THE ENVIRONMENTAL IMPACTS OF A DESKTOP COMPUTER: INFLUENCE OF CHOICE OF FUNCTIONAL UNIT, SYSTEM BOUNDARY AND USER BEHAVIOUR

DATORA IETEKME UZ VIDĒI ATKARĪBĀ NO IZVĒLĒTĀS FUNKCIONĀLĀS VIENĪBAS, SISTĒMAS ROBEŽAS, UN PATĒRĒTĀJA UZVEDĪBAS

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Introduction

Pollution prevention during product design phase gains its importance over the other, more historically known principle – pollution reduction in the end of pipe. This approach requires prediction of potential environmental impacts to be avoided or reduced and prioritisation of the most efficient action areas.

Currently the most appropriate method for this purpose is life cycle assessment (further on LCA) - a method for accounting and attributing all environmental impacts occurring during life time of a product, starting with production of raw materials and ending with disposing of or recycling the wasted product in the end of product's life. As reported in a study, *life cycle assessment (LCA) is increasingly used to identify such priorities but can be misleading* [1], if the performers of the study are disregarding gaps of the information and limitations of methodology. One important step in order to achieve good results is proper definition of the functional unit and bordering for the LCA research.

Nowadays electronic products play an important role in our daily life, and this is one of the fastest growing product areas. For example, from 2004 to 2008 the number of computers in Latvian households has doubled (from 235820 to 50 9846 units) [2] and currently a half of all Latvian households owns a computer.

This study reports research results on the environmental impacts of a control unit of a desktop computer, and the role of various factors, e.g., consumer behaviour,

technical requirements etc. There is quite a number of life cycle assessments on computers performed [3, 4, 5, 6, 7], and some of them emphasize the difficulties of the finding the right functional unit. The current study contributes to the discussions on the functional unit.

Methodology

In our work we performed simplified LCA using eco-indicators -99 approach [8], which summarizes the environmental damage in milipoints. The system boundary and life cycle phases, included in the study, are shown in the Figure 1. The reason for exclusion of production and transportation is lack of information about these phases.

Five control units of outdated desktop computers, disposed by their users, were assessed. The desktop units were dismantled on site and weighed on KERN-49N balances; the materials were identified visually, as well as using inventory data from one of the studies [3]. The inventory results were quite close to each other, and we include in this article information only from two computers with most complete electricity measurements. Characteristics of the computers are shown in Table 1.

We measured electricity consumption during various regimes (working mode, sleep mode, standby). Each regime was running 10 minutes; the electricity consumption was measured each minute with power meter Etech PM-300.

Fig.1. System boundary of the study

Grey boxes/arrows: included in the study; white boxes /arrows: excluded from the study

Table 1.

Characteristics of the computers included in the study

Tested desktop unit (further on DTU)	Abbreviation	RAM (MB)	Year of production	CPU model
1. desktop unit	1DTU	384	2000	Intel Pentium III MHz 650
2.desktop unit	2DTU	512	1998	Intel Pentium III 550 Mhz

Definition of functional unit and system boundary

The definition of the functional unit and system boundary plays an important role during LCA studies, since it expresses the environmental damage per unit of function delivered by the product. Screening the studies on computers mentioned above [3, 4, 5, 6, 7], we saw, that the final choice of all authors for functional unit for all computers was one desktop computer. An EU study on personal computers (2005) explains: „since personal computers are used to fulfill so many different needs, it is impossible to find one technical performance measure that could represent all these needs in a good way”[4].

Additionally, some of the studies specify lifetime, technical specification and other parameters, an overview see in Table 2.

In our study we have chosen as a functional unit a desktop computer, i.e. the control unit. In order to see how the environmental impact depends on various circumstances (depending on consumer behaviour, life span, recycling), we developed various scenarios,

leaving such parameters as life span and recycling as variables.

Electricity consumption

In Table 3 an overview on the electricity consumption during various regimes is shown. The energy consumption depending on the chosen software run differs up to 20%. Internet and communication programs are among largest electricity consumers, which can be explained by large file exchange.

Modelling consumer behaviour

To model consumer behaviour, besides measured computers we also included in research a hypothetical computer complying with the Energy Star requirements for year 2004 [9] (see table 4).

Table 2.

Functional unit of a desktop computer in different LCA studies

Source	Functional unit	Additional specifications
EU 1998 [3]	3 elements: a control unit, a monitor and a keyboard; can be analysed together or separately	Power consumption: 60 Watts for control unit (incl. power consumption of the keyboard) PC has no energy saving facilities consuming 160 Watts when turned on. The lifetime: 3 years. The PC is estimated to be turned on for 8 hours per day, 230 days per year. Altogether it runs for 5520 hours during its lifetime. Detailed technical specifications.
EU 2005 (EuP) [4]	1 computer (desktops and laptops)	Alternatives discussed: “euros of computer” or “computer years”
EU 2006 [5]	One desktop unit	Detailed technical specifications Distribution: Shipping within Europe (1000 km - Ireland) Use: Max mode: 152 W PC , Min mode: 80 W PC, Sleep mode: 1,4 W PC Off mode: 1 W PC / 1 W monitor Years of use: 4 End of Life: 16,75 % to incineration, 18,25 % to landfill, 65 % to recycling
China 2009 [6]	Desktop PC system a control unit, a monitor(CRT un LCD), a keyboard mouse	The functional unit is a desktop PC system which consists of four different subunits: desktop computer itself, the screen, keyboard and the mouse. The examined PC system (incl. technical specifications) is 4.2 h per day active and 2.6 h per day in either standby or sleep mode (assuming a 40% office and 60% home use of the PC system) during 6 years before the complete system is handed over for EoL treatment. For the distribution and the subsequent use of the desktop PC system, an export amount of 10% of the production volume (to Europe, the United States but also other Asian countries) is assumed, based on the current trade statistics of China
Korea 2006 [7]	Spatial context: a personal computer made, used and disposed of in Korea	Technical specifications Manufactured in Korea in 2001 Temporal context: the life span of a PC, as suggested by authorities, is assumed to be 4 years

Based on personal experience of the project team, we developed four potential user scenarios – a very “green” consumer (unplugging computer every night), an energy saving consumer (switching off but not unplugging the computer every night – potentially the most typical behaviour), two grades of a less aware consumer (leaving computer in sleeping mode during nights, switching off during holidays) and the worst case (disabling sleeping mode regime). We calculated electricity consumption over one year for 230 working days minus 24 vacation days, 8 hours working day, and 1 h lunch break. The results can be seen in Figure 2.

Although the energy consumption during work differed from computer to computer, in case of the very green consumer and energy saving consumer the total yearly energy consumption for all cases (Energy Star, both tested computers) is close compared to the other

consumer behaviour types. The less aware the consumer behaves, the more increases the energy consumption for tested computers, but energy consumption for the hypothetical Energy Star computer is not significantly changing: thus, the requirements of Energy Star are designed to achieve energy efficiency independently from consumer behaviour. However, as soon the consumer disables sleeping mode, even the computer complying with Energy Star loses the advantage. From this modelling we can conclude that the biggest influence on the energy consumption is raised by the ability of the sleeping mode. Nevertheless, the very “green” consumer can achieve nearly the same efficiency.

Table 3.

Electricity consumption of a personal computer desktop control unit during different working regimes (W/h)

	1 DTU	2 DTU
Standby (turn off)	9	8
Sleep mode (0.5 h after non-use)		39
Idle mode	55	57
Microsoft Office	61	
Processing large files	67	77
Internet	69	77
Skype, MSN	69	72
Games	57	61
Video	62	72
Music	56	65
Many processes	67	77
Medium (result)	63	72
Medium/Idle mode	1.15	1.25

Table 4.

Energy consumption of a hypothetical computer, complying with Energy Star requirements (W/h)

after turning off	2
automatically 0.5 h after non-working period	4
switch on, no process	50
medium	60 (calculated)

Choice of scenarios

For further research of the environmental impacts of the desktop computer control unit we developed following scenarios based on the inventory results on the 2nd tested computer (2DTU):

1. Base scenario:
 - most common consumer behaviour based on researchers own experience, e.g. leaving

computer in sleeping mode during nights, switching off during holidays (see figure 2),

- 4 year service life (medium age of the computers delivered to the recycling company, as reported during the interview with this company performed by the project team);
 - 25% of the computers recycled (situation for Latvia – as reported by the Latvian Ministry of the Environment [10, 11], in the year 2008 the amount of the electronic products placed on the market are 12,494 kg/ person, but the processed electronic waste is 2,512 kg / person; unfortunately we do not have more precise data, but, taking into account growth of the electronic market, we can assume, that less than 25% of the electronic waste on the market is going to recycling streams)
 - EU average energy supply
 - Produced in China, combined transport sea/ road
2. Second use of the case
 3. Service life expanded to 6 years (recalculated to 4 years)
 4. Computer complying with the Energy Star requirements [9]
 5. Achieving 70% of materials recycling (assumption of the study for Ecodesign directive – currently 60% of the computers are recycled in Europe [4])
 6. Best consumer behaviour (see figure 2)
 7. Switch to Austrian energy net (since Austrian energy net has one of highest share of renewable sources in the EU [12])
 8. Switch to own, renewable energy supply (solar energy)
 9. Change of transporting mode (aircraft instead of combined sea/road transport)
 10. The best option from all scenarios (2nd use of the case, prolonged service life).

Results from this modelling are presented in the figure 3. From the graph we can see, that the options for improvements lie in different areas emphasizing importance to consider entire life cycle including production of raw materials and disposing of, since solutions can be found in very different areas.

Fig.2. Yearly energy consumption of the desktop computer control unit

Fig.3. Changes of relative environmental impact of the control unit of the desktop computer by various scenarios (base scenario = 100%)

With regard to functional unit, a focus to the actual function is important and too many limitations are reducing potential for finding the action areas. For example, if we define strict service life in definition of functional unit (e.g., four years) we would lose information on impacts of prolongation of service life.

In case of researched computer – DTU2, prolongation of the service life can reduce environmental impact by 14%, but second use of the materials (e.g., case) by 6%. A study on laptop computer even emphasizes the reuse instead of recycling: *Because we have seen that the control unit is the main contributor to environmental impact from the recycling process, our results suggest that increased reuse of the control unit, or alternatively, redesign of the control unit, offers the most effective strategy for improving life cycle environmental management of NBs [notebooks] and diminishing their negative contribution to environmental impact* [13].

This is an option disliked by both – producers and consumers. Current tendencies of the developing electronic market show rapid replacement of the electronic products by newer models. The designers and engineers claim, that “most consumers dislike maintaining, servicing, or repairing their products, and designs that do not minimise or eliminate the need for such maintenance and repair are more likely to become commercial failures” [14], making strategies for second use and longer service life (maintenance instead of replacement) less attractive for producers. Such products are less attractive for an average consumer, but there is a potential for a green procurement – institutions act differently as private persons, as well as consumer awareness building.

According to the working plan by the directive on Ecodesign for energy using products new standards for computers will be issued soon [15], putting on stricter requirements for producers. However, in Figure 3 we can see, that the environmental impacts can be reduced significantly also by measures independent from product producers (greening the national energy supply or improving waste management -increasing product stream going for recycling). This demonstrates the importance of the systemic approach when planning measures in the environmental policy.

In this study we included rather old computers, one can ask, what would be different in case of more actual models. Our preliminary results show, that the energy consumption during working mode of newer models even increases due to increasing capacity of processor, and we saw positive correlation among electricity consumption and processors’ capacity. However, in standby and sleep mode electricity consumption for newer models should be lower, since more and more computers are complying with requirements of Energy Star.

Conclusion

In this study we researched environmental impacts of a desktop computer and demonstrated that actions for improvements lie in different areas. The study concludes that approach of defining functional unit must be sufficiently flexible to avoid discounting areas of potential actions. Therefore with regard to computers we agree with other authors using functional unit “one computer” but suggest not binding to its service life or usage time, but develop several scenarios varying these parameters.

The study also demonstrates importance of systemic approach when assessing complex product systems – as more complex the system is, as more wide the scene for potential actions. We conclude that regarding computers, which belong to energy using and material intensive products, the measures to reduce environmental impacts lie not only with producer and user of a particular product, but also with the entire national energy supply and waste management system. Improvements here can significantly reduce environmental impacts of such products.

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Jana Simanovska, Māra Šteina, Kārlis Valters, Gatis Bažbauers, Datora ietekme uz vidi atkarībā no izvēlētās funkcionālās vienības, sistēmas robežas, un patērētāja uzvedības

Vides politikā aizvien vairāk pieaug vērība piesārņojuma novēršanai jau produkta un ražošanas procesa dizaina (projektēšanas) posmā, salīdzinot ar citu, vēsturiski pazīstamāku principu – piesārņojuma novēršanu «caurules galā». Šīs pieejas īstenošanai nepieciešams paredzēt produkta vai procesa iespējamo ietekmi uz vidi, un arī izvēlēties visefektīvākos pasākumus, kā šo ietekmi samazināt. Šobrīd šim mērķim vispiemērotā metode ir dzīves cikla analīze – metode, ar kuras palīdzību uzskaita visas produkta vai procesa radītās ietekmes uz vidi katrā produkta dzīves cikla posmā, sākot ar izejmateriālu ražošanu un beidzot ar atkritumos nonākušā produkta otrreizējo pārstrādi vai noglabāšanu. Tomēr, ja analīzes veicēji izvēlas neatbilstošu metodiku, vai interpretējot rezultātus, neņem vērā trūkstošās informācijas ietekmi, var nonākt pie kļūdainiem secinājumiem.

Šeit aprakstītā pētījuma laikā mēs pētījām galda datoru ietekmi uz vidi, izmantojot vienkāršotu dzīves cikla analīzes metodi – Indikatorus' 99, un izstrādājām vairākus scenārijus (pagarinot produkta dzīves ilgumu, mainot patērētāja uzvedību, enerģijas piegādi). Pētījuma rezultāti liecina, ka pasākumi ietekmes uz vidi mazināšanai ir veicami dažādās jomās. Funkcionālā vienība ir jādēfinē pietiekami elastīgi, lai izslēgtu to, ka pētījuma veicēji nepamana svarīgas jomas pasākumu veikšanai. Tāpēc, līdzīgi citiem autoriem, mēs piekrītam, ka datora gadījumā funkcionālā vienība var būt „1 dators”, bet neiesakām piesaistīt to pie dzīves ilguma, vai

izmantošanas laika, tā vietā izstrādājot vairākus scenārijus, mainot šos parametrus.

Pētījums arī parāda sistēmiskas pieejas nepieciešamību, vērtējot kompleksu produktu sistēmu ietekmi uz vidi. Mēs secinām, ka datoru gadījumā, kas ir energo- un materiālietilpīgi produkti, pasākumi vides ietekmes mazināšanai jāveic nevien produktu ražotāja un lietotāja līmenī, bet arī nacionālā līmenī, piemēram, mazinot nacionālās enerģijas apgādes sistēmas ietekmi uz vidi, kā arī pilnveidojot atkritumu apsaimniekošanas sistēmu. Uzlabojumi šajās jomās ievērojami var samazināt materiālietilpīgu un energoietilpīgu produktu ietekmi uz vidi.

Jana Simanovska, Māra Šteina, Kārlis Valters, Gatis Bažbauers, The environmental impacts of a desktop computer: influence of choice of functional unit, system boundary and user behaviour

The pollution prevention during the design phase of products and processes in environmental policy gains its importance over the other, more historically known principle – pollution reduction in the end-of-pipe. This approach requires prediction of potential environmental impacts to be avoided or reduced and a prioritisation of the most efficient areas for action. Currently the most appropriate method for this purpose is life cycle assessment (LCA)- a method for accounting and attributing all environmental impacts which arise during the life time of a product, starting with the production of raw materials and ending with the disposal, or recycling of the wasted product at the end of life. The LCA, however, can be misleading if the performers of the study disregard gaps of information and the limitations of the chosen methodology.

During the study we researched the environmental impact of desktop computers, using a simplified LCA method - Indicators' 99, and by developing various scenarios (changing service life, user behaviour, energy supply etc).

The study demonstrates that actions for improvements lie in very different areas. The study also concludes that the approach of defining functional unit must be sufficiently flexible in order to avoid discounting areas of potential actions. Therefore, with regard to computers we agree with other authors using the functional unit "one computer" but suggest not to bind this to service life or usage time, but to develop several scenarios varying these parameters.

The study also demonstrates the importance of a systemic approach when assessing complex product systems – as more complex the system is, the more broad the scope for potential actions. We conclude that, regarding computers, which belong to energy using and material- intensive products, the measures to reduce environmental impacts lie not only with the producer and user of the particular product, but also with the whole national energy supply and waste management system. Improvements in the latter areas can significantly reduce the environmental impacts of such products.

Яна Симаковска, Мара Штейна, Карлис Вальтерс, Гатис Бажауэрс, Влияние на окружающую среду настольного компьютера в зависимости от выбранной функциональной единицы, границ системы и поведения пользователя

В политике окружающей среды всё больше увеличивается значение предотвращения отходов уже на стадии дизайна (проектирования) продукта и

процесса, в сравнении с другим, исторически более известным принципом - уменьшение отходов „в конце трубы”. Для осуществления такого подхода необходимо предусмотреть возможное влияние продукта или процесса на окружающую среду, а так же выбрать наиболее эффективные меры по уменьшению этого влияния. Сейчас самый лучший метод для достижения этой цели - анализ жизненного цикла - метод, с помощью которого учитывают всё произведённое влияние продукта или процесса в каждом участке жизненного цикла продукта, начиная с производства исходных материалов и заканчивая вторичной переработкой или захоронением, попавшего в отходы, продукта. Однако, если исполнители анализа выбирают несоответствующую методику или, интерпретируя результаты, не берут во внимание влияние отсутствующей информации, можно прийти к ошибочным выводам.

Во время здесь описанного исследования мы изучали влияние портативного компьютера на окружающую среду, используя упрощённый метод анализа жизненного цикла - Indicators' 99, и разработали несколько сценариев (увеличив длительность жизни продукта, меняя поведение потребителя, поставку энергии). Результаты исследования показывают, что меры по уменьшению влияния на окружающую среду могут быть произведены в разных областях. Функциональную единицу необходимо определить достаточно эластично, чтобы исключить то, что исполнители исследования не увидели важные области для выполнения мер. Поэтому, в сравнении с другими авторами, мы согласны, что в случае компьютера, функциональная единица может быть „1 компьютер”, но не рекомендуем привязывать это к длительности жизни или времени использования, вместо этого разработав несколько сценариев, меняя эти параметры.

Исследование также показывает необходимость системного подхода, анализируя влияние на окружающую среду сложных систем продукта- чем сложнее система, тем шире область потенциальных мер. Мы подытоживаем, как в случае с компьютером, где продукты энерго- и материалоемкие, меры по уменьшению влияния на окружающую среду необходимо выполнять не только на уровне производителей и потребителя продукта, но и на национальном уровне, например, уменьшить влияние на окружающую среду системы национального энергообеспечения, а так же усовершенствуя систему менеджмента отходов. Усовершенствования в этих областях могут значительно уменьшить влияние материалоемких и энергоёмких продуктов на окружающую среду.