

Environmental and economic evaluation of the accelerated replacement of domestic appliances

Case study refrigerators and freezers

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Final report

– Revised Version 2007 –

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Preface to revised version 2007

In the present version, a number of minor mistakes, which were discovered in the former version while conducting other thematically related studies, have been conscientiously corrected. The originally pronounced assumptions regarding content and method, however, remain unmodified. Also, the general conclusions of the study are not to be changed in any manner.

Totalling, the outcome of the study's revision is a reduction of the calculated payback periods, especially regarding the impact category 'greenhouse potential', and, to a smaller extent, the total environmental impact. Therefore, the early replacement of cold appliances ecologically can be regarded as even more advantageous; excluding chest freezers, however, where (early) replacement ecologically is not beneficial.

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Notation of numbers

The numbers in this study are written according to DIN 1333 (“Zahlenangaben”) and DIN 5008 (“Schreib- und Gestaltregeln für Textverarbeitung“). This means that the comma “,” is the separator between the integer and the decimal part of a number. Numbers with more than three digits are divided by a blank in groups of three digits (in case of monetary values the numbers are divided by a dot in groups of three digits).

Examples:

- The price of electricity is 0,18 € per kWh
- Germany has 82 000 000 inhabitants
- The price of a television set is 1.499,- €

Due to calculational reasons the numbers of some data in this study suggest a higher precision than there is in reality. Please note that in general only two counting digits can be assumed as level of precision.

Abbreviations

CED	Cumulative Energy Demand
CFC	Chlorofluorocarbon
Ct.	Euro-cent
€	Euro
EEI	Energy efficiency index
GWP	Global Warming Potential
HC	Hydrocarbon
HFC	Fluorinated Hydrocarbon
ISO 14040 ff.	International standards ISO 14040 to 14043 describing principles, the framework and certain minimal requirements for conducting and reporting LCA studies.
kWh	kilowatt hour
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
WEEE	Directive 2002/96/EC of the European Parliament and the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE)

1 Executive summary

1.1 Goal of the study

The goal of this study is to compare the further use of existing appliances in stock with the acquisition and use of a new appliance in 2005, considering both environmental and economic aspects in an individual households' perspective.

The intended audience of this study is the European Committee of Manufacturers of Domestic Equipment (CECED). The results are meant for internal and external communication purposes.

1.2 Methodological approach

To carry out the described task of the study, the environmental impacts of the further use of cold appliances in stock of different age are compared with the acquisition and use of a new appliance in 2005. In case of the acquisition of a new appliance the impacts of the recycling of the old appliance is fully allocated to this alternative. The environmental assessment (LCA) is based on the methodology of life cycle assessment according to ISO 14040 ff.¹ The cost analysis is conducted in terms of life cycle costs (LCC), taking into account the total costs of ownership for private households along the whole life cycle.

1.3 Scope

The functional unit of the system under consideration is defined as "use of a cold appliance of the below specified category, age, size and energy efficiency class in a private household". For the streamlined LCA the use period is the life span of the product under consideration (i.e. 14 years for refrigerators and fridge-freezers and 17 years for upright and chest freezers). For the evaluation of the accelerated replacement the environmental impacts and the costs are calculated on an annual basis for the years from 2005 to 2025 (21 years).

All data in this study represent the German situation.

For the environmental assessment three main life cycle phases of cold appliances are distinguished: production, use and end-of-life treatment (in this case: recycling). In case of the LCC only acquisition costs and operating costs (for electricity supply during the use phase) are considered.

Four product categories are distinguished: refrigerators, 2-door fridge-freezers, upright freezers and chest freezers. For each product category six alternatives were compared: Further use of appliances in stock from 1980, 1985, 1990, 1995 and 2000 (alternatives 1 to

¹ Against the requirements of ISO 14040 ff. some formal points couldn't be considered (e.g. review process and documentation of the full inventory results are missing, a single indicator is calculated by weighting several indicator results).

5), and acquisition and use of a new appliance of 2005 (with energy efficiency class A+) (alternative 6).

As sensitivity analyses the replacement by new appliances with a) energy efficiency class A and b) energy efficiency class A++ is regarded.

The following impact categories / indicators were chosen for the comparison of these alternatives: primary energy demand (with the indicator cumulative energy demand, CED), global warming potential (GWP), ozone depletion potential (ODP), total environmental burden and life cycle costs (LCC).

In total the following results were produced:

- an LCA and LCC of a new appliance of the regarded four product categories;
- variation of the environmental impacts and the connected costs with respect to the year of manufacture of the appliance
 - in the use phase (specific electricity demand) and
 - through recycling (different used refrigerants and foaming agents according to the year of manufacture result in different environmental impacts);
- full time series of indicator results from 2005 until 2025 for in total six alternatives
 - for the four cold appliance categories,
 - for the four environmental indicators and the costs and
 - for the three replacement variations (A+ in the base case, A and A++ in the sensitivity analyses).

1.4 Limitations

Energy consumption of old and new appliances:

The study represents the average, not specific appliances in stock of a certain year of manufacture. The calculations are based on the *standard* energy consumption according to EN 153. Potential differences between the actual and the stated energy demand due to different user habits (number of openings, frosting of surfaces), ambient conditions (room temperature) or ageing of materials are not considered. As base case the acquisition of a new appliance of the energy efficiency class “A+” is chosen. However there are also appliances with better or worse energy efficiency on the market.

End-of-life treatment:

A proper recycling according to the WEEE directive² is assumed without any deficits in its implementation. The full allocation of recycling of the old appliance to the alternative “acquisition of a new appliance” leading to comparably high ODP impacts for this alternative is questionable. However this allocation problem cannot be solved in an ideal way.

² Directive 2002/96/EC of the European Parliament and the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE).

Acquisition costs:

Due to a big bandwidth of the market prices of cold appliances an estimation of purchase prices for new appliances is difficult and bears the risk of being not representative for an individual purchasing decision.

1.5 Main results (accelerated replacement)

- The **payback periods** depend on the type of appliance, the regarded indicator, the age of the 'old' (to be replaced) appliance and the energy demand of the new appliance. In general it can be stated, that the newer the old appliance and the higher the energy demand of the new model is, the longer are the payback periods. Therefore the longest payback periods are found for old appliances of the year 2000 to be replaced by an A-class model.³
- The **environmental payback periods**, when replacing old refrigerators, fridge-freezers and upright freezers with new A+ or A++ models, are quite similar and mostly below 5 years, sometimes even shorter than one year. When the appliances are replaced with an **A++-appliance**, the environmental payback periods are always below five years. In case of chest freezers they are much higher than those of the other three categories and are mostly above 5 years, often even longer than the assumed life span of a freezer of 17 years.
- The **cost payback periods** are much higher than the environmental payback periods. However due to the bandwidth of the purchase prices and the uncertainty regarding their dependency on the energy efficiency class, the results of the costs are afflicted with a higher degree of uncertainty compared to those of the environmental impacts.
- The payback periods regarding the **primary energy demand (CED)** are very low (i.e. between less than one and five years) for almost all appliance categories, all appliances in stock to be replaced and all efficiency classes of the new appliance.
- The payback periods regarding the **global warming potential (GWP)** and the **total environmental burden** are slightly higher than those regarding the CED. In case of refrigerators and upright freezers they are also for nearly all cases lower than 5 years. In case of fridge-freezers the payback periods are slightly higher compared to those of refrigerators and upright freezers. However, when the old appliances are replaced by A+ or A++-models they are also mostly below 5 years.
- The results of the **ozone depletion potential** are not meaningful as these results only represent the very high impacts through recycling of old appliances with CFCs and

³ In case of chest freezers there is hardly any difference between the replacement by an A and by an A+-model. This results from the difference in the calculation schemes defined in directive 2003/66/EC (for calculating the maximum energy demand of A+- and A++-models) and directive 1994/2/EC (for calculating the maximum energy demand of A- to G-models).

HFCs – which occurs anyway at any time. The methodological issue of allocation is strongly relevant here.

1.6 Conclusions

The environmental impacts of new cold appliances mainly result from the electricity demand during the use phase (80% to 90%). The production contributes only between 10% and 20% and the end-of-life phase is almost negligible (if the appliances are properly recycled). The purchase of an appliance however is more relevant in financial terms than the production in environmental terms and accounts for 35% to 45% of the life cycle costs.

The specific energy demand of appliances on the market has been reduced substantially over the last decades. However, especially with the introduction of the two new energy label classes A+ and A++, it becomes obvious that the energy demand of the actually purchased appliances is still too high, i.e. that consumers did (and still do) not buy the most efficient appliances available on the market.

The question if it is “worth” to further use an existing cold appliance or to substitute it and use a new model cannot be answered absolutely. The answer depends on the individual evaluation of the time span, which is acceptable for the environmental and economic pay-back period. In this study 5 years for environmental or economic amortisation were defined as a time period that justifies the substitution. With this measure, the replacement of the different cold appliances is environmentally justified (i.e. regarding the total environmental burden) under the following conditions:

- Refrigerators; replacement by
 - ‘A++’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A+’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A’-model: 1980 to 1995-appliances
- Fridge-freezers; replacement by
 - ‘A++’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A+’-model: 1980 to 1995-appliances
 - ‘A’-model: 1980 to 1990-appliances
- Upright freezer; replacement by
 - ‘A++’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A+’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A’-model: all regarded appliances in stock (1985 to 2000)
- Chest freezer; replacement by
 - ‘A++’-model: 1980-appliances
 - ‘A+’-model: 1980-appliances
 - ‘A’-model: 1980-appliances

Regarding the cost payback periods only the replacement of upright freezers manufactured in 1980 with 'A'- and 'A+'-models is justified. However this result has to be handled with care as the cost data is afflicted with a quite high degree of variability and uncertainty.

The outcomes of this study hence support the conclusion that in case of refrigerators, fridge-freezers and upright freezers the replacement of appliances in stock, which are older than five to ten years and still functioning, environmentally makes sense, if they are replaced by high efficient new appliances (i.e. appliances of the energy efficiency classes A+ or A++).

Next to the high efficiency of the new model the proper recycling of old appliances is very important in order to make such an accelerated replacement reasonable. Especially in old appliances chlorofluorocarbons (CFCs) and fluorinated hydrocarbons (HFCs) were used as refrigerants and foaming agents, which contribute strongly to ozone depletion and to the greenhouse effect (global warming). In newer appliances the contained volatile organic carbons (butane, pentane) strongly contribute to photochemical ozone creation.

2 Background and goal of the study

In Germany the market saturation rate of refrigerators in 2003 was 115 % and of freezers 74 %⁴ (see <http://www.destatis.de/basis/d/evs/budtab63.php>, last updated on 15 October 2004). Both figures were quite stable in recent years which indicate that the market is saturated and purchasing activities are dominated by replacement of existing appliances.

The time of replacement can be determined by several factors, e.g. failure of the old appliance or changing needs of the households. Another reason for a replacement of an existing appliance could be the presumably lower energy demand of a new one. Depending on the difference in energy demand and the respective costs the purchase of a new appliance (even though the old one is still working) might amortise within a short time, both in terms of environmental impacts and costs for production / acquisition.

For an *individual household* the question “Does it make sense to further use an old refrigerator or freezer or is it better (in environmental and economic terms) to buy a new one?” depends on the question, in what time the additional environmental impacts through production of the new appliance and end-of-life-treatment of the old one are compensated through the lower electricity demand of the new one. The same question has to be answered on the cost side (acquisition costs versus lower running costs).

The electricity demand of both the old and the new appliance depends on various parameters, like type (e.g. refrigerator or fridge-freezer?), age, specific energy efficiency or volume (e.g. the size of refrigerators on the German market varies between some 50 and 400 litres).

Considering the share of refrigerating and freezing at the total residential electricity consumption in Europe⁵ and the age distribution in stock⁶ a considerable saving potential in energy demand and the respective emission of greenhouse gases is foreseeable when older appliances are replaced. Especially regarding to political goals (like the Kyoto protocol) the replacement of old appliances might therefore be important in a *macro-economic sense*.

Compared to other domestic appliances in case of cold appliances the end-of-life treatment of the old appliances is of especially high importance: as in older appliances chlorofluorocarbons (CFCs) or fluorinated hydrocarbons (HFCs) were used as cooling and foaming agents, their end-of-life treatment might result in an initial increase of the total emissions of greenhouse gases or ozone depleting substances.

⁴ A number of more than 100 % results from the fact, that there are households that own more than one cold appliance.

⁵ e.g. in Germany for each appliance this share has been around 8% in 2002; i.e. 11,3 TWh p.a. for both refrigerating and freezing (see VDEW 2003)

⁶ 37% of all refrigerators and freezers in Germany were bought in 1992 or before, i.e. are older than 13 years, see GfK 2003a

The goal of this study is to compare the further use of existing appliances in stock with the acquisition and use of a new appliance in 2005, considering both environmental⁷ and economic aspects in an individual households' perspective.

The intended audience of this study is the European Committee of Manufacturers of Domestic Equipment (CECED). The results are meant for internal and external communication purposes.

3 General methodological approach

To get an idea of the magnitude of the different life cycle stages (production, use, end-of-life) of different cold appliances, first a streamlined life cycle assessment (LCA) and life cycle costing (LCC) of a new appliance of the regarded product categories is conducted (for specification of the product categories see section 4.4).

As this study compares the use of old appliances with the acquisition and use of new ones, the variation of the environmental impacts of appliances and the connected costs according to their age has to be investigated. In the study at hand, differences occur especially

- in the use phase (regarding the year of manufacture, the decreasing specific electricity demand of later produced appliances leads to lower environmental impacts and costs) and
- during recycling (different used refrigerants and foaming agents with respect to year of manufacture result in different global warming potential, ozone depletion potential and total environmental burden through the recycling process).

These differences will be shown in section 6.2 to better understand the results of the evaluation of the accelerated replacement.

Finally, to answer the main question of this study, the relevant alternatives with all connected implications are compared (for specification of the alternatives see section 4.5). This means, the further use of an old appliance in stock (of different age) is compared to the acquisition and use of a new one. In the latter case also the recycling of the old appliance is assumed to take place in the year of replacement. Therefore the environmental impacts (and the costs) of the recycling is fully allocated to the alternative "buying a new appliance". This procedure gives a realistic picture of the variation of environmental impacts and costs in time with respect to the different regarded alternatives.

⁷ According to ISO 14014 ff. the environmental side will be regarded from "cradle to grave" to prevent that environmental load is shifted between different stages of the physical life cycle of a product.

For each alternative the environmental impacts and the costs connected to the considered life cycle phases of the respective appliances are calculated on an annual basis (per year). These annual values are then cumulated to give the total environmental impacts and costs after one, two, three,... up to ten years of use. Thus it can be determined after what time period the initial environmental impact through acquisition and recycling is compensated by the lower impacts during the use phase through the more efficient new appliance (= payback period). In case of the costs it is determined after what time period the purchase price is compensated by the lower costs during the use phase.

The following figure illustrates this general approach.

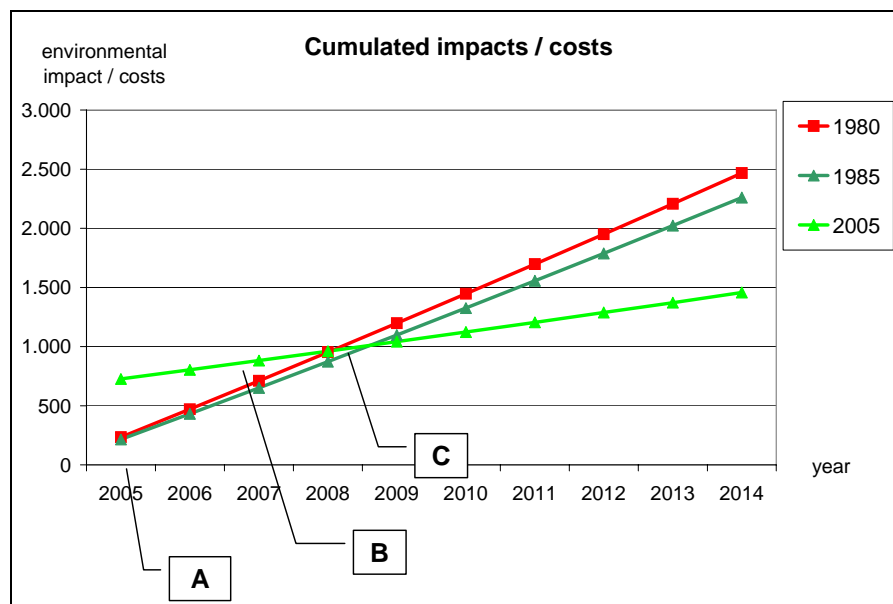


Figure 3-1 General approach of determination of payback period of accelerated replacement of cold appliances in stock

Legend:

A: In 2005

- either acquisition and use of a new appliance + recycling of the old one („2005“) or
- further use of the old appliance („1980“, „1985“)

B: According to annual electricity demand: smaller or bigger slope of cumulated impact / cost

C: Intersection: cumulated impacts of production and use of the new appliance and recycling of the old one (“2005“) is equal to the cumulated impacts of the mere use of the old appliance („1980“, „1985“)

In the following section (section 4) the system boundaries and the regarded alternatives are described in more detail.

4 Scope

4.1 Functional unit

The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. The functional unit of the system under consideration is defined as “use of a cold appliance of the below specified category, age, size and energy efficiency class in a private household”. For the streamlined LCA the use period is the life span of the product under consideration (i.e. 14 years for refrigerators and fridge-freezers and 17 years for upright and chest freezers). For the evaluation of the accelerated replacement the environmental impacts and costs are calculated on an annual basis for the years from 2005 to 2025 (21 years).

Other differences between the cold appliances of different age than differences in their specific energy consumption are not considered (e.g. noise, special features,...).

4.2 Geographical scope

The geographical scope has to be fixed as the results may depend on country specific data concerning technological specifications of cold appliances, end-of-life-management etc. as well as background data on the delivery of electricity. All data in this study represent the German situation.

4.3 System boundaries

The **environmental impacts** of the compared alternatives are assessed according to the international standards ISO 14040 ff for LCA. For the environmental assessment three main life cycle phases of cold appliances are distinguished (see Figure 4-1):

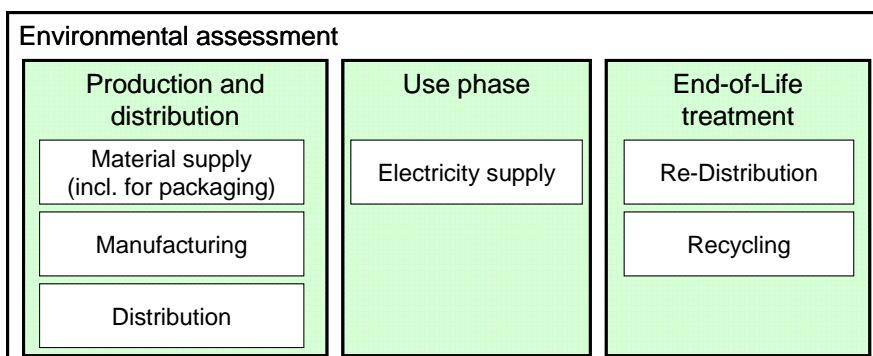


Figure 4-1 Distinguished life cycle phases for the environmental assessment of cold appliances

For the streamlined LCA the production, use and recycling of a new appliance of the four regarded product categories is modelled. The parameter setting to model the life cycle phases are specified in section 5.

For the **economic analysis** all costs that are connected to the regarded alternatives from the viewpoint of a specific actor over the whole life cycle of the product are considered. Usually this means, that the total costs of ownership are calculated.⁸ Considered cost types are for example acquisition costs, costs for operating media and cost for repair, maintenance or end-of-life treatment. Auxiliary investment costs (e.g. interests) can be taken into account. Future costs can be discounted to give the net present value of the year 2005. External costs are not considered. Usually external costs represent a certain environmental issue. In cases when the environmental side is regarded by itself this would mean a double-counting of the environmental side.⁹

In this study the costs are calculated for private households. Considered cost types are acquisition costs (here: purchase price for appliances) and costs for electricity supply. Cost for repair or maintenance are not considered. The costs for the end-of-life-treatment / recycling are assumed to be included in the purchase price. For the next 21 years (2005 with 2025) the annual costs and, with a discount rate of 5 %, the annual net present value (in 2005) is calculated.

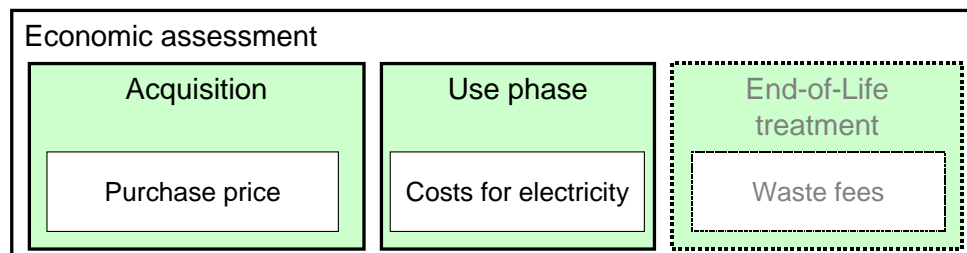


Figure 4-2 Distinguished life cycle phases for the life cycle costing of cold appliances

For the streamlined LCC the production and use of a new appliance of the four regarded product categories is modelled.

As mentioned before, the impacts of the use phase and through recycling vary depending on the age of the regarded appliance. Therefore the electricity demand and the connected impacts in the use phase are modelled for appliances manufactured in the years between 1980 and 2005. The impacts through recycling vary due to different used refrigerants and foaming agents. Depending on the age four categories (type I to IV) were defined. Additionally, to represent different sizes of appliances the production of a “small” and a “large” appliance was modelled. (see Figure 4-3).

⁸ In some cases costs for a specific actor can also occur when the product is not owned by this actor anymore, e.g. costs for redistribution and recycling of appliances for manufacturers.

⁹ Of course there can be cases in which it seems reasonable to integrate external costs. For example if a legislation rule can be foreseen that internalises external costs into the costs for certain media. In these cases costs that are currently external and would not be considered are likely to be internal costs in a relevant time span. To give a realistic picture of the cost side they can and should be regarded.

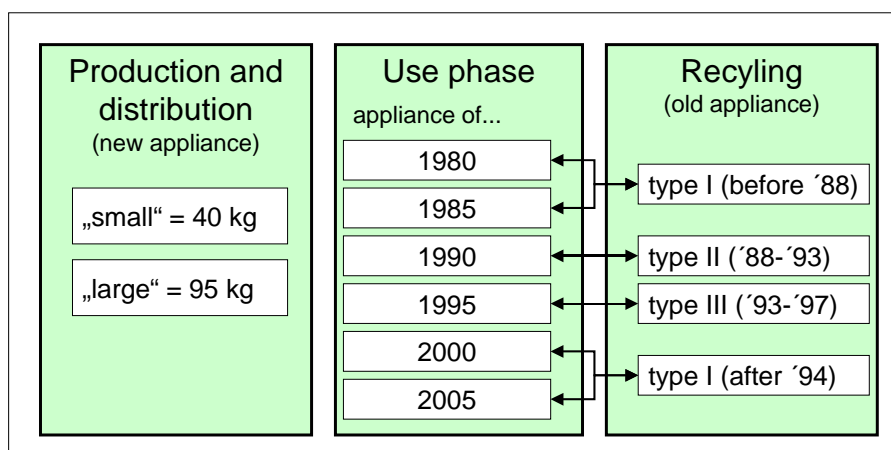


Figure 4-3 Variations of parameters of the life cycle phases by size and age

4.4 Regarded product categories

The accelerated replacement of the following four categories of household electric refrigerators, freezers and combinations thereof with the capacity specified in Table 4-1 is assessed.

Table 4-1 Considered appliances types and capacity

Appliance type	Fresh food volume	Frozen food volume
Refrigerator	155 litres	
2-Door fridge / freezer	200 litres	90 litres
Upright freezer	--	190 litres
Chest freezer	--	190 litres

Only appliances with vapour compression refrigeration cycle are within the scope of the study. It is assumed that the appliances do not have a no-frost technology.¹⁰

¹⁰ The no-frost technology is taken into account to calculate the standard electricity consumption according to EN 153. The calculated standard electricity demand of appliances with no-frost technology is slightly higher than of appliances without this technology. However when considering real life conditions appliances without no-frost technology might have a higher electricity demand due to the frosting of surfaces.

4.5 Regarded alternatives

To answer the question, if it is better to further use an existing appliance or to replace it by a new one, the following alternatives are compared:

Table 4-2 Compared alternatives and considered life cycle phases

Alternative	Considered life cycle phases	Abbreviation
Further use of an appliance of 1980	<ul style="list-style-type: none"> ▪ Use (old appliance) 	1980
Further use of an appliance of 1985	<ul style="list-style-type: none"> ▪ Use (old appliance) 	1985
Further use of an appliance of 1990	<ul style="list-style-type: none"> ▪ Use (old appliance) 	1990
Further use of an appliance of 1990	<ul style="list-style-type: none"> ▪ Use (old appliance) 	1995
Further use of an appliance of 2000	<ul style="list-style-type: none"> ▪ Use (old appliance) 	2000
Acquisition and use of a new appliance in 2005	<ul style="list-style-type: none"> ▪ Recycling (old appliance) ▪ Production/Purchase (new appliance) ▪ Use (new appliance) 	2005

In case of the **existing (old) appliances** only the use phase is modelled. As electricity consumption the standard electricity consumption according to EN 153 is assumed. Potential differences between the actual and the stated energy demand due to different user habits or ageing of materials are not considered as no reliable quantitative data is available to the authors.

In case of the **replacement alternative** the production and distribution of a new appliance and its use and the recycling of the existing appliance are considered. This means that the recycling of the old appliance is allocated in total to the replacement alternative. This is reasonable as it represents the real situation: even though the recycling would take place anyway, the environmental impacts are realised in the year of replacement.¹¹ To give a realistic picture of all impacts that are connected to the chosen alternative, these impacts are considered in the replacement alternative. However this approach bears some methodological obstacles as the recycling of old appliances would take place anyway – sooner or later. Especially in the case of the ozone depletion potential the approach gives interesting results: a relevant ozone depletion potential only occurs when cold appliances including CFCs (i.e. appliances which are manufactured before 1993) are replaced. The contribution of the electricity demand to ODP during use phase is negligible. Therefore the ODP through recycling of appliances manufactured in 1980, 1985 and 1990 will not be amortised through lower ODP through use of a new appliance (see result section 6). With the argument, that the old appliance has to be treated as waste anyway at a certain time in the future, the allocation of the environmental impact to the new appliance is questionable,

¹¹ If assumed that the replaced appliance is recycled immediately.

however represents a conservative approach. This point should be borne in mind when interpreting the results and drawing conclusions.

Like in case of the old appliances, as electricity consumption during the use phase the standard electricity consumption according to EN 153 is assumed. Potential differences between the actual and the stated energy demand due to different user habits are not considered.

4.6 Environmental impact and methodology of impact assessment

“Environmental impact” can be represented by several impact categories. Due to time and financial restrictions only a limited number of indicators could be regarded. In the study at hand the following impact categories are considered as the most relevant ones for the system under consideration:

- Primary energy demand (indicator: cumulative energy demand, CED),
- Global warming potential (GWP),
- Ozone depletion potential (ODP),
- Total environmental burden (determined by method EcoGrade),
- Integrated in the total environmental burden are also the indicators Photochemical ozone creation potential (POCP) and Acidification potential (AP).

4.6.1 Cumulative energy demand (CED) (indicator for primary energy demand)

The requirement of energy resources is inventoried on the basis of the cumulative energy demand (CED), in German known as “Kumulierter Energie-Aufwand (KEA)”. The CED specifies all non-renewable (i.e. fossil and nuclear energy) and renewable energy sources as primary energy values. It is calculated on the basis of the net calorific value and is expressed in kilojoules (kJ). Primary energy demand that cannot clearly be specified as non-renewable or renewable is subsumed in the class “CED, others”. Due to the analysis on the primary energy level, characterisation factors are not necessary. Finally, the different CED classes are aggregated to the total CED.

4.6.2 Global warming potential (GWP)

The global warming potential represents the contribution of anthropogenic emissions to the radiative forcing or heat radiation absorption in the atmosphere and therefore a measure to express the so-called “greenhouse-effect” (CML 2001). Pollutants, which contribute to the global warming phenomenon are inventoried and aggregated taking into account their Global Warming Potential (GWP). The GWP denotes the pollutant impact of the different substances in relation to carbon dioxide (CO₂). As an indicator for the emission of greenhouse gases the global warming potential is expressed in terms of CO₂ equivalents. 100 years are set as the inventory period for calculating values; potential indirect effects were not included.

Characterisation factors are chosen according to CML (2004).

4.6.3 Ozone depletion potential (ODP)

Substances which are responsible for the thinning of the stratospheric ozone layer are added to this category. The halogens of these matters are able to reduce the quantity of ozone-molecules in the stratosphere by a cyclic, catalytic decomposition with the effect that more of the ultraviolet radiation hits the earth's surface. More UV radiation leads to increasing rates of skin cancer and damages to plants. The relative ozone depletion potential of a substance is expressed in relation to that of trichlorofluoromethane (also known as R-11 or CFC-11).

Characterisation factors are chosen according to CML (2004).

4.6.4 Total environmental burden

The indicator total environmental burden is measured in environmental target points (calculated with EcoGrade method). The aggregation method is described more detailed in Möller et al. 2005.

Within EcoGrade, the ecological relevance is investigated by relating the impact indicator results to their correspondent environmental targets. The applied environmental targets refer to target values, which were defined within international environmental policy making. These target values indicate the emission level, to which a certain environmental impact has to be reduced. Due to the application of internationally negotiated and binding targets, this approach considers the overall relevance of the different impact indicators and thus incorporates the elements of normalization, grouping and weighting within a single step.

The following impact categories are chosen for this step:

- Global warming potential,
- Acidification potential,
- Eutrophication potential,
- Photochemical ozone creation potential.

Other impact indicators are not taken into account either because the impacts play a more decisive role in social impacts (e.g. resource depletion) or it is not possible to quantify or operationalise the target in terms of LCI data (e.g. ozone depletion potential).

Acidification potential (AP), Eutrophication potential (EP) and Photochemical ozone creation potential (POCP)

All three indicators are determined to calculate the total environmental burden (see following section). In case of the variation of the environmental impacts through the recycling of the cold appliances according to their year of manufacture, the POCP is shown separately to explain the resulting total environmental burden. In all other cases only the three above mentioned single indicators (primary energy demand, global warming potential and ozone depletion potential) are shown separately.

Pollutants which are acids or cause acidification processes in air, water and soil will be inventoried and aggregated taking into account their *Acidification Potential (AP)*. The problem of acid rain has gradually abated, however the long term effects on soil, vegetation and edaphone (the sum of all soil organisms) is still problematic. Concerning the correlation

between acids in air, water and soil, a single measure was chosen to assess acidification (CML 2001). AP denotes the pollutant effect of a substance as an acidifier defined as the number of H⁺-ions produced relative to sulphur dioxide (SO₂). As an indicator for pollution, the acidification potential is expressed in terms of SO₂ equivalents. Regarding the quantitative contribution the major acids or acidifiers are ammonia, nitrogen oxides and sulphur dioxide.

Nutrient enrichment in water and soil can cause a shift in species composition and an increasing biomass production in aquatic and terrestrial ecosystems (CML 2001). In aquatic ecosystems added biomass can lead to a consumption of oxygen (CML 2001). The *Eutrophication Potential (EP)* for the relevant emissions is assessed with respect to that of phosphate in order to enable phosphate as a reference. In addition, the chemical oxygen demand is used as a measure for the entry of organic carbon. As a simplification it is assumed that all emissions of nutrients (N and P) into the air, water and soil and of organic matter to water can be aggregated into a single measure, because this method allows both terrestrial and aquatic eutrophication to be assessed (CML 2001). Eutrophication potential is expressed in terms of PO₄³⁻ equivalents.

Pollutants which contribute to tropospheric ozone formation are aggregated within the *Photochemical Ozone Creation Potential (POCP)*. The formation of reactive chemical compounds such as ozone under the influence of sunlight through photochemical oxidation of volatile organic compounds (VOC) and carbon monoxide under the presence of nitrogen oxides (NO_x) (CML 2001) is often referred as photochemical smog or summer smog. Ozone causes harmful effects on the human respiratory systems and affects plants. The POCP is expressed in ethylene equivalents.

For all three indicators characterisation factors are chosen according to CML (2004).

4.7 Allocation procedures

In the study at hand the following allocation procedure is applied:

- Recycling: the credits for the recycling of those materials, which are modelled to be produced from primary materials, are equally allocated to the first and the second life cycle of the material in question. Therefore only 50 % of the recycled material is credited against the environmental impacts of the system. If secondary material was already considered in the material supply no credits were given for recycled material. (see also section 5.3)
- In modules used to model certain materials or the supply chain of energy sources the implied allocation rules are taken over.

4.8 Critical review

According to ISO 14040 ff. a critical review shall be conducted for LCA studies used to make a comparative assertion that is disclosed to the public and shall employ the critical review process outlined in the standard. Please note that for this study no critical review was conducted.

4.9 Limitations

The following restrictions apply to the results of the study and have to be kept in mind when drawing conclusions:

- For the appliances in stock only an *average* energy consumption is considered. For a certain household with a specific appliance the result might differ from the results given in this report.
- As energy consumption of the refrigerators and freezers the *standard* energy consumption according to EN 153 is assumed. Potential differences between the actual and the stated energy demand due to different user habits (number of openings, frosting of surfaces), ambient conditions (room temperature) or ageing of materials are not considered.
- As new appliance which substitutes the existing one, an appliance of the energy efficiency class “A+” is chosen. However there are also appliances with better or worse energy efficiency on the market. To investigate the sensitivity of the results against the energy efficiency class of the new appliance two sensitivity analyses are conducted (see section 5.2).
- Regarding the recycling of the old appliances, a proper recycling according to the WEEE directive¹² is assumed without any deficits in its implementation. The recycling of the old appliance is fully allocated to the alternative “acquisition of a new appliance”. This assumption is questionable however this allocation problem cannot be solved in an ideal way.
- Due to a big bandwidth in market prices (between but also within certain energy efficiency classes) an estimation of purchase prices for new appliances is difficult and bears the risk of being not representative for an individual purchasing decision.

¹² Directive 2002/96/EC of the European Parliament and the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE).

5 Data sources, assumptions and calculations

5.1 Production and distribution

For the alternative “acquisition and use of a new appliance” the environmental impact of the production and distribution of the four regarded appliance types has to be modelled. In the study at hand as a simplification two categories were modelled:

- “small” = 40 kg
- “large” = 95 kg

It was assumed that the relative material composition is the same for both sizes, neglecting the fact, that there are parts of a refrigerator / freezer which are not directly correlated to the size. The amount of packaging material and the distribution parameters are assumed to be constant for both sizes.

Each appliance type is characterised by a certain size. For the streamlined LCA a life span of 14 and 17 years respectively is assumed (see Table 5-1) (GfK 2003 b).

Table 5-1 Size of the considered appliances and life span

Appliance type	Size	Average life span ¹³
Refrigerator	“small”	14 years
2-Door fridge/ freezer	“large”	14 years
Upright freezer	“large”	17 years
Chest freezer	“large”	17 years

To calculate the environmental impact of the **production**, the production of the used materials and the manufacturing process itself is considered.

The material composition of the appliances was approximated with confidential data from B/S/H and Electrolux. To model the impacts of the material supply data from publicly available data bases are used (Umberto®, GEMIS, etc.).

The manufacturing process itself was modelled with confidential data from B/S/H and Electrolux regarding energy demand, energy source, amount of waste etc.

¹³ Only relevant for streamlined LCA and LCC.

Regarding the **distribution** the following parameters were assumed:

Table 5-2 Assumed distribution parameters

	Distance	Transport system	Loading (by weight)
production – warehouse	400 km	truck (26 t)	outw.:50 % home: empty
warehouse – customer	60 km	truck (26 t)	outw.:50 % home: empty

5.2 Use phase: electricity demand

The use phase is mainly characterised by the electricity demand of the appliances. The electricity demand is differentiated according to product category and year of manufacture.

For the *appliances in stock* the energy demand is derived from fleet average figures (BSH 2005a).

The mostly sold energy efficiency class of new refrigerators, fridge-freezers and upright freezers in 2004 was 'A', for chest freezers 'A+' (BSH 2005b). Thus as energy consumption values for the new appliance the standard electricity consumption of appliances of these energy classes seems reasonable. However, as this study has a more prospective character and for better comparability of the different appliance categories, for refrigerators, fridge-freezers and upright freezers a more ambitious assumption is chosen: as electricity demand of the *new appliances* in all four categories the standard electricity consumption of an 'A+'-class appliance according to EN 153 is assumed (base case).

Nevertheless the relevance of the energy efficiency class of the new appliance should be investigated. Therefore, as sensitivity analysis the acquisition of 'A'- (less efficient than in base case) and 'A++'-appliances (more efficient than in base case) is calculated.

Table 8-1 to Table 8-4 in the annex list the absolute electricity demand of the regarded old and new appliances and the corresponding energy efficiency indices, differentiated by year of manufacture and energy efficiency class (for 2005-appliance).

5.3 End-of-life treatment

In the end-of-life phase the following parameters regarding the **re-distribution** were assumed:

Table 5-3 Assumed distribution parameters

	Distance	Transport system	Loading (by weight)
customer – collection point	Not considered		
collection point – recycling plant	200 km	truck (26 t)	outw.: 80% home: not considered

The energy demand (electricity and gas for heating), the auxiliaries (liquid nitrogen) and the emissions (dust) of the **recycling process** itself were assumed according to the environmental statement of a recycling plant in Germany. (L+N Recycling GmbH 1999)

Regarding the recycling of the materials after decomposition, the following assumptions were made:

- 30 % of the polystyrene was assumed to substitute primary polystyrene;
- 70 % of the polystyrene and 100 % of all other plastics were assumed to be recycled thermally;
- 37,5 % of the steel was assumed to substitute iron (recycling rate: 75%; 50 % thereof is credited against the environmental impacts of the system under consideration);
- Aluminium and copper: no credits as secondary material were already considered in the material supply.

The end-of-life treatment of the replaced cold appliances is important as especially in appliances which were produced before 1993 chlorofluorocarbons (CFC) were used as refrigerant (R12) and as foaming agent for the polyurethane (PUR)-foam (R11). CFCs have a high ozone depletion potential (ODP) and a high global warming potential (GWP). The release of these substances into the atmosphere during the recycling process results in high impacts in these categories. In the time period between 1993 and 1997 CFCs were substituted by the fluorinated hydrocarbon R134a. This has a lower ODP but still a quite high GWP. Therefore from 1994 onwards appliances were (also) produced with isobutane (R600a) as refrigerant and pentane as foaming agent (see Gabel et al. 1998).

In the study at hand four categories with regard to the age of the appliance were defined. They differ in the type and amount of refrigerant and foaming agent used. **Type I** contains CFCs (R11 and R12) both as refrigerant and foaming agent. From 1988 onwards the amount of CFCs used could be reduced (**type II**). **Type III** appliances use the fluorinated hydrocarbon R134a as refrigerant and foaming agent. In **type IV** appliances isobutane is used as refrigerant and pentane as foaming agent. The specification of the absolute amount of refrigerant and foaming agent of each type (for both “small” and “large” appliances) and of the chemicals can be found in Table 8-5 and Table 8-6 in the annex.

Depending on their year of manufacture the appliances in stock (and for the streamlined LCA also the new appliances) are assigned to the four types as shown in the following figure.

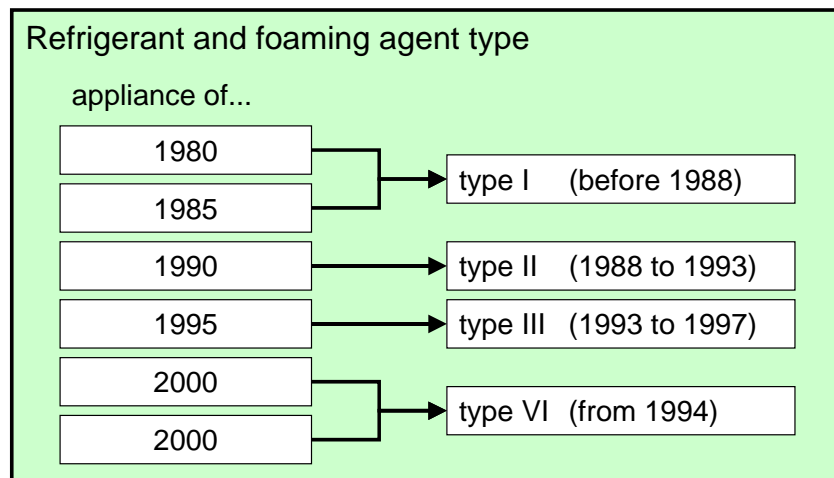


Figure 5-1 Assignment of appliances to refrigerant and foaming agent type according to their year of manufacture

Regarding the fate of the refrigerants and foaming agent the following assumptions were made:

- R11, R12 and R134a: 90% are retained within the recycling process (cryo-technology), 10% are released into the atmosphere;
- Isobutane and pentane: 100% are released into the atmosphere.

Leakages of refrigerants and emissions resulting from diffusion of foaming agents during the use phase are not considered. Therefore all environmental burdens related to refrigerants and foaming agents are allocated to the recycling phase and thus to the “acquisition and use of a new appliance”-alternative.

5.4 Costs

Due to a big variation in market prices (between but also within certain energy efficiency classes) an estimation of purchase prices for new appliances is difficult and bears the risk of being not representative for an individual purchasing decision.

Average data for the four regarded product categories is available from BSH (2005c). This data is assumed as purchase price in the base case (purchasing of ‘A+’-appliances) and also in case of purchasing an ‘A’-appliance. In addition NEI 2004 gives some data differentiated by energy efficiency class. For ‘A++’-appliances as a rough estimation a 50% higher price than for A or A+-appliances is assumed.

The **purchase prices** of the regarded types are given in the following table (for A and A+: prices between Feb 2004 and Jan 2005; for A++: 50% higher price than for A or A+-appliance; derived from NEI 2004):

Table 5-4 Purchase prices of the regarded appliance types.

Type of appliance	Price (A, A+)	Price (A++)	Life span ¹⁴
Refrigerator	290,- Euro	435,- Euro	14 years
Fridge-freezer	510,- Euro	765,- Euro	14 years
Upright freezer	350,- Euro	525,- Euro	17 years
Chest freezer	340,- Euro	510,- Euro	17 years

Price per kWh electricity:

- in 2005: 0,192 Euro/kWh (own compilation in 4/2005),
- in 2020: 0,249 Euro/kWh (Prognos 1999),
- between 2005 and 2020 and after 2020: linear inter- and extrapolation (1,5 to 2% increase p.a.).

Costs for repairs:

- no repairs assumed.

Costs for end-of-life treatment:

- assumed to be already included in purchase price.

Discounting:

In case of the streamlined LCC of new appliances, future costs are not discounted.

In case of the calculations regarding the accelerated replacement, future costs are discounted to give the net present value (NPV) in 2005 with a discount rate of 5%.

5.5 Summary of assumptions and snap shot of impact assessment and costs

Please note that the calculations of environmental impacts and costs in the following compilation are only valid for the year 2005. The costs for electricity supply are assumed to increase with time (see above) and, similarly, as the primary energy sources for electricity supply change with time, the environmental impacts of its production. The calculations in the whole model are more exact (as it considers these changes and additionally uses a dynamic calculation method for the costs calculation). However, the values here shall illustrate the magnitude of difference between old/new cold appliances and the saving potential.

¹⁴ Only relevant for streamlined LCA and LCC.

Table 5-5 Specification of the size, volume and purchase prices of the regarded appliances

Appliance parameters, purchase price (valid for 2005-appliance)						
	size of appliance	Fresh food volume	Frozen food volume	purchase price (A, A+)	purchase price (A+)	Average life span
refrigerator	"small"	155 litres		290,00 €	435,00 €	14 years
fridge-freezer	"large"	200 litres	90 litres	510,00 €	765,00 €	14 years
upright freezer	"large"	--	190 litres	350,00 €	525,00 €	17 years
chest freezer	"large"	--	190 litres	340,00 €	510,00 €	17 years

Table 5-6 Specification of the electricity demand and price and of the recycling type of the four regarded appliance categories with respect to the year of manufacture

electricity demand [kWh / appliance and year]	1980	1985	1990	1995	2000	2005 (A+)	
refrigerator	363	333	301	251	212	118	
fridge-freezer	759	528	563	418	392	255	
upright freezer	702	523	500	483	472	224	
chest freezer	437	268	252	223	215	201	
electricity costs in 2005 [€/ kWh]							
for all appliances	(increase to 0,249 in 2020)					0,192	
recycling type	1980	1985	1990	1995	2000	2005	
refrigerator	I	I	II	III	IV	IV	
fridge-freezer	I	I	II	III	IV	IV	
upright freezer	I	I	II	III	IV	IV	
chest freezer	I	I	II	III	IV	IV	

Table 5-7 Results of the environmental impact assessment and the life cycle costing for the year 2005 (see introductory comment of this section) of the four regarded appliance categories with respect to the year of manufacture

Results for 2005 (use phase)	1980	1985	1990	1995	2000	2005 (A+)
Impact Assessment (use phase)						
primary energy demand (CED) (in 2005) [MJ p.a.]						
refrigerator	3771	3459	3130	2612	2206	1225
fridge-freezer	7892	5493	5856	4348	4073	2652
upright freezer	7298	5438	5200	5027	4904	2332
chest freezer	4543	2784	2618	2315	2236	2086
global warming potential (GWP) (in 2005) [kg CO ₂ -Equ. p.a.]						
refrigerator	236	216	196	163	138	77
fridge-freezer	493	343	366	272	255	166
upright freezer	456	340	325	314	307	146
chest freezer	284	174	164	145	140	130
ozone depletion potential (ODP) (in 2005) [kg R11-Equ. p.a.]						
refrigerator	3,6E-08	3,3E-08	3,0E-08	2,5E-08	2,1E-08	1,2E-08
fridge-freezer	7,6E-08	5,3E-08	5,6E-08	4,2E-08	3,9E-08	2,6E-08
upright freezer	7,0E-08	5,2E-08	5,0E-08	4,8E-08	4,7E-08	2,2E-08
chest freezer	4,4E-08	2,7E-08	2,5E-08	2,2E-08	2,1E-08	2,0E-08
total environmental burden (in 2005) [micro points p.a.]						
refrigerator	802	735	665	555	469	260
fridge-freezer	1678	1167	1245	924	866	564
upright freezer	1551	1156	1105	1068	1042	496
chest freezer	966	592	556	492	475	443
Costs (use phase) [Euro p.a.]						
refrigerator	70,-	64,-	58,-	48,-	41,-	23,-
fridge-freezer	146,-	101,-	108,-	80,-	75,-	49,-
upright freezer	135,-	100,-	96,-	93,-	91,-	43,-
chest freezer	84,-	51,-	48,-	43,-	41,-	39,-

5.6 Snap shot of annual saving potential

These figures give a rough estimation on the annual saving potential, when replacing an old appliance in stock with a new A+-class model to give a first impression of the magnitude of possible savings. These figures are based on the price and impacts of electricity supply in 2005. The whole calculation model to calculate the payback periods takes into account the development of the prices and environmental impacts of the electricity supply with time. Therefore the final results presented in section 6 might vary from the rough figures shown here (see also comment of previous section).

Table 5-8 Approximate annual saving potential (see introductory comment of this section) of the four regarded appliance categories with respect to the year of manufacture

Saving potential	1980	1985	1990	1995	2000	2005 (A+)
Savings (Inventory):						
additional electricity consumption [kWh p.a.]						
refrigerator	245	215	183	133	94	0
fridge-freezer	504	273	308	163	137	0
upright freezer	478	299	276	259	247	0
chest freezer	236	67	51	22	14	0
Savings (Impact Assessment):						
additional CED (in 2005) [MJ p.a.]						
refrigerator	2.546	2.235	1.905	1.387	981	0
fridge-freezer	5.240	2.840	3.204	1.696	1.420	0
upright freezer	4.966	3.106	2.868	2.695	2.572	0
chest freezer	2.457	697	532	229	149	0
additional GWP (in 2005) [kg CO ₂ -Equ. p.a.]						
refrigerator	159	140	119	87	61	0
fridge-freezer	328	178	200	106	89	0
upright freezer	310	194	179	168	161	0
chest freezer	154	44	33	14	9	0
additional ODP (in 2005) [kg R11-Equ. p.a.]						
refrigerator	2,4E-08	2,1E-08	1,8E-08	1,3E-08	9,4E-09	0,0E+00
fridge-freezer	5,0E-08	2,7E-08	3,1E-08	1,6E-08	1,4E-08	0,0E+00
upright freezer	4,8E-08	3,0E-08	2,8E-08	2,6E-08	2,5E-08	0,0E+00
chest freezer	2,4E-08	6,7E-09	5,1E-09	2,2E-09	1,4E-09	0,0E+00
additional total environmental burden (in 2005) [micro points p.a.]						
refrigerator	541	475	405	295	209	0
fridge-freezer	1.114	604	681	360	302	0
upright freezer	1.056	660	610	573	547	0
chest freezer	522	148	113	49	32	0
Savings (Costs) [Euro p.a.]:						
refrigerator	47,-	41,-	35,-	25,-	18,-	0,-
fridge-freezer	97,-	52,-	59,-	31,-	26,-	0,-
upright freezer	92,-	57,-	53,-	50,-	48,-	0,-
chest freezer	45,-	12,-	9,-	4,-	2,-	0,-

6 Results

All results shown in this section refer to the scope and assumptions outlined in section 4 and 5 and the limitations outlined in section 4.9. Especially the consideration of potential differences between the stated and the actual energy demand due to ageing of materials would tend to result in shorter payback periods compared to the calculated ones (see results in section 6.3).

6.1 Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) of new appliances

The life cycle assessment and life cycle costing analyse the whole life cycle of a new cold appliance of the four specified categories with the above described features, which is operated for 14 years (refrigerators, fridge-freezers) or 17 years (upright and chest freezers). Thus the results in this section represent the cumulated impacts of the use of these appliances over their whole assumed life span of 14 and 17 years respectively.

The following figures show the environmental impacts in the regarded impact categories (primary energy demand (CED), global warming potential (GWP), ozone depletion potential (ODP) and total environmental burden (total)) of the production, use and recycling of new refrigerators, fridge-freezers, upright and chest freezers (of the above described size and energy efficiency) and the costs of the purchase and use of the respective appliance.

Additionally the relative contribution of the life cycle phases to the total impact category results / costs is shown in a table directly below the figures.

Results:

- Regarding the environmental impacts it can be seen that the use phase is the most important life cycle phase. It contributes to the total impact category results between approximately 80% (total environmental burden) and 90% (GWP, CED). Therefore the use phase seems the most important life cycle phase for potential savings in environmental impact.
- The production of the appliances contributes to the total environmental impacts with a percentage between some 10% and 20%.
- The contribution of the recycling is either very low (total environmental burden) or even negative (CED, GWP). The negative impacts are caused by the credits resulting from the recycling of certain materials which compensate the impacts through re-distribution and the recycling process itself.
- The contribution of the life cycle phases to the ODP is not meaningful, as the total ODP through the production, use and recycling of a new (!) cold appliance is only very low - $1,7E-08$ to $3,8E-08$ kg R11-equivalents.
- Regarding the impacts of the two freezer categories, it can be seen that it is more environmental friendly to operate a chest freezer than to operate an upright freezer of the same size and energy efficiency class.

- From a cost point of view the purchase contributes to approximately 35% to 45% to the life cycle costs of the appliances. This means the purchase is more relevant in financial terms than the production in environmental terms. Please note, that in the cost calculation the forecasted development of electricity prices is included. In contrast to the calculation of the payback period, the costs occurring in the future are not discounted to give the net present value.
- The lower the contribution of the production / acquisition of the appliance is, the faster will these impacts / costs be amortised through lower consumption values and the respective environmental impacts / costs in the use phase.

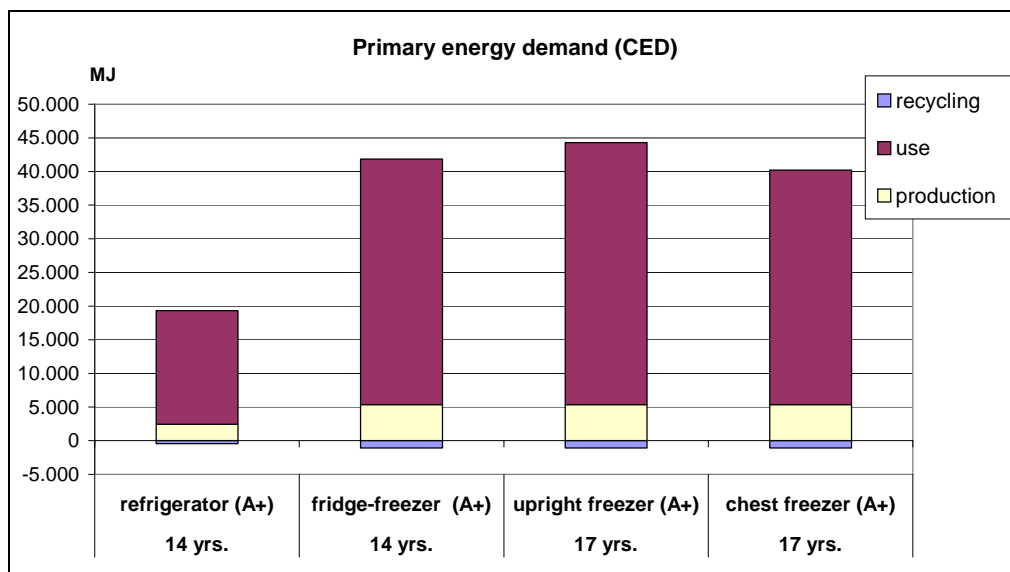


Figure 6-1 Primary energy demand (CED) of the production, use and recycling of cold appliances of the four regarded categories.

Table 6-1 Relative contribution of the life cycle phases to the primary energy demand (CED)

CED	Production	Use	Recycling	SUM
refrigerator (A+)	13%	90%	-2%	100%
fridge-freezer (A+)	13%	90%	-3%	100%
upright freezer (A+)	12%	90%	-3%	100%
chest freezer (A+)	14%	89%	-3%	100%

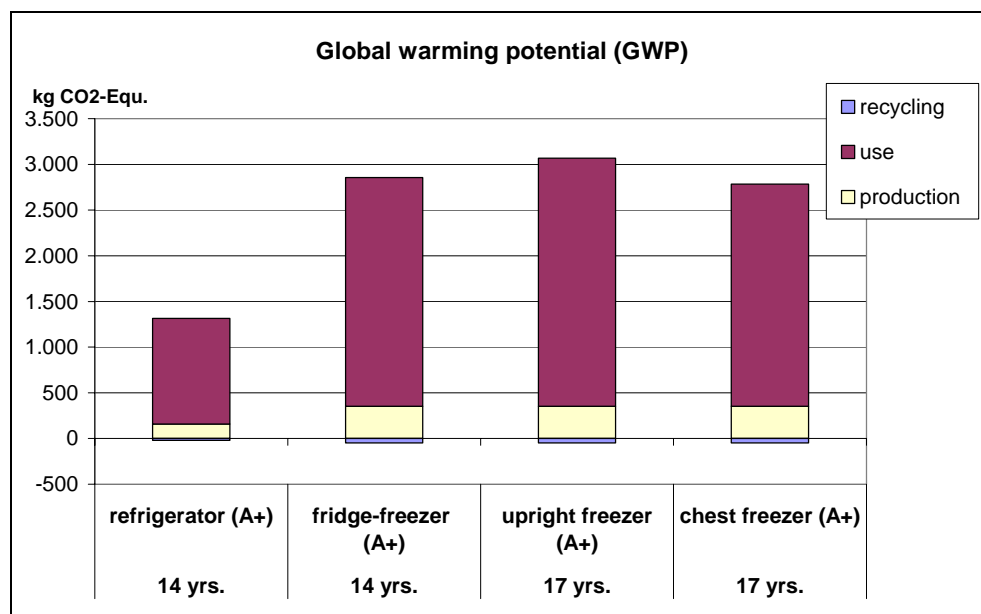


Figure 6-2 Global warming potential (GWP) of the production, use and recycling of cold appliances of the four regarded categories.

Table 6-2 Relative contribution of the life cycle phases to the global warming potential (GWP)

GWP	Production	Use	Recycling	SUM
refrigerator (A+)	12%	89%	-2%	100%
fridge-freezer (A+)	13%	89%	-2%	100%
upright freezer (A+)	12%	90%	-2%	100%
chest freezer (A+)	13%	89%	-2%	100%

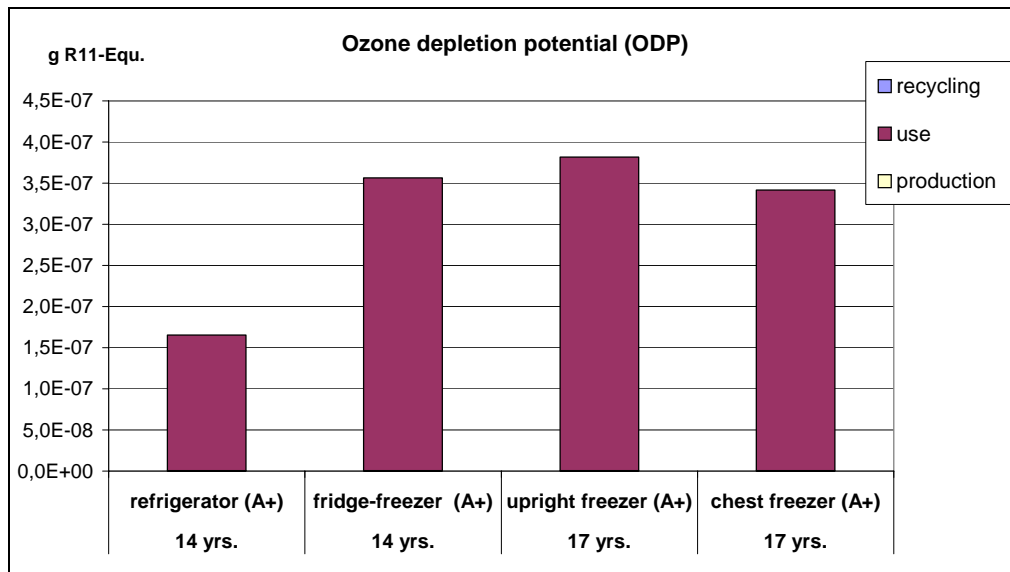


Figure 6-3 Ozone depletion potential (ODP) of the production, use and recycling of cold appliances of the four regarded categories.

Table 6-3 Relative contribution of the life cycle phases to the ozone depletion potential (ODP)

ODP	Production	Use	Recycling	SUM
refrigerator (A+)	0%	100%	0%	100%
fridge-freezer (A+)	0%	100%	0%	100%
upright freezer (A+)	0%	100%	0%	100%
chest freezer (A+)	0%	100%	0%	100%

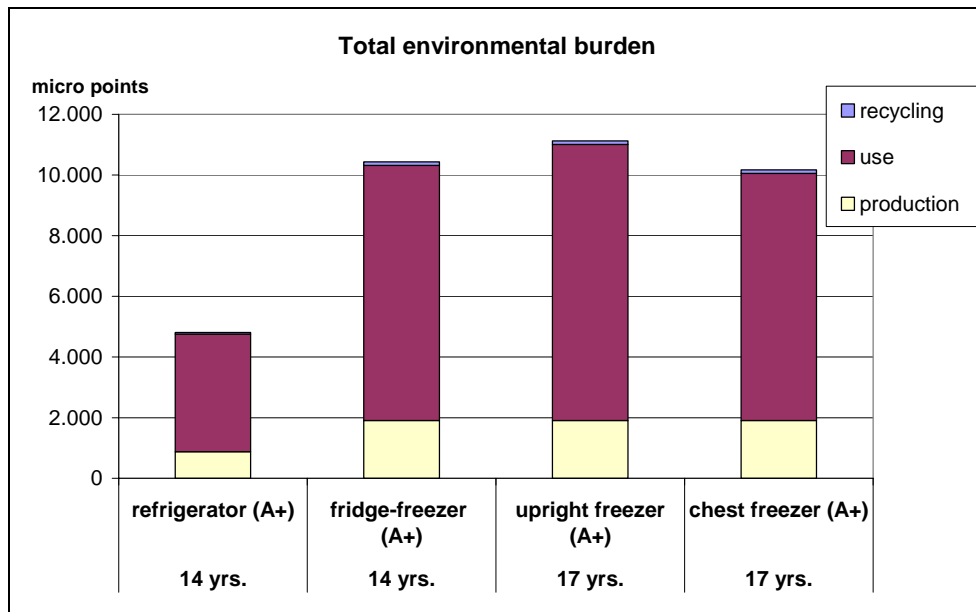


Figure 6-4 Total environmental burden of the production, use and recycling of cold appliances of the four regarded categories.

Table 6-4 Relative contribution of the life cycle phases to the total environmental burden

Total Environmental Burden	Production	Use	Recycling	SUM
refrigerator (A+)	18%	81%	1%	100%
fridge-freezer (A+)	18%	81%	1%	100%
upright freezer (A+)	17%	82%	1%	100%
chest freezer (A+)	19%	80%	1%	100%

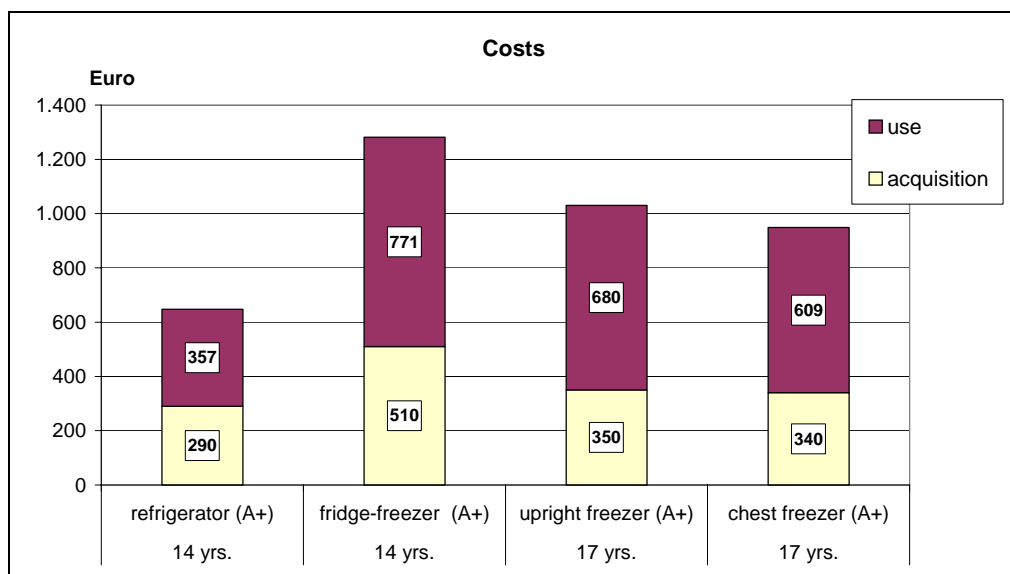


Figure 6-5 Costs of the purchase and use of cold appliances of the four regarded categories

Table 6-5 Relative contribution of the life cycle phases to the total costs.

Costs	Acquisition	Use	Recycling	SUM
refrigerator (A+)	45%	55%	0%	100%
fridge-freezer (A+)	40%	60%	0%	100%
upright freezer (A+)	34%	66%	0%	100%
chest freezer (A+)	36%	64%	0%	100%

6.2 Variation of environmental impacts depending on age of appliance

6.2.1 Electricity demand in the use phase

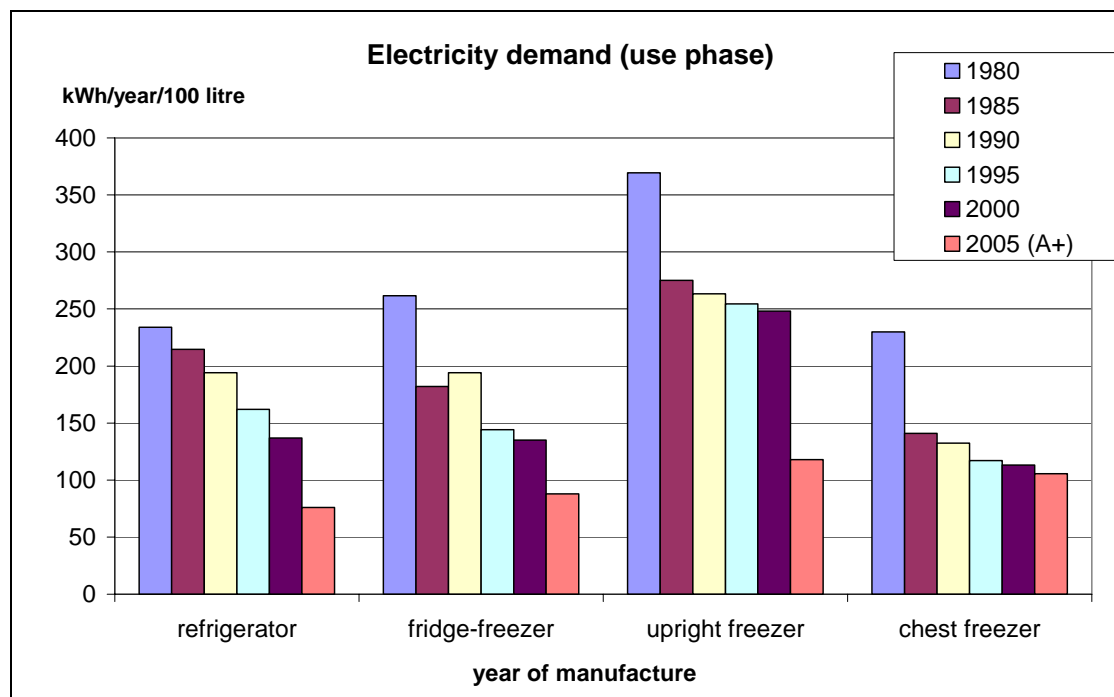


Figure 6-6 Electricity demand of cold appliances in the use phase

The figure shows the specific electricity demand of old appliances manufactured between 1980 and 2000 and of new appliances of the energy efficiency class A+ (which is presumably lower than the average electricity demand of actually purchased appliances).

It can be seen that in all categories the electricity consumption was decreasing with later year of manufacture. Especially in case of the upright freezer the electricity consumption of older appliances is much higher than that of a new 'A+'-class model.

Comparing upright and chest freezers the standard electricity demand of a chest freezer is lower than that of an upright freezer of the same size and energy efficiency class.

6.2.2 Environmental impacts of recycling

As described in section 5.3 the environmental impact through the recycling of the old appliances varies according to the year of their manufacture, mainly caused by differences in the type of used refrigerants and foaming agents.

The following figures show the environmental impacts through recycling of the described "small" and "large" appliances of different age. Please note that the ozone depletion potential is not integrated into the total environmental burden as there are no operationalisable target values available. This has to be kept in mind when interpreting the results.

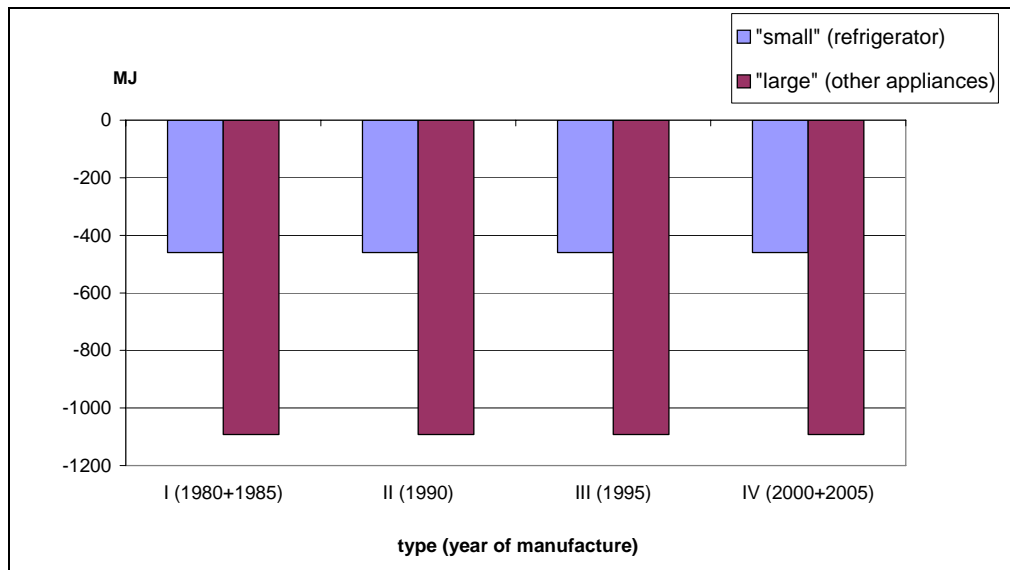


Figure 6-7 Cumulative energy demand (CED) of the recycling of “small” and “large” cold appliances of different age

The primary energy demand (CED) does not vary according to the year of manufacture as it is independent from the used refrigerants and foaming agent.

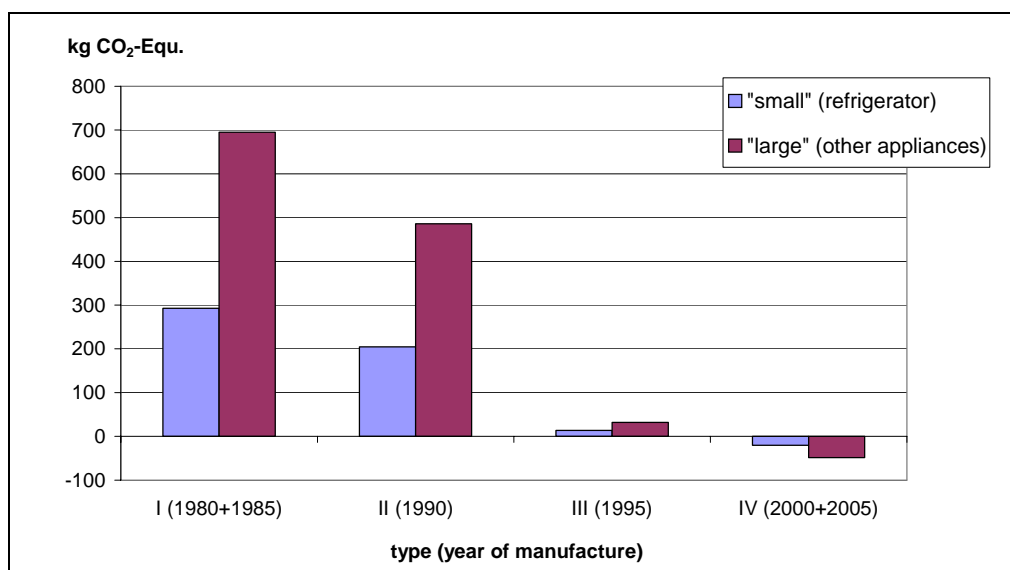


Figure 6-8 Global warming potential (GWP) of the recycling of “small” and “large” cold appliances of different age

The GWP through recycling decreases significantly with later years of manufacture. Even though it is assumed that only 10 % of the amount of refrigerants and foaming agent is released into the atmosphere, the total GWP of the recycling of older appliances is quite high. For type I appliances (1980 and 1985) the GWP of recycling is almost as high as the GWP through the production process (see Figure 6-2 [Global warming potential (GWP) of the production, use and recycling of cold appliances of the four regarded categories] in section 6.1).

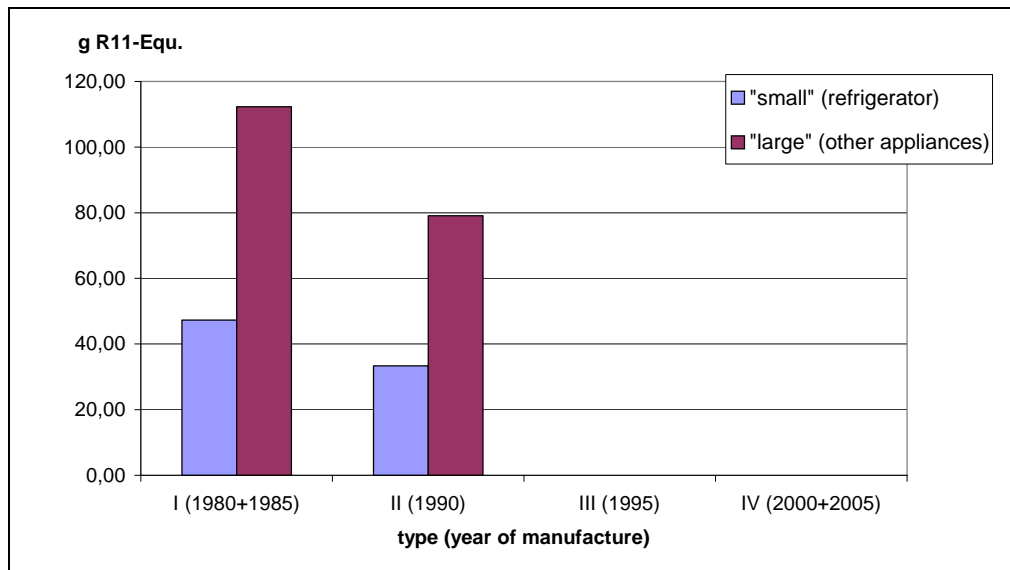


Figure 6-9 Ozone depletion potential (ODP) of the recycling of “small” and “large” cold appliances of different age

A similar picture as the GWP gives the ODP. The ODP of the recycling of type I and type II-appliances (use of CFCs) is quite high, whereas the recycling of newer appliances (type III and IV) does not contribute to the ODP at all.

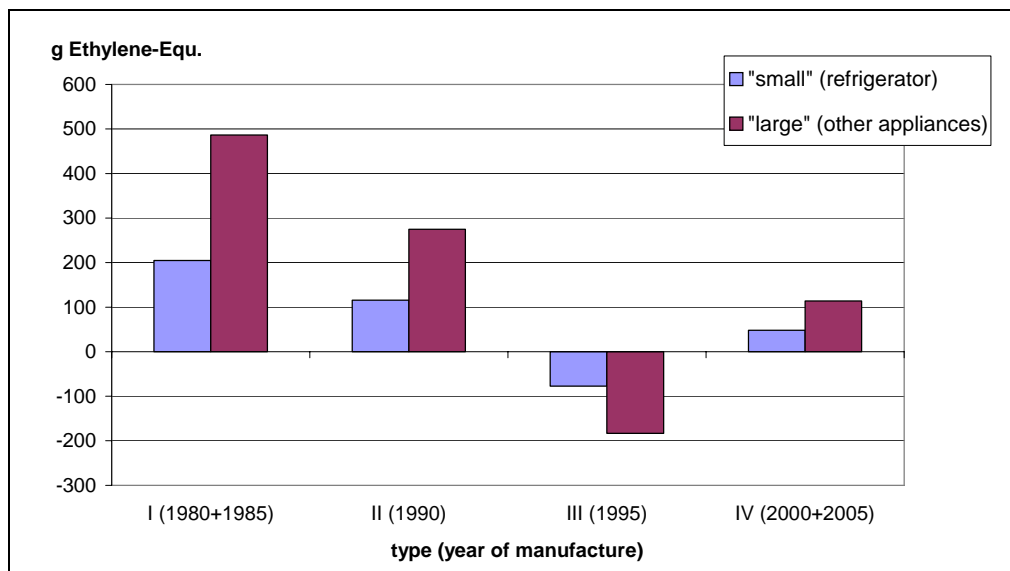


Figure 6-10 Total environmental burden of the recycling of “small” and “large” cold appliances of different age

The total environmental burden as shown in Figure 6-10 is the lowest (even negative) for the recycling of the type III appliance. Please note that the ODP is not included here. This would result in an even worse result of the recycling of type I and type II-appliances. The higher total environmental impact of the type IV appliance compared to type III appliances results from its impacts in the impact category “photochemical ozone creation potential” (POCP),

which is included in the total environmental burden, and which is higher for type IV than for type III-appliances.

To illustrate this development, the results of the POCP are shown in the following figure.

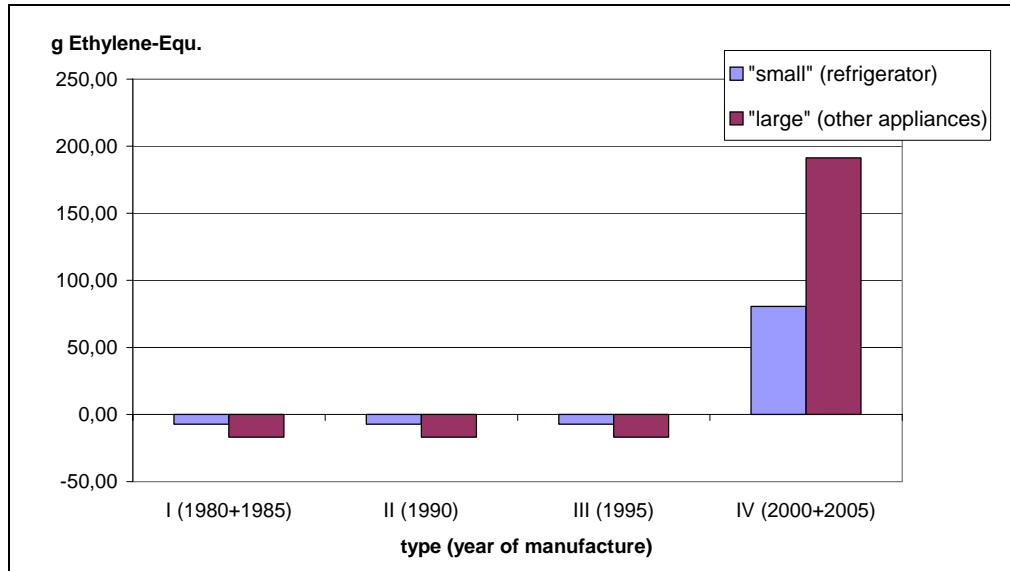


Figure 6-11 Photochemical ozone creation potential of the recycling of “small” and “large” cold appliances of different age

The high POCP of type IV–appliances results from the use of isobutane and pentane as refrigerants and foaming agents. Both are assumed to be not retained in the recycling process but fully released into the atmosphere (according to the assumptions described in section 5.3).

6.3 Comparison of further use vs. replacement of appliance in stock

For each alternative the environmental impacts and the costs connected to considered life cycle phases of the respective appliances are calculated on an annual basis (per year). These annual values are then cumulated to give the total environmental impacts and costs after one, two, three,... up to ten years of use. Thus it can be determined after what time period the initial environmental impact through acquisition and recycling is compensated by the lower impacts during the use phase through the more efficient new appliance (= payback period). In case of the costs it is determined after what time period the purchase price is compensated by the lower costs during the use phase.

The figures show for the year 2005:

- either acquisition and use of a new appliance + recycling of the old one („2005“) or
- further use of the old appliance („1980“, „1985“)

According to the annual electricity demand a smaller or bigger slope of cumulated impact / cost of the different curves results. At the intersection of the curves, the cumulated impacts of production and use of the new appliance and recycling of the old one (“2005“) is equal to the cumulated impacts of the mere use of the old appliance („1980“, „1985“).

For this step of the study a full range of results was produced:

- for the four cold appliance categories,
- for the four environmental indicators and the costs,
- for the three replacement variations (A+ in base case, A and A++ respectively in sensitivity analyses).

For each of these variations full time series from 2005 until 2025 for the six alternatives (further use of appliances of different age (alternative 1 to 5) and the alternative of acquisition and use of a new appliance) were calculated.

Additionally the impact of the alternative “acquisition and use of a new appliance” in the impact categories global warming potential (GWP), ozone depletion potential (ODP) and total environmental burden depends on the age of the old appliance (as the impacts through recycling of the old one depends on its year of manufacture). If these results should be presented in figures, this would result in four figures for each of these three indicators. (In case of the primary energy demand (CED) and the costs, there are no differences in the environmental impact through recycling of the old one. Therefore here one figure is sufficient to compare all six alternatives.)

Considering this amount of data, the presentation of the results has to be focused on the most relevant information. The following depiction of the results is chosen:

- First all base case results of a fridge-freezer (as an example) will be shown in 14 figures (CED and costs: one figure each, GWP, ODP and total environmental burden: four figures each).

- Then the payback periods for all appliance categories, for each indicator and the costs are shown in tables. The payback periods were either calculated (environmental payback periods) or determined from the result tables in the calculation model (financial payback periods).
- To facilitate the direct comparison of the base case results (replacement by 'A+'-appliance) with those of the sensitivity analyses (replacement by 'A' or 'A++'-appliance), tables with the payback periods of these analyses are directly placed above ('A') and below ('A++') the respective tables of the base case.

6.3.1 Fridge-freezer, base case (replacement by 'A+'-appliance)

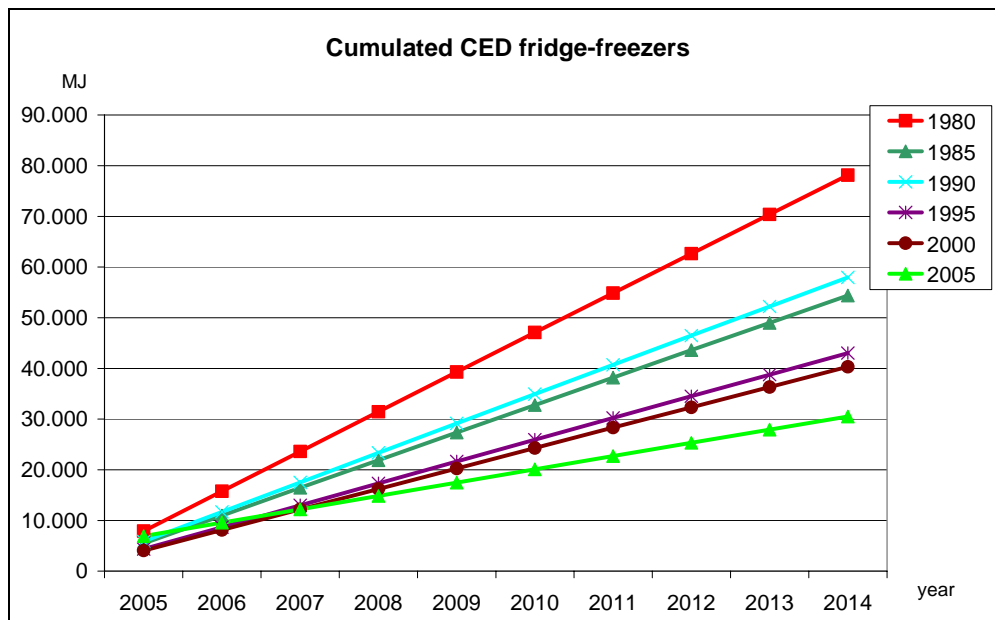


Figure 6-12 Cumulated primary energy demand (CED) of all regarded alternatives from 2005 until 2014, fridge-freezers

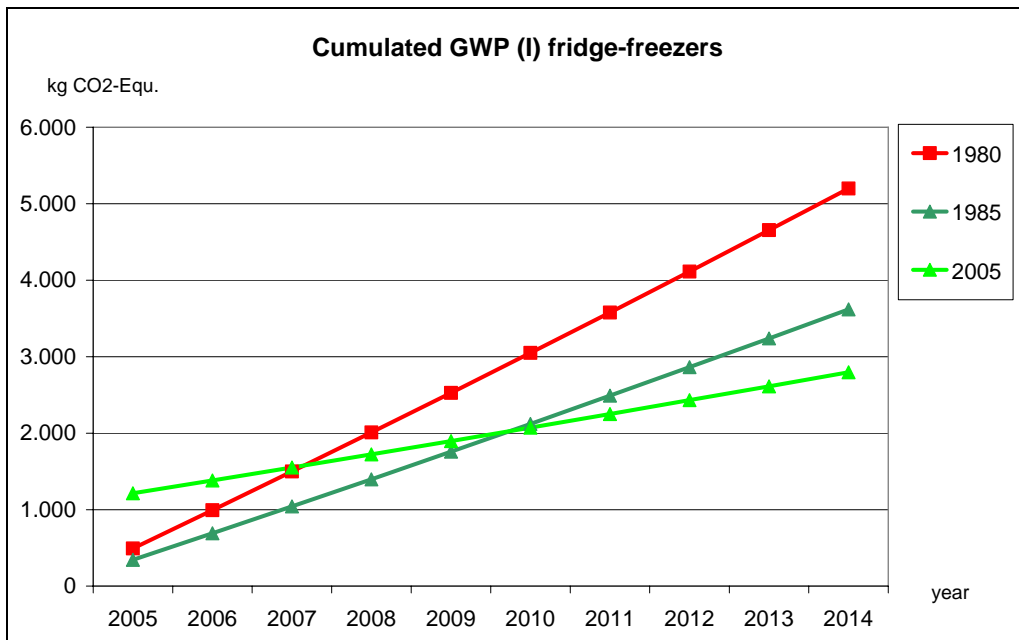


Figure 6-13 Cumulated global warming potential (GWP) of the regarded alternatives (2005 replaces 1980- or 1985-appliance) from 2005 until 2014, fridge-freezers

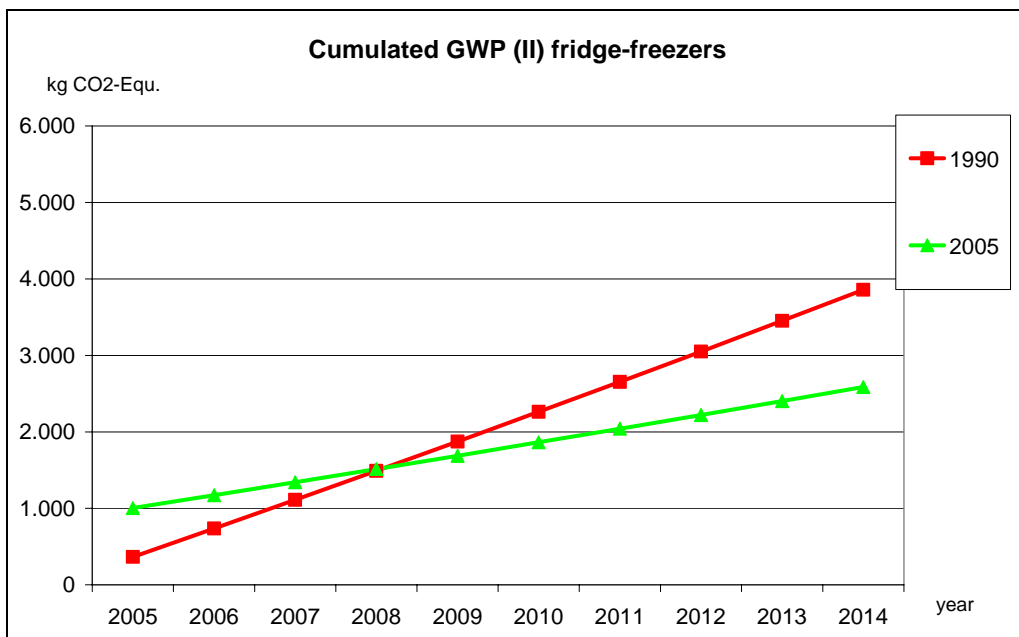


Figure 6-14 Cumulated global warming potential (GWP) of the regarded alternatives (2005 replaces 1990-appliance) from 2005 until 2014, fridge-freezers

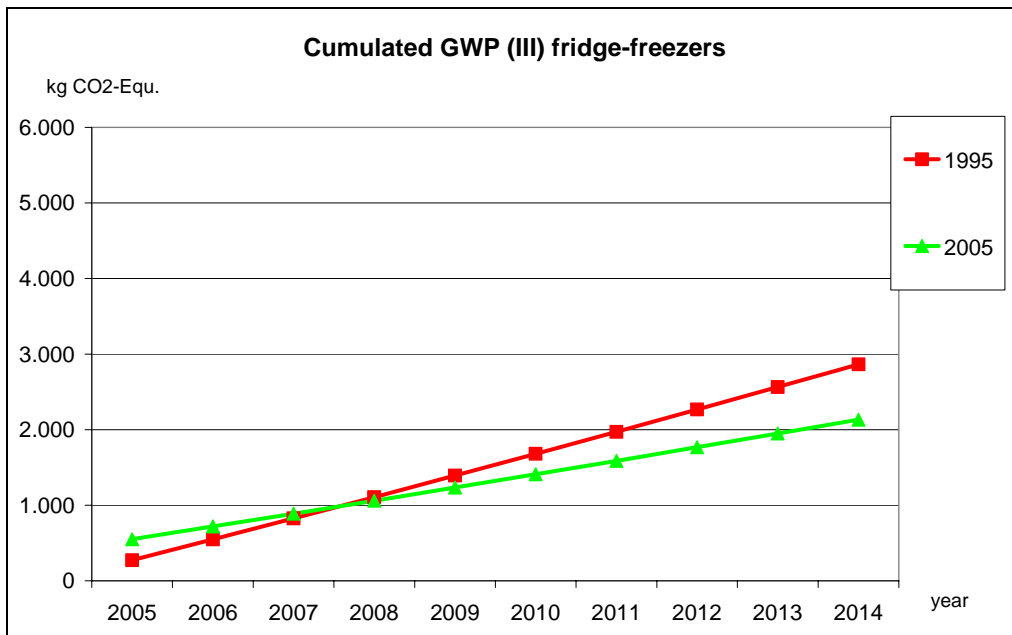


Figure 6-15 Cumulated global warming potential (GWP) of the regarded alternatives (2005 replaces 1995-appliance) from 2005 until 2014, fridge-freezers

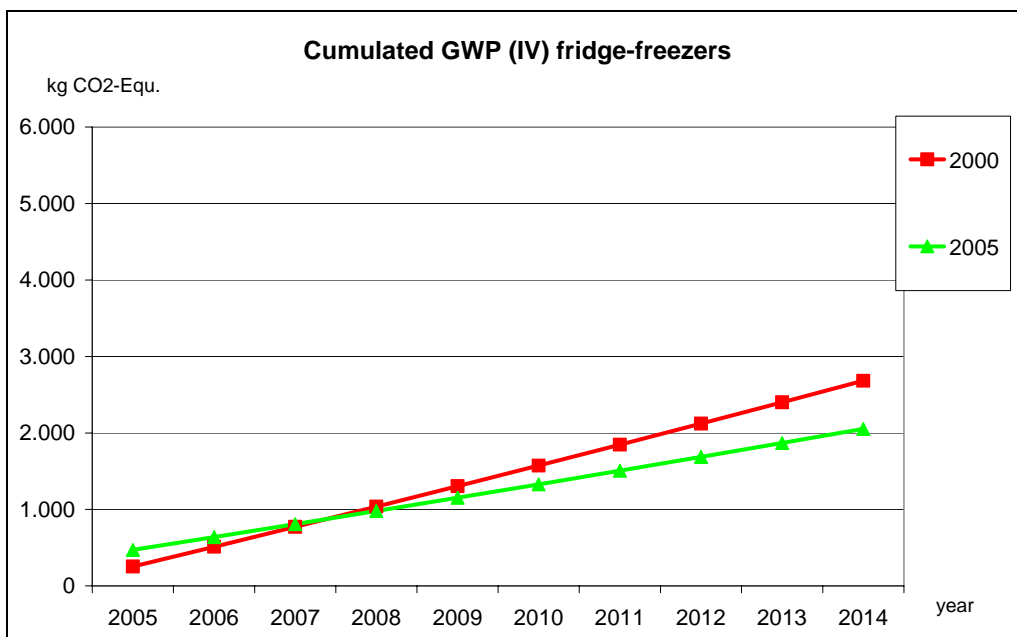


Figure 6-16 Cumulated global warming potential (GWP) of the regarded alternatives (2005 replaces 2000-appliance) from 2005 until 2014, fridge-freezers

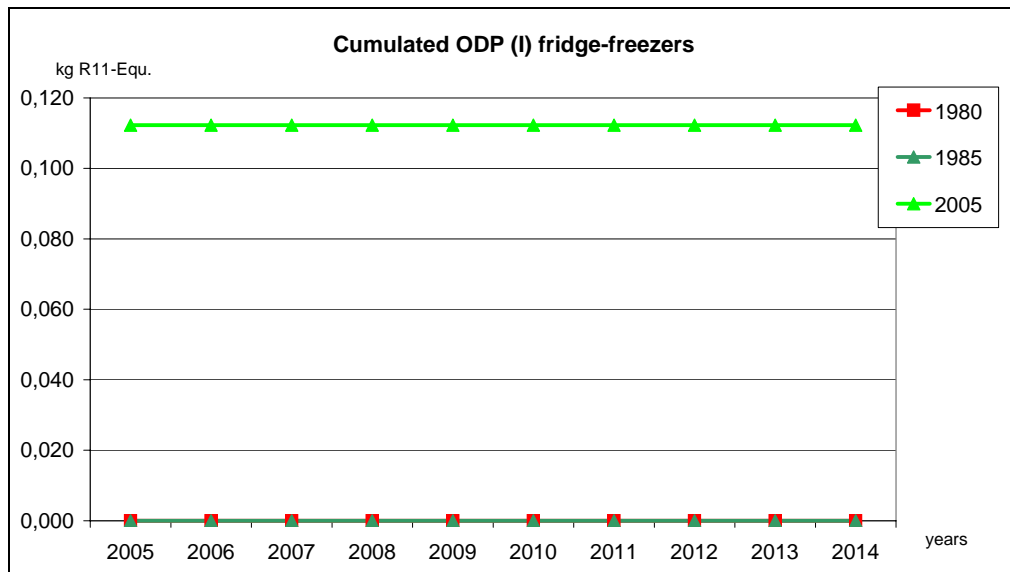


Figure 6-17 Cumulated ozone depletion potential (ODP) of the regarded alternatives (2005 replaces 1980- or 1985-appliance) from 2005 until 2014, fridge-freezers.

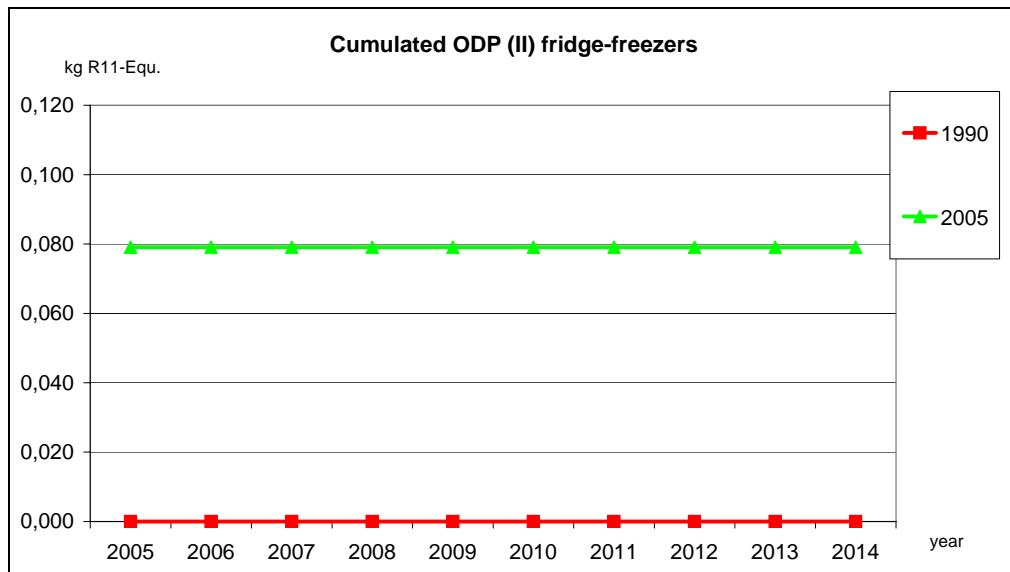


Figure 6-18 Cumulated ozone depletion potential (ODP) of the regarded alternatives (2005 replaces 1990-appliance) from 2005 until 2014, fridge-freezers

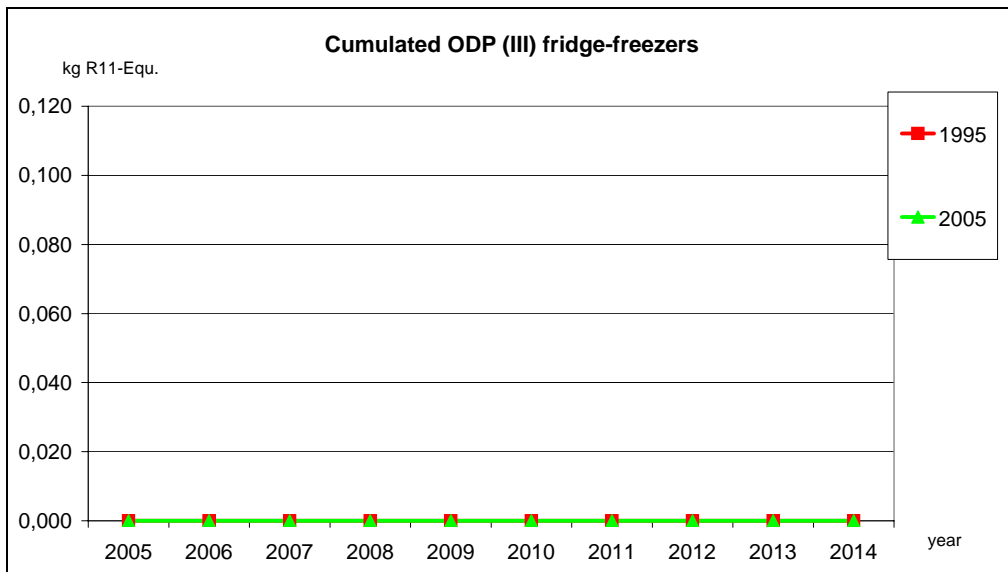


Figure 6-19 Cumulated ozone depletion potential (ODP) of the regarded alternatives (2005 replaces 1995-appliance) from 2005 until 2014, fridge-freezers.

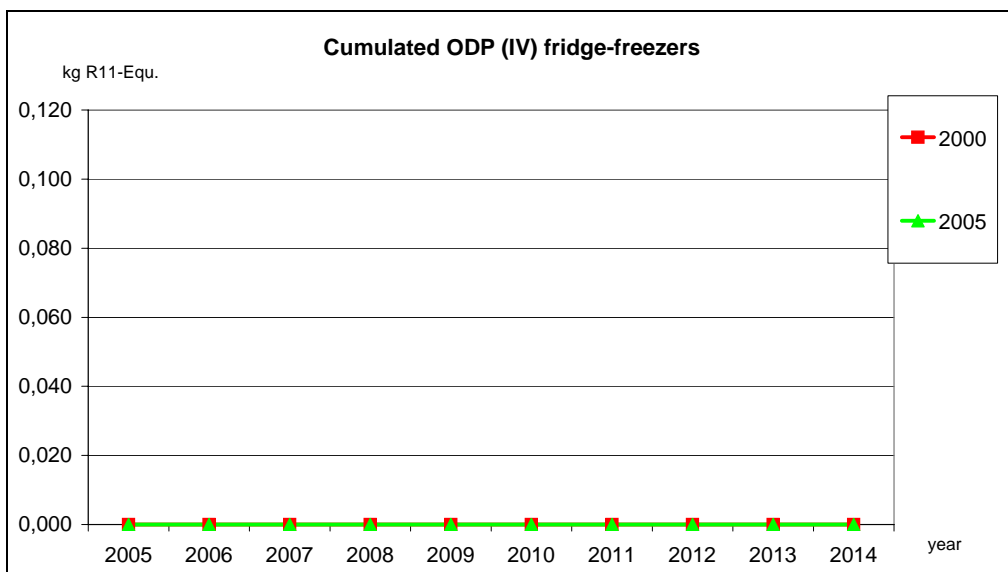


Figure 6-20 Cumulated ozone depletion potential (ODP) of the regarded alternatives (2005 replaces 2000-appliance) from 2005 until 2014, fridge-freezers.

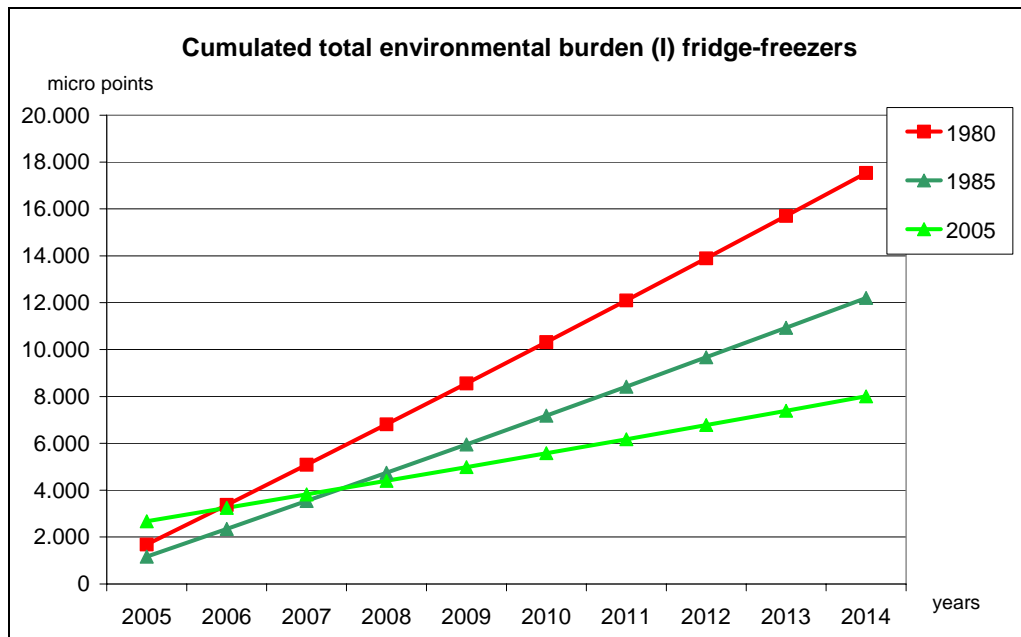


Figure 6-21 Cumulated total environmental burden of the regarded alternatives (2005 replaces 1980-or 1985-appliance) from 2005 until 2014, fridge-freezers.

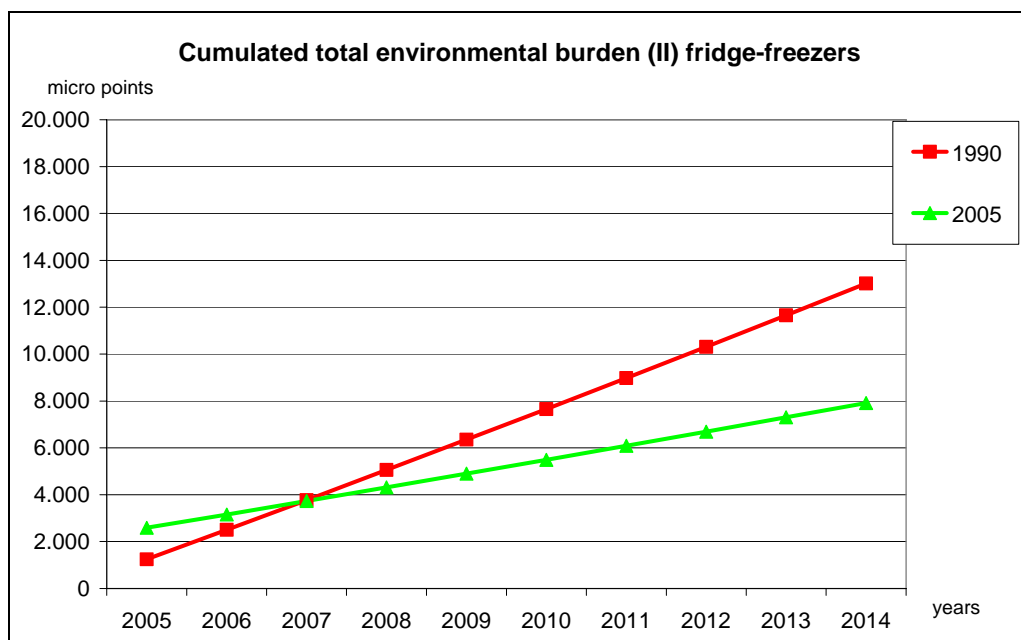


Figure 6-22 Cumulated total environmental burden of the regarded alternatives (2005 replaces 1990-appliance) from 2005 until 2014, fridge-freezers.

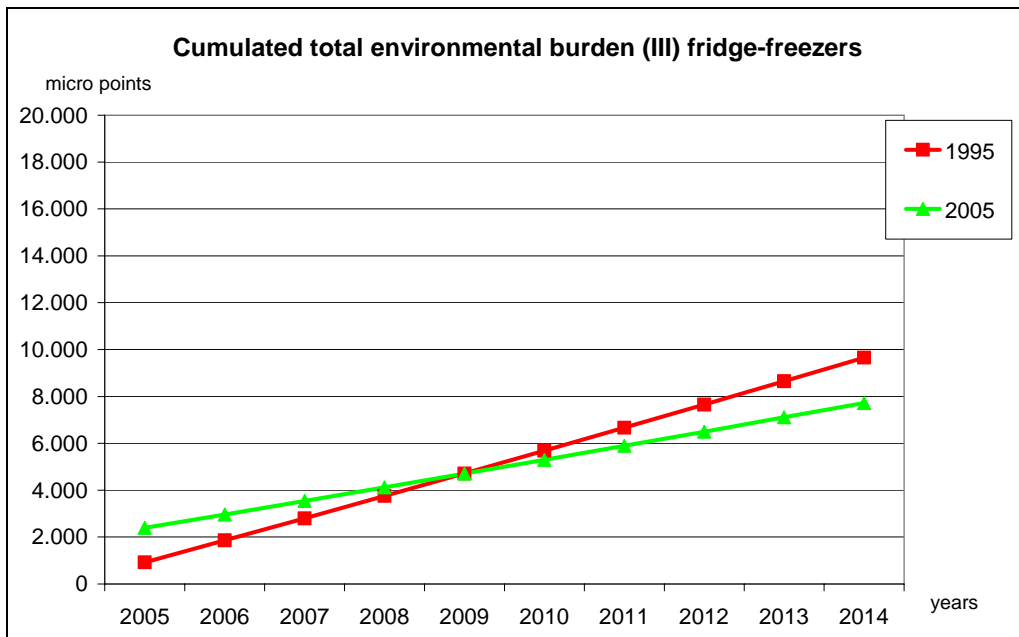


Figure 6-23 Cumulated total environmental burden of the regarded alternatives (2005 replaces 1995-appliance) from 2005 until 2014, fridge-freezers.

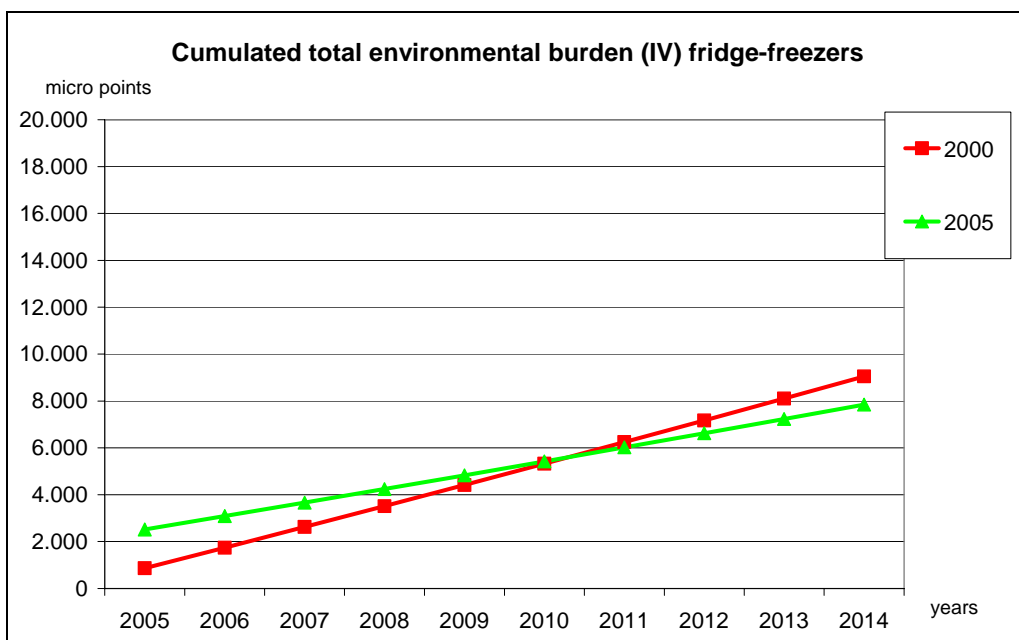


Figure 6-24 Cumulated total environmental burden of the regarded alternatives (2005 replaces 2000-appliance) from 2005 until 2014, fridge-freezers

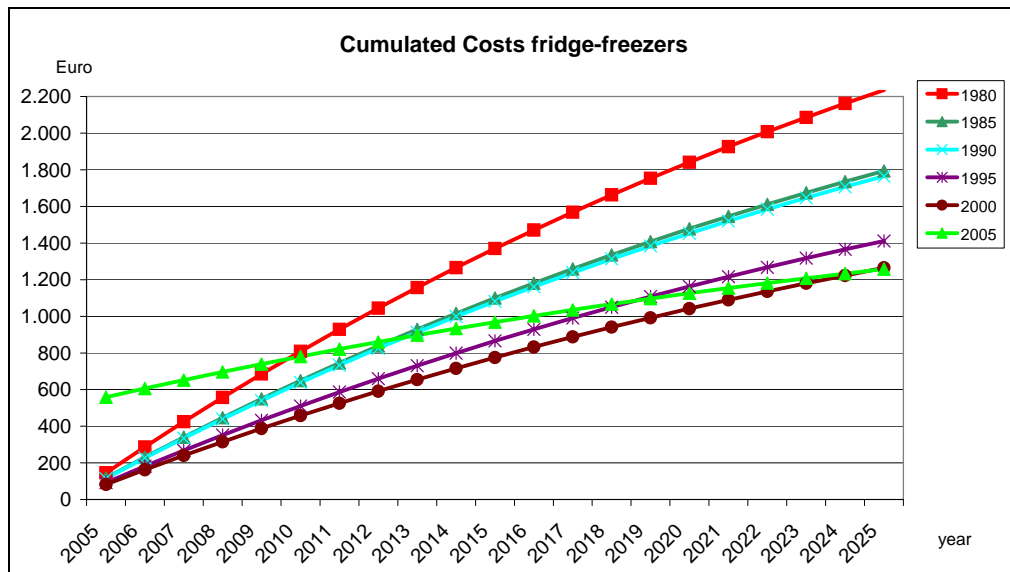


Figure 6-25 Cumulated life cycle costs of all regarded alternatives from 2005 until 2014, fridge-freezers.

6.3.2 Calculated / derived payback periods

For better determination of the influence of the energy efficiency class of the new appliance on the payback periods, first the payback periods of the sensitivity ‚A‘ (replacement by a new appliance with energy efficiency class A), then those of the base case (replacement by a new appliance with energy efficiency class A+), and finally those of the sensitivity ‚A++‘ (replacement by a new appliance with energy efficiency class A++) are shown.

6.3.2.1 Refrigerators

Refrigerator (new A)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,9	3,2	2.269.655	2,2	9
replacement 1985-appliance	1,1	3,7	2.651.281	2,6	10
replacement 1990-appliance	1,3	3,6	2.271.443	2,9	13
replacement 1995-appliance	2,0	2,6	0	3,6	> 21
replacement 2000-appliance	3,3	3,5	0	6,9	> 21

Refrigerator (new A+)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,8	2,7	1.930.911	1,9	7
replacement 1985-appliance	0,9	3,1	2.200.361	2,2	8
replacement 1990-appliance	1,0	2,9	1.818.313	2,3	10
replacement 1995-appliance	1,4	1,9	0	2,6	14
replacement 2000-appliance	2,0	2,1	0	4,2	> 21

Refrigerator (new A++)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,7	2,4	1.697.103	1,7	10
replacement 1985-appliance	0,8	2,6	1.901.792	1,9	11
replacement 1990-appliance	0,9	2,4	1.535.549	2,0	13
replacement 1995-appliance	1,1	1,5	0	2,1	18
replacement 2000-appliance	1,5	1,6	0	3,1	> 21

6.3.2.2 Fridge-Freezer

Fridge-Freezer (new A)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	1,0	3,6	2.627.539	2,4	7
replacement 1985-appliance	2,1	7,8	5.734.659	5,3	18
replacement 1990-appliance	1,8	5,3	3.426.801	4,1	15
replacement 1995-appliance	4,9	6,6	0	8,7	> 21
replacement 2000-appliance	7,1	7,6	0	14,9	> 21

Fridge-Freezer (new A+)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,8	3,0	2.228.514	2,1	6
replacement 1985-appliance	1,5	5,6	4.111.297	3,8	12
replacement 1990-appliance	1,3	4,0	2.568.080	3,1	10
replacement 1995-appliance	2,5	3,4	0	4,6	> 21
replacement 2000-appliance	3,0	3,3	0	6,4	> 21

Fridge-Freezer (new A++)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,7	2,6	1.937.553	1,8	8
replacement 1985-appliance	1,2	4,4	3.226.754	3,0	15
replacement 1990-appliance	1,1	3,2	2.065.311	2,5	13
replacement 1995-appliance	1,7	2,4	0	3,1	> 21
replacement 2000-appliance	2,0	2,1	0	4,1	> 21

6.3.2.3 Upright freezer

upright freezer (new A)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,9	3,5	2.558.126	2,4	5
replacement 1985-appliance	1,6	5,9	4.318.328	4,0	8
replacement 1990-appliance	1,7	5,2	3.335.976	4,0	9
replacement 1995-appliance	1,9	2,5	0	3,4	10
replacement 2000-appliance	2,0	2,1	0	4,2	11

upright freezer (new A+)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,9	3,2	2.351.224	2,2	5
replacement 1985-appliance	1,4	5,1	3.759.820	3,5	7
replacement 1990-appliance	1,5	4,4	2.868.715	3,4	8
replacement 1995-appliance	1,6	2,2	0	2,9	8
replacement 2000-appliance	1,7	1,8	0	3,5	9

upright freezer (new A++)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	0,8	2,8	2.072.526	1,9	6
replacement 1985-appliance	1,1	4,2	3.094.414	2,9	9
replacement 1990-appliance	1,2	3,6	2.326.841	2,8	10
replacement 1995-appliance	1,3	1,7	0	2,3	10
replacement 2000-appliance	1,3	1,4	0	2,8	11

6.3.2.4 Chest freezer

chest freezer (new A)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	1,7	6,4	4.727.738	4,4	9
replacement 1985-appliance	6,1	22,4	16.440.910	15,2	> 21
replacement 1990-appliance	7,9	23,4	15.112.379	18,0	> 21
replacement 1995-appliance	17,9	24,2	0	32,1	> 21
replacement 2000-appliance	26,6	28,5	0	56,1	> 21

chest freezer (new A+)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	1,8	6,5	4.752.357	4,4	9
replacement 1985-appliance	6,2	22,8	16.742.516	15,4	> 21
replacement 1990-appliance	8,1	23,9	15.476.120	18,5	> 21
replacement 1995-appliance	18,9	25,5	0	33,9	> 21
replacement 2000-appliance	28,9	30,9	0	60,9	> 21

chest freezer (new A++)	CED	GWP	ODP	Total env. burden	Costs
<i>in years</i>					
replacement 1980-appliance	1,4	5,2	3.822.766	3,5	11
replacement 1985-appliance	3,3	12,3	9.017.379	8,3	> 21
replacement 1990-appliance	3,8	11,3	7.286.275	8,7	> 21
replacement 1995-appliance	5,2	7,1	0	9,4	> 21
replacement 2000-appliance	5,8	6,2	0	12,2	> 21

6.3.3 Comparison of base case and sensitivity analyses

As an example to interpret the tables, for fridge-freezers the payback periods of the primary energy demand (CED), the global warming potential (GWP), the total environmental burden and the costs with respect to the energy efficiency class of the new appliance (A, A+ or A++) are shown in the following figures (please mind the different scaling of the time axis between environmental and cost payback periods!).

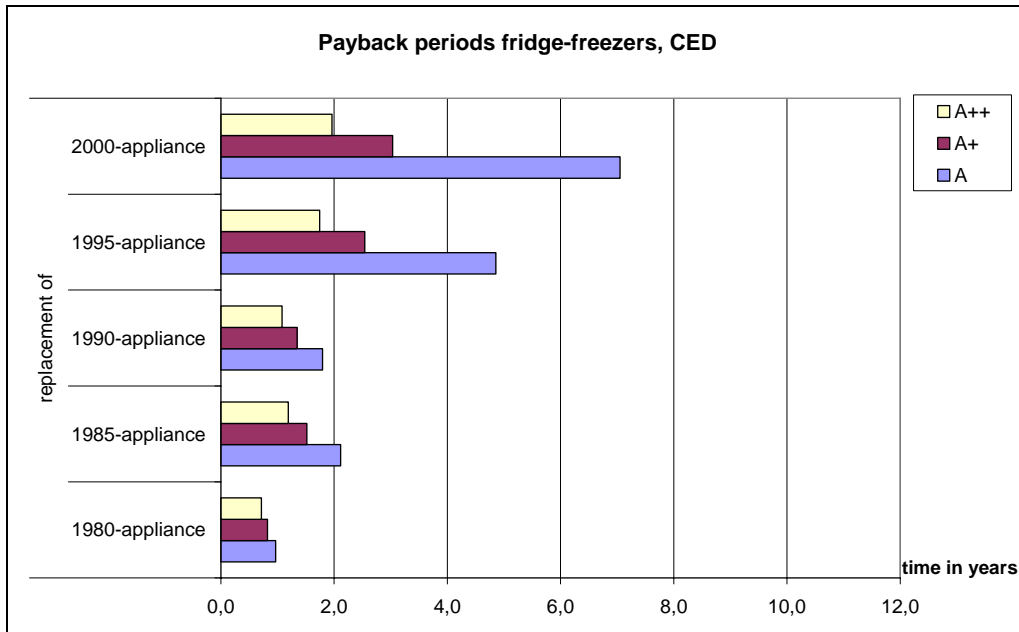


Figure 6-26 Payback periods of the primary energy demand (CED) with respect to the energy efficiency class of the new appliance, example fridge-freezers

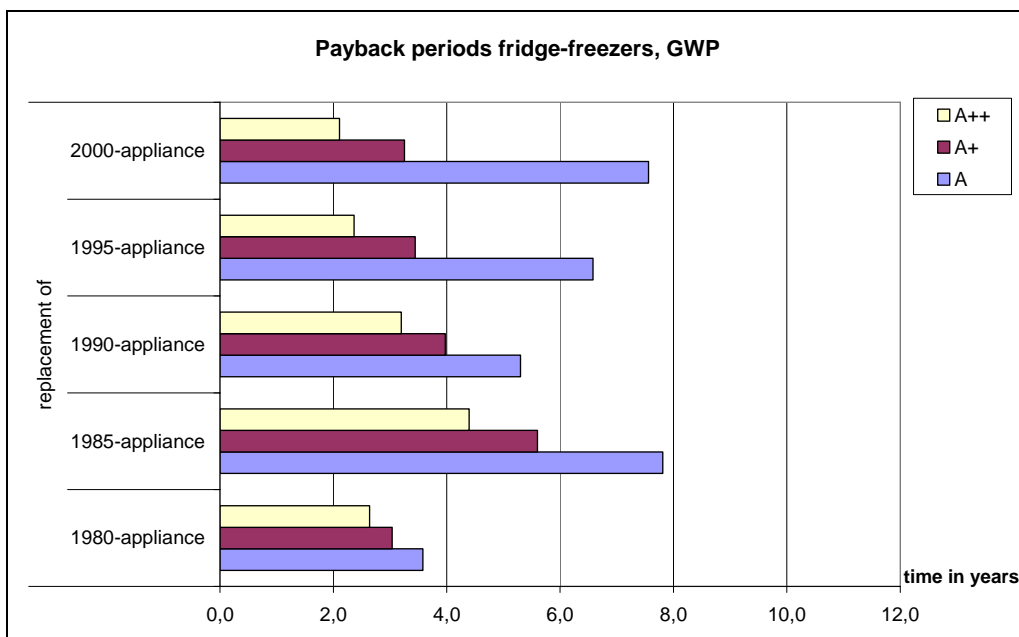


Figure 6-27 Payback periods of the global warming potential (GWP) with respect to the energy efficiency class of the new appliance, example fridge-freezers

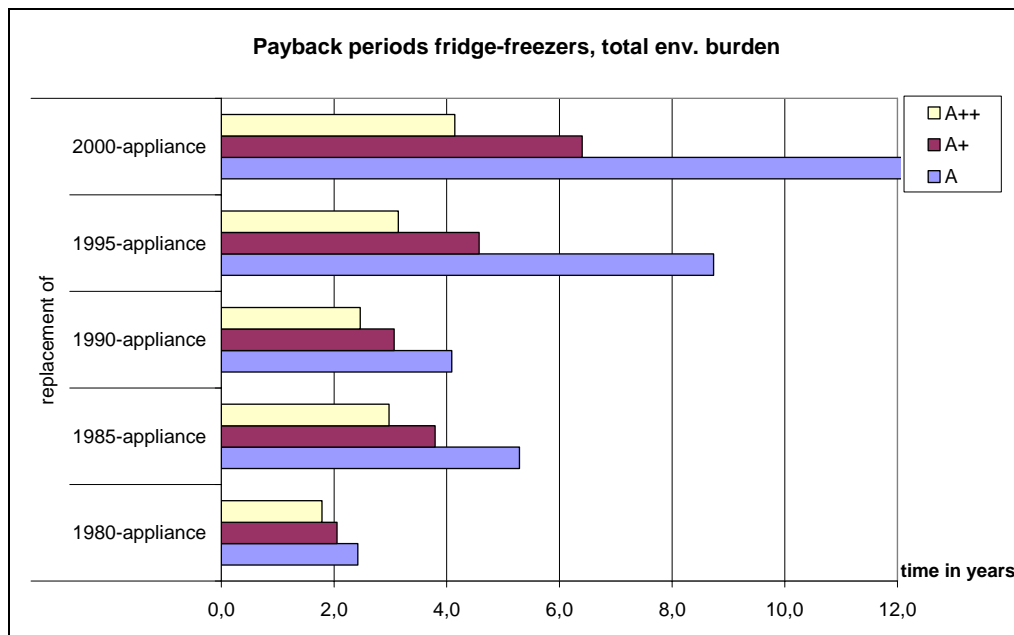


Figure 6-28 Payback periods of the total environmental burden with respect to the energy efficiency class of the new appliance, example fridge-freezers

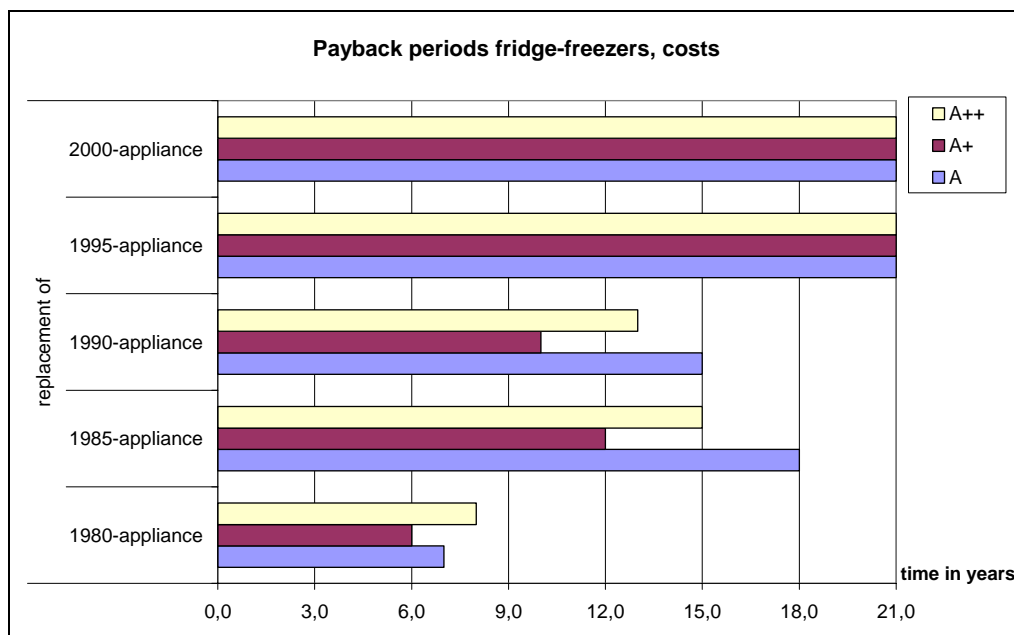


Figure 6-29 Payback periods of the costs with respect to the energy efficiency class of the new appliance, example fridge-freezers

Especially when comparing the payback periods of the environmental indicators (primary energy demand (CED), global warming potential (GWP) and total environmental burden) in case of fridge-freezers, it can be seen that the results quite strongly depend on the energy efficiency class of the new appliance: The better the energy efficiency class of the new appliance is, the shorter is the payback period. This effect is the more relevant the newer the 'old appliance' is.

Regarding the costs, the interpretation of the results is somewhat more difficult. This arises from the fact, that the differences in the purchase price of new appliances of different energy efficiency classes are only roughly estimated. The price of 'A' and 'A+'-appliances are assumed to be the same, the price of an 'A++'-appliance is assumed to be 50 % higher than that of the 'A-' and 'A+'-appliances.

6.4 Main results (accelerated replacement)

- The **payback periods** depend on the type of appliance, the regarded indicator, the age of the 'old' (to be replaced) appliance and the energy demand of the new appliance. In general it can be stated, that the newer the old appliance and the higher the energy demand of the new model is, the longer are the payback periods. Therefore the longest payback periods are found for old appliances of the year 2000 to be replaced by an A-class model.¹⁵
- The **environmental payback periods**, when replacing old refrigerators, fridge-freezers and upright freezers with new A+ or A++ models, are quite similar and mostly below 5 years, sometimes even shorter than one year. When the appliances are replaced with an **A++-appliance**, the environmental payback periods are always below five years. In case of chest freezers they are much higher than those of the other three categories and are mostly above 5 years, often even longer than the assumed life span of a freezer of 17 years.
- The **cost payback periods** are much higher than the environmental payback periods. However due to the bandwidth of the purchase prices and the uncertainty regarding their dependency on the energy efficiency class, the results of the costs are afflicted with a higher degree of uncertainty compared to those of the environmental impacts.
- The payback periods regarding the **primary energy demand (CED)** are very low (i.e. between less than one and five years) for almost all appliance categories, all appliances in stock to be replaced and all efficiency classes of the new appliance.
- The payback periods regarding the **global warming potential (GWP)** and the **total environmental burden** are slightly higher than those regarding the CED. In case of refrigerators and upright freezers they are also for nearly all cases lower than 5 years. In case of fridge-freezers the payback periods are slightly higher compared to those of refrigerators and upright freezers. However, when the old appliances are replaced by A+ or A++-models they are also mostly below 5 years.

¹⁵ In case of chest freezers there is hardly any difference between the replacement by an A and by an A++-model. This results from the difference in the calculation schemes defined in directive 2003/66/EC (for calculating the maximum energy demand of A+- and A++-models) and directive 1994/2/EC (for calculating the maximum energy demand of A- to G-models).

- The results of the **ozone depletion potential** are not meaningful as these results only represent the very high impacts through recycling of old appliances with CFCs and HFCs – which occurs anyway at any time. The methodological issue of allocation is strongly relevant here.

6.5 Conclusions

The environmental impacts of new cold appliances mainly result from the electricity demand during the use phase (80% to 90%). The production contributes only between 10% and 20% and the end-of-life phase is almost negligible (if the appliances are properly recycled). The purchase of an appliance however is more relevant in financial terms than the production in environmental terms and accounts for 35% to 45% of the life cycle costs.

The specific energy demand of appliances on the market has been reduced substantially over the last decades. However, especially with the introduction of the two new energy label classes A+ and A++, it becomes obvious that the energy demand of the actually purchased appliances is still too high, i.e. that consumers did (and still do) not buy the most efficient appliances available on the market.

The question if it is “worth” to further use an existing cold appliance or to substitute it and use a new model cannot be answered absolutely. The answer depends on the individual evaluation of the time span, which is acceptable for the environmental and economic pay-back period. In this study 5 years for environmental or economic amortisation were defined as a time period that justifies the substitution. With this measure, the replacement of the different cold appliances is environmentally justified (i.e. regarding the total environmental burden) under the following conditions:

- Refrigerators; replacement by
 - ‘A++’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A+’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A’-model: 1980 to 1995-appliances
- Fridge-freezers; replacement by
 - ‘A++’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A+’-model: 1980 to 1995-appliances
 - ‘A’-model: 1980 to 1990-appliances
- Upright freezer; replacement by
 - ‘A++’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A+’-model: all regarded appliances in stock (1985 to 2000)
 - ‘A’-model: all regarded appliances in stock (1985 to 2000)
- Chest freezer; replacement by
 - ‘A++’-model: 1980-appliances
 - ‘A+’-model: 1980-appliances
 - ‘A’-model: 1980-appliances

Regarding the cost payback periods only the replacement of upright freezers manufactured in 1980 with 'A'- and 'A+'-models is justified. However this result has to be handled with care as the cost data is afflicted with a quite high degree of variability and uncertainty.

The outcomes of this study hence support the conclusion that in case of refrigerators, fridge-freezers and upright freezers the replacement of appliances in stock, which are older than five to ten years and still functioning, environmentally makes sense, if they are replaced by high efficient new appliances (i.e. appliances of the energy efficiency classes A+ or A++).

Next to the high efficiency of the new model the proper recycling of old appliances is very important in order to make such an accelerated replacement reasonable. Especially in old appliances chlorofluorocarbons (CFCs) and fluorinated hydrocarbons (HFCs) were used as refrigerants and foaming agents, which contribute strongly to ozone depletion and to the greenhouse effect (global warming). In newer appliances the contained volatile organic carbons (butane, pentane) strongly contribute to photochemical ozone creation.

7 References

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8 Annex

Table 8-1 Average and maximum energy demand of refrigerators differentiated by the year of manufacture (average) and energy efficiency class (maximum) (in kWh).

Year of manufacture	1980	1985	1990	1995	2000	2005 (A)	2005 (A+)	2005 (A++)
per appliance and year	363	333	301	251	212	154	118	84
per 100 litres and year	234	215	194	162	137	100	76	54
EEI	129	118	107	89	75	55	42	30

Table 8-2 Average and maximum energy demand of fridge-freezers differentiated by the year of manufacture (average) and energy efficiency class (maximum) (in kWh).

Year of manufacture	1980	1985	1990	1995	2000	2005 (A)	2005 (A+)	2005 (A++)
per appliance and year	759	528	563	418	392	334	255	182
per 100 litres and year	262	182	194	144	135	115	88	63
EEI	125	87	93	69	64	55	42	30

Table 8-3 Average and maximum energy demand of upright freezers differentiated by the year of manufacture (average) and energy efficiency class (maximum) (in kWh).

Year of manufacture	1980	1985	1990	1995	2000	2005 (A)	2005 (A+)	2005 (A++)
per appliance and year	702	523	500	483	472	263	224	160
per 100 litres and year	369	275	263	254	248	91	77	55
EEI ¹⁶	147	109	104	101	98	55	42	30

Table 8-4 Average and maximum energy demand of chest freezers differentiated by the year of manufacture (average) and energy efficiency class (maximum) (in kWh).

Year of manufacture	1980	1985	1990	1995	2000	2005 (A)	2005 (A+)	2005 (A++)
per appliance and year	437	268	252	223	215	199	201	143
per 100 litres and year	230	141	132	117	113	69	69	49
EEI ¹⁶	120	74	69	61	59	55	42	30

¹⁶ Energy efficiency index of A+ and A++ according to 2003/66/EC. If the maximum energy demand of these efficiency classes in case of upright and chest freezers is related to energy efficiency class "D" (which is calculated according to 94/2/EC and has by definition a maximum index of 100), then higher "effective" indices are obtained (see e.g. the maximum allowed energy demand of chest freezers in class A and A+).

Table 8-5 Type and amount of refrigerant and foaming agent according to year of manufacture¹⁷

Type	I	II	III	IV
i.e.	before 1988	1988 – 1993	1993 - 1997	from 1994
Refrigerant	R12	R12	R134a	R600a
„small“	0,140	0,105	0,095	0,036
„large“ appliance	0,332	0,249	0,226	0,085
Foaming agent (PUR-foam)	R11	R11	R134a	Pentane
„small“ appliance	0,358	0,247	0,165	0,194
„large“ appliance	0,851	0,587	0,392	0,460

Table 8-6 Specification of the chemicals used as refrigerant and foaming agent

Technical name	class	Chemical formula	Chemical name
R11	Chlorofluorocarbon (CFC)	CCl_3F_1	
R12	Chlorofluorocarbon (CFC)	CCl_2F_2	
R134a	Fluorinated hydrocarbon (HFC)	$\text{CF}_3\text{CH}_2\text{F}$	
R600a	Hydrocarbon (HC)	$\text{CH}(\text{CH}_3)_3$	Isobutane
c-pentane	Hydrocarbon (HC)	C_5H_{10}	Cyclo-Pentane
n-pentane	Hydrocarbon (HC)	C_5H_{12}	Normal-Pentane

¹⁷ Own categories according to Gabel et al. 1998.