The Eco-Efficiency of Reuse Centres Critically Explored - The Washing Machine Case

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Abstract

By repairing and reselling used products, reuse centres aim at creating low-skill jobs while offering low-cost and environmentally beneficial products. However, due to a combination of decreased efficiency of worn-out products and technological progress embodied in new products, lifetime extension of old products is sometimes not the most beneficial scenario from both an environmental and economic point of view. This paper investigates this trade-off for the case of washing machines. For selected types of washing machines, critical reuse ages are determined above which reuse is environmentally or economically undesirable. A sensitivity analysis shows that these critical reuse ages are often sensitive to small changes of the input parameters.

Keywords

Reuse, total cost of ownership, life cycle environmental impact, life time optimisation, washing machine

1 INTRODUCTION

Four levels of waste management can be distinguished, ranging from waste prevention as the ideal situation, over product or component reuse on a second level, to recycling on the third level and finally incineration as the least favourable environmental situation [1]. This hierarchy is also better known as *"the ladder of Lansink"*. However, waste prevention is still hard to realise as it requires a radical shift in the mindset op consumers. Product reuse on the other hand is easier to obtain and is normally environmentally benign compared to material recycling due to the reduced consumption of resources and the preservation of functional product properties. Reuse centres have made a successful business out of this second level of waste management. In Flanders they employ about 1700 low skilled workers and are still growing. [2] The activities of reuse centres are based on a social, economic and ecological pillar. Creating low skilled jobs in Flanders and offering affordable common consumer products to people with low purchasing power fits into both the social and economic pillar. Providing an environmentally better alternative to new products by enlarging the product life cycle duration encompasses the last pillar. However, Dewulf et al [4] proved for the case of refrigerators that in some scenarios the economic and environmental objectives of reuse centres can be violated by extending the product life cycle.

Product performances often improve over time because of technological innovations. A higher efficiency of resource consumption results in less operational costs and reduced environmental impact. For example, from 1998 to 2003 electricity consumption by new refrigerators dropped by 20% [3]. Therefore, a delayed introduction of higher efficiency products results not only in a higher environmental burden, but also a higher operational cost. Both are not compliant with the environmental and economic targets of the reuse centres.

A second stimulant to opt for product life time optimisation, rather than for blind prolongation, is the decreasing efficiency during the products' life time. Dewulf et al [4] described the deterioration of the foam properties of the insulation materials, due to the diffusion of the blowing agents, which causes an increase of energy consumption and environmental impact.

In this paper, a similar analysis will be presented, focussing on washing machines. Taking into account the significant differences of the technical parameters between both appliances, the developed model was adjusted and fine-tuned to cover the desired scope. Next to electricity use, water consumption is also considered. In this study, detergent consumption is not taken into account since this factor mainly depends on consumer behaviour and not on the type of washing machine in use. Next to these technical differences, it can also be noted that washing machines, in contrast with refrigerators, operate only a few times a week, whereas refrigerators operate continuously.

Literature review

In literature some publications can be found concerning life time optimisation of washing machines [5] [6]. The Öko-institut conducted a study about washing machine utilisation in Germany [7] [8]. Two parts of this German study are relevant for this paper. A first part calculates the optimal lifetime for an up-to-date washing machine taking into account various technological developments. A second part analyses whether washing machines with different years of construction, ranging from 1985 to 2004, should be replaced by new washing machines or should be kept in use.

The first part of the study calculates three scenarios for washing combined with drying for washing machines with different life spans, ranging from 1000 to 5000 wash cycles and over a defined period of 22 years. The life span is expressed in the number of washing cycles a machine can technically support. All three scenarios assume constant electricity and fresh water prices over these 22 years. Also the environmental impact for water and electricity supply is assumed constant. The study takes into account different technological and behavioural developments for which the optimal lifespan is calculated from an environmental and economic point of view. In all three scenarios the dryer dominates both the environmental and economic impact.

The second part of the Öko-institute study determines whether it is better to buy a new washing machine today (in 2005) or to continue using an old device. Depending on the age of the washing machine under consideration and the evaluation criteria (GWP, CED, total environmental burden or an economic criterion), different conclusions can be drawn. The results of this study are relevant for manufacturers with respect to the life span their washing machines should be designed for.

This paper differs from the German study in so far that it has a strong focus on reuse centre policies. In addition, the German study did not take into account a deterioration rate caused by the degrading of parts. Electricity consumption, which is measured per washing cycle, will increase because of wearing components and the forming of lime scale on the heating elements. This issue will be regarded in this paper as a potential factor to shorten the optimal life cycle span. Furthermore, this paper does take into account discounting factors, whereas these where ignored in the German study.

The following paragraph describes a reference scenario and explains the methodological approach of the study.

2 RESEARCH APPROACH AND BASIC PREMISES

2.1 Total cost of ownership

Washing machines currently on the market

On the market, washing machines are available in many different configurations. The European directive with regard to energy labelling of household washing machines, introduced in 1992 and implemented from 1996 onwards, obliges suppliers of washing machines to inform customers about the major properties of the appliance, such as: energy class, washing and drying results, speed, water consumption and maximum capacity. This information has to be available on a specific technical data sheet. Next to these properties, washing machines also differ in functional abilities. This implies the environmental impact of washing machines differs according to the brand and machine type. For example, a load-adjustment programme is a frequently occurring function that is capable of reducing water and electricity consumption up to 25% by adjusting the amount of water needed according to the amount of laundry in the washing drum [7].

In respect to the energy use of the washing machine, seven different energy classes are defined, ranging from A, energy use of 0,19 kWh or less per kg of washed goods for a 60°C cotton cycle, to G, energy use of 0,39 kWh or more under the same circumstances. This classification is introduced by an EU directive from 1995 [9]. Since the implementation of the directive in 1996, the energy efficiency of washing machines has improved drastically. As a result, almost all currently available machines on the market have an A -label, which makes it hard for washing machine producers to differentiate their products from the ones offered by competitors. For this reason, some large manufacturers, like Bosch and Siemens, have introduced the A+ label, which represents washing machines with a maximum energy consumption of 0,17 kWh per kg of laundry, as a new standard. However, this A+ label is not yet officially recognised by the EU.

The last few years, a trend towards faster spinning washing machines can be observed. Since 1993 the average spinning speed has increased from 977 rpm [10] towards 1110 rpm. [7]. In general, the higher the spinning speed, the higher the initial purchase price [20] [21] [22] [23] and the more water will be removed from the laundry. Clothes washed and centrifuged at 1000 rpm still have a residual humidity of 62% whereas a 1400 rpm cycle results in a humidity of only 52% [8]. A second trend towards washing machines with higher load capacities can be observed. The Öko-institute compared *5-kilo to 7-kilo* type washing machines and concluded that customer behaviour is most important with respect to the resulting eco-impact. End-users can either adapt their habits to the *7-kilo-machine* and run less cycles or run the same number of cycles as they did before with a *5 kilo-machine*. Logically, the first scenario is more eco-efficient.

Reuse centres

The demand for washing machines from reuse centres is higher than the available supply. People buy what is offered at reuse centres. The perception of people buying such a machine is that they bought a product that should be cheaper than a new one. For this reason reuse centres should in principle only offer washing machines which have a lower total cost of ownership (TCO) than a typical new machine purchased in a regular shop. Paragraph 3.1 calculates this TCO for 2nd hand washing machines and compares them with a baseline reference.

Reuse centres systematically select washing machines that run 1000 rpm or more and which have at least an A-label. B-labelled machines are supplied for a lower price (see table 4: average 2nd hand prices) to social institutes asking for cheap washing machines. Whether these washing machines are indeed cheaper from a TCO perspective, is discussed in section 3.1.

Classification

In this study washing machines are classified according to their energy-class, which is further divided into high and low water consuming machines, respectively using more than 45 litres/cycle and equal or less than 45 litres/cycle.

Initial assumptions

Only front load machines are considered, since top load machines are rarely sold in Flanders. A technical lifetime of 15 years is assumed, which is a common assumption in literature [7] [11]. Only energy class A+ and A are considered here since in 2003 90% of all sold washing machines already had an A-label [12].

Table 1: TCO for 4 scenarios

	Energy class			
	A+		A	
	≤45 l	>45 l	≤45 l	>45 l
Machine name	I	II	III	IV
Data points	9	7	3	14
Purchase cost new (EUR)	594 €	443 €	441 €	454 €
2nd hand Purchase cost (EUR)	198 €	148 €	147 €	151 €
Initial energy consumption (kWh/washcycle)	0,85	0,85	0,94	0,94
Initial energy consumption (KWh/year)	113	113	125	124
Total energy cost (EUR)	299 €	299 €	332 €	329 €
Initial water consumption (Litre/wash cycle)	43	51	44	50
Initial water consumption (Litre/year)	7506	9000	7758	8825
Total water cost (EUR)	361 €	433 €	373 €	425 €
Total operational cost (EUR)	660 €	732 €	705 €	754 €
Total cost of ownership (EUR)	**1.254 €**	**1.175 €**	**1.146 €**	**1.209 €**

Aesthetic appearances are not considered for this study since the target groups in this study are people with limited budget, mainly concerned about costs and functional properties. For this reason only characteristics as specified on the technical data sheets provided by the suppliers according to the EU directive and costs are taken into account. In this study, the many available electronic functions on a washing machine are also not considered since they differ a lot from brand to brand and generic conclusions were envisaged.

It is finally assumed that each washing machine is used until it reaches its technical lifetime *L*. After this period, people dispose of their washing machine and buy another one of the same age as the previously purchased machine.

Determination of baseline reference

Since customers of 2nd hand shops focus on low-cost solutions, the washing machine with the lowest TCO is chosen as a reference. Table 1 and figure 1 illustrate the TCO of 4 different washing machine types with an A or A+ energy label. Please note that the data in this table are averages from a collection of data gathered from a thorough internet survey [20] [21] [22] [23].

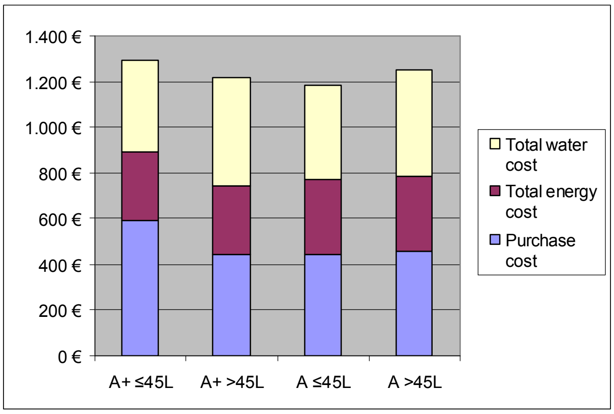


Figure 1: TCO for 4 categories of washing machines

The difference between the machine with the lowest (A class, ≤45 l) and the highest (A+ class, >45 l) total cost of ownership is calculated to be only about 100 EUR over a lifespan of 15 years. In absolute figures, machine III has the lowest TCO, however, this machine is rather hard to find on the market, whereas machine II is easier to obtain. For this reason, machine II is chosen to be the reference machine. It is a device that can process 5 kg of laundry, with a maximum spinning speed of 1200 rpm, an energy label A+ and a water consumption of more than 45 litres per cycle.

Price evolutions

Water prices have been increasing approximately 4% per year over the past 10 years (Figure 2). To forecast the next 15 years, the same rate is applied.

Electricity prices are hard to forecast since no clear trend (see figure 3) can be derived from past data gathered from the Ecodata database [13]. Liberalisation of the energy market and European directives that oblige European countries to produce more sustainable energy could have respectively a decreasing and increasing effect on the energy prices.

Because of these two counteracting influences, a constant energy price is initially assumed. Scenarios with a 150% and a 200% price increase by 2020 will, however, be considered in the sensitivity analysis in section 4.1 to deal with this highly uncertain parameter.

Historical data about discounted purchase prices for washing machines sold in Belgium [13] show an average price decrease of about 1% per year (Figure 4).

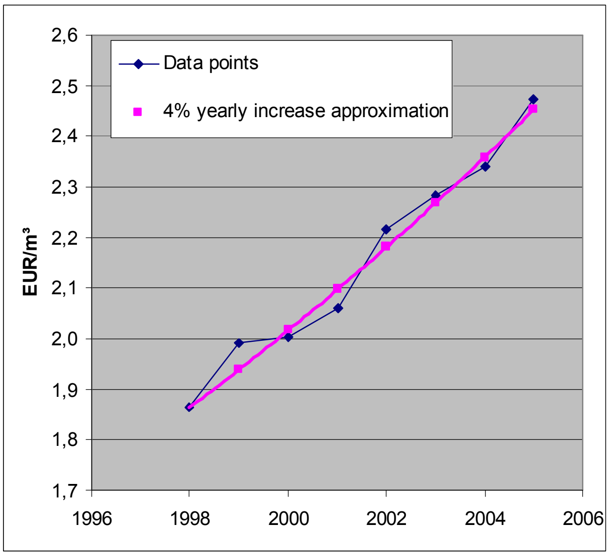


Figure 2: Evolution of water prices in Flanders

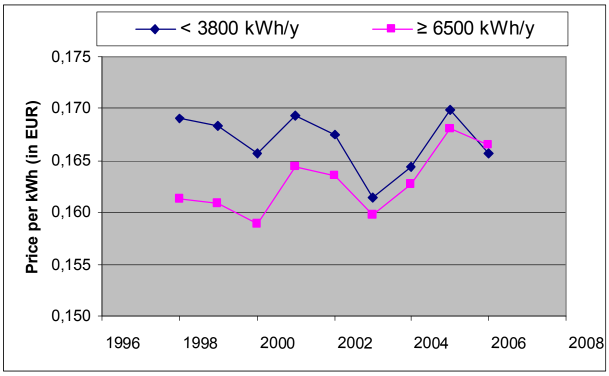


Figure 3: Evolution of electricity prices in Flanders

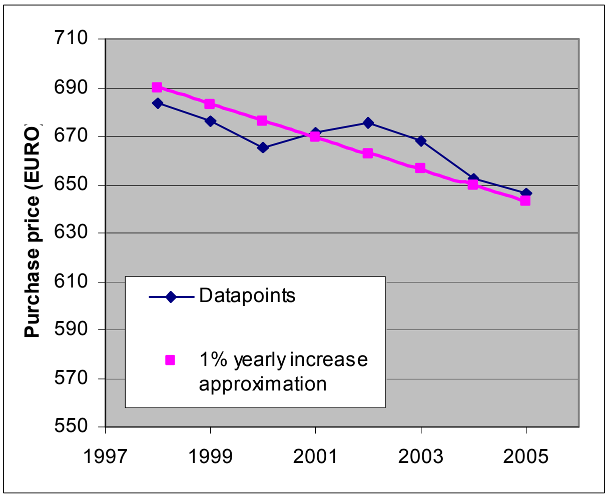


Figure 4: Evolution of purchase prices

Deterioration data

Increasing water and electricity consumption result in higher total operational costs. It is however unlikely that water consumption increases in such a way that it has a significant impact on operational costs. If water is spilled somehow, this is quickly noticed and followed by either repair or replacement of the malfunctioning device. Electricity consumption on the other hand can increase without anyone noticing. The Öko-institute study [7] and other studies found in literature [5] [6] did not take into account this aspect. Moving or rotating parts, like belts and pulleys, motor drive, pumps or bearings, are liable to wear. How fast these parts deteriorate is subject of discussion and is probably a major reason why previous studies ignored this factor. No experimental data are yet available. Assumptions about deterioration are based on general data found in literature and the authors' judgement. A test set-up of a washing machine motor is planned in cooperation with ESAT (KULeuven, Department of Electro technique). To collect data about the effect of lime scale on electricity consumption and on the wearing of bearings, two additional test set-ups are planned in cooperation with *Revision centre Tienen*.

Lime scale forms on the heating resistor of a washing machine because of a combination of hard tap water and high temperatures. Because lime scale has a poor thermal conductivity, the heating element requires more time to realise the preset water temperature. According to research conducted by the Department of Energy of United States, a layer of lime scale with only 0,8mm thickness can cause 8,5% loss in efficiency. Other sources [14] [15] show an average of 10% loss of efficiency for 1mm of lime scale.

A sensitivity analysis in paragraph 4 clarifies the impact of the accuracy of the utilized assumptions.

Table 2 Deterioration data:

	Min	Max	Ref
Motor	0.5%	1%	[16]
Belt and pulley	5%	10%	[17] [18]
Lime on heating elements	5%/mm	15%/mm	[14] [15]

User profile

On average a household of 3 persons runs 175 washing cycles each year [7]. Table 3 summarises the number of washing cycles per year for a specific washing temperature and the amount of electricity needed to process one kilogram of laundry at that temperature [7].

Table 3: Wash temperatures

Wash temp.	Cycles per year	Cycles per year (in %)	kWh/kg
95°	16	9%	0,32
60°	60	34%	0,19
40°	63	36%	0,10
30°	37	21%	0,07

2.2 Total environmental impact

The eco-efficiency indicator 99 method [19] is used to measure the environmental impact of materials production, material processing, transportation, use phase and disposal.

Impact of materials, process energy, transportation and disposal.

Data from the Öko-institute, containing the material weights of six different washing machines, are used to determine the environmental impact of material production and disposal. This impact is assumed to be constant over time for all considered washing machines.

Most of the weight of a washing machine can be attributed to metals (58%). Plastics represent 11 % of the total weight and other materials, dominated by the weight of concrete but also containing PCB's, glass and cardboard, together have a share of 30 % of the total weight. In terms of impact caused by materials, aluminium, steel and cast iron respectively cause 25 %, 20% and 14% of the total environmental material impact, whereas all plastics together represent about 27%. The total impact of materials is in absolute figures equal to 12,5 eco-indicator-99 (EI99) points. In order to convert these materials into the final product, process energy requirements of 66 kWh are reported [3].

Together with the material impact, this brings the total production impact to approximately 13,9 EI99 points.

Washing machines are recycled in specialised centres where the metal fraction, glass and concrete are sorted out. The rest fraction is incinerated afterwards [23]. The recycled materials get credits according to the eco-indicator 99 method. Metals and glass are assumed to be 100% recyclable. In absolute figures the disposal of a washing machine according to this scenario accounts for about -5,5 EI99 points. The negative value can be explained by the large metal fraction that can be recycled efficiently.

It is estimated that the washing machine is transported with a 16-ton truck over a distance of 400 km, which results in 1,36 EI99 points.

Impact of use phase

The use phase causes a variable environmental impact because of electricity and fresh water consumption figures depending on the type of washing machine considered. Consumption figures for the predefined washing machines categories are gathered from a thorough internet survey [21] [22] [23] [24].

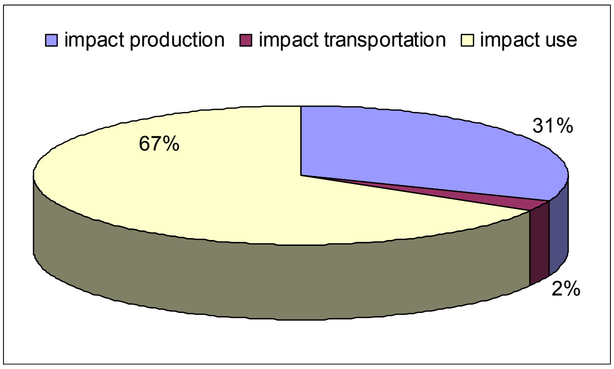


Figure 5: Total environmental impact of washing machine II

Detergent consumption also has an important environmental impact, but is mainly depending on user habits rather than the type of washing machine and is therefore not taken into account in this calculation.

Figure 5 clearly shows the major impact of the use phase (67%).

Figure 6 and 7 summarise the impact of the four described washing machines. Washing machine I has the lowest impact (57,1 points) closely followed by machine II (58,1 points). Machine III and IV count for respectively 62,0 and 61,9 points.

From figure 7 it is clear that energy consumption has a bigger environmental impact than water consumption. Shifting from an A class to an A+-class reduces the environmental impact with about 4 eco-points or 9% over 15 years. Shifting from high to low water consuming washing machines saves only 0,2 eco-points or about 0,5% over 15 years.

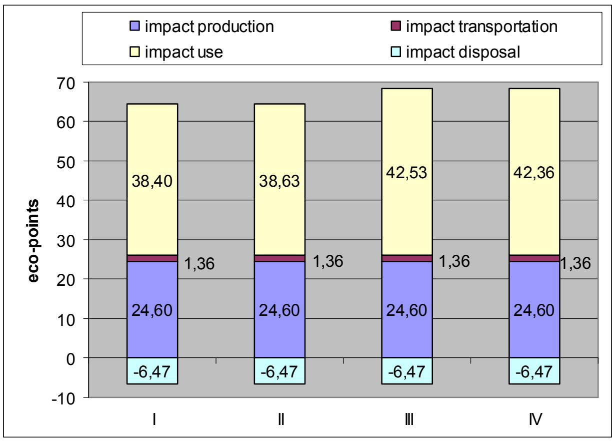


Figure 6: Environmental impact per type of washing machine

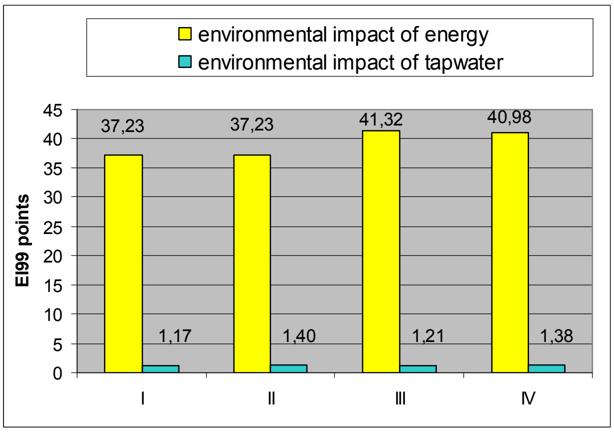


Figure 7: Environmental impact due to electricity and water consumption per type of washing machine

3 ASSESSMENT OF REUSE SCENARIOS

3.1 Total cost of ownership

This paragraph calculates the TCO of washing machines with different reuse ages, energy labels and water consumption figures over a period of 15 years. A washing machine of reuse age R, bought at a reuse centre will on average only last for (L-R) years, since reuse centres can not prolong the technical lifespan L of washing machines. As a consequence, multiple washing machines of reuse age R have to be bought to cover the period of 15 years.

In the developed model, the purchase price is evenly distributed over these (L-R) years ensuring that the sum of the present values equals the present value of the initial purchase price. However, some washing machines will only be used for part of their technical lifetime. To compensate this, only the corresponding part of the purchase price is allocated in the developed model.

Sales prices for washing machines are set on an individual basis based on factors such as: machine brand, energy class, maximum load capacity, spin speed, and appearance. Next to that reuse centres target a sales price of about one third of the average new-price on the market. Currently sales prices (Table 4) range from 130 to 150 EUR for regular machines and from 150 to 180 EUR for washing machines of the Miele brand. This brand is typically more expensive, and has also more expensive spare parts.

In the developed model assumptions about future washing machine performance and prices have to be made. Electricity consumption per washing cycle has been decreasing about 1,9% per year (average figure based on data from [7]). Water consumption per washing cycle has even been decreasing with about 4% per year (average figure based on data from [7]) Furthermore a yearly decreasing purchase price of 1% is derived from the database of Ecodata [13] These three evolutions will be taken into account when modelling future performances.

Table 4: Average 2nd hand sales

	Energy class		
	A+	A	B
Age A < 5 years	155 €	155 €	115 €
5 years ≤ age A < 10 years	140 €	140 €	100 €
10 years ≤ age A < 15 years	125 €	125 €	85 €

Based on the described input data, figure 8 shows the Total cost of ownership of 6 washing machines, differing from each other in energy class, water consumption and reuse age, and compares these with the baseline reference. From the figure, it can be concluded that 2nd hand washing machines with a reuse age lower than 6 years are a little cheaper compared to the baseline reference, independent of the concerned washing machine type. Washing machines older than 10 years have a TCO higher than this baseline reference. From the figure it is however clear that the intersection points of the baseline reference with the TCO curves of every machine is highly sensitive to the position of the baseline reference. A thorough sensitivity analysis deals with this. The curves of all washing machine types incline to infinity when they approach the reuse age of 15 years due to the assumption of technical breakdown at that age.

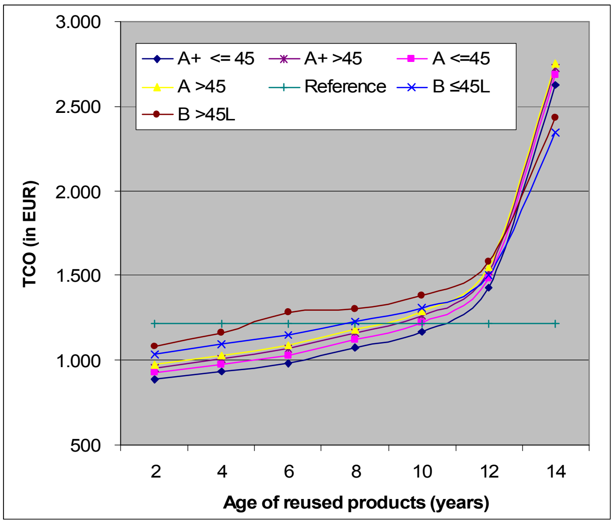


Figure 8: TOC of washing machines of different energy classes, water consumption and reuse ages (R), compared to the baseline reference

From figure 8 it can also be concluded that washing machines with the same reuse ages, but different energy classes have about the same TCO. This can be explained because the savings made by consuming less energy are particularly lost by a higher initial purchase price.

Another conclusion is that washing machines of the same energy class, but with different water consumption figures, have almost the same TCO. The difference in water consumption between, for example, washing machine I and II is 8 litres per washing cycle, or about 1,5m³ per year, and only costs an additional 3 EUR per year.

3.2 Total environmental impact

Purchasing and using a new washing machine induces an initial production, a use and, at the end of its technical life, a disposal impact. Purchasing a 2nd hand washing machine on the other hand, only induces a use impact because the environmental impact at reuse centres is negligible.

The environmental impact of 2nd hand washing machines during their use phase is due to electricity and water consumption, which is explained earlier in this text.

From figure 9 it can be concluded that reuse centres should not supply B-labelled washing machines at all, while A+ or A- types can be supplied until they reach an initial reuse age of 15 years. Similar to the analysis of the TCO of 2nd hand washing machines, the water consumption does not result in a significantly different impact.

Note that the curves show a limited slope at the intersection with the baseline reference. Consequently, the critical reuse age promises to be sensitive to small changes in this reference scenario. In the next paragraph a sensitivity analysis will focus on this issue.

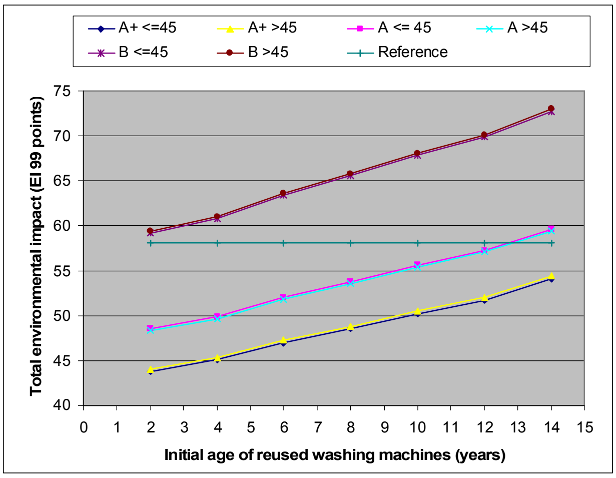


Figure 9: Total environmental impact of using washing machines of different types compared to the baseline reference

4 SENSITIVITY ANALYSIS

The objective of the developed model is to be able to decide under which circumstances specific types of washing machines should not be supplied by reuse centres. However, the input parameters for this model are subject to uncertainty. How reliable the obtained critical reuse ages are will be investigated in the following sensitivity analysis.

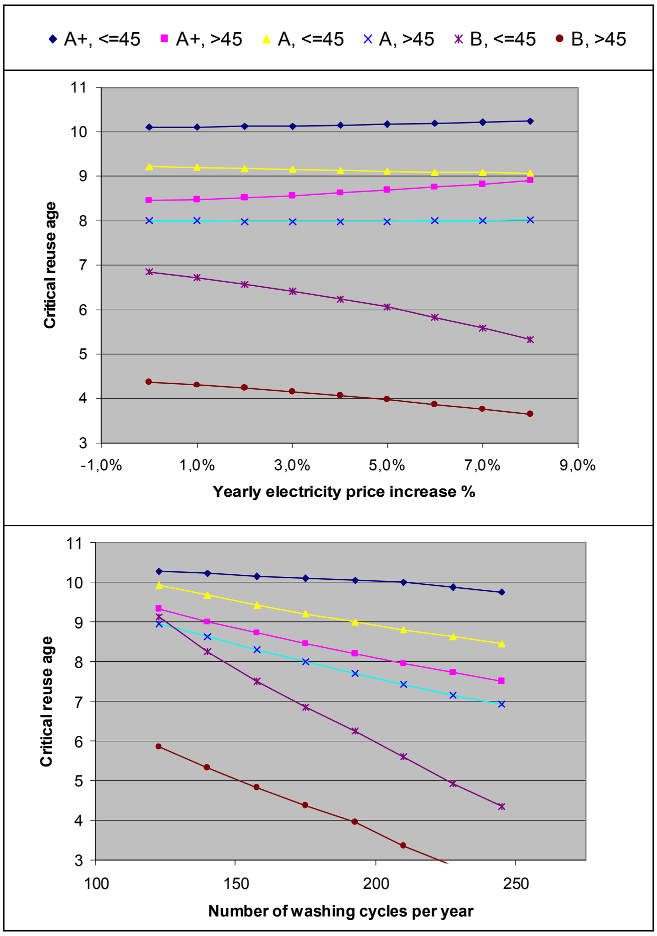
Table 5: Causes of uncertainty

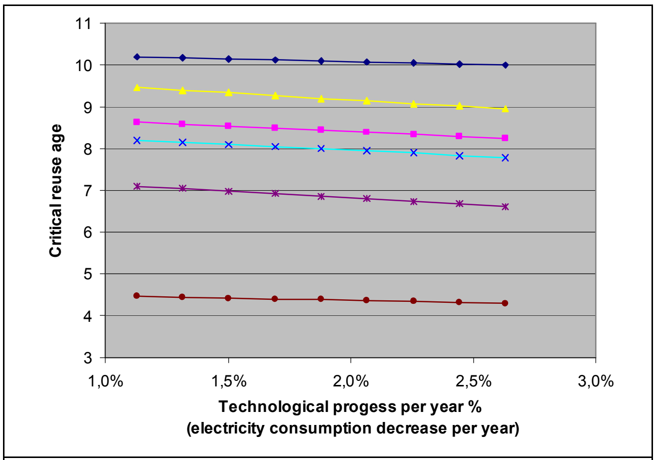
Parameter	Cause of uncertainty
Electricity prices	Electricity supplier
	Different type of contracts
Water prices	Regional policies
	Different type of contracts
Purchase price (new)	Different brands, models
	Place of distribution
Purchase price (2nd hand)	No strict pricing policy at reuse centres
Yearly electricity price evolution	Forecasting uncertainty
Yearly water price evolution	Forecasting uncertainty
Yearly purchase price evolution	Forecasting uncertainty
Real interest rate	Forecasting uncertainty
Technological progress	Forecasting uncertainty
Decreasing efficiency	Different quality of components
	Limited data available
Number of washing cycles	Household profiles
Electricity consumption of washing machine	Outdated energy classification
Technical lifetime *L*	Technical quality of components
	Household profiles
Production impact	Different brands and models

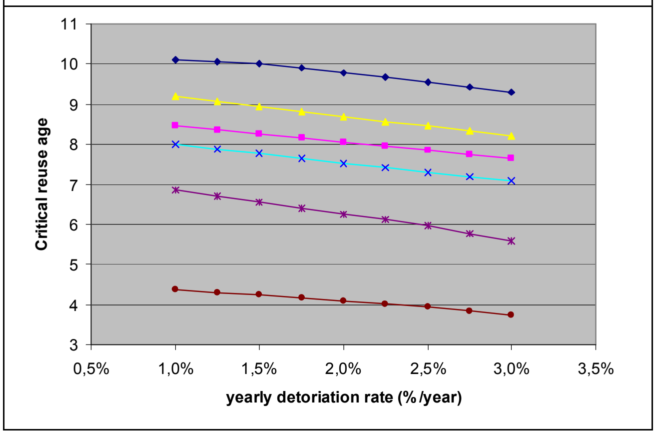
4.1 Total cost of ownership

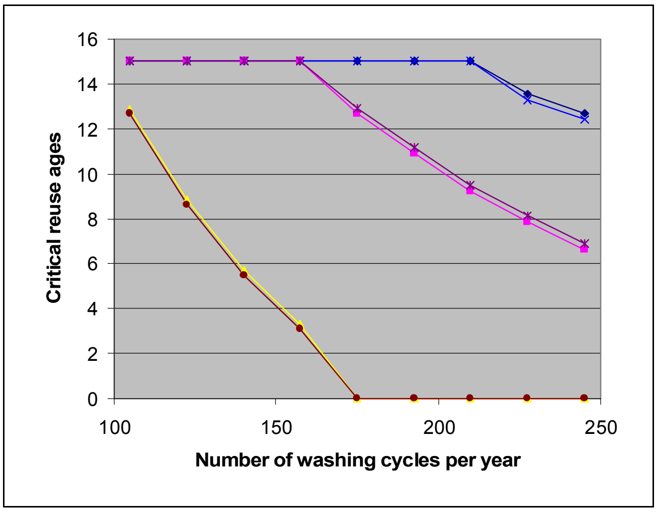
The total cost of ownership is influenced by the parameters listed in table 5. The sensitivity of the critical reuse ages to a selection of these parameters is depicted in Table 6. From de four graphs it is clear that the devices with low class energy labels are rather sensitive to variations. Consequently, the resulting critical reuse ages should be interpreted with care. However, B-class washing machines hardly ever exceed a critical reuse age of 7 years. The high water consuming B-types consistently have an even lower critical reuse age.

Table 6: Sensitivity of economically critical reuse age to variations of input parameters







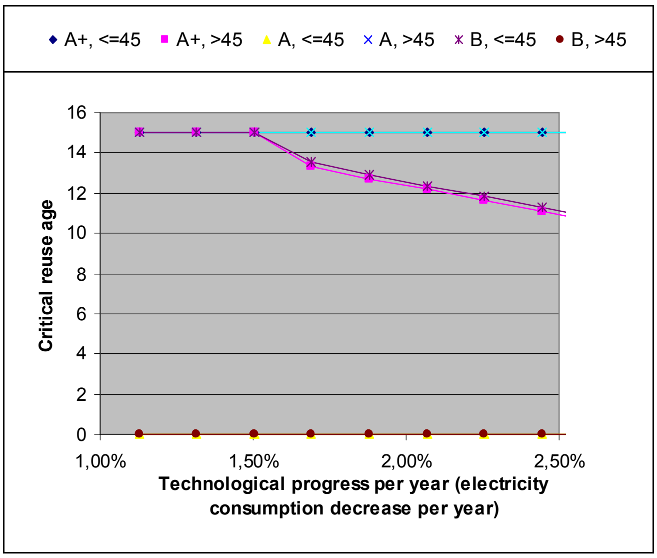


From the second graph of Table 6 it is clear that the critical reuse age is very sensitive to the number of washing cycles per year. Initially 175 cycles a year were assumed [7]. However other studies apply figures ranging from 230 cycles/year [10] up to 300 cycles per year [5]. Taking into account these higher washing rates, critical reuse ages of lower-energy classes decrease very fast.

4.2 Total environmental impact

In the following graphs some washing machines types have a critical reuse age of 0 or 15 years. Zero means it is never appropriate to reuse that type of washing machine while 15 indicates reuse is always beneficial. Table 7 clearly shows that B-labelled washing machines should not be reused from an environmental point of view.

Table 7: Sensitivity of the environmentally critical reuse age to variations of the input parameters



5 CONCLUSIONS AND FUTURE RESEARCH

Reuse centres aim at offering cheap and environmentally beneficial products. However, similar to what was demonstrated for refrigerators by Dewulf et al [4], , this paper indicates that the reuse of low end products can result in both a higher total cost and a higher total environmental impact than the purchase of a new appliance. Depending on age, energy class and water consumption, second hand washing machines can be classified into three groups:

- Group 1: Both environmentally and economically beneficial compared to the purchase of a new washing machine.
- Group 2: Environmentally or economically beneficial compared to the purchase of a new washing machine.
- Group 3: Neither environmentally nor economically beneficial compared to the purchase of a new washing machine.

Figure 10: Graphical representation of critical reuse boundaries

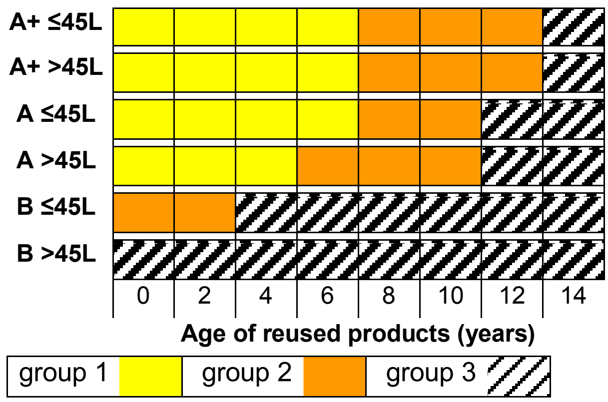


Figure 10 shows the critical reuse age boundaries for the 6 types of washing machines. It is clear that washing machines belonging to group 1 should be reused whereas group 3 types should not be reused.

In this model, an average number of 175 washing cycles per year was assumed. However, large households or families with young children run more cycles, resulting in a substantial increase of electricity and water consumption. Providing these people with B-labelled machines should therefore be reduced.

Because the focus of this paper is on reuse centre activities, it is appropriate to stress their social commitment. Their resulting social impact is however difficult to model, but should not be denied in future research.

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