit that can only be achieved if all possible measures are taken to avoid incorrect sorting. In addition to the baseline calculation for a sorting error rate of 1 %, sensitivity calculations for sorting error rates of 5 % have been performed for Variants 2–4. For variant 4 a further sensitivity calculation has been made for a 10 % sorting error rate because, in this case, sorting takes place at local waste-collection centres where trained staff may not be available and members of the public may have to sort the appliances themselves.

1.4 Results

The baseline calculation of this life cycle assessment assumes that 20 % of the waste appliances contain hydrocarbons and 80 % are CFC-containing appliances. This corresponds to the proportions to be expected in the near future.
The following table gives an overview of the results of the impact assessment for all seven impact categories considered. Positive values indicate adverse environmental impact while negative values indicate favourable environmental impact. In the latter case, the credits from the recycling processes outweigh the adverse environmental effects. The best variant from an environmental point of view is joint processing (variant 1) and the values are shown on a dark grey background. The worst variant in each impact category is shown against a light grey background.

Table 1-1 Results of impact assessment (absolute values; proportion of HC-containing appliances – 20 %)

Variant		1 Joint processing	2 Parallel processing	3 HC-appliances: Step 2 in shredder	4 HC-appliances: Steps 1+2 in shredder
Greenhouse effect	1000 t CO_2-eq per year	-193	-169	-155	-128
Ozone depletion potential	kg R11-eq per year	1,207	4,116	6,573	8,609
Photochemical oxidants	kg ethylene-eq per year	-15,032	3,828	28,221	38,035
Acidification	t SO_2-eq / year	-967	-959	-947	-948
Eutrophication	t PO_4-eq / year	-62	-62	-60.3	-60.9
Particulate matter	t PM_{10}-eq / year	-1035	-1,027	-1,013	-1015
Cumulative energy expenditure (CEE)	PJ	-2.64	-2.63	-2.60	-2.60

The table shows that the results for the impact categories ozone-depletion potential, greenhouse effect and photochemical oxidants differ considerably from one another. These impact categories are considered in more depth below.
The results for acidification, eutrophication, particulate matter and cumulative energy expenditure lie very close together, with deviations of between 2 and 4 %. In view of the general level of uncertainty in the data, such small deviations cannot be taken as clear indications of an environmental advantage or disadvantage associated with a particular variant.

1.4.1 Greenhouse effect

The main factors responsible for the greenhouse effect are energy-related CO_2 emissions and CFC emissions. Because of the credits from recycling processes, the overall result is a favourable environmental impact that represents between 0.013 and 0.019 % of Germany's total greenhouse gas emissions. Expressed in tonnes the annual benefit is between 128,000 and 193,000 tonnes of CO_2 equivalent.
The best variant from an ecological point of view is the joint processing of CFC-containing and HC-containing appliances. The worst is variant 4 in which HC-containing appliances are disposed of entirely in an auto shredder.
The following figure shows the extent to which the different processes contribute to the result. The sum for all processes is shown by the dark right-hand bar in each case.

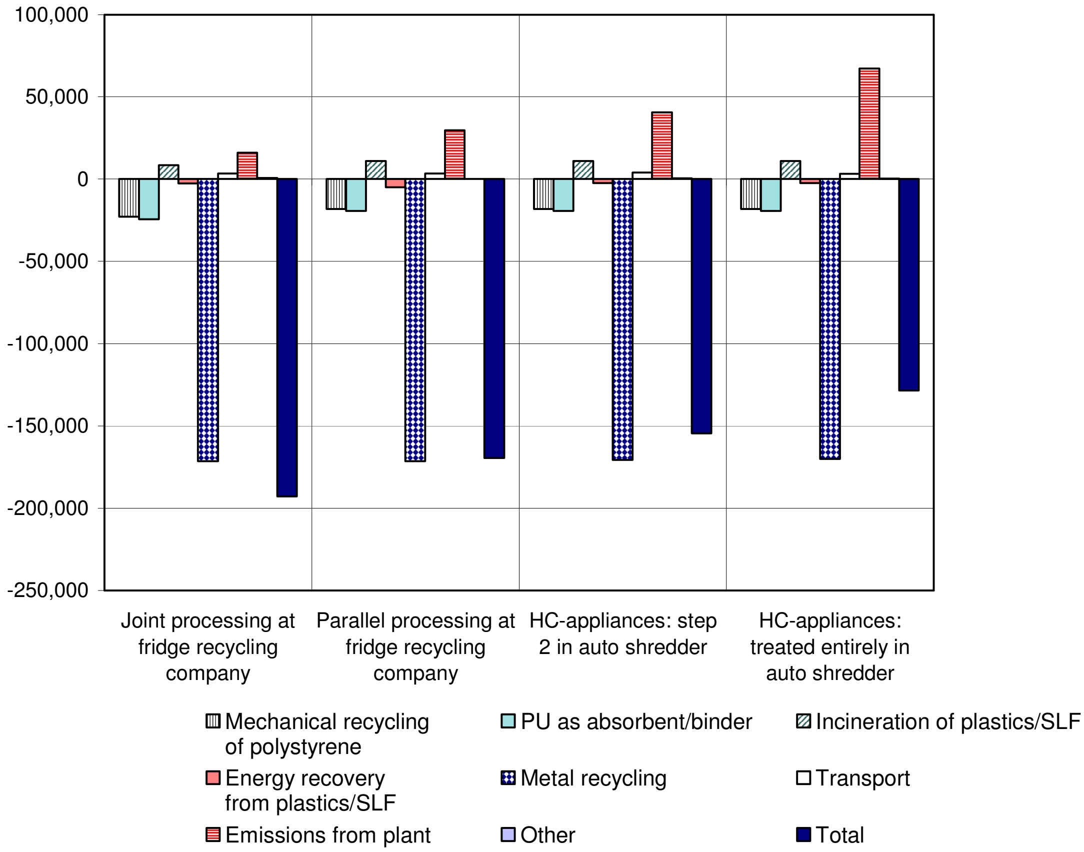


Figure 1.11 Results for the greenhouse effect and contribution of each individual process (proportion of HC-containing appliances: 20 %) in t CO_2 equivalent per year

The greatest differences with respect to greenhouse activity stem from the emissions from the fridge recycling plants, shredders and post-shredders, and the CFC emissions and hydrocarbon emissions from the relevant output streams (emissions from the post-processing of polyurethane and the CFC-containing refrigerant oil). The crucial factors determining the difference in greenhouse effect are the emissions of the CFCs R11 and R12.

1.4.2 Ozone depletion potential

The ozone depletion potential is determined exclusively by the R11 and R12 emissions. The diagram shows the ozone depletion potential for the individual processing variants and the different sensitivity analyses.

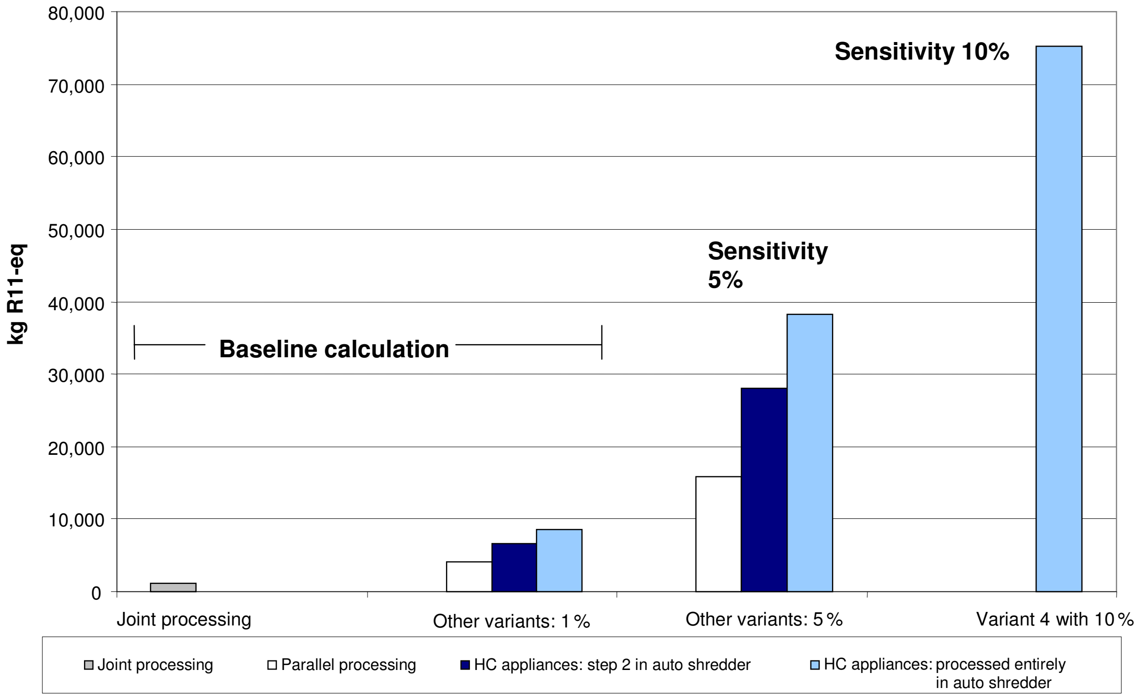


Figure 1.2 Ozone depletion potential for the baseline calculation and for the sensitivity calculations that assume different sorting error rates

In the baseline calculation, which assumes a sorting error rate of 1 %, joint processing yields the lowest ozone depletion potential (ODP) of about 1200 kg R11 equivalent/year. The ODP for parallel processing and for variant 3 (HC-containing appliances: step 2 processing in auto shredder) is considerably higher, at around 4000–6500 kg R11 equivalent/year. Variant 4 (HC-containing appliances treated entirely in an auto shredder) is even higher, with about 8600 kg R11 equivalent/year. The differences are almost entirely due to emissions from missorted CFC-containing appliances.

The different processing variants account for between 0.4 and 2.8 % of the emission potential associated with recently introduced ozone depleting substances. Relative to Germany's overall ODP burden (i.e. old emissions and potential new emissions), the values lie between 0.04 and 0.08 % for variant 1 (joint processing) and 0.3 and 0.6 % for variant 4 (HC-containing appliances treated entirely in an auto shredder). Greater precision is not possible because only rough quantitative estimates can be made regarding old emissions.

The diagram above also shows that the ODP increases dramatically at higher sorting error rates. In variant 4 the ODP rises to 38,000 and 75,000 t R11 equivalent for sorting error rates of 5 and 10 % respectively. These values are 32 and 62 times that for joint processing. These values represent up to 25 % of Germany's ODP (relative to the emission potential of recently introduced ozone depleting substances) or up to 3 % of the national ODP (relative to total emissions, i.e. previous emissions and potential new emissions).

1.4.3 Photochemical oxidants

The results for the impact category 'photochemical oxidants' are shown in Table 1-1 and demonstrate that variant 1 yields a total environmental benefit of about -15,000 kg ethylene equivalent per year. By contrast, the other variants result in environmental burdens. The critical factors here are the isobutane and cyclopentane emissions. As a result, the greatest environmental burden is associated with variant 4.

Although these values represent only a very small fraction of Germany's total photochemical oxidant burden (0.006 % for variant 4), it is important to realize, when interpreting these results, that summer smog formation is a local and temporary process. Hence even small quantities of photochemical oxidant precursors can make a significant contribution to local ground-level ozone formation for a limited period of time. This means that even low levels of hydrocarbon emissions should be avoided if at all possible.

1.4.4 Sensitivity analyses

Sensitivity analyses were carried out for the following parameters:

- Fraction of HC-containing appliances (baseline calculation 20 %; sensitivity analysis 50 %)
- Sorting error rate (baseline calculation 1 %; sensitivity analyses 5 and 10 %)
- Disposal of the CFCs recovered (baseline calculation: 100 % high-temperature combustion; sensitivity analysis: 50 % high-temperature combustion / 50 % high-temperature cracking)
- CFC decomposition rates during downstream processing of polyurethane foam
- Treatment of polystyrene in parallel processing (baseline calculation: incineration in cement works; sensitivity analysis: mechanical recycling)
- Missorting of HC-containing appliances.

The sensitivity analyses show that the sorting error rate has a decisive influence on the LCA results. The other parameters also had an effect on the result but do not alter the overall conclusion. The results of the sensitivity analyses for the different sorting error rates in terms of ozone depletion potential are shown in section 1.4.2.

1.5 Conclusion

The irrefutable conclusion drawn from the life cycle assessment is that variant 1 (i.e. joint processing in a single recycling plant) is the most environmentally friendly treatment process.

With respect to the greenhouse effect, variant 4 achieved only about 66 % of the savings in CO_2 equivalent that are obtainable with variant 1. Variant 1 represents a saving of about 0.02 % of total greenhouse gas emissions in Germany. The use of variant 1 therefore results in additional savings of about 24,000 to 65,000 tonnes CO_2 equivalent per year compared to the use of Variants 2 to 4. As climate protection is seen as a particularly important and urgent issue, all measures that achieve reductions in greenhouse gas emissions of this magnitude are significant.

In the case of ozone depletion potential, the difference between the variants is even more marked. Variant 1 differs from Variants 2 to 4 by a factor of 3 to 7 at a sorting error rate of 1 %. The ODP levels for the four processing variants are still high and represent in the worst case almost 3 % of Germany's emission potential associated with recently introduced ozone depleting substances. At a sorting error rate of 5 %, the ODP for variant 4 would be about 32 times higher than that for joint processing. An additional sensitivity calculation was performed for variant 4 with an even higher sorting error rate of 10 % as in this variant refrigeration devices are sorted at local waste-collection depots. If the staff at the numerous waste-collection centres are not suitably trained, or if the sorting is left to members of the public, a sorting error rate of this magnitude is realistic. In this case the ozone depletion potential would be 62 times higher than in joint processing and would represent about 25 % of Germany's current emission potential associated with recently introduced ozone depleting substances.

If the formation of photo-oxidants is considered, variant 1 results in a net environmental benefit while all other variants lead to an additional environmental burden. The fraction of these photo-oxidants relative to total emissions of photo-oxidants in Germany is relatively low (< 006 %). However, because even small amounts of photochemical oxidant precursors can contribute to the formation of ground-level ozone, it is imperative that all avoidable hydrocarbon emissions are eliminated.

The differences between the variants with respect to acidification, eutrophication, PM_{10} and energy consumption (expressed as cumulative energy expenditure) are so small that within the precision achievable in a life cycle assessment the results can be treated as effectively equal.