Repair or Buy a New One?
The Environmental Consequences for Electronics

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Abstract

It's a dogma that a long product lifetime is always an environmental benefit. But this is not always so in the case of electronics. The electronics sector contains active products, i.e. they consume electricity during use. A lower energy consumption in a new product may therefore "pay" for the total "fixed burden" of producing and disposing both the new and old products.

The dynamics of this mechanism has been investigated by an LCA screening of four product groups: televisions, PC's, mobile phones and frequency converters. Two product generations into the future were included in terms of the prevailing expectations for technological innovation. The environmental effects of new technology on these four product groups were assessed to determine the best environmental choice between the following two scenarios:

- **Buy a new product and dispose of the old one, OR**
- **Prolong the life of the product through repair.**

This paper will discuss methods and results, including the best purchase strategy or the best repair strategy.

Keywords
End-of-life strategies, Life Cycle Assessment, electronics

INTRODUCTION
The project "Environmental Consequences of Life Time Extension of Electronics Products" was initiated to determine the environmentally correct action to take when an electronics product breaks down. Should it be repaired to extend its lifetime, or should it be disposed of and replaced with a new product? In the case of electronics it is not always the best strategy to extend lifetime. A new product may have a lower energy consumption in use, and the related environmental savings may in fact "pay" for the environmental effects of disposing of the old product, and producing the new product. So, buying a new product and disposing of the old may in fact, in some cases, be the best environmental choice. It may even be environmentally preferable to dispose of a product that is still functional because a new product with a lower energy consumption has entered the market. This is schematically illustrated in Figure 1, which shows the development in the accumulated environmental load over time. For all active products, there is a "fixed burden" associated with production and disposal, and a "variable burden" associated with the product's use, as the graph illustrates.

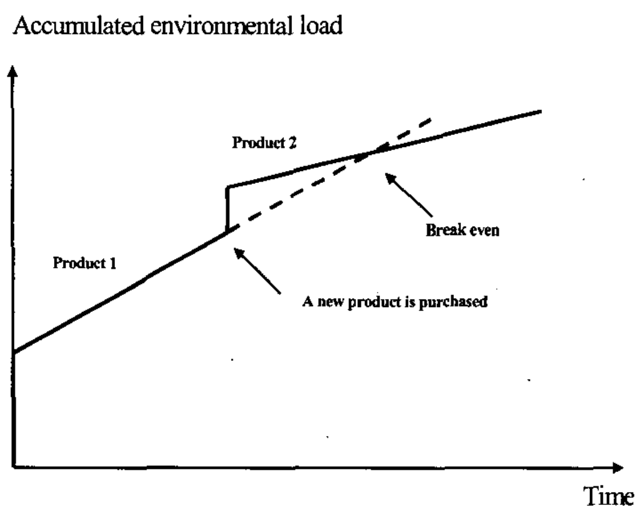

Figure 1. Buying a new product is preferable.

METHOD & GENERIC SCENARIOS
The total life cycle environmental load of an electronics product can be divided into a "fixed burden" and a "variable burden". The variable burden encompasses the environmental consequences related to the use of the product. To put it simply, this burden is proportional to the time of use, hence the term "variable burden". The longer the product is in use, the higher the total load contribution from that variable burden. The fixed burden is the environmental load associated with life cycle stages other than use, e.g. raw material extraction, the production of the product and its disposal/recycling. In figure 1, the fixed burden is the vertical contribution to the total accumulated load and the

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variable burden is the sloped line. The fixed burden is instantaneous, because the time line is the use time with the consumer, and it covers life cycle stages both before and after the use stage.

The calculations are based on quantitative measures of both the fixed burden and the variable burden. The starting point was the known and expected bill of materials (BOMs), and the known and expected use-stage energy consumption for four product generations: generation -1 (previous generation to the reference year 2002); generation 0 (the 2002 generation); generation +1 (the next product generation compared to 2002) and generation +2 (the following generation). The fixed burden was assessed from the BOMs, using the newly developed tool "A Designers Guide to Eco-Conscious Design of Electrical and Electronic Equipment". This tool was developed by the Institute for Product Development, the Danish Toxicology Center and GN-Teknik [1].

This tool is specifically aimed at companies that develop electronics, and assesses environmental consequences by means of two parameters: the energy parameter (E-parameter) and the resource consumption parameter (R-parameter). The E-parameter measures the primary energy consumption in all life cycle stages in terms of MJ. The R-parameter measures the consumption of materials resources in terms of the unit mille person reserve (mPR). This unit is also utilized in the Danish EDIP LCA method [2]. The starting point is a BOM. The R-parameter only includes materials resources, whereas energy carriers are covered intrinsically by the E-parameter. The calculations have taken the beneficial effects from product recycling into account. The main parameter for the assessments in this study has been the E-parameter, which has been proved by a number of LCA studies to be the dominant life cycle environmental determinant, given that production and disposal takes place under controlled circumstances, and that the problems associated with hazardous substance emissions have been effectively dealt with.

The R- and E-parameters have been calculated for future product generations by establishing what functional units will be in future products and extrapolating the sizes of these functional units compared to generation 0 for existing functional units and making new assessments of BOM's for future functional units. The generic content of functional units in future products has been assessed through interviews with a number of R&D staff from selected European electronics manufacturers.

A number of generic scenarios have been investigated. The consumer may wish to buy a new product and dispose of the old product, either because the old product is broken or because a new and more modern product offers additional features and functionality at a competitive price. In this situation, a new product may have either a lower or a higher variable burden. It is generally not an overall environmental benefit to buy a new product if the variable burden is higher in this product. But where the variable burden is lower, it may be environmentally beneficial to replace the old product, since the margin of the variable burden may in fact "pay" for the additional fixed burdens.

A product may be repaired when it fails, alternatively a new product may replace it. The two cases must be compared to determine the best environmental choice. The present study has achieved this by playing through a series of scenarios. It is generally assumed that the consumer will buy the prevailing product generation on the market at any given time. This is schematically shown in figure 2, where an old product is replaced by a future product generation with a lower variable burden.

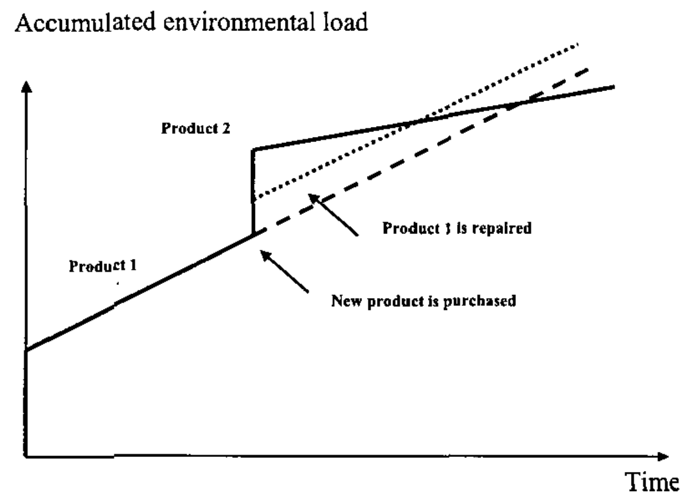

Fig. 2. Repair or buy a new one?

The issue of up-grading products has also been covered. Under the methodological framework of this study, the dynamics of this situation corresponds to the dynamics of repair.

ELECTRONICS IN THE FUTURE

The present study has focused on four product types: televisions, mobile phones, regular Internet PC's and frequency converters, thus covering a spread of domestic, office and industry applications.

The flat screen plasma television is expected to reach an affordable price by 2006, and thus become the next generation of "ordinary" televisions. The standard screen size is expected to be larger than today, around 32" and in the 16:9 format. Generation +1 is expected to dominate the market for a period of 5 years, and the subsequent generation +2 will therefore enter the market in around 2011. This television is still expected to be a plasma television but a built-in DVD will probably be standard. The effect consumption will most likely be about 200 W for a 2006 plasma television but is expected to drop to about 150 W in 2011. In comparison, the current 28" standard CRT type consumes about 90 W. The plasma television will, however, have somewhat lower stand-by consumption, but this does not outweigh the high operation consumption.

Coming generations of mobile phones will enter the market within the next few years. The next generation +1 is GPRS telephones (General Packed Radio Service) and could popularly be termed Internet phones, since they will make Internet access via phone hook-ups commonplace. This generation will typically have a somewhat larger color display and about an approx. 50% increase in operational energy consumption, compared to the SMS phones. The following generation +2, the so-called EDGE phones (Enhanced Data rates for Global Evolution), could popularly be called the video-phones, since they will include the possibility for transfer of real-life images. These will have an even larger video display and an energy consumption of about 2.5 times today's standard.

Based on past developments, the Internet PC will no doubt become faster, and a fairly large LCD screen is already the market norm in many countries. A lower energy consumption is associated with the shift in technology to LCD screens, both for operational and stand-by consumption. The LCD screen is expected to be the major change in terms of environmental performance for regular Internet PC's over the coming two product generations. The time span between generations is short – about 1.5 years. A 17" TFT screen is expected to be standard for generation +1 and this will result in an approx. 30% increase in operational energy consumption. The stand-by consumption, however, will probably decrease from about 5W in generation 0 to 3W in generation +1. The screen size will probably still be a 17" flat screen for generation +2, however, with lower operational and stand-by energy consumptions. The operational consumption will likely fall from about 40W in generation +1 to 35W in generation +2. The CPU energy consumption will probably remain unchanged. The screen's stand-by consumption will decrease from about 3W in generation +1 to 2W in generation +2, whereas CPU stand-by will drop from 3W to about 0.5W. Generation +2 will probably feature blue tooth technology but this is expected to have little direct environmental consequence.

Frequency converters are expected to steadily become more efficient over the coming two product generations. This has environmental significance because the converters often relay relatively large amounts of energy, and even a minor increase in efficiency will be associated with a large change in the variable burden in absolute terms. Efficiencies of generations +1 and +2 will be about 2% and 4% higher respectively. Although there will be changes in ease of operation and materials choice, the expected progress towards increased efficiency is by far the most environmentally significant development.

SPECIFIC SCENARIOS AND DETAILED CONCLUSIONS

The following tables show specific scenarios and conclusions.

Table 1. The study covered 7 specific scenarios for televisions

Scenario	Scenario description	Scenario conclusion
TV1	Generation -1 is replaced by generation 0 after 5 years – both are standard CRT televisions but the energy consumptions (variable burden) are lower in generation 0, so the curves intersect in future.	Curves intersect at year 15, 10 years after replacement. Since the lifetime is expected to be 10 years, the best environmental choice is to keep the old one.
TV2	Generation -1 is replaced by generation +1 after 10 years	The curves diverge, since the set has a higher variable burden. This action is not environmentally preferable.
TV3	Generation 0 is replaced by generation +1 after 5 years	The conclusion is the same as for scenarioTV2
TV4	Generation 0 is replaced by generation +2 after 10 years	The curves diverge. Even though generation +2's energy consumption is lower than generation +1, it is still larger than the traditional CRT television. This action is not environmentally preferable.
TV5	Generation +1 is replaced by generation +2 after 5 years	The curves intersect at year 10 after 5 years. If generation +1 is kept for 10 years it corresponds in environmental terms to buying a generation +2 when it enters the market in year 5.
TV6	Generation -1 has the basic chassis (electronics) replaced compared to purchase of generation 0 after 5 years.	The curves intersect at year 14 after 9 years. The environmental burden associated with this repair scenario is quite small, and the best environmental choice is to replace the electronics.
TV7	Generation +1 has the basic chassis (electronics) replaced compared to purchase of generation +2 after 5 years.	The curves intersect at year 10 after 5 years. Replacing the electronics is environmentally preferable if generation +1 is not kept for longer than 5 years.

Table 2. The study covered 5 specific scenarios for mobile phones

Scenario	Scenario description	Scenario conclusion
MT1	Generation -1 is replaced by generation 0 after 2 years	The two curves will never intersect, because the variable burden of generation 0 is higher than for generation –1. It is not the best environmental choice to buy a new mobile phone.
MT2	Generation –1 is replaced by generation +1 after 3 years	The conclusion is the same as for scenario MT1. The effect is more pronounced since the difference of the variable burden is greater.
MT3	Generation 0 is replaced by generation +2 after 3 years	Same conclusion as above.
MT4	Generation 0 has the PWB replaced, compared to purchase of generation +1 after 2 years	The two curves will never intersect, since the variable burden rises with each generation. The best environmental choice is to have the old product repaired. This scenario looks at the repair scenario with the highest associated fixed burden; this conclusion therefore applies to all other realistic repair scenarios.
MT5	Comparison between all 4 generations.	The variable burden increases with each new generation. It will generally not be an environmental advantage to select a new purchase instead of repair within these generations.

Table 3. The study covered 9 specific scenarios for Internet PC's

Scenario	Scenario description	Scenario conclusion
PC1	Generation -1 is replaced by generation +1 after 3 years	The curves intersect at year 10, after 7 years. Replacing is not the best environmental choice as the life expectancy for a PC is less than this.
PC2	Generation 0 with CRT screen is replaced by generation +2 after 3 years	The curves intersect at year 8.5, after 5.5 years. The variable burden is smaller for generation +2 since this generation features a TFT screen but the environmental benefit is not strong enough to warrant the purchase.
PC3	Generation 0 with a 15" TFT screen is replaced by generation +2 after 3 years	The curves do not intersect within the studied time frame. It is generally not preferable to replace the old PC, since both products feature TFT screens with a low energy consumption.
PC4	Generation 0 with a CRT screen gets a 15" TFT screen after 1 year	The curves intersect at year 4.5, after 3.5 years. When keeping a PC for this long, it is an overall environmental benefit to get a TFT screen.
PC5	Generation 0 with a CRT screen is compared to generation 0 with a 15" TFT screen	The curves intersect at just under 3 years. When keeping a PC for over 3 years, the best environmental choice is a PC with a TFT screen.
PC6	Generation -1 has its processor and motherboard replaced, compared to purchase of a new generation 0 with a 15" TFT screen after 3 years	The curves intersect at year 7.5, after 4.5 years. The fixed burden associated with the replacement is marginal. The same applies to replacing the CD-Rom drives, hard discs, floppy discs, keyboards, modems and mouse, which are associated with fixed burdens of the same size or less. Where generation 0 is purchased with a 15" TFT screen, it must have a lifetime of over 4.5 years for the action to be environmentally preferable. On the other hand, it is always a better environmental choice to repair a generation –1, compared to buying a generation 0 with a CRT screen.
PC7	Generation -1 has its processor and motherboard replaced, compared to purchase of a new generation +1 after 3 years	The curves intersect at year 10, after 7 years. The environmentally best action is to repair the old PC, not buying a new generation +1.
PC8	Generation 0 has its processor and motherboard replaced, compared to purchase of a new generation +2 after 3 years	The curves do not intersect within the studies time frame. Repair is the best environmental choice.
PC9	Generation -1 has its processor and motherboard replaced, compared to purchase of a new generation +1 after 3 years, or a new generation +2 after 5 years.	Curves intersect after approx. 10 years for both new generations. The preferable option is repair and life time extension.

Table 4. The study covered 3 specific scenarios for frequency converters

Scenario	Scenario description	Scenario conclusion
FQ1	Generation -1 is replaced by generation 0 after 6 years	The curves intersect at 7 years, after just 1 year. The environmentally preferable action is to get the new generation and dispose of the old product.
FQ2	Generation -1 is replaced by generation +1 after 12 years	Basically same as above.
FQ3	Generation -1 has basic PWB replaced compared to purchase of new generation 0 after 6 years.	Same as above. Repair is not the best environmental choice. Instead new products should be purchased upon entry to the market.

GENERAL CONCLUSIONS

The consumer preference for larger and larger televisions, and not least the market introduction of the new plasma televisions, points to products with increasing energy consumption, even through stand-by consumption will decrease. With the increase in energy consumption it is not generally an environmental advantage to replace the old products. Old televisions should rather be repaired, when dysfunctional.

The coming generations of mobile phones will be capable of transmitting increasingly larger amounts of data. They will have more features and increased functionality. Energy consumption is expected to increase correspondingly over the next two product generations. There is mostly for this reason no environmental argument for replacing old mobile phones – they should be repaired instead.

Today, the stationary Internet PC with a conventional CRT screen is a mature product. Energy consumption for this configuration is slowly being optimized, although there may be a big difference between brands. On the other hand, the new flat screens represent an environmentally better solution due to their lower energy consumption. A flat screen is therefore the best environmental choice when purchasing a new Internet PC. It may in some cases be environmentally advantageous to replace CRT screens with LCD screens. It is not advantageous to get another CRT screen if the old one fails or is considered too small.

The project has also focussed on frequency converters as an example of industrial electronics with a high energy consumption. The efficiency of these products will slowly increase, and since the difference in variable burden is large in absolute terms, it is generally the best environmental choice to buy new products when they enter the market and dispose of the old ones; even if the old product still works.

DISCUSSION

This study has only scratched the surface of what must be said to be a very complex field. The general model with a division of the total environmental burden into a fixed burden and a variable burden seems to work quite well, and allows a simple interpretation of scenarios. This looks deceptively simple, since calculating the sizes of fixed and variable burdens requires both LCA tools and LCA data, and is quite demanding in terms of resources. Calculating exact measures with current LCA methods remains problematic.

Another issue is the scenario dynamics as they evolve further into the future. In this study the authors have only looked two product generations into the future (this is really as far as we are comfortable in looking) and we have based our conclusions on the dynamics of only four generations in total. Clearly the scenario dynamics should include secondary and higher order effects as three or more generations evolve into the future.

Finally, we would like to make a few comments on how realistic the scenarios are. Obviously we have had to make a number of assumptions to find an "average" contemporary product, which could then act as the basis for predicting the BOMs of future products and their appearance. The "average" contemporary product is a simplification, and today's products represent a wide spread in technological solutions and basic parameters. Making exact predictions of what future products will look like cannot in principle be done, we can only look into the crystal ball of R&D departments. This could be done with greater accuracy if it was the company and not a consultant doing the calculations.

With this study, we hope to have contributed to the ongoing debate on the best end-of-life scenario for electronics, and at least to have pierced the dogma that a long product lifetime is always an environmental benefit.

REFERENCES

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[2] H. Wenzel, M. Hauschild, L. Alting, "Environmental Assessment of Products – Volume 1: Methodologies, Tools and Case Studies in Product Development", Chapman & Hall, 1997.