TIMELY REPLACEMENT OF WHITE GOODS

INVESTIGATION OF MODERN APPLIANCES IN A LCA

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Introduction and Goal of the Project

Timely replacement of electric household appliances (white goods) is often thought to be a beneficial option due to the energy efficiency improvements in modern appliances. Such conclusions are often solely based on comparing the direct with the indirect (grey) energy input. The conclusions are mostly deduced from the large dominance of the use over the production phase, disregarding other environmental effects. In this study two modern and efficient appliances, a washing machine and a fridge freezer, are analysed with the more comprehensive indicators ecological scarcity 97 and Eco-indicator 99. The full life cycle of the white goods with raw material extraction, production, distribution, operation, maintenance and disposal has been investigated. Furthermore, special attention was given to the electronic components.

Theoretical Background

Three factors determine if a timely replacement makes sense or not:

1. the life-span of the new appliance ($t_{L,new}$)
2. the production and disposal of the new appliance (P_{new})
3. the differences in the use phase (U) resulting from the higher efficiency of the new over the old appliance (ΔU)

The replacement is worthwhile when the annual savings in operation (1) are larger than the annual amortisation of the new appliance (A_{new}) (2). This leads to equation (3) with $R < 1$ to indicate a beneficial timely replacement (the more so the closer to zero). In other words, the savings in the use phase have at least to pay for the additional amortisation due to the timely replacement.

$$\Delta U = U_{\text{old appliance}} - U_{\text{new appliance}} \quad (1)$$

$$\Delta U > A_{new} = P_{new} / t_{L,new} \quad (2)$$

$$R = A_{new} / \Delta U \qquad (R < 1 \Rightarrow \text{beneficial replacement}) \quad (3)$$

The Study

The full life cycle of the white goods with raw material extraction, production, distribution, operation, maintenance and disposal has been investigated. Furthermore, electronic components, which tend to have a high environmental impact in relation to their weight, were evaluated in detail. The impact assessment in the LCA was conducted with the Eco-indicator 99 (EI'99) and the ecological scarcity 97 (UBP'97) methods. The cumulative energy demand (CED) was also calculated to represent an energy based analysis. The results from the fridge freezer study are very similar to the results of the washing machine presented here in detail.

Washing Machine

A modern, energy and water efficient washing machine was analysed. The appliance was assumed to be used in Switzerland by one single family, which results in 300 washings a year on average. The machine uses 49 litre of water and 0.94 kWh of electricity per standard washing (a mix of different washing programmes). The expected life-span of the machine is 15 years.

The results from the cumulative energy demand (CED) in Figure 1 show a dominant role of the direct electricity consumption during the operation of the washing machine (approx. 83%) confirming this kind of findings from older studies. This dominance is less pronounced when the ecological scarcity points are applied (approx. 71%). However, in the evaluation with the Eco-indicator 99 the direct electricity consumption contributes only 36% of the points, while the production & distribution (53%) becomes the dominating phase. This is contradicting the common notion of the use phase being the most important phase in the life cycle. Chromium steel is the most important product accounting for about 30 to 40% to production & distribution, whereas the electronic components contribute about 5%. In this phase the most important emissions are particles (EI'99 and UBP'97), chromium into air (EI'99) and NO_x (UBP'97).

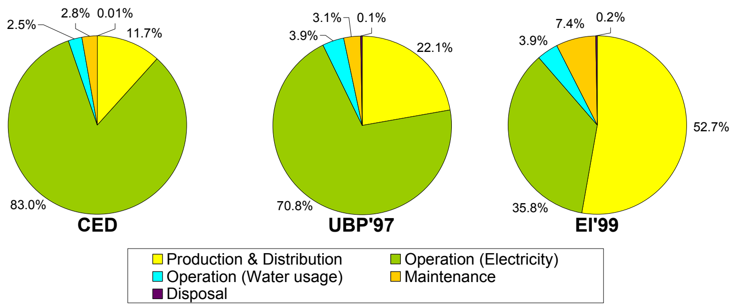

Figure 1: The relative shares of the different life cycle stages as resulting from the calculation of the cumulative energy demand (CED), the ecological scarcity points 97 (UBP'97) and the Eco-indicator points 99 (EI'99) for a modern washing machine.

The results indicate that a significantly higher efficiency improvement between the old and the new machine (ΔU) is needed to make the timely replacement worthwhile when more comprehensive indicators are applied.

To illustrate, the $A_{new}/\Delta U$ ratio (R) was calculated for all three evaluation methods likewise. It was arbitrarily assumed that the modern washing machine analysed in this study is 25% more efficient than the replaced one. As can be seen in Table 1, the ratio is far below 1 for the CED demonstrating that a timely replacement is largely beneficial. This is less pronounced for the UBP'97 with a R-value just under one. Using EI'99 for the evaluation shows that a timely replacement is not favourable anymore, as the amortisation of the production (A_{new}) is higher than the savings due to the replacement appliance (ΔU) – the savings of energy are too small to pay for the additional amortisation.

Table 1: Results from the calculation of a timely replacement of the washing machine calculated with cumulative energy demand (CED), ecological scarcity '97 (UBP'97) and Eco-indicator '99 (EI'99). A timely replacement is a beneficial option, if the condition $R < 1$ is fulfilled.

	CED	UBP'97	EI'99
$R = A_{new}/\Delta U$	0.42	0.94	5.04
Replacement is:	beneficial	slightly beneficial	not beneficial

Conclusions

Evaluations of timely replacements with more environmentally comprehensive indicators, like ecological scarcity '97 and Eco-indicator '99, tend to result in a lower importance of the use phase of white goods compared to cumulative energy demand. As a consequence, a timely replacement becomes less beneficial or even disadvantageous. An evaluation based on energy or energy related data can, therefore, lead to wrong conclusions from an environmental point of view. This becomes particularly true for highly efficient appliances like the ones analysed.

The outcome also depends on the use pattern (i.e. how often or intensively an appliance is used) and the electricity mix (i.e. the location of use). The first aspect largely determines how much electricity is consumed, while the latter one determines how strong it is counted in the evaluation with the more comprehensive indicators. In order to make decisions on timely replacement it is, therefore, essential to consider such aspects carefully.

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Introduction

It is often thought that a timely replacement of electric household appliances (white goods) can make sense due to the energy efficiency improvements in modern appliances. Such conclusions are often solely based on comparing the direct with the indirect (grey) energy input – i.e. from the large dominance of the use over the production phase (e.g. [1, 2]) – and disregarding other environmental effects. In this study two modern and efficient appliances, a fridge freezer (A+ label) and a washing machine (AAB label), are analysed with the more comprehensive indicators ecological scarcity 97 and Eco-indicator 99.

Theoretical Background to Timely Replacement

Three factors determine according to [3] if a timely replacement makes sense or not:

1. the life-span of the new appliance ($t_{L,new}$)
2. the production and disposal of the new appliance (P_{new})
3. the savings in the use phase resulting from the higher efficiency of the new over the old appliance (ΔU)

The replacement is worthwhile when the annual savings in operation ($\Delta U = U_{old\ appliance} - U_{new\ appliance}$) are larger than the annual amortisation of the new appliance ($A_{new} = P_{new} / t_{L,new}$): $\Delta U > A_{new}$. This leads to $R = A_{new} / \Delta U$ with $R < 1$ to indicate a beneficial timely replacement (the more so the closer to zero). In other words, the savings in the use phase have at least to pay for the additional amortisation due to the timely replacement. This simplified approach, which is independent of the point in time of the replacement, is valid only for a short time perspective. On a long term view, it might be more favourable to wait for an even more efficient appliance, which results in a larger ΔU and eventually in a better overall result. However, this approach needs assumptions on the development of the efficiency into the future, which contains an additional degree of uncertainty. An extended description of both approaches including the complete mathematical background, are presented in [3]. A similar approach, but for evaluating the optimum lifespan of a population of appliances, instead of a single one, has been proposed by [2].

Timely Replacement Analysis of White Goods

The full life cycle of the white goods with raw material extraction, production, distribution, operation, maintenance and disposal has been investigated. Furthermore, electronic components, which tend to have a high environmental impact in relation to their weight, were evaluated in detail. The impact assessment in the LCA was conducted with the Eco-indicator 99 (EI'99) and the ecological scarcity 97 (UBP'97) methods. The cumulative energy demand (CED) was also calculated to represent an energy based analysis.

Washing Machine

A modern, energy and water efficient washing machine was analysed [4]. The appliance was assumed to be used in Switzerland by one single family, which results in 300 washings a year on average. The machine uses 49 litre of water and 0.94 kWh of electricity per standard washing (a mix of different washing programmes). The expected life-span of the machine is 15 years.

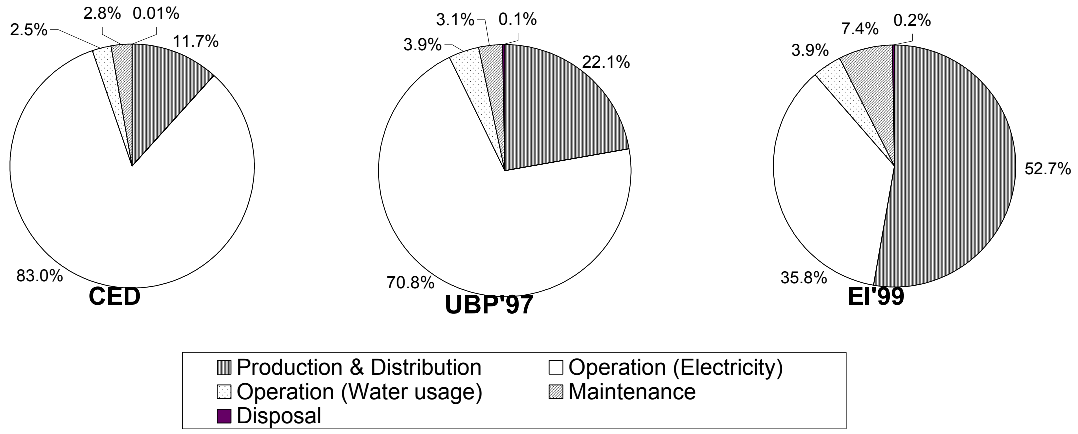

Figure 1: The relative shares of the different life cycle stages as resulting from the calculation of the cumulative energy demand (CED), the ecological scarcity points 97 (UBP'97) and the Eco-indicator points 99 (EI'99) for a modern washing machine.

The results from the cumulative energy demand (CED) in Figure 1 show a dominant role of the direct electricity consumption during operation (approx. 83%) confirming this kind of findings from older studies [1, 2]. This dominance is less pronounced when the ecological scarcity points are applied (approx. 71%). However, in the evaluation with the Eco-indicator 99 the direct electricity consumption contributes only 36% of the points, while the production & distribution (53%) becomes the dominating phase.

The latter result means that a significantly higher efficiency improvement between the old and the new machine (ΔU) is needed to make the timely replacement worthwhile when more comprehensive indicators are applied. To illustrate, the $A_{new}/\Delta U$ ratio (R) was calculated with the arbitrary assumption that the new washing machine (the one analysed in the study) is 25% more efficient than the replaced one and for all three evaluation methods likewise. As can be seen in Table 1, the ratio is far below 1 for the CED demonstrating that a timely replacement is largely beneficial with this assessment. This is less pronounced for the UBP'97 with a R-value just under one. Using EI'99 for the evaluation shows that a timely replacement is not favourable anymore, as the amortisation of the production (A_{new}) is higher than the savings from the replacement (ΔU) – the savings are too small to pay for the additional amortisation.

Table 1: Overview of the results for the washing machine calculated with cumulative energy demand (CED), ecological scarcity ’97 (UBP’97) and Eco-indicator ’99 (EI’99). A timely replacement is a beneficial option, if the condition $A_{new}/\Delta U < 1$ is fulfilled, i.e. R smaller than 1.

	CED (MJ-eq./a)	**UBP'97** (UBP/a)	**EI'99** (pts./a)
Amortisation (New machine) (A_{new})	4.2E+02	3.9E+04	3.60
Operation (New machine) (U_{new})	3.0E+03	1.2E+05	2.14
Operation (Old machine) (U_{old})	3.9E+03	1.6E+05	2.85
$\Delta U = U_{old} - U_{new}$	9.8E+02	4.1E+04	0.71
$R = A_{new}/\Delta U$	**0.42**	**0.94**	**5.04**

Whether or not timely replacement is advantageous not only depends on the evaluation method, but also on the assumption of the number of washings per year. The more often the machine is used, for example, the more important the use phase becomes and, hence, the higher the potential savings (*ΔU*), which in turn lowers the ratio *R*. The country of operation needs also to be considered, since the effects from the electricity consumption contributes an important share in the assessments of the washing machine. Country or site specific electricity mixes that score differently from the Swiss electricity mix used in this study, will result in an increased or decreased importance of the use phase [5]. These aspects can significantly influence the decision on timely replacements.

Fridge Freezer

A modern, energy efficient fridge freezer (a fridge and a separate freezer combined in a single appliance) was analysed for this study [6]. The net volume is 192 l for the fridge and 92 l for the freezer compartment. The annual energy consumption is 194 kWh. The fridge freezer is assumed to be operated in Switzerland and, as a consequence, using the Swiss supply electricity mix.

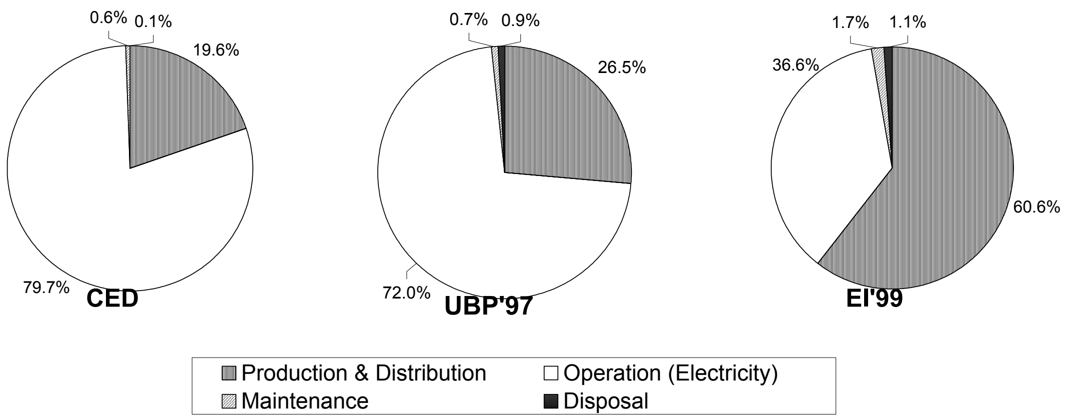

Figure 2: The relative shares of the different life cycle stages as results of the calculation of the cumulative energy demand (CED), the ecological scarcity points 97 (UBP’97) and the Eco-indicator points 99 (EI’99) for a modern washing machine.

The LCA results of the fridge freezer are rather similar to those of the washing machine. The direct electricity consumption during operation is the most important in cumulative energy demand (approx. 80%), a bit less in UBP’97 (72%) and in EI’99 production & distribution (61%) becomes more important than the electricity consumption (37%).

It is to be expected that the efficiency of the fridge freezer deteriorates over time due to aging of e.g. the insulation material, the seals and the cooling system itself leading to a certain underestimation of the use phase. This effect is mainly associated with cooling appliances, however. For other types of white goods the deterioration in efficiency is expected to be of minor importance [2].

Conclusions

Evaluations of timely replacements with more environmentally comprehensive indicators, like ecological scarcity '97 and Eco-indicator '99, tend to result in a lower importance of the use phase of white goods compared to cumulative energy demand. As a consequence, a timely replacement becomes less beneficial or even disadvantageous. An evaluation based on energy or energy related data can, therefore, lead to wrong conclusions from an environmental point of view.

The outcome also depends on the use pattern (i.e. how often or intensively an appliance is used) and the electricity mix (i.e. the location of use). The first aspect largely determines how much electricity is consumed, while the latter one determines how strong it is counted in the evaluation with the more comprehensive indicators. In order to make decisions on timely replacement it is, therefore, essential to consider these aspects carefully.

To achieve a high efficiency during operation the appliances are equipped with elaborate electronic controls, thicker insulations and other technical means, which turn the production more complex and in the case of the fridge freezer also more material consuming (increasing A_{new}). However, this might be balanced out by optimised construction and materials. On the other side the potential for savings is becoming smaller for efficient devices (decreasing ΔU), since they converge to the limitations of a technology (law of diminishing returns) [2]. The latter effect can, therefore, induce a shift towards a higher share of the production phase in all evaluation methods (R is becoming larger). This implies that the more efficient an appliance is, the less favourable a timely replacement might become. [2] found also an increased optimum life-span for newer appliances involving the same effect.

It can be said, as a final conclusion, that from a comprehensive environmental analysis an extended service life can become the more environmentally beneficial option than an early replacement. This becomes particularly true for highly efficient appliances like the ones analysed.

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