Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

# Eco-Efficiency Analysis of Washing machines

## – Life Cycle Assessment and determination of optimal life span –

Commissioned by
Electrolux - AEG Hausgeräte GmbH and
BSH Bosch und Siemens Hausgeräte GmbH

Final report
(revised extended version including results of phase 2)

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**Authors**

Ina Rüdenauer

Carl-Otto Gensch

Dietlinde Quack

**Öko-Institut e.V.**
**Geschäftsstelle Freiburg**
Postfach 6226
D-79038 Freiburg
**Tel.** +49 (0) 7 61 – 45 295-0
**Fax** +49 (0) 7 61 – 47 54 37

**Hausadresse**
Binzengrün 34a
D-79114 Freiburg
**Tel.** +49 (0) 761 – 45 295-0
**Fax** +49 (0) 761 – 47 54 37

**Büro Darmstadt**
Rheinstr. 95
D-64295 Darmstadt
**Tel.** +49 (0) 6151 – 81 91 - 0
**Fax** +49 (0) 6151 – 81 91 33

**Büro Berlin**
Novalisstr. 10
D-10115 Berlin
**Tel.** +49 (0) 30 – 28 04 86-80
**Fax** +49 (0) 30 – 28 04 86-88

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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.

## General abbreviations

| | |
|---|---|
| ct. | Euro-cent |
| EEA | Eco-efficiency Analysis |
| € | Euro |
| 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 |
| n.a. | not applicable |
| WEEE | Directive 2002/96/EC of the European Parliament and the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE) |

# 1 Background and goal of the study

## 1.1 Background

Due to technological advance during the last 10 to 15 years of both washing machines and detergents, significant reductions of energy and water consumption could be realised in the field of private laundry. Although new developments in chemistry of detergents or sensor technology in washing machines (e.g. detection of the load of the washing machine or the staining of laundry) may result in additional savings, future savings of energy and water consumption might be lower compared to the savings realised in the past years. Furthermore the way consumers operate their washing machine (programme settings and load) influences strongly energy consumption, water consumption and costs.

Life Cycle Assessment (LCA) has shown, that the use-phase is dominant compared to the production or end-of-life phase of washing machines. But it should be taken into account that these LCA-results are about 10 years old and meanwhile several parameters affecting the results of the LCA may vary:

- machine technology has changed (e.g. more plastic, electronic).
- by implementation of the WEEE-directive the end of life-management of washing machines will change (70 to 80% recycling rates),
- consumers' behaviour (like choice of washing temperature) and socio-demographic trends (influencing the load) have changed (and these trends may continue in future).

## 1.2 Goal

Against this background Electrolux and B/S/H Bosch und Siemens Hausgeräte jointly commissioned Öko-Institut e.V. to carry out this study. The major tasks of this study were as follows:

1. update Life Cycle Assessment for washing machines and compare with results of previous LCA-studies,
2. compare the acquisition and use of a washing machine with larger rated capacity to the acquisition and use of a washing machine with a rated capacity of 5 kg under environmental and economic aspects
3. calculate scenarios for the future taking into account various possible technological and behavioural developments and

conclude which life span a washing machine of today should have, achieving minimal environmental impact and least life cycle costs for the consumer,

4. analyse in terms of LCA the best choice of washing-machines' life span by comparing the situation of 15 years in the past with today.

The study was carried out stepwise: In a first phase (February to July 2004) the tasks 1, 3 and 4 were accomplished. In a second phase (July to October 2004), some data gaps were filled (e.g. concerning the production parameters of certain washing machines) and the comparison of washing machines of different size (task 2) was drawn.

## 1.3 Application and not intended uses of results

The results can be applied for:

- strategic decisions of manufacturers
- information of the interested public

The following restrictions apply to the results:

- The study is based on average data. In case of individual purchase decisions the parameters influencing the results might differ from the assumed average data. Examples of such data are the cost for fresh water supply and waste water treatment that vary to a quite great extend within the geographical scope of the study (Germany). Therefore in individual purchase decisions the answer to the risen questions might be different from the answers given in this study.
- The results are only valid for the geographical scope of this study (Germany). There are different parameters that strongly depend on the country or climatic conditions. Examples of those parameters are:
  - use of electric tumble driers: the use of driers might not be necessary in countries with other climatic conditions
  - electricity supply: the primary energy sources are different in most countries
  - consumer behaviour, washing habits
- In task 3 the intrinsic assumption is underlying that households use their washing machines until the maximum life span. This is hypothetically as often households replace their washing machines earlier due to other reasons than the breakdown of the machine.

In section 2 the methodological approach will be described in detail. The considered system, background information about data and assumptions and the calculated scenarios are characterised in section 3. While section 4 summarises the results of the study the conclusions are outlined in section 5.

# 2 Methodological approach

As mentioned above, in this study four main tasks have to be carried out:

1. What are the environmental impacts of a washing machine over its whole life cycle (production, distribution, use and end-of-life-treatment)?
2. Does it make sense[1] to buy a washing machine with a larger loading capacity compared to the so far “standard” 5 kg-machine?
3. What is the optimal life span of a washing machine regarding the next approximately 20 years?
4. Does it make sense to further use an old washing machine or is it better (in environmental and economic terms) to buy a new one?

Each of these questions has to be tackled a little bit different. But for each question it is necessary to determine the environmental impact and the costs for private households that are connected with washing machines in the different stages of their life cycle.

The following main life cycle stages have to be distinguished:

- Production and distribution of a washing machine (including raw material supply)
- Use phase: washing and drying of clothes
- End-of-life treatment of washing machine

For the first question the environmental impacts and costs are calculated for a *“current” washing machine model (rated capacity of 5 kg)*, calculated with maybe changing consumer behaviour and other parameters over the expected life span of this washing machine.

For the second question the environmental impact and costs calculated for a *“current” washing machine model with a larger rated capacity (e.g. 7 kg)* have to be compared to those of a standard 5 kg-machine. Both environmental impact and costs have to be calculated for a defined time span, not for the life span of the two washing machine types

[1] Under environmental and economic aspects (economic: for private households).

that are compared.[2] The environmental impact and the costs are calculated over the next approximately 20 years (exactly: 22 years, from 2004 until 2025).

For the third question, also the development of the specific consumption figures and the spin speed of *future washing machines* have to be considered. Only then it can be analysed if it is better to use a washing machine as long as possible or to substitute it more often to realise the efficiency gains of future washing machines. Equally as for the second question, the environmental impacts and the costs are calculated over the next approximately 20 years (exactly: 22 years, from 2004 until 2025) for different assumed life spans of washing machines. A long life span results in a small number of used washing machines (and subsequently smaller environmental impact and costs for production and end-of-life-treatment) but maybe in higher impacts during the use phase (as potential efficiency gains are not realised), whereas a shorter life span results in higher impact and costs for production and end-of-life-treatment but presumably in lower impacts and costs through usage. To examine if and how the obtained results change with different possible future developments three scenarios are defined.

For the fourth question the consumption figures of *existing washing machines in stock* that are probably still in use have to be investigated and compared with the environmental impact and the costs of the production/purchase and the use of a “current” washing machine. The acquisition of a new washing machine is always connected with additional environmental impact (due to the production of the machine) and additional initial costs compared to the further use of the old washing machine. This means that it has to be analysed, how long it takes, to save these additional impact and costs by using a new washing machine with potentially lower environmental impact and costs during the use phase. Depending on the differences in consumption figures this will take more or less time. Of course the additional impact and costs are amortised the faster the bigger the differences between the consumption figures of “old” and “new” are.

For all questions both the environmental impact and the costs (for private households) for the different stages of the life cycle of a washing machine have to be assessed. For the environmental assessment a Life Cycle Assessment (LCA) according to ISO 14040 ff. is

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[2] This results from the fact, that the life span is defined by the number of washing cycles. With the assumption of a fix annual amount of laundry and relative loading of the machine, the annual number of washing cycles might be smaller when a larger washing machine is used compared to the use if a 5 kg-machine. This would then result in different life spans in years for the compared machine types.

conducted. For cost calculation the Life Cycle Costs are calculated. Both assessments can be combined in an Eco-Efficiency Analysis to give a comprehensive picture. In the following sections, first the Eco-Efficiency Analysis of the Öko-Institut (section 2.1), then the applied scenario technique (section 2.2) is described in more detail.

## 2.1 Eco-Efficiency analysis

The eco-efficiency analysis of the Öko-Institut is a tool to assess different alternatives to fulfil a defined consumer need both under an environmental and economic perspective. "Eco-efficiency" therefore means the combined assessment of environmental and economic impacts under a life cycle perspective.[3]

The eco-efficiency analysis is based on the methodology of life cycle assessment (LCA) according to ISO 14040 ff. (to assess the ecological aspects of products and processes) and on a calculation of the life cycle costs. Figure 1 gives an overview of the steps.

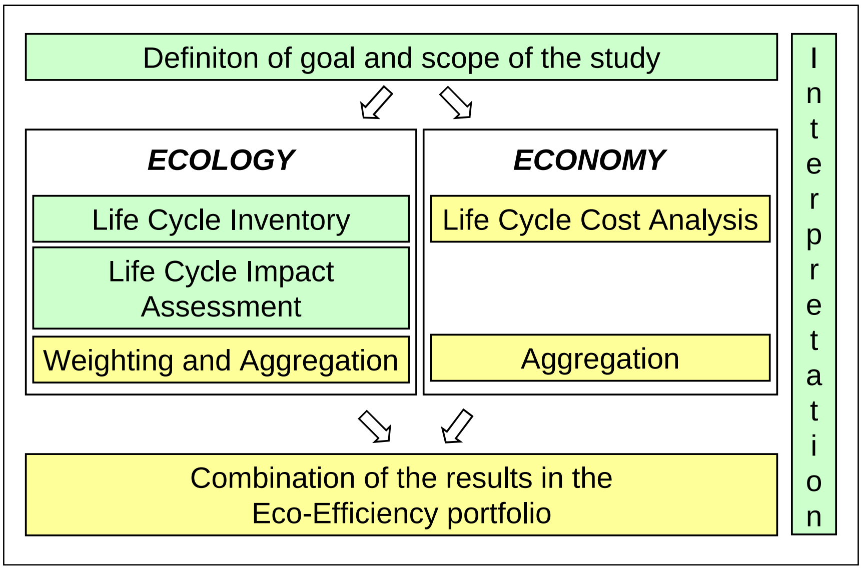


Figure 1 General proceeding of the eco-efficiency analysis

The green indicated steps are equivalent to those in the LCA standards. The yellow indicated steps go beyond the standards.

3 In contrast the economic life-cycle of a product, the expression „life cycle" is used like in LCA terminology, meaning the consideration of a system "from cradle to grave". Typical steps of the (physical) life cycle of a product are raw material production, manufacturing, distribution, use phase, end-of-life treatment.

### 2.1.1 Life Cycle Assessment (LCA)

The Life Cycle Assessment (environmental assessment) is conducted according to international standard ISO 14040 ff. Single steps are goal and scope definition, inventory analysis, impact assessment and interpretation (see also Figure 1).

*Goal and scope definition*:

This step has to be conducted both for the environmental and the economic analysis. Therefore some additional aspects have to be included. Next to the definition of the goal and the system boundaries of the analysis the definition of the functional unit is a major part of this step. The functional unit acts as measure of the performance of the system and provides the reference to which all inputs and outputs are related. In order to ensure a common basis for the analyses in case of an eco-efficiency analysis the function and the system boundaries of the analysed systems have to be identical for both environmental and economic assessment. As the cost data have to be collected on an actor specific base (see above section 2.1), the actor (actors) for which the life cycle costs are going to be calculated has (have) to be chosen.

*Life Cycle Inventory*:

First the material and energy flows are modelled to give the life cycle inventory of the considered alternatives. All upstream and downstream processes of the analysed system are modelled, thus all the material and energy flows are traced back to their initial extraction from and final emission to the environment.

*Life Cycle Impact Assessment:*

To describe the impacts that are connected with the calculated elementary flows an impact assessment is conducted. The input and output flows are assigned to impact categories (classification), described in common units (characterisation) and aggregated to the impact category indicator result.

The following impact categories are considered:

- primary energy demand (indicator: cumulated energy demand CED)
- metallic resources demand
- global warming potential (GWP)
- acidification potential (AP)
- aquatic and terrestrial eutrophication potential ($EP_a$, $EP_t$)
- photochemical ozone creation potential (POCP)

The total environmental burden (aggregated indicator that aggregates different indicators with the method EcoGrade, see section 2.1.2) is calculated from the results in these impact categories. Please note that the calculation of the aggregated indicator goes beyond the ISO standards.

In this study only the results of the primary energy demand (CED), the global warming potential (GWP) and the total environmental burden are represented.

*Interpretation*:

For interpretation the main contributors to the results are identified. Furthermore the robustness of the results is traced back through sensitivity considerations. The kind of sensitivity analysis depends on the specific task. The relevant parameters are described in 3.8).

### 2.1.2 Weighting and Aggregation of the environmental indicator results

In the ISO standards the aggregation of different impact categories to a single environmental indicator is <u>not</u> allowed. In practice actors already go beyond ISO standards and weight and aggregate the environmental results to single scores, when applying environmental or eco-efficiency analyses in comparative studies for decision-making. Especially in companies this is often done internally on basis of a company specific weighting method.

Due to practical applicability and in order to support possible decisions as far as possible the Öko-Institut also weights and aggregates the results of the different impact categories to a single score. This total environmental burden can then be compared to the costs. In the following paragraph the weighting method "*EcoGrade*" which is used and developed by the Öko-Institut is shortly described:

The considered impact categories[4] are weighted by putting them in relation to national or international environmental target figures. Thus the proportion with which the specific results contribute to the total amount in the respective impact category is obtained. With the definition that each target figure equals one million environmental target points, the environmental target points of the alternatives in the different categories are obtained. These can then be summed up to get the total environmental burden of the alternatives.[5] The advantage of this method is that the results on the one hand are put in relation to an absolute value, thus determining their importance with respect to an external reference. On the other hand these absolute values are the result of a societal discussion process reflecting the im-

[4] Energy resources consumption (CED), metallic resources consumption, global warming potential (GWP), acidification potential (AP), aquatic eutrophication potential (aEP), terrestrial eutrophication potential (tEP), photochemical ozone creation potential (POCP).

[5] Bunke et al. 2004, Bunke et al. 2002.

portance the society ascribes to a specific environmental problem. In principle the more important the problem is considered by society the more ambitious are the target figures set in the specific category.

### 2.1.3 Life Cycle Costing (LCC)

The economic analysis is based on the method of a direct calculation of actual costs. All costs that are connected to the regarded alternatives are calculated from the viewpoint of a specific actor. For which actor the costs are calculated has to be defined according to the goal and scope of the respective study. Different types of life cycle costs are acquisition costs (e.g. price for appliances or machines), costs for operating media (e.g. costs for water, electricity, detergents), cost of repair, maintenance or disposal. Auxiliary investment costs (e.g. interests) can be taken into account. Depending on the system under consideration future costs might be discounted.

In general external costs are not considered. Usually external costs represent a certain environmental issue. As in the eco-efficiency analysis the environmental side is regarded by itself this would mean a double-counting of the environmental side.[6]

### 2.1.4 Consolidation of LCA and LCC

To consider the relative importance of the environmental and economic results, the total environmental burden and the life cycle costs have to be referred to an external reference. This step is similar to the normalisation step in life cycle impact assessment, where results of different impact categories are referred to an external reference to show the magnitude of impacts.

The reference for the "normalisation" of the environmental dimension can be the total environmental impact of a certain country or region (e.g. the geographic scope of the study). For the costs the corresponding external reference has to be taken (e.g. gross domestic product GDP). It is important to use the same system boundaries for these reference values in order to avoid misinterpretations by different scales.

With this last step the final values are obtained and can be plotted in a two-dimensional eco-efficiency graph, as depicted in Figure 1. Please note that the graph has an inverted scale:

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[6] 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 in this case.

low costs are plotted to the right, a low environmental burden to the top. Thus alternatives are the more eco-efficient the closer they are to the upper right corner of the portfolio.

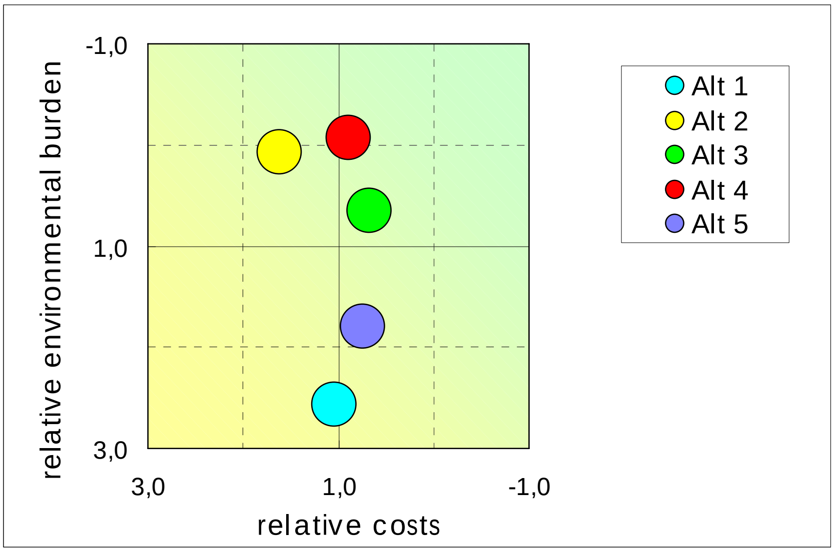


Figure 2	Eco-efficiency portfolio

## 2.2 Scenario technique

The scenario technique aims to show possible futures on the basis of a scientific process but without the claim to forecast the future. Instead it is the goal of scenarios to spread out possible ways and consequences of development, thus giving support to decision makers.

The scenario technique comprises several steps including in the first place a system description and clarifying of the question to answer.[7] On the basis of these data and with the support of a discussion with internal and external experts the critical key parameters can be identified and their future development can be outlined. In the next steps consistent sets of possible developments of these parameters has to be defined and the different scenarios can be described. Usually one of the scenarios, serving as a reference, describes a business as usual situation with no or only few changes. In addition one or two other (or even more) scenarios are defined giving a clue how major changes would form other futures with different impacts and consequences.

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[7] See also Gausenmeier et al. 1996.

# 3 Scope and data base of the study

Washing and drying of clothes is a quite complex system that is influenced by a lot of parameters.

Not only the consumption figures of the used washing machine and the potentially used tumble drier determines the overall environmental impact and the costs of doing laundry, but also the type of laundry, consumer behaviour like choice of temperature, load of washing machine and drier, dosage of detergents, etc. Besides also more general parameters like the way the used electricity is produced play a role.

The following chapters describe the regarded system "washing and drying of private laundry": the functional unit(s), the system boundaries and the used data.

## 3.1 Function and functional unit

The function of the system under consideration is defined as "washing of clothes in private households". As it is regarded to be relevant for the results, in task 3 and task 4 the function is extended and includes also the drying of clothes in private households.

The functional unit of this study is therefore defined as follows:

- Task 1 and task 2: "Washing of a certain amount of laundry in private consumers' households."
- Task 3 and task 4 "Washing and drying of a certain amount of laundry in private consumers' households."

The specific amount of laundry depends on the task and the regarded household size. In the study at hand in the base case alternatives the calculations are made for a household of three people. Table 1 describes the specification of the functional unit for the different tasks. Differences in the performance of washing machines of different age or life span were not considered. Especially older washing machines in stock might have a worse washing performance than new washing machines. In those cases higher level of detergent dosage or higher wash temperatures might be necessary to reach the same performance as new washing machines have.[8] This is an important issue which should be considered in future studies.

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[8] See e.g. washing performance tests carried out in 2004 by the section *Household and Appliance Technology* of the University of Bonn.

Table 1 Specification of functional unit.

| Task | Description | Amount of laundry |
|---|---|---|
| 1 update LCA | Amount of laundry that can be washed within the life span of a washing machine<br>(Life span: 2 000 cycles) | Household of 3 people: 8 080 kg<br>Calculated from:<br>▪ Number of washing cycles: 175 cycles p.a.<br>▪ Resulting life span: 11,4 years<br>▪ Annual amount of laundry: 707 kg |
| 2 comparison: standard vs. large washing machines | Amount of laundry that is washed within the regarded time period of 22 years<br>(2004 with 2025) | Household of 3 people: 15 556 kg |
| 3 optimal life span | Amount of laundry that is washed and dried within the regarded time period of 22 years<br>(2004 with 2025) | Household of 3 people: 15 556 kg<br>“Small” household: 6 653 kg<br>(number of washing cycles: 75 cycles p.a.)<br>“Large” household: 23 065 kg<br>(number of washing cycles: 260 cycles p.a.) |
| 4 substitution of machines in stock | Annual amount of laundry that is washed and dried, over a period of ten years | Household of 3 people:<br>10 * 707 kg = 7 070 kg |

## 3.2 System boundaries

### 3.2.1 Geographical scope

The geographical scope has to be fixed as the results may depend on country specific background data concerning consumer behaviour, technological specifications of washing machines, end-of-life-management etc. as well as delivery of energy and water. All data in this study represent the German situation.

### 3.2.2 Regarded processes

Basically the whole (physical) life cycle of washing machines is regarded. This includes the production, distribution, use and end-of-life-treatment of washing machines. Due to lack of data the collection of old washing machines and their disassembly is not included in the analysis. However credits for the recycling of certain materials according to the requirements of the WEEE-directive are included.

The focus of the study is on the average washing machine in the market. This means in task 1 and task 2 average consumption figures of washing machines in the market in 2004 are taken, not consumption figures of best available machines. In task 3 the development of the average consumption figures are estimated. In task 4 average consumption figures of washing machines in stock and of washing machines in the market 2004 are taken. In all cases there might be washing machines with special features that are not covered by this study.

The drying of clothes is only partly included as the focus of the analysis are washing machines. Nevertheless some aspects of washing machines (mainly spin speed) influence the energy consumption of the subsequent drying process. Therefore the drying process itself is included in task 3 and 4 whereas the production, distribution and end-of-life-treatment of tumble driers are not included at all.

Figure 3 gives an overview of the analysed system and processes. When not stated differently, the credits are directly subtracted from the environmental impacts of the production and distribution phase (especially in task 3).

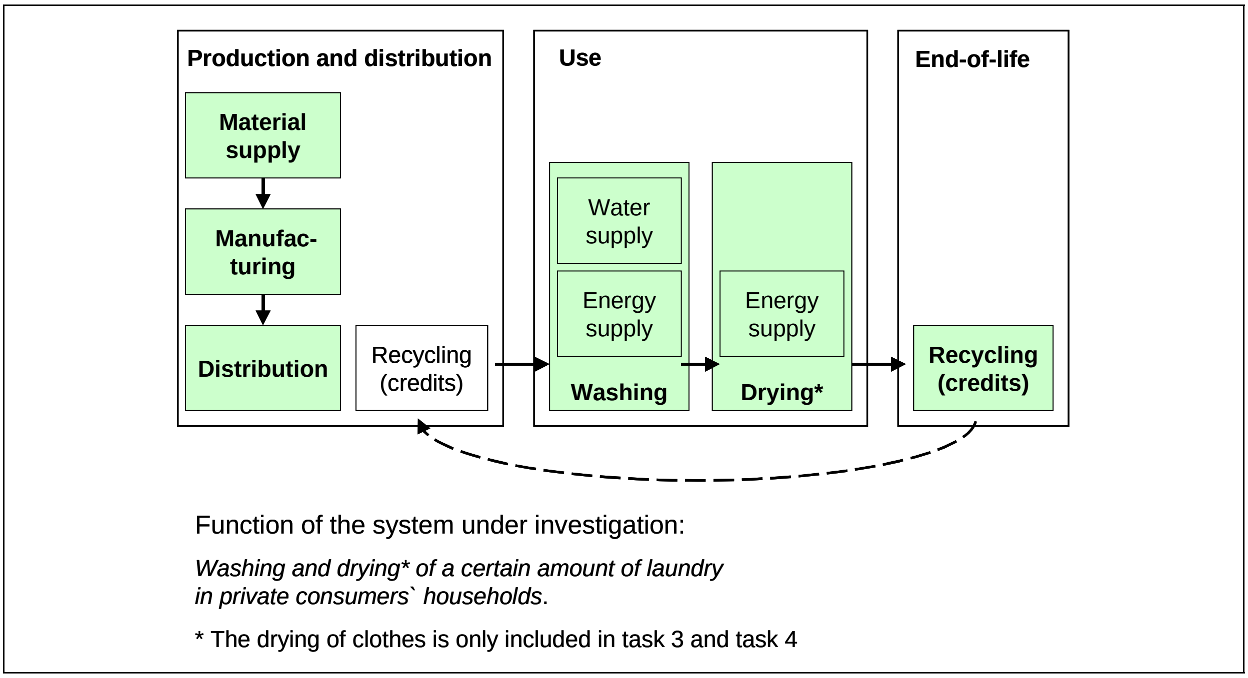


Figure 3 Regarded system and processes

As depicted in Figure 3 the following modules are included in the analysis:

- Production of raw materials for the washing machine
- Manufacturing/assembly of the washing machine
- Distribution of the washing machines from manufacturers to private households
- Washing process in private households
- Drying process in private households in electric condenser drier
- Recycling of washing machines: credits for recycled materials of washing machines
- Background processes: fresh water and electricity supply

Not included are the following modules:

- Collection and disassembly of old washing machines (no data available)
- Production and distribution of electric tumble driers (not relevant)
- End-of-life treatment electric tumble driers (not relevant)
- Credits for recycled materials of tumble driers (not relevant)
- Impacts related to the production and use of detergents (not relevant)
- Environmental impacts of waste water treatment (no data available)

### 3.2.3 Significance

With regard to the environmental impact the included modules cover approximately 97 % of the total life cycle of washing machines. This is an estimation when assumed that the environmental impacts of the collection and disassembly of used washing machines are in the same magnitude as those of manufacturing and distribution.

The costs for collection and disassembly are assumed to be included in the general waste fees or (in future) in the prices for washing machines.

## 3.3 Allocation procedures

In the study at hand no general allocation rules have to be applied explicitly. Only the credits for recycling of materials are equally allocated to the first and the second life cycle of the material in question and therefore only 50 % of the recycled material is credited against the environmental impacts of the system.

In modules used to model certain materials or the supply chain of energy sources the implied allocation rules are taken over.

## 3.4 Impacts and methodology of impact assessment

See section 2.1.1

## 3.5 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.

## 3.6 Life Cycle Costing

The life cycle cost analysis is based on the method of a direct calculation of actual costs in the sense of total costs of ownership. These costs are calculated for private households. The following cost types are considered:

- Acquisition costs
- Energy costs
- Cost for fresh water supply and waste water treatment

The life cycle costs represent the total costs over the regarded life span of a washing machine (task 1) or the regarded time period (task 2, 3 and 4). A future development of prices for washing machines, electricity, fresh water supply and waste water treatment is assumed. There is no discounting rate assumed. External costs are not included.

## 3.7 Data base

### 3.7.1 Production

The production phase is subdivided in three parts:

- upstream processes of materials (material supply),
- manufacturing and
- distribution.

**Material composition and upstream processes for material supply**

To check potential differences in the environmental impacts of machines of different price segments in the market, the composition of five washing machines was analysed. Additionally a washing machine with a larger rated capacity was analysed.

- machine I: low price segment
- machine II.1: medium price segment, simple design
- machine II.2: medium price segment, average design
- machine II.3: medium price segment, elaborate design
- machine III: high price segment
- machine L: large rated capacity

The material composition of all machines is shown in Table 2. The upstream processes for the material supply were modelled with data of different data-bases (the data sources for these processes are shown in Table 3).

Table 2 Material composition of the analysed washing machines (figures represent one washing machine).

| **Material** | **machine I** | **machine II.1** | **machine II.2** | **machine II.3** | **machine III** | **machine L** |
|---|---|---|---|---|---|---|
| ***UNIT*** | | | ***g*** | | | |
| Acryl-Butadien-Styrol (ABS) | 1.228 | 1.851 | 1.863 | 1.850 | 1.196 | 1.850 |
| Aluminium | 2.313 | 3.209 | 4.124 | 5.211 | 3.608 | 5.021 |
| Brass | 73 | 20 | 20 | 20 | - | 20 |
| Cable | 781 | 286 | 302 | 303 | 952 | 303 |
| Carboran 40% | - | 10.574 | 11.505 | 11.289 | 775 | - |
| Chipboard | 2.057 | 2.350 | 2.350 | 2.350 | 2.468 | 2.350 |
| Concrete | 22.740 | 18.680 | 18.680 | 18.910 | 0 | 17.090 |
| Copper | 925 | 579 | 747 | 765 | 1.027 | 765 |
| Cotton with phenolic binder | 525 | 198 | 378 | 999 | 1.620 | 999 |
| Electronic Components | 362 | 482 | 537 | 968 | 1.929 | 968 |
| Ethylen-Propylen-Copolymer (EPDM) | 2.220 | 2.673 | 2.942 | 2.981 | 2.960 | 2.981 |
| Glass | 1.931 | 1.688 | 1.688 | 1.688 | 1.476 | 1.688 |
| Gray cast iron | 1.304 | 1.400 | 1.920 | 3.140 | 28.780 | 7.860 |
| Polyacryl (PA) | 17 | 77 | 59 | 65 | - | 65 |
| Polyethylen (PE) | - | - | - | 6 | 27 | 6 |
| Polymethylmethacrylat (PMMA) | 3 | 0 | 56 | 47 | 185 | 47 |
| Polyoxymethylen (POM) | - | 58 | 46 | 49 | 26 | 49 |
| Polypropylen (PP) | 175 | 859 | 1.055 | 1.060 | 489 | 1.060 |
| PP 20% mineral filler | 421 | - | - | - | 41 | - |
| PP 40% mineral filler | 8.012 | - | - | - | 1.410 | 11.288 |
| Polystryrene (PS) | 219 | - | - | - | - | - |
| Steel | 24.320 | 26.045 | 26.470 | 27.935 | 44.733 | 27.935 |
| Other materials (not considered) | 2.118 | 1.152 | 1.188 | 1.434 | 3.350 | 1.434 |
| **Subtotal machine** | **71.743** | **72.180** | **75.928** | **81.071** | **97.052** | **83.780** |

Table 2 (continuation).

| Material | machine I | machine II.1 | machine II.2 | machine II.3 | machine III | machine L |
|---|---|---|---|---|---|---|
| ***UNIT*** | ***g*** | | | | | |
| Wood | 422 | 1.100 | 1.100 | 1.100 | 1.100 | 1.100 |
| Corrugated cardboard | 499 | 1.300 | 1.300 | 1.300 | 1.300 | 1.300 |
| Polystryrene (PS) | 192 | 500 | 500 | 500 | 500 | 500 |
| Shrinking foil (PE) | 77 | 200 | 200 | 200 | 200 | 200 |
| Polyacryl (PA) | 38 | 100 | 100 | 100 | 100 | 100 |
| Paper | 58 | 150 | 150 | 150 | 150 | 150 |
| **Subtotal packaging** | **1 286** | **3 350** | **3 350** | **3 350** | **3 350** | **3 350** |
| **SUM TOTAL** | **73 029** | **75 530** | **79 278** | **84 421** | **100 402** | **87 130** |

Table 3 Overview of the data sources for the production of materials, energy and transportation.

| Area | Module | Data source |
|---|---|---|
| Metals | Production of the above listed metals | Umberto 4.2 |
| | Processing of metals (e.g. casting) | Umberto 4.2 |
| Plastics | Production of the above listed plastics | Umberto 4.2 |
| | Processing of plastics (e.g. injection moulding, foil production) | Umberto 4.2 |
| Other materials | Chipboard | Fritsche et al. 2003 |
| | Cotton | Umberto 4.2 |
| | Electronic Components and cables | Umberto 4.2 and GaBi 2001 |
| | Glass | Fritsche et al. 2003 |
| | Concrete | Fritsche et al. 2003 |
| | Packaging material | Umberto 4.2 |
| Energy generation | Energy grid Germany | Enquete 2002: fuel mix<br>Fritsche et al. 2003: power plant mix |
| Transport | Average Truck | Umberto 4.2 |

Manufacturing and distribution is assumed to be the same for all regarded washing machines.

For the **manufacturing** data from [AEG 2003] were used in combination with personal information by [AEG 2004, oral communication]. Incorporated were data for: energy demand, water demand and waste generation.

The **distribution** was calculated according to information provided by [AEG 2004, oral communication]. For the whole distance impacts were calculated on the basis of 50 % transport by truck (an average truck with 50 % workload; one way full; home trip empty) and 50 % transport by train (electric railway line). It was neglected that often a car is used to transport the washing machine from retailers to households. The included distances are shown in the following table.

Table 4 Assumption for distribution route [AEG 2004, oral communication].

| Distribution route | Distance | Unit |
|---|---|---|
| Average distance plant to central storehouses: | 250 | km |
| Average distance central storehouses to retailer | 80 | km |
| Average distance retailer to private households | 10 | km |
| **Sum** | **340** | **km** |

### 3.7.2 Use phase

In the use phase besides the washing process itself, in task 3 and 4 also the drying of clothes in private households is considered. In case of the washing process both water and energy supply, in case of drying energy supply is regarded.

To model the use phase the specific consumption figures of the used washing machines and driers and the consumer behaviour have to be specified.

#### 3.7.2.1 Water and energy consumption of fully loaded cycles (past and current situation)

In the past the average specific water and energy consumption of washing machines at the different washing temperatures decreased to a quite large extend.

Table 5 gives an overview of this development for washing machines on the market between 1970 and 2004. In this study the energy and water consumption figures of the year 2004 are taken to represent the current situation (year 2004).

Table 5 Specific energy and water consumption of washing machines from 1970 to 2004[9].

| **Year of manufacture** | **1970** | **1975** | **1980** | **1985** | **1990** | **1995** | **2000** | **2004** |
|---|---|---|---|---|---|---|---|---|
| **Energy consumption (kWh/kg)** | | | | | | | | |
| 30°C | 0,18 | 0,16 | 0,13 | 0,11 | 0,09 | 0,08 | 0,07 | 0,07 |
| 40°C | 0,29 | 0,26 | 0,22 | 0,18 | 0,15 | 0,13 | 0,12 | 0,11 |
| 60°C | 0,53 | 0,47 | 0,40 | 0,34 | 0,27 | 0,23 | 0,22 | 0,20 |
| 90°C | 0,87 | 0,76 | 0,65 | 0,55 | 0,44 | 0,38 | 0,36 | 0,32 |
| **Water consumption (litre/kg)** | | | | | | | | |
| All temperatures | 39,9 | 35,2 | 30,6 | 25,9 | 21,2 | 15,8 | 12,1 | 9,7 |

As it is assumed that in the future washing machines have a 20°C-cycle, the initial energy consumption of this temperature is approximated from the average energy consumption at 60°C in the year of introduction according to the following equation:

$$E\,(20°C, 2010) = 20\,\% * E\,(60°C, yyyy) + 80\,\% * E\,(60°C, yyyy) / \Delta T\,(60°C) * \Delta T\,(20°C)$$
$$= 0{,}264\ \text{kWh}$$

with

yyyy = year of introduction of 20°C-wash cycle
E (x°C, y) = energy demand at temperature x at year y
$\Delta T$ (60°C) = 45 K
$\Delta T$ (20°C) = 5 K

It is assumed that 80 % of energy consumption of 60°C cotton programme is used for heating of the main wash water.

Please not that these specific consumption figures are assumed for both the standard 5 kg-machine and the machine with larger capacity (7 kg, relevant in task 2, comparison: standard vs. large washing machines).

In a sensitivity analysis of task 2 a more optimistic assumption is made: It is assumed that 30 % of the energy consumption of a 5 kg-washing machine stays constant and only 70 % is increased according to the larger capacity. This results in smaller specific energy and water

[9] Stamminger 2004.

consumption figures for a 7 kg-washing machine as depicted in Table 6. Thus the consumption figures are reduced by approximately 9 % compared to a standard washing machine.

Table 6 Specific energy and water consumption of large washing machines in 2004, sensitivity analysis.

| **Year of manufacture** | **2004** |
|---|---|
| **Energy consumption (kWh/kg)** | |
| 30°C | 0,06 |
| 40°C | 0,10 |
| 60°C | 0,18 |
| 90°C | 0,29 |
| **Water consumption (litre/kg)** | |
| All temperatures | 8,9 |

#### 3.7.2.2 Future minimum water consumption of fully loaded cycles (5 kg-machines)

To estimate the future development of the water and energy consumption figures, the future minimum water consumption has to be estimated.

The possibility of washing with totally different solvents than water in the future is not considered in this study as the whole infrastructure of private laundry is designed for the use of water. Moreover the consideration of usage of other solvents would exceed the scope of this study.

A reduction of water used for the washing process itself is physically limited due to the water uptake of the clothes and the fact that the dirt has to be removed by the water. It is assumed that with current machine technology the lowest water level for the suds of a standard 5-kg machine therefore is 11 litres in a fully loaded cotton programme (1 litre as basis amount and 2 litres per kg laundry). As lowest amount of water needed for each rinsing cycle 8 litres are assumed. With three rinsing cycles per washing cycle this results in 24 litres for rinsing and 35 litres for the whole cycle.

A further reduction of these figures could only be reached through higher mechanical action (e.g. wringing of the laundry or (stronger) spinning during the washing process itself and between the several rinsing steps).

Nevertheless, there are seen several other technologies that might lead to a further reduction of the amount of needed fresh water:

**Recycling of water from the last rinsing cycle**

Due to economic considerations the possibility of this technology is not seen as a major trend. According to information from manufacturers the costs for introducing this feature into washing machines are quite high, as next to the water tank a sterilisation device to prevent algae- or germ-growth (e.g. UV-lamps) had to be installed. The additional costs for the final consumer are estimated to be approximately 250,- €. On the other side there are the savings due to reduced water consumption. Assuming a reduction of water consumption of 10 litres per cycle the feature results in cost savings over the life span of approximately 80,- €.[10] These savings are small compared to the cost increase resulting from installation a water recycling device. Therefore a development of this technology seems unlikely.

**Use of rainwater**

There are already washing machines on the market that are able to use rainwater.[11] With this technology there are seen both technological challenges in cistern technology and similar hygienic challenges (algae- or germ-growth) as described in the paragraph above (recycling of water from the last rinsing cycle). Besides these two facts to an increasing extend the seepage of rainwater in housing areas is both demanded for and fostered resulting in a smaller amount of available rainwater.

Also interesting for this discussion is the calculation of the amount of rainwater both for people living in detached family houses and for people living in apartment buildings to see if there is enough water available for the laundry at all. The annual precipitation in Germany is between 700 and 800 mm. For people living in detached family houses with an estimated roof area of 120 $m^2$ the annual collectable amount of water is 96 $m^3$ (with 800 mm precipitation p.a.). In apartment buildings (15 storeys with four flats each, roof area of 250 $m^2$) the amount of available rainwater is only 3.3 $m^3$ per flat. The annual amount of water needed for washing lies between approximately 5 $m^3$ (for single households) and 10 $m^3$ (for 4-people household).[12] It can be seen that the amount of rainwater would be sufficient for detached family houses, whereas in apartment building there would not be enough rainwater available for the laundry.

Therefore the usage of rainwater was not considered in this study.

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[10] Total number of washing cycles: 2079 (see Stiftung Warentest), Water price: 4,- €/$m^3$.

[11] e.g. Miele W 455 WPS.

[12] Annual number of washing cycles: 111 p.a. in a single household, 211 p.a. in a 4-people household; water consumption: 46 litres / cycle.

**Better turbid sensor technologies**

Better turbid sensors might lead to the reduction of the number of rinsing cycles when they indicate a sufficient low level of turbidity. Already in the mid 1990s the number of rinsing cycles was reduced to three from formerly four or five[13]. Therefore it does not seem to be possible to avoid another rinsing cycle in properly loaded washing cycles with adequate dosage of the detergent. There might be a reduction potential when the washing machine is not fully loaded. Consequences of better turbid sensors might therefore be considered in those cases.

**Neutralisation agent in the first rinsing cycle**

Another possibility of reducing the number of rinsing cycles is to utilise an neutralisation agent in the first rinsing cycle. This agent is supposed to have a low ph-value, thus neutralising the relatively high (alkaline) ph-value of the laundry after the washing process. This also might result in a reduction of the number of necessary rinsing cycles from three to only two.

In this study, the **minimum possible water consumption** of fully loaded washing machines with a rated capacity of 5 kg in a cotton programme is assumed to be 35 litre (11 litre for the suds, 8 litre for each of three rinsing cycles).

A further reduction seems only possible in not fully loaded cycles (by reducing number of rinsing cycles or through automatic load adjustment (see section 3.7.2.4)) or in special programmes.

#### 3.7.2.3 Future minimum energy consumption of fully loaded cycles (5 kg-machines)

During a washing cycle energy is needed for heating the water and certain parts of the washing machine and for mechanical action and pumping.

The energy needed for heating can be approximately calculated with the mass and heat capacity of the amount of water and the other parts that are heated during a washing cycle and the difference between initial and final temperature. Table 7 gives an overview of the used parameters.

[13] SAVE II 2001, p. 35.

Table 7 Parameters to calculate the minimum energy consumption of the washing cycles.

| Part to be heated | Material | Heat Capacity (Cp) | Mass | Initial temperature* | Comment |
|---|---|---|---|---|---|
| | | kJ/(kg*K) | Kg | °C | |
| Water | Water | 4.19 | 11 | 15 | minimum amount of suds |
| Drum | Steal | 0.42 | 5 | 23 | |
| Tub | Polypropylene | 2.5 | 2,5 | 23 | mass 10 kg, ¼ is assumed to be heated |
| Clothes | Cotton | 1.3 | 5 | 23 | |

*according to EN 60456

Approximately 20 % of energy consumption in a 60°C cotton program is needed for mechanical action and pumping.[14] In a modern A-class washing machine this equals 0,19 kWh. It is assumed that this value is constant for all regarded washing temperatures and stays constant in the future.

To calculate the future minimum energy consumption that can be reached at all with the assumed minimum water consumption of 35 litres, the heating energy consumption is calculated for the nominal temperatures of 20°C, 30°C, 40°C, 60°C and 95°C (the real final temperature might differ from these stated one to some extend) with the described parameters.[15]

Table 8 shows the calculated minimum energy consumption for the different temperatures with the above mentioned parameters in comparison with the energy consumption of the currently best available machines and the current fleet average [Stamminger 2004 a]. Please not that the figures apply to a 5 kg-washing machine.

14 SAVE II 2001, p. 35, see also Langgassner 2001.

15 It is assumed that washing cycles at 20°C might be possible in future. Therefore also for this nominal temperature the minimum energy consumption is calculated. The values of the real temperatures where obtained from manufacturers (Klug 2004, personal information).

Table 8 Minimum energy consumption per cycle at different wash temperatures.

| **Nominal temperature** | **20 °C** | **30 °C** | **40 °C** | **60 °C** | **95 °C** |
|---|---|---|---|---|---|
| | kWh/cycle | kWh/cycle | kWh/cycle | kWh/cycle | kWh/cycle |
| *Heating energy consumption* | *0,06* | *0,10* | *0,28* | *0,64* | *1,15* |
| *Mechanical energy consumption* | *0,19* | *0,19* | *0,19* | *0,19* | *0,19* |
| total minimum energy consumption | 0,25 | 0,29 | 0,47 | 0,83 | 1,34 |
| A-class machine 2004 | n.a. | 0,32 | 0,52 | 0,95 | 1,54 |
| fleet average 2004 | n.a. | 0,33 | 0,54 | 0,98 | 1,59 |

With these calculations the future minimum energy consumption turns out to be 10 to 13 % lower than that of the currently best available machines (*A-class machine 2004*). The average energy consumption of all washing machines in the market in 2004 (*fleet average 2004*) is slightly higher than that of the best available machines.

Further reductions in energy consumption could be reached through several technological options:

### Heat pump

One possibility to further reduce energy consumption is the installation of a heat pump to recover heating energy from the suds. A difficulty is the fact, that the heat is not recovered at the same time as energy for heating of the next washing cycle is required. Therefore the heat would have to be stored or used for other applications in the household. Both possibilities are seen to be too complicated to be realised within the next years. Additionally the trend goes to lower washing temperatures, resulting in smaller amounts of energy that could be recovered from the wash cycle. This results in rather small energy and cost savings through the heat pump.

### “hot-fill”

An often discussed feature for saving energy is the “hot-fill” where water is heated outside the machine by efficient water heaters. A reduction potential results if the water heating outside the washing machine is more efficient compared to the electric water heating within the washing machine. Next to the direct efficiency of heat generation this mainly depends on the primary energy sources used for the energy supply. Possible water heating systems outside the washing machine are the available central or district heating system of the regarded household. To prevent lower washing performances (some stains require a lower initial temperature) the initial temperature of the hot-fill has to be restricted to a starting temperature just below 40°C. To allow for this initial temperature and also for washing cycles at lower temperatures two tabs (one for hot water and one for cold water) and a thermostatic mixing valve are necessary. The relatively low initial temperature lowers the energy saving potential of this technology.[16]

As the reduction potential of these technologies seems rather small it is not assumed that they are introduced in the “average” washing machine within the regarded time period. Of course there might be certain machines on the market having these features. As the focus lies on standard washing machines these are not covered by this study.

#### 3.7.2.4 Automatic load adjustment

At currently available washing machines with automatic load adjustment (both 5 kg- and 7 kg-machines) the water and energy consumption is assumed to be reduced by 15 % at a loading of 60 %.

Due to lower prices for modern control systems it is expected that automatic load adjustment can be improved significantly within the next years. An almost linear reduction of the water and energy consumption values seems possible.

Table 9 shows the possible water and energy consumption figures for a future 5 kg-washing machine (with minimum water and energy consumption when fully loaded as above calculated). A water level of 1 litre independently from load is assumed.

[16] SAVE II 2001; p. 44.

Table 9 Water and energy consumption with future load adjustment system[17].

| **Load** | Unit | | **5 kg** | **3.75 kg** | **2.5 kg** | **1.5 kg** |
|---|---|---|---|---|---|---|
| Water (suds) | Litre | | 11 | 8,5 | 6 | 4 |
| Water (per rinsing cycle) | Litre | | 8 | 6,25 | 4,5 | 3,1 |
| | | *Temp* | | | | |
| Total energy consumption | kWh | *20°C* | 0,25 | 0,23 | 0,22 | 0,21 |
| | kWh | *30°C* | 0,29 | 0,27 | 0,25 | 0,23 |
| | kWh | *40°C* | 0,47 | 0,41 | 0,35 | 0,30 |
| | kWh | *60°C* | 0,83 | 0,70 | 0,57 | 0,46 |
| | kWh | *95°C* | 1,34 | 1,10 | 0,87 | 0,68 |

#### 3.7.2.5 Spin speed and drying of clothes

The drying of clothes is only regarded in task 3 (scenarios to calculate optimal life span) and task 4 (further use or substitution of old washing machines). In task 1 (LCA washing machine) and task 2 (comparison standard vs. large washing machine) the drying process is not considered as it is regarded as not relevant to answer the corresponding questions.

To dry wet clothes energy is needed in any case. The more water is removed by mechanical treatment (usually through spinning in the washing machine) the less thermal energy is required for subsequently drying. The additional energy demand through higher spin speeds is negligible compared to the reductions in thermal energy demand.

When the laundry is dried on a clothes line outside heated rooms, besides direct sun or wind energy no other energy source is needed. In all other cases additional energy is needed that is usually supplied by the residential heating system or, in case a tumble drier is used, by electricity or natural gas.[18]

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17 For full loading these figures are equal to those calculated above. The figures for lower loading are calculated according to the following equation:
amount of water (suds) = 1 L + (11 – 1 L) / 5 kg * load (kg)
amount of water (rinsing) = 1 L + (8 – 1 L) / 5 kg * load (kg)
With this reduced water demand the minimum energy demand is calculated as described above (see section 3.7.2.3).

18 See also Gensch/Rüdenauer 2004.

### Spin speed

The development of the spin speed of washing machines in EU between 1997 and 2002 is available from CECED database. With data for Germany from 1996 to 1998 it can be seen that the average spin speed in Germany had been significantly higher in those years (by approximately 200 rpm to 250 rpm). It is assumed that the difference between European and German machines decreased to only 100 per minute in 2002. Table 10 shows these developments.

Table 10 Development of the average spin speed of machines in the market from 1997 to 2002 in the EU.

| **Year of manufacture** | **Unit** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** |
|---|---|---|---|---|---|---|---|
| spin speed Europe | rpm | 828 | 858 | 828 | 903 | 977 | 1 010 |
| | | **9-12/1997** | **5-8/1998** | | | | |
| Spin speed Germany[19] | rpm | 1 023 | 1 050 | 997 | 1 049 | 1 100 | 1 110 |
| Difference to EU data | rpm | 195 | 192 | 169 | 146 | 123 | 100 |

### Drying system

To calculate the influence of differences in spin speed on the energy demand for the drying process the specific energy demand of a conventional condenser drier is taken. The energy demand against percentage of water remaining after spin is assumed according to Table 11.

Table 11 Spin speed and energy demand with respect to remaining water after spin[20].

| **Water remaining after spin (cotton)** | Unit | **62 %** | **56 %** | **52 %** | **49 %** |
|---|---|---|---|---|---|
| Corresponding approximately spin speed | rpm | 1 000 | 1 200 | 1 400 | 1 600 |
| Relative energy demand (‘cotton dry’ programme) | % | 100 | 90 | 86 | 82 |
| Specific energy demand (‘cotton dry’ programme) | kWh/kg | 0,70 | 0,64 | 0,60 | 0,57 |

[19] Own calculations from proportion of spin speed classes. From 1999 to 2002 extrapolated with decreasing difference to European data.

[20] Stamminger 2004 b.

#### 3.7.2.6 Type of laundry and consumer behaviour in 2004

The choice of wash temperature and the loading of washing cycles strongly depend on the type of laundry in private households.

With this assumption several types of washing cycles types that account for a certain amount of the laundry can be derived from figures about the composition of the laundry, the use of the different washing temperatures and the loading of the washing machines. Table 12 shows the data on the composition, washing temperatures and load.

Table 12 Composition of private laundry, used washing temperatures and load (in 2001)[21].

| **Type of the laundry** | | | **temperature** | | | **Load** | |
|---|---|---|---|---|---|---|---|
| Big white wash | 23 % | | 95°C | 9 % | | full | 60 % |
| Other coloured wash | 35 % | | 60°C | 34 % | | ¾ | 28 % |
| fine coloured wash | 22 % | | 40°C | 36 % | | ½ | 10 % |
| Easy to clean/synthetics | 10 % | | 30°C | 21 % | | < ½ | 2 % |
| Delicates | 8 % | | | | | | |
| Wool | 2 % | | | | | | |

Table 13 shows the derived proportion of laundry that is washed in different washing cycle types in 2001. With the annual amount of laundry per household[22] the annual amount of laundry and number of washing cycles for the different cycle types can be calculated. The annual amount of per cycle type for different household sizes is shown in Table 13.

21 GfK 2001.

22 Own calculations from IKW 2002 and ASEW (n.d.).

Table 13 Proportion and amount of laundry washed in different washing cycle types in 2001

| Cycle type | Load | Proportion of laundry | Annual amount of laundry | | |
|---|---|---|---|---|---|
| | | | Household with 3 people | Small household | Large house-hold |
| 95°C, full | 5 kg | 9% | 64 kg | 27 kg | 94 kg |
| 60°C, full | 5 kg | 34% | 240 kg | 103 kg | 356 kg |
| 40°C, full | 5 kg | 13% | 90 kg | 39 kg | 134 kg |
| 40°C, ¾ | 3,75 kg | 23% | 164 kg | 70 kg | 244 kg |
| 30°C, full | 5 kg | 4% | 30 kg | 13 kg | 45 kg |
| 30°C, ¾ | 3,75 kg | 5% | 34 kg | 14 kg | 50 kg |
| 30°C, ½ | 2,5 kg | 10% | 71 kg | 30 kg | 105 kg |
| 30°C, < ½ | 2,5 kg | 2% | 14 kg | 6 kg | 21 kg |
| TOTAL | | 100% | 707 kg | 302 kg | 1 048 kg |

#### 3.7.2.7 Future development of consumer behaviour

The current consumer behaviour might change in the forthcoming years according to certain influencing parameters. Some of those are discussed in the following.

**Changes in composition of laundry: influence on loading and used washing programme**

The trend to more delicates and synthetics and the differentiated use of the washing machine (“short programmes with low loading and low temperatures” vs. “classic programmes with higher loading and broader temperature range”) might lead to a higher amount of washing cycles at lower temperatures and lower loading (“short programmes”). At the same time the availability of combined 40°C and 60°C programmes might lead to more fully loaded cycles at 40°C instead of 60°C and/or partial load.

**Separate compartment for water softeners: influence on dosage of detergents?**

A separate compartment similar to that in dishwashers was proposed as possible development also in washing machines. Nevertheless for dishwashers a contradictory trend can be stated: according to the detergent industry there are more and more “2 in 1”- or “3 in 1”-products (a combination of detergent and water softener (“2 in 1”) and additionally rinsing aids (“3 in 1”)) on the market. Additionally the importance of softening of water has decreased within the last 20 years as the proportion of anionic surfactants in detergents has decreased.

The development of a separate compartment for water softeners is assumed to be unlikely. Additionally there is seen no influence on the results of this study.

**Load size indicator to measure the size of the wash load: influence on loading and dosage of detergent?**

Load size indicators are already realised in several washing machines. These machines have an LCD-display where the reached proportion of the recommended load is indicated. In addition they also indicate what this means for the dosage of detergent.[23]

Even though there is no consumer research data on the influence of this feature available to the authors, it can be assumed that it has at least a positive influence on loading as the users get a direct feedback on their behaviour. A possible influence on the dosage of the detergents is not relevant for this study, as the impacts connected with the use of detergents are not considered.

Another possibility is the combination of a load size indicator with an automatic dosage system (ADS). Both appliance manufacturers and detergent industry consider a broad introduction of this technology as very unlikely.[24]

**Enzyme use in detergents: influence on wash temperatures?**

The total amount of enzyme use in detergents has not increased in the last years. Between 1994 and 2002 the amount of enzymes used in all kinds of detergents rose from 3 600 (1994) to 6 900 (1996). Until 2002 the amount decreased to 3’900 again.

Nevertheless there are developments in the type of enzymes. To date the main task is the development of enzymes that can substitute chemical bleaching agents that need temperatures of 45°C to fulfil their function. In case of stain removal modern enzymes allow already washing at quite low temperatures. Depending on the type of laundry and the degree of soiling, this means washing at 20°C with good results is already possible.

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[23] In German this feature is called “Beladungserkennung mit Dosierempfehlung”.

[24] Oral communication of manufacturers and of the German Cosmetic, Toiletry, Perfumery and Detergent Association (Industrieverband Körperpflege- und Waschmittel e. V., IKW) 2004.

**Possibility of updating**

The current range of products with update possibility is quite high even though consumers use this possibility only to a minor degree. The usage might increase if it is more convenient for consumers, e.g. through a service contract with the manufacturer that is already included in the purchase price or the possibility to download relevant programmes and update the machine from the Internet. Of course next to low effort the user benefit has to be clear to accept this effort.

Nevertheless the consequences of updating on the results of this study are not clear.

#### 3.7.2.8 Consumer behaviour with larger washing machines

In case a household buys a washing machine with a larger rated capacity (e.g. 6 or 7 kg) instead of a 5 kg-machine, two alternatives in consumer behaviour are considered in this study:

- the *relative* loading of the washing machine through the consumer is the same as with 5 kg-washing machines (see Table 13). In this case with the same annual amount of laundry the total number of washing cycles is reduced.
- the *absolute* loading of the washing machine is the same as with 5 kg-washing machines. This might happen if a household stays with the habits adopted while using a 5 kg-machine.

In the study at hand, the first possibility (same relative loading) serves as basic assumption for task 2 (comparison: 5 kg- vs. 7 kg-machines). In a sensitivity analysis it is investigated how the results change when the second possibility (same absolute loading) is assumed.

#### 3.7.2.9 Further parameters

**Quality, number of repairs**

Nowadays washing machines are usually not repaired anymore but directly substituted. Depending on the distribution structure the use of an old washing machine on the second hand market seems more likely. This means the old washing machine is taken back when the new one is delivered. The old one is then repaired (and maybe updated) by a retailer and then resold.

The costs and environmental impact of the repair of washing machines are not considered in this study.

**Sound level**

Within this study the sound level of washing machine might decrease due to certain developments in engine technology. The sound level is not considered as an environmental impact category in this study.

### 3.7.3 End-of-Life

The calculation of the end of life phase of the washing machines concentrates on the credits that can be given for material recycling. As it is outlined in section 4.2 earlier studies showed that the impact of the end of life phase – redistribution, shredding, landfill – is negligible compared to the impacts of other phases. This might not be the case for eventual credits for recycling.

According to WEEE, which defines the requirements for material recycling, the proportion of white goods that has to be recycled on a material recycling basis lies at 75 %. Only materials that supposedly can be recycled are included into the balance-sheet for calculation credits: steel, iron, copper, and aluminium within the metal fraction, ABS and Carboran in the plastic fraction. The credits are given for only 50 % of these materials on a basis of primary material production. This approach reflects the fact that the credits have to be equally allocated to the first and the second life cycle of the material in question. Besides that, the approach also corresponds to the procedure chosen in [UBA 2000].

Table 14 Overview of the total material content in the analysed washing machines that most probably will be recycled (figures represent one washing machine).

| **Material** | **Amount in washing machine (in g)** | | | | | |
|---|---|---|---|---|---|---|
| **total** | **machine I** | **machine II.1** | **machine II.2** | **machine II.3** | **machine III** | **machine L** |
| ABS | 1 228 | 1 850 | 1 860 | 1 850 | 1 196 | 1 850 |
| Aluminium | 2 313 | 3 210 | 4.120 | 5 210 | 3 608 | 5 021 |
| Carboran | 8 012 | 10 570 | 11 500 | 11 290 | 1 410 | 11 288 |
| Copper | 925 | 580 | 750 | 770 | 1 027 | 765 |
| Iron | 1 304 | 1 400 | 1 920 | 3 140 | 28 780 | 7 860 |
| Steel | 24 320 | 26 050 | 26 470 | 27 940 | 44 733 | 27 935 |

Table 15 Overview of the material content, for which credits are given on a basis of primary material production (figures represent one washing machine).

| Material | Amount in washing machine that is given credits for [g] | | | | | |
|---|---|---|---|---|---|---|
| **credited** | **machine I** | **machine II.1** | **machine II.2** | **machine II.3** | **machine III** | **machine L** |
| ABS | 461 | 694 | 698 | 694 | 449 | 694 |
| Aluminium | 867 | 1 204 | 1 545 | 1 954 | 1 353 | 1 883 |
| Carboran | 3 005 | 3 964 | 4 313 | 4 234 | 529 | 4 233 |
| Copper | 347 | 218 | 281 | 289 | 385 | 287 |
| Iron | 489 | 525 | 720 | 1 178 | 10 793 | 2 948 |
| Steel | 9 120 | 9 769 | 9 926 | 10 478 | 16 775 | 10 476 |

### 3.7.4 Energy and water supply

#### 3.7.4.1 Water supply

The environmental impact for the supply of water is calculated according to the demand of electric energy for pumping and processing.[25] Not included are any additives necessary for water processing (e.g. $O_3$, $H_2O_2$). We assume that no major changes of the energy demand will occur during the period of the scenarios (2004 until 2025).

Table 16 Overview of the demand of electric energy for the supply of water according to [Jolliet et al. 2002].

| | Unit | Demand of electric energy |
|---|---|---|
| Energy for pumps | kWh/m³ | 0,35 |
| Water processing | kWh/m³ | 0,41 |
| **Sum** | **kWh/m³** | **0,76** |

#### 3.7.4.2 Energy supply

The environmental impact connected to the supply of electric energy depends on the electric grid it is based on. The grid, that is basis for our calculations was defined according to the future scenarios developed by [Enquete 2002].

25 Jolliet et al. 2002.

In this study we refer to the "Referenzszenario" ("reference scenario"), which is illustrated in the following table.

Table 17 Overview of the energy scenario used in the study (according to [Enquete 2002]).

| **Energy source** | **Referenzszenario** | |
|---|---|---|
| | **2004** | **2025** |
| Hard coal | 25,4% | 35,5% |
| Lignite | 25,6% | 31,2% |
| Fuel oil | 0,8% | 0,1% |
| Natural gas | 11,0% | 11,1% |
| Nuclear power | 28,0% | 6,9% |
| Water power | 4,3% | 4,4% |
| Wind | 2,3% | 6,8% |
| Photovoltaic | 0,0% | 0,2% |
| Other fuels | 2,6% | 3,8% |
| Sum | 100,0% | 100,0% |

### 3.7.5 Cost parameters

The following costs are calculated in the study:

- Acquisition costs for the washing machine (price)
- Costs for electricity supply (price per kWh)
- Costs for water supply (price per $m^3$)

In case of the **acquisition costs** of the washing machines two differentiations have to be made: on the one hand cost differences between washing machines with different life span, on the other hand the price development until 2025.

Table 18 shows the costs assumed for washing machines with different life spans.[26]

Table 18 Costs for washing machines with different life spans.

| **Life span** | **Average price (in 2004)** | |
|---|---|---|
| | 5-kg-machine | 7kg-machine |
| 1 000 washing cycles | 250, - € | n.a. |
| 2 000 washing cycles | 500, - € | 700, - € |
| 5 000 washing cycles | 850, - € | n.a. |

The acquisition costs for life spans between 1 000 and 2 000 and between 2 000 and 5 000 are linearly interpolated (which represents a possible future market situation where washing machines with continuously varying life spans are available). Please note that this does not represent the current situation, where the market can basically be divided into two categories: those with an assumed life span of approximately 2 000 cycles and those with an assumed life span of 5 000 cycles.

The assumed *future development* of the prices is different for the three scenarios and is outlined in the section “Setting of the parameter for the three tasks“ (section 3.8).

The current average **costs for fresh water and waste water treatment** are assumed to be 4, - €/m3. For all scenarios a future increase by 2 % is assumed.[27]

The current average **costs for electricity** are 0,18 ct/kWh.[28] For all scenarios it is assumed that this price rises up to 0,249 in 2020.[29] This development is further extrapolated.

Costs for interests are not considered, as the costs are relatively small compared to total household expenditures.

Costs for repairs are not considered (see section 3.7.2.9). Costs for disposal are currently included in the general waste fee and therefore not considered in this study. Through WEEE implementation in the future they are expected to be included in the purchase price.

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[26] Own research based on internet search engine, 2004.

[27] Geiler 2004

[28] Own compilation (in 2/2003).

[29] Prognos 1999.

## 3.8 Setting of the parameters for the four tasks

The following sections describe the concrete setting and development of the parameters discussed in section 3.3.

### 3.8.1 Task 1 (update LCA washing machine)

The following table gives an overview of the setting of the parameters:

Table 19 Setting of the parameters for LCA update.

| Parameter | Setting |
|---|---|
| Production and recycling | Production and recycling parameters of *machine II.2* |
| Life span of washing machine | 2 000 cycles |
| **USE:** | |
| Specific energy and water consumption of washing machine | Consumption figures of a washing machine in the market 2004, according to [Stamminger 2004a] |
| Average spin speed | 1 110 rpm[30] (only for drying of clothes for comparison!) |
| Consumer behaviour | Current consumer behaviour, constant over the expected life span |
| Drier use | Use of condenser drier for 80 % of the laundry (only for comparison!) |
| Energy consumption of drier | See Table 11 (only for comparison!) |
| Water and energy supply | See section 3.7.4 |
| **COSTS:** | |
| Acquisition costs | 500, - € (see also section 3.7.5) |
| Costs for water and energy supply | see section 3.7.5 |

30 This is a calculated value based on statistic data of spin speed in Europe and Germany. See also section 3.7.2.5.

### 3.8.2 Task 2 (comparison: standard vs. large washing machines)

The following table gives an overview of the setting of the parameters.

Table 20 Setting of the parameters for comparison 5 kg- vs. 7 kg-machines.

| **Parameter** | **Setting** |
|---|---|
| Production and recycling | 5 kg-machine: production and recycling parameters of *machine II.2*<br>7 kg-machine: production and recycling parameters of *machine L* |
| Life span of washing machine | 2 000 cycles |
| **USE:** | |
| Specific energy and water consumption of washing machine | Consumption figures of a washing machine in the market 2004, according to [Stamminger 2004a]<br>**Sensitivity (2)**: only 70 % of the specific consumption figures of a standard washing machine (5 kg) are increased due to larger capacity |
| Average spin speed | Not relevant |
| Consumer behaviour | Current consumer behaviour, constant over the expected life span. For 7 kg-machines the same *relative* loading than for 5 kg-machines.<br>**Sensitivity (1)**: same *absolute* loading of 7 kg-machine |
| Drier use | No use of drier assumed |
| Energy consumption of drier | See Table 11 |
| Water and energy supply | See section 3.7.4 |
| **COSTS:** | |
| Acquisition costs | 5 kg-machine: 500, - € (see also section 3.7.5)<br>7 kg-machine: 700, - € (see also section 3.7.5) |
| Costs for water and energy supply | see section 3.7.5 |

### 3.8.3 Task 3 (scenarios to calculate optimal life span)

The main question concerning the future scenarios is, what **life span** a washing machine should have to result in the lowest environmental impacts and lowest costs over the regarded time period. The results can be used for strategic decisions of manufacturers with respect to the life span their washing machines are designed for.

Therefore the environmental impacts and the direct costs for private households have to be calculated for different life spans of washing machines. In the study at hand the life span is varied between 1 000 cycles and 5 000 cycles. The results give the total environmental impact and the costs cumulated over the next 22 years (2004 with 2025) against the life span of washing machines.

<u>For task 3 the parameters have to be varied in two dimensions</u>:

The <u>first dimension</u> is the variation of the production parameters and acquisition costs according to the life span of the washing machine. In order to extend the life span of a washing machine from 1 000 to 5 000 cycles the production has to be changed, e.g. more or other material has to be used. To represent machines with different life spans, the *material composition* and *production and recycling parameters* of the analysed washing machines are assumed according to the following table:

Table 21 Production and recycling parameters according to life span of washing machines.

| **Life span** | **Assumed production and recycling parameters of:** |
|---|---|
| 1 000 washing cycles | machine I |
| 2 000 washing cycles | machine II.2 |
| 5 000 washing cycles | machine III |

Please note that this assumption is based on the consideration, that washing machines, that are built to last 1 000 washing cycles do not have to be constructed in the same quality as washing machines that should last 5 000 cycles. We do not imply that *machine I* necessarily has a life span of only 1 000 cycles. The production parameters of this washing machine only represent a simpler construction type.

The environmental impact in the production phase for *life spans between 1 000 and 2 000 and between 2 000 and 5 000* are linearly interpolated (which represents a possible future market situation where washing machines with continuously varying life spans are available). Please note that this does not represent the current situation, where the market can basically be divided into two categories: those with a life span of approximately 2 000 cycles and those with an assumed life span of 5 000 cycles.

Analogous assumptions are made for the *acquisition costs* of washing machines with different life spans. This is already outlined in section 3.7.5 (Cost parameters).

The second dimension is the change of parameters with time. As the study covers a time span of 22 years (2004 with 2025) the development of several parameters within this period has to be defined.

To examine if and how the obtained results change with different possible future developments three scenarios are defined. All scenarios have the same starting point, i.e. the situation in 2004 and the same end point, i.e. 2025.

In the base case all scenarios are calculated for a household size of 3 people. The amount of laundry and the number of washing cycles stays constant for all scenarios over the regarded time period. For all scenarios it is assumed that an electric condenser drier is used. The environmental impact of the production and the recycling parameters of the different washing machines are assumed to stay constant with time.

Parameters that influence the environmental and economic impact that might change over the next 22 years are:

- consumer behaviour (usage of different washing temperatures, loading, …),
- specific energy and water consumption figures of the regarded washing machines,
- spin speed of the washing machines,
- primary energy sources of electricity supply,
- prices for washing machines, electricity and water supply.

In all scenarios a common development of the following parameters is assumed:

- environmental impacts of fresh water supply (see section 3.7.4.1),
- primary energy sources of electricity supply (see section 3.7.4.2),
- fresh water prices (see section 3.7.5),
- electricity prices (see section 3.7.5).

A different development is assumed for the following parameters:

- consumer behaviour (usage of different washing temperatures, loading, …),
- specific energy and water consumption figures of the regarded washing machines,

- spin speed of the regarded washing machines,
- acquisition costs for washing machines.

The development for the latter parameters is described in the following sections for each scenario.

#### 3.8.3.1 Scenario 1 “no progress”

To give a potential “worst case” in this scenario no development in consumer behaviour, consumption figures and spin speed is assumed.

This means the use of different washing cycle types does not change. Also the overall average energy and water consumption of the washing machines, the load adjustment technology and the spin speed stay constant at the currently reached level. The drier is used for 80 % of the laundry.

Concerning the acquisition costs for washing machines it is assumed that a fall in prices by 1 % per year appears.

#### 3.8.3.2 Scenario 2 “trend”

For the consumer behaviour it is assumed that there is a moderate shift to lower washing temperatures (decrease of 95°C and 60°C-cycles, increase of 40°C and 30°C-cycles). There is a slight trend to differentiated use of the washing machine: both the use of “short programmes with low loading and temperatures” and the use of “classic programmes with higher loading and medium to high temperatures” increase.

The following developments are assumed:

- Proportion of 95°C cycles decreases by almost half
- Proportion of 60°C cycles decreases
- Proportion of 40°C cycles increases, with an shift from ¾ load to full load
- Proportion of 30°C cycles increases

The resulting figures can be seen in Table 22.

Table 22 Development of the use of different washing cycles in Scenario 2 (trend).

| **Cycle type** | **Loading** | **Proportion of laundry** | | | |
|---|---|---|---|---|---|
| | **kg** | **2001** | **Development** | **2025** | **Change** |
| 95°C, full | 5 | 9% | Decreases to | 5% | -4 |
| 60°C, full | 5 | 34% | Decreases to | 25% | -9 |
| 40°C, full | 5 | 13% | Increases to | 25% | +12 |
| 40°C, ¾ | 3,75 | 23% | Decreases to | 17% | -6 |
| 30°C, full | 5 | 4% | Increases to | 11% | +7 |
| 30°C, ¾ | 3,75 | 5% | Decreases to | 2% | -3 |
| 30°C, ½ | 2,5 | 10% | Increases to | 13% | +3 |
| 30°C, less than ½ | 1,5 | 2% | Stays constant | 2% | - |
| *Sum* | | *100%* | | *100%* | |

The average water and energy consumption of new washing machines on the marked is assumed to decrease to the lowest possible level until 2015 (i.e. within approximately 10 years time).[31] Next to the technological development this also requires that there are only washing machines with such a low water and energy consumption on the market. Also the load adjustment system is assumed to develop to the "best possible" level at this time (see section 3.7.2.4)

The average spin speed of new washing machines on the marked is assumed to increase by approximately 200 rpm (up to 1 300 rpm) until 2025 with a faster increase within the next 5 to 10 years. The drier is used for 80 % of the laundry.

The nominal prices for washing machines are assumed to stay constant.

#### 3.8.3.3 Scenario 3 "innovation"

For the consumer behaviour the trends of the "trend" scenario are assumed to be stronger (lower temperature choice, stronger differentiation in full vs. quite low loading).

Additionally it is assumed that through use of appropriate enzymes in detergents, it is possible to do some laundry at 20°C (with machines on the market that allow for washing at this temperature from 2010 onwards). The minimum energy consumption of the 20°C cycle is

[31] Please note that this is a quite ambitious assumption as the average of all washing machines in the market is assumed to be at this low level.

reached 5 years later than the minimum energy consumption of the other temperatures (i.e. in 2020).

The following developments are assumed:

- As of 2010 there is a 20°C cycle. In the starting year (2010) it is used for 2% of the laundry. The loading is half full or ¾.
- The proportion of 95°C cycles decreases to almost zero. Only a small amount of laundry is washed at 95°C.
- The proportion of 60°C cycles decreases stronger than in trend scenario
- The proportion of 40°C cycles slightly decreases. The proportion of „40°C, full" increases, the proportion of „40°C, ¾" decreases
- The proportion of 30°C cycles increases, with a shift to higher load
- The proportion of 20°C cycles strongly increases as of 2010

The resulting figures can be seen Table 23.

Table 23 Development of the use of different washing cycles in Scenario 3 (innovation).

| **Cycle type** | **Loading** | **Proportion of laundry** | | | |
|---|---|---|---|---|---|
| | **Kg** | **2001/ 2010**** | **Development** | **2025** | **Change** |
| 95°C, full | 5 | 9% | Decreases to | 1% | -8 |
| 60°C, full | 5 | 34% | Decreases to | 15% | -19 |
| 40°C, full | 5 | 13% | Increases to | 31% | +18 |
| 40°C, ¾ | 3,75 | 23% | Decreases to | 2% | -21 |
| 30°C, full | 5 | 4% | Increases to | 21% | +17 |
| 30°C, ¾ | 3,75 | 5% | Decreases to | 1% | -4 |
| 30°C, ½ | 2,5 | 10% | Decreases to | 5% | -5 |
| 30°C, less than ½ | 1,5 | 2% | Stays constant | 2% | - |
| 20°C, ¾ | 3,75 | 1%** | Increases to | 13% | +13 (12**)% |
| 20°C, ½ | 2,5 | 1%** | Increases to | 9% | +9 (8**)% |
| *Sum* | | *100%* | | *100%* | |

** Situation in 2010 and respective change between 2010 and 2025.

The decrease of water and energy consumption of new washing machines on the marked is assumed as in Scenario 2. This means the minimum water and energy consumption is reached in 2015. Equally the load adjustment is assumed to be at the “best possible” level in 2015.[32]

The average spin speed of new washing machines on the marked is assumed to increase by approximately 350 rpm (up to 1450 rpm) until 2025 with a faster increase within the next 5 to 10 years. The drier is used for 80 % of the laundry.

The nominal prices for washing machines are assumed to slightly increase by 1 % per year.

For a better overview the development of usage of different washing temperatures and of the loading in the different scenarios is shown in Table 24 and Table 25.

Table 24 Starting point (2001) and end point (2025) situation of the usage of different washing temperatures.

| | **Start 2001 (2010**)** | **No progress** | **Trend 2025** | | **Innovation 2025** | |
|---|---|---|---|---|---|---|
| | | | | Difference | | Difference |
| 95°C | 9% | n.d. | 5% | - 4% | 1% | - 8% |
| 60°C | 34% | n.d. | 25% | - 9% | 15% | - 19% |
| 40°C | 36% | n.d. | 42% | 6% | 33% | - 3% |
| 30°C | 21% | n.d. | 28% | 7% | 29% | 8% |
| 20°C | 0%/1%** | - | 0% | 0% | 22% | 22% |
| SUM | 100% | | 100% | 0% | 100% | 0% |

** situation in 2010 and respective change between 2010 and 2025.
n.d. = no development

Table 25 Starting point (2001) and end point (2025) situation of loading of the washing machine.

| | **Start 2001** | **No progress** | **Trend 2025** | | **Innovation 2025** | |
|---|---|---|---|---|---|---|
| | | | | Difference | | Difference |
| Full | 60% | n.d. | 66% | 6% | 68% | 8% |
| ¾ | 28% | n.d. | 19% | - 9% | 16% | - 12% |
| ½ | 10% | n.d. | 13% | 3% | 14% | 4% |
| < ½ | 2% | n.d. | 2% | 0% | 2% | 0% |
| SUM | 100% | | 100% | 0% | 100% | 0% |

n.d. = no development

32 Please note that as in scenario 2 (trend) this is a quite ambitious assumption as the average of all washing machines in the market is assumed to be at this low level.

#### 3.8.3.4 Sensitivity analyses

As a sensitivity analysis of task 3 two variations of the household size (i.e. the amount of laundry and the number of washing cycles per year) are calculated:

- small household with only 75 washing cycles per year and
- large households with 260 washing cycles per year.

### 3.8.4 Task 4 (further use or substitution of old washing machine)

Five alternatives are assessed:

- Further use of a washing machine of 1985 from 2004 to 2013,
- Further use of a washing machine of 1990 from 2004 to 2013,
- Further use of a washing machine of 1995 from 2004 to 2013,
- Further use of a washing machine of 2000 from 2004 to 2013,
- Acquisition of a new washing machine in 2004 and use of this washing machine from 2004 to 2013.

The parameters are set as follows:

Table 26 Setting of the parameters for task 4.

| **Parameter** | **Setting** |
|---|---|
| Production and recycling | Parameters of machine II.2 |
| USE: | |
| Specific energy and water consumption of washing machine | according to [Stamminger 2004a] (see Table 5) for 1985, 1990, 1995, 2000 and 2004. |
| Spin speed | 1985: 900 rpm<br>1890: 950 rpm<br>1995: 1 000 rpm<br>2000: 1 050 rpm<br>2004: 1 100 rpm |
| Consumer behaviour | Current consumer behaviour, no change in regarded time period |
| Drier use | Use of condenser drier |
| Energy consumption of drier | See Table 11 |
| Water and energy supply | See section 3.7.4 |
| COSTS: | |
| Acquisition costs | 500,- € (see also section 3.7.5) |
| Costs for water and energy supply | see section 3.7.5 |

The environmental impact and costs are calculated over the next ten years to determine the payback period through lower consumption figures of the new washing machine during the use phase.

Please note that costs for repair of existing washing machines are not considered and that it is assumed that a condenser drier is used.

# 4 Results

## 4.1 Results Task 1 (update LCA washing machine)

Goal of task 1 was to update existing Life Cycle Assessments of washing machines to determine the environmental impact connected with the production, distribution, use and end-of-life-treatment of a washing machine.

All results shown in this section refer to the defined functional unit as described in section 3.1 ("Washing of the amount of laundry that can be washed within the life span of a washing machine (2 000 cycles) in private consumers' households")

The results of the LCA show that the overall environmental impact of the life cycle of a standard washing machine amount to about 17 467 MJ resp. 16 674 MJ when credits for recycling at the end of life are accounted for. The absolute results for CED, GWP and the cumulated total environmental burden are listed in Table 27 differentiated by life cycle phase.

Table 27 Results of the updated LCA for the life cycle of one washing machine (machine II.2): absolute results.

| **Life cycle phase** | **CED** | **GWP** | **Cumulated environmental burden** |
|---|---|---|---|
| Unit | MJ | kg $CO_2$-Equivalents | micro UZBP |
| Material supply | 3 074 | 285 | 1 617 |
| Manufacturing | 406 | 27 | 72 |
| Distribution | 28 | 2 | 20 |
| *Subtotal "production"* | 3 508 | 314 | 1 709 |
| Energy supply | 13 248 | 938 | 2 988 |
| Water supply | 711 | 50 | 160 |
| *Subtotal "use"* | 13 959 | 988 | 3 048 |
| *Subtotal "production and use"* | 17 467 | 1 302 | 4 856 |
| End of life* | -793 | -55 | -396 |
| **Total** | **16 674** | **1 247** | **4 460** |

* Credits for recycling

The subsequent table shows the relative share of the life cycle phases for the three considered impact categories. The most important contribution to the CED originates with 80 % from the use phase. Therein the energy supply makes up for 95 %, the water supply only for 5 %. The second position is taken by the material precombustion, referring to upstream processes, which are differentiated by material groups as shown in Figure 6. Manufacturing and distribution are of low importance compared to the overall result and the weight of the other phases.

The results of the other impact categories are similar to the one of CED, although an increasing share of the production phase can be seen.

Table 28 Results of the updated LCA for the life cycle of one washing machine (machine II.2): relative share of the life cycle phases.

| | **CED** | **GWP** | **Cumulated total environmental burden** |
|---|---|---|---|
| Material supply | 17,6% | 21,9% | 33,3% |
| Manufacturing | 2,3% | 2,1% | 1,5% |
| Distribution | 0,2% | 0,2% | 0,4% |
| *Subtotal "production"* | *20,1%* | *24,2%* | *35,2%* |
| Energy supply | 75,8% | 72,0% | 61,5% |
| Water supply | 4,1% | 3,8% | 3,3% |
| *Subtotal "use"* | *79,9%* | *75,8%* | *64,8%* |
| **Total** | **100,0%** | **100,0%** | **100,0%** |
| End of life, credits for recycling | -4,5% | -4,2% | -8,2% |

Figure 4 shows the CED of the different life cycle phases without consideration of the credits for recycling (production and distribution: material supply, manufacturing, distribution; use phase: energy supply, water supply). Interesting is a comparison of the CED and the costs (see Figure 5). Whereas for example the energy supply accounts for 76 % of the total CED, it accounts for only 22 % of the life cycle costs (for the private households).

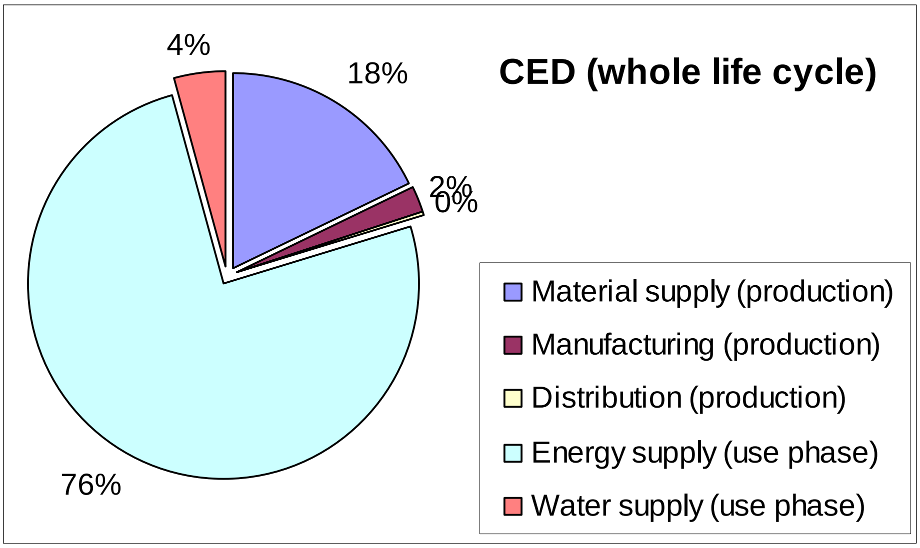


Figure 4 CED of the life cycle phases (without consideration of credits for recycling).

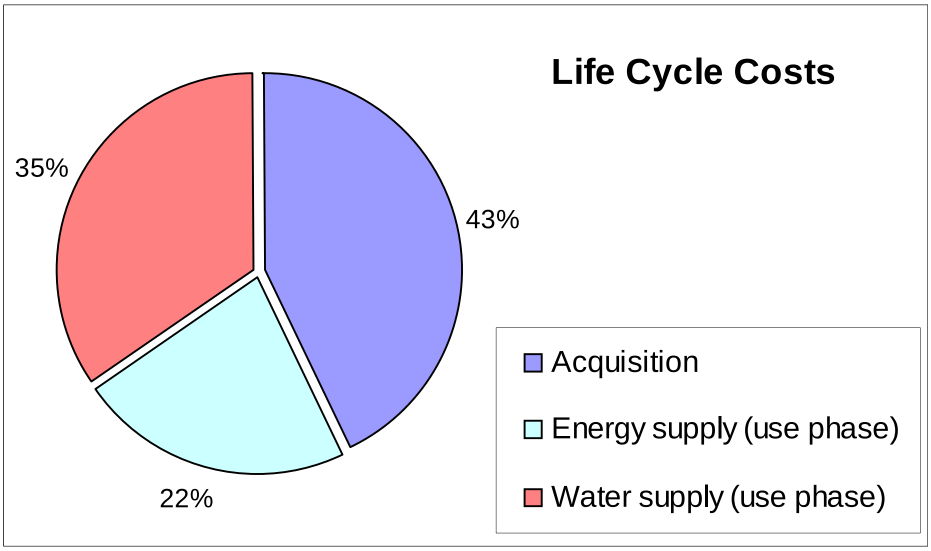


Figure 5 Life Cycle Costs of a washing machine.

Figure 6 gives a more detailed picture of the material supply. It shows the CED of the production of the different material groups that have to be supplied for manufacturing a washing machine.

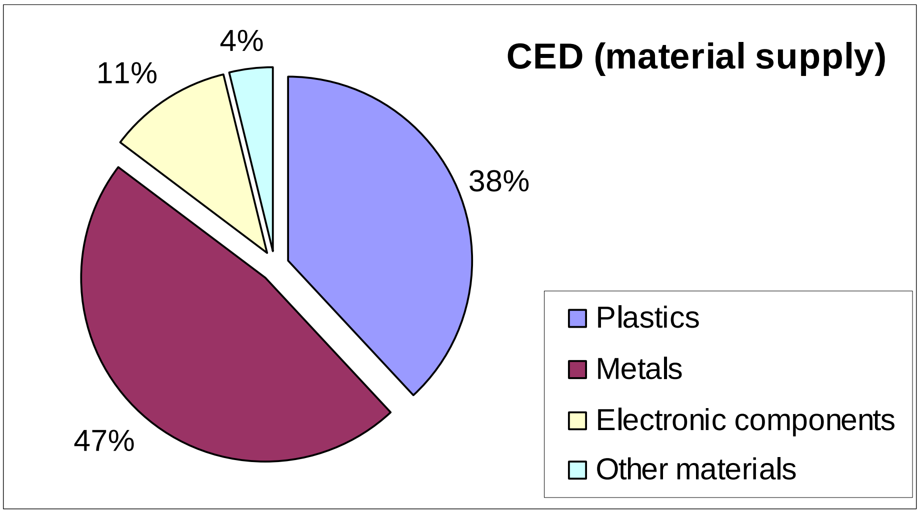


Figure 6 Contribution of the different material groups to the CED of the material supply.

To give an impression of the magnitude of the environmental impacts of the whole life cycle of a washing machine, Figure 7 compares the CED of the different life cycle phases and the total life cycle with the CED of the drying process (use of a condenser drier). The drying of laundry has by far more impact (factor 2,5) than the whole life cycle of a washing machine.

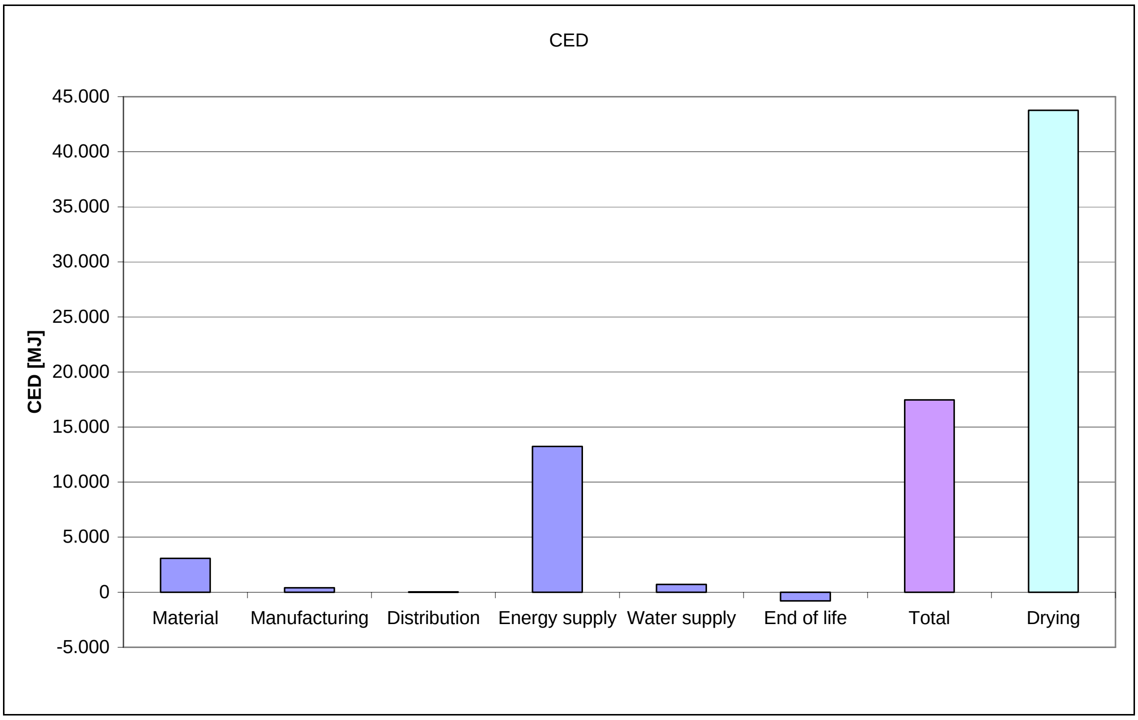


Figure 7 CED of the life cycle of one washing machine (machine II.2) in comparison to the CED of drying.

The differences between the five analysed standard washing machines (rated capacity: 5 kg, see section 3.7.1) are in the range of ±20 % compared to machine II.2. Figure 8 shows the CED of the production and distribution, of the credits for recycling and of the “total” (= production and distribution less credits) for the regarded 5 kg-washing machines.

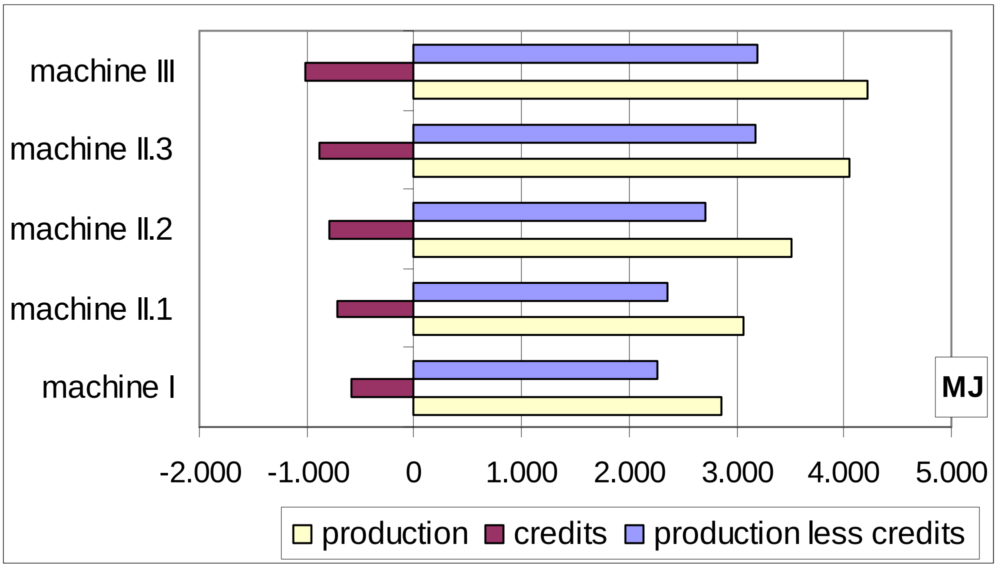


Figure 8 CED of the production of the different washing machines.

The results of the other impact categories (GWP, total environmental burden) are similar to the one of CED.

## 4.2 Comparison to the results of other studies

In order to rank the results of this study within the range of other investigations, a comparison had been done to data from literature. In Table 29 an overview is given concerning the assumptions and the general framework of the selected studies. This information has to be kept in mind when doing the comparison.

Table 29 Data background.

| Study | Materials | Manufacturing | Distribution | Use phase | CED (use phase)/cycle | End of life |
|---|---|---|---|---|---|---|
| Current study [Rüdenauer et al. 2004] | Manufacturer data | Manufacturer data | 170 km train 170 km truck | 11,4 years life-span with 175 washing cycles per year; 2.000 washing cycles per lifespan | Mix of programs and loading, see section 3.7.2.6 | Credits for recycling of materials |
| Behrendt et al. 2004 | Dismantled washing machine | Not specified | 750 km train 300 km big truck 30 km small truck | 10 years life-span with 240 washing cycles per year; 2.400 washing cycles per life span | Cotton 60°C 5 kg loading (EPD 2001) | Redistribution 150 km train 300 km big truck 30 km small truck |
| Szczepanowki 2001 | Dismantled washing machine | Manufacturer data | Not specified | 15 years life-span with 209 washing cycles per year; 3.135 washing cycles per life span | Cotton 60°C (according to European union eco-labelling directive) | Redistribution, shredding, landfill |
| Ebersperger 1996 | Dismantled washing machine | Not specified | Not specified | 10 years life-span with 172 washing cycles per year; 1.720 washing cycles per life span | Mix of programs and loading, not specified repair, sewage treatment | Redistribution, shredding and sortation, landfill |
| Strubel und Gensch 1996 | Manufacturer data Multiplied by factor 2 for rejections etc. | Included in materials | 150 km train 300 km big truck 30 km small truck | 15 years life-span with 180 washing cycles per year; 2.700 washing cycles per life span | Cotton 60°C 4 kg loading | Redistribution, assumptions equal to distribution |
| Durrant et al. 1991 | Manufacturer data | 5% of material production (estimation of manufacturers) | 300 km truck | 14 years life-span with 250 washing cycles per year; 3.500 washing cycles per life span | Mix of hot and economy wash | Shredding (EMPA 1984) |

In the subsequent table the absolute results of all selected studies and the current study are given, differentiated by life cycle phase. It can be seen that the results of the current study greatly lie within the magnitude of the other results. Concerning the use phase a trend can be identified towards higher efficiency of the use phase, with regard to both energy and water demand. Accordingly the current study shows the lowest impact of all studies under investigation. Also it has to be mentioned that a comparison only can be done concerning impact per washing cycle as the number of washing cycle per life span is quite different. As the assumption for the phases manufacturing, distribution and end of life are very different, these phases are mostly not comparable.

Table 30: Cumulated energy demand of the different life cycle phases of one washing machine

| Study | Material supply | Manufacturing | Distribution | Use phase* | CED/washing cycle | End of life |
|---|---|---|---|---|---|---|
| Current study | 3 340 MJ | 400 MJ | 30 MJ | 13 860 MJ | 7 MJ | -800 MJ |
| Behrendt et al. 2004 | 2 600 – 3 000 MJ | 900 MJ | 100 MJ | 20 000 MJ standardised data<br>33 000 MJ measured data | 8 MJ<br>14 MJ | 75 MJ |
| Szczepanowki 2001 | 2 808 MJ | 198 MJ | | 29 700 MJ** | 9,5 MJ** | - |
| Ebersperger 1996 | 3 787 MJ | 573 MJ<br>includes distribution | Included in manufacturing | 18 340 MJ*** | 10,7 MJ | 64,5 MJ |
| Strubel und Gensch 1996 | 6 910 MJ | Included in production | 70,6 MJ | 29 700 MJ | 11 MJ | 70,6 MJ |
| Durrant et al. 1991 | 1 970 MJ | 99 MJ | 145 MJ | 48 000 MJ | 14 MJ | 33 MJ |

* without detergent

** electricity grid of the European union (Fritsche et al. 2003)

*** includes sewage treatment and repairs

Looking at the relative share of life cycle phases (see Table 31) it can be seen that the production phase increases its relative share. This might be due to the gain of efficiency during the use phase as mentioned above.

Table 31 Share of the different life cycle phases concerning the cumulative energy demand

| Study | Material supply | Manufacturing | Distribution | Use phase | End of life |
|---|---|---|---|---|---|
| Current study | 19,8% | 2,4% | 0,2% | 82,4% | -4,8% |
| Current study without credits for end of life | 18,9% | 2,3% | 0,2% | 78,6% | 0% |
| Behrendt et al. 2004 standardised data for use phase | 11,7% | 3,8% | 0,4% | 83,8% | 0,3% |
| Behrendt et al. 2004 measured data for use phase | 7,6% | 2,4% | 0,3% | 89,5% | 0,2% |
| Szczepanowki 2001 | 8,6% | 0,6% | - | 90,8% | - |
| Ebersperger 1996 | 16,6% | 2,5% | Included in manufacturing | 80,6% | 0,3% |
| Strubel und Gensch 1996 | 18,8% | Included in production | 0,2% | 80,8% | 0,2% |
| Durrant et al. 1991 | 3,9% | 0,2% | 0,3% | 95,5% | 0,1% |

## 4.4 Results Task 3 (scenarios to calculate optimal life span)

Goal of task 3 was to compare the environmental impact and the costs of washing and drying of clothes with washing machines with different life span. This can only be done, when the impact is regarded during a defined time period for all alternatives.

All results shown in this section refer to the defined functional unit as described in section 3.1 ("Washing and drying of the amount of laundry that can be washed within the regarded time period (22 years) in private consumers' households"). This means all results are cumulated values (environmental impacts and costs) over the regarded time period of 22 years

During the stated time period the regarded household of 3 people washes in total 3 850 times. Depending on the assumed life span of the washing machine this requires a different number of washing machines that is bought and used during this period. For example with an assumed life span of 1 000 cycles this household has to buy 3,85 washing machines in contrast to a life span of 4000 where only approximately 1 washing machine has to be bought (and produced).

The results for life spans above 4 000 cycles are not representative anymore as the total number of cycles is around 4 000 cycles. At those life spans the only difference is the decreasing number of required washing machines.

### 4.4.1 Base case

Figure 15 shows the development of the cumulated energy demand for scenario 1 (no progress).

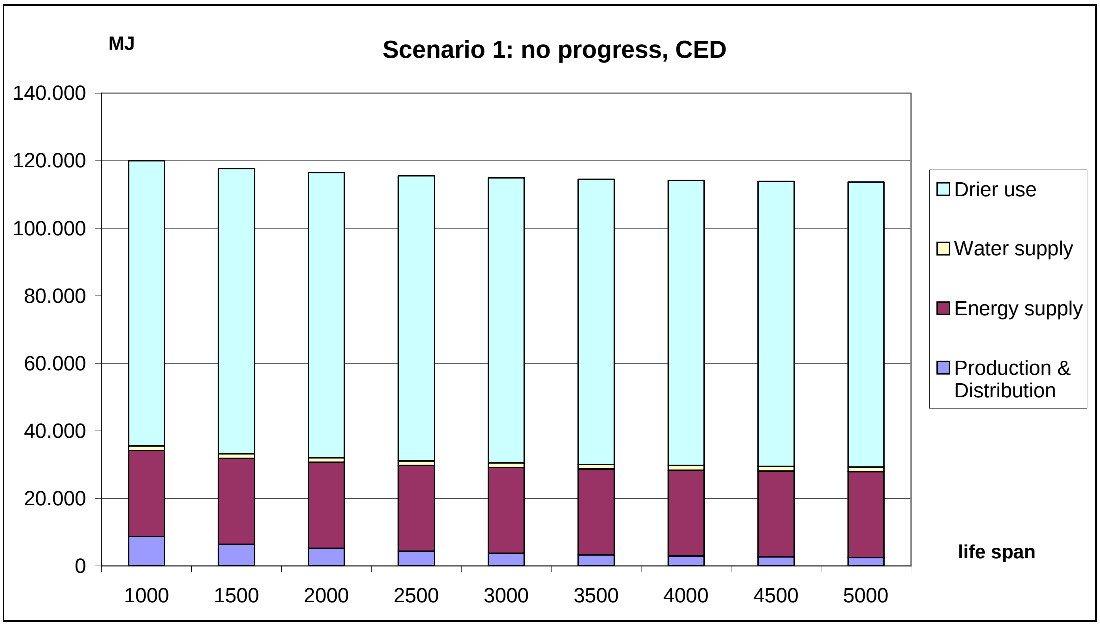


Figure 15 CED of Scenario 1.

It can be seen that the CED over the total period continuously slightly decreases the longer the life span of the washing machine is. The total CED is dominated by the energy consumption of the drier.

Figure 16 shows the costs for scenario 1. The costs show a similar picture than the CED, with the use phase having a slightly lower importance.

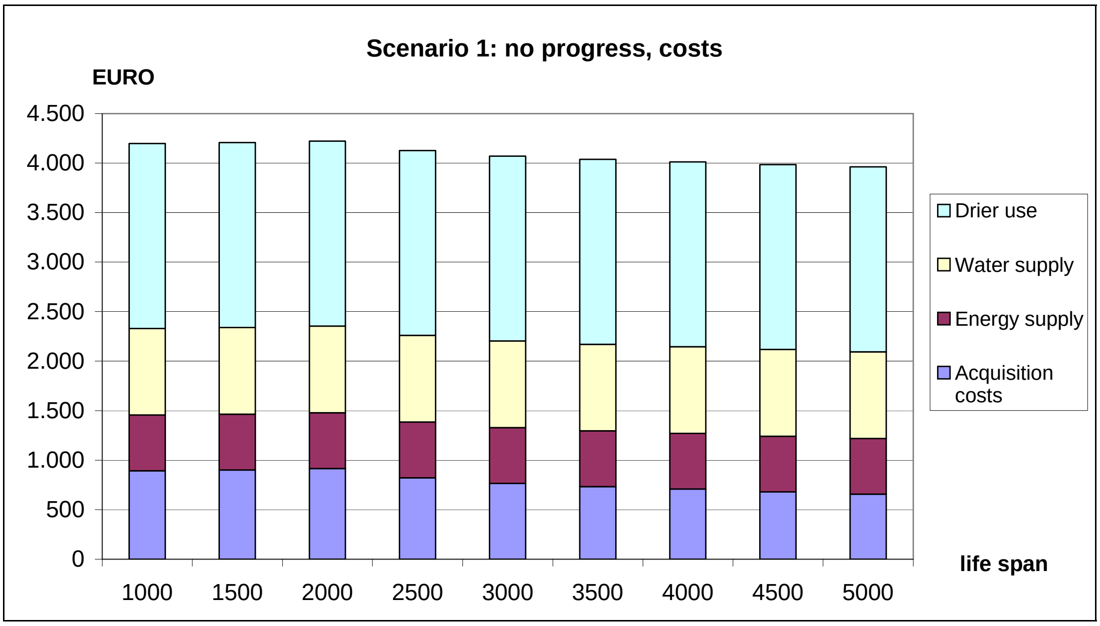


Figure 16 Total costs in Scenario 1.

As there are no improvements in future washing machine technology there are no savings during the use phase that could amortise additional impacts and additional costs for the production/the purchase of washing machines in case of a shorter life span compared to a longer life span.

Therefore a longer life span is advantageous both under environmental and cost considerations. Nevertheless the advantages are quite small, as firstly the production phase/acquisition costs only have a minor contribution to the total results and secondly both environmental impacts and acquisition costs of washing machines with longer life spans are higher (per machine) than those of machines with shorter life span.

Figure 17 and Figure 18 show the CED and the costs for the second scenario (trend).

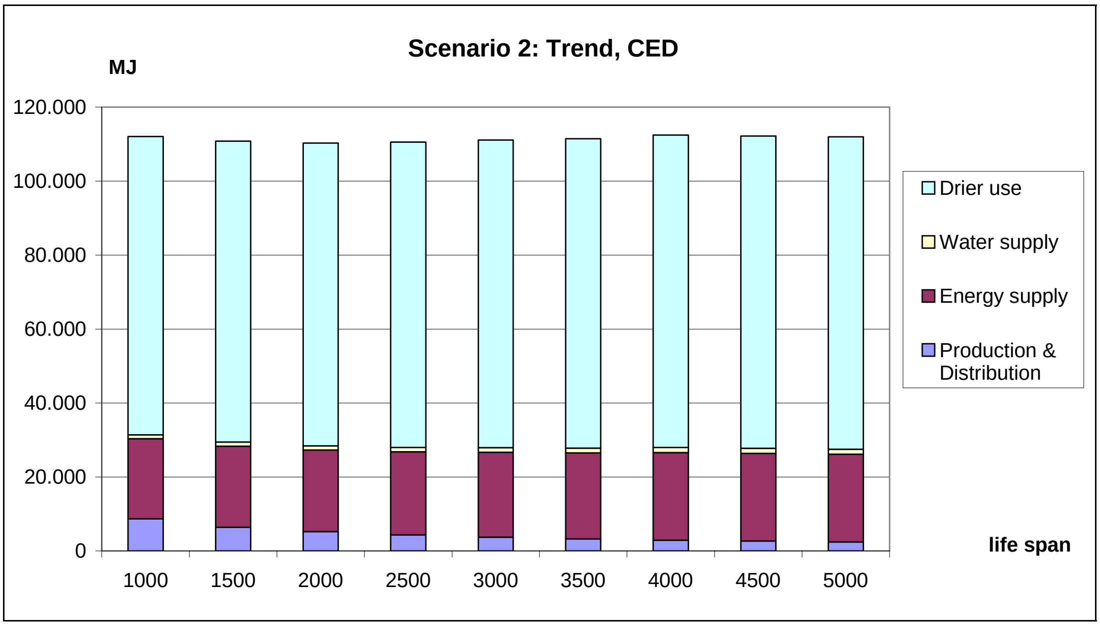


Figure 17 CED Scenario 2

Again, the variation of the CED against life span is very small. It can be seen that the CED over the total period has a slight minimum at a life span of 2 000 cycles. Compared to the CED of the alternative with a life span of 4 000 cycles the difference is approximately 2 200 MJ which equals an increase of CED of 2 %.

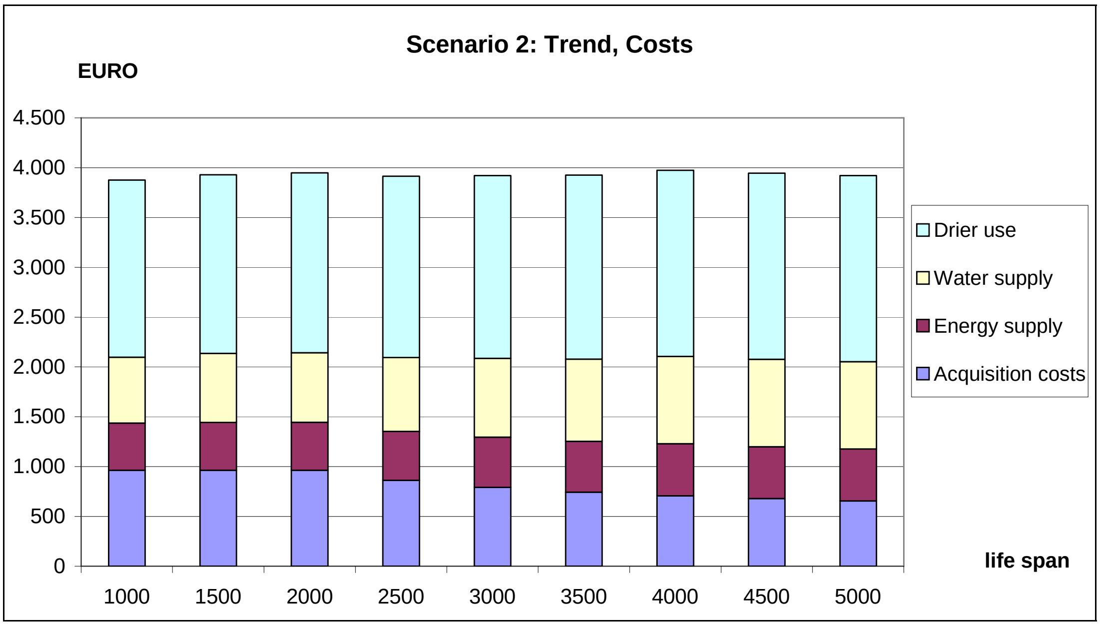


Figure 18 Total costs in Scenario 2.

The costs vary to an even smaller degree than the environmental impacts. There are slight minima at life spans of 1 000 and of 3 000 to 3 500 cycles. The cost difference of washing machines with a life span of 2 000 cycles and those with a life span of 4 000 cycles are below 1 %.

Figure 19 and Figure 20 show the CED and the costs for the third scenario (innovation).

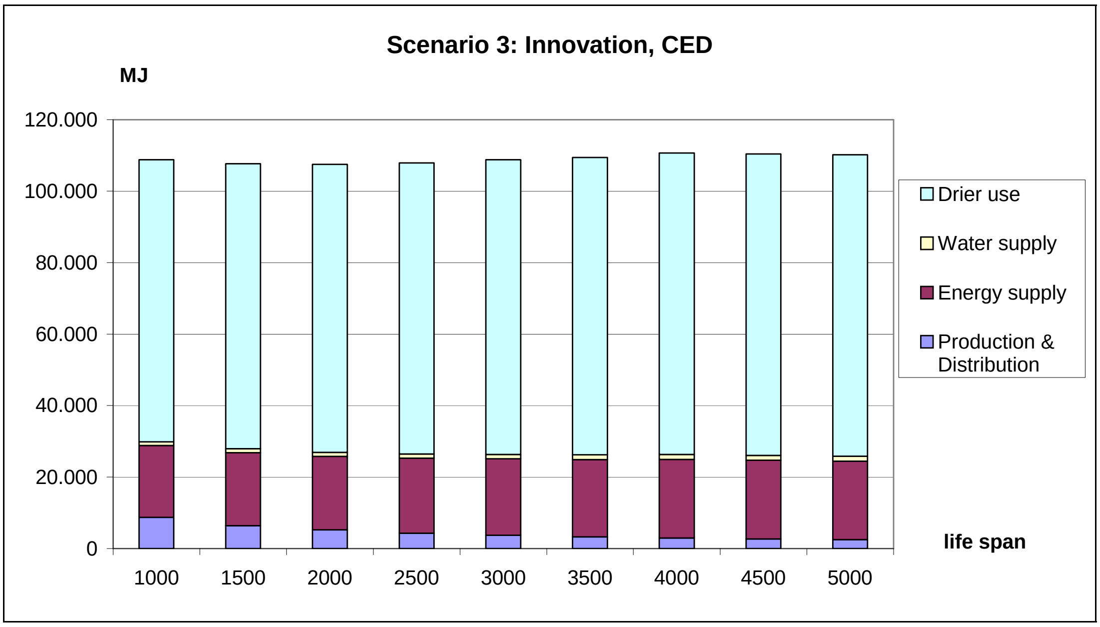


Figure 19 CED Scenario 3.

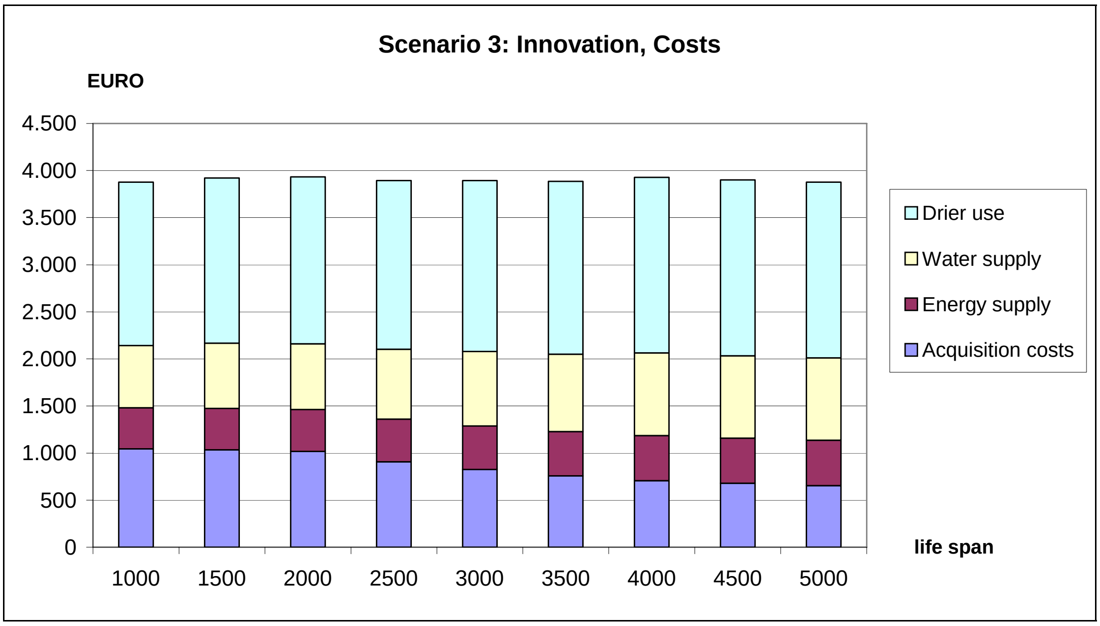


Figure 20 Total costs Scenario 3.

Regarding the third scenario the picture is basically the same as in the scenario trend. Again the costs show a relative minimum at life spans of 1 000 cycles and of 2 500 to 3 500 cycles. The variation of the costs is within 1,5 % relative to the lowest life cycle costs (at a life span of 1 000 cycles).

Figure 21 shows the combined environmental and cost assessment in the eco-efficiency portfolio for scenario 3. All alternatives with a life span between 1 500 and 5 000 cycles are relatively close together. Only the alternative with a very short life span is the least eco-efficient. But these differences might not be considered as significant, as the variation is within +/- 1 %

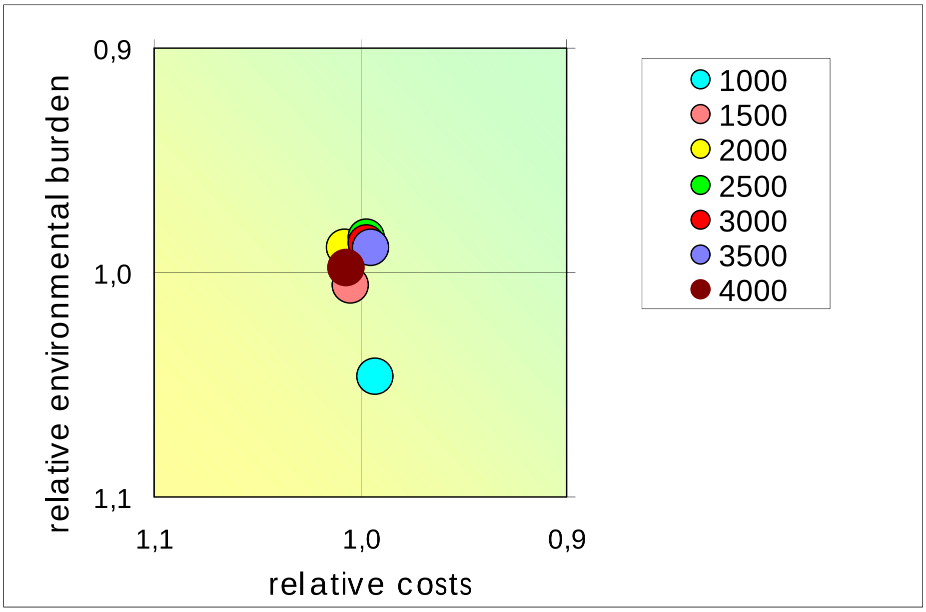


Figure 21 Eco-efficiency portfolio of scenario 3 (base case).

### 4.4.2 Robustness of results against possible future developments

Figure 22 and Figure 23 show a cross comparison of the results of the regarded scenarios. It can be seen that the differences between the scenarios are relative small. This means the results are quite robust against different future developments.

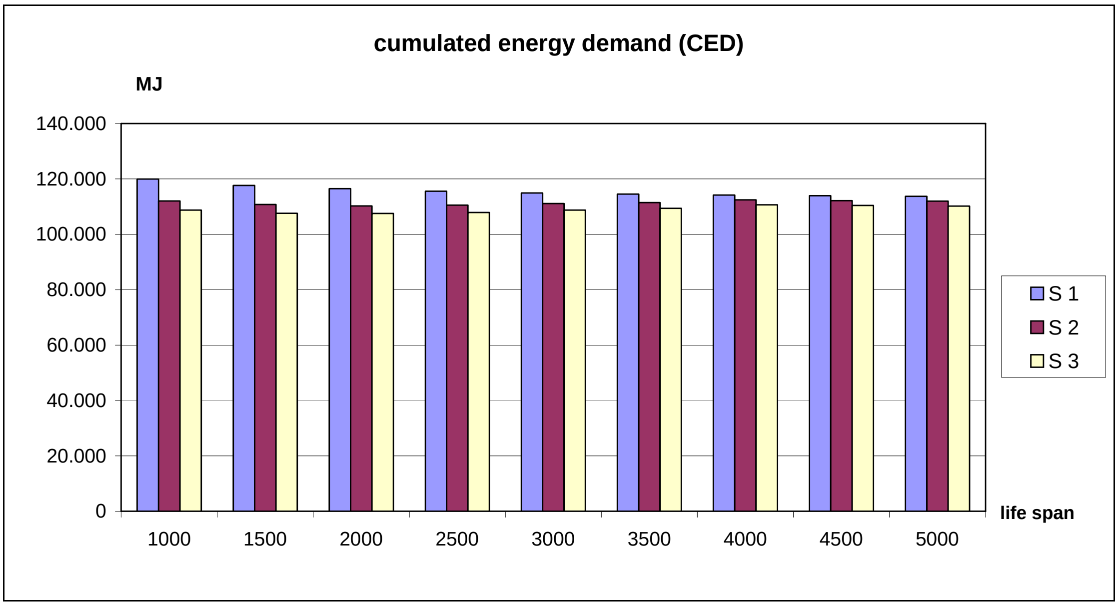


Figure 22 Cross comparison of the CED between the regarded scenarios.

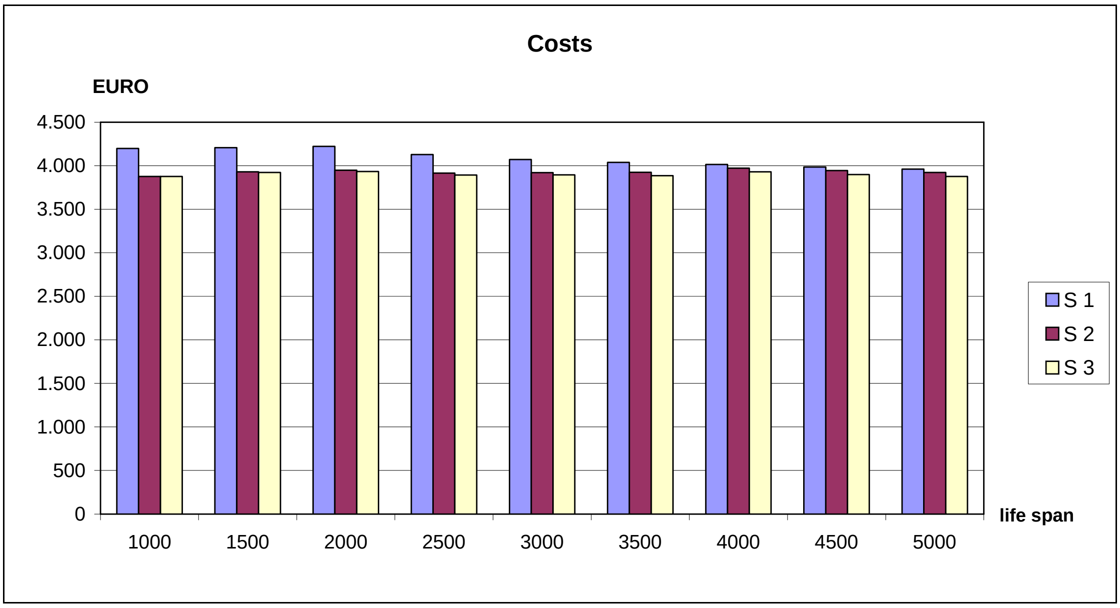


Figure 23 Cross comparison of the costs between the regarded scenarios.

### 4.4.3 Sensitivity analyses

The results of the sensitivity analyses are shown for scenario 3 (innovation). Here potential differences between the alternatives (different life spans) are expected to be the biggest.

#### 4.4.3.1 Different household size: small household with 75 cycles per year

According to the size of the household the annual amount of laundry differs in contrast to the household regarded in the base case (household with 3 people). The following diagrams show the results of the calculations with reduced annual amount of laundry and annual number of washing cycles. During this time period the small households wash in total 1 650 times.

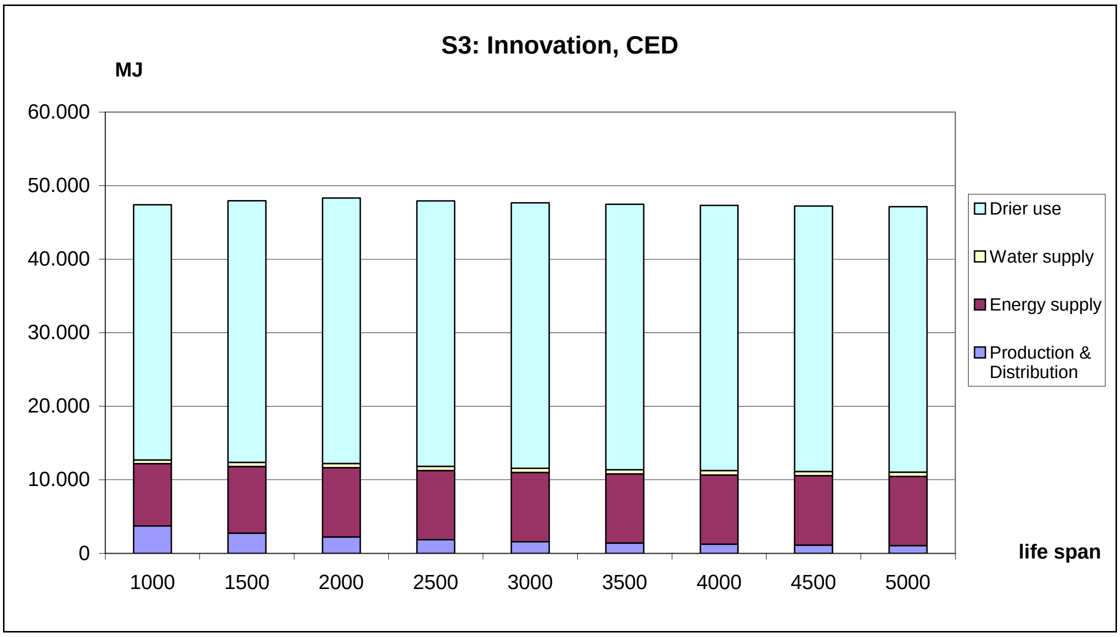


Figure 24 CED Scenario 3, small households (75 cycles p.a.).

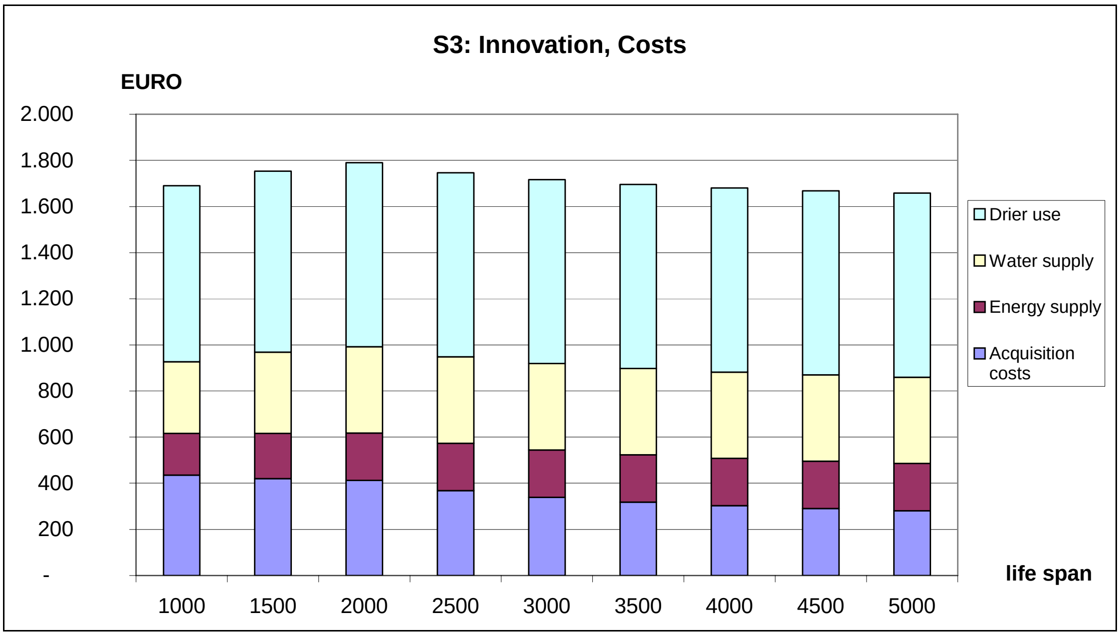


Figure 25 Total costs Scenario 3, small households (75 cycles p.a.).

As expected there is practically no difference in the CED between the regarded alternatives. This results from the regarded time period of 22 years. The total number of washing cycles over this period for a household with an annual number of washing cycles of only 75 cycles is 1 650 cycles. This means within this period only with a life span of 1 000 and 1 500 cycles the washing machine is substituted at all.

The cost difference is bigger than in the base case. This is a result of the quite low number of washing cycles. Therefore the differences in acquisition costs play a more important role. The decrease of costs between life spans of 2 000 and 5 000 washing cycles results from the fact already mentioned in the last paragraph: for these life spans there is no machine substitution within the regarded time span. Therefore for a washing machine with a life span of 5 000 cycles only 1/3 of the acquisition costs are accounted for.

This might not represent the real situation in households, where a washing machine might not be used for more than 20 years even though the maximum life span (in cycles) is not reached yet.

#### 4.4.3.2 Different household size: large household with 260 cycles per year

The following diagrams show the results of the calculations with increased annual amount of laundry and annual number of washing cycles. During this time period the large households wash in total 5 720 times.

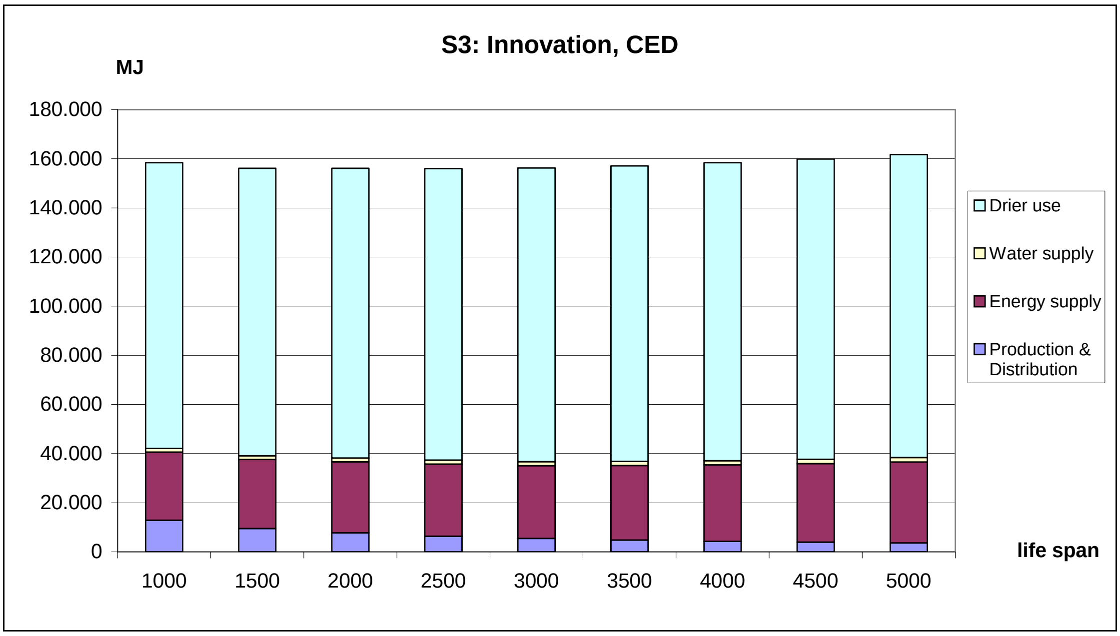


Figure 26 CED Scenario 3, large households (260 cycles p.a.).

In contrast to the small households, the development of the CED when regarding large households has a minimum at life span of 2 000 cycles. The difference to the highest values at a life span of 1 000 and 5 000 cycles is 5 800 MJ (4 %).

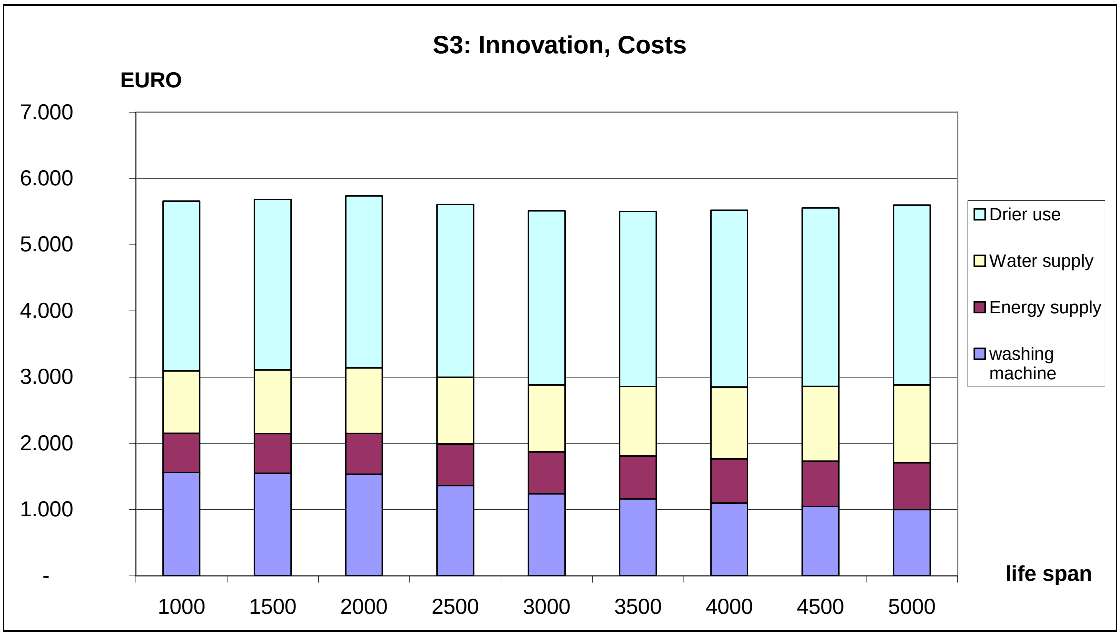


Figure 27 Costs Scenario 3, large households (260 cycles p.a.).

The cost show a relative minimum at a life span of 3 500 cycles and a peak at a life span of 2 000 cycles and 5 000 cycles. The difference between the life cycle costs at 3 500 cycles and 2 000 cycles is 230,- € (4 %), between 3 500 cycles and 5 000 cycles is 100,- € (2 %).

Figure 28 shows the eco-efficiency portfolio for the sensitivity analysis. Please note that here other alternatives are shown than in the previous eco-efficiency portfolios. Again the differences between all alternatives are very small (within +/- 1 %). Within this small range, the alternative with a life span of 1 000 cycles is the least eco-efficient one. The alternatives with life spans of 2 000 and 5 000 cycles and with a life span between 3 000 and 4 000 cycles almost have the same eco-efficiency.

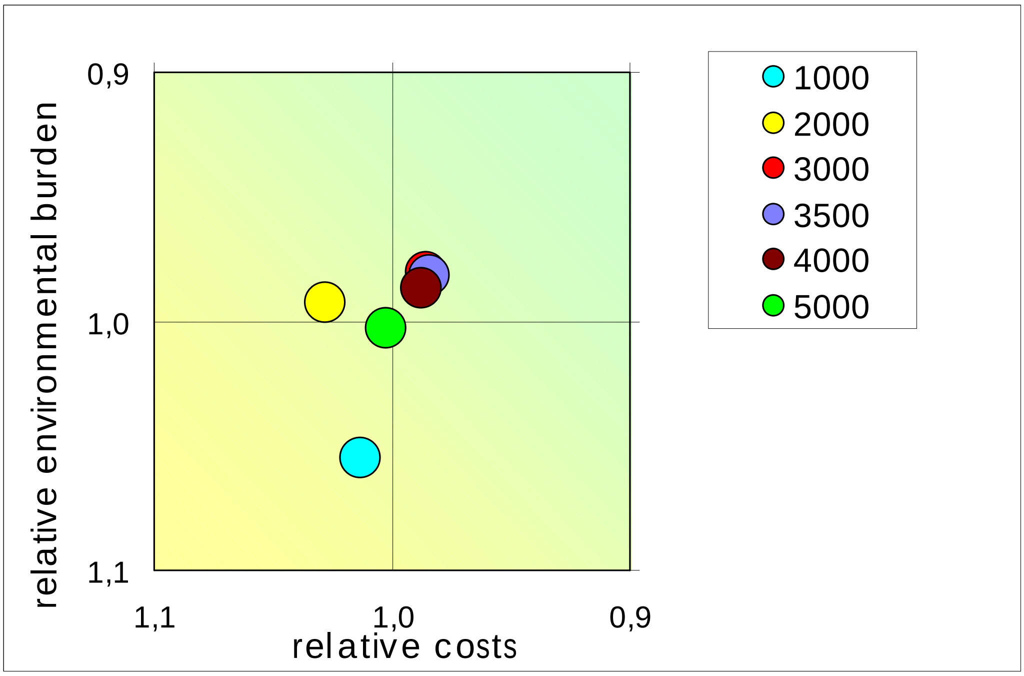


Figure 28 Eco-efficiency portfolio of scenario 3 (sensitivity large households).

### 4.4.4 Cross-comparison of the results of the different household sizes

To give a picture of the relevance of the differences between the regarded life spans, a cross comparison between the households is conducted. Figure 29 and Figure 30 show the CED and the costs in Scenario 3 for all regarded household sizes.

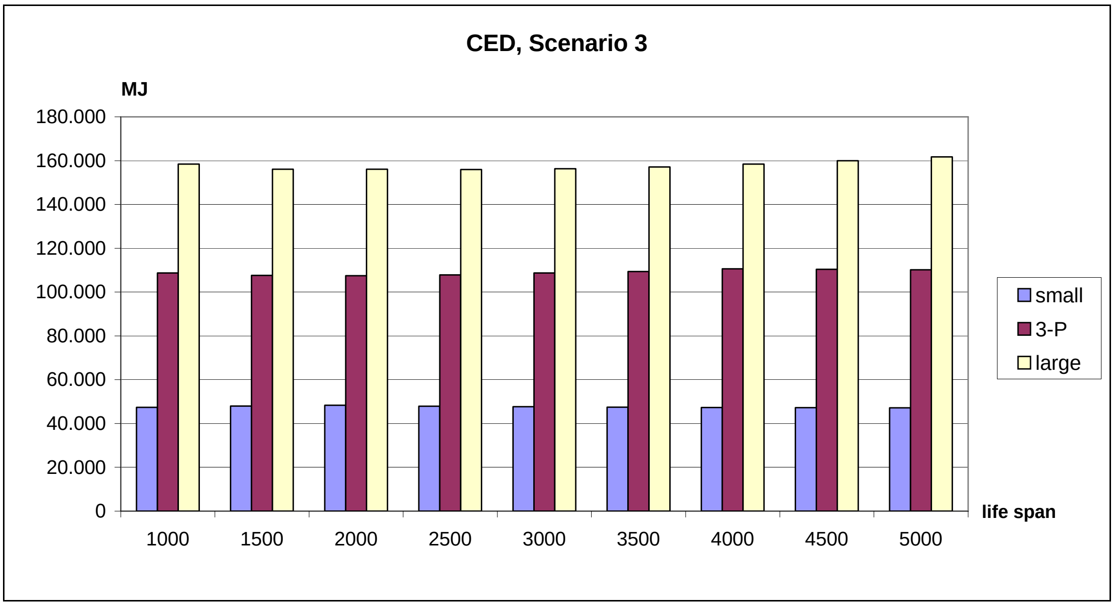


Figure 29 Cross comparison of the CED between the household sizes.

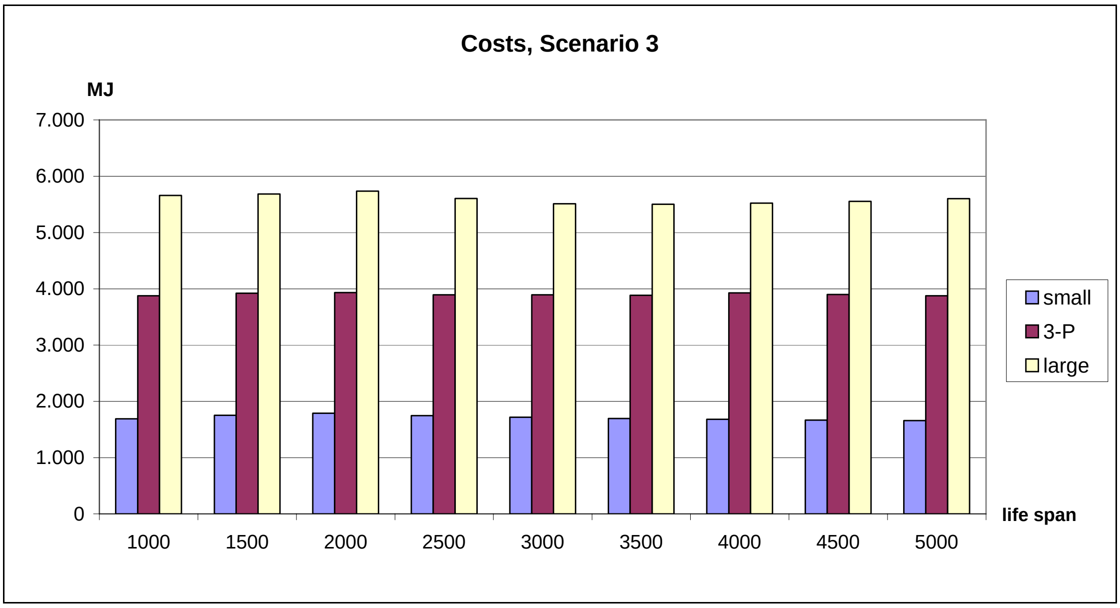


Figure 30 Cross comparison of the costs between the household sizes.

It can be seen that the differences between different household sizes are much bigger than the differences between different life spans.

### 4.4.5 Relevance of results in comparison to overall household impacts and expenditures

To give an idea about the relevance of the achievable savings for private households, the results of the scenarios are compared to the total environmental impacts and expenditures of private households.

The total environmental impacts of private households were calculated in a material flow analysis by Öko-Institut in 2003.[33] The annual cumulated energy demand (CED) of an average German household is about 220 000 MJ. In the innovation scenario the maximum difference of the CED is 3 100 MJ in 22 years for a household with 3 people (between a life span of 2 000 and 4 000 cycles). This equals approximately 140 MJ per year and represent 0,06 % of the total CED of an average household.

The total expenditures of private households within Germany were 1.200.000.000,- € in 2003.[34] This means each household spent 30.813,- € in 2003.

In the innovation scenario the maximum differences of the costs are 57,- € in 22 years (between 2 000 cycles and 1 000 cycles) and 52,- € in 22 years (between 1 000 cycles and 4 000 cycles), with 1 000 being the life span with the minimum life cycle costs. This equals 2,60 € resp. 2,40 € per year, representing 0,008 % of the total annual expenditures of an average private household.

Please note, that both the total CED and the total expenditures are calculated for the "statistic" average household with a size of 2,14 people. The environmental and cost savings through different life spans are calculated for a household size of 3 people. This means that the proportion of the savings is even a bit smaller than the calculated percentages.

Another picture of the relevance of the differences between the regarded alternatives is already given through the cross comparison between different household sizes (see section 4.4.4).

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33 Quack/Rüdenauer 2003.

34 Stat. Bundesamt 2004.

## 4.5 Results Task 4 (further use or substitution of old washing machine)

Goal of task 4 was to compare the environmental impact and the costs of further use of an existing washing machine with the acquisition and use of a new one.

Please note that

- costs and environmental impact through repair of existing washing machines is not considered,
- it is assumed that a condenser drier is used for 80 % of the laundry,
- differences in the performance of old and new washing machines are not considered. The consideration of this aspect might lead to shorter payback periods than the calculated ones.

All results shown in this section refer to the defined functional unit as described in section 3.1 ("Washing and drying of the annual amount of laundry over a time period of ten years in private consumers' households").

For correct interpretation of the figures some general explanation are given:

- "1985" means that a washing machine that was bought in 1985 is further used over the next ten years. "1990", "1995" and "2000" respectively. "2004" means that in 2004 a new washing machine is bought and used over the same time period.
- "cumulated" means, that the total environmental impact or costs (both production (including credits for recycled materials) and use of washing machine and drier) of each year starting in 2004 is cumulated. The alternative where the new washing machine is used has a higher CED value and higher costs in 2004 as here the production(the acquisition is considered. But, due to the lower consumption figures and the higher spin speed of the new washing machine and the subsequently lower energy demand of the drier, in this case the additional CED and costs for energy and water consumption is lower than in the other alternatives. Each year the consumption figures and costs of the use phase are added to the environmental impact/costs of the previous year(s). The intersection of the lines mark the time when the additional CED from production/the additional costs from acquisition is amortised through the lower consumption figures/costs during the use phase.

Figure 31 shows the cumulated CED of the five different alternatives.

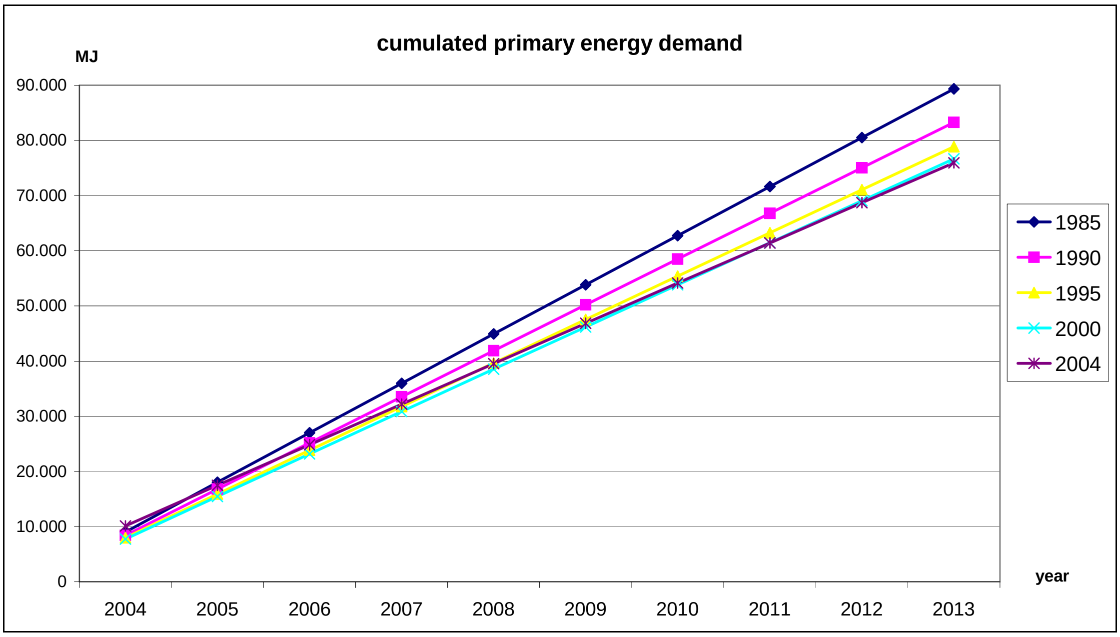


Figure 31 Cumulated primary energy demand old vs. new washing machine.

It can be seen that the differences of the cumulated CED between the alternatives are quite small. Nevertheless the additional CED for production of a new washing machine is amortised in all cases within the next ten years.

Table 36 shows the underlying figures of the cumulated CED. The years, where the acquisition a new washing machine in 2004 is amortised, are grey highlighted. It can be seen that for a washing machine bought in 1985 already within the second year the acquisition of a new one in 2004 is better in terms of CED. For a washing machine of 1990 this is the case within the third year of usage, for a washing machine of 1995 in the fifth year of usage and for a washing machine of 2000 in the eighth year of usage.

Table 36 Cumulated CED for use of old or a new washing machine.

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985** | 9 025 | 18 029 | 27 014 | 35 979 | 44 924 | 53 848 | 62 753 | 71 638 | 80 503 | 89 348 |
| **1990** | 8 413 | 16 807 | 25 183 | 33 541 | 41 879 | 50 199 | 58 500 | 66 783 | 75 047 | 83 293 |
| **1995** | 7 967 | 15 917 | 23 849 | 31 764 | 39 660 | 47 540 | 55 401 | 63 245 | 71 071 | 78 880 |
| **2000** | 7 742 | 15 467 | 23 174 | 30 865 | 38 538 | 46 195 | 53 834 | 61 456 | 69 061 | 76 649 |
| **2004** | 10 113 | 17 494 | 24 859 | 32 208 | 39 540 | 46 856 | 54 156 | 61 439 | 68 706 | 75 956 |

The same calculation is conducted for the global warming potential, the total environmental burden and of course the costs. This is depicted in the following figures and tables.

The cumulated global warming potential shows a similar picture as the cumulated CED. Nevertheless the substitution of a washing machine of the year 2000 in 2004 is not amortised in term of global warming potential within the next ten years.

Table 37 shows the underlying figures of the cumulated GWP. It can be seen that in all cases it takes longer to amortise the additional GWP of the production of a new washing machine than to amortise the additional CED.

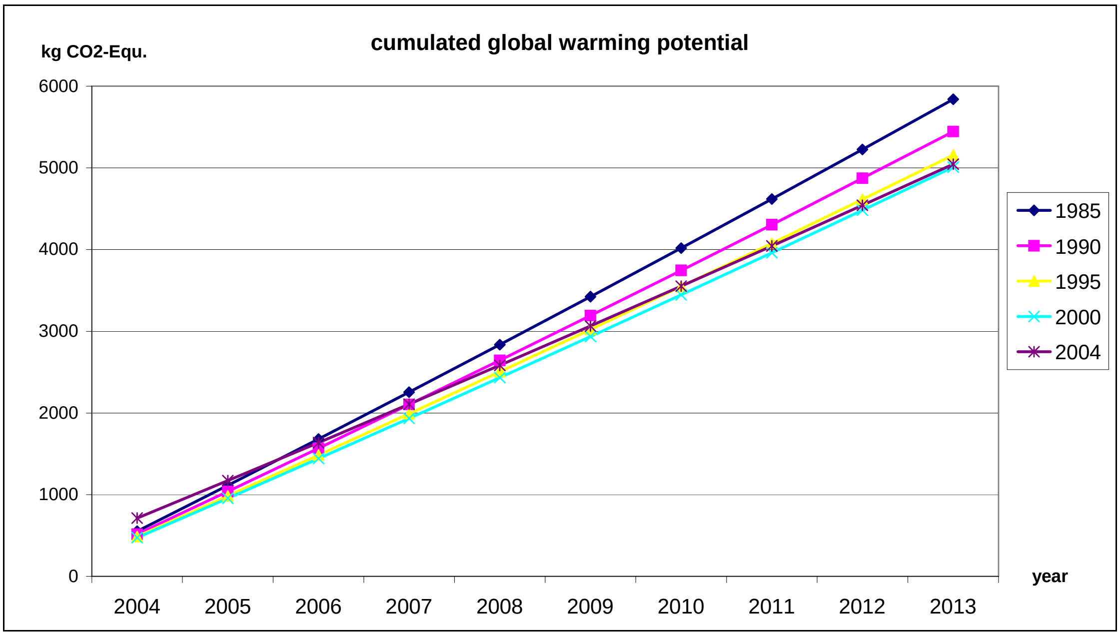


Figure 32 Cumulated global warming potential old vs. new washing machine.

Table 37 Cumulated GWP for use of old or a new washing machine.

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985** | 554 | 1 114 | 1 681 | 2 255 | 2 836 | 3 423 | 4 017 | 4 618 | 5 226 | 5 840 |
| **1990** | 516 | 1 039 | 1 567 | 2 102 | 2 644 | 3 191 | 3 745 | 4 305 | 4 872 | 5 444 |
| **1995** | 489 | 984 | 1 484 | 1 991 | 2 504 | 3 022 | 3 547 | 4 077 | 4 614 | 5 156 |
| **2000** | 475 | 956 | 1 442 | 1 935 | 2 433 | 2 937 | 3 446 | 3 962 | 4 483 | 5 010 |
| **2004** | 713 | 1 172 | 1 637 | 2 107 | 2 583 | 3 065 | 3 552 | 4 044 | 4 543 | 5 046 |

When regarding the total environmental burden (see Figure 33 and Table 38) it can be seen that only for washing machines of 1985 and 1990 the acquisition of a new washing machine is amortised within the next 10 years. In the former case it takes approximately four years, in the latter approximately seven years.

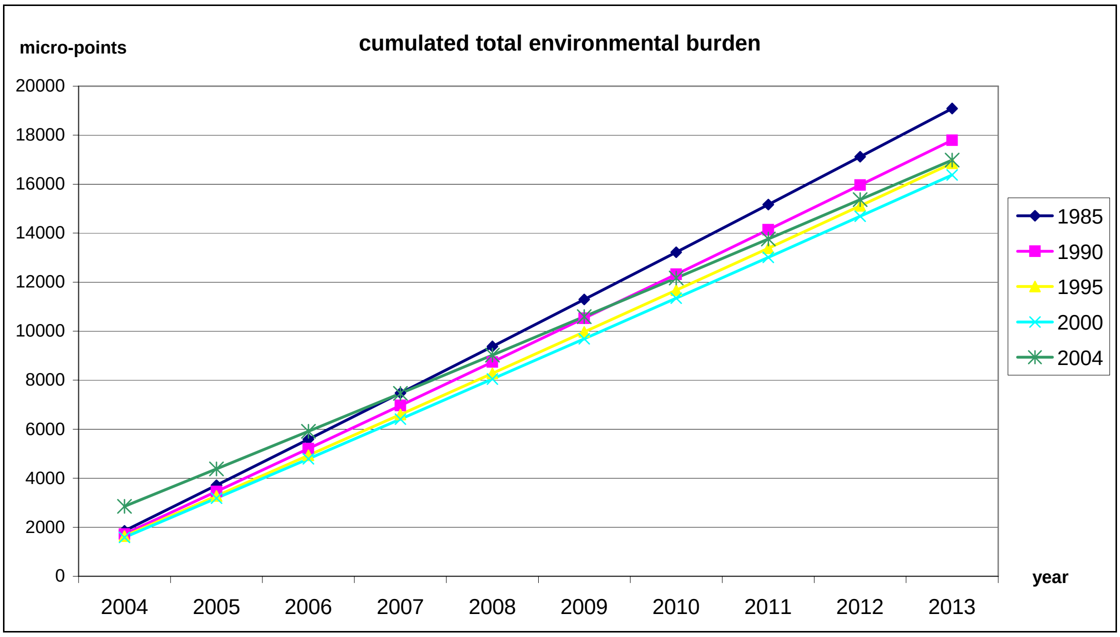


Figure 33 Cumulated total environmental burdens old vs. new washing machine.

Table 38 Cumulated total environmental burden for use of old or a new washing machine.

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985** | 1 849 | 3 712 | 5 587 | 7 476 | 9 378 | 11 294 | 13 222 | 15 164 | 17 119 | 19 087 |
| **1990** | 1 724 | 3 460 | 5 209 | 6 969 | 8 743 | 10 528 | 12 326 | 14 136 | 15 959 | 17 794 |
| **1995** | 1 633 | 3 277 | 4 933 | 6 600 | 8 279 | 9 970 | 11 673 | 13 387 | 15 113 | 16 851 |
| **2000** | 1 586 | 3 184 | 4 793 | 6 413 | 8 045 | 9 688 | 11 343 | 13 009 | 14 686 | 16 374 |
| **2004** | 2 849 | 4 376 | 5 913 | 7 462 | 9 021 | 10 591 | 12 172 | 13 764 | 15 366 | 16 980 |

When regarding the total costs (see Figure 34 and Table 39) it can be seen that also only for washing machines of 1985 and 1990 the acquisition of a new washing machine is amortised within the next 10 years. In the former case it takes approximately six years, in the latter approximately nine years.

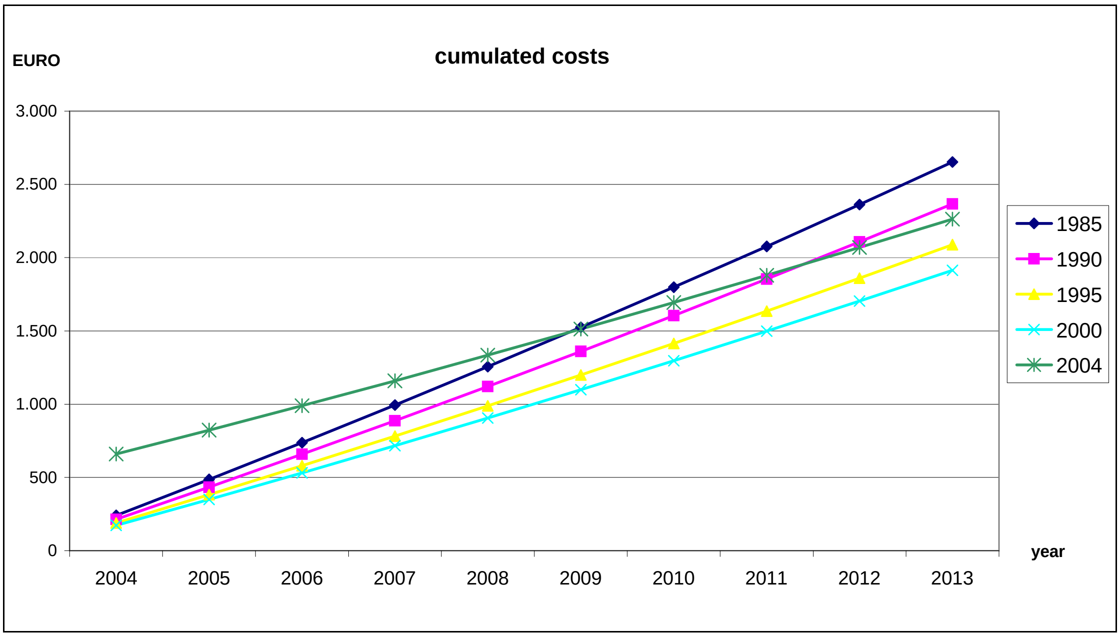


Figure 34 Cumulated costs old vs. new washing machine.

Table 39 Cumulated life cycle costs for use of old or a new washing machine.

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1985** | 240 | 486 | 737 | 994 | 1.256 | 1.524 | 1.798 | 2.077 | 2.362 | 2.652 |
| **1990** | 214 | 434 | 658 | 887 | 1.121 | 1.360 | 1.604 | 1.854 | 2.108 | 2.367 |
| **1995** | 189 | 382 | 580 | 782 | 989 | 1.200 | 1.415 | 1.635 | 1.860 | 2.088 |
| **2000** | 173 | 350 | 531 | 717 | 906 | 1.099 | 1.297 | 1.498 | 1.704 | 1.913 |
| **2004** | 659 | 823 | 989 | 1.160 | 1.334 | 1.512 | 1.694 | 1.880 | 2.069 | 2.263 |

# 5 Conclusions

Please note that these conclusions strongly depend on the assumptions made to define the parameters of the regarded life cycle phases. Also the conclusions correspond to the intended use of the study (see section 1.3).

## 5.1 Task 1 (update LCA washing machine)

- The results displayed in this study are in the same magnitude as the results of other studies as a comparison with literature showed. The use phase is still the most important origin of CED (80%), GWP (76%) and cumulated total environmental burden (65%). Due to the improvements in efficiency during the use phase a relative shift of environmental impacts towards the production phase can be seen.
- The contribution of the electronic components to material supply (11 %) is of considerable importance.
- The results refer to a washing machine of the above listed material composition. In case major changes occur, e.g. an increase in electronic components, the production phase would gain more importance. This would require another update of the LCA.

## 5.2 Task 2 (comparison: 5 kg- vs. 7 kg-machines)

- There is a slight reduction potential in the total environmental impact through acquisition and use of larger washing machines. The reduction potential result from fewer washing machines that have to be produced and recycled. Nevertheless there is also a potential for higher environmental impact and costs through the acquisition and use of larger washing machines. Which potential (slight reduction or increase) will be realised depends on the consumer behaviour (same relative or absolute loading of the large washing machine as the standard washing machine).
- The acquisition and use of large washing machines leads to lower costs only in the case of lower specific consumption figures (sens_2) and same relative loading. In the base case the acquisition and use of large washing machines is slightly more expensive than the acquisition and use of standard machines.
- In the case that the consumers stay with their use patterns in terms of same *absolute* loading (sens_1) the acquisition and use of a large washing machine results in both higher environmental impact and higher costs. This means in this case the acquisition of a large washing machine would be contra productive when heading for lower environmental burden and lower costs. This also applies when the large machine has lower specific consumption figures.

- As long as large washing machines have the same specific energy demand (per kg laundry) than 5 kg-machines there is no reduction in environmental impacts and costs during the use phase. Only if large washing machines have a lower specific energy and water demand (sens_2) a reduction can be expected.

## 5.3 Task 3 (scenarios to calculate optimal life span)

- In all scenarios a certain influence of the life span both on environmental impacts and costs can be stated.
- However the difference in the environmental impact of different life spans of washing machines is small compared to
  a) the variation through different household sizes (respectively consumer behaviour);
  b) the overall environmental impact of private households. The maximum difference of 3 % of the CED is equivalent to 3 100 MJ in 22 years. This is equivalent to 90 litres of light fuel oil for heating (or 4 litres per year) – an average building in stock needs approximately 20 litres per $m^2$ per year.
- The economic differences for private households are also very small. The biggest difference between a life span of 1 000 and 2 000 cycles is 57,- € in 22 years or 2,60 € per year – at total expenditures of more than 30.000,- € per household per year.
- For small households the differences are smaller as they do not have so much laundry and therefore do not substitute washing machines with a longer life span than 1 500 in the regarded 22 years. For bigger households the differences are slightly higher.
- The relatively small differences of environmental impacts and costs between the regarded life spans for all regarded scenarios can be seen ambivalent.
  On the one hand there is no environmental or economic incentive to either substitute an existing washing machine very quickly or to use it for a very long time.
  On the other side this gives manufacturers and consumers the opportunity to keep other qualities in mind when they design or think of buying (or not buying) a new washing machine. This might be quicker washing cycles, better performance, aesthetic considerations, noise reduction etc. It seems as if washing machines are to a great extend already designed for low environmental impact and costs. Future achievements seem not so important as they were in the past.

## 5.4 Task 4 (further use or substitution of old washing machine)

Please note that costs for repair of existing washing machines are not considered and that it is assumed that a condenser drier is used. Also differences in the performance of old and new washing machines are not considered.

The question if it is “worth” to further use an existing washing machine 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 we define 5 years for environmental or economic amortisation as a time period that justifies the substitution.

In practice the decision to substitute the washing machine is probably determined by other reasons like the break-down of the existing machine, which would make a repair necessary, or the move to another accommodation.

Against the defined payback period of 5 years the following conclusion can be drawn (please note that these conclusions depend on the assumptions made):

- When regarding the cumulated energy demand, the substitution of washing machines of the years 1985, 1990 and 1995 with a new model is justified. The payback periods are approximately 2, 3 and 5 years respectively.
- When regarding the global warming potential only the substitution of washing machines of 1985 and 1990 with a new model is justified. The payback periods are approximately 3 and 5 years respectively. Washing machines of 1995 have a payback period of approximately 8 years.
- When regarding the total environmental burden (expressed in environmental points calculated with EcoGrade), only the substitution of washing machines of 1985 is justified with a payback period of approximately 4 years. Washing machines of 1995 and 2000 don’t amortise in environmental terms within the regarded time period of 10 years.
- Under economic perspective the substitution of none of the regarded washing machines amortises within 5 years. Even in case of the 19-year-old washing machine it takes up to 6 years before the savings equal the additional acquisition costs.

# 6 References


| | |
|---|---|
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