Preparatory study for implementing measures of the Ecodesign Directive 2009/125/EC

DG ENTR Lot 9 - Enterprise servers and data equipment

Task 5: Environment & Economics

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Glossary

BC	Base-Case
BoM	Bill of Materials
CPU	Central Processing Unit
CRM	Critical Raw Materials
DAE	Disk Array Enclosure
ErP	Energy-related Products
EU	European Union
HDD	Hard Disk Drive
IC	Integrated Circuit
LCA	Life Cycle Analysis
LCC	Life Cycle Costs
MEErP	Methodology for the Ecodesign of Energy-related Products
ODD	Optical Disk Drive
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
POP	Persistent Organic Pollutants
PSU	Power Supply Unit
PUE	Power usage effectiveness
SLCC	Societal Life Cycle Costs
SNIA	Storage Networking Industry Association
SPEC	Standard Performance Evaluation Corporation
TDP	Thermal Design Power

Introduction

This task provides an environmental and economic assessment of the average EU enterprise servers and data equipment covered in the DG ENTR Lot 9 preparatory study, also known as the “Base-Cases” (BCs). **A BC is “a conscious abstraction of reality” used to represent the average of a range of similar products on the market.** The aim of the assessment is to quantify:

- The environmental impacts of the selected Base-Cases throughout their lifetime;
- The economic Life Cycle Costs (LCC); and
- The Societal Life Cycle Costs (SLCC).

The assessment includes all stages of the BC lifetime from the extraction of the materials contained within its components, to the disposal of these materials at the end-of-life. The environmental impacts are determined by a well-established methodology known as Life Cycle Analysis (LCA). In this study a simplified LCA tool is used to calculate the environmental impacts and LCC as well as SLCC. The tool, which is called EcoReport, is part of the Methodology for the Ecodesign of Energy-related Products (MEErP, 2011), required by the European Commission for undertaking all preparatory studies under the Ecodesign Directive[1].

The MEErP is the successor of the former Methodology Study Eco-design of Energy-using products (MEEuP), developed in 2005. Some of the main changes in the MEErP, and the additional material efficiency module, with respect to MEEuP and taken into account for Task 5 are:

- A “new materials sheet” that allows adding extra materials to the EcoReport;
- The consideration of new policies, such as the REACH Directive and the strategy for Critical Raw Materials (CRM) and a CRM calculator included in EcoReport;
- A recyclability benefit rate (RBR) for bulk and technical plastics (potential output for future recycling);
- A new data set for recycled materials;
- New LCC equations, including an escalation rate of energy prices;
- Base Case Life Cycle Costs for society using extended LCC equations with a CO_2 stock price, societal damage certain emissions, etc.

While this study was completed as comprehensively and accurately as possible, it relies on data which were extrapolated from literature and information provided by stakeholders. The performance of real-life appliances can vary substantially from the data provided in this report. This is understood and mitigated as much as possible, while handling and calculating the data during the analysis, however some approximations are ultimately unavoidable.

The results of the study are nevertheless valuable as they represent the best indication to date of the environmental impacts of the ENTR Lot 9 enterprise servers and data equipment in the EU-28. The description of the BC is the synthesis of the results of Tasks 1 to 4 of this preparatory study. The environmental and life cycle cost analyses of the selected BC provide the main results of this study and it serves as the point-of-reference for Task 6 (design options) and Task 7 (scenarios, policy-, impact-, and sensitivity analysis).

[1] The tool is available for download on the EC site: http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/methodology/index_en.htm

1.Overview of Base-Cases

According to the Ecodesign Directive (2009/125/EC), the products subject to future establishment of implementing measures should meet three criteria:

- Significant market share;
- Significant environmental impact; and
- Significant improvement potential.

The implementing measures target appliances that are common on the EU market, bear a large environmental burden, and have the potential to improve their environmental performance. An appliance that does not meet any of these three criteria provides little opportunity for policy action, and therefore is not considered as a BC. As previously mentioned, BCs are not necessarily representative of real products. **When two products have a similar functionality, bill of materials (BoM), technology and efficiency, they can be represented by a single BC.** For further justification of the criteria for selecting Base-Cases, please refer to the MEErP methodology. It has to be noted that products that are not considered as a Base-Case are not automatically excluded from a potential regulation in the future.

During the consultation process DIGITALEUROPE suggested the following base cases to the project team:

Table 1: Base Cases as suggested by DIGITALEUROPE

<table>
<tr><th>Server</th><th>Storage</th></tr>
<tr><td>IBM 8284 2 socket power resilient server</td><td>Online 2, IBM Flash 840 with 4 to 12 SSD Flash devices: 7 configurations, transaction optimized</td></tr>
<tr><td>IBM 7145 4 socket x86 resilient server</td><td>Online 3, NetApp midrange storage system, with 36 to 48 2.5” and 3.5” 7.2 K and 10 K drives: 8 configurations, streaming optimized.</td></tr>
<tr><td>IBM 5458 1 socket x86 managed server</td><td>Online 4, HP StorServe 7000, with 42 to 88 2.5” 10K Drives: 3 configurations, streaming optimized.</td></tr>
<tr><td>Intel 2 socket x86 with 1 socket populated managed server</td><td rowspan="3">Online 4, EMC VNC 5800, with 5 configurations with 125 to 325 2.5” and 3.5” 10 K and 15 K drives optimized for transactions and 5 configurations with 75 to 200 2.5” and 3.5” 10 K and 15 K drives optimized for streaming.</td></tr>
<tr><td>Dell 2 socket x86 managed server</td></tr>
<tr><td>Dell 2 socket x86 blade server</td></tr>
</table>

After thorough examination of the different base cases proposed by DIGITALEUROPE and by making use of the above criteria as guidelines, three most appropriate BCs have been retained for this study. The equipment covered by the Lot 9 preparatory study depends to a very large extent on its configuration, for which reason a limited, but still representative amount of BC have been retained.

As far as servers are concerned, resilient servers represented only around 1.25% of EU-28 sales in 2012 and can therefore not be considered as a base case. A 2 socket server with only 1 populated socket is used sub-optimally and it is not possible to deduce from market data which part of 2 socket servers are underpopulated. Since 2 socket servers represent more than 70% of annual sales, the analysis concentrates on this market segment, distinguishing between rack and blade servers, as presented in the end of Task 4.

DIGITALEUROPE suggested to focus on four storage base cases, of which two are Online 4 systems. However, Online 4 products belong to the upper bound of the midrange storage class (situated between 100k$ and 250k$) and represent only around 3% of annual sales. Furthermore, the suggestion to use SSD Flash devices for the Online 2 category seems not to be fully representative for this category, since most of Online 2 storage systems are JBOD with or without a RAID controller[2]. For this reason, a virtual base case was constructed which is covering both Online 2 and Online 3 systems, representing 54% of annual sales (see

[2] http://snia.org/sites/default/files/Emerald%20Training%20-%20Emerald%20Storage%20Taxonomy.pdf , p.14

Chapter 2.1.2.2 and 2.5.3.4 in Task 2). 41% of sales stem from Online 1 systems, which are considered to be consumer products and not relevant to be considered as a Base Case.

To sum up, Table 2 shows the selection of the three BC, based on information gathered from industry stakeholders and technical literature. The total energy consumption of the product stock at EU-28 level is estimated for the year 2012. For all calculations, a PUE of 2.0 has been assumed (see Task 3).

Table 2: Overview of product Base-Cases (BC)[3]

Product Category	EU Installed Stock (2012)	EU Annual Sales (2012)	Annual operating hours	Base-Case
Rack Server	11 900 000	2 600 000	8 760	BC-1
Blade System (with 8 blade servers)	350 000	77 900	8 760	BC-2
Storage System (hybrid system in the SNIA Online 2-3 category)	613 000	93 400	8 760	BC-3

The following table summarizes the retained technical specificities of the different base cases.

Table 3: Summary of technical specificities of selected Base-Cases (BC)

Base Cases	Description
BC-1: Rack Server (Integrated)	• Technology level: Year 2012 • 2 CPU socket (Intel E5-26XX), typical configuration according to SERT (average 2,3 GHz) • Memory: 96 GB • Storage: 4 HDDs • Internal cooling: Heat sink material • Heat pipes • 4 fans with a power consumption of 4-5 Watt at 25 – 50% load and 12-15 Watt per fan at max load or higher temperatures (30°C). • PSU (80plus silver) / redundancy: 2 x 400 W (AC/DC) • No extra power management • Power consumption according to SERT (idle: 150W / 25% Load 200W) • Use pattern: 5h@idle + 19h@25%load * 365 days * 4 years • Infrastructure Overhead / PUE: 2.0
BC-2: Blade System (8 servers, modular)	• Technology level: Year 2012 • 2 CPU socket (Intel E5-26XX), typical configuration according to SERT (average 2,3 GHz), per server • Memory: 96 GB, per server • Storage: 2 HDDs, per server • Internal cooling: Heat sink material • Fans and heat pipes • PSU (80plus silver) : 4 x 1600 W (AC/DC), system • No extra power management • Power consumption according to SERT (idle: 150W / 25% Load 200W), per server • Use pattern: 5h@idle + 19h@25%load*365*4 years • Infrastructure overhead / PUE: 2.0
BC-3 Storage (virtual product, hybrid system)	• Category: Online 2-3 (SNIA taxonomy), virtual product • Technology level: year 2012 • ½ Controller • Media mix: 3.5 HDD, 2.5 HDD, SSD / total capacity ca. 40 TB • 2 Disk Area Enclosures (DAE) containing a mix of 3.5 inch and 2.5 inch HDDs as well as SSDs. • Components: PCB (controller), connectors, PSU, Fans, Housing • Power consumption according to SNIA averages. • Disk utilization / use pattern: 5 hours idle / 19 hours load x 365 x 6 years • Infrastructure Overhead / PUE: 2.0

[3] Figures for EU annual sales have been retained from information provided by Digital Europe, whereas Figures for the storage system have been calculated with Data from Gartner (see Task 2). EU installed stock data was calculated by means of the stock model. Annual operating hours represent non-stop operation (24 h x 365 days).

2.Product-Specific Inputs

In this section, a description of the characteristics of the selected Base-Cases and the specific inputs needed for the environmental and economic analysis are presented, as well as the justification of all assumptions made.

The information used in the environmental and economic analysis of the Base-Cases hereunder is provided by stakeholders and completed with information taken from publicly available literature.

The electricity rates are taken from the MEErP and are adjusted by an annual escalation rate (4%). A comparison with Eurostat data shows that the obtained electricity price matches with the current rate. A discount rate of 4% (same for all Base-Cases) was obtained from the MEErP. The discount rate is used for the Life Cycle Cost (LCC) analysis and the Societal Life Cycle Costs (SLCC). The MEErP also allows adding new materials and their respective environmental impacts manually in a separate sheet. Since the available categories were considered to be sufficient for the available data, no use was made from this option. The following subsections present the different inputs considered for the Base-Cases.

2.1. Enterprise Servers

2.1.1. Inputs in the production and distribution phase of a Rack Server

The table below shows the bill of materials of BC-1, a rack server, as presented in Task 4.

Table 4: Bill of Materials of BC-1 (Rack Server)

Component	Material	Weight (g)	Component	Material	Weight (g)
Chassis	Metal Body	12 265	PSUs (2*400W)	Low-alloyed steel	1 027
	Plastics	348		Chromium steel	66
	Plastics	282		Brass	42
	Aluminium	249		Copper	9
	Copper	179		Zinc	7
	Electronic components	131		Aluminium	491
Fans (4)	Steel	386		High Density Polyethylene	184
	Copper	78		Polyvinylchloride (PVC)	92
	Iron based	55		Paper	50
	Plastic (PBT-GF30)	206		Electronic components	1 101
	Plastic (PCABSFR40)	21		Solder	31
	Plastic (undefined)	200		PCB	326
HDDs (4)	Steel	12	CPU Heat Sink	Copper	442
	Low alloyed steel	222		Steel	140
	Aluminium	1 335	Mainboard	Controller board	1 667
	PCB	179	Memory	PCB	97
				IC	38
ODD	Low alloyed steel	115	Expansion Card	PCB	349
	Copper	7	Cables	Brass	7
	Aluminium	1		Copper	81
	High Density Polyethylene (HDPE)	28		Zinc 0.166 kg	96
	Acrylonitrile-Butadiene-Styrene	12		High Density Polyethylene	104
	Polycarbonate (PC)	7		Polyvinylchloride (PVC)	145
	Electronic components (capacitors,	8		Polyurethane (PUR)	2
	Solder	2		Synthetic rubber	35
	PCB	9	Packaging	Cartons	3629
CPUs (2)	Copper	31		HDPE/ unspecified plastics	78
	Gold	0,4		GPPS/ Styrofoam	1 026
	PCB	21			
	IC	2			
Total weight of BC-1: 27 748 g					

Above data have been obtained and aggregated from several industry stakeholders and internet research. Furthermore, JRC IES provided detailed BoM for servers and some their components (e.g. HDD, PSU and fans)[4]. The total weight of BC-1 amounts to around 27.7 kg, of which the chassis represents an important part (44%). The mainboard does not include memory and CPUs, which are listed and evaluated as separate items. The packaging consists mainly of cardboard and different sorts of plastics.

[4] JRC-IES (2015). Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements for enterprise servers, Draft report.

2.1.2. Inputs in the production and distribution phase of a Blade System

The following table shows the bill of materials of the second BC which represents a blade system with an enclosure for 16 slots, containing 8 blade servers (50% populated, see Figure 1).

Table 5: Bill of Materials of BC-2 (Blade System with 8 blade servers)

Enclosure		
Component	**Material**	**Weight (g)**
Chassis	Steel	87 000
Fans (6)	Steel	964
	Copper	194
	Iron based	137
	Plastic (PBT-GF30)	515
	Plastic (PCABSFR40)	52
	Plastic (undefined)	499
PSUs (4)	Low-alloyed steel	4 981
	Chromium steel	319
	Brass	202
	Copper	43
	Zinc	32
	Aluminium	2 384
	High Density Polyethylene (HDPE)	894
	Polyvinylchloride (PVC)	447
	Paper	245
	Electronic components	5 343
	Solder	149
	PCB	1 581
Total weight of enclosure		**105 981 g**

Figure 1: Illustration of BC-2

8 Blade Servers					
Component	**Material**	**Weight (g)**	**Component**	**Material**	**Weight (g)**
Chassis	Steel	33 600	**HDDs (16)**	Steel	47
CPUs (16)	Copper	244		Low alloyed Steel	888
	Gold	3		Aluminium	5 341
	PCB	170		PCB	717
	IC	15	**Packaging**	Cartons	14 969
CPU Heat Sinks	Copper	1 688		HDPE/ unspecified plastics	321
	Steel	560		GPPS/ Styrofoam	4 233
Memory	PCB	773	**Mainboards**	Controller Board	6 451
	IC	307			
Total weight of 8 Blade Servers: 70 327g					
Total weight of BC-2: 176 308 g					

Component data have been directly provided by stakeholders and refined through internet research. The enclosure amounts to around 60% of overall weight, largely dominated by the chassis. An average blade server weights around 6.3 kg (without packaging). Like in BC-1, memory and CPUs are listed separately of the mainboard.

2.1.3. Inputs in the use phase

Table 6: Inputs in the use phase for BC-1 and BC-2[5]

	BC1 - Rack Server	BC2 - Blade System
Product life in years	4	4
On-mode: Direct Energy consumption per year (in kWh)	1 661 kWh	13 286 kWh
Indirect energy consumption overhead (PUE)	2	2

2.1.4. Inputs in the distribution phase

Table 7: Inputs in the distribution phase for BC-1 and BC-2

	BC1 - Rack Server	BC2 - Blade System
ICT or Consumer Product <15kg?	NO	NO
Installed Appliance?	YES	YES
Volume of packaged final product in m^3	0.04	0.51

Information on the volume of packaged final products has been obtained from documents received directly from the stakeholders or from product information available on stakeholders' websites.

2.1.5. Inputs in the end-of-life phase of BC-1 and BC-2

The following table shows the end-of-life assumptions for BC-1 and BC-2 as shown in Task 3.

Table 8: Inputs in the end-of-life phase of BC-1 and BC-2

	Plastics	Ferro	Non-ferro	Coating	Electronics	Misc.
Re-Use	50%					
Material Recycling	5%	45%			36.5%	43%
Heat Recovery	44%	0%			12.5%	1%
Non-recovery incineration	0.5%	0%			0.5%	5%
Landfill	0.5%	5%[6]			0.5%	1%
Total	100%	100%			100%	100%

[5] Inputs for the use-phase have been retained from Task 3 (5h idle & 19h load at 25% and using SERT data). For all the equipment an indirect energy consumption overhead (PUE) of 2 has been retained.
[6] This value cannot be changed in the EcoReport tool.

2.1.6. Economic inputs

Table 9: Economic inputs for BC-1 and BC-2[7]

	BC1 - Rack Server	BC2 - Blade System
Annual sales 2012 (units)	2 600 000	77 900
EU stock 2012 (units)	11 900 000	350 000
Average product purchase price (€)	2 500 €	65 000 €
Installation costs (€)	330 €	460 €
Electricity rate (€/kWh; non-domestic, excl. VAT)	0.12 €	0.12 €
Repair & maintenance costs (incl. VAT; €/year)	180 €	180 €
Discount rate	4%	4%

Average product purchase prices, installation costs and repair and maintenance costs have been calculated from values taken from stakeholders' websites. Since the price range of products is very high, these values should be interpreted cautiously, since they are attributed to the specific BC and are not necessary representative for all product varieties. The electricity rate is taken from the MEErP and adjusted by a yearly escalation rate (4%).

2.2.Enterprise Storage

2.2.1. Inputs in the production and distribution phase of BC-3

The table below shows the bill of materials of BC-3, a virtual storage unit with ½ controller, two disk array enclosures (DAEs) and a storage media mix consisting of 16.66 (+2.69 spare) 3.5 inch HDDs, 12.07 (+1.95 spare) 2.5 inch HDDs and 2.87 SSDs. The cabin is not considered and the storage media mix comes with around 40 TB capacity. The figure on the right shows an illustration of BC-3:

Figure 2: Illustration of the DAEs in BC-3

Table 10: Bill of Materials of BC-3

Controller (1/2)					
Component	Material	Weight (g)	**Component**	Material	Weight (g)
Controller	Steel	7 450	**PSU controller**	Mainboard	825
	Stainless steel	1 680		Cables	20
	Aluminum sheet	287		Chassis and bulk material	889
	Copper	520	**PSU Fans**	Steel	110
	ABS	510		Copper	65
	PET	39		Iron based	13
	HDPE	87		Nylon 6	9
	PP	18		PC	35
	PC	31		ABS	19
	Nylon 6	5	**Packaging**	Cartons	3 629
	PVC	85		HDPE/ unspecified plastics	78
	Other plastics	12		GPPS/ Styrofoam	1 026
	Printed circuit board	577			
Total weight of controller: 18 020 g					
Disc Array Enclosures (2)					

[7] The economic inputs for BC-1 and BC-2 are based on figures presented in Task 2. Annual sales data were provided by Digital Europe. The EU stock has been calculated by means of the stock model.

Chassis	PC	406	**Fans in PSUs (8)**	Steel	563
	ABS	92		Copper	332
	Steel sheet part	15 374		Iron based	66
	Zinc Part	298		Nylon 6	47
	Steel Machined Part	3		PC	177
PSUs in DAEs (4)	Mainboard	4 217		ABS	95
	Cables	104	**Controller cards (4)**	Electronics	2 308
	Chassis and bulk materials	4 546	**Mid plane boards (2)**	Electronics	920
Total weight of DAEs: 29 554 g					
Storage Media Mix (40.1 TB)					
3.5 HDD (19.35)	Steel	58	**2.5 HDD (14.01)**	Steel	278
	Low Alloyed Steel	1 103		Low Alloyed Steel	211
	Aluminium	6 637		Aluminium	2 562
	PCB	890		PCB	123
SSDs (2.86)	Electronic components	172		ABS	7
	IC	5			
Total weight of Storage Media Mix: 12 050 g					
Total weight BC-4 (SNIA Online 2/3): 59 623 g					

BC-3 contains 2 DAEs which together make up for almost 50% of the total weight. 30% of the weight is coming from the controller and the rest can be attributed to storage media (20%). As can be seen from above table, aluminium constitutes the largest share of the total weight of the storage media mix (76%).

The EcoReport tool includes a parameter for spare parts, which is fixed to 1% and cannot be adjusted. For this reason, spare HDDs have been added to the bill of materials in order to assure the proper functioning of the storage system over its lifetime and to take into account a higher replacement rate.

2.2.2. Inputs in the use phase

The following table presents the inputs for BC-3 during the use phase.

Table 11: Inputs in the use phase for BC-3[8]

	BC3 – Storage System
Product life in years	6
On-mode: Energy consumption per year (in kWh)	3 279 kWh
Indirect energy consumption overhead (PUE)	2

2.2.3. Distribution phase

Table 12: Inputs in the distribution phase

	BC3 – Storage System
ICT or Consumer Product <15kg?	NO
Installed Appliance?	YES
Volume of packaged final product in m^3	0.072

Information on the volume of packaged final products has been obtained from documents received directly from the stakeholders or from product information available on stakeholders' websites.

[8] Inputs for the use-phase have been retained from Task 3 (5h idle & 19h load at 25%). For all the equipment an indirect energy consumption overhead (PUE) of 2 has been considered.

2.2.4. Inputs in the end-of-life phase of BC-3

Table 13: Inputs in the end-of-life phase of the storage system

	Plastics	Ferro	Non-ferro	Coating	Electronics	Misc.
Re-Use	25%					
Material Recycling	5%	70%			50%	68%
Heat Recovery	69%	0%			24%	1%
Non-recovery incineration	0.5%	0%			0.5%	5%
Landfill	0.5%	5%[9]			0.5%	1%
Total	100%	100%			100%	100%

2.2.5. Economic inputs

Table 14: Economic inputs for BC-3

	BC3 – Storage System
Annual sales 2012 (units)	93 400
EU stock 2012 (units)	613 000
Average product purchase price (€)	23 000 €
Installation costs (€)	130 €
Electricity rate (€/kWh)	0.12 €
Repair & maintenance costs (incl. VAT; €/year)	210 €
Discount rate	4%

The economic inputs were taken from Task 2 as well as the stock model. Again, average product purchase prices, installation costs and repair and maintenance costs were calculated from values taken from stakeholders' websites and are not necessary representative for all product varieties.

[9] This value cannot be changed in the EcoReport tool.

3.Base-Case Environmental Impact Assessment

3.1.Scope of the Environmental Impact Assessment

3.1.1. Environmental Impact Categories of the EcoReport

Using the EcoReport tool and the above inputs, it is possible to calculate environmental impacts for the following phases of a product life:

- Raw Materials Use and Manufacturing;
- Distribution;
- Use phase;
- End-of-Life Phase.

This chapter provides the environmental impacts of the Base-Cases throughout all the life cycle stages. The results were calculated using the EcoReport tool of the MEErP, based on the inputs presented in the previous section. The MEErP tracks 15 environmental impact categories, classified in three main categories:

- Resources and waste:
    - Total energy (GER - gross energy requirement)
        - of which electricity (in primary MJ)
    - Water (process)
    - Water (cooling)
    - Waste, non-hazardous/landfill
    - Waste, hazardous/incinerated
- Emissions (air):
    - Greenhouse gases in GWP100
    - Acidification, emissions
    - Volatile organic compounds (VOC)
    - Persistent organic pollutants (POP)
    - Heavy metals into air
    - Polycyclic aromatic hydrocarbons (PAHs)
    - Particulate matter (PM, dust)
- Emissions (water):
    - Heavy metals into water
    - Eutrophication

Apart of the environmental input assessment via the EcoReport, the MEErP requires to analyse the existence and impact of hazardous substances as defined in the RoHS Directive as well as critical raw materials (CRM).

3.1.2. Hazardous substances and Critical Raw Materials in Enterprise Servers and Storage Equipment

The RoHS Directive restricts the use of six hazardous materials (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE)) in the manufacturing process of electrical equipment to be sold in the EU. The Directive has an exemption which is specific to servers for “lead in solders for servers, storage and storage array systems, network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications.” The main reason for this exemption is that solder joints are subjected to significant stress due to thermal cycling, and solders with lead have historically been more tolerant and have higher reliability than lead-free solders.[10]

In February 2011 the EC published a communication on Critical Raw Materials (CRM)[11] which proposed a list of 14 raw materials that are critical to the EU in the sense of:

- High import dependency;
- Limited possibilities of substitutability;
- No or very limited recycling rate.

This list has been updated in May 2014 to 20 raw materials. Six new CRM were added, while Tantalum was removed. Furthermore, rare earth elements were split up into heavy and light rare earth elements. Most CRM are used not as single construction materials to build parts and components. Instead, they are alloying elements, additives, coatings, agents, etc. and used in very small fractions during the production of major materials like aluminium, steel or plastics. Hence, a very comprehensive and long list of variations of these main materials would be necessary in order to capture the CRM indicator. For this reason it is not yet possible to realise an analysis on a structural and universal basis in the EcoReport. However, it is possible to do this manually on an ad-hoc basis, i.e. once a product group is known and once the specific alloys in a bill-of-materials have been identified it can be converted to a CRM indicator in 'Sb eq' (Antimony) according to Table 15, which is defined in the MEErP and referring to the first list with 14 CRM.

Table 15: Critical Raw Material index

CRM	GE	Be	Ta	In	PGM*	Ga	Sb	W	Nb	REM**	Co	C	CaF2	Mg
Index in Sb mass eq* **	18	12	9	9	8	8	1	0.2	0.04	0.03	0.02	0.01	0.001	0.0005

*PMG = Platinum Materials Group = Pt, Pd, Rh, Ru, OS, Ir; **REM=Rare Earth Materials = fifteen lanthanoids, scandium, yttrium; *** = kg antimony equivalent per kg of critical raw material

The report *Information on Chemicals in Electronic Products* states that "the main hazardous substances that could be found in electronic products are: lead, mercury, cadmium, zinc, yttrium, chromium, beryllium, nickel, brominated flame retardants, antimony trioxide, halogenated flame retardants, tin, polyvinyl chloride, PVC, and phthalates."[12]

Furthermore, the report mentions that lead, mercury and cadmium can e.g. be found in batteries and solder can contain different metals, lead or tin. In printed circuit boards, cadmium occurs in certain components together with other hazardous metals such as lead, chromium, beryllium, zinc, mercury, and nickel. Brominated flame retardants and antimony trioxide are also often used in PCBs. Wiring is often coated in PVC, which frequently contains numerous additives, such as heavy metal compounds or softeners such as phthalates.

Data published by the German Environmental Agency on integrated circuits, manufactured using back-end processes indicates the following silicon and tin contents per piece[13]: $23.7*10^{-6}$ kg for silicon and $26.3*10^{-6}$ kg for tin respectively.[14] Thus, silicon accounts for 14.6% of the overall chip weight, while tin makes up 16.2%.

The *Server Supplemental Background Information*[15]*,* published by the Green Electronics Council in February 2013 provides additional server related information about the composition and construction of servers and specific environmental performance criteria. It lists several JIG101[16] declarable substances found in servers and its purpose, shown in Table 16.

[10] http://www.epeat.net/wp-content/uploads/2012/11/ServerPrimer2012.pdf , p.35

[11] TACKLING THE CHALLENGES IN COMMODITY MARKETS AND ON RAW MATERIALS, COM(2011)25 final of 2.2.2011

[12] Information on Chemicals in Electronic Products - A study of needs, gaps, obstacles and solutions to provide and access information on chemicals in electronic products (TemaNord 2011:524)

[13] DRAM DDR3 chip with an area of 43 mm^2 and a storage capacity of 1 GB.

[14] http://www.probas.umweltbundesamt.de/php/themen.php?&prozessid={D522DCCE-C11F-401A-AF2B-849E6B61EAE2}&id=12650020864&step=4&search=

[15] http://standards.nsf.org/apps/group_public/download.php/22018/Server%20Supplemental%20Information%20-%20Final.docx

[16] JOINT INDUSTRY GUIDE (JIG) Material Composition Declaration for Electrotechnical Products: https://www.ce.org/CorporateSite/media/Standards-Media/Standards%20Listings/JIG-101-Ed-41-120521.pdf

Table 16: JIG101 declarable substances found in servers

Substances found in servers	Purposes
• Antimony trioxide (CAS 1309-64-4) • Antimony/Antimony Compounds • Arsenic/Arsenic Compounds • Beryllium/Beryllium Compounds • Bismuth/ Bismuth Compounds • Bisphenol A (CAS 80-05-7) • Brominated Flame Retardants (other than PBBs or PBDEs) • Chlorinated Flame Retardants • Di (2-ethylhexyl) phthalate (DEHP) (CAS 117-81-7) • Nickel • Perchlorate • PVC	A general list of applications include: • Ceramics • Plasticizers • Flame retardants • Solder • Hardware plating • Battery coin cells • Insulator resins

Neodymium and other rare earth elements are often used in permanent magnets, several of which can be found inside the chassis of HDDs. The most dominant magnets are the permanent magnets of the voice coil motor (VCM). These are usually two identical kidney-shaped magnets, each attached to a metal plate. Some of the 3.5-inch and most 2.5-inch HDDs only contain one magnet. Further magnets are built into the read/write head and the spindle motor.[17] Following the disassembly of 147 HDDs from 1990 onwards (130 of which were usable), the same study found an average weight of 16.3 g per magnet in 3.5-inch HDDs and of 2.5 g in 2.5-inch drives. The subsequent analysis of the samples by resonance frequency analysis resulted in an average content of 25% neodymium, 5.3% praseodymium and 66% iron.[17] Measurements of separated magnets from HDDs delivered a neodymium concentration in the magnets of 23-25% and concentrations of praseodymium, dysprosium and terbium between 0.01% and 4%.[18] While manual disassembly allows in principle for all magnetic material to be recovered, shredding leads to very low recovery rates (<10%).[19]

In a recent technical report on “the environmental footprint and material efficiency support for product policy”, the JRC summarized the following critical raw materials included in enterprise servers:

Table 17: Content of diverse critical raw materials (CRMs) in parts included in enterprise servers[20]

Part	Material	Symbol	Content
HDD	**Dysprosium**	Dy	Average content in magnets (in mass): 20% Nd; 5% PR; 5% Dy; 1% Tb (Du and Graedel 2011). Content in HDD (in mass): 60 mg Dy; 1 044 mg Nd; 145 mg Pr (Buchert, Manhart et al. 2012).
	Neodymium	Nd	
	Praesodynium	Pr	
	Terbium	Tb	
PCBs	**Palladium**	Pd	Poor PCB: 10-100 [mg/kg]; Rich PCB: 100-470 [mg/kg] (Reuter, Hudson et al. 2013); average content: 50-2200 ppm (Duan, Hou et al. 2011).

[17] Zepf, V., 2013. Rare earth elements: A new approach to the nexus of supply, demand and use : exemplified along the use of neodymium in permanent magnets, Berlin and London: Springer.

[18] Rotter, V.S., Ueberschaar, M. & Chancerel, P., 2013. Rückgewinnung von Spurenmetallen aus Elektroaltgeräten. In K. J. Thomé-Kozmiensky & D. Goldmann, eds. Recycling und Rohstoffe - Band 6. Neuruppin: TK Verlag Karl Thomé-Kozmiensky.

[19] Sprecher, B. et al., 2014. Life cycle inventory of the production of rare earths and the subsequent production of NdFeB rare earth permanent magnets. Environmental science & technology, 48(7), pp.3951–8.

[20] JRC-IES (2015). Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements for enterprise servers, Draft report.

	Platinum	Pt	Rich PCB : 7-40 [mg/kg] (Reuter, Hudson et al. 2013); average content: 4.6-30 ppm (Duan, Hou et al. 2011).
	Antimony	Sb	Average content (in mass): 0.4-20 ppm (Khaliq, Rhamdhani et al. 2014); Average content (in mass) in: motherboard (0.06%); average PCB (0.4%) (Duan, Hou et al. 2011).
	Silicon	Si	Content of SiO_2 in various PCB: 15-24.7% (in mass) (Duan, Hou et al. 2011) Average content: 15-41.86% (Khaliq, Rhamdhani et al. 2014).
	Gallium	Ga	Content in average PCB: 13 ppm [Ewasteguide.info, 2014].
	Germanium	Ge	Content in average PCB: 16 ppm [Ewasteguide.info, 2014].
	Cobalt	Co	Average content in computer PCB: 12 [mg/kg] (Hall and Williams 2007); content in mixed PCB: 4000 ppm (Yoo, Jeong et al. 2009).
Batteries	**Cobalt**	Co	Mean content in mixed lithium-ion battery packs (in mass) 13.8% (Buchert, Manhart et al. 2012).
	Lithium	Li	Content in button/coin batteries 0.05-0.10 g Content in prismatic secondary batteries 0.30-3.10 g (Talens Peiró, Villalba Méndez et al. 2013).

Based on these information (average values) and the bill of materials of the different base cases, the weight of several CRMs was estimated. The following table shows a summary of CRMS used in PCBs and HDDs in the different product groups.

Table 18: Estimated weight of diverse critical raw materials contained in the PCBs and HDDs of the Base Cases

Material	BC-1 (g)	BC-2 (g)	BC-3 (g)
Dysprosium	0.24	0.96	2.00
Neodymium	4.18	16.70	34.83
Praesodynium	0.58	2.32	4.84
Palladium	0.93	2.06	2.41
Platinum	0.09	0.20	0.24
Antimony	0.02	0.34	0.40
Silicon	11.01	24.40	28.53
Gallium	0.05	0.11	0.13
Germanium	0.06	0.14	0.16
Cobalt	0.05	0.10	0.12

Since information is only available from literature and for specific parts like HDDs or PCBs, these values need to be considered as a lower-bound estimations.

The JRC-IES analysis of material efficiency requirements for enterprise servers found that the main critical raw materials are located in HDD, diverse PCBs and connectors as well as in batteries. The most important weight of CRM is coming from Neodymium in the magnets of the HDD, followed by silicon in the die of integrated circuits and cobalt in batteries[21].

[21] JRC-IES (2015). Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements for enterprise servers, Draft report.

While the EcoReport tool does not allow to take into account CRMs as a direct input which translates into environmental impacts, it provides a conversion table to calculate a CRM indicator in grams Antimony (Sb) equivalent for several CRM (not the entire list). The following table shows outputs for five CRM:

Table 19: CRMs in the base cases

Material	Characterization factor [kg Sb eq./kg]	BC-1		BC-2		BC-3	
		g	CRM indicator (g)	g	CRM indicator (g)	g	CRM indicator (g)
Germanium (Ge)	18.00	0.06	1.11	0.14	2.47	0.16	2.89
Gallium (Ga)	8.00	0.05	0.40	0.11	0.89	0.13	1.04
Antimony (Sb)	1.00	0.02	0.02	0.34	0.34	0.40	0.40
Neodymium (Nd)	0.03	4.18	0.12	16.70	0.50	34.83	1.04
Cobalt (Co)	0.02	0.05	0.0009	0.10	0.002	0.12	0.002
Total		**4.36**	1.66	**17.4**	4.21	**35.64**	5.38

The CRM indicator is not an environmental indicator, but describes the scarcity of a material from an economic perspective. The following table shows the total weight of considered CRMs and the CRM indicators contained in sold products and the current stock at the EU level:

Table 20: CRM indicators in EU sales and stock for the base cases (2012)

	BC-1 (Rack)		BC-2 (Blade)		BC-3 (Storage)	
	CRM	CRM indicator (Sb equivalent)	CRM	CRM indicator (Sb equivalent)	CRM	CRM indicator (Sb equivalent)
Total Sales (2012) in t	11	4.3	1.4	0.3	3.3	0.50
Total Stock (2012) in t	52	19.8	6	1.5	22	3.30

According to the MEErP, the total EU consumption of CRMs is around 3 550 t Sb equivalent per year (2006/2007 values). The sum of the three CRM indicators is 5.1 t Sb equivalent (0.14%).

3.1.3. Recyclability benefit rate (RBR)

The new EcoReport tool allows calculating a recyclability benefit rate (BRB) for bulk and technical plastics, intended to compare different end-of-life scenarios under different design options.

The following inputs are required:

- Recyclable plastic parts;
- Downcycling index *k* (A higher downcycling index *k* means a higher quality of the recycled material);
- Recycling rate for recyclable parts (RCR).

The output recyclability benefit rate shows the potential credit through recycling of plastics. No detailed downcycling and recycling rates could be obtained for the different plastic parts because of lack of data. However, a test using 5% mechanical recycling rates and the standard MEErP downcycling rates shows that the impact of this additional variable can be neglected.

The analysis presented in the sub-sections below allows the most significant environmental impacts to be determined by the EcoReport tool. It will also be used as a reference when analysing the improvement potential of design options in Task 6.

3.2.Enterprise Servers

3.2.1. BC-1 Rack Server

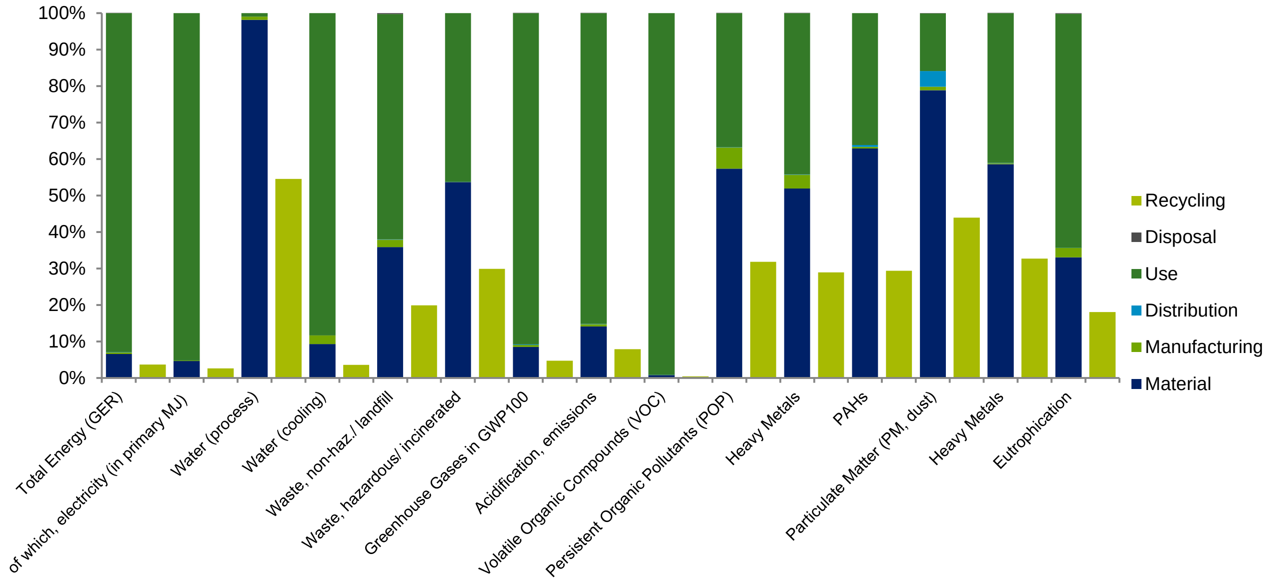

Figure 3: Distribution of BC-1 environmental impacts by life cycle phase[22]

The results of the environmental analysis of BC-1 (rack server) are shown in Figure 3 and in Table 21. According to these, the energy consumption during the use phase is by far the predominant aspect contributing to the environmental impacts from the product's entire life cycle.

The use phase contributes with more than 85% of the overall environmental impacts to 6 environmental impact categories:

- Total Energy (GER): 93%
  - of which, electricity: 95%
- Water for cooling: 88%[23]
- Greenhouse Gases in GWP100: 91%
- Acidification, emissions: 85%
- Volatile Organic Compounds (VOC): 99%

On the other hand, the material part contributes to a large share of the environmental impact for several air and water related emissions like Persistant Organic Pollutants (POP), heavy metals, Polycyclic Aromatic Hydrocarbons (PAHs) or Particulate Matter (PM) as well as on the waste part.

Because of the relatively high re-use and recycling rates, the end-of-life phase plays an important role in reducing the environmental impact of the product. This is particularly true for air and water related emissions such as POPs, PM and heavy metals.

[22] The left column of each category shows the negative environmental impacts, whereas the right column shows the credits coming from recycling during the end-of-life phase.

[23] In the Ecoreport tool "Water for cooling" refers to water used during the production phase.

Table 21: Life cycle impacts (per unit) of BC-1: Rack Server

Life Cycle phases	Unit	PRODUCTION			Distribution	Use	End-of-life			Total
Resources Use and Emissions		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit	balance	
Total Energy (GER)	MJ	8 451	552	**9 002**	92	**119 659**	9	-4 654	-4 646	**124 107**
of which, electricity (in primary MJ)	MJ	5 809	245	**6 053**	0	**119 632**	0	-3 239	-3 239	**122 446**
Water (process)	ltr	1 730	16	**1 746**	0	**17**	0	-961	-961	**802**
Water (cooling)	ltr	560	142	**702**	0	**5 320**	0	-212	-212	**5 811**
Waste, non-haz./ landfill	g	36 016	2 011	**38 027**	70	**61 981**	298	-19 990	-19 693	**80 385**
Waste, hazardous/ incinerated	g	2 214	4	**2 218**	1	**1 909**	0	-1 233	-1 233	**2 895**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	475	33	**508**	7	**5 109**	0	-263	-263	**5 361**
Acidification, emissions	g SO_2 eq.	3 747	154	**3 901**	20	**22 624**	0	-2 080	-2 080	**24 465**
Volatile Organic Compounds (VOC)	g	19	2	**22**	1	**2 671**	0	-11	-11	**2 683**
Persistent Organic Pollutants (POP)	ng i-Teq	442	45	**487**	0	**283**	0	-245	-245	**525**
Heavy Metals	mg Ni eq.	1 435	105	**1 540**	4	**1 223**	0	-801	-801	**1 966**
PAHs	mg Ni eq.	493	3	**497**	4	**284**	0	-231	-231	**555**
Particulate Matter (PM, dust)	g	2 506	31	**2 538**	137	**503**	2	-1 398	-1 396	**1 782**
Emissions (Water)										
Heavy Metals	mg Hg/20	744	3	**748**	0	**522**	0	-415	-415	**855**
Eutrophication	g PO_4	12	1	**13**	0	**23**	0	-6	-6	**29**

3.2.2. BC-2 Blade System

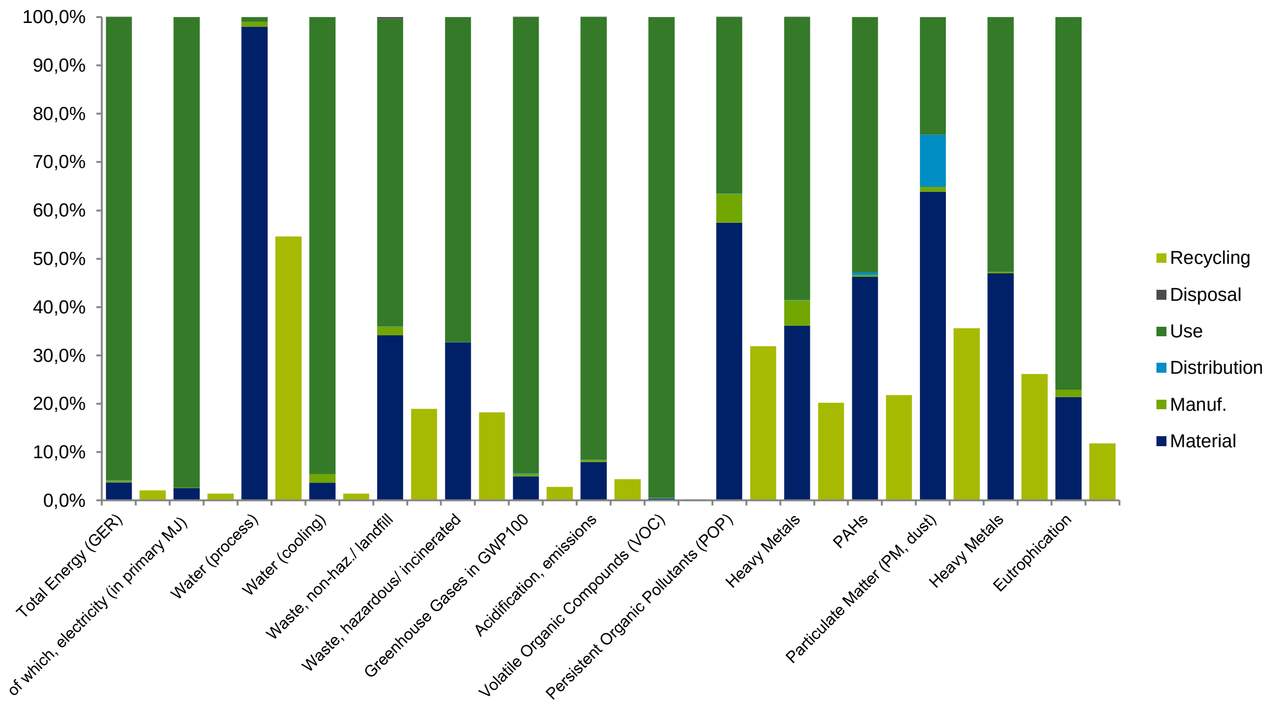

Figure 4: Distribution of BC-2 environmental impacts by life cycle phase[24]

The results of the environmental analysis of BC-2 (Blade System with enclosure and 8 blade servers) are shown in Figure 4 and Table 22. Similarly to BC-1, the use phase plays a major role. It makes up for more than 85% of the impact in 6 categories:

- Total Energy (GER): 95.9%
  - of which, electricity: 97.3%
- Water for cooling: 94.5%[25]
- Greenhouse Gases in GWP100: 94.4%
- Acidification, emissions: 91.6%
- Volatile Organic Compounds (VOC): 99.4%

The material phase contributes once again to a large share of the environmental impact for several air and water related emissions like POPs, heavy metals in air and water, PAHs or PM as well as on the waste part (~40%).

Equally, the relatively high re-use and recycling rates make the end-of-life phase play an important role in reducing the environmental impact of the product.

One has to keep in mind that the blade system comprises 8 blade servers (50% populated). Dividing the outputs presented in Table 22 by 8 shows that on a per-server level, the outputs are slightly below those of the BC-1 rack server presented beforehand.

[24] The left column of each category shows the negative environmental impacts, whereas the right column shows the credits coming from recycling during the end-of-life phase.

[25] In the Ecoreport tool "Water for cooling" refers to water used during the production phase.

Table 22: Life cycle impact (per unit) of BC-2: Blade System

Life Cycle phases	Unit	PRODUCTION			Distribution	Use	End-of-life			Total
Resources Use and Emissions		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit	balance	
Total Energy (GER)	MJ	37 180	3 265	40 445	568	956 964	43	-20 570	-20 527	**977 450**
of which, electricity (in primary MJ)	MJ	24 824	1 611	26 435	1	956 840	0	-13 852	-13 852	**969 425**
Water (process)	ltr	6 620	66	6 686	0	66	0	-3 686	-3 686	**3 066**
Water (cooling)	ltr	1 650	808	2 458	0	42 532	0	-629	-629	**44 361**
Waste, non-haz./ landfill	g	265 878	14 068	279 946	283	495 623	2 580	-147 635	-145 055	**630 797**
Waste, hazardous/ incinerated	g	7 379	17	7 396	6	15 167	0	-4 116	-4 116	**18 452**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	2 174	193	2 367	38	40 855	0	-1 207	-1 207	**42 053**
Acidification, emissions	g SO_2 eq.	15 679	874	16 554	114	180 846	2	-8 720	-8 718	**188 796**
Volatile Organic Compounds (VOC)	g	98	11	108	11	21 365	0	-55	-55	**21 429**
Persistent Organic Pollutants (POP)	ng i-Teq	3 568	372	3 940	2	2 268	1	-1 981	-1 980	**4 230**
Heavy Metals	mg Ni eq.	6 017	868	6 884	14	9 732	2	-3 358	-3 357	**13 274**
PAHs	mg Ni eq.	1 973	12	1 986	25	2 252	0	-930	-930	**3 333**
Particulate Matter (PM, dust)	g	10 327	161	10 488	1 743	3 930	11	-5 763	-5 752	**10 409**
Emissions (Water)										
Heavy Metals	mg Hg/20	3 706	28	3 734	0	4 155	0	-2 066	-2 066	**5 823**
Eutrophication	g PO_4	50	4	54	0	181	0	-28	-28	**207**

3.2.3. Carbon footprint benchmark with publicly available studies[26]

The following table shows a comparison of calculated carbon footprints for different servers and the two server Base-Cases. The values for BC-2 have been scaled down to a one-server level.

Table 23: Server carbon footprints comparison

	Dell Power Edge R710	Dell Power Edge R720	Fujitsu PRIMERGY RX300	IBM Rack-mounted Server	BC-1	BC-2 (scaled to one blade server, with allocated infrastructure)
Year	2011	2012	2010	Around 2008	2010-2012	2010-2012
Processor(s)	2	2	1	NA	2	2
HDD	4	4	1	NA	4	2
PSU	2	2	1	NA	2	NA
Lifetime	4	4	5	3 – 10 (distribution with 6 years being most likely)	4	4
Electricity Grid	US	US	German	NA	EU	EU
Use pattern	12h @ 148W idle and 12h @ 285W full workload	NA	119W @ 30% w orkload	NA	5h @ 150W idle and 19h @ 25% load	5h @ 150W idle and 19h @ 25% load
Energy consumption per year (kWh)	1 897	NA	1 042	NA	1 661	1 661
CO_2 eq. (kg)	6 360 (50% utilisation)	5210 (50% utilisation)	3 750 (30 % utilisation)	6 636 (use-phase mean)	5 361 (20% utilisation)	5 256 (20% utilisation)
CO_2 eq. (idle, kg)	4 470	NA	NA	NA	NA	NA
CO_2 eq. (100% utilisation, kg)	8 240	NA	NA	NA	NA	NA

The comparison with publicly available studies shows that the reported value for the carbon footprint is globally in line with those reported in other studies and using other LCA software. The CO_2 eq. values calculated for BC-1 and BC-2 are below the ones reported for the Dell Power Edge R710 or the IBM rack mounted server, which could result from higher utilisation rates and differences in the energy mix of the countries. The base case estimations are fully in line with the carbon footprint of the Dell Power Edge R720. The following graph gives an overview over the different carbon footprints.

[26] See Server Primer – Understanding the current state of the industry, available online at http://www.epeat.net/wp-content/uploads/2012/11/ServerPrimer2012.pdf

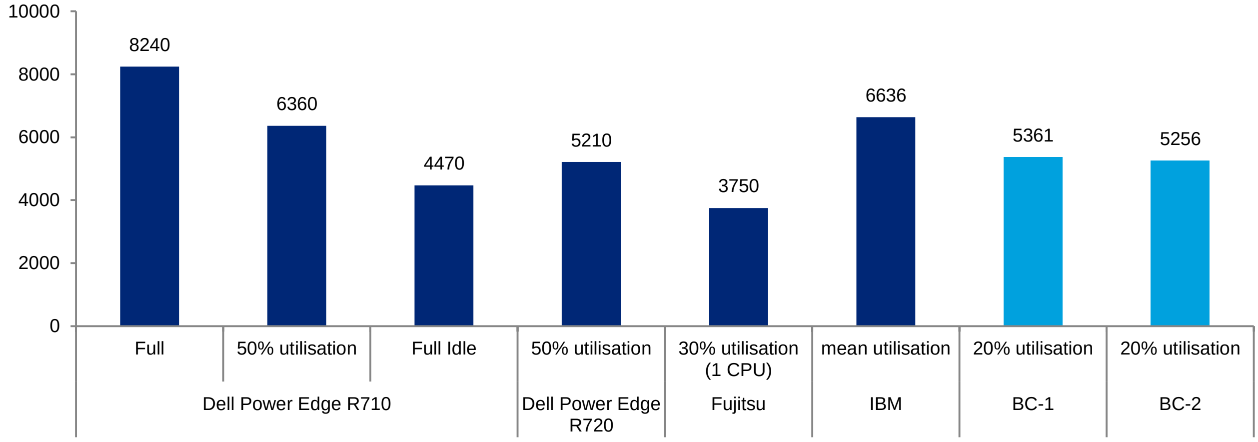

Figure 5: Carbon footprint benchmark with publicly available studies (kg CO_2 eq.)

3.2.4. Alternative inputs for the BC-1 (Rack Server) Ecoreport

Different stakeholders noted that the production phase might be underrepresented in the outputs of the EcoReport tool. The EcoReport allows adding « Extra Materials » to refine the analysis and alternative data for the three impact categories *Primary Energy, Greenhouse Gases* and *Acidification* could be obtained from the study for material efficiency of servers by JRC IES (built on GaBi inventory data and material declarations) and implemented in the BC-1 EcoReport (Rack Server)[27].

«Extra materials» included are: CPU; DDR card; Expansion Card; Main Board; PCB of ODD, HDD, and PSU; PCB in the Chassis.

The following table shows the relative differences of the Ecoreport outputs with alternative inputs for the three impact categories.

Table 24: Comparison with alternative inputs

Life Cycle phases	PRODUCTION			Distribution	Use	End-of-Life	Total
Resources Use and Emissions	Material	Manuf.	Total				
Other Resources & Waste							
Total Energy (GER)	28%	-23%	25%	0%	0%	10%	1%
of which, electricity (in primary MJ)	35%	-1%	33%	0%	0%	17%	1%
Emissions (Air)							
Greenhouse Gases in GWP100	46%	-27%	41%	0%	0%	28%	3%
Acidification, emissions	25%	-31%	22%	0%	0%	9%	3%

When comparing the outputs resulting from alternative inputs for the three categories with the initial outputs, it can be observed that the impact of the production phase differs significantly.

However, because of the strong preponderance of the use phase, the total impact stays relatively modest (1-3%).

[27] The JRC IES study was still ongoing when the Lot 9 preparatory study was drafted.

3.2.5. Some preliminary LCA results from ongoing JRC study[28]

JRC's study to assess the potential environmental impact of a rack-optimized enterprise server was conducted at the same time as the Lot 9 preparatory study and was not yet finalized when this report was drafted.

In its preliminary results for the life cycle impact assessment where almost the same bill of materials as in the Lot 9 study was used, the overall findings of the Lot 9 preparatory study that the use phase is the predominant phase could be confirmed.

However, the more detailed LCA (using the GaBi inventory data and material declarations) showed that the manufacturing phase plays a higher role than the Ecoreport outcomes would suggest. The study found that while some environmental impact categories are greater for the manufacturing phase, others are more important for the use phase.

For instance, while the global warming potential is strongly related to electricity consumption during the use phase, categories linked to resource use such as abiotic depletion potential have a higher impact on the manufacturing phase. The study suggests that abiotic depletion for elements (ADP_{el}) is one of the most relevant categories for material efficiency.

Furthermore, the impact assessment shows that all results for the environmental impact categories for end-of-life suggest that recycling of the server helps to reduce the potential environmental impact over its complete life cycle.

Applying the Resource Assessment of Products method (REAPro)[29] and calculating a reusability benefit index, the study finds that the reuse of components into remanufactured servers can imply some significant environmental benefits in terms of avoided production of new components such as HDD or memory cards. It is suggested that while a server that is equipped with some reused components could have lower energy efficiency as compared to a new server, the overall environmental benefits dominate.

[28] JRC-IES (2015). Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements for enterprise servers, Draft report.

[29] Ardente, F. and F. Mathieux (2014). "Identification and assessment of product's measures to improve resource efficiency: the case-study of an Energy Using Product." Journal of Cleaner Production 83: 126-141.

3.3. Storage Equipment

3.3.1. BC-3 Storage Unit

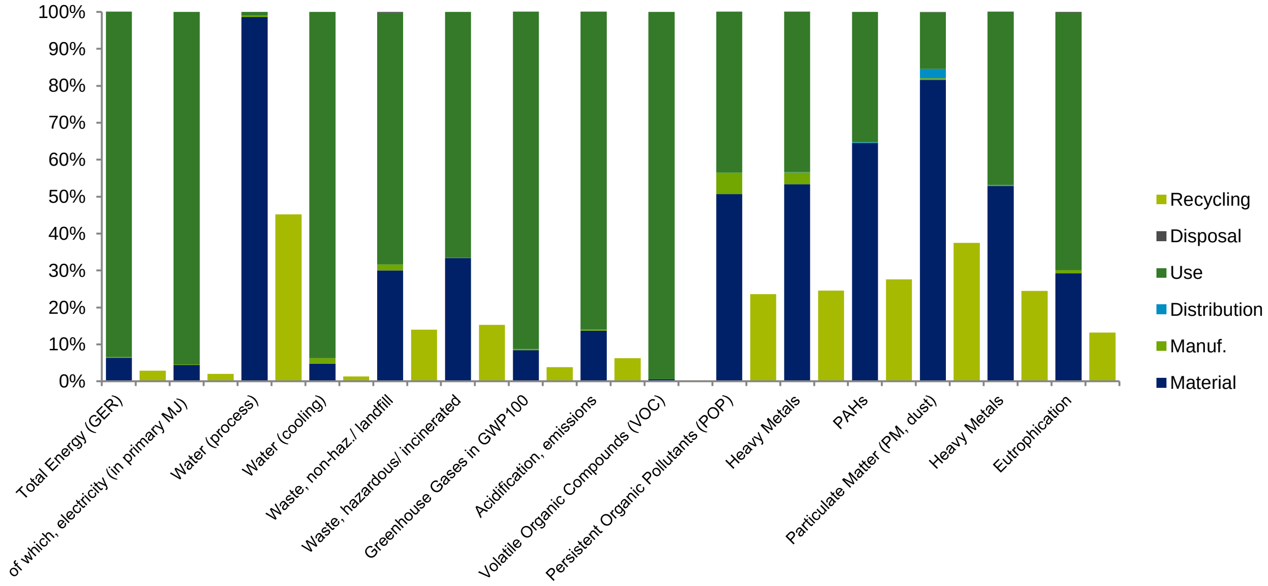

Figure 6: Distribution of BC-3 environmental impacts by life cycle phase[30]

The results of the environmental analysis of BC-3 (Storage Unit with 2 DAEs) are shown in Figure 6 and in Table 25. According to these, the energy consumption during the use phase is the most predominant aspect contributing to the environmental impacts from the product's entire life cycle. However, due to the high material share of the DAEs, the material part also plays an important role, in particular for POPs, heavy metals, PAHs and especially for particulate matter (PM).

Like in the previous Base-Cases, the use phase plays an important role. It makes up for more than 85% of the impact in 6 categories:

- Total Energy (GER): 93%
  - of which, electricity: 95%
- Water for cooling: 94%[31]
- Greenhouse Gases in GWP100: 91%
- Acidification, emissions: 86%
- Volatile Organic Compounds (VOC): 99%

The material phase again makes up a significant share of the environmental impact for several air and water related emissions like POPs, heavy metals in air and water, PAHs or PM.

Equally, the relatively high re-use and recycling rates make the end-of-life phase play an important role in reducing the environmental impact of the product.

[30] The left column of each category shows the negative environmental impacts, whereas the right column shows the credits coming from recycling during the end-of-life phase.
[31] In the Ecoreport tool "Water for cooling" refers to water used during the production phase.

Table 25: Life cycle impact (per unit) of BC-3: Storage Unit

Life Cycle phases -->	Unit	PRODUCTION			Distribution	Use	END-OF-LIFE			Total
Resources Use and Emissions		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit	balance	
Total Energy (GER)	MJ	24 052	1 014	25 066	124	354 373	25	-10 990	-10 965	**368 597**
of which, electricity (in primary MJ)	MJ	16 674	510	17 184	0	354 299	0	-7 656	-7 656	**363 827**
Water (process)	ltr	4 484	19	4 503	0	45	0	-2 055	-2 055	**2 493**
Water (cooling)	ltr	808	251	1 060	0	15 747	0	-223	-223	**16 584**
Waste, non-haz./ landfill	g	80 933	4 385	85 318	84	183 305	676	-37 595	-36 919	**231 789**
Waste, hazardous/ incinerated	g	2 819	5	2 823	2	5 616	0	-1 291	-1 291	**7 150**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	1 398	57	1 455	9	15 131	0	-641	-641	**15 954**
Acidification, emissions	g SO_2 eq.	10 682	255	10 937	27	66 998	1	-4 900	-4 899	**73 063**
Volatile Organic Compounds (VOC)	g	49	2	51	2	7 909	0	-23	-23	**7 940**
Persistent Organic Pollutants (POP)	ng i-Teq	976	114	1 089	0	836	0	-455	-455	**1 471**
Heavy Metals	mg Ni eq.	4 462	265	4 727	4	3 625	1	-2 054	-2 052	**6 304**
PAHs	mg Ni eq.	1 546	3	1 548	6	842	0	-660	-660	**1 736**
Particulate Matter (PM, dust)	g	7 945	44	7 989	247	1 496	8	-3 651	-3 643	**6 089**
Emissions (Water)										
Heavy Metals	mg Hg/20	1 745	9	1 753	0	1 542	0	-806	-806	**2 490**
Eutrophication	g PO_4	28	1	29	0	67	0	-13	-13	**84**

4. Base-Case Life Cycle Costs for consumers and the society

4.1. Base-Case life cycle costs for consumers

This section presents the results of the Life Cycle Cost (LCC) analysis of the Base-Cases using the EcoReport tool. In this analysis, all the consumer expenditures throughout the life span of the product are considered, which include:

- Average sales prices of the Base-Cases (in Euro);
- Average installation costs (in Euro);
- Average repair and maintenance costs (in Euro);
- Average electricity rates (in Euro Cent/kWh);
- Average lifetime of the Base-Case (in years);
- Average annual energy consumption (in kWh).

In the following Tasks, this analysis will serve to compare the total expenditure of the different design options identified for each Base-Case. The life cycle costs are calculated as follows:

$$LCC = PP + PWF * OE + EoL$$

Where PP is the purchase and installation price, OE is the operating expense and PWF is the present worth factor, calculated as follows[32]:

$$PWF = 1 - \left(\frac{1+e}{1+d}\right) * \left[1 - \left(\frac{1+e}{1+d}\right)^N\right]$$

N is the product life in years, d represents the discount rate and e is the inflation-corrected annual growth rate of OE (e.g. the escalation rate for energy). If $e = d$, the formula $LCC = PP + N * OE + EoL$ is used. Table 26 presents the EcoReport outcomes of the LCC calculations for all base-cases in ENTR Lot 9. It is important to note that both the calculations of electricity costs and the maintenance and repair costs (OE) are affected by PWF.

Table 26: Life Cycle Costs for the three Base-Cases

	BC-1 Rack Server	BC-2 Blade System	BC-3 Storage Unit
Product price (€)	2 500	65 000	23 000
Installation costs (€)	330	460	130
Electricity (€)	1 594	12 755	4 722
Repair & maintenance (€)	180	180	210
Total (€)	**4 604**	**78 395**	**28 062**

The following graphs show the division of the different costs over the life cycle.

[32] The old formula of the MEEuP: $PWF = \frac{1-\frac{1}{(1+d)^N}}{d}$ has been replaced.

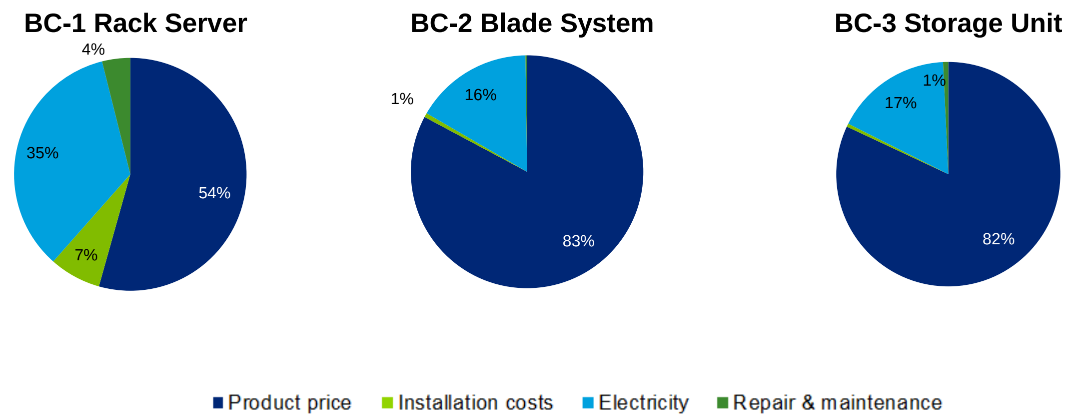

Figure 7: Life cycle costs breakdown, by cost categories

It can be observed that the share of electricity costs is particularly high for BC-1 (>30%).

4.2.Base-Case life cycle costs for the society

The MEErP adds to the usual product life cycle costs external damages (externalities) which occur on a society level in order to estimate the full life cycle costs for the society. The calculations are based on the following formula:

$$Societal\ LCC = LCC\ consumer + LCC\ ext.damages$$

Where:

$$LCC\ ext.damages = PPdamages + N * OEdamages + EoL\ damages$$

And

- PPdamages = Impacts (GWP in kg CO_2 eq., AP in kg SO_2 eq., etc.) in Production and Distribution phase x Damage unit value (in €/kg)
- OEdamages = Impacts in Use Phase x Damage unit value
- EoLdamages = Impacts in End of Life Phase x Damage unit value

The input parameters for external marginal costs to society are defined in the methodology:

Table 27: Monetary values for external marginal costs to society

Impacts	GWP-100 (per kg CO_2 eq.)	AP (per kg SO_2 eq.)	VOC (per kg VOC)	PM (per kg PM)
External marginal costs to society (€)	0.014	16.00	2.80	37.50

Using the above formula and values, the following life cycle costs for society were calculated by means of the EcoReport tool:

Table 28: Total Societal Life Cycle Costs

	BC-1 Rack Server	BC-2 Blade System	BC-3 Storage Unit
PP damages (€)	46	228	244
N*OE damages (€)	274	2 191	813
EoL damages (€)	23	103	108
Total External Damages (€)	**343**	**2 522**	**1 165**
LCC (excl. ext. damages) (€)	**4 605**	**78 395**	**28 062**
Total Societal LCC (€)	**4 948**	**80 916**	**29 227**

While for the rack servers the external costs amount to 7% of the total societal LCC, they make up only 3% for the blade system and around 4% for the storage base-case.

5.EU Totals

In this section, the environmental impact data and the Life Cycle Cost (LCC) data are aggregated at the EU-28 level using stock and market data from Task 2. It is assumed that the entire installed stock in the EU-28 in 2012 is represented by the Base-Cases.

5.1. Life-cycle environmental impact at the EU-28 level

5.1.1. Annual impact of production, use and (estimated) disposal of the existing EU stock

The aggregated results of the life cycle environmental impacts per year corresponding to the EU stock of products are presented in Table 29. The total primary energy consumption per year of the EU stock of each of the Base-Cases in 2012 is between 43 PJ (primary energy) for storage systems and 419 PJ for rack servers. Together, the three Base-Cases amount to a total energy consumption of around 558 PJ/year. A comparison to Lot 3[33] (Personal Computers and Computer Monitors) EU-25 output for 2005 data is also given in the last column for informative purpose.

Table 29: EU Total annual impact of stock of products

Resources Use and Emissions	Unit	BC- 1 (Rack Server)	BC-2 (Blade-System)	BC-3 (Storage Online 2-3)	Total	ENER Lot 3 (2005)
Other Resources & Waste						
Total Energy (GER)	**PJ**	419	96	43	**558**	585
of which, electricity	**PJ**	411	95	42	**548**	
Water (process)	**mln. m^3**	5	1	0	**6**	
Water (cooling)	**mln. m^3**	19	4	2	**25**	
Waste, non-haz./ landfill	**kt**	304	70	29	**403**	
Waste, hazardous/ incinerated	**kt**	12	2	1	**15**	
Emissions (Air)						
Greenhouse Gases in GWP100	mt CO_2 eq.	18	4	2	**24**	28
Acidification, emissions	kt SO_2 eq.	85	19	9	**113**	170
Volatile Organic Compounds (VOC)	Kt	9	2	1	**12**	1
Persistent Organic Pollutants (POP)	g i-Teq	2	1	0	**3**	11
Heavy Metals (Air)	ton Ni eq.	8	1	1	**10**	22
PAHs	ton Ni eq.	2	0	0	**2**	9
Particulate Matter (PM, dust)	Kt	9	1	1	**11**	40
Emissions (Water)						
Heavy Metals (Water)	ton Hg/20	4	1	0	**5**	24
Eutrophication	kt PO_4	0	0	0	**0**	0

The greenhouse gas (GHG) emissions per year are between 2 mt CO_2 eq. for BC-2 and 18 mt CO_2 eq. for BC-1. Annual heavy metal emissions into water go up to 5 tons Hg/20 for all the products, while acidification emissions are between 9 kt SO_2 eq. and 85kt SO_2 eq. per year.

[33] https://www.energimyndigheten.se/Global/F%C3%B6retag/Ekodesign/Ekodesign/Datorer/EuP_Lot3_PC_FinalReport.pdf

5.1.2. Life cycle environmental impact of new products

In this sub-chapter the life cycle environmental impacts of new products (2012) are presented.

Table 30: EU Total Impact of new products (2012) over their lifetime

Resources Use and Emissions	Unit	BC-1 (Rack Server)	BC-2 (Blade-System)	BC-3 (Storage Unit)	Total
Other Resources & Waste					
Total Energy (GER)	PJ	323	76	34	**433**
of which, electricity	PJ	318	76	34	**428**
Water (process)	mln. m^3	2	0	0	**2**
Water (cooling)	mln. m^3	15	3	2	**20**
Waste, non-haz./ landfill	kt	209	49	22	**280**
Waste, hazardous/ incinerated	kt	8	1	1	**10**
Emissions (Air)					
Greenhouse Gases in GWP100	mt CO_2 eq.	14	3	1	**18**
Acidification, emissions	kt SO_2 eq.	64	15	7	**86**
Volatile Organic Compounds (VOC)	Kt	7	2	1	**10**
Persistent Organic Pollutants (POP)	g i-Teq	1	0	0	**1**
Heavy Metals	ton Ni eq.	5	1	1	**7**
PAHs	ton Ni eq.	1	0	0	**1**
Particulate Matter (PM, dust)	Kt	5	1	1	**7**
Emissions (Water)					
Heavy Metals	ton Hg/20	2	0	0	**2**
Eutrophication	kt PO_4	0	0	0	**0**

5.2.Life-cycle costs at the EU-28 level

The aggregated results of the annual consumer expenditure per Base-Case in the EU-28 based on the year 2012 are presented in Table 31. This represents the total expenditure at EU level per year, assuming that the Base-Cases represent the entire installed stock in the EU-28.

Electricity costs make up 37% of the total life-cycle costs for rack servers, 18% of blade systems and also 18% of the storage Base-Case. These results show the importance of studying further the possible improvement options of the energy efficiency of Lot 9 enterprise servers and storage equipment.

Table 31: Total annual consumer expenditure in the EU-28 in million €

	BC-1 Rack Server	BC-2 Blade System	BC-3 Storage System	Total
Product price (m €)	6 500	5 064	2 148	**13 712**
Installation costs (m €)	858	36	12	**906**
Electricity (m €)	4 743	1 113	482	**6 338**
Repair & maintenance (m €)	536	16	21	**573**
Total (m €)	**12 637**	**6 228**	**2 664**	**21 529**

As the table shows, every year EU-28 consumers are spending more than € 21 billion in the purchase and operation of the representative products under consideration. And each time a consumer makes a buying decision, the decision is not just on a purchase price, but on the total Life Cycle Costs (LCC) of the product -- including running costs discounted to their net present value.

Within the LCC, the product acquisition is responsible for 64% of the total costs. In terms of annual expenditure, the EU-28 running costs amount to € 7 billion and the purchase and installation costs make up around € 14.6 billion.

5.3.Social Life-cycle costs at EU-28 level

Adding the external costs to society to the LCC gives the total annual social life-cycle costs on the EU-28 level.

Table 32: Total annual social life-cycle costs in the EU-28

	BC-1 (Rack Server)	BC-2 (Blade System)	BC-3 (Storage System)	Total
PP damages (m €)	215	29	22	**266**
N*OE damages (m €)	816	191	83	**1 090**
EoL damages (m €)	113	14	10	**137**
Total External Damages (m €)	**1145**	**234**	**116**	**1 495**
LCC (excl. ext. damages) (m €)	12 637	6 228	2 664	**21 529**
Total Societal LCC (m €)	**13 781**	**6 462**	**2 779**	**23 022**

As can be seen from the table, the total social externalities amount to around 6% of the total societal LCC.

5.4.EU-28 total system impact

The figures presented in the table below allow the comparison with EU totals, as regards resource use and emissions. Electricity has been converted to a more familiar unit of TWh.

Table 33: Summary Environmental Impacts EU-Stock, in percentages of the EU total impacts[34]

Materials		BC-1 Rack	BC-2 Blade System	BC-3 Storage System	EU totals
Materials					
Plastics	Mt	0,015%	0,001%	0,001%	48
Ferrous metals	Mt	0,018%	0,005%	0,001%	206
Non-ferrous metals	Mt	0,040%	0,004%	0,005%	20
Other resources & waste					
Total Energy (GER)	**PJ**	**0,554%**	**0,127%**	**0,056%**	**75 697**
of which, electricity	**TWh**	**1,632%**	**0,376%**	**0,166%**	**2 800**
Water (process)*	mln.m^3	0,002%	0,000%	0,000%	247 000
Waste, non-haz./ landfill*	Mt	0,010%	0,002%	0,001%	2 947
Waste, hazardous/ incinerated*	kton	0,014%	0,002%	0,001%	89
Emissions (Air)					
Greenhouse Gases in GWP100	mt CO_2 eq.	0,36%	0,08%	0,04%	5 054
Acidifying agents (AP)	kt SO_2 eq.	0,38%	0,08%	0,04%	22 432
Volatile Org. Compounds (VOC)	kt	0,10%	0,02%	0,01%	8 951
Persistent Org. Pollutants (POP)	g i-Teq.	0,10%	0,02%	0,01%	2 212
Heavy Metals (HM)	ton Ni eq.	0,14%	0,03%	0,01%	5 903
PAHs	ton Ni eq.	0,16%	0,03%	0,02%	1 369
Particulate Matter (PM, dust)	kt	0,24%	0,04%	0,03%	3 522
Emissions (Water)					
Heavy Metals (HM)	ton Hg/20	0,03%	0,01%	0,00%	12 853
Eutrophication (EP)	kt PO_4	0,01%	0,00%	0,00%	900

As far as electricity consumption is concerned, the three base cases sum up to around 2.2% of the EU electricity consumption. These results can be considered to be in line to those found in a study conducted by the Ökoinstitut and IZM, reporting that data centres (incl. networking) were responsible for around 2.6 % of overall European electricity consumption in 2011[35].

[34] The totals annual impact in the table allows comparison with EU totals and with other products, as regards resource use and emissions. Electricity was converted to a more familiar unit of TWh [1 TWh= 0.0105 PJ].

[35] Öko-Institut/IZM Study on the practical application of the new framework methodology for measuring the environmental impact of ICT - cost/benefit analysis (SMART 2012/0064) : http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=6916

6.Conclusion

Task 5 report presents the results of the analysis of the environmental impacts and economic costs of three Base-Cases that are thought to represent the most relevant products in scope of Lot 9.

The selection of Base-Cases and subsequent analysis was based upon the market analysis presented in Task 2, the consumer behaviour described in Task 3 and the technical analysis of products carried out in Task 4.

The Base-Cases were constructed as an “abstraction” of the average product in the market representing a wide range of products considered in the Lot 9 preparatory study. The Base-Cases are used to estimate the environmental impacts of enterprise servers and storage equipment products in the EU-28.

The results of the analysis show that as far as energy consumption is concerned, the use phase is largely predominant in the environmental impact in each Base-Case. These findings could be confirmed by a parallel study conducted by the JRC, which at the same time emphasizes that the manufacturing phase plays an important role in the whole life cycle, in particular when it comes to abiotic depletion for elements.

Re-use and recycling rates are already relatively high for enterprise servers and storage equipment (B2B products) and the end-of-life phase plays an important role in reducing the environmental impact of the products.

On the economic side, energy consumption (electricity) is the second largest contributor to the overall Life Cycle Costs for all products, after purchasing costs. Installation and maintenance costs represent a relatively small share of the total consumer expenditure.

The external damages to society vary from one product group to another, but were calculated to account for almost € 1.5 bn per year on an EU-28 level, representing around 6% of the total societal life cycle costs.

When looking at the EU-28 total system impacts, the three Base Cases together amount for around 2.2% of total European electricity consumption (including both direct and indirect effects).