2005-015-en

Eco-Efficiency Analysis of Washing machines

Refinement of Task 4: Further use versus substitution of washing machines in stock

Final report

commissioned by:
European Committee of Domestic Equipment Manufacturers (CECED)

Freiburg, March 18th, 2005

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1 Background and goal

1.1 Background

Öko-Institut conducted the study "Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span" for Electrolux - AEG Hausgeräte GmbH and BSH Bosch und Siemens Hausgeräte GmbH (Rüdenauer et al. 2004). In this "base study" four main questions were addressed:

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 (in environmental and economic terms) 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 to buy a new one?

Task 4 was tackled in a very simplified way to get a first impression on the issue of accelerated replacement. It was assumed that the new washing machine is bought in 2004 and thus all environmental impacts through production and the acquisition costs occur at once in 2004. For all washing machines (in stock and the new one) it was assumed that they would not break down within the next ten years (the time period which was regarded). Thus it was investigated, if and when the environmental impacts through production and the acquisition costs of a new washing machine amortize by its lower energy and water consumption figures. The consumption values from 1985 to 1991 were taken from Stiftung Warentest (average figures for the 90°C-program). The values from 1996 onwards were taken from CECED database (average figures for the 60°C-program). The values for 1995 were interpolated, the values for the other programs were calculated according to a fix ratio. Differences between the initial performance of elder washing machines and their performance, when they are used nowadays under current conditions (due to ageing or changes in the system (detergent formulation etc.)) were not considered.

1.2 Goal

To get a more precise view on this issue, CECED asked Öko-Institut to investigate the question of accelerated replacement of washing machines in more detail. The following subtasks were defined[1]:

1.2.1 Subtask 1: General refinement of calculation model

As described above task 4 in the original study was calculated in a very simplified way. In the refinement the costs will be discounted with a discount rate appropriate to private households. Failure rates of washing machines in stock will be considered in an adequate way (through consideration of environmental impacts and costs for repairs or through substitution of elder washing machines within the regarded time period).

Due to lack of data differences between the initial performance of elder washing machines and their performance, when they are used nowadays under current conditions will not be included in the model (see also section 2.1 and corresponding footnote)

1.2.2 Subtask 2: Sensitivity analysis: influence of in/exclusion of drier

So far the use of driers is included in the calculations. It is assumed that driers are used during the whole year for 80 % of the annual laundry. In Subtask 2 the basic assumption is refined and two sensitivity analyses will be conducted:

- Sensitivity 1: drier use only during half of the year (i.e. only for approximately half of the annual laundry)
- Sensitivity 1: no inclusion of drier use in the calculations

The assumptions are described in section 2.6.4 below.

1.2.3 Subtask 3: Sensitivity analysis: “high-end-machines” and “low-end-machines”

So far the calculations are based on average energy and water consumption figures of washing machines of different age. Nevertheless in the past the consumption figures and the spin speed of washing machines in the market were within a broader range than it is the case today. To see weather the results change when high-end- or low-end-washing machines are regarded, two sensitivity analyses will be conducted.

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1 As task 4 of the original study is to be refined, the tasks that will be carried out are called subtasks

1.3 Application and not intended use of the study

The results can be applied for:

- strategic decisions of manufacturers
- information of the interested public

The following restrictions apply to the results:

- 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 (including 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

The study at hand is a refinement of task four of the study “Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span” which was conducted in 2004 for Electrolux - AEG Hausgeräte GmbH and BSH Bosch und Siemens Hausgeräte GmbH (Rüdenauer et al. 2004).

Therefore all general remarks on the methodological approach (section 2) and on the scope and data base (section 3) of that study apply also to this refinement.

The respecting information is partly repeated here to the extend which is directly necessary to understand the calculations and results of this refinement. Some of the input data are changed (e.g. water and energy consumption figures and spin speed of washing machines of different age).

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. For this study no critical review was conducted.

2 Scope and data base of the study

2.1 Function and functional unit

The function of the system under consideration is defined as "Washing and drying of the annual amount of laundry in private households of three people (i.e. 707 kg p.a.), calculated over a time period of ten years"

Differences between the initial performance of older washing machines and their performance, when they are used under current conditions are 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.[2]

2.2 Regarded alternatives and conducted sensitivity analyses

In the study at hand in the base case calculations 'average' washing machines are regarded to calculate the environmental and economic implications of an accelerated replacement of appliances in stock. Five alternatives are calculated:

1. Further use of a washing machine of 1985
2. Further use of a washing machine of 1990
3. Further use of a washing machine of 1995
4. Further use of a washing machine of 2000
5. Acquisition and use of a new washing machine in 2004

In the base case calculations the use of a drier is included. This is varied in two sensitivity analyses (see section 2.6.4).

In this refinement the question of accelerated replacement shall also be answered from the viewpoint of households that own 'high-end' or 'low-end' washing machines as significant differences in the results were expected (see section 1.2.3).

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

Therefore the following base case scenario and sensitivity analyses are calculated:

Base case scenario:

Replacement of average washing machines of different age with an average washing machine in 2004.

Sensitivity 'high-end':

Replacement of 'high-end' washing machines of different age with a 'high-end' washing machine in 2004.

Sensitivity 'low-end':

Replacement of 'low-end' washing machines of different age with a 'low-end' washing machine in 2004.

The 'high-end', 'average' and 'low-end' washing machines are different regarding their

- production parameters
- specific energy- and water demand
- availability and efficiency of an automatic load adjustment system
- spin speed (influencing the subsequent drying process)
- number of necessary repairs, failure rates
- amount of recyclable materials

The specifications of these parameters and of the consumer behaviour is described in section 2.6 Data base.

2.3 System boundaries

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. The supply chains of energy or material supply might also cover other countries/regions.

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 (see the following figure).

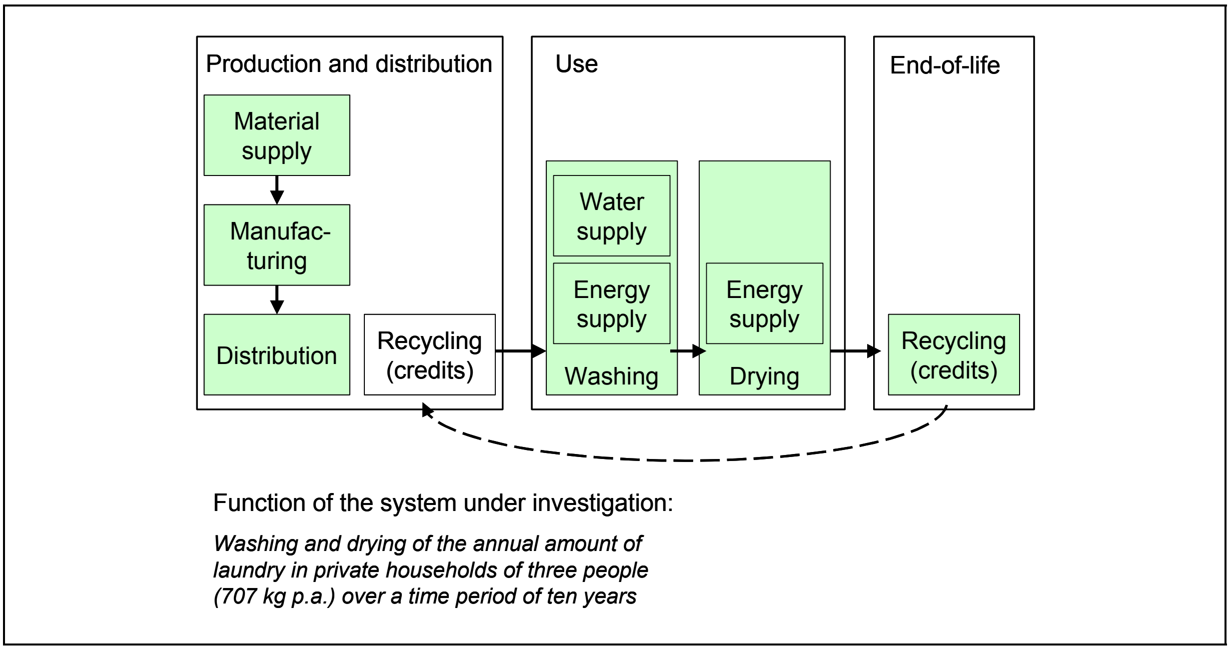

Figure 1 Regarded system and processes

As it is assumed that the washing performance is the same for older and new washing machines there are consequently no differences in either the use of certain washing temperatures or the amount of detergent used. This means:

- the same consumer behaviour regarding washing temperature and loading is assumed
- detergents are not included in the study (as there are no differences between the regarded alternatives)

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 credits 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. Due to the minor relevance of the recycling credits this allocation procedure does not significantly influence the results.

The spin speed of washing machines influences the energy consumption of the subsequent drying process. Therefore the drying process itself is included in the base case whereas the production, distribution and end-of-life-treatment of tumble driers is not included as this is not affected by the spin speed of washing machines. Sensitivity analyses are conducted to investigate the influence of the inclusion of the drying process on the results.

2.4 Environmental impact assessment

As environmental indicators the cumulated energy demand (CED) and the global warming potential (GWP) are regarded.

2.5 Life Cycle Costing

To assess the economic implications the life cycle costs in terms of total costs of ownership of the private households are calculated. The following cost types are considered:

- Acquisition costs
- Energy costs
- Cost for fresh water supply (including costs for waste water treatment)
- 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.

The life cycle costs represent the total annual costs for the time period of ten years. A future development of prices for washing machines, electricity, fresh water supply and waste water treatment is assumed. Furthermore for all costs a discount rate of 5 % is assumed.[3] External costs are not included.[4]

2.6 Data base

2.6.1 Production

The production can be subdivided in

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

[3] Depending on the rationale for setting the discount rate it might be chosen between some 2 and 10 %. Taking into account the not realised interests when spending the money instead of placing it with a bank, only small numbers are realistic. If a household in contrast has to borrow money for the investment, higher discount rates are reasonable. In the study at hand an intermediate discount rate is chosen.

[4] External costs can be defined as value changes caused by a business transaction but not included in its price or as side-effects of economic activity, e.g. impacts on human health or ecosystems through the release of toxic substances, damage to buildings caused by acidifying agents etc.

The *material supply and the respective upstream processes* are modelled for three types of washing machines with a rated capacity of 5 kg (see Table 1, for further details see Rüdenauer et al. 2004).

Table 1 Considered types of washing machines

Type	**Name (see Rüdenauer et al. 2004)**	**Description (representing differences in material composition and weight)**
high-end-machines	machine I	high price segment (total weight: 97 kg)
average machines	machine II.2	medium price segment, average design (76 kg)
Low-end-machines	machine III	low price segment (72 kg)

The *manufacturing* and *distribution* was considered to be identical for all three regarded washing machines. There are no changes compared to the modelling in Rüdenauer et al. 2004.

2.6.2 Water and energy consumption of fully loaded cycles

In recent years the average specific water and energy consumption of washing machines at the different washing temperatures decreased to a quite large extend. In 2004 nearly all (96 %) front loader washing machines with a rated capacity of at least 5 kg on the German market belonged to the energy efficiency class “A”. Only 3,5 % belonged to the energy efficiency class “B”, and only 0,5 % to “C”. Even washing machines of the low price segment had an energy efficiency label “A”.

Most 5-kg A-class washing machines have a specific energy demand of 0,19 kWh/kg based on standard test results for ‘60°C cotton’ cycle. However, especially washing machines with a rated capacity of 6 kg have an even lower energy demand of 0,17 kWh/kg (so called “A+” classification).

The values for water consumption differ to a greater extend. In 2004 the specific water consumption of front loader washing machines with a rated capacity of at least 5 kg on the German market varied between approximately 6 an 10 litres/kg in the ‘60°C cotton’ cycle.

For the years 1998, 1999 and 2000, Schlohmann et al. (2001) gives an overview of the Development of sales figures of electric domestic appliances with respect to energy efficiency classes (see the following table).

Table 2 Development of sales figures of washing machines with respect to energy efficiency classes (modified according to Schlohmann et al. (2001))

Energy efficiency class	**energy demand (C)**	**1998**	**1999**	**2000**
A	C ≤ 0,19	26%	41%	54%
B	0,19 < C ≤ 0,23	44%	39%	35%
C	0,23 < C ≤ 0,27	19%	16%	9%
D	0,27 < C ≤ 0,31	4%	2%	1%
E	0,31 < C ≤ 0,35	0%	0%	0%
other (no declaration etc.)		6%	2%	2%
		100%	**100%**	**100%**

Most public data is available for the standard ‘60°C cotton’ programme. StiWa (2004) also gives figures for 30°C and 40°C programmes. The remaining numbers are either measurements by manufacturers or estimated values (through inter- and extrapolation and considering the typical relation of energy demand between the different washing temperatures).

There are no further reductions in water and energy demand in the forthcoming years assumed.

The following tables give an overview of the assumed development of energy and water consumption for ‘high-end-‘, ‘average’ and ‘low-end-’ washing machines on the market between 1985 and 2004.

Table 3 Specific energy demand of washing machines of different age and performance in kWh per kg[5]

Year of manufacture		1985	1990	1995	2000	2004
30°C	high-end	0,10	0,08	0,07	0,07	0,07
	average	0,11	0,09	0,08	0,08	0,07
	low-end	0,12	0,10	0,09	0,09	0,08
40°C	high-end	0,15	0,12	0,11	0,10	0,09
	average	0,19	0,15	0,13	0,12	0,10
	low-end	0,22	0,18	0,14	0,13	0,11
60°C	high-end	0,30	0,24	0,19	0,19	0,17
	average	0,34	0,27	0,23	0,22	0,19
	low-end	0,38	0,30	0,27	0,24	0,19
90°C	high-end	0,40	0,36	0,34	0,34	0,32
	average	0,55	0,44	0,38	0,36	0,32
	low-end	0,70	0,52	0,42	0,37	0,33

Table 4 Specific water demand of washing machines of different age and performance in litre per kg[5]

Year of manufacture		1985	1990	1995	2000	2004
30°C	high-end	23,1	18,4	13,0	11,0	7,5
	average	25,9	21,2	15,8	12,1	10,0
	low-end	28,7	24,0	18,6	12,7	10,0
40°C	high-end	23,1	18,4	13,0	11,0	7,5
	average	25,9	21,2	15,8	12,1	10,0
	low-end	28,7	24,0	18,6	12,7	10,0
60°C	high-end	21,0	13,6	11,8	9,0	7,5
	average	25,9	21,2	15,8	12,1	9,7
	low-end	30,8	28,8	19,8	13,7	9,7
90°C	high-end	21,0	13,6	11,8	11,0	7,5
	average	25,9	21,2	15,8	12,1	10,0
	low-end	30,8	28,8	19,8	12,7	10,0

5 The energy and water demand figures are mainly based on Stamminger (2004a) and Miele (2005), considering data from NEI (2001), NEI (2004), StiWa (2004), Schlohmann et al. (2001). The data is partly measured, partly taken from published consumption figures and partly extrapolated.

2.6.3 Automatic load adjustment

Load adjustment was introduced roughly in the middle of the 1980ies. During the 1990ies electronic control systems were introduced. Today good automatic load adjustment systems reach approximately 80 % of the water reduction potential.

The following table gives an overview of the assumed automatic load adjustment systems for the different washing machine types between 1985 and today. Three different systems are defined: A, B and C. 'N' means, that no automatic load adjustment system is available (see the following table).

Table 5 Automatic load adjustment systems for the different washing machine types between 1985 and today

Year of manufacture	**1985**	**1990**	**1995**	**2000**	**2004**
high-end	A	interpolation	B	interpolation	C
Average	N	A	interpolation	interpolation	B
low-end	N	N	N	A	A

A is the most simple system: the water demand is reduced by 15 % at a loading of 60 %. At lower loadings the water demand is not reduced any further.

B is a more advanced system. The water demand is reduced by 60 % of the total reduction potential (i.e. the percentage of reduction of loading, with consideration of a certain amount of water that cannot be reduced).

C is the currently best available technique. The water demand is reduced by 80 % of the total reduction potential (i.e. the percentage of reduction of loading, with consideration of a certain amount of water that cannot be reduced).

The energy reduction is calculated with the amount of reduced water and laundry, the difference between the initial and the final temperature and the heat capacity of water and laundry (here: as simplification cotton is chosen as fabric).

The following tables show the relative water and energy reduction assumed for the different automatic load adjustment systems.

Table 6 Relative water and energy reduction through automatic load adjustment system A[6]

Relative loading		100%	75%	60%	50%	30%
	declared temperature					
Relative reduction water	all temperatures	0%	9%	15%	15%	15%
Relative reduction energy	30°C	0%	4%	6%	6%	6%
	40°C	0%	6%	10%	10%	11%
	60°C	0%	8%	13%	13%	14%
	95°C	0%	9%	14%	15%	16%

Table 7 Relative water and energy reduction through automatic load adjustment system B

Relative loading		100%	75%	60%	50%	30%
	declared temperature					
Relative reduction water	all temperatures	0%	12%	19%	24%	33%
Relative reduction energy	30°C	0%	5%	8%	10%	14%
	40°C	0%	8%	13%	16%	23%
	60°C	0%	10%	16%	20%	28%
	95°C	0%	11%	18%	22%	31%

Table 8 Relative water and energy reduction through automatic load adjustment system C

Relative loading		100%	75%	60%	50%	30%
	declared temperature					
Relative reduction water	all temperatures	0%	16%	25%	31%	44%
Relative reduction energy	30°C	0%	7%	11%	14%	19%
	40°C	0%	10%	17%	21%	29%
	60°C	0%	13%	21%	26%	36%
	95°C	0%	14%	23%	28%	40%

6 The further reduction of the energy demand even though the water demand is constant arises from the reduction of laundry.

2.6.4 Spin speed and drying of clothes

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 the subsequent 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.[7]

Therefore the spin speed of the washing machine plays an important role when assessing the implications of accelerated replacement of washing machines in stock. Again there is a development in time and there are differences between washing machines, that were/are on the market at the same time.

The following table shows the assumed development of the spin speed for ‘high-end-‘, ‘average’ and ‘low-end-’ washing machines on the market between 1985 and 2004.

Table 9 Spin speed of washing machines of different age and performance in rpm[8]

Year of manufacture	**Unit**	**1985**	**1990**	**1995**	**2000***	**2004***
High-end	rpm	1200	1400	1600	1600	1800
average	rpm	1000	1000	1000	1200	1400
low-end	rpm	800	800	800	1000	1000

* According to NEI (2001) there were two front loader machines with a spin speed of 1800 rpm on the German market in 2001 (rated capacity of more than 5 kg). Nevertheless it seems more realistic to assume 1600 rpm for a ‘typical’ high-end machine. Similarly there is a washing machine with a spin speed of 2000 rpm on the market in 2005. However this cannot be seen as a ‘typical’ high-end machine.

The energy demand of a condenser drier against percentage of water remaining after spin and spin speed of the washing machine is assumed according to the following table.

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7 See also Gensch/Rüdenauer 2004.

8 Own estimation based on data derived from proportion of spin speed classes in Germany and Europe between 1997 and 2002 (Europe) and 1996 and 1998 (Germany), NEI (2001), NEI (2004), information of manufacturers and own market surveys.

Table 10 Spin speed and energy demand with respect to remaining water after spin[9]

Water remaining after spin (cotton)	Unit	**70%**	**62%**	**56%**	**52%**	**49%**	**47%**
Corresponding spin speed	rpm	800	1000	1200	1400	1600	1800
Relative energy demand ('dry cotton' prog.)	%	100	90	82	77	74	71
Specific energy demand ('dry cotton' prog.)	kWh/kg	0,78	0,70	0,64	0,60	0,57	0,55
Water remaining after spin (easy to clean)[10]	Unit		**50%**				
Corresponding spin speed	rpm		1 000				
Relative energy demand ('easy to clean' prog.)	%		100				
Specific energy demand ('easy to clean' prog.)	kWh/kg		0,44				

According to subtask 2 three scenarios regarding the use of electric driers are defined:

Base case scenario:

It is assumed that a drier is used for 90 % of the laundry during the whole year (80 % cotton and 10 % easy-to-clean). During the heating period (in Germany approximately 6 months per year) the remaining 10 % ('delicates') are dried on a clothes line inside heated rooms.[11] To approximate the heating energy needed to dry this laundry, the energy demand of 'easy-to-clean' is assumed. In summer the remaining 10 % are dried on a clothes line outside heated rooms. In this case no electric or heating energy is needed.

The following figure shows for which kind of laundry which energy demand is used.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
delicates	e	e	e	n	n	n	n	n	n	e	e	e
easy-to-clean	e	e	e	e	e	e	e	e	e	e	e	e
cotton	c	c	c	c	c	c	c	c	c	c	c	c

key:

n	no additional energy needed
e	energy of 'easy-to-clean' programme
c	energy of 'dry cotton' programme

9 Stamminger 2004b, Gensch/Rüdenauer 2004

10 in case of easy-to-clean fabric in all cases the same energy demand is used.

11 for the type of fabric see below section 2.6.5

Sensitivity drier 1 (use of a drier only during the heating period)

It is assumed that a drier is used for 90 % of the laundry during the heating period. The remaining 10 % are dried on a clothes line inside heated rooms. As above the heating energy needed to dry this laundry is approximated with the energy demand of “easy-to-clean”.

During the summer all laundry is dried on a clothes line outside heated rooms. To dry this laundry no electric or heating energy is needed.

As above the following figure shows for which kind of laundry which energy demand is used.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
delicates	e	e	e	n	n	n	n	n	n	e	e	e
easy-to-clean	e	e	e	n	n	n	n	n	n	e	e	e
cotton	c	c	c	n	n	n	n	n	n	c	c	c

Sensitivity drier 2 (no use of a drier, energy demand for drying is not considered)

In this case it is assumed that no drier is used at all. Additionally all laundry is assumed to be dried on clothes lines outside heated rooms during the whole year. Thus no electric or heating energy is needed to dry the laundry.

2.6.5 Type of laundry and consumer behaviour

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

Several types of washing cycles that account for a certain amount of the laundry are derived from figures about

- the composition of the laundry,
- the use of the different washing temperatures and
- the loading of the washing machines.

(for details see Rüdenauer et al. (2004))

Table 11 shows the derived washing cycle types (specified by washing temperature and loading) and the proportion of laundry that is washed in these cycle types. With the annual amount of laundry per household[12] the annual amount of laundry and number of washing cycles for the different cycle types can be calculated.

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[12] Own calculations from IKW 2002 and ASEW (n.d.)

Table 11 Proportion, amount of laundry and number of cycles washed in different washing cycle types (in 2001)

Cycle type	**Load**	**Proportion of laundry**	**Amount of laundry …**	**Number of cycles …**
			…per cycle type and year	
95°C, full	5 kg	9%	64 kg	13
60°C, full	5 kg	34%	240 kg	48
40°C, full	5 kg	13%	90 kg	18
40°C, ¾	3,75 kg	23%	164 kg	44
30°C, full	5 kg	4%	30 kg	6
30°C, ¾	3,75 kg	5%	34 kg	9
30°C, ½	2,5 kg	10%	71 kg	28
30°C, < ½	2,5 kg	2%	14 kg	9
TOTAL		***100%***	***707 kg***	***175***

It is assumed that there are no major changes in the consumer behaviour within the regarded time span, i.e. the derived cycle types and their use by an average household of three people is regarded to be constant over the next ten years.

2.6.6 Repairs and failure rates

2.6.6.1 Repairs

GfK (2004a) gives figures about the average costs and the percentage of repairs per year.

- The average costs for all repairs between 01/2003 and 12/2003 were 114,5 Euro.
- The percentage of repairs of all regarded washing machines was 6,5 % per year.

For both figures a clear dependency on the age of the regarded machines could not be determined. Data from ServiceBarometer (2005) confirm the percentage of repairs (sample size: 17 825 people of which 16 934 (~ 95 %) own a washing machine. The total number of repairs was 2 847, of which 1 110 (39 %) were washing machines. This results in a percentage of repairs of 6,6 %).

2.6.6.2 Failure rates, average life span

According to GfK (2003) the average useful life of the previous washing machine was 12,9 years in 2003. However the life span of washing machines in households varies to a great extend depending on the year of construction and on their quality. For example more than 16 % of the washing machines in stock are older than 13 years (see GfK (2004b)). Even washing machines which are older than 25 years can be found in current households. On the other hand new washing machines of the low price level might already break down after 3 to 5 years of use (Behrendt et al. 2004).

2.6.6.3 Assumptions concerning repairs and failure rates

As reliable and consistent data on repairs (if and at what age of the washing machine) is only scarcely available and failure rates of washing machines vary to a great extend, in the first step of subtask 1 (base case) it is assumed that the washing machines in stock do not need to be repaired and do not break down within the regarded time period. This assumption is equivalent to the assumptions made in the original study.

As a second step of subtask 1 repairs are included into the calculations at different times to investigate the magnitude of their influence on the environmental and economic results.

As a further step failures instead of repairs are included into the calculations at various times to investigate the magnitude of their influence on the environmental and economic results. The specific time of the failures is chosen equivalent to that of repairs.

The following figure shows, at what time repairs/failures are assumed in the base case for the washing machines of different age.

wasching machine of ...	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
... 1985		R/F								
... 1990				R/F						
... 1995						R/F				
... 2000								R/F		
... 2004	A									

Figure 2 Assumed specific time of repairs/failures for average washing machines of different age

key:

A	**A**cquisition of a new machine
R/F	**R**epair of washing machine in stock or: **F**ailure and acquisition of a new machine

The environmental impact of an "average repair" is modelled according to the following assumptions:

- 20 km with a light van (two way drive for visits by technical service)
- production of a door gasket (930 g Ethylen-Propylen-Copolymer (EPDM)) as spare-part

The sensitivity analyses with respect to drier use (subtask 2) are calculated with the basic assumption that the washing machines in stock do not need to be repaired and do not break down within the regarded time period.

In case of the sensitivity analyses of subtask 3 (high-end, low-end machines), different times of repairs / failures are assumed (see the following figures).

Sensitivity 'high-end':

Replacement of a 'high-end' washing machine with a 'high-end' washing machine

wasching machine of ...	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
... 1985		R/F								
... 1990							R/F			
... 1995										
... 2000										
... 2004	A									

Figure 3 Assumed specific time of failures for washing machines of different age in the sensitivity analysis 'high-end with high-end'

Sensitivity 'low-end':

Replacement of a 'low-end' washing machine with a 'low-end' washing machine

wasching machine of ...	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
... 1985		R/F					R/F			
... 1990			R/F					R/F		
... 1995				R/F					R/F	
... 2000					R/F					R/F
... 2004	A					R/F				

Figure 4 Assumed specific time of failures for washing machines of different age in the sensitivity analysis 'low-end with low-end'

2.6.7 End-of-life treatment

The calculation of the end of life phase of the washing machines concentrates on the credits that can be given for material 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).

2.6.8 Energy and water supply

2.6.8.1 Water supply

As in Rüdenauer et al. (2004) the environmental impact for the supply of water is calculated according to the demand of electric energy for pumping and processing.[13] 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).

The electric energy for the supply of water is 0,76 kWh/m³ (which is in relation to the energy consumption of the washing machine itself of minor relevance).

2.6.8.2 Energy supply

The environmental impact connected to the supply of electric energy depends on the electric grid it is based on. As in Rüdenauer et al. (2004) the grid, that is basis for our calculations was defined according to the future scenarios developed by Enquete (2002).

In this study we refer to the "Referenzszenario" ("reference scenario") of Enquete (2002).

2.6.9 Cost parameters

The following costs are included in the study:

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

In case of the **acquisition costs** of the washing machines two differentiations have to be made: on the one hand cost differences between 'high-end', 'average' and 'low-end' washing machines, on the other hand the price development within the regarded time period (in case

[13] Jolliet et al. 2002.

a washing machine in stock is replaced not today but in e.g. three years time). In this study it is assumed that a fall in prices by 1 % per year takes place.

Table 12 gives an overview of the costs assumed for the washing machine types for the years 2004 to 2013.[14]

Table 12 Costs for washing machines

Year of manufacture	Unit	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
high-end	Euro	850	845	840	836	831	826	821	817	812	807
average	Euro	500	495	490	486	481	476	471	467	462	457
low-end	Euro	250	248	245	243	240	238	235	233	231	228

The average **costs for fresh water and waste water treatment** are assumed to be 4,- €/m^3 in 2004. A future increase by 2 % p.a. is assumed.[15]

The average **costs for electricity** is assumed to be 0,18 ct/kWh in 2004.[16] It is assumed that this price rises up to 0,249 in 2020.[17] In between the price is linearly interpolated.

Average **costs for repairs** are considered to be 114,5 Euro. There is no development assumed.

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.

In total a **discount rate** of 5 % is applied to calculate the cash value for the year 2004.

Residual values for the washing machine in case of its early replacement are not considered. The goal of the study is to investigate the environmental and economic consequences of an accelerated replacement of washing machines. Potential environmental savings through more efficient new machines can only be realised when old washing

14 Own research based on internet search engine, 2004.

15 Geiler 2004

16 Own compilation (in 2/2003).

17 Prognos 1999

machines are not further used in other households. Therefore in the study at hand it is assumed that the washing machines are not sold on the second-hand-market but are directly disposed (and recycled).

3 Results

The results section shows for each subtask the cumulated energy demand (CED), the global warming potential (GWP) and the costs of the 5 regarded alternatives (see 2.2) as figure and additionally the corresponding values. The time when the further use of an old washing machine is less advantageous (i.e. higher environmental impacts or higher costs) than the acquisition and use of a new one in 2004 is highlighted in the tables.

In subtask 2 and 3 the base case results are repeated to facilitate the identification of the consequences of the sensitivity analyses.

3.1 Subtask 1: General refinement of calculation model

3.1.1 Cumulated energy demand

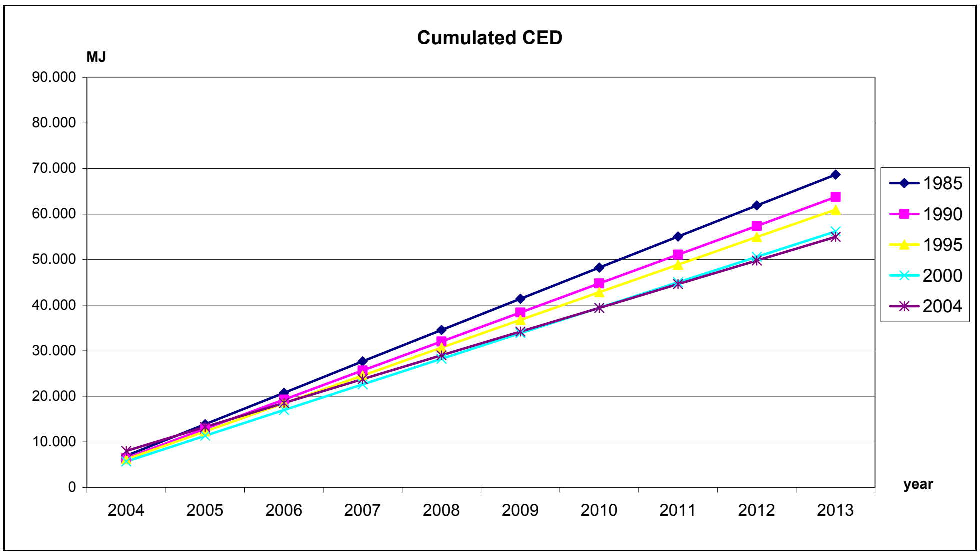

Figure 5 CED base case

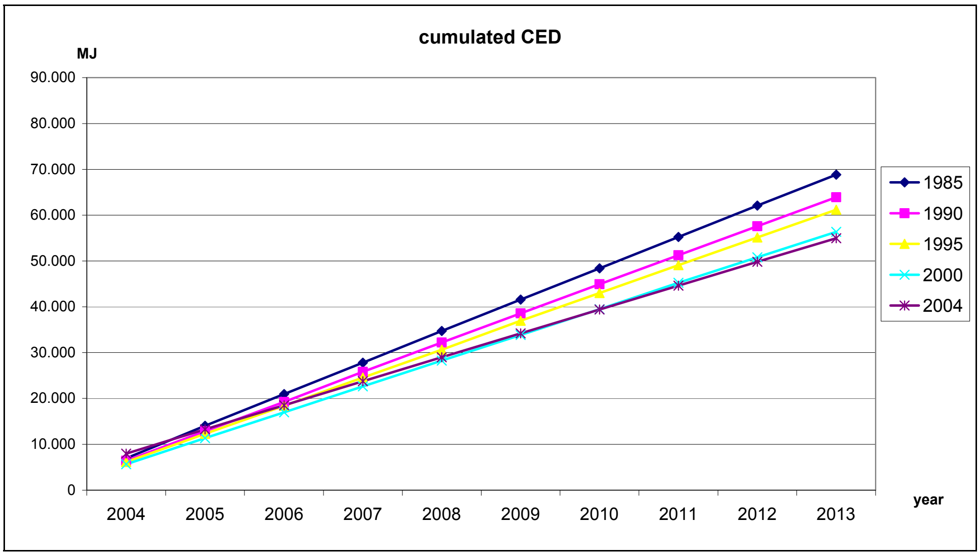

Figure 6 CED base case, incl. repairs

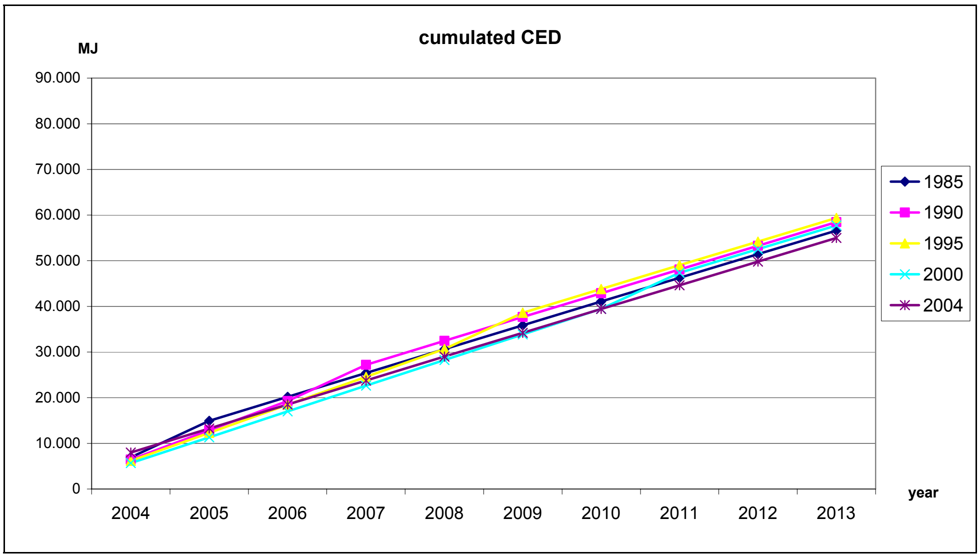

Figure 7 CED base case, incl. failures

CED (in MJ) (base case)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	6.937	**13.860**	**20.766**	**27.658**	**34.534**	**41.395**	**48.240**	**55.070**	**61.884**	**68.684**
1990	6.436	12.857	**19.264**	**25.657**	**32.036**	**38.400**	**44.750**	**51.086**	**57.408**	**63.715**
1995	6.161	12.308	18.441	**24.561**	**30.667**	**36.759**	**42.838**	**48.903**	**54.954**	**60.992**
2000	5.675	11.338	16.988	22.625	28.250	33.862	**39.462**	**45.049**	**50.624**	**56.186**
2004	7.994	13.260	18.516	23.759	28.991	34.211	39.419	44.616	49.801	54.975

CED (in MJ) (base case, incl. repairs)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	6.937	**14.037**	**20.943**	**27.835**	**34.711**	**41.572**	**48.417**	**55.247**	**62.061**	**68.861**
1990	6.436	12.857	**19.264**	**25.834**	**32.213**	**38.577**	**44.927**	**51.263**	**57.585**	**63.892**
1995	6.161	12.308	18.441	**24.561**	**30.667**	**36.936**	**43.015**	**49.080**	**55.131**	**61.169**
2000	5.675	11.338	16.988	22.625	28.250	33.862	**39.462**	**45.226**	**50.801**	**56.363**
2004	7.994	13.260	18.516	23.759	28.991	34.211	39.419	44.616	49.801	54.975

CED (in MJ) (base case, incl. failure)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	6.937	**14.919**	**20.175**	**25.418**	**30.650**	**35.870**	**41.078**	**46.275**	**51.460**	**56.633**
1990	6.436	12.857	**19.264**	**27.223**	**32.454**	**37.675**	**42.883**	**48.080**	**53.265**	**58.438**
1995	6.161	12.308	18.441	**24.561**	**30.667**	**38.602**	**43.810**	**49.007**	**54.192**	**59.365**
2000	5.675	11.338	16.988	22.625	28.250	33.862	**39.462**	**47.374**	**52.559**	**57.732**
2004	7.994	13.260	18.516	23.759	28.991	34.211	39.419	44.616	49.801	54.975

The differences between the CED of the regarded alternatives in ten years time is smaller when failures are assumed compared to the base case without failures or with consideration of repairs.

However the break-even points are not affected by the inclusion of repairs or failures. The break-even point of the washing machine of 1985 is reached already after 1 year. The break-even point of the substitution of washing machines of 1990 and 1995 is reached after 2 and 3 years respectively. In case of the washing machine of 2000 it would take 6 years.

3.1.2 Global warming potential

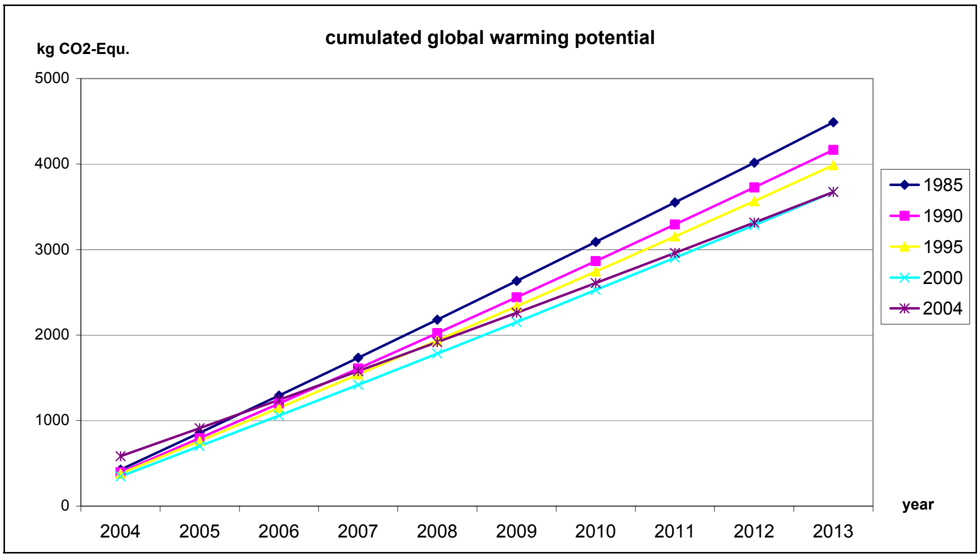

Figure 8 GWP base case

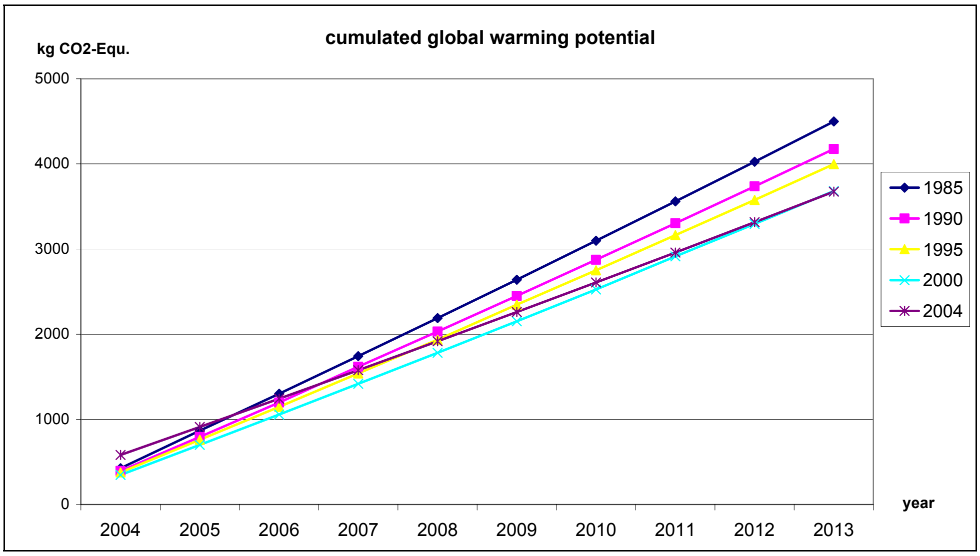

Figure 9 GWP base case with repairs

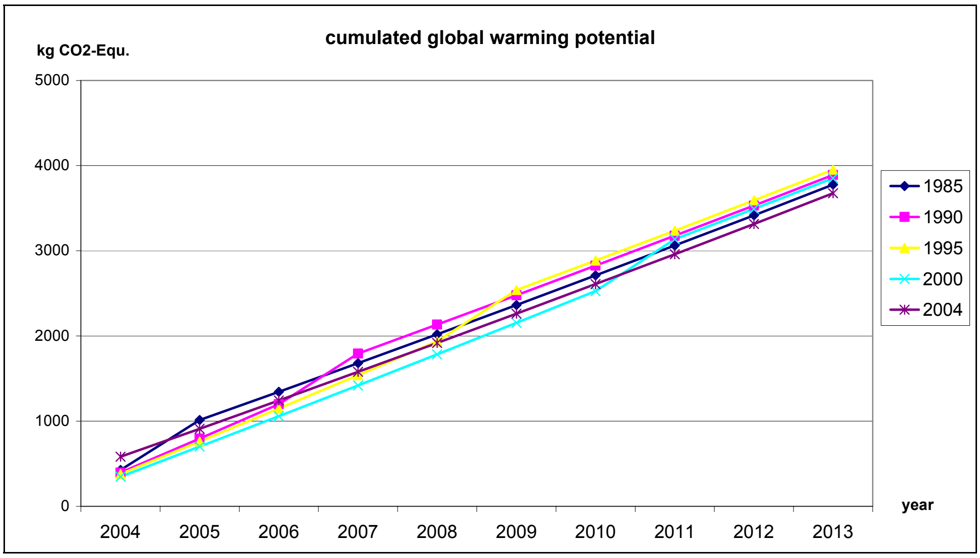

Figure 10 GWP base case with failures

GWP (in Kg CO2-Equ.) (base case)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	430	860	**1.290**	**1.730**	**2.180**	**2.630**	**3.090**	**3.550**	**4.020**	**4.490**
1990	390	790	1.200	**1.610**	**2.020**	**2.440**	**2.860**	**3.290**	**3.730**	**4.160**
1995	380	760	1.150	1.540	**1.940**	**2.340**	**2.740**	**3.150**	**3.570**	**3.990**
2000	350	700	1.060	1.420	1.780	2.150	2.530	2.900	3.290	**3.670**
2004	580	910	1.240	1.580	1.920	2.260	2.610	2.960	3.320	3.670

GWP (in Kg CO2-Equ.) (base case, incl. repairs)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	430	870	**1.300**	**1.740**	**2.190**	**2.640**	**3.100**	**3.560**	**4.030**	**4.500**
1990	390	790	1.200	**1.620**	**2.030**	**2.450**	**2.870**	**3.300**	**3.740**	**4.170**
1995	380	760	1.150	1.540	**1.940**	**2.350**	**2.750**	**3.160**	**3.580**	**4.000**
2000	350	700	1.060	1.420	1.780	2.150	2.530	2.910	3.300	**3.680**
2004	580	910	1.240	1.580	1.920	2.260	2.610	2.960	3.320	3.670

GWP (in CO2-Equ.) (base case, incl. failure)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	430	**1.010**	**1.340**	**1.680**	**2.020**	**2.360**	**2.710**	**3.060**	**3.420**	**3.780**
1990	390	790	1.200	**1.790**	**2.130**	**2.480**	**2.820**	**3.180**	**3.530**	**3.890**
1995	380	760	1.150	1.540	**1.940**	**2.540**	**2.890**	**3.240**	**3.590**	**3.950**
2000	350	700	1.060	1.420	1.780	2.150	2.530	**3.140**	**3.490**	**3.850**
2004	580	910	1.240	1.580	1.920	2.260	2.610	2.960	3.320	3.670

The GWP is also not very much affected by the consideration of repairs. However if failures are included the break-even points of the GWP are partly shifted to earlier years: 1 year in case of the 1985-machine, 2 years in case of the 2000-machine.

Regarding the base case including failures the break-even point of the washing machine of 1985 is reached already after 1 year. The break-even point of the substitution of washing machines of 1990, 1995 and 2000 is reached one year later than in case of the CED, after 3, 4 and 7 years respectively.

3.1.3 Costs

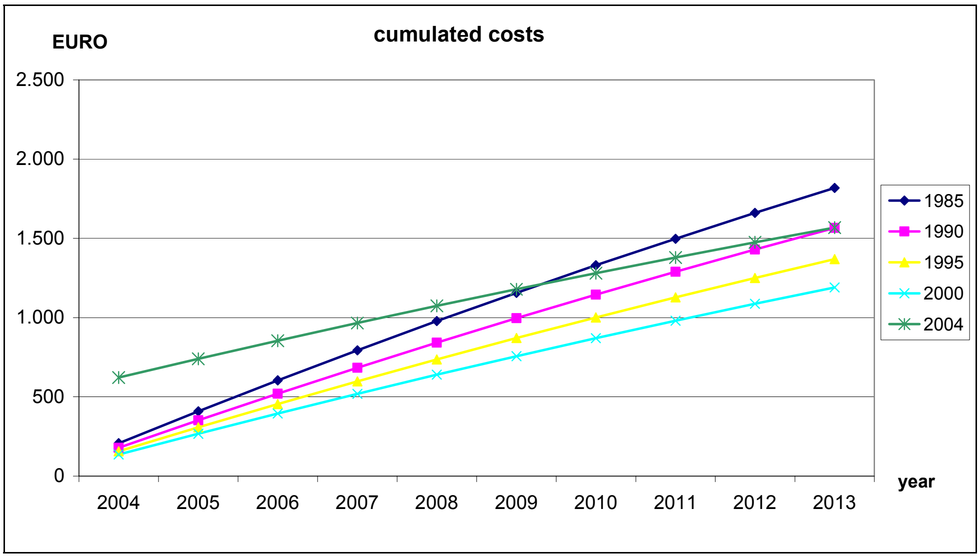

Figure 11 Costs base case

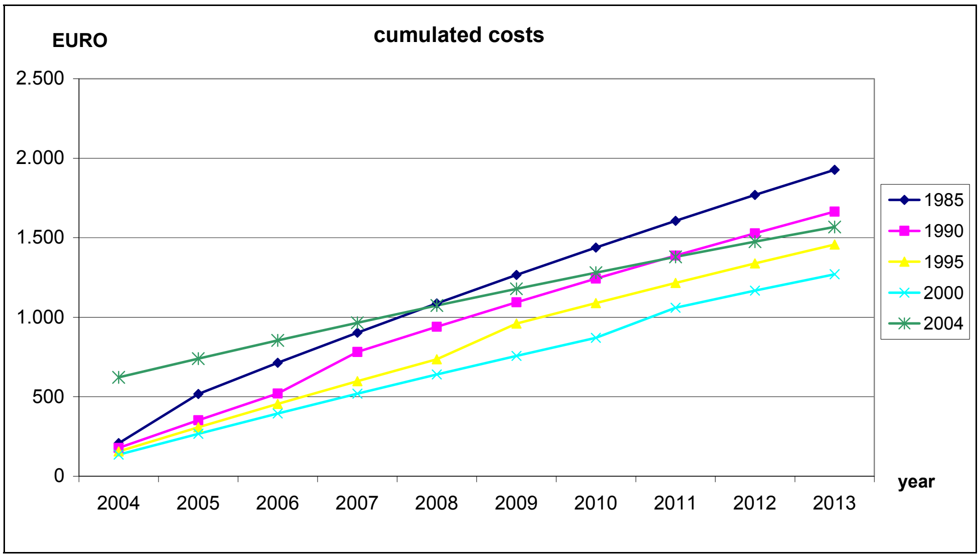

Figure 12 Costs base case with repairs

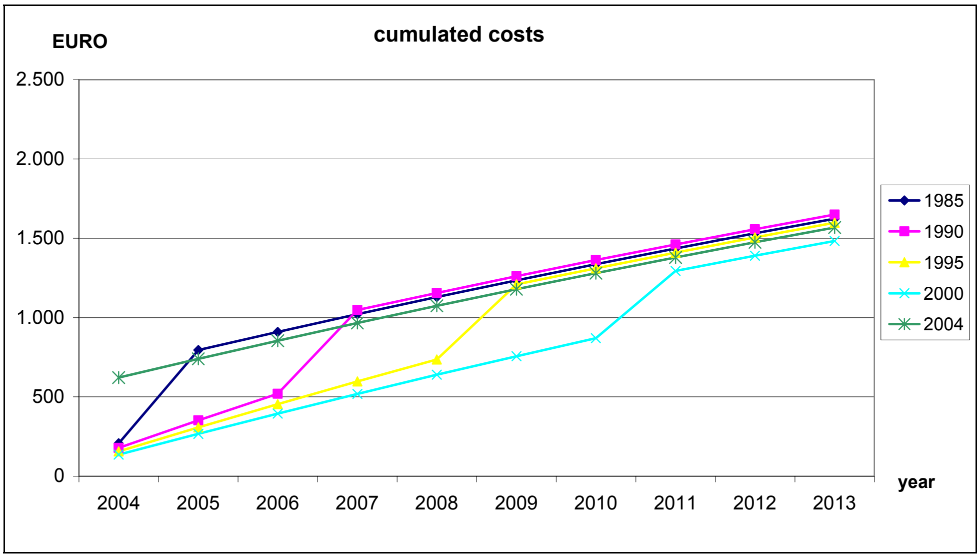

Figure 13 Costs base case with failures

Costs (in Euro) (base case)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	210	410	600	790	980	1.160	**1.330**	**1.500**	**1.660**	**1.820**
1990	180	350	520	680	840	1.000	1.140	1.290	1.430	**1.570**
1995	160	310	450	600	740	870	1.000	1.130	1.250	1.370
2000	140	270	400	520	640	760	870	980	1.090	1.190
2004	620	740	850	970	1.070	1.180	1.280	1.380	1.470	1.570

Costs in Euro (base case, incl. repairs)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	210	520	710	900	**1.090**	**1.270**	**1.440**	**1.610**	**1.770**	**1.930**
1990	180	350	520	780	940	1.090	1.240	**1.390**	**1.530**	**1.660**
1995	160	310	450	600	740	960	1.090	1.220	1.340	1.460
2000	140	270	400	520	640	760	870	1.060	1.170	1.270
2004	620	740	850	970	1.070	1.180	1.280	1.380	1.470	1.570

Costs (in Euro) (base case, incl. failure)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	210	**800**	**910**	**1.020**	**1.130**	**1.230**	**1.340**	**1.440**	**1.530**	**1.620**
1990	180	350	520	**1.050**	**1.160**	**1.260**	**1.360**	**1.460**	**1.560**	**1.650**
1995	160	310	450	600	740	**1.210**	**1.310**	**1.410**	**1.510**	**1.600**
2000	140	270	400	520	640	760	870	1.290	1.390	1.480
2004	620	740	850	970	1.070	1.180	1.280	1.380	1.470	1.570

The break-even points of the costs are later than those of the environmental impacts. The costs also show a higher sensitivity regarding both repairs and failures.

In the base case without consideration of repairs or failures only the substitution of washing machines of 1985 and 1990 show break-even points within 10 years. In case of inclusion of repairs the break-even point for the substitution of a washing machine of 1985 is reached already after 4 years (base case: 6 years) and for the substitution of a washing machine of

1990 after 8 years (base case: not reached within 10 years). Still the substitution of washing machines of 1995 and 2000 is more expensive than their further use.

In case of inclusion of potential failures the break-even points are shifted further to earlier years. For the substitution of a washing machine of 1985 it is reached after already 1 year, of a washing machine of 1990 after 3 years and of a washing machine of 1995 after 5 years. Only in case of the machine of 2000 it is not reached within 10 years time.

3.2 Subtask 2: Influence of inclusion of drier

To see the difference between the base case scenario and the two sensitivity analyses regarding the use of driers, the figures and values of the CED, the GWP and the costs of the base case are repeated here, in direct connection with the figures and values of the CED, the GWP and the costs of the sensitivity analyses.

Sensitivity drier 1: use of a drier only during the heating period

Sensitivity drier 2: no use of a drier, energy demand for drying is not considered

3.2.1 Cumulated energy demand

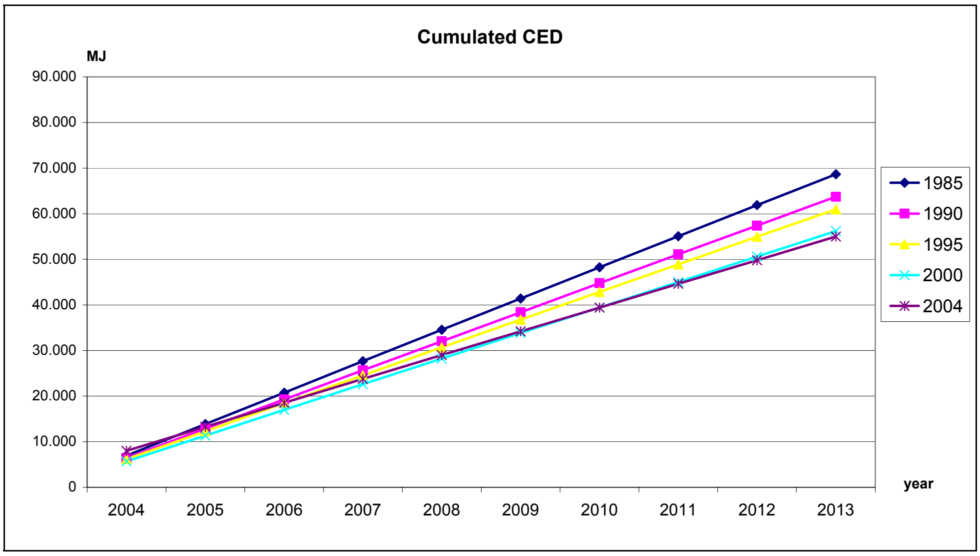

Figure 14 CED base case

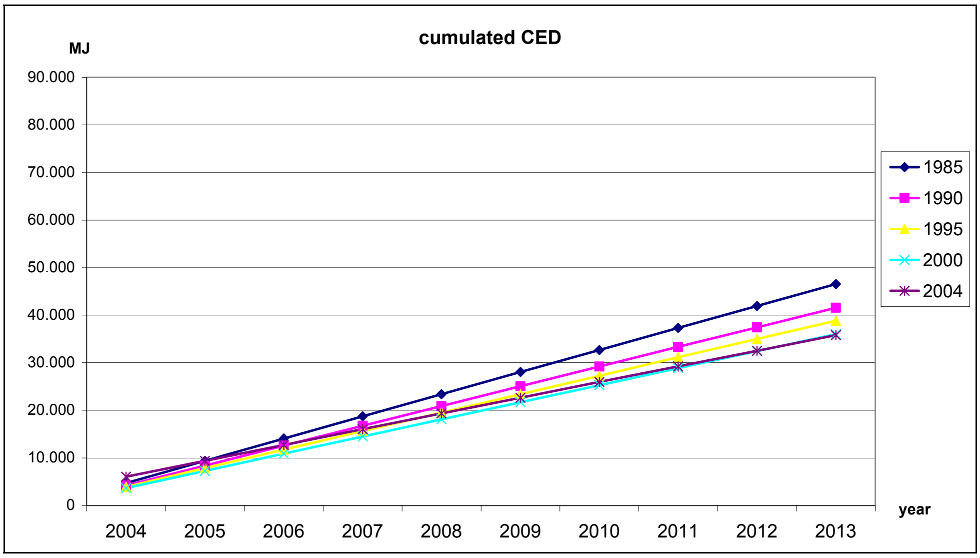

Figure 15 CED sensitivity 'drier 1', use of a drier only during the heating period

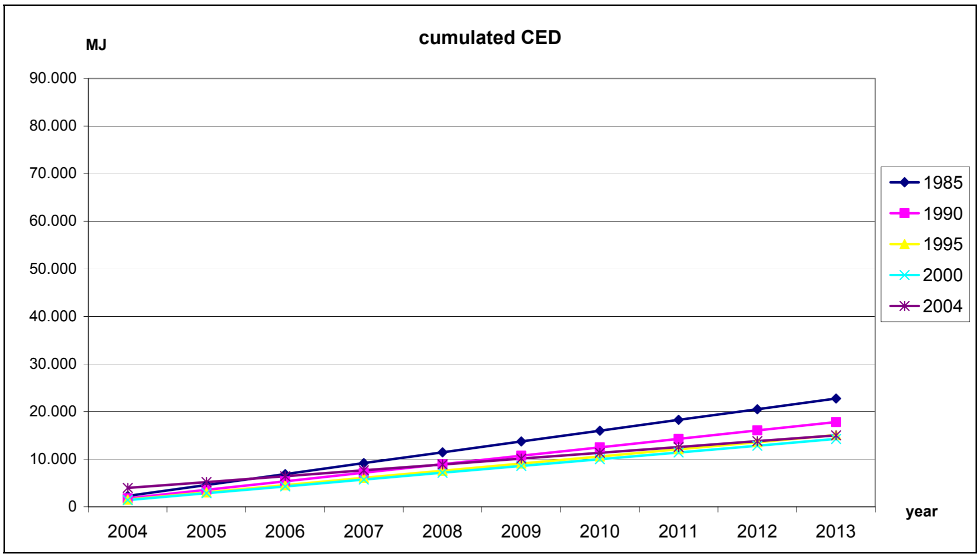

Figure 16 CED sensitivity 'drier 2', no use of a drier, energy demand for drying is not considered

CED (in MJ) (base case)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	6.937	**13.860**	**20.766**	**27.658**	**34.534**	**41.395**	**48.240**	**55.070**	**61.884**	**68.684**
1990	6.436	12.857	**19.264**	**25.657**	**32.036**	**38.400**	**44.750**	**51.086**	**57.408**	**63.715**
1995	6.161	12.308	18.441	**24.561**	**30.667**	**36.759**	**42.838**	**48.903**	**54.954**	**60.992**
2000	5.675	11.338	16.988	22.625	28.250	33.862	**39.462**	**45.049**	**50.624**	**56.186**
2004	7.994	13.260	18.516	23.759	28.991	34.211	39.419	44.616	49.801	54.975

CED (in MJ) (sensitivity, drier 1)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	4.700	9.390	**14.070**	**18.739**	**23.398**	**28.046**	**32.684**	**37.312**	**41.929**	**46.536**
1990	4.199	8.388	12.568	**16.738**	**20.900**	**25.052**	**29.194**	**33.328**	**37.452**	**41.567**
1995	3.923	7.838	11.744	15.642	**19.531**	**23.411**	**27.282**	**31.145**	**34.999**	**38.844**
2000	3.638	7.269	10.891	14.506	18.112	21.710	25.300	28.882	32.456	**36.022**
2004	6.057	9.392	12.719	16.039	19.351	22.656	25.954	29.244	32.527	35.803

CED (in MJ) (sensitivity, drier 2)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	2.301	4.597	**6.888**	**9.174**	**11.455**	**13.731**	**16.001**	**18.267**	**20.527**	**22.783**
1990	1.799	3.595	5.386	7.173	**8.957**	**10.736**	**12.512**	**14.283**	**16.050**	**17.814**
1995	1.524	3.045	4.563	6.077	7.588	9.095	10.599	12.100	13.597	**15.091**
2000	1.440	2.876	4.310	5.740	7.167	8.590	10.011	11.428	12.843	14.254
2004	3.959	5.199	6.437	7.673	8.905	10.135	11.362	12.586	13.807	15.026

3.2.2 Global warming potential

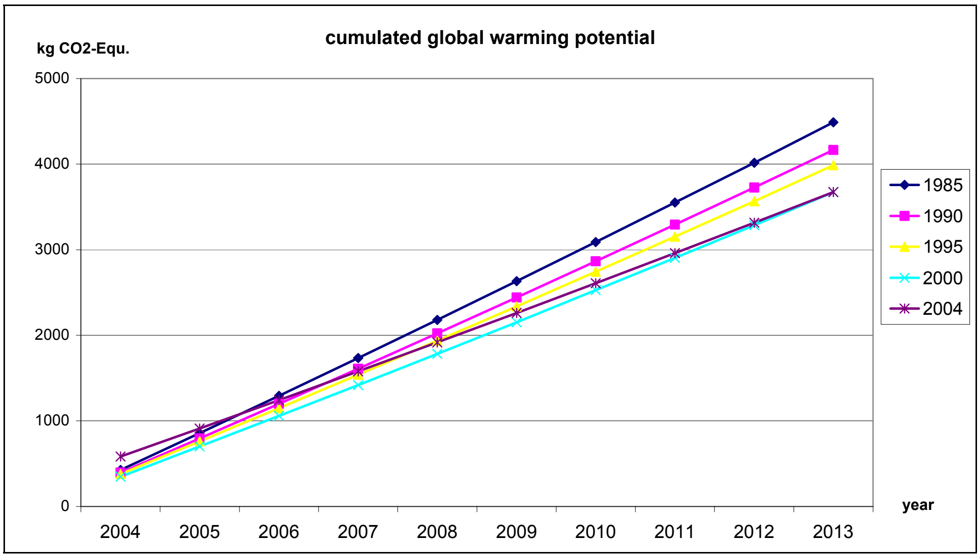

Figure 17 GWP base case

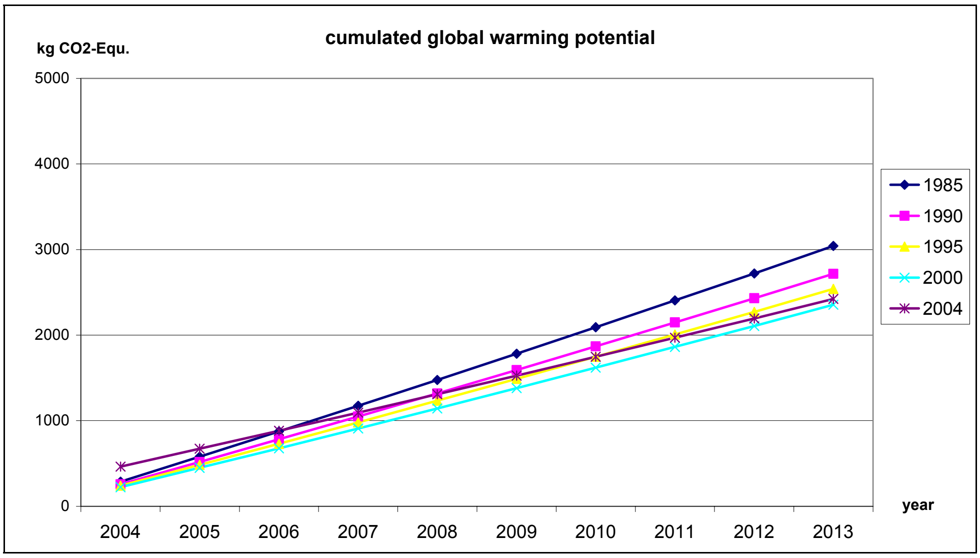

Figure 18 GWP sensitivity ‘drier 1’, use of a drier only during the heating period

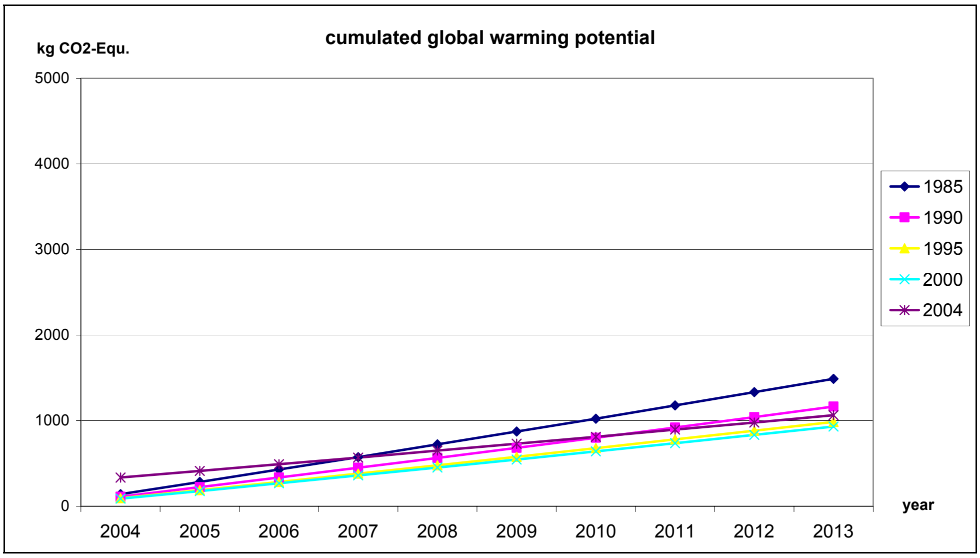

Figure 19 GWP sensitivity ‘drier 2’, no use of a drier, energy demand for drying is not considered

GWP (in Kg CO2-Equ.) (base case)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	430	860	**1.290**	**1.730**	**2.180**	**2.630**	**3.090**	**3.550**	**4.020**	**4.490**
1990	390	790	1.200	**1.610**	**2.020**	**2.440**	**2.860**	**3.290**	**3.730**	**4.160**
1995	380	760	1.150	1.540	**1.940**	**2.340**	**2.740**	**3.150**	**3.570**	**3.990**
2000	350	700	1.060	1.420	1.780	2.150	2.530	2.900	3.290	**3.670**
2004	580	910	1.240	1.580	1.920	2.260	2.610	2.960	3.320	3.670

GWP (in CO2-Equ.) (sensitivity, drier 1)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	290	580	**880**	**1.170**	**1.480**	**1.780**	**2.090**	**2.410**	**2.720**	**3.040**
1990	260	520	780	1.050	**1.320**	**1.590**	**1.870**	**2.150**	**2.430**	**2.720**
1995	240	480	730	980	1.230	1.490	**1.750**	**2.010**	**2.270**	**2.540**
2000	220	450	680	910	1.140	1.380	1.620	1.860	2.110	2.350
2004	460	670	880	1.090	1.310	1.530	1.750	1.970	2.190	2.420

GWP (in CO2-Equ.) (sensitivity drier 2)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	140	280	430	**580**	**720**	**870**	**1.020**	**1.180**	**1.330**	**1.490**
1990	110	220	340	450	570	680	800	**920**	**1.040**	**1.160**
1995	90	190	280	380	480	580	680	780	880	990
2000	90	180	270	360	450	550	640	740	830	930
2004	340	410	490	570	650	730	810	900	980	1.060

Comparing the figures, it can be seen that both the total CED and the total GWP are much lower if the drying process is not included in the calculation.

Regarding the corresponding break-even points, it can be seen that the break even points are reached earlier if driers are considered.

In case of no energy demand for the drying process is considered (sensitivity “drier 2”), the substitution of washing machines of 1995 and 2000 doesn’t amortize within 10 years. The break-even point in case of the substitution of the 1990-machine is reached after 7 years, that of the 1985-machine already after 3 years.

If it is assumed that a drier is used during the heating period the break-even point of the 1985-machine is reached 1 year earlier. That of the 1990-machine is reached 3 years earlier and even for the 1995-machine the substitution amortizes after 6 years.

If it is assumed that driers are used during the whole year, the break-even points of the 1990- and 1995-machine are additionally shifted 1 or 2 years respectively to earlier times. Even in case of the 2000-machine the break even point is reached after 9 years.

Please not that if clothes are not dried within a tumble drier but on a clothes line within heated rooms at least during the heating period additional energy is necessary. This is usually supplied by the space heating system. However the amount of energy needed is difficult to be quantified.[18]

3.2.3 Costs

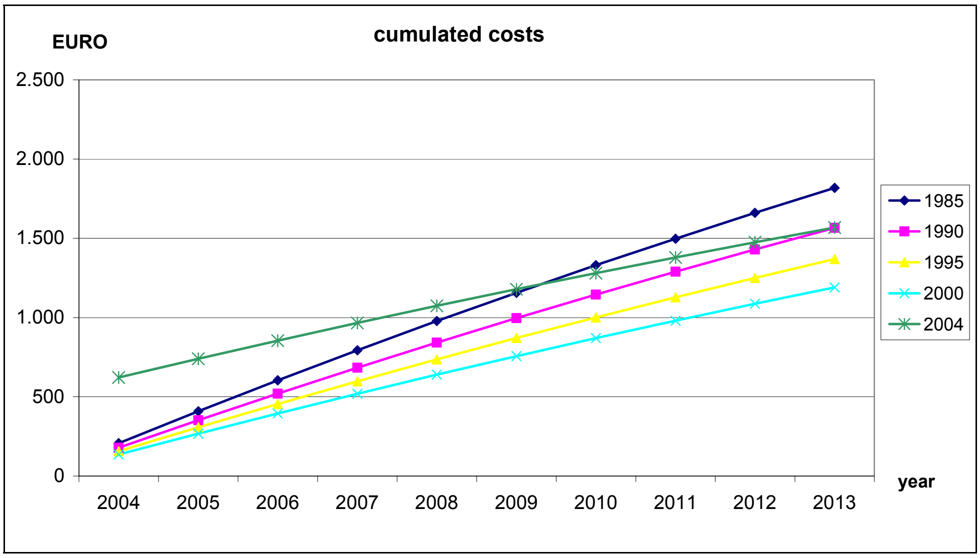

Figure 20 Costs base case

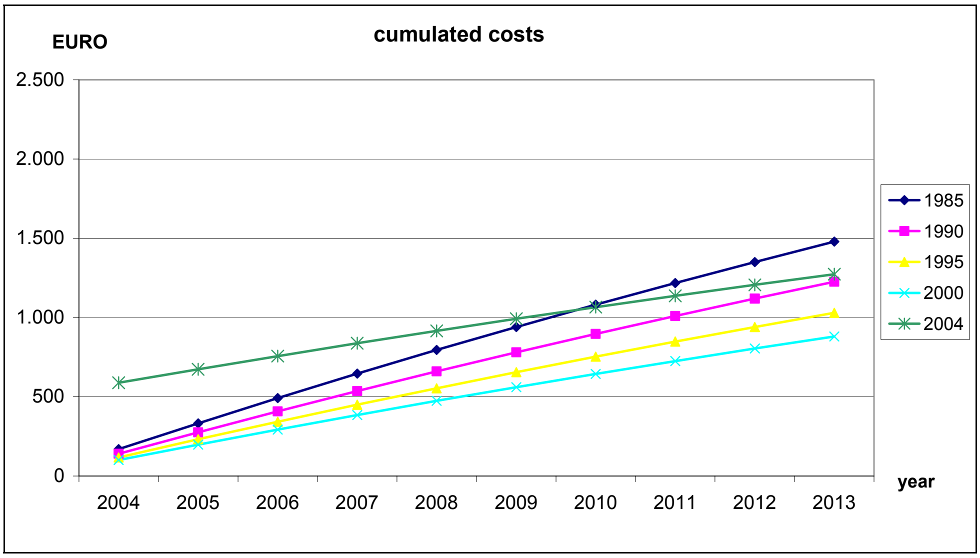

Figure 21 Costs sensitivity ‘drier 1’, use of a drier only during the heating period

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[18] See also Gensch/Rüdenauer 2004 and Rüdenauer/Gensch 2004.

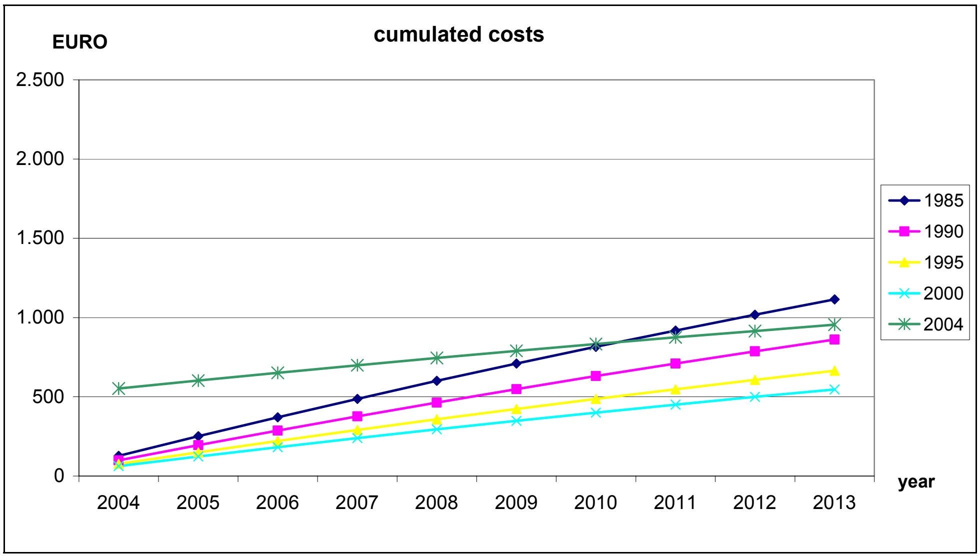

Figure 22 Costs sensitivity ‘drier 2’, no use of a drier, energy demand for drying is not considered

Costs (in Euro) (base case)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	210	410	600	790	980	1.160	**1.330**	**1.500**	**1.660**	**1.820**
1990	180	350	520	680	840	1.000	1.140	1.290	1.430	**1.570**
1995	160	310	450	600	740	870	1.000	1.130	1.250	1.370
2000	140	270	400	520	640	760	870	980	1.090	1.190
2004	620	740	850	970	1.070	1.180	1.280	1.380	1.470	1.570
Costs (in Euro) (sensitivity, drier 1)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	170	330	490	650	800	940	**1.080**	**1.220**	**1.350**	**1.480**
1990	140	280	410	540	660	780	900	1.010	1.120	1.230
1995	120	230	340	450	550	650	750	850	940	1.030
2000	100	200	290	380	470	560	640	730	800	880
2004	590	670	760	840	920	990	1.070	1.140	1.210	1.270
Costs (in Euro) (sensitivity drier 2)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	130	250	370	490	600	710	820	**920**	**1.020**	**1.110**
1990	100	190	290	380	460	550	630	710	790	860
1995	80	150	220	290	360	420	490	550	610	660
2000	60	120	180	240	290	350	400	450	500	550
2004	550	600	650	700	740	790	830	870	920	950

Like with the environmental indicators the costs are lower when driers are not included and the break-even points are (slightly) shifted to later times.

If it is assumed that driers are used during the whole year, the break-even point in case of the substitution of the 1990-machine is reached after 9 years, that of the 1985-machine already after 6 years.

If it is assumed that a drier is used during the heating period (sensitivity “drier 1”), the break-even point of the 1990-machine is not reached within 10 years anymore.

In case of no energy demand for the drying process is considered (sensitivity “drier 2”), additionally the break-even point of the 1995-machine are shifted 1 year to later times.

3.3 Subtask 3: “high-end-machines” and “low-end-machines”

To compare the results of the sensitivity analyses with those of the base case (including failures) the figures of the CED the GWP and the costs of the base case are repeated here. First the results of “low-end with low-end”, then the base case (= “average with average”) and finally the results of “high-end with high-end” are shown.

3.3.1 Cumulated energy demand

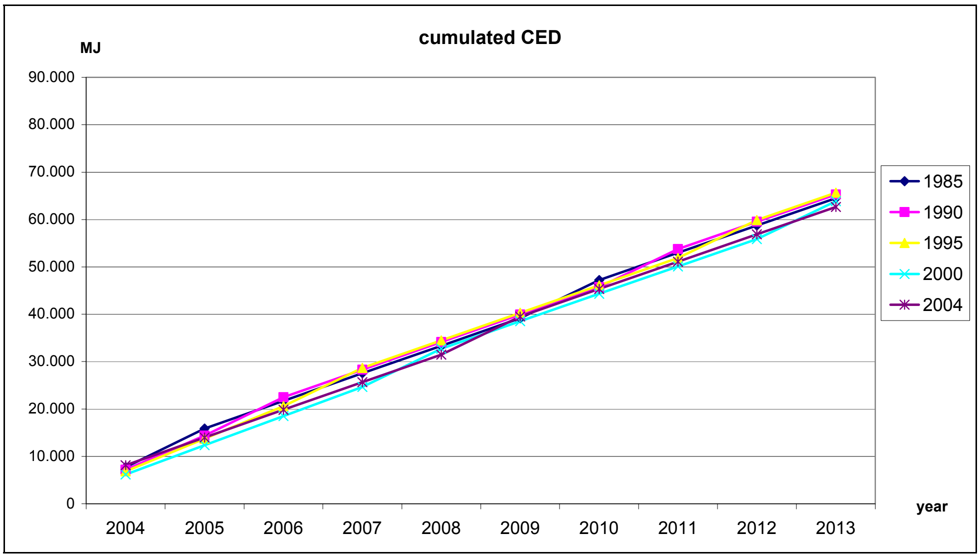

Figure 23 CED of sensitivity ‘low-end’ with ‘low-end’

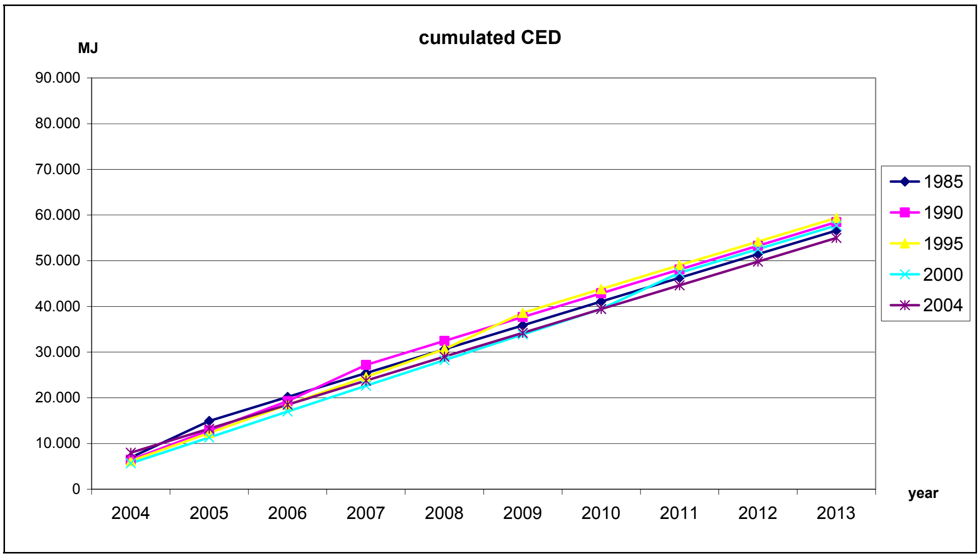

Figure 24 CED base case with failures

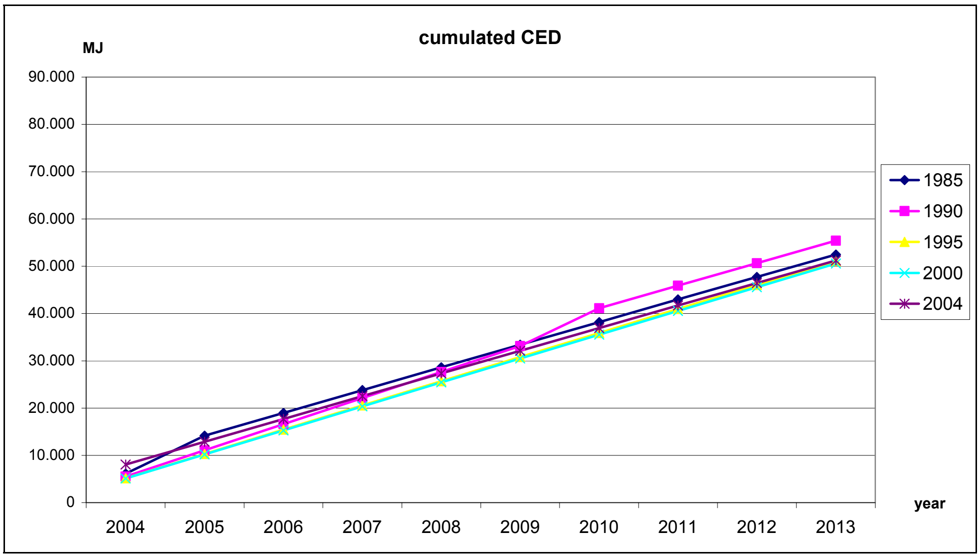

Figure 25 CED of sensitivity ‘high-end’ with ‘high-end’

CED (in MJ) (sensitivity 'low with low')										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	7.756	**15.874**	**21.716**	**27.546**	**33.362**	**39.165**	**47.218**	**52.995**	**58.759**	**64.511**
1990	7.204	**14.392**	**22.497**	**28.326**	**34.142**	**39.946**	**45.736**	**53.776**	**59.540**	**65.291**
1995	6.879	13.743	**20.592**	**28.684**	**34.500**	**40.304**	**46.094**	**51.871**	**59.898**	**65.649**
2000	6.182	12.351	18.505	24.647	**32.725**	38.529	44.319	50.096	55.860	**63.874**
2004	8.131	13.986	19.828	25.657	31.474	39.539	45.330	51.107	56.871	62.622

CED (in MJ) (base case, incl. failure)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	6.937	**14.919**	**20.175**	**25.418**	**30.650**	**35.870**	**41.078**	**46.275**	**51.460**	**56.633**
1990	6.436	12.857	**19.264**	**27.223**	**32.454**	**37.675**	**42.883**	**48.080**	**53.265**	**58.438**
1995	6.161	12.308	18.441	**24.561**	**30.667**	**38.602**	**43.810**	**49.007**	**54.192**	**59.365**
2000	5.675	11.338	16.988	22.625	28.250	33.862	**39.462**	**47.374**	**52.559**	**57.732**
2004	7.994	13.260	18.516	23.759	28.991	34.211	39.419	44.616	49.801	54.975

CED (in MJ) (sensitivity 'high with high')										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	6.121	**14.163**	**18.992**	**23.810**	**28.617**	**33.414**	**38.200**	**42.975**	**47.740**	**52.494**
1990	5.553	11.095	16.623	22.140	**27.644**	**33.136**	**41.123**	**45.899**	**50.663**	**55.417**
1995	5.160	10.309	15.446	20.572	25.686	30.789	35.881	40.961	46.029	51.087
2000	5.109	10.208	15.294	20.370	25.434	30.487	35.528	40.559	45.577	50.585
2004	8.052	12.892	17.721	22.539	27.346	32.143	36.929	41.704	46.469	51.223

3.3.2 Global warming potential

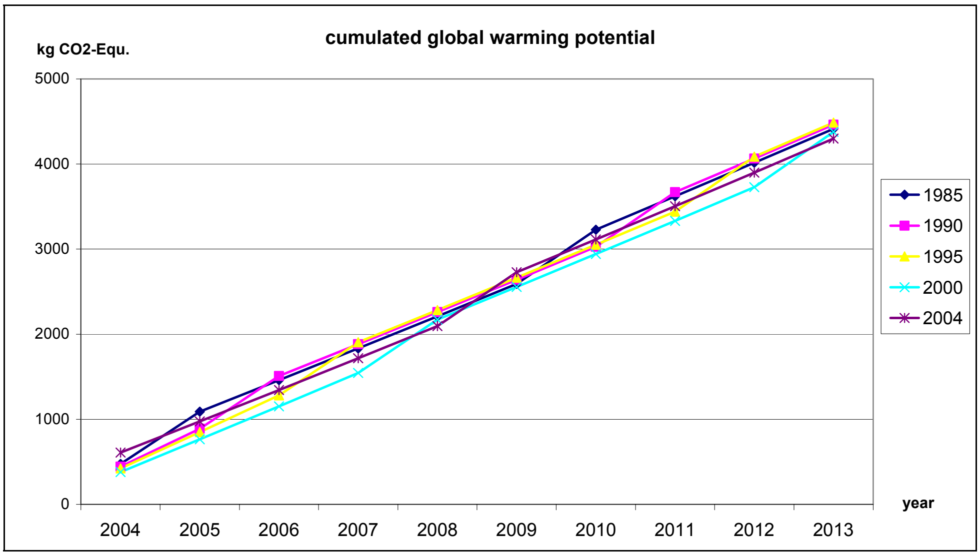

Figure 26 GWP of sensitivity ‘low-end’ with ‘low-end’

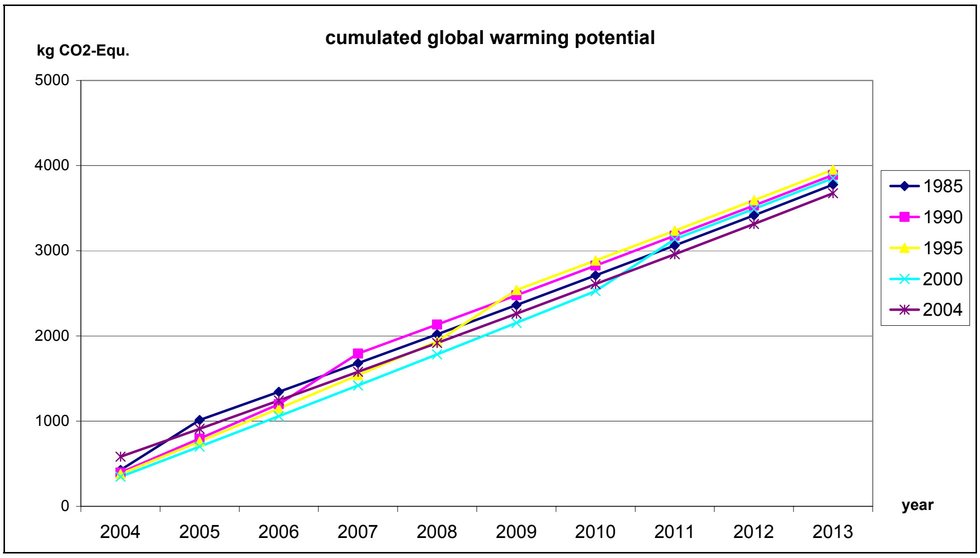

Figure 27 GWP base case with failures

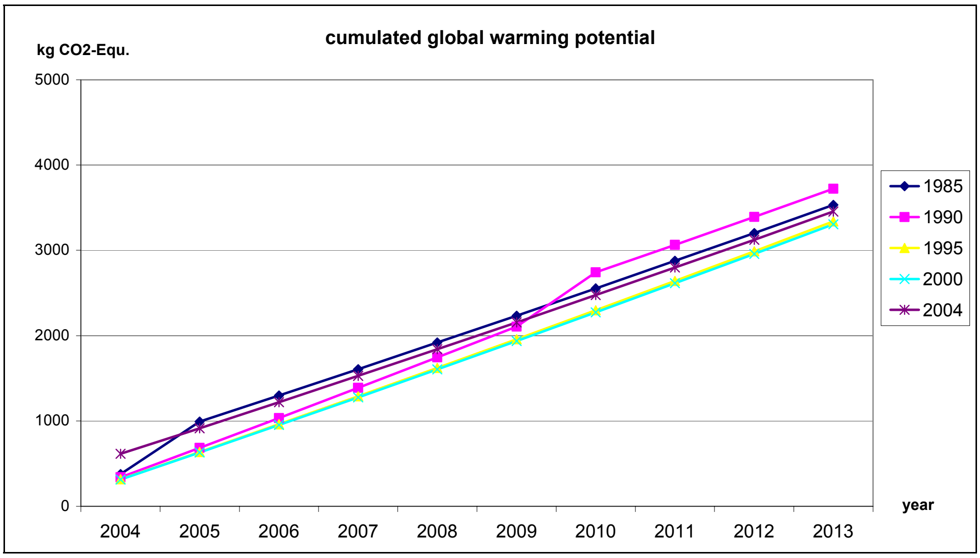

Figure 28 GWP of sensitivity 'high-end' with 'high-end'

GWP (in CO2-Equ.) (sensitivity 'low with low')										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	480	**1.090**	**1.460**	**1.830**	**2.210**	2.590	**3.230**	**3.620**	**4.020**	**4.410**
1990	440	890	**1.510**	**1.880**	**2.260**	2.640	3.030	**3.670**	**4.060**	**4.460**
1995	420	850	1.280	**1.910**	**2.280**	2.660	3.050	3.440	**4.090**	**4.490**
2000	380	760	1.150	1.540	2.170	2.560	2.940	3.330	3.730	**4.380**
2004	610	980	1.340	1.720	2.090	2.730	3.110	3.500	3.900	4.300

GWP (in CO2-Equ.) (base case, incl. failure)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	430	**1.010**	**1.340**	**1.680**	**2.020**	**2.360**	**2.710**	**3.060**	**3.420**	**3.780**
1990	390	790	1.200	**1.790**	**2.130**	**2.480**	**2.820**	**3.180**	**3.530**	**3.890**
1995	380	760	1.150	1.540	**1.940**	**2.540**	**2.890**	**3.240**	**3.590**	**3.950**
2000	350	700	1.060	1.420	1.780	2.150	2.530	**3.140**	**3.490**	**3.850**
2004	580	910	1.240	1.580	1.920	2.260	2.610	2.960	3.320	3.670

GWP (in CO2-Equ.) (sensitivity 'high with high')										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	380	**990**	**1.300**	**1.610**	**1.920**	**2.230**	**2.550**	**2.880**	**3.200**	**3.530**
1990	340	690	1.030	1.390	1.750	2.110	**2.740**	**3.060**	**3.390**	**3.720**
1995	320	640	960	1.290	1.620	1.960	2.300	2.640	2.990	3.340
2000	310	630	950	1.280	1.610	1.940	2.270	2.610	2.960	3.310
2004	610	920	1.220	1.530	1.840	2.160	2.480	2.800	3.120	3.460

Taking into consideration deviations from the average energy and water consumption figures (base case assumptions) the following results can be seen.

The development of the CED and the GWP within the next 10 years doesn’t show very big differences between the alternatives.

However the break-even point for the replacement of the washing machine of 1985 is reached in all three cases after 1 year.

When comparing the three scenarios it can be seen that the break-even points are shifted to later times when going from “low-end” via “average” to “high-end”. In case of the low-end machines, when the “new” machine of 2004 has to be replaced in 2009 again, the GWP rises again above the GWP of the other alternatives. In case of the “high-end” machines, for machines of 1995 and 2000 the break-even points are not reached within the regarded time period of ten years.

3.3.3 Costs

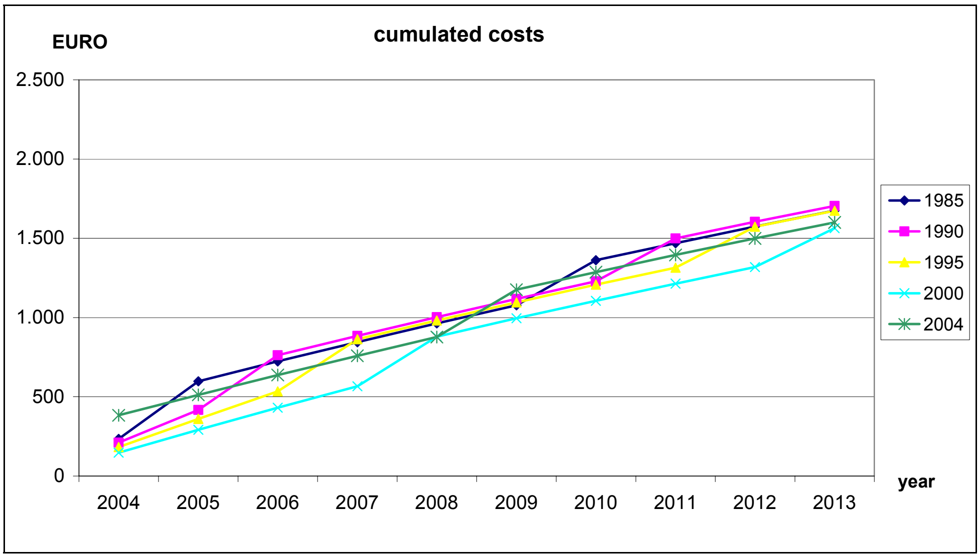

Figure 29 costs of sensitivity ‘low-end’ with ‘low-end’

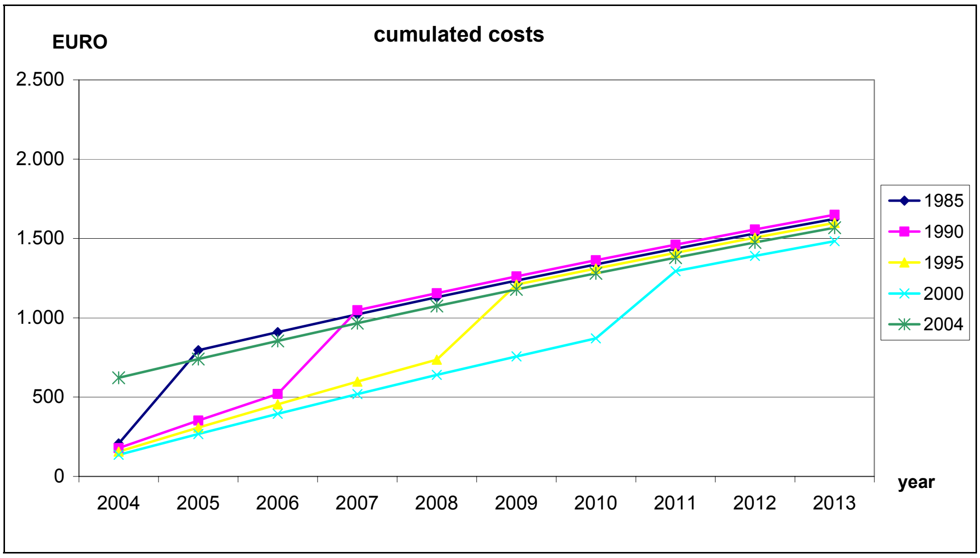

Figure 30 costs base case with failures

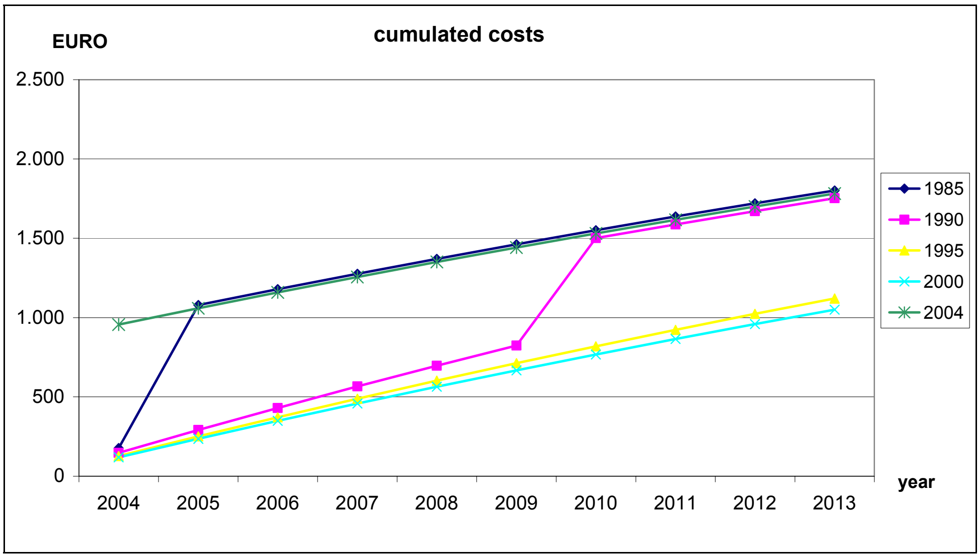

Figure 31 costs of sensitivity 'high-end' with 'high-end'

costs (in Euro) (sensitivity 'low with low')										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	230	**600**	**720**	**840**	**960**	1.080	**1.360**	**1.470**	**1.570**	**1.680**
1990	210	420	**760**	**880**	**1.000**	1.120	1.230	**1.500**	**1.600**	**1.700**
1995	180	360	530	**860**	**980**	1.100	1.210	1.310	**1.570**	**1.670**
2000	150	290	430	570	**880**	990	1.110	1.210	1.320	1.560
2004	380	510	640	760	880	1.180	1.290	1.390	1.500	1.600

Costs (in Euro) (base case, incl. failure)										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	210	**800**	**910**	**1.020**	**1.130**	**1.230**	**1.340**	**1.440**	**1.530**	**1.620**
1990	180	350	520	**1.050**	**1.160**	**1.260**	**1.360**	**1.460**	**1.560**	**1.650**
1995	160	310	450	600	740	**1.210**	**1.310**	**1.410**	**1.510**	**1.600**
2000	140	270	400	520	640	760	870	1.290	1.390	1.480
2004	620	740	850	970	1.070	1.180	1.280	1.380	1.470	1.570

costs (in Euro) (sensitivity 'high with high')										
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
1985	180	**1.080**	**1.180**	**1.280**	**1.370**	**1.460**	**1.550**	**1.640**	**1.720**	**1.800**
1990	150	290	430	570	700	820	1.500	1.590	1.670	1.750
1995	130	250	370	490	600	710	820	920	1.020	1.120
2000	120	240	350	460	560	670	770	860	960	1.050
2004	960	1.060	1.160	1.260	1.350	1.440	1.530	1.620	1.700	1.780

The development of the costs shows a bigger difference between the alternatives than the environmental indicator results. However especially for low end and average machines cumulated costs after 10 years don't differ to a great extend. The maximum difference in 2013 between the costs of the low-end alternatives is 140,- € (approximately 8 % of maximum costs). For the average alternatives the maximum difference between the alternatives is 170,- € (10 %).

For the costs the same tendency as for the GWP can be seen: the break-even points are shifted to later years when going from “low-end” via “average” to “high-end”. Again in the low-end scenario the costs of the 2004-alternative rise above the costs of the other alternatives when in 2009 the formerly new machine is replaced again.

4 Conclusions

The conclusions which were drawn in the "base study" with respect to task 4 are repeated here (in italics). Then the differences and further conclusions resulting from this refinement are outlined.

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.*

Inclusion of repairs and failures (Subtask 1)

- It is not clear at what point in time repairs or failures occur. But it is quite sure that there will be repairs or failures at least in case of low-end and average machines.

- When including repairs there is practically no difference regarding the CED and the GWP compared to the base case. Regarding the costs the break-even points of the 1985- and the 1990-machine are two years earlier compared to the base case.
- In case of failures on the one hand the break-even points of the GWP and the costs are shifted to earlier years, but on the other hand the final differences of the cumulated CED, GWP and costs after the whole ten years are smaller than in the base case. This results from the fact, that the water and energy consumption after failure and replacement is as low as if the machine is replaced immediately (in 2004). For the costs the shift of the break-even points to earlier years is the most obvious.

Inclusion/Exclusion of the use of driers

- When driers are used only during the heating period (sensitivity analysis “drier 1”) or no energy demand for drying is not considered (sensitivity analysis “drier 2”) the absolute figures of CED, GWP and the costs are significantly lower.
- In both sensitivity analyses, the break-even points are shifted to later years. This results from the fact that there is an additional reduction potential in the field of energy demand of drying of clothes through the replacement of older washing machines with presumably lower spin speeds. This is not considered when the energy demand for drying of clothes is not included in the calculations.
- With regard to the results of sensitivity analysis “drier 2” (no use of a drier, energy demand for drying is not considered) it has to be kept in mind, that if clothes are not dried within a tumble drier but on a clothes line within heated rooms, at least during the heating period additional energy is necessary. This is usually supplied by the space heating system. However the amount of energy needed is difficult to be quantified and therefore not included in the calculations of the sensitivity analysis “drier 2”..[19]

Sensitivity analyses high-end-machines and low-end-machines

- As these sensitivity analyses consider failures, as in the base case calculation (including failures) the final differences of the cumulated CED, GWP and costs after ten years are relatively small.
- However it can be seen that the break-even points are earlier in case of the “low-end” machines and later in case of the “high-end” machine compared to the average machines.

[19] See also Gensch/Rüdenauer 2004 and Rüdenauer/Gensch 2004.

- The differences in the development of the costs of the alternatives are bigger than the environmental differences. However especially for low-end and average machines the cumulated costs after 10 years show only minor differences. For example the largest cost difference in case of the “low-end” machines is 100,-€ in 10 years, which means an 8 % reduction compared to the highest costs.
- The differences might be more distinct if a “low-end” machine is replaced by an average or a “high-end” machine.

5 References

ASEW (n.d.)	ASEW - Arbeitsgemeinschaft für sparsame Energie- und Wasserverwendung im VKU, www.asew.de.
Behrendt et al. 2004	Behrendt, S.; Erdmann, L.; Baldas, O.; Wolfrum, K.; Ökologische Optimierung von Gebrauchtgeräten. Entwicklung von technischen Lösungen zur energieeffizienten Aufrüstung von gebrauchten Waschmaschinen. Berlin, 2004.
Enquete 2002	Enquete-Kommission "Nachhaltige Energieversorgung unter den Bedingungen der Globalisierung und der Liberalisierung" Deutscher Bundestag. Drucksache 14/9400; Berlin 2. Juli 2002.
Geiler 2004	„Einflussfaktoren auf die künftige Wasserpreis- und Abwassergebührenentwicklung“, expertise by Nik Geiler (Working Group “Water” of BBU (Bundesverband Bürgerinitiativen im Umweltschutz)), Freiburg 2004.
Gensch/Rüdenauer 2004	Gensch, C.-O. und I. Rüdenauer; Ökologische und ökonomische Betrachtung von Wäschetrocknungssystemen; in: Hauswirtschaft und Wissenschaft (HuW), Aachen 1/2004, 12 –19.
GfK 2000	GfK Marketing Services (ed,); Daten zum Verkauf und Energieverbrauch elektrischer Haushaltsgroßgeräte in Deutschland. Nürnberg 2000.
GfK 2001	Henkel, Wäschetagebuch, conducted by ‘GfK Marktforschung’ from middle of August to beginning of October 2001 (confidential data)
GfK 2003	GfK Panel Services; MDA Presentation Consumer Panel D, Year 2003
GfK 2004a	GfK Electro*Scope; Consumer-Panel Deutschland; ELECTRO SERVICE BAROMETER; ZEITRAUM: 2003-06/2004
GfK 2004b	GfK Electro*Scope; Ba-National 2004; 01.01.2004; ‚Bestand nach Anschaffungsjahren’
IKW 2002	IKW (ed.); „Informationsserie Wasch- und Reinigungsmittel“, April 2002.
Jolliet et al. 2002	Jolliet, O.; Brugger-Bronchi, V.; Crettaz, P.; Lopes, P.-M.; Ökobilanz von Trinkwasserversorgung und Regenwassernutzung. BUWAL (ed.): Umweltmaterialien 147 Wasserversorgung. Bundesamt für Umwelt, Wald und Landschaft; Bern 2002.
Miele 2005	Technical data by Miele & Cie. GmbH & Co., February 2005
NEI 2001	Data base of domestic appliances of Niedrig-Energie-Instituts (NEI), 5/2001; Detmold 2001.
NEI 2004	Data base of domestic appliances of Niedrig-Energie-Instituts (NEI), 2004; Detmold 2004.
Prognos 1999	Prognos; EWI. Die längerfristige Entwicklung der Energiemärkte im Zeichen von Wettbewerb und Umwelt. Im Auftrag des Bundesministers für Wirtschaft. Basel/Köln 1999.

Rüdenauer et al. 2004	Rüdenauer, I.; Gensch, C.-O.; Quack, D.; Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span. Freiburg 2004.
Rüdenauer/Gensch 2004	Rüdenauer, I.; Gensch, C.-O.; Energy demand of tumble driers with respect to differences in technology and ambient conditions. Freiburg 2004
Schlomann et al. 2001	Schlomann, B.; Eichhammer, W.; Gruber, E.; Kling, N.; Mannsbart, W.; Stöckle, F.; Evaluierung zur Umsetzung der Energieverbrauchs-kennzeichnungsverordnung (EnVKV). Projektnummer 28/00. Abschlussbericht an das Bundesministerium für Wirtschaft und Technologie. Fraunhofer Institut für Systemtechnik und Innovations-forschung (ISI), Karlsurhe, Nürnberg 2001.
ServiceBarometer 2005	ServiceBarometer AG (ed.); Kundenmonitor Deutschland 2004 Elektrohaushaltsgroßgeräte. München 2005.
Stamminger 2004a	University of Bonn, Prof. Stamminger: data from Stiftung Warentest and CECED, mean and extrapolated values; Bonn 2004. Unpublished.
Stamminger 2004b	University of Bonn, Prof. Stamminger: data on dryer energy consump-tion in connection with spin speed; Bonn 2004. Unpublished.
StiWa2004	Stiftung Warentest (ed.); Sparsame Waschmaschinen. Broschüre, Oktober 2004.
UBA 2000	Umweltbundesamt (ed.). Ökobilanz für Getränkeverpackungen II. Texte 37/00. Umweltbundesamt; Berlin 2000.