European Commission

Preparatory study on the Review of Regulation 617/2013 (Lot 3)

Computers and Computer Servers

Simplified tasks 5 & 6 report

Base cases and Design options

Final version for consultation

2nd of February 2017

VITO NV
Boeretang 200
2400 Mol
Belgium
vito.be

Viegand Maagøe A/S
Nr. Farimagsgade 37
1364 Copenhagen K
Denmark
viegandmaagoe.dk

Prepared by:

Viegand Maagøe and VITO
Study team: Larisa Maya-Drysdale, Michelle Peled, Jonathan Wood, Mette Rames and Jan Viegand (Viegand Maagøe)
Quality manager: Wai Chung Lam (VITO)
Website design and management: Karel Styns (VITO)
Contract manager: Karolien Peeters (VITO)

Prepared for:

European Commission
DG ENER C.3
Office: DM24 04/048
B-1049 Brussels, Belgium

Contact person: Paolo Tosoratti
E-mail: Paolo.TOSORATTI@ec.europa.eu

Project website: computerregulationreview.eu

Specific contract no.: ENER/C3/2012-418 LOT1/11/FV 2015-543
Implements Framework Contract: ENER/C3/2012-418 LOT N° 1

This study was ordered and paid for by the European Commission, Directorate-General for Energy.

The information and views set out in this study are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

This report has been prepared by the authors to the best of their ability and knowledge. The authors do not assume liability for any damage, material or immaterial, that may arise from the use of the report or the information contained therein.

More information on the European Union is available on the internet (http://europa.eu).

Table of contents

List of tables

List of figures

Abbreviations

AC	Alternate Current
AVFS	Adaptive Voltage and Frequency Scaling
B2B	Business to Business
B2C	Business to Consumers
BAT	Best Available Technology
BOM	Bill of Materials
CCFL	Cold cathode fluorescent lamp
CPU	Central processing unit
DBEF	Dual Brightness Enhancement Film
DC	Direct Current
dGfx	Discrete Graphic Card
DFS	Dynamic frequency scaling
DIY	Do-it-yourself
DVS	Dynamic voltage scaling
EC	European Commission
EEE	Electrical and electronic equipment
EGA	External graphics adapter
EMEA	Europe, Middle East and Africa
EPA	Environmental Protection Agency (USA)
EPS	External power supply
ESOs	European Standardisation Organisations
EU	European Union
GHG	Greenhouse Gases
GPU	Graphics processing unit
GWP	Global Warming Potential
HDD	Hard disk drives
iGfx	Integrated graphics processing unit
IPS	Internal power supply
JRC	Joint Research Centre
LCD	Liquid crystal display
LED	Light emitting diode
Li-ion	Lithium-ion battery
NiCad	Nickel-Cadmium battery
NiMH	Nickel-metal hydride battery
ODD	Optical disk drive
OS	Operating System
PCB	Printed Circuit Board
PRO	Producer Responsibility Organisation
PSR	Panel self-refresh
PSU	Power Supply Unit
RAM	Random access memory
SME	Small and medium enterprise

SoC	State of charge of a battery
SRAM	Static RAM
SSD	Solid state drives
SSHD	Solid state hybrid drive
VR	Virtual Reality
WEEE	Waste Electrical and Electronic Equipment

Introduction to the task reports

This is the introduction to the interim report of the preparatory study on the Review of Regulation 617/2013 (Lot 3) for Computers and Computer Servers. The interim report has been split into five tasks, following the structure of the MEErP methodology. Each task report has been uploaded individually in the project's website. These task reports present the technical basis to define future ecodesign and/or energy labelling requirements based on the existing Regulation (EU) No 617/2013.

The task reports start with the definition of the scope for this review study (i.e. task 1), which assesses the current scope of the existing regulation in light of recent developments with relevant legislation, standardisation and voluntary agreements in the EU and abroad. The assessment results in a refined scope for this review study.

Following it is task 2, which updates the annual sales and stock of the products in scope according to recent and future market trends and estimates future stocks. Furthermore, it provides an update on these trends as well as on consumer expenditure data, which will be used on the assessment of additional life cycle consumer costs if or when setting new requirements.

Next task is task 3, which presents a detailed overview of use patterns of products in scope according to consumer use and technological developments. It also provides an analysis of other aspects that affect the energy consumption during the use of these products, such as component technologies, power supply load efficiency and user interface in particular power management practices. Furthermore, it also touches on aspects that are important for material and resource efficiency such as repair, maintenance and replacement practices, and it gives an overview of what happens to these products at their end of life. Finally, this task also touches on standardised methods to quantify energy consumption in the different power modes, touching on the active mode, and it presents an overview of the energy consumption of products in scope based on manufacturers and ENERGY STAR database information.

Task 4 presents an analysis of current average technologies at product and component level, and it identifies the Best Available Technologies both at product and component level. An overview of the technical specifications as well as their overall energy consumption is provided when data is available. Finally, the chapter concludes with an overview of the product configurations in terms of components and key materials of current average and Best Available Technologies placed on the European market.

Simplified tasks 5 & 6 report presents the base cases, which will be later used to define the current and future impact of the current computer regulation if no action is taken. The report shows the base cases energy consumption at product category level and their life cycle costs. It also provides a high-level overview of the life cycle global warming potential of desktops and notebooks giving an idea of the contribution of each life cycle stage to the overall environmental impact. Finally, it presents some identified design options which will be used to define reviewed ecodesign requirements.

Task 7.1 report presents the policy options for an amended ecodesign regulation on computers and computer servers. The options have been developed based on the work throughout this review study, dialogue with stakeholders and with the European Commission. The report presents an overview of the barriers and opportunities for the reviewed energy efficiency policy options, and the rationale for the new material efficiency policy options. This report will be the basis to calculate the estimated energy and material savings potentials by implementing these policy options, in comparison to no action (i.e. Business as Usual – BAU).

The task reports follow the MEErP methodology, with some adaptations which suit the study goals

5. Introduction to tasks 5 & 6 report

Tasks 5 and 6 as in MEErP have been merged into one task report for this review study. This has been done to give a better understanding on the process for selecting the base cases and the subsequent identification of design options which are used to set the ecodesign requirements. There are two sets of ecodesign requirements: (i) energy efficiency requirements, and, (ii) material efficiency requirements. These are presented in task 7.1 report.

This report is a 'simplified' version, as it focuses on the presentation of the base cases and their life cycle costs and environmental impacts, and of some identified design options that present energy efficiency improvement potential. A more extended version will be elaborated after the stakeholders meeting with the expectation that input from the stakeholders will help to refine the information and assumptions used to define the base cases, their LCCs and their life cycle environmental impacts. Furthermore, with the expectation that their input will also help to refine the definition of the design options and of the policy options for reviewed ecodesign/energy labelling requirements.

In the first section of this report, the base cases are presented. These have been defined according to the average technologies identified in the task 4 report, but covering also other technologies in order to have enough energy data points from the ENERGY STAR database to establish the power demands in the different power modes. More energy points were necessary because the base cases were defined not only at product type, as it was done in task 4, but also at product category level. The power demand values at product category level are the basis to establish the default policy option, which is the 'Business as Usual' (BAU). The energy data points from the ENERGY STAR database are from products placed on the market in the years 2015 and 2016.

In the second section, the Life Cycle Costs (LCC) of the base cases is presented based on the information about production, use and end-of-life which have been presented in previous chapters. The calculation of the LCC was done at a product type level, as no detailed costs information exists for each product category. The LCCs will be used to calculate the improvement costs to the consumers when reviewing the current ecodesign energy efficiency requirements, and will be presented in the next version of this report.

In the third section, a literature review of the life cycle environmental impacts of the product types in scope of this study is presented. This is based on LCA studies of relevant product types. An LCA of the average technologies presented in the task 4 report will be presented in the next version of this report. The LCA results will then be compared to the environmental benefits when defining the new ecodesign material efficiency requirements. These will also be presented in the next version of this report.

In the fourth section, several design options which present a potential for energy efficiency improvement have been identified. Care has been placed to identify options which are believed not to result in significant variations to the functionality or performance of the products compared to the base cases, and which do not place excessive product redesign costs on manufacturers.

5.1 Definition of base cases

In the previous sections, data has been handled on product-type level, but in the following section the energy consumption data will be analysed at product-category level according to the categories of ENERGY STAR 6. These product categories are defined based on product features and installed components, as seen in Table 1. This is possible because the analysis is based on the ENEGY STAR data, which includes information on the product categories, and it is necessary in order to understand how potential new ecodesign requirements may differ between the product categories.

Table 1. ENERGY STAR 6 product categories.[1]

Category name	Graphics capability	Desktop and integrated desktop Performance score	Notebook computer performance score
0	Any graphics	P≤3	P≤2
I1	Integrated or switchable graphics	3<P≤6	2<P≤5.2
I2		6<P≤7	5.2<P≤8
I3		P>7	P>8
D1	Discrete Graphics	3<P≤9	2<P≤9
D2		P>9	P>9

5.1.1 Average energy consumption of base cases BAU

Since the EU ENERGY STAR database did not contain sufficient data for an in-depth energy analysis at product-category level, the newest version of the US ENERGY STAR database from November 2016 was used for the following analysis. Even though the US ENERGY STAR database includes products only marketed in the USA, the products are estimated not vary substantially from products on the EU market.

For each product type the average power consumption (watts) in each power mode is shown for the product types, and if relevant for the product categories. For each product category, only the products sold on the European market in 2015 and 2016 and reported according to the "conventional" use profile were considered. The number of products in the database after filtering for each of these criteria are presented below. The power consumption data was found by calculating the mean of all the products in each category fulfilling these criteria.

5.1.1.1 Desktop computers

For the Desktop computer type, there are more than 1,000 products in the ENERGY STAR database, but only 328 are compliant with the sorting-criteria, as shown in Table 2. As for Notebook computers, most of the products are in category I1-I3, however for desktops computers the share of products in the D1 and D2 category are larger. This is consistent with desktops in general having a higher performance than notebooks.

Table 2. Desktop computers data point count.

Total number of products	1,295 products
Products sold in Europe	1,110 products
From year 2015/2016	461 products
"conventional" use profile	328 products

The power consumption data and ETEC values in Table 3 shows that this higher performance also result in higher power consumption in all of the power modes for all categories, except for category 0. However, since this category is very unusual for desktop computers it only includes a single product in the analysis (Table 2), and the power consumption listed for category 0 is therefore very uncertain. Furthermore, the

[1] Performance score is defined as CPU cores times base speed per core. From ENERGY STAR v6 specifications.

fact that the category is so uncommon for desktop computers, it will also not have a large influence on the overall energy consumption of the stock.

Even in the short idle mode, which is influenced by the screen consumption for notebook computers, the desktop computers have power demand. This clearly shows the efficiency of notebooks are highly influenced by the use in battery mode and subsequent consumer demand for long battery life.

Table 3. Average power consumption data for Desktop computers.

Parameter	Overall	Category 0	Category I1	Category I2	Category I3	Category D1	Category D2
Number of products in each category	328	1	69	67	75	57	59
Measured power consumption - averages for each category							
Off mode power (W)	0.643	0.20	0.610	0.667	0.633	0.667	0.649
Sleep mode power (W)	1.767	0.40	1.581	1.651	1.868	1.804	1.975
Short idle mode power (W)	23.47	5.40	17.54	19.23	22.13	28.70	32.16
Long idle mode power (W)	22.14	5.10	16.33	17.93	20.77	27.45	30.61
Other parameters - averages for each category							
E TEC value (kWh)	103.6	23.1	77.28	84.9	96.98	127.5	142.0
EPS average efficiency (%)	85.7	-	86.4	86.4	84.0	86.4	84.0
PSU rated power (W)	238.9	-	190.9	207.1	254.4	246.4	296.4
IPS efficiency, 100% load (%)	84.0	-	84.3	83.9	84.2	83.9	84.1
IPS efficiency, 50% load (%)	86.8	-	86.9	86.7	87.0	86.6	87.0
IPS efficiency, 20% load (%)	84.5	-	84.5	84.2	84.8	84.2	84.7
IPS efficiency, 10% load (%)	79.3	-	79.0	79.1	79.6	79.1	79.8

5.1.1.2 Integrated desktop computers

Fewer integrated desktop computers than desktop computers were found in the ENERGY STAR database, below 1,000, and only 214 products lived up to the sorting criteria, as seen in Table 4. The share between product categories resembled more that of Notebook computers than desktop computers, with the highest shares of products in categories I1-I3, and only few in D1 and D2. Again, this was expected as Integrated desktop computers in general have lower performance than desktop computers.

Table 4. Integrated Desktop computers data point count.

Total number of products	945 products
Products sold in Europe	819 products
From year 2015/2016	233 products
“conventional” use profile	214 products

As observed in Table 5, the average power demands for integrated desktop computers are generally in the same range as desktop computers in off, sleep and long idle mode, but higher in short idle. This is because the power demand of the screen is only relevant in short idle mode, which is tested before the display automatically powers down.

Table 5. Average power consumption data for Integrated Desktop computers.

Parameter	Overall	Category 0	Category I1	Category I2	Category I3	Category D1	Category D2
Number of products in each category	214	6	73	51	67	6	11
Measured power consumption - averages for each category							
Off mode power (W)	0.520	0.367	0.481	0.478	0.552	0.50	0.864
Sleep mode power (W)	1.72	1.60	1.39	1.45	2.05	3.15	2.53
Short idle mode power (W)	32.8	24.6	39.7	31.0	35.6	33.6	48.0
Long idle mode power (W)	17.8	11.6	15.8	16.6	19.3	21.2	28.9
Other parameters - averages for each category							
E TEC value (kWh)	123.5	91.13	111.6	116.6	134.1	133.1	185.4
EPS average efficiency (%)	89.7	-	90.0	90.2	89.0	-	-
PSU rated power (W)	142.3	67.5	139.4	139.4	156.2	147.5	227.8
IPS efficiency, 100% load (%)	90.5	-	90.6	90.8	90.4	90.0	90.0
IPS efficiency, 50% load (%)	91.9	-	91.8	92.0	91.7	92.5	92.5
IPS efficiency, 20% load (%)	90.1	-	90.2	90.3	89.8	90.5	90.5
IPS efficiency, 10% load (%)	85.9	-	85.6	85.9	85.9	86.5	86.5

5.1.1.3 Notebook computers

The database included more than 2,000 notebook computers, but after filtering according the relevant market, years and use profile, only 749 products remained, as shown in Table 6. The categorisation of notebook computers shows that the notebooks in categories I1-I3 are by far the most frequent in the ENERGY STAR database.

Table 6. Notebook computers data point count.

Total number of products	2,273 products
Products sold in Europe	2,043 products
From year 2015/2016	847 products
"conventional" use profile	749 products

For each of the categories the power consumption, ETEC and relevant PSU efficiencies are given in Table 7. For notebook computers, only the external power supply units are relevant, and for those the average efficiency and rated power are available in the ENERGY STAR database.

Table 7. Average power consumption data for Notebook computers.

Parameter	Overall	Category 0	Category I1	Category I2	Category I3	Category D1	Category D2
Number of products in each category	749	7	379	199	108	11	31
Measured power consumptions - averages for each category							
Off mode Power (W)	0.322	0.243	0.310	0.323	0.334	0.427	0.390
Sleep mode power (W)	0.742	0.457	0.665	0.709	0.875	0.827	1.474
Short idle mode power (W)	8.009	6.257	6.959	7.055	9.597	7.636	21.952
Long idle mode power (W)	5.06	3.40	4.190	4.360	6.272	4.755	16.522
Other parameters - averages for each category							
E TEC value (kWh)	27.70	20.97	23.95	24.39	33.294	26.64	77.145
EPS average efficiency (%)	88.6	88.0	88.4	88.3	89.1	88.5	90.0
PSU rated power (W)	71.11	26.0	54.16	54.85	105.3	61.67	155.0

5.1.1.4 Table/slate computers

The ENERGY STAR database included 169 tablet/slate computers, 66 of which fit the sorting criteria, as seen in Table 8.

Table 8. Slate/Tablet computers data point count.

Total number of products	169 products
Products sold in Europe	120 products
From year 2015/2016	92 products
"conventional" testing	66 products

There are no tablets with discrete graphics (category D1 and D2), and most are in the low-performing category I1 as expected. Therefore, the power demand is also accordingly low, as seen in Table 9.

Table 9. Average power consumption data for Slate/Tablet computers.

Parameter	Overall	Category 0	Category I1	Category I2	Category I3
Number of products in each category	66	1	35	19	11
Measured power consumption - averages for each category					
Off mode Power (W)	0.420	0.30	0.443	0.289	0.582
Sleep mode power (W)	0.797	0.40	0.623	1.14	0.800
Short idle mode power (W)	5.742	6.90	4.93	6.97	6.11
Long idle mode power (W)	5.50	3.10	1.71	2.21	2.34
Other parameters - averages for each category					
E TEC value (kWh)	17.6	11.9	16.7	16.8	21.6
EPS average efficiency (%)	85.4	-	85.9	83.9	86.0
PSU rated power (W)	31.25	-	35.9	36.1	10.8
EPS Efficiency, 10% load (%)	85.8	-	86.0	83.8	89.0

5.1.1.5 Portable all-in-one computers

The Portable-all-in-one computers are not very common on the market, and as seen in Table 10, there are only 8 products in the ENERGY STAR database. Only 2 of these fit the sorting criteria, and these are both category I1.

Table 10. Portable All-in-one computers data point count.

Total number of products	8 products
Products sold in Europe	7 products
From year 2015/2016	2 products
"conventional" use profile	2 products

The average value in Table 11 is devised from 2 products, both in category I1.

Table 11. Average power consumption data for Portable All-in-one computers.

Parameter	Average value	Unit	No. of data points
Measured power consumptions			
Off mode Power	0.40	W	2
Sleep mode power	1.00	W	2
Short idle mode power	31.4	W	2
Long idle mode power	16.3	W	2
Other parameters			
E TEC value	114.2	kWh	2
EPS average efficiency	88.0	%	2
PSU rated power output	110	W	2

5.1.1.6 Workstation computers

Table 12 shows that there are only 41 Workstation computers in the ENERGY STAR database, and only 6 of them fulfil the sorting criteria. The very low number of products in the database is due to a number of factors. First of all, the market for workstations is low compared to most of the other computer types. Second, workstation computers are very high performing computers designed to handle demanding tasks, and it is thus not as easy to fulfil the ENERGY STAR criteria as it is for other computer types.

Table 12. Workstation computers data point count.

Total number of products	41 products
Products sold in Europe	35 products
From year 2015/2016	8 products
"conventional" use profile	6 products

There are no subcategories for workstation computers, and hence only the overall average values for power consumption is shown in Table 13. The data shows that the power demands are significantly higher for workstations than the other computer types, which is expected because workstations are specifically designed for performance-demanding tasks. Furthermore, workstations have not previously been regulated regarding their energy consumption, so except for natural technical development, no efforts have been required on energy savings for workstations.

Despite the high power demands seen in Table 13, it is expected that workstations with higher performance are on the market. They are not included in the ENERGY STAR database because they could not live up to the ENERGY STAR criteria. The average workstation power demands are thus most likely higher than these data shows.

Table 13. Average power consumption data for Workstation computers.

Parameter	Average value	Unit	No. of data points
Measured power consumptions			
Off mode Power	1.717	W	6
Sleep mode power	4.20	W	6
Short idle mode power	54.15	W	6
Long idle mode power	52.85	W	6
Max mode power	231.2	W	6
Other parameters			
P TEC value	30.52	kWh	6
PSU rated power output		W	No data
EPS average efficiency		%	No data
IPS efficiency at 100% load	89.6	%	5
IPS efficiency at 50% load	92.0	%	5
IPS efficiency at 20% load	90.6	%	5
IPS efficiency at 10% load	86.5	%	5

5.1.1.7 Thin client computers

Thin clients is a small product group in the ENERGY STAR database, which only includes 56 thin client computers in total, as seen in Table 14. Only 11 of these match the criteria set up for this analysis.

Table 14. Thin Client computers data point count.

Total number of products	56 products
Products sold in Europe	40 products
From year 2015/2016	14 products
"conventional" use profile	11 products

For Thin Clients, the power mode consumptions were listed two different places in the database (column U, T and O and in Column CL, CO, CM), both are listed below.

Table 15. Average power consumption data for Thin Client computers.

Parameter	Average value 2	Unit	No. of data points
Measured power consumptions			
Off mode Power	0.873	W	11
Sleep mode power	1.430	W	11
Short idle mode power	9.027	W	11
Long idle mode power	8.372	W	11
Other parameters			
E TEC value	42.32	kWh	11
EPS average efficiency	87.0	%	2
PSU rated power output		W	No data

5.1.1.8 Integrated thin client computers

For integrated thin clients, there are even fewer products compared to other product types in the ENERGY STAR database (i.e. only 10 in total). None of them are compliant with the sorting criteria of the market, year and use profile (see Table 16).

Table 16. Integrated Thin Client computers data point count.

Total number of products	10 products
Products sold in Europe	10 products
From year 2015/2016	4 products
"conventional" use profile	0 products

5.2 Life Cycle Costs of base cases

5.2.1 Purchase price and installation costs

The purchase prices are the same as the average prices listed in the task 2 report (section 2.4.1), combined with the share of each product category in the ENERGY STAR database to obtain the weighted average base case purchase price. The workstation purchase price is the average of high-end desktops in categories I2, I3, D1 and D2. In accordance with Chapter 2, no installation cost will be assumed for computers sold as B2C, and for B2B the costs will be covered by the service agreement, which is included in the repair and maintenance cost.

5.2.2 Repair and maintenance costs

The repair and maintenance costs vary between B2C and B2B end-users. B2B end-users typically have an in-house IT-department responsible for the maintenance or a service agreement with an external service provider. B2C end-users will typically either purchase an extended warranty or pay for repair and maintenance directly, as the need appears.

For private end-users extended warranties are the most typical way of ensuring cheap repair and maintenance of the computer. These warranties typically cover computers for a 3-year period from the time of purchase and include both phone support and onsite support. Extended warranty prices were obtained for 12 manufacturers and retailers, and the average price was 251 EUR for three years, which is payed once over each product's lifetime. However, not all consumers choose to buy these warranties, and many consumer sites advice against purchasing[2]. According to PC world[3], 63% of users bought extended warranties for their computers.

For those consumers that do not buy an extended warranty, repairs must be paid for separately as they occur. According to a consumer reports survey, computers (notebooks and desktops) have a 24% repair rate[4] during the 3-year period when the extended warranty is covering. The costs of typical repairs collected from Lenovo by Digital Trends[5] are shown in Table 17, which are supported by an internet search for average prices.

Table 17. Typical repair costs for PCs.

Component	Cost, EUR
Motherboard	475
DVD drive	190
Hard drive	285
Minor tablet damage	238
Multiple part replacement	570
LCD display	428
Average	**364**

According to a study made by EY[6] on companies' outsourcing of services, around 25% of companies in the 8 surveyed countries outsource their IT services, while 75% keep them in-house. The companies outsourcing their IT services, typically base it on either a monthly price per computer/user or an hourly fee. The monthly agreements are more

[2] http://www.consumerreports.org/cro/extended-warranties/buying-guide.htm
[3] http://www.pcworld.com/article/124856/article.html?page=0
[4] http://www.digitaltrends.com/mobile/extended-warranties-are-they-worth-it-ask-an-expert/
[5] http://www.digitaltrends.com/mobile/extended-warranties-are-they-worth-it-ask-an-expert/
[6] http://www.ey.com/Publication/vwLUAssets/Outsourcing_in_Europe_2013/$FILE/EY-outsourcing-survey.pdf

highly recommended in the market[7], and it was assumed that of the 25% outsourcing IT services, 30% used the hour paid maintenance, while 70% had monthly subscriptions.

An online search for service providers in Europe showed that with no subscription the hourly fees ranged between 60-150 EUR, with an average of 88.2 EUR. The monthly fees were generally lower than the hourly fee, and the monthly prices per computer/user ranged between 24-60 EUR, with an average value of 41.5 EUR.

The price of in-house IT management is much more complex to calculate, as it depends on the company structure, number of employees etc., which makes it very difficult even for the companies themselves to assess their IT costs[8]. However, the costs are likely to be higher for the in-house IT management, since the most common reason for outsourcing is to reduce costs[9]. According to EY, however, 12% of those who choose to *insource* IT-services again, do so because they could not realise their cost savings when outsourcing[10].

According to various cost examples, in-house IT management is 1.6 to 2.5 times higher for small businesses than outsourced services[11], but the benefit of outsourcing generally decreases with company size. It is therefore assumed that the majority of companies having service agreement with external suppliers are small and medium sized, whereas the larger companies have in-house IT service. Hence the companies are assumed to choose the most cost efficient solution for their needs, and the cost is therefore not assumed to differ by more than a factor 1.3.

Based on the above considerations the average repair and maintenance costs for each base case are calculated using the following assumptions:

- 7.5% of the B2B computers are covered with an hourly-paid service agreement at an average price of 88.2 EUR/hour, spending one hour each month during the computer's lifetime.
- 17.5% of B2B computers are covered with a monthly-paid service agreement at an average price of 41.5 EUR per computer per month throughout the lifetime.
- 75% of the B2B computers are maintained by in-house IT service at an average price of 1.3 times the price of a monthly-paid service agreement, i.e. 54 EUR/month.
- 63% of B2C computers are purchased with an extended warranty lasting 3 years after purchase, and not renewed hereafter.
- Of the remaining 37% of B2C computers, 24% are repaired at the average cost of 364 EUR once in their lifetime.

These assumptions are close to those of a study performed by a warranty provider of mobile personal computers[12], which showed that around 1/3 of laptops had at least one

[7] http://www.techdonut.co.uk/it/it-support/it-support-contracts
[8] https://blueocean.ca/quick-guide-comparing-house-vs-outsourced-contact-center-costs/
[9] http://www.tekexpress.co.uk/news-91-in-house-it-support-vs-outsourcing.html
[10] http://www.ey.com/Publication/vwLUAssets/Outsourcing_in_Europe_2013/$FILE/EY-outsourcing-survey.pdf
[11] http://nssit.com/what-is-the-cost-of-it-support-for-small-business/ and http://marcusnt.com/technology/cost-comparisons/ and http://www.myitpros.com/myitpros-blog/numbers-house-versus-managed-services-costs
[12] https://www.squaretrade.com/htm/pdf/SquareTrade_laptop_reliability_1109.pdf

failure during the first three years. However, the costs of repairs are higher than those found in the preparatory study Lot 3 for computers and displays from 2007.

The average price for B2C and B2B computers is weighted according to the market split in 2015 for each base case. The results are shown in Table 24. The differences in maintenance and repair costs for the different computer types are caused by differences in lifetimes and the share sold as B2B vs. B2C. The B2B costs are significantly higher.

5.2.3 Upgrade costs

A computer upgrade in this context means upgrading hardware components that are "perceived" as becoming slow (mostly because of heavier software or additional features included in newer versions) compared to new ones with increasing performance, but keeping the majority of the computer components unchanged. In the LOT 3 previous preparatory study it was estimated that in 2007 around 2% of end-users would upgrade their computers to achieve a better performance. This estimate was based on a stakeholder questionnaire performed by Swerea IVF[13] with 16 respondents including stakeholders in both the computer and monitor industry from companies in Europe, USA and Asia[14].

The previous preparatory study suggested that only 2% of end-users chose to upgrade, and these were primarily private consumers. The remaining 98% of end-users would not upgrade. However, recently performed online research suggests that the upgrading rate is markedly higher. A survey from march 2016 conducted by Spiceworks on behalf of Crucial[15], showed that 50% of IT decision-makers in USA, UK, Germany and France chose to upgrade company PCs rather than replace them. This survey targets the decision makers specifically and involves more than 350 respondents, working with both desktops and laptops. The answer to which action they take when a desktop or notebook is perceived as slowing down or having performance issues, is shown in Figure 1. According to the survey, upgrading is often chosen due to direct cost constraints, whereas replacement is chosen due to time constraints.

[13] http://www.swerea.se/en/ivf
[14] According to the Preparatory study on Personal Computers (desktops and Laptops) and Computer Monitors EuP preparatory study, TREN/D1/40-2005, Lot 3.
[15] http://www.crucial.com/usa/en/should-you-upgrade-or-replace-old-computers-IT-ssd-ram

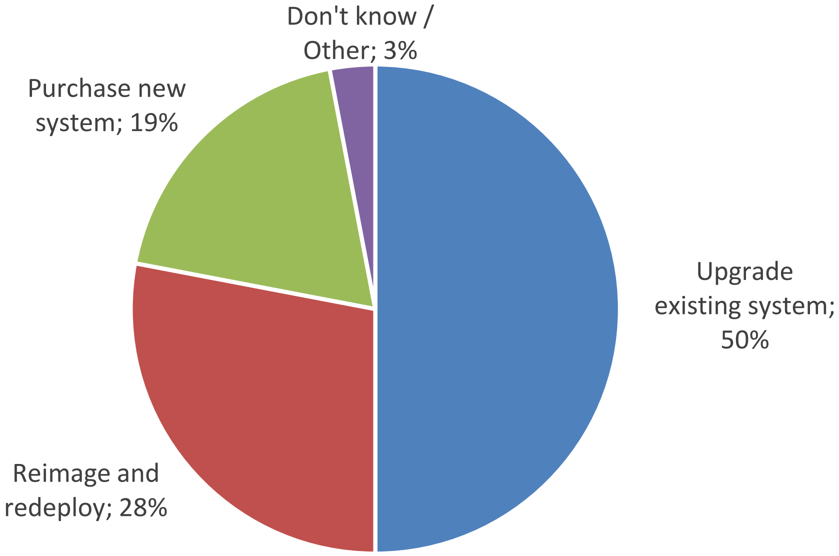

Figure 1. Survey results showing actions taken by IT managers to increase performance.

The survey from Crucial[16] does not distinguish between desktops and notebooks, but in general desktops are more upgradable compared to notebooks. Notebooks are becoming even less upgradable due to soldered-in components. The number of times each computer is upgraded during its lifetime is not specified in the Crucial survey, but due to the better upgradability potential of desktops it is assumed that they upgraded more often, or at least with more different components at the time, than notebooks.

Notebooks usually only allow for upgrading of RAM, hard drive and replacement of the original battery[17]. However, notebooks also allow for batteries with bigger energy capacity. Desktops on the other hand can, in addition to RAM and hard drive, have their CPU, GPU, Wi-Fi cards, video cards, cooling systems and power supply upgraded or exchanged (not including mini PCs).

Upgrading does not always result in longer product lifetime. A total of 52% of the IT managers covered by the Crucial survey reported typical computer refresh cycles to be 3-4 years. In these cases, it appears that upgrading is done to improve the performance of the computers in that period. One potential reason for not extending the product lifetime, is that the cost of maintaining hardware for more than 4 years starts to outweigh the cost benefits of not buying new[18].

Workstations are very upgradable, and considering their higher purchase price, longer lifetime and high performance demands, they are assumed to be upgraded more frequently than desktops and often with more than one upgrade per computer.

Based on the above information the assumption in Table 18 were made regarding upgrades for the different computer types.

Table 18. Assumption of upgrade-rates used in LCC calculations.

Base case	B2C upgrade rate	B2B upgrade Rate

[16] http://www.crucial.com/usa/en/should-you-upgrade-or-replace-old-computers-IT-ssd-ram

[17] http://www.computerhope.com/issues/ch000618.htm and http://www.howtogeek.com/192016/what-you-need-to-know-about-upgrading-your-laptops-hardware/ and http://www.pcadvisor.co.uk/how-to/laptop/how-add-graphics-card-your-laptop-3364133/

[18] https://www.quora.com/After-how-many-years-should-you-replace-a-desktop-or-laptop-computer-running-Windows

Desktops	50%	50%
Notebooks	40%	50%
Workstations	70%	70%
All other	0%	0%

The cost of upgrading depends on which type of upgrade is performed, and costs also vary between the computer types as mentioned above. The distribution of upgrade types is estimated for desktops, notebooks and workstations are shown in Table 19. Hence, installing more RAM is considered the most prevalent form of upgrade for all three computer types, with 60-80% of the upgraded share getting a RAM upgrade.

Table 19. Estimated types of upgrades for desktops, notebooks and workstations.

Base case	RAM upgraded	Storage upgraded	GPU upgraded	Battery upgraded or replaced	CPU upgraded	Cooling upgraded
Desktop	75%	25%	30%	0%	5%	2.5%
Notebook	60%	10%	0%	75%	0%	0%
Workstation	80%	25%	50%	0%	10%	10%

Desk research for prices of upgrade components and spare parts were performed, which resulted in the average prices shown in Table 20.

Table 20. Upgrade prices for various components[19].

Upgrade	Price (EUR)
HDD 750 GB / 2 TB	130
SSD 120 GB	80
SSD 256 GB	210
SSD 500 GB	380
RAM 4 GB	55
RAM 8 GB	75
CPU i7	720
CPU i5	550
PCI-based wifi card	60
Case	115
CPU cooler	50
Fans	15
Liquid cooling	210
Laptop battery (6 cell)	62
Laptop battery (9 cell)	132
GPU 3 GB	95

When combining the prices, upgrade rates and type distribution with the market split for each of the three computer types, the average cost for upgrades shown in Table 24 are obtained. Not surprisingly, the average amount spent on upgrades for workstations (195 EUR) is higher than for desktops (102 EUR) and notebooks (54 EUR).

5.2.4 Costs in use phase: electricity

The use phase costs are calculated based on the costs of electricity consumption, as upgrades, repair and maintenance are handled separately. The electricity consumption is calculated for each base case separately, using the ETEC values (PTEC for workstations)

[19] http://www.pcworld.com/article/2019575/10-killer-pc-upgrades-for-less-than-250.html and general search on webshops

to represent the electricity consumption in idle, sleep and off modes for one year, and multiplying with expected years of lifetime. However, the active state energy consumption is not included in the ETEC (nor PTEC) values, and had to be established separately for each base case. Furthermore, not all computers on the market are ENERGY STAR compliant, and energy consumption had to be adjusted accordingly. Both calculations are explained in detail below.

5.2.4.1 Active state power demand

The active state power demands (W) used within the calculations are based on findings for computers where both idle and active state power demands were measured.. An average "Idle vs. Active" factor was calculated by dividing active state power demand by the short idle mode power demand for all the measured data. The factor fluctuated between 1.4 and 4.7 depending on the type of task performed in the active state. The average "idle vs. active" factor is 2.57, which is multiplied by short idle mode power demand for each base case to obtain the active mode power demands seen in Table 21.

Table 21. Active state power demand for each base case based on short idle mode power demand for each base case.

Computer type	Short idle (W)	Active (W)	Active time
Desktop	22.9	58.8	14.7%
Integrated desktop	32.9	84.6	14.7%
Notebook	7.1	18.2	12.6%
Slate/tablet	4.1	10.5	12.6%
Thin Client	14.4	37.0	14.7%
Integrated thin client	14.4	37.0	14.7%
Portable all-in-one	0.4	1.03	12.6%
Workstation	69.5	178.5	20.0%

Since the ETEC formula in the ENERGY STAR 6 specifications are calculated as energy consumption across a whole year (8 760 hours), the time spent in active states for each base case had to be subtracted from time spent in one of the other power modes. As described in task 3, the percentage of time computers spend in active states can be estimated. The average active state time for both desktops and notebooks was estimated to be 42% of the total on-time (i.e. time spent in short idle) (see task 3 report). This 42% is therefore assumed for all base cases except workstations. For workstations, the amount of time spent in active states is assumed to be higher than for other computer types because workstations are used for complicated tasks, hence spend more time actively processing data. It is assumed that workstations spend 50% of on-time in an active state.

The on-time is assumed to be the time spent in short idle mode according to the ENERGY STAR 6 specification. This is 35% of the time for desktops, integrated desktops, thin clients and integrated thin clients, 30% for notebooks, slate/tablets and portable all-in-ones, and 40% for workstations. Hence, the active state time ends up being 14.7%, 12.6% and 20% of total on-time as shown in Table 21.

5.2.4.2 IPS efficiency

It was assumed that many of the non-ENERGY STAR qualified products are not qualified due to poor IPS efficiencies, as ENERGY STAR requires a basic 80-Plus certified IPS. The minimum required IPS efficiencies in ENERGY STAR as well as efficiencies for an assumed average non-qualified IPS[20] are given in Table 22.

Table 22. Efficiencies of an 80-plus basic IPS (required in ENERGY STAR) and an average non-qualified IPS at 25%; 50% and 100% load.

Load-%	80-plus basic	Non-qualified
25%	82%	70%
50%	85%	75%
100%	82%	70%

The market penetration rates for ENERGY STAR qualified products in each base case was not available for Europe at the time of writing, so the ENERGY STAR market penetration in 2015 in USA was used as approximation[21]. The market penetration rates for each base case are shown in Table 23. For notebooks, no changes were made due to the high penetration rates, but for all other base cases the energy consumption was corrected based on the IPS efficiencies in Table 22. The electricity costs were then calculated based on the average European electricity price for industry and private consumers and the market split B2B and B2C computer sales.

Table 23. ENERGY STAR market penetration rates for each base case.

Base case	Market penetration	Comments
Desktop	39%	
Integrated desktop	39%	Assumed same as desktops
Notebook	95%	Not equipped with IPS
Slate/tablet	29%	Not equipped with IPS
Thin Client	39%	Assumed same as desktops
Integrated thin client	39%	Assumed same as desktops
Portable all-in-one	39%	Assumed same as desktops
Workstation	10%	

5.2.5 Disposal costs

As described in the task 2 report, the disposal costs for computers as well as other electronics are determined in part by the WEEE directive[22] and its implementation in each Member State. However, despite the producer responsibility principle in the WEEE directive, large discrepancies exist among the Member States regarding who is responsible for the physical and financial implementation of the directive[23], and sometimes differences exist also on the municipality level within Member States.

According to an article by Huisman and Magalini[24], four basic models for implementation exist in the Member States, which are shown in Figure 2. According to the article, however, only two of these models are actually used in practice; the CC and RCC model. In the CC model the producers carry the cost of handling the WEEE, whereas in the RCC the end-users reimburse the producers and end up paying.

[20] https://www.techpowerup.com/forums/threads/how-does-psu-efficiency-affect-me-and-do-i-really-need-an-80-plus-gold-power-supply.129456/

[21] https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2015_USD_Summary_Report.pdf?df58-1c35

[22] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) – recast.

[23] http://ec.europa.eu/environment/waste/weee/pdf/final_rep_okopol.pdf

[24] Jaco Huisman, Federico Magalini, "Management of WEEE&Cost Models across the EU Could the EPR principle lead US to a better Environmental Policy?", , vol. 00, no. , pp. 143-148, 2007, doi:10.1109/ISEE.2007.369383. Link: http://www.wf-reptoolhost.org/att/literature/2006_Management%20of%20WEEE%20and%20cost%20models_Huisman.magalini.pdf

Cost Model	Description	WEEE Split Hist./New	Financial Responsibility
CC	Producers pay Compliance Costs to Compliance Scheme. No Visible Fee paid by Final Users.	Not Needed / None	Producers
CC&VF	Producers pay Compliance Costs to Compliance Scheme. Final Users pay Visible Fee for financing Historical WEEE.	Needed	Producers for New WEEE Final Users for Historical WEEE
RCC	Producers pay Compliance Costs to Compliance Scheme. Final Users pay Visible Fee covering both Historical and New WEEE.	Not needed / None	Producers pay in advance but later fully reimbursed by Final Users.
RF	Final Users pay a Recycling Fee when buying new equipment for financing the current (SRF) or future (ARF) management of WEEE.	Not Needed / None	Final Users

Figure 2. Table directly from the article by Huisman and Magalini, showing the four basic cost models for implementing the WEEE Directive in member states.

The Scottish Environment Protection Agency, SEPA, made a guideline for companies regarding how to dispose of WEEE[25], which gives an overview of company-paid and producer-paid WEEE handling options. The guide shows that the treatment of both the historical and the new WEEE can be paid for by the company itself or by the producer, depending on what the company chooses. However, for historical WEEE it requires the product to be replaced with a new and equivalent type to put the financial responsibility on the producer.

Since it is not possible to get the full picture of computer waste handling in all Member States, a number of simplified assumptions were made. First of all, it was assumed that private users do not pay for the handling and recycling of disposed computers, but only commercial end users do. Based on the SEPA guide, and because most commercial users would most likely want hard disks to be shredded for data safety reasons, it is assumed that 70% of the commercial users pay for the disposal of their computers.

The costs of disposing computers also varies significantly between Member States, which company is chosen to handle the disposal, the type of computer, and how many computers are handed in at a time. Average prices from various examples were found for desktops and notebooks, and the price for hard disk shredding and disposing of the computer were around 30 EUR for Desktops and 21 EUR for notebooks[26]. The disposal prices shown in Table 24 takes into account the assumed share of end-users that pay for the disposal themselves.

5.2.6 Overview of Life Cycle Costs

The life cycle costs of each base case are shown in Table 24 with the distribution shown in Figure 3.

[25] https://www.sepa.org.uk/media/36478/weee-disposal-guidance-for-business.pd
[26] http://assureditd.com/recyclimator.php and http://www.bostonelectronicwaste.com/DataDestructionPriceListERC-100022-101-1.pdf

Table 24. Life Cycle Costs for each computer type, all numbers in EUR.

Base cases at product type level	Purchase Price	Installation	Repair & Maintenance	Upgrades	Use	Disposal	**Total**
Desktop	1 612 €	0 €	2 901 €	97 €	110 €	15 €	€
Integrated Desktop	1 069 €	0 €	2 901 €	0 €	195 €	15 €	€
Notebook	1 346 €	0 €	1 411 €	54 €	27 €	6 €	€
Slate/Tablet	1 182 €	0 €	1 407 €	0 €	8 €	10 €	€
Portable All-in-one	2 608 €	0 €	1 322 €	0 €	103 €	5 €	€
Thin Client	869 €	0 €	3 262 €	0 €	53 €	15 €	€
Integrated Thin Client	460 €	0 €	3 262 €	0 €	53 €	15 €	€
Workstation	2 826 €	0 €	4 348 €	195 €	180 €	20 €	€

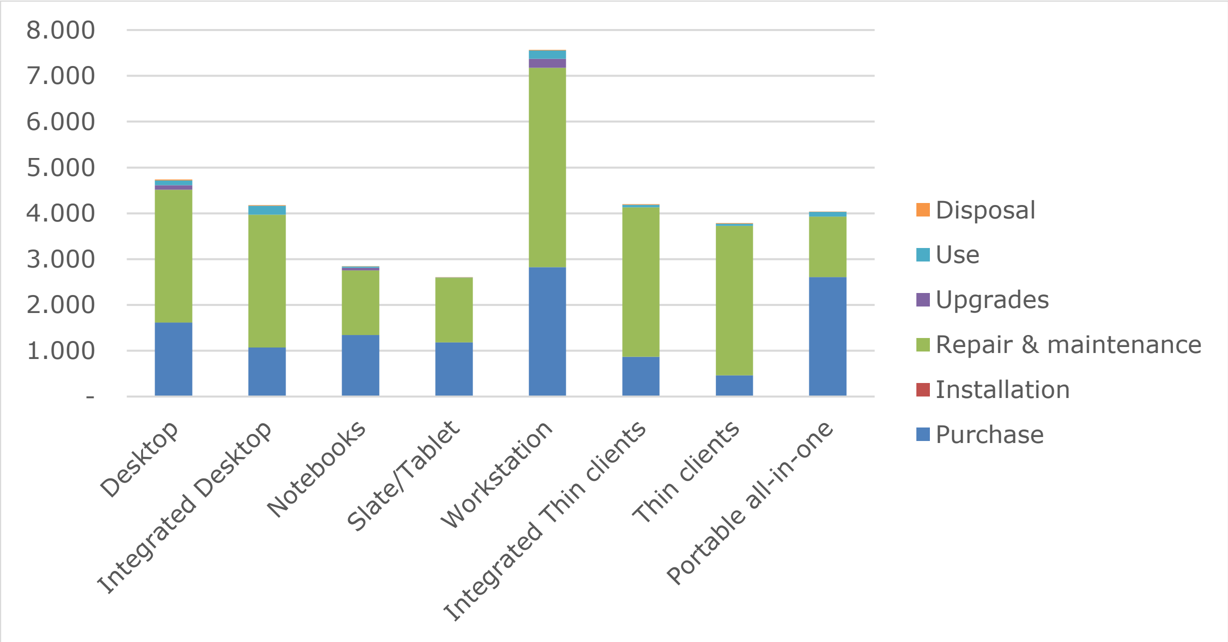

Figure 3. Distribution of life cycle costs for each computer type.

Both Table 24 and Figure 3 show that the repair and maintenance costs are the dominant for most of the base cases at product type level, and that the purchase price is also important. This means that the service agreement and extended warranty play an important role on the life cycle costs of personal computers, both for B2C and B2B users.

The importance of purchase price is still eminent in spite of the availability of cheaper products in the market. Furthermore, the costs during the use phase are very small or insignificant, even when including the costs of having the computers in active mode. For integrated desktops and workstations the use phase is visible due to the use of the screen in integrated desktops and the higher share of active mode for workstations.

The estimated disposal costs though very small present high uncertainty if other costs models are used by some Member States where the end-user takes more responsibility. However, it is assumed that in most cases this will be absorbed by the purchase price and thus only visible as part of the purchase price.

5.3 Literature review of life cycle GHG of personal computers

In recent years there have been numerous LCA studies done on computer products and systems. As shown in a recent study from 2014[27] the results of LCA studies for computer products and systems vary considerably in terms of results and methods. This can be due to different reasons, such as different product configurations and therefore different components within the computer, or studies including accessories such as monitors, keyboards or mice within the system boundary. Finally, the differences are also because the studies have different data sources and/or methodology.

Despite these varying results, as noted by the JRC[28] , more recently studies are demonstrating that the production phase of computer products has a higher impact than the use phase.

This has been shown in one recent study from 2016[29]. This study compared the GWP impact of three different computer types being investigated for green procurement in the German Federal Environment Agency. This study also demonstrated why it is not possible to simply compare the environmental impact of one type of computer with another due to different service lifetimes of the computer types. In the study three computer types were compared, being a computer workspace with either a desktop PC, notebook PC, or mini PC. Each had an external monitor, mouse and keyboard. The notebook had a docking station. The study is a good case example in demonstrating the differences between environmental impact methodologies between studies. The study did not look at the computer systems in isolation but rather with other necessary components at a workstation. In addition, it looked at the products over an observation period of 10 years. Within the 10 years, the different computer systems would be replaced numerous times depending on their service life. The notebook had the lowest service life (3 years) and thus the notebook had the highest environmental impact since it had to be replaced the most times. Because over the 10-year observation period, it would need to be replaced at least three times, based on the studies assumptions, the notebook actually had the highest impact caused by manufacturing the third replacement. The study also assumed that the computer products would be replaced by an identical model which is not likely in a period of 10 years, considering the fast technological development of products like notebooks and their wide product configurations.

This study demonstrates one example of the methodology dictating the environmental impact of the product. Despite the uniqueness of the methodology, the study showed for all computer products that the production phase had a higher impact than the use phase. The computer product with least impact was the mini pc which had lowest material

[27] Prakash, S. Baron, Y. Liu, R. Proske, M. Schlosser, A. (2014) Study on the practical application of the new framework methodology for measuring the environmental impact of ICT – cost/benefit analysis. Prepared for the European Commission.

[28] Marwede, M. Clemm, C. Dimitrova, G. (2016) Analysis of material efficiency aspects of personal computers product group. Technical support for Environmental Footprinting, material efficiency in product policy and the Europena Platform on LCA. JRC Technical Report. European Commission. 2016

[29] Prakash, S. Kohler, A. Liu, R. Stobbe, L. Proske, M. Schischke, K. (2016) Paradigm Shift in Green IT – Extending the Life-Times of Computers in the Public Authorities in Germany. Electronics Goes Green 2016+, Berlin, September 2016.

impact and the lowest use phase electricity consumption. Despite having the lowest impact it too had a higher manufacturing impact which accounted for 64% of the GWP impact.

The GWP impact from manufacturing computers ranges according to different studies[30]. The GWP from manufacturing desktop computers and notebook computers ranges from 200-800 kg CO_2 eq per device and 100-400 kg CO_2 eq per device, respectively. Similar ranges are also demonstrated in other studies[31] which show a range for the manufacturing GWP for desktop pc, notebook pc and mini pc from 130-480 kg CO_2-eq, 80-130 kg CO_2-eq, 60-90 kg CO_2-eq, respectively (Figure 4).

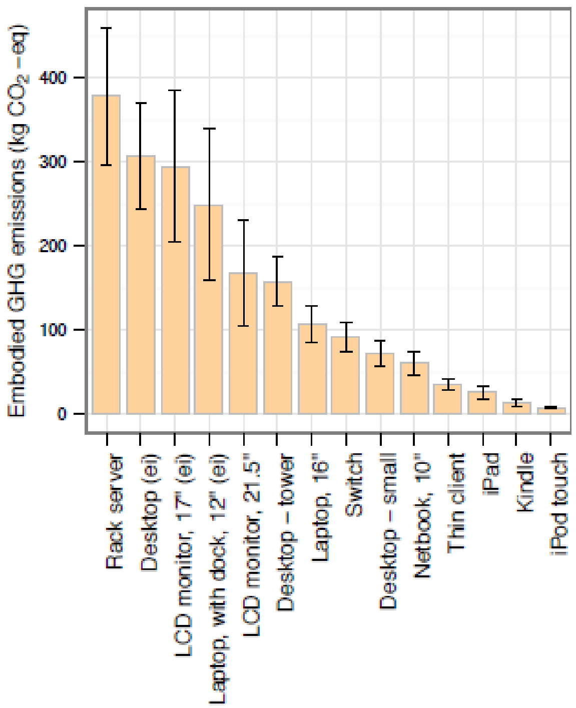

Figure 4. Mean embodied greenhouse gas emissions with error bars for different computer types[32].

Depending on the assumptions made, the production phase may represent between 56% and 75% of a notebook's greenhouse gas emissions[33].

Company environmental data is also demonstrating this trend. For example, for the Apple Mac Pro from 2013, Apple reports that the product, with a service life of 4 years, has a production impact of 65%[34] . Furthermore, the production GWP impact for the Mac

---

[30] Malmodin, J., Lundén, D., Moberg, Å., Andersson, G., Nilsson, M., 2014. Life Cycle Assessment of ICT. Journal of Industrial Ecology 18, 829–845.
[31] Teehan, P. (2014) Integrative approaches to environmental life cycle assessment of consumer electronics and connected media. PhD thesis. The University of British Columbia. June 2014.
[32] Teehan, P. (2014) Integrative approaches to environmental life cycle assessment of consumer electronics and connected media. PhD thesis. The University of British Columbia. June 2014.
[33] Prakash, S. Kohler, A. Liu, R. Stobbe, L. Proske, M. Schiscke, K. (2016) Paradigm Shift in Green IT – Extending the Life-Times of Computers in the Public Authorities in Germany. Electronics Goes Green 2016+, Berlin, September 2016.
[34] Apple (2013) Mac Pro Environmental report. Downloaded from http://images.apple.com/environment/pdf/products/desktops/MacPro_PER_oct2013.pdf

Mini accounts for 90% of the total impact of the product life cycle[35].This is in accordance with Prakash (2016)[36] which also showed that the mini pc had a lower impact than the traditional tower desktop computers and a larger contribution to the GWP impact from the production stage. This is both because of the electricity consumption in the use phase and the production impact.

For the integrated desktop computer, the Apple 21.5 iMac from 2015 with service life of 4 years, has a GWP impact for manufacturing that accounts for 55% of the impact and the electricity use impact accounts for 36% of the life cycle impact[37].

Notebooks from Apple, for example for the 13 inch MacBook pro from 2012 with a service life of 4 years, also have a low GWP impact for the use stage compared to manufacturing, with manufacturing accounting for 75% of the GWP impact[38].

Other studies have also demonstrated that the manufacturing impact has the largest contribution to the environmental impact as well[39]). This study investigated the impact of a computer CPU along with the monitor and keyboard where the computer had a service life of 5 years. It showed that the production phase (of the CPU, monitor and keyboard) had an impact of 60%.

This trend has not always been like this. The use phase has had a higher impact than the production phase[40]. A study compared the GWP of different studies that had investigated typical desktop PCs without a monitor[41]. All the reviewed studies in this study had investigated the manufacturing and use phase GWP impact of a typical desktop computer. In some studies the GWP impact is higher for the use stage and in some it is lower than for manufacturing, and in fact most studies showed a higher impact for the use phase (Figure 5). But it is important to note that the reviewed studies are relatively old ranging from the mid to late 2000s. Since this period, the computer processing units of other components have become more energy efficient and hence the trend has shifted to a higher manufacturing impact in the life cycle of the computer.

---

[35] Apple (2014) Mac Mini Environmental report. Downloaded from http://images.apple.com/environment/pdf/products/desktops/Macmini_PER_oct2014.pdf

[36] Prakash, S. Kohler, A. Liu, R. Stobbe, L. Proske, M. Schischke, K. (2016) Paradigm Shift in Green IT – Extending the Life-Times of Computers in the Public Authorities in Germany. Electronics Goes Green 2016+, Berlin, September 2016.

[37] Apple (2015) iMac Environmental report. Downloaded from http://images.apple.com/environment/pdf/products/desktops/21_5inch_iMac_PER_Oct2015.pdf

[38] Apple (2012) MacBook Pro Environmental report. Downloaded from http://images.apple.com/environment/pdf/products/notebooks/13inchMacBookPro_PER_june2012.pdf

[39] Sirait, Marudut and Biswas, Wahidul and Boswell, Brian. 2012. Personal Computer Life Cycle Assessment Study: The Case of Western Australia, in Seliger, G. and Kili?, S.E. (ed), 10th Global Conference on Sustainable Manufacturing, Oct 31-Nov 2 2012. Istanbul, Turkey: Middle East Technical University METU.

[40] Teehan, P. (2014) Integrative approaches to environmental life cycle assessment of consumer electronics and connected media. PhD thesis. The University of British Columbia. June 2014.

[41] Teehan, P. (2014) Integrative approaches to environmental life cycle assessment of consumer electronics and connected media. PhD thesis. The University of British Columbia. June 2014.

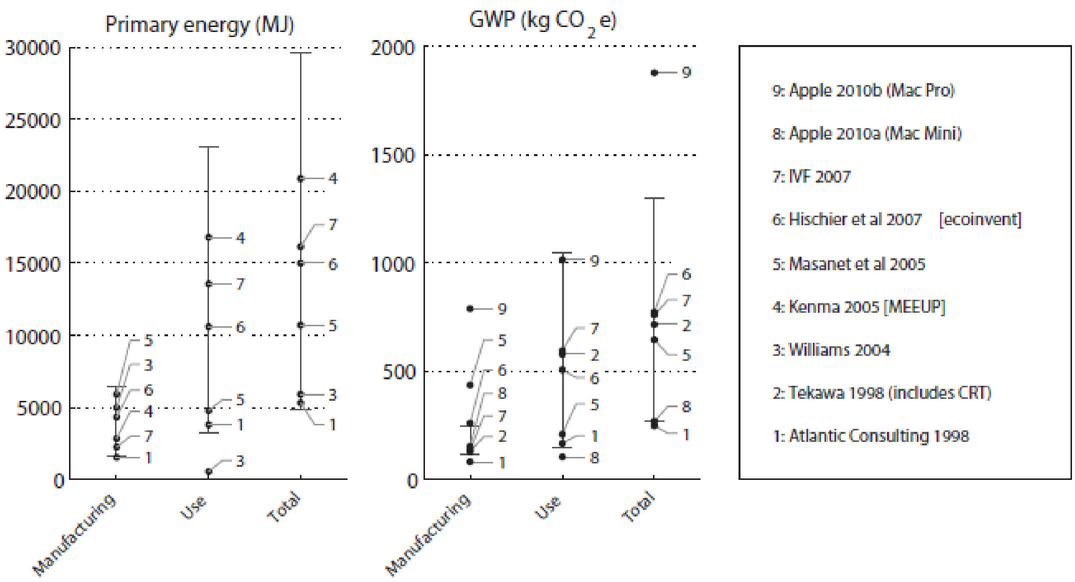

Figure 5. Overall primary energy and GWP results from numerous studies for a typical desktop PC without display[42].

Prakesh (2016) [43] mentions that the main impact from manufacturing comes from producing the active microelectronic comments such as RAM, which together with the motherboard and SSD, account for more than 84% of the notebooks manufacturing greenhouse gas emissions in their study. The manufacturing impacts from these components have also been shown to be high in other studies[44] .

Specific components such as HDD[45] demonstrate a dominance of manufacturing in the total impact of the component's lifetime for GWP as well. Here, the use stage accounts for 15% of the impact and manufacturing just under 80% with a service life of 3 years.

In regards to end-of-life recovery of materials it is shown in an Oeko-Insitute study [46] that most of the raw materials used in notebooks is lost completely at end-of-life. This study investigated the end-of-life of notebooks from private consumers in Germany in 2010 and assumed around 50% of raw material losses take place in the collection phase. Losses of important raw materials such as gold, occur during the pre-treatment and post-treatment of the devices. This means that recycling credits to be accredited to the life cycle of the product are minimal for these notebook computers. In regards to GWP of

[42] Teehan, P. (2014) Integrative approaches to environmental life cycle assessment of consumer electronics and connected media. PhD thesis. The University of British Columbia. June 2014.
[43] Prakash, S. Kohler, A. Liu, R. Stobbe, L. Proske, M. Schischke, K. (2016) Paradigm Shift in Green IT – Extending the Life-Times of Computers in the Public Authorities in Germany. Electronics Goes Green 2016+, Berlin, September 2016.
[44] Teehan, P. (2014) Integrative approaches to environmental life cycle assessment of consumer electronics and connected media. PhD thesis. The University of British Columbia. June 2014.
[45] Seagate (2011) Barracuda LP HDD Product Life Cycle Analysis Summary. Downloaded from http://www.seagate.com/files/www-content/global-citizenship/en-us/docs/final-barracuda-lca-summary-report-ams-3-24-14-10-1-2013.pdf
[46] Buchert, M., Manhart, A., Bleher, D., Pingel, D.; Recycling critical raw materials from waste electronic equipment, Oeko-Institut e.V., Commissioned by: North Rhine-Westphalian State Agency for Nature Conservation, Environmental Affairs and Consumer Protection (LANUV), Recklinghausen, 2012

end-of-life treatment, this is shown to be small since it involves mostly shredding the discarded computers and this is shown to be minimal in recent studies[47][48]

5.4 Identification of design options

Given the complexity in computer design there are a myriad of design options that can be employed to increase energy efficiency. This section presents some of the different design options that could be applicable to the three base-cases. The design options introduced below have been chosen as they meet the following criteria:

- Do not result in significant variations to the functionality or performance of the products compared to the base-cases
- Have a significant potential for environmental improvement
- Do not place excessive product redesign costs on manufacturers

Improvement options are provided covering various aspects of computer design. They cover product, component and software design opportunities.

5.4.1 Design Option 1: Power Supply Unit (PSU) (Increased Efficiency)

It was shown in the task 4 report that the level of efficiencies found in IPS vary significantly both in terms of differences between products and in terms of differences between loading level efficiencies. There are many IPS on the market that offer increased levels of efficiencies across a range of loading levels. The 80PLUS programme includes a registration database which provides details about the varying efficiencies of IPS including whether they meet one of the pre-defined higher efficiency performance specifications (e.g. 80PLUS Gold, Platinum or Titanium). Using higher efficiency IPS will save considerable amounts of energy compared to lower efficiency IPS. The current EU ecodesign (617/2013) regulations on computers includes requirements on IPS efficiency but these are set at a relatively low level of efficiency. There appears to be sufficient potential to consider adoption of higher energy efficient IPS in EU initiatives.

5.4.2 Design Option 2: Power Supply Unit (PSU) (Switching)

Task 4 report shows that IPS are very inefficient at low loads. That is, when a computer is only drawing a small amount of power through an IPS the rate at which the IPS converts the ac mains power into dc current is inefficient. Low loading levels are becoming more common due to the increasing delta between idle mode power demand and IPS rated output. This delta is growing as a result of manufacturers taking steps to reduce idle mode power demand. One potential method of reducing low load efficiencies is through the development of two-stage IPS. In these designs, a separate lower powered IPS circuit provides power to the computer at when only small amounts of power are required. This has the effect, of running a lower powered IPS at a higher loading rate in order to achieve higher efficiencies. An example of a two-stage IPS was introduced during discussions on the development of the Californian computer energy efficiency regulation[49].

---

[47] Prakash, S. Kohler, A. Liu, R. Stobbe, L. Proske, M. Schiscke, K. (2016) Paradigm Shift in Green IT – Extending the Life-Times of Computers in the Public Authorities in Germany. Electronics Goes Green 2016+, Berlin, September 2016.

[48] Sirait, Marudut and Biswas, Wahidul and Boswell, Brian. 2012. Personal Computer Life Cycle Assessment Study: The Case of Western Australia, in Seliger, G. and Kili?, S.E. (ed), 10th Global Conference on Sustainable Manufacturing, Oct 31-Nov 2 2012. Istanbul, Turkey: Middle East Technical University METU.

[49] Aggios Comments: California Energy Commission Draft 2 Workshop on Computers - Technical Demo, available from http://docketpublic.energy.ca.gov/PublicDocuments/14-AAER-02/TN211230_20160425T101319_Aggios_Comments_AGGIOS_Title_20_Workshop_2016_04_26.pdf

5.4.3 Design Option 3: External Power Supply Unit (EPS) (Connection Type)

Common connection types used on EPS provide the opportunity to reduce the number of EPS sold each year. As an example, USB-Type C connection sockets can be used in conjunction with a USB EPS to provide up to 100W for charging batteries in computers. If standard EPS connection types, such those based on the USB Type-C connection, become common it could encourage manufacturers to avoid automatically shipping new EPS's with each new computer. Purchasers could be given a choice about whether they require a new EPS when purchasing a new computer, as many may already have a suitable EPS in their possession. The total amount of material used for EPS for computers would be reduced if less EPS's were placed on the market. This could result in material savings and reduced electronic WEEE.

5.4.4 Design Option 3: Storage Devices

There several different types of devices used to permanently store data within a computer. The Task 4 report showed that newer storage devices such as SSD can have significantly lower power demands than older types of storage products such as HDD. Table 25 provides some example ranges of power demands associated with some of the main storage devices used in personal computers.

Table 25. Example Power Demand Values for Common Storage Device Types.

Storage Product Type	Sub-Type	Idle	Standby/Sleep
3.5" HDD	Single platter	2.5 to 3.5 W	0.4 to 1.2 W
	Multi platter	4.0 to 7.6 W	0.5 to 1.6 W
SSD	2.5"	0.02 to 2.1 W	≈0W
	PCIe	0.09 to 1.4 W	

SSD provide another possible improvement option from an energy in use point of view, especially when they replace 3.5 inch HDD. Whilst the costs of SSD continues to fall they still command a price premium per GB of storage over HDD. Smaller, less expensive SSD used to store a computer's operating system and commonly available files, provide a potential cost effective way to realise the energy savings features of SSD in personal computers.

SSD are already significantly more energy efficient than HDD but additional improvement opportunities are still available for SSD. Many SSD support advanced power management functionalities but these are not always supported by computers themselves. Successful implementation of enhanced power management capabilities in SSD provide a further opportunity for energy savings. Fully exploiting the energy savings provided by SSD, however, would involve a redesign of the file system management software, but in the other hand it results in faster wake-up time from off and from standby modes thus encouraging shorter intervals when switching from on-mode into stand-by/off mode, as it was previously described in the task 3 report.

5.4.5 Design Option 4: Integrated Displays

The integrated displays used in some computer types can account for a large proportion of overall energy use. Whilst, many of these displays have already adopted energy saving technologies, such as exchanging CFL backlighting for more efficient LED backlighting, further energy efficiency opportunities remain. Quantum dot technology, which allows for more light to pass from backlights to the front of a display, due to the production of monochromatic light rather than light that needs to be filtered, may be able to provide significant energy savings in integrated displays. However, since integrated desktop computers are comparable to desktop computers in terms of ecodesign requirements, the energy performance will not only look at the energy efficiency at display level, but it will account for other factors related to data processing and material efficiency.

5.4.6 Design Option 5: Central Processing Units (CPUs)

The level of energy efficiency found in CPUs has been increasing since they first became mainstream components in electronic devices. Power management functionalities such as voltage and frequency controls have been effective in reducing CPU power demand during periods of inactivity. In addition, current leakage issues have been partially addressed using innovative insulating materials in novel three-dimensional transistor gates. Further reductions in the size of CPU transistors (i.e. down to 7nm and 5nm) are likely to result in further increases in CPU efficiencies above what has already been seen in the market. These future efficiency increases are a promising design option to promote further energy savings.

Advanced power management functionality within CPU's are another promising design feature that could save more energy in the future. Better and wider implementation of SI0x states across CPUs and SoC designs hold promise for future energy savings.

5.4.7 Design Option 6: Graphics Processing Units (GPU)

The idle state power demands of discrete GPU (dGfx) have been substantially reduced since the development of the current ecodesign regulation on computers. These achievements have been made using power management technologies previously only found in CPUs. But as with CPU's further design opportunities exist for saving energy in these products. Increasing usage of insulating materials and improved transistor design will be required to offset the potential for increase current leakage as transistor size reduces further.

The inclusion of higher bandwidth memories in integrated GPU (iGfx) will likely increase the level of performance of these devices considerably, to the point where they may be able to replace some higher specification dGfx. Given that power demand in an iGfx can be controlled to a greater degree than in dGFx, these iGfx performance improvements are a potentially important design option offering further energy savings.

5.4.8 Advanced Power Management

Most personal computers include some power management capabilities, where either the entire device or individual components are powered down during periods of inactivity. Whilst these established power management technologies have undoubtedly saved a large amount of energy, they are not without their flaws. Some power management functionality can be unreliable, with computers refusing to wake quickly following a power down event, or functionality being lost on waking. These issues can cause user frustration and result in the disabling of these energy savings design features.

New advanced power management functionalities, which involve full hardware integration, are likely the most important design option for further energy savings in computers. As an example, Microsoft's Modern Standby advanced power management functionality aims to support very fast power down and wake times which do not impact the usability of computers.