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DG ENTR Lot 9 - Enterprise servers and data equipment

Task 6: Design Options

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Glossary

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BAT	Best Available Technology
BNAT	Best Not yet Available Technologies
COMS	Capacity Optimisation Methods Software
DO	Design Option
LCC	Life Cycle Cost
LLCC	Least Life Cycle Costs
MEErP	Methodology for the Ecodesign of Energy-related Products
PSU	Power Supply Unit
PUE	Power Usage Effectiveness
SSD	Solid State Drive

Introduction

This task has the goal to quantitatively analyse design improvement options, based on the improvement design options described in Task 4 for each of the product base-cases. Since technology is changing very quickly in the IT sector, it is not completely obvious which technology can be considered as an improvement option or is in effect already standard technology.

Furthermore, overall quantification of improvement options is challenging because of the variety of possible product configuration options which is an important characteristic of the ENTR Lot 9 product scope. However, it seems justified to treat the improvement options presented as generic improvement options, although they are not suited for all product applications and operating environments. These conditions are typically determined by specific service level agreements and respective selection, configuration and management of the respective enterprise server and storage equipment. The ENTR Lot 9 team recognizes these limiting factors.

The environmental impacts of each of these options are calculated by using the MEErP EcoReport. The economic impacts of each design option are assessed in terms of Life Cycle Cost (LCC). The Life Cycle Cost assessment is an important part of the overall analysis, since it shows the impact that design options may have on the cost to users over the whole lifetime of the product.

The assessment of both environmental and economic impacts allows the identification of design improvement options with the Least Life Cycle Costs (LLCC) and the one that results in the most significant reductions in environmental impacts, the so-called Best Available Technology (BAT).

Best not yet Available Technologies (BNAT) are also discussed, assessing long-term improvement potential for enterprise servers and storage equipment.

1. Identification of design options

This section presents the different improvement options which are applicable to the three base-cases. These design options are carefully selected keeping in mind that they:

- Should not result in significant variations in the functionality and the performance parameter of the equipment as compared to the base-cases.
- Have a significant potential for environmental performance improvement.
- Do not entail excessive costs on the manufacturer.

Although these guidelines have been followed throughout the assessment as good as possible, some options which might be questioned from an economic point of view have been still retained for illustrative purposes. The reason for keeping these options from time to time is the speed of technological change and associated falls in prices that might make them attractive.

Improvement options are investigated on four different levels: components, configurations, control and material efficiency. In this case, control is used synonymously for power management and adaptation to operational conditions including load and inlet temperature.

The following table gives an overview over the different improvement options considered in this task.

Table 1: Overview over different improvement options for the base-cases

Design Options	Description	Level	Rack Server	Blade System	Storage System
DO-1	PSU (different 80 PLUS categories)	Component	X	X	X
DO-2	Storage Media (SSD)	Component	X	X	
DO-3	ASHRAE A1	Control	X	X	X
DO-4	ASHRAE A2	Control	X	X	X
DO-5	Advanced processor power management (APPM)	Control	X	X	
DO-6	Full Configuration	Configuration		X	
DO-7	Storage Capacity Optimisation	Configuration			X
DO-8	Increased Reuse Rate	Material Efficiency			X

1.1. Base-Case 1: Rack Servers

1.1.1. Design Option 1: Power Supply Unit (PSU)

As described in Task 4, efficient power supply units play a crucial role when it comes to energy savings. 80 PLUS Gold, Platinum or Titanium power supply units provide major energy-efficiency advantages as compared to lower rated PSUs (e.g. Silver or Bronze). One design option is therefore to consider the improvement potential that lies behind higher rated PSUs.

There are in general two possible operation configurations for redundant PSUs (see Task 4): On/Balanced where both PSUs are active, providing roughly the same power output (45%/55%) and On/Standby where one PSU is fully active and provides most of the output and the other one is on standby with minimum power output (97,5%/2,5%). It has to be noted that redundant power supplies configured with an on/standby capability are not appropriate for some data centre configurations.

The following table shows the different configurations for a resulting 200W active mode as well as for a variation of the base case with a 250W active mode, resulting from an increase of the average utilization rate[1]. The PSU output power shows the power draw of the server, the PSU load level refers to the level of the respective power draw of the server.

Table 2: Configurations for redundant PSUs

Configuration	PSU	Capacity [W]	Active Load Distribution	PSU Output Power [W]	PSU Load Level
Balanced Mode (Active : 200W)	PSU1	400	55,0%	110	27,5%
	PSU2	400	45,0%	90	22,5%
On/Standby Mode (Active : 200W)	PSU1	400	97,5%	195	48,8%
	PSU2	400	2,5%	5	1,3%
Balanced Mode (Active : 250W)	PSU1	400	55,0%	137,5	34,4%
	PSU2	400	45,0%	112,5	28,1%
On/Standby Mode (Active : 250W)	PSU1	400	97,5%	243,75	60,9%
	PSU2	400	2,5%	6,25	1,6%

Based on these configurations the following table shows the respective power losses that are related to the different cases. The base case is coloured in grey.

[1] 250 Watts is the power draw at about 50% load. This means however not, that the utilization level is 50%!

Table 3: Power output and losses for different PSU configurations

		80 PLUS Silver			80 PLUS Gold			80 PLUS Platinum		
Configuration	PSU	output power [W]	losses [W]	losses total [W]	output power [W]	losses [W]	losses total [W]	output power [W]	losses [W]	losses total [W]
Balanced Mode (Active : 200W)	PSU1	95,1	14,9	27,9	98,4	11,6	21,9	100,6	9,4	18,0
	PSU2	77,0	13,0		79,7	10,3		81,5	8,6	
On/Standby Mode (Active : 200W)	PSU1	173,3	21,7	23,2	179,2	15,8	17,3	183,2	11,8	13,3
	PSU2	3,5	1,5		3,5	1,5		3,5	1,5	
Balanced Mode (Active : 250W)	PSU1	120,3	17,2	32,3	124,4	13,1	24,8	127,1	10,4	19,9
	PSU2	97,4	15,1		100,7	11,8		103,0	9,5	
On/Standby Mode (Active : 250W)	PSU1	217,4	26,3	28,2	224,7	19,0	20,9	230,1	13,6	15,5
	PSU2	4,4	1,9		4,4	1,9		4,4	1,9	

Not surprisingly, it can be observed that power losses decrease significantly when moving from an 80 PLUS silver to a gold or platinum PSU. The following table summarizes the differences in power output and respective losses as compared to the 80 Plus Silver PSU:

Table 4: Differences in power output and losses as compared to the respective 80 Plus Silver PSU, in %

80 Plus Category	Configuration	PSU	output power	losses	losses total
80 PLUS Gold	*Balanced Mode* (Active : 200W)	PSU1	3%	-22%	-21%
		PSU2	4%	-21%	
	On/Standby Mode (Active : 200W)	PSU1	3%	-27%	-25%
		PSU2	0%	0%	
	Balanced Mode(Active : 250W)	PSU1	3%	-24%	-23%
		PSU2	3%	-22%	
	On/Standby Mode(Active : 250W)	PSU1	3%	-28%	-26%
		PSU2	0%	0%	
80 PLUS Platinum	*Balanced Mode* (Active : 200W)	PSU1	6%	-37%	-36%
		PSU2	6%	-34%	
	On/Standby Mode (Active : 200W)	PSU1	6%	-45%	-43%
		PSU2	0%	0%	
	Balanced Mode(Active : 250W)	PSU1	6%	-40%	-38%
		PSU2	6%	-37%	
	On/Standby Mode(Active : 250W)	PSU1	6%	-48%	-45%
		PSU2	0%	0%	

Table 5: Annual electricity consumption of a rack server with different PSUs (200W active, 150W idle)

Option	PSU	kWh/year	% Base Case
Base Case	**200 W Active - Balanced Mode - Silver**	**1660,8**	**100%**
DO-1.1	200 W Active - Balanced Mode - Gold	1610,9	97,0%
DO-1.2	200 W Active - Balanced Mode - Platinum	1578,2	95,0%
DO-1.4	200 W Active - On/Standby Mode - Silver	1623,0	97,7%
DO-1.5	200 W Active - On/Standby Mode - Gold	1574,5	94,8%
DO-1.6	200 W Active - On/Standby Mode - Platinum	1540,9	92,8%

The table above shows the reduction of annual electricity consumption for the different PSU options. Switching from an 80 Plus Silver PSU in balanced mode to an 80 Plus Platinum PSU in On/Standby mode can save up to 7.2% of electricity. The total life cycle impact will be shown later in the report.

The following table shows, for illustrative purposes, the electricity consumption with different PSUs at higher active power draw (250W active, 150W idle), they will not be considered as an additional design options:

Table 6: Annual electricity consumption of a rack server with different PSUs (250W active, 150W idle)

PSU	kWh/year	% Reference (Balanced Silver)
250 W Active - Balanced Mode - Silver	2007,5	100,0%
250 W Active - Balanced Mode - Gold	1947,3	97,0%
250 W Active - Balanced Mode - Platinum	1907,9	95,0%
250 W Active - On/Standby Mode - Silver	1974,6	98,4%
250 W Active - On/Standby Mode - Gold	1915,9	95,4%
250 W Active - On/Standby Mode - Platinum	1872,5	93,3%

1.1.2. Design Option 2: Storage Media

Another possible improvement option from an environmental point of view can be seen in the replacement of HDDs with more energy efficient SSD, which typically come in a 2.5 inch form factor. It has to be kept in mind that 2.5 inch HDD have a somewhat different performance than 3.5 inch HDD due to typically higher RPM and less capacity (See Task 4). The purpose of this exercise, however, is to make a theoretical trade-off, omitting at a first stage some functional and economic considerations, which are important: there is a cost factor of 5 to 10 between SSD and HDD.

Figure 1 shows the average power consumption of 3.5 inch HDDs and SSDs as well as active and idle consumption of SSDs for different capacities. This data was already presented in Task 4.

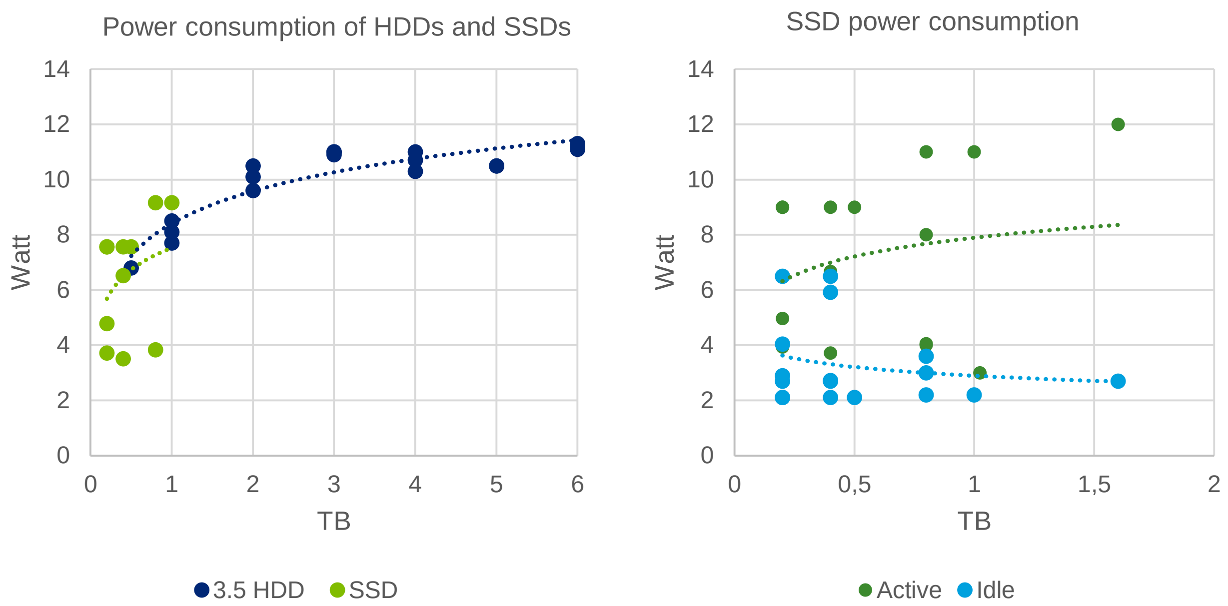


Figure 1: Power consumption of exemplary enterprise HDDs and SSDs

It can be observed that the power consumption of SSD can vary significantly and that there exist SSD that come with relatively low average power consumption as compared to HDD. However, since HDD can reach capacities much larger than SSDs, more units of the latter are needed to reach the same total capacity. Taking apart economic considerations for the time being, an informative exercise can consist in estimating the potential energy savings attained when replacing HDD with more energy efficient SSD. The following table shows a summary of selected design options related to storage media:

Table 7: Design options for storage media in a rack server

	# Drives	GB	Total Capacity (GB)	Active (W)	Idle (W)	Active 19h (in KWh)	Idle 5h (in KWh)	Total daily power (kWh/day)	Δ % BC
BC (HDD)	4	1 600	6 400	10	7	0,76	0,14	0,90	0%
DO-2.1	8	800	6 400	4	2	0,61	0,08	0,69	-24%
						Active 14h (in KWh)	Idle 10h (in KWh)		
DO-2.2	8	800	6 400	4	2	0.448	0.16	0.61	-32%

The DO-2.2 option is for illustrative purposes only and has not been considered as a final option for impacts shown in the next chapter.

1.1.3. Design Options 3 and 4 : ASHRAE A1 and A2

The idea behind these improvement options is a higher inlet temperature based on allowances ASHRAE A1 or A2 or (free) fresh air cooling. As a consequence of the reduction in cooling capacity or cooling provision, the power usage effectiveness (PUE) of a data centre can improve at the system level.

As already discussed in previous chapters, the PUE is a measure of how much energy is used by the computing equipment, as compared to required cooling and other overhead. For the three base cases, initially a PUE of 2.0 was considered, which is considered to represent an average value according to stakeholders and literature review (see Task 3). The lower the PUE, the more efficient the data centre (as an infrastructure) is. A PUE is always above 1.0 which would be the ideal case, but cannot be reached in practice.

According to SNIA, modern best practice PUE in 2010 was around 1.25[2]. In a 2014 survey organised by the Uptime Institute, about half of the operators targeted PUE between 1.2 and 1.5[3]. In 2015, Google reported a PUE of around 1.1[4] for their data centres. **For this design option, a PUE of 1.4 was considered in conjunction with the ASHRAE A1 and a PUE of 1.3 with the ASHRAE A2 improvement option during most of the time of the year.** In the total life cycle assessment this is reflected in the annual "active-mode" hours.

Since the PUE takes into account, both the total facility energy as well as the IT equipment energy, it is not entirely related to the product, but rather to the whole data centre system (extended system scope, see Task 3). Equipment designed for A1 or A2 operation should be designed that there are overall energy savings from running at the higher server inlet temperature.

The idea behind this option is that that an increase of the inlet temperature can reduce the overall design, configuration and resulting energy consumption of the cooling infrastructure in the data centre, while the power consumption of the IT only slightly increases due to an increase in internal air flow demand and respective fan power consumption (increased fan speed).

For instance, an increase of the server inlet temperature from 22°C to 30°C would require fans to run at a higher rate, increasing the power consumption of the IT equipment, but reducing the overall energy consumption considering the PUE. The following table shows the assumptions for these design options.

[2] http://www.snia.org/sites/default/education/tutozzrials/2010/fall/green/AlanYoder_Green_Storage_Technologies-2.pdf

[3] http://www.datacenterknowledge.com/archives/2014/06/02/survey-industry-average-data-center-pue-stays-nearly-flat-four-years/

[4] http://www.google.com/about/datacenters/efficiency/internal/

Table 8: Assumptions behind the ASHRAE A1 and A2 design options:

Option	Description
Base Case	12 Months / 24h with PUE 2.0 and average fan speed of 5W under load (total fans 20W and active mode 200W / idle is at 150W).
Design Option: ASHRAE A1	7 Months / 24 h (winter, spring and fall) with PUE 1.4 (free cooling) and double fan speed at 10 W (total fans 40W and active mode 220W / idle stays the same at 150W).
	4 Months / 24h (summer but avg. below 30°C) with PUE 1.4 (still free cooling) and triple fan speed 15 W (total fans 60W and active mode 240W / idle increase with double fan speed to 170W).
	1 Month / 24h (high summer with over 30°C) with PUE 1.8 (here the server needs external cooling) and triple fan speed 15 W (total fans 60W and active mode 240W / idle increase with triple fan speed to 190W).
Design Option: ASHRAE A2	7 Months / 24 h (winter, spring and fall) with PUE 1.3 (free cooling) and double fan speed at 10 W (total fans 40W and active mode 220W / idle stays the same at 150W).
	4 Months / 24h (summer but avg. below 30°C) with PUE 1.3 (still free cooling) and triple fan speed 15 W (total fans 60W and active mode 240W / idle increase with double fan speed to 170W).
	1 Month / 24h (high summer with over 30°C) with PUE 1.6 (here the server needs external cooling) and triple fan speed 15 W (total fans 60W and active mode 240W / idle increase with triple fan speed to 190W).

1.1.4. Design Option 5: Advanced processor power management

Advanced processor power management such as adaptive voltage operation (also called adaptive clocking) addresses the processor voltage fluctuations by temporarily reducing clock frequency instead of providing higher voltages to address momentary voltage deviations. It also includes the monitoring of processor voltages which occurs at a fraction of a billionth of a second. Industry reported that this can lead to around 5% less power consumption and improvements in work per unit of energy consumed.

1.2.Base-Case 2 : Blade System

1.2.1. Design Option 1: Power Supply Unit (PSU)

Table 9: Configurations for redundant PSUs

Configuration	PSU	Capacity [W]	Active Load Distribution	output Power [W]	PSU Load Level
Balanced Mode (Active : 1600W)	PSU1	3200	55,0%	880	27,5%
	PSU2	3200	45,0%	720	22,5%
On/Standby Mode (Active : 1600W)	PSU1	3200	97,5%	1560	48,8%
	PSU2	3200	2,5%	40	1,3%
Balanced Mode (Active : 2000W)	PSU1	3200	55,0%	1100	34,4%
	PSU2	3200	45,0%	900	28,1%
On/Standby Mode (Active : 2000W)	PSU1	3200	97,5%	1950	60,9%
	PSU2	3200	2,5%	50	1,6%

Table 10: Power output and losses for different PSU configurations

		80 PLUS Silver			80 PLUS Gold			80 PLUS Platinum			80 PLUS Titanium		
Configuration	PSU	output power [W]	losses [W]	losses total [W]	output power [W]	losses [W]	losses total [W]	output power [W]	losses [W]	losses total [W]	output power [W]	losses [W]	losses total [W]
Balanced Mode (Active : 1600W)	PSU1	760,7	119,3	223,6	787,1	92,9	175,6	804,4	75,6	144,0	834,7	45,3	86,3
	PSU2	615,7	104,3		637,3	82,7		651,6	68,4		679,0	41,0	
On/Standby Mode (Active : 1600W)	PSU1	1386,8	173,2	185,2	1433,6	126,4	138,4	1465,5	94,5	106,5	1497,2	62,8	74,8
	PSU2	28,0	12,0		28,0	12,0		28,0	12,0		28,0	12,0	
Balanced Mode(Active : 2000W)	PSU1	962,6	137,4	258,5	995,6	104,4	198,5	1017,2	82,8	159,2	1017,2	82,8	159,2
	PSU2	778,9	121,1		805,9	94,1		823,6	76,4		823,6	76,4	
On/Standby Mode(Active : 2000W)	PSU1	1739,3	210,7	225,7	1797,8	152,2	167,2	1841,0	109,0	124,0	1841,0	109,0	124,0
	PSU2	35,0	15,0		35,0	15,0		35,0	15,0		35,0	15,0	

As in 1.1.1, the above tables show the power output losses for different PSU categories. For the blade system, the 80 PLUS titanium category was added. The table below shows the differences in power output and losses as compared to the 80 PLUS Silver category.

Table 11: Differences in power output and losses as compared to the respective 80 Plus Silver PSU, in %

80 Plus Category	Configuration	PSU	output power [%]	losses [%]	losses total [%]
80 PLUS Gold	*Balanced Mode* (Active : 1600W)	PSU1	3%	-22%	-21%
		PSU2	4%	-21%	
	On/Standby Mode (Active : 1600W)	PSU1	3%	-27%	-25%
		PSU2	0%	0%	
	Balanced Mode(Active : 2000W)	PSU1	3%	-24%	-23%
		PSU2	3%	-22%	
	On/Standby Mode(Active : 2000W)	PSU1	3%	-28%	-26%
		PSU2	0%	0%	
80 PLUS Platinum	*Balanced Mode* (Active : 1600W)	PSU1	6%	-37%	-36%
		PSU2	6%	-34%	
	On/Standby Mode (Active : 1600W)	PSU1	6%	-45%	-43%
		PSU2	0%	0%	
	Balanced Mode(Active : 2000W)	PSU1	6%	-40%	-38%
		PSU2	6%	-37%	
	On/Standby Mode(Active : 2000W)	PSU1	6%	-48%	-45%
		PSU2	0%	0%	
80 PLUS Titanium	*Balanced Mode* (Active : 1600W)	PSU1	10%	-62%	-61%
		PSU2	10%	-61%	
	On/Standby Mode (Active : 1600W)	PSU1	8%	-64%	-60%
		PSU2	0%	0%	
	Balanced Mode(Active : 2000W)	PSU1	6%	-40%	-38%
		PSU2	6%	-37%	
	On/Standby Mode(Active : 2000W)	PSU1	6%	-48%	-45%
		PSU2	0%	0%	

When compared to the BC, the titanium PSU in On/Standby Mode consumes almost 10% less electricity per year.

Table 12: Annual electricity consumption of a blade system with different PSUs

Option	PSU	kWh/year	% Base Case
Base Case	1600 W Active - Balanced Mode - Silver	13 286,0	100%
DO-1.1	1600 W Active - Balanced Mode - Gold	12 887,4	97,0%
DO-1.2	1600 W Active - Balanced Mode - Platinum	12 625,5	95,0%
DO-1.3	1600 W Active - Balanced Mode - Titanium	12 225,4	92,0%
DO-1.4	1600 W Active - On/Standby Mode - Silver	12 984,3	97,7%
DO-1.5	1600 W Active - On/Standby Mode - Gold	12 595,7	94,8%
DO-1.6	1600 W Active - On/Standby Mode - Platinum	12 326,9	92,8%
DO-1.7	1600 W Active - On/Standby Mode - Titanium	12 107,1	91,1%

1.2.2. Design Option 2: Storage Media

Following the same principle as in 1.1.2, the next table shows an alternative storage media configuration. Here again, already knowing that this option is most likely not viable from an economic point of view, the interest behind this option lies behind the hypothetical energy consumption gains with respect to using SSDs instead of HDDs.

Table 13: Design options for storage media in a blade system

	# Drives	GB	Total Capacity (GB)	Active (W)	Idle (W)	Active 19h (in KWh)	Idle 5h (in KWh)	Total daily power (kWh/day)	∆ % BC
BC (HDD)	16	1 600	25 600	10	7	3,0	0,6	3,6	0%
DO-2.1	32	800	25 600	4	2	2,4	0,4	2,8	-24%
	# Drives	GB	Total Capacity (GB)	Active (W)	Idle (W)	Active 14h (in KWh)	Idle 10h (in KWh)	Total daily power (kWh/day)	∆ % BC
DO-2.2	32	800	25 600	4	2	1,8	0,6	2,4	-32%

The DO-2.2 option is for illustrative purposes only and has not been considered as a final option for impacts shown in the next chapter.

1.2.3. Design Options 3 and 4: ASHRAE A1 and A2

This design option is based on the same assumptions as 1.1.3.

1.2.4. Design Option 5: Advanced processor power management

This design option is based on the same assumptions as 1.1.4.

1.2.5. Design Option 6: Full configuration vs. reduced configuration

The idea behind this improvement option is a better utilisation of the existing hardware (consolidation). It shows the potential energy savings that are derived from using a fully configured blade system instead of two half configured systems (two BC). The following figures illustrate the two configurations:

Figure 2: Two half configured blade systems

Figure 3: Fully configured blade system

This option is a theoretical case, since one of the advantages of blade systems is the ease of scalability – starting from a half populated blade chassis to a full one.

The direct comparison of the energy consumption of one fully configured blade system with 16 blades and two half configured blade systems (2x8 blades) shows that the fully configured unit consumes around 22% less energy with the same 80 PLUS PSU categories.

Table 14: Comparison of the electricity consumption of two half configured blade systems with different PSUs[5]

PSU	2 half configured	Fully configured	Δ%
	kWh/year	kWh/year	
200 W Active - Balanced Mode - Silver	26 572,0	20759,4	-22%
200 W Active - Balanced Mode - Gold	25 774,8	20136,6	
200 W Active - Balanced Mode - Platinum	25 251,0	19727,3	
200 W Active - Balanced Mode - Titanium	24 450,8	19102,2	
200 W Active - On/Standby Mode - Silver	25 968,6	20288,0	
200 W Active - On/Standby Mode - Gold	25 191,4	19680,8	
200 W Active - On/Standby Mode - Platinum	24 653,8	19260,8	
200 W Active - On/Standby Mode - Titanium	24 083,4	18815,1	

1.3.Base-Case 3: Storage System

For the storage system, DO-2 was not considered because of the important economic impact this would have had on the product. Instead, two other options *Storage Capacity Optimization* and *Increased Reuse* (Material Efficiency) were studied.

1.3.1. Design Option 1: Power Supply Unit (PSU)

This design option follows the same logic as shown in 1.1.1 and 1.2.1. The following table summarizes the annual electricity consumption of the storage system with different 80 PLUS PSU categories.

[5] For the power calculation the HP Power Advisor tool was used, available online : http://www8.hp.com/us/en/products/servers/solutions.html?compURI=1439951

Table 15: Annual electricity consumption of a storage system with different PSUs

Option	PSU	kWh/year	% Base Case
Base Case	200 W Active - Balanced Mode - Silver	3 279,0	100%
	200 W Active - Balanced Mode - Gold	3 180,6	97,0%
	200 W Active - Balanced Mode - Platinum	3 116,0	95,0%
	200 W Active - Balanced Mode - Titanium	3 019,3	92,1%
	200 W Active - On/Standby Mode - Silver	3 205,0	97,7%
	200 W Active - On/Standby Mode - Gold	3 109,0	94,8%
	200 W Active - On/Standby Mode - Platinum	3 042,6	92,8%
	200 W Active - On/Standby Mode - Titanium	2 973,7	90,7%

1.3.2. Design Option 3 and 4: ASHRAE A1 and A2

This design option is following the same assumptions as in 1.1.3. and 1.2.3.

1.3.3. Design Option 7: Storage Capacity Optimization

Capacity Optimisation Methods Software (COMS) are a set of techniques which reduce the capacity required to store a particular data set, which yields to indirect energy savings. Examples of COMS are compression, data de-duplication, thin provision or delta snapshots (see Task 4).

All COMS make it possible to store more data in less space. Less physical storage devices result in direct power savings. These savings can vary significantly based on application uptime, data set types, performance objectives, etc. As an example, SNIA[6] showed that deduplication and compression can lead to 25%-40% of capacity savings, thin provisioning might move from 30%-80%. These higher savings result very often from highly virtualized systems.

According to EMC[7], thin provisioning can result in a 50%-75% reduction in the use of physical storage, depending on the management policies of the data centre. The 75% reduction occurs in combination with aggressive monitoring of utilization – where utilization denotes the percent of disk space used to store and manage data. Systematic use of tiered storage results in further energy use reductions due to the shift from faster to slower media, also including an online to near-online shift.

As far as power savings are concerned, SNIA[6] reports that these can range between 20-30%. For this reason, an estimation with 25% storage resource (and power) savings due to COMS is performed. At the same time it is assumed that COMS do not come for free and add 10% of purchase costs on the storage system. It has to be noted that some of the COMS require additional hardware and active time (e.g. at night when the system is running through a deduplication routine). However, since there would be innumerous product combinations, only one representative option has been retained.

1.3.4. Design Option 8: Increased Material Efficiency

In this design option the re-use rate of the storage system is increased to 50%, as it is assumed to be the case for servers (see Task 5).

The modelling of reuse is not sufficiently described in the MEErP. The Ecoreport tool credits an amount of 75% of the impact for material production, while impacts related to manufacturing are not included, a point that can be relevant, since the benefits of the manufacturing part when reusing a component can be significant. The limitations of the Ecoreport tool with respect to reuse are further discussed later in the impact assessment in section 2.3.4.

[6] http://www.snia.org/sites/default/education/tutorials/2010/fall/green/AlanYoder_Green_Storage_Technologies-2.pdf
[7] http://www.emc.com/collateral/customer-profiles/h8872-aerospec-cp.pdf

2.Impacts

2.1.Base-Case 1: Rack Servers

Task 5 identified that the use phase is responsible for the largest part of the environmental impact for the three base cases and that reducing total energy consumption during use phase would be an effective way to reduce the overall impacts.

Task 4 identified some improvement options that aim to reduce the total energy consumption. Each of the improvement options applicable to BC 1 and its relative impact on the product price compared to the base-case are shown below.

2.1.1. Design Option 1: Power Supply Unit (PSU)

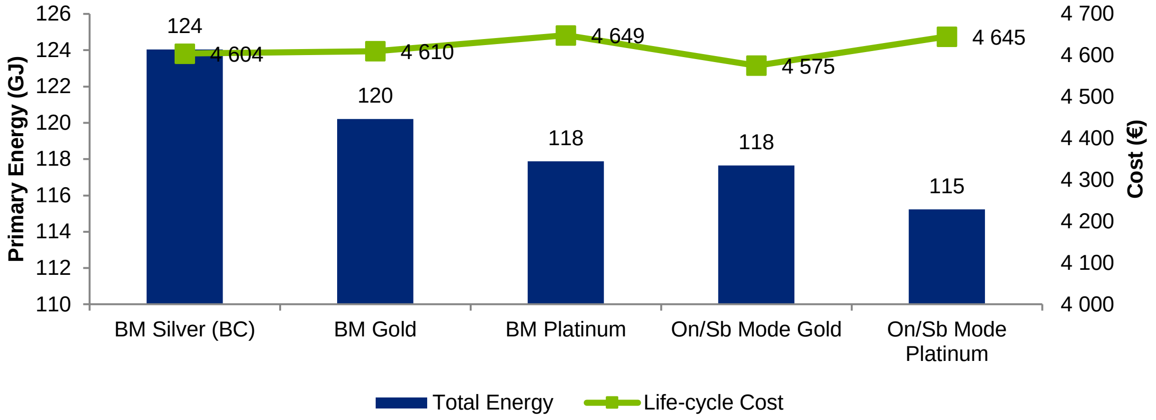


Figure 4: Primary energy consumption and life-cycle costs of a rack server with different PSUs

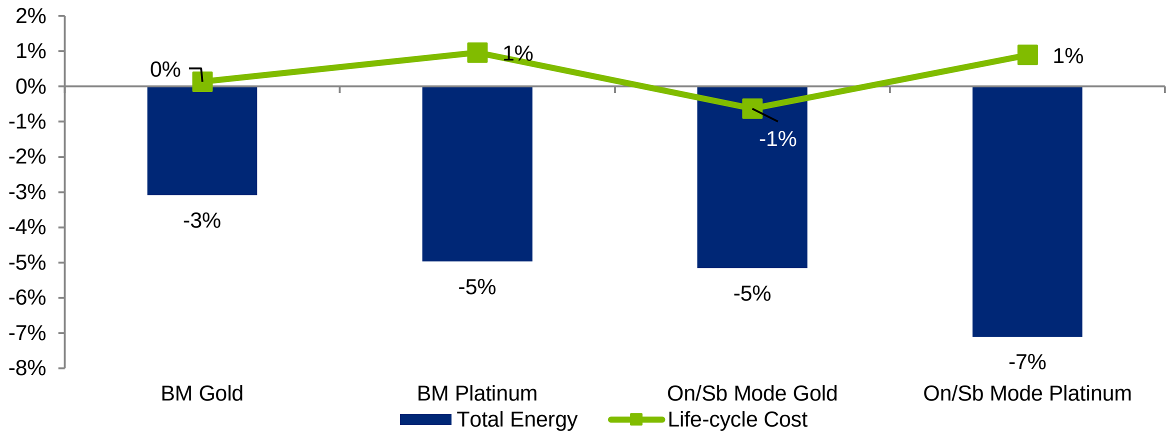


Figure 5: Primary energy consumption and life-cycle costs as compared to the BC (in %)

It can be observed from above figures that the use of a more efficient power supply unit can reduce energy consumption up to 7% as compared to the base case (80 PLUS Silver), while total life-cycle costs remain relatively f (from -1% for 80 PLUS Gold in On/Sb mode to +1% for 80 PLUS Platinum in On/sb mode).

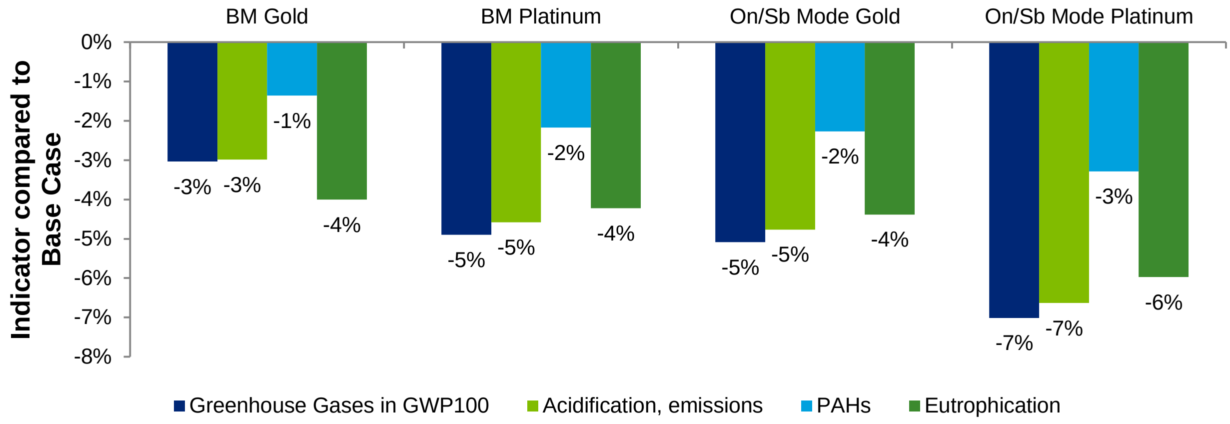


Figure 6: Environmental indicators as compared to the BC

As a direct consequence of reduced total energy consumption, the environmental indicators of the EcoReport indicate that the use of a more efficient PSU can lead up to 7% les GHG emissions, 7% less SO2 eq. emissions, 3% less polycyclic aromatic hydrocarbons (PAH) and 6% less eutrophication.

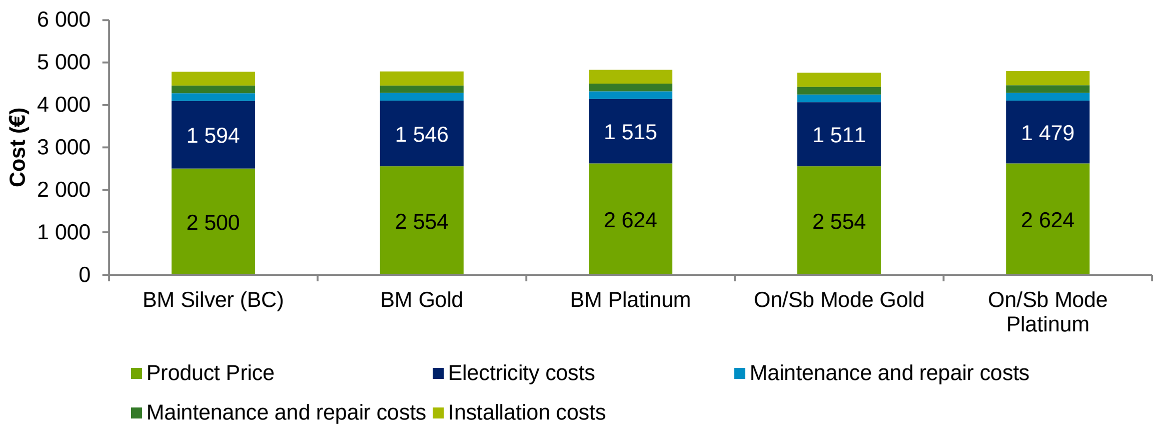


Figure 7: Cost structures of the different PSU options

When compared to the BC, the different PSU design options allow making electricity cost savings that cover the extra costs for the more efficient PSU over their life time.

2.1.2. Design Option 2: Storage Media

Under this design option 4 HDDs were replaced by 8 SSDs, keeping constant the total capacity.

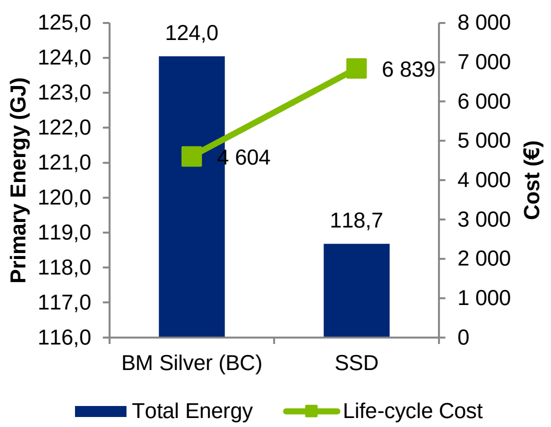


Figure 8: Primary energy consumption and life-cycle costs of a rack server equiped with SSDs

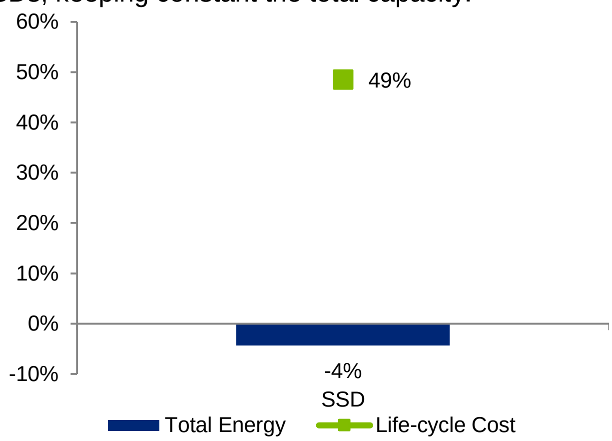


Figure 9: Primary energy consumption and life-cycle costs as compared to the BC (in %)

From the above figures is becomes clear that even though some energy savings can be realised (-4%) through this option, the cost factor (which can be up to 10 in certain cases) is too important to keep this option as a viable alternative.

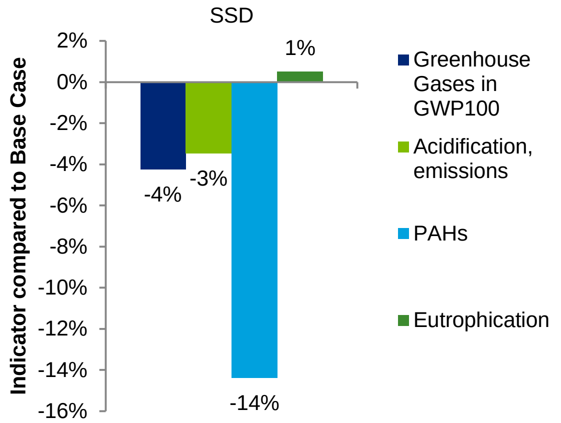


Figure 10: Environmental indicators for the SSD design option

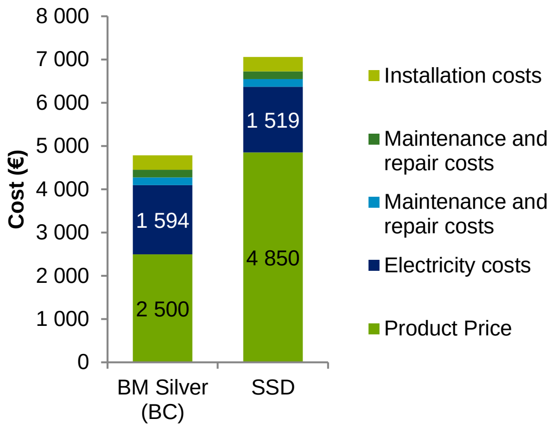


Figure 11: Different cost components of SSD design option

Replacing HDDs by SSDs can reduce the environmental impact, but almost doubles the product price (keeping constant the capacity). At the same time one has to keep in mind that in comparison to HDD, the production of SSD is considerably more energy intensive (see Task 4), which might be not properly reflected through the Ecoreport outputs.

2.1.3. Design Option 3 and 4: ASHRAE A1 and A2

The following figures show the EcoReport results for the design options ASHRAE 1 and ASHRAE A2 for a rack server:

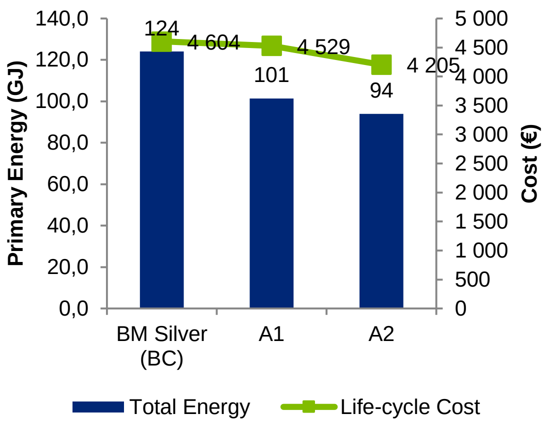


Figure 12: Total energy consumption and life-cycle costs for a rack server under the A1 and A2 options

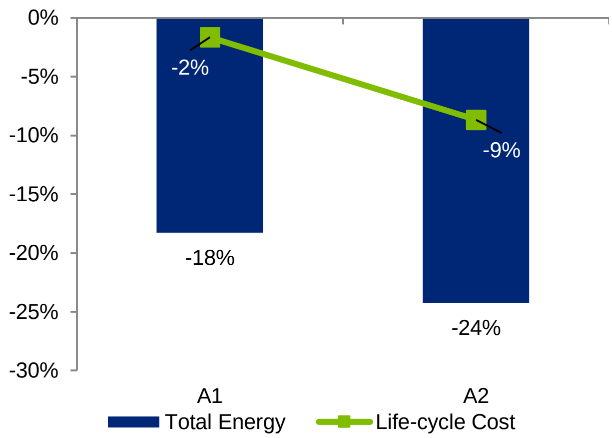


Figure 13: Total energy consumption and LCC for a rack server under the A1 and A2 options (% BC)

It has to be noted that the actual cost impact will be in the reduced cooling infrastructure on the data centre level (CAPEX), which is not shown here. Above figures suggest that these design options (see 1.1.3) could lead to total energy savings up to 18% and 24% on the data centre level, respectively (direct and indirect effects combined). It has to be noted that these values are upper bound estimations, since it will depend on the data centre manager at which temperature the data centre will be operated to also guarantee reasonable working conditions for the staff.

While the direct electricity consumption of the product will increase slightly due to an increase in internal air flow demand and respective fan power consumption (increased fan speed), the indirect electricity consumption will be reduced significantly. The Ecoreport tool allows to define inputs for both, the direct and the indirect electricity consumption separately.

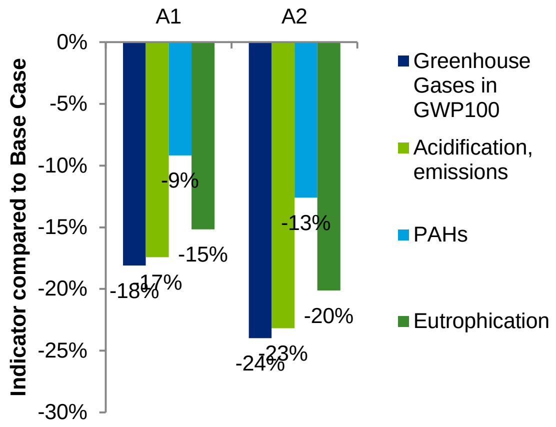


Figure 14: Environmental indicators for the A1 design option

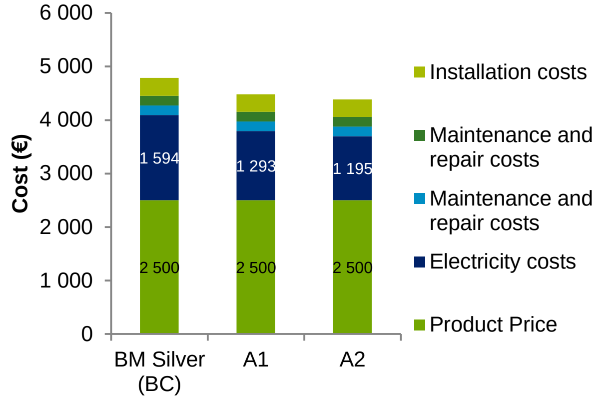


Figure 15: Different cost components of the A1 design option

The environmental indicators suggest that this improvement option can reduce the GHG emissions and the electricity bill by up to 18% for the A1 and up to 24% for the A2 design option. **According to an expert, data centre managers can save up to 4% in operational energy costs for every degree of upward change in the set point[8].**

2.1.4. Design Option 5: Advanced processor power management (APPM)

The following figures present the Ecoreport outcomes for Design Option 5:

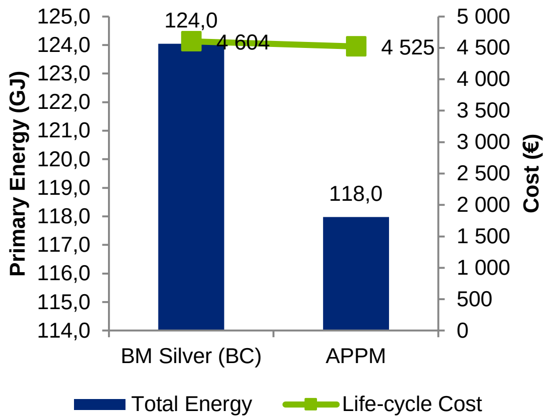


Figure 16: Total energy consumption and life-cycle costs for a rack server under the APPM option

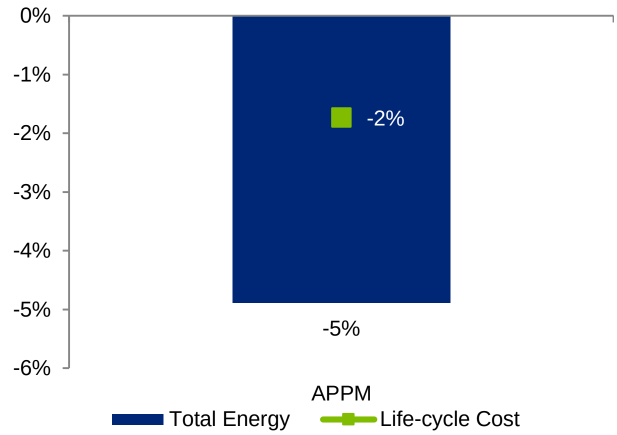


Figure 17: Total energy consumption and life-cycle costs for a rack server under the APPM option (% BC)

[8] http://www.datacenterknowledge.com/archives/2008/10/14/google-raise-your-data-center-temperature/

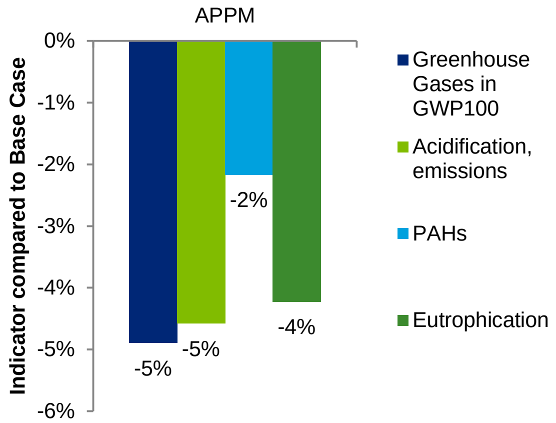


Figure 18: Environmental indicators for the APPM design option

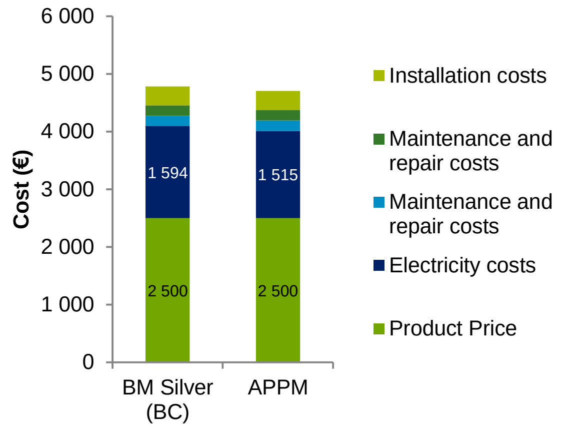


Figure 19: Different cost components of the APPM design option

As described in 1.1.4, this design option assumes that 5% of energy can be saved through advanced processor power management. This translates into 2% life-cycle cost savings and GHG reductions of 5%.

2.1.1. Best available (BA) product

The “Best Available” product is a combination of an On/Sb Mode Platinum PSU (DO-1.6), ASHRAE A2 (DO-4) and advanced processor power management (DO-5). The Ecoreport outcomes are as follows:

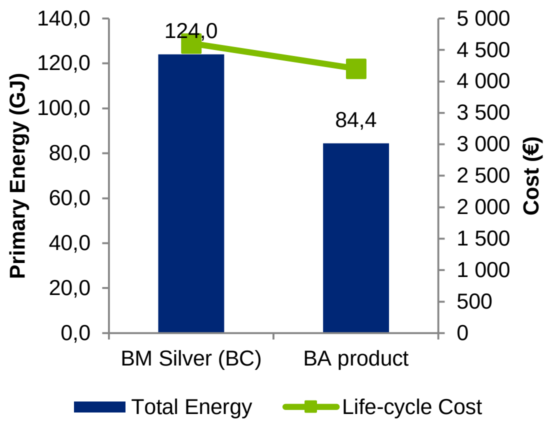


Figure 20: Total energy consumption and life-cycle costs for a rack server under the BA option

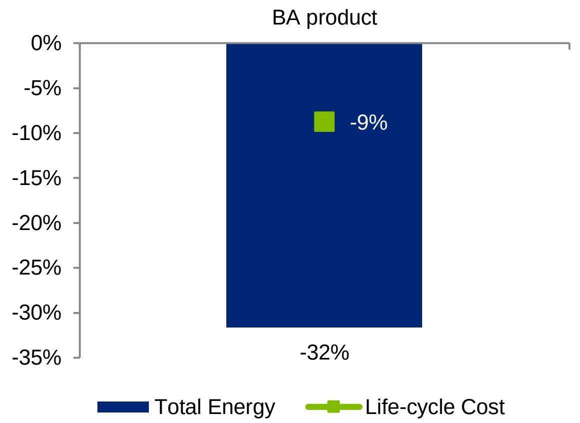


Figure 21: Total energy consumption and life-cycle costs for a rack server under the BA option (% BC)

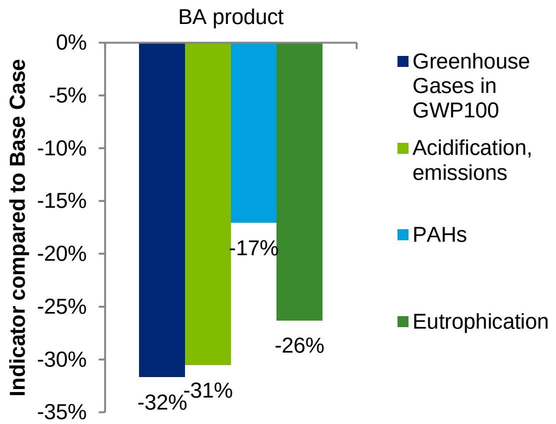


Figure 22: Environmental indicators for the BA design option

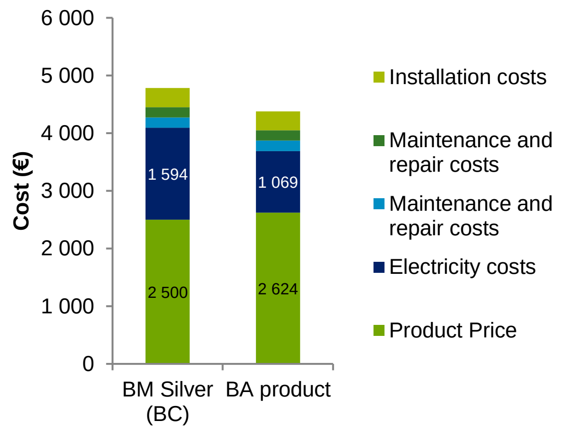


Figure 23: Different cost components of the BA design option

2.1.2. Summary of the Design Option impacts for a rack server (BC 1)

This subchapter shows a summary of above mentioned design options and the “Best Available” product. It has to be noted that combination of the scenarios will result in complex interactions which cannot be simulated with certainty by means of the EcoReport tool. For this reason, the BA design option should be rather seen as an extreme case.

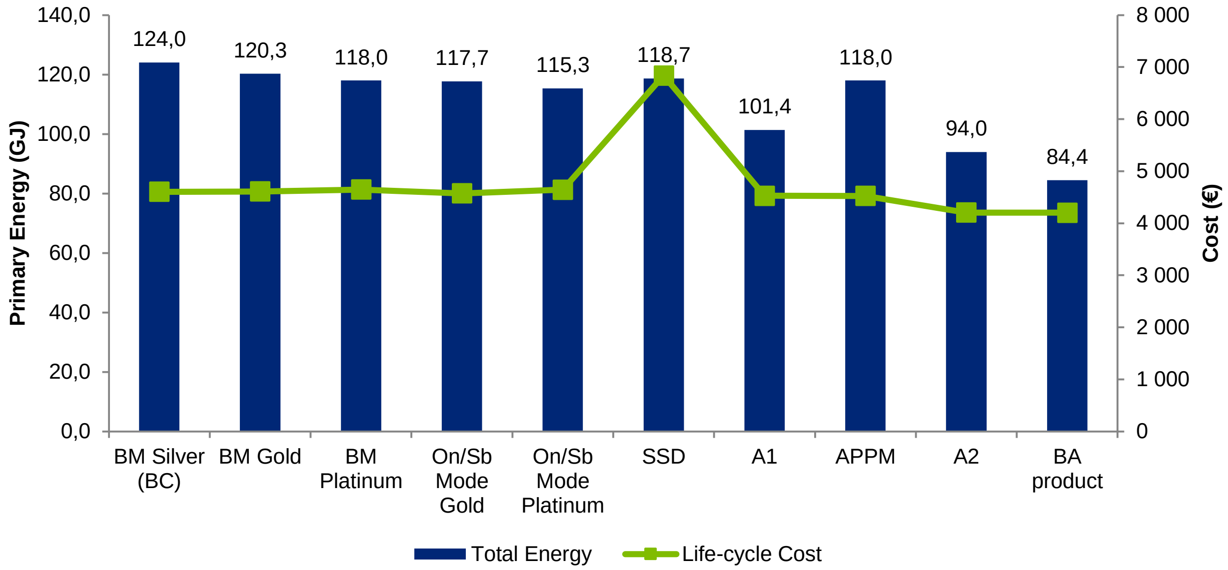


Figure 24: Summary of primary energy consumption versus life-cycle costs for the different design options

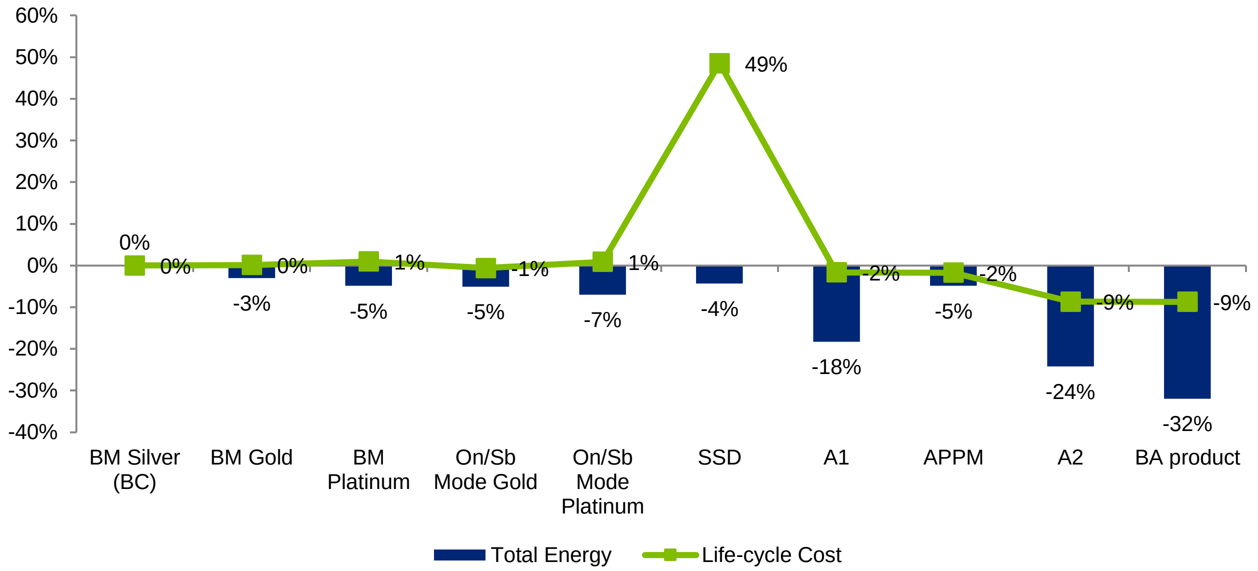


Figure 25: Differences in primary energy consumption and life-cycle costs as compared to the BC

Above figures on life-cycle costs and total energy consumption show that the ASHRAE A1 and A2, highly efficient PSUs and advanced processor power management options can lead to significant energy savings. The SSD option is not viable from an economic point of view, even though some energy savings can be realised. The Best Available product which in this case combines an on/sb mode platinum PSU under ASHRAE A2 conditions and additional advanced processor power management shows that savings up to 32% of total energy seem to be possible, accompanied by 9% of life-cycle cost savings.

The following figure shows the environmental impacts as compared to the BC.

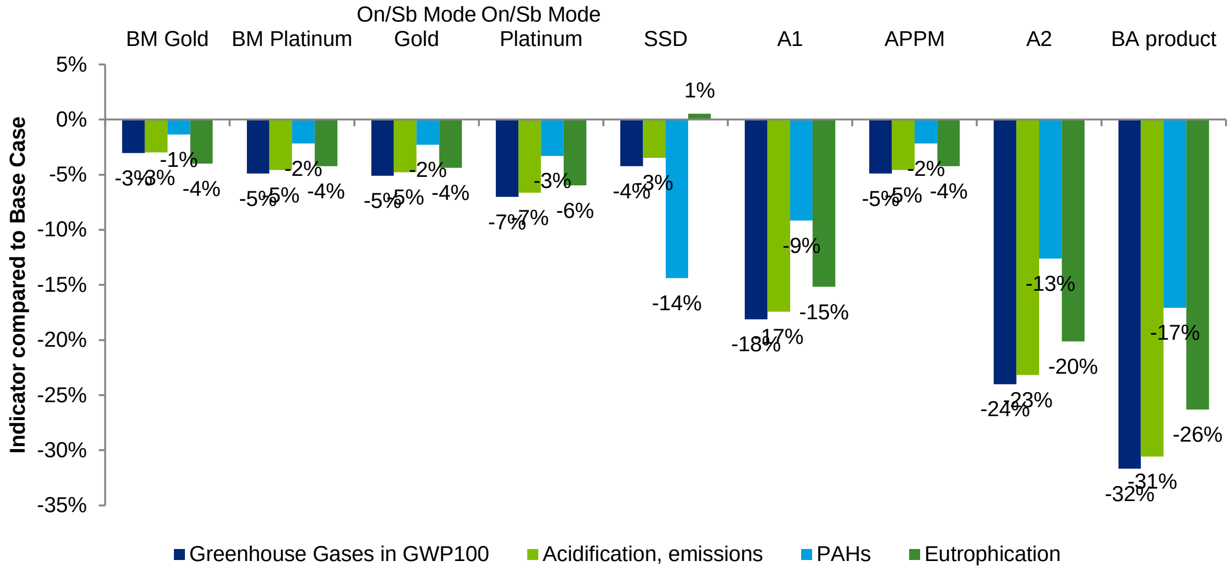


Figure 26: Overview over environmental indicators for the different options

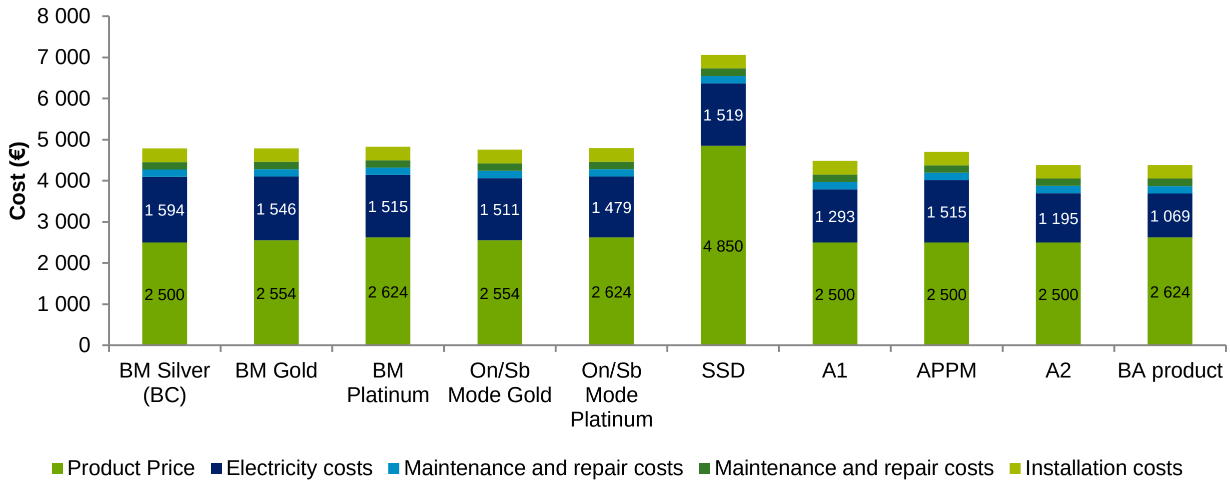


Figure 27: Overview of the cost structures of the different options

Depending on the design option, operation costs can vary significantly.

2.2. Base-Case 2: Blade System

2.2.1. Design Option 1: Power Supply Unit (PSU)

Design option 1 for the second base case also includes the 80 PLUS Titanium category, instead of the 80 PLUS Gold category. The relative savings of the 80 Plus Gold category can be compared to those in Base Case 1 and are therefore omitted in the presentation.

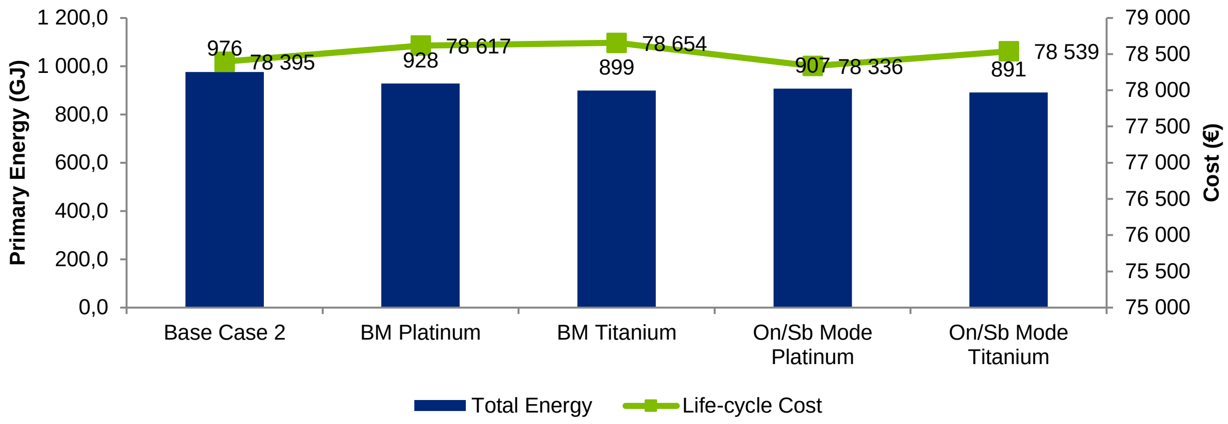
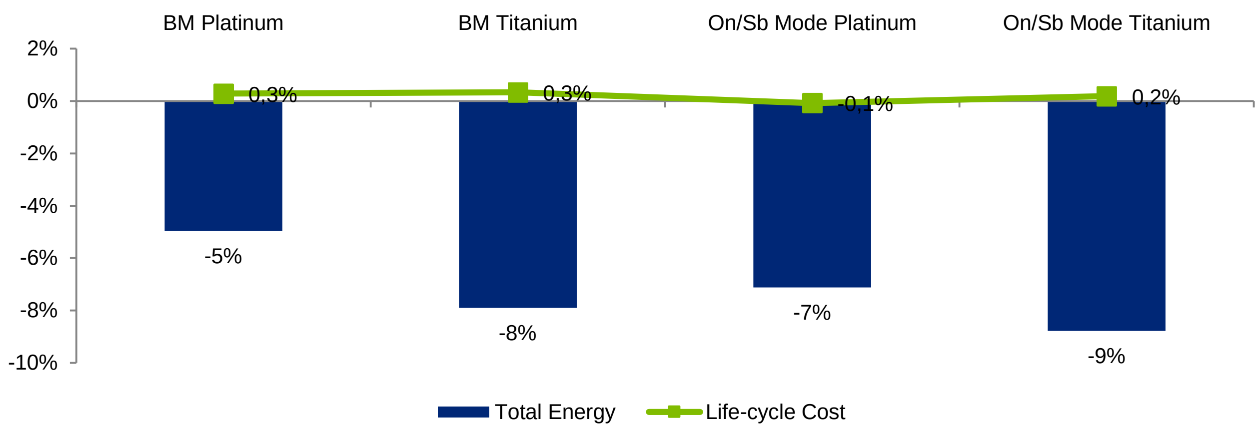


Figure 28: Primary energy consumption and life-cycle costs of a blade system with different PSUs



It can be observed from the figures that the use of a more efficient PSU in the blade system can reduce energy consumption up to 9% as compared to the base case (80 PLUS Silver). As in the first base case, total life-cycle costs remain flat (+0.2% 80 PLUS Titanium in On/Sb Mode).

Figure 29: Primary energy consumption and life-cycle costs of PSUs as compared to the BC (in %)

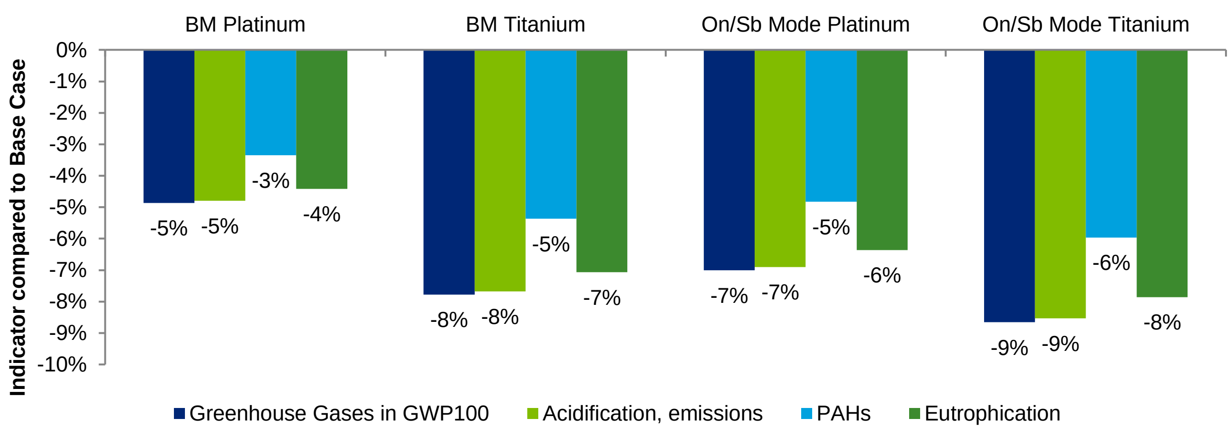


Figure 30: Overview over environmental indicators for the different PSU options

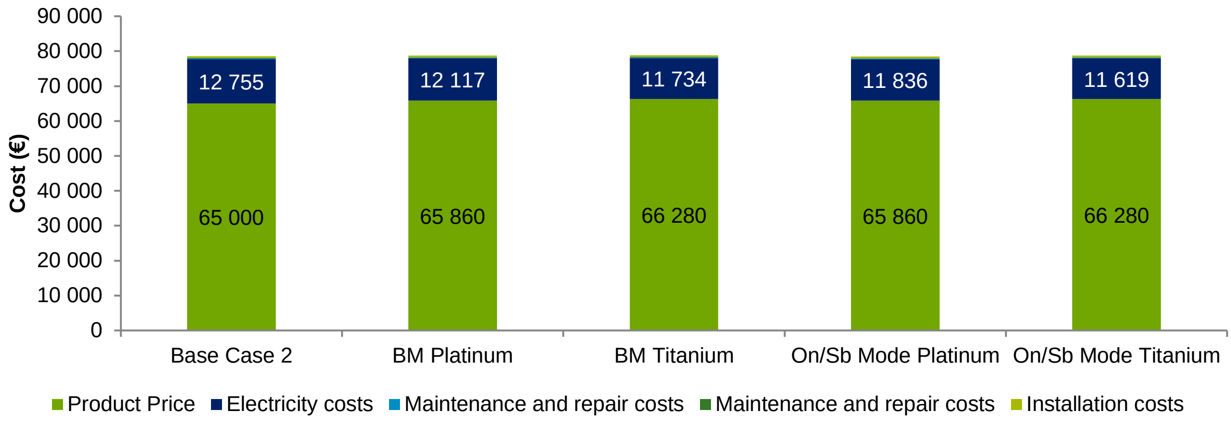


Figure 31: Overview over the cost structure of different PSU options

2.2.2. Design Option 2: Storage Media

Under this design option 16 HDD were replaced by 32 SSD.

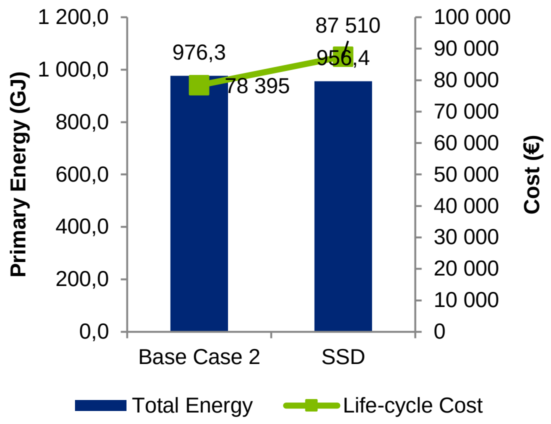


Figure 32: Primary energy consumption and life-cycle costs of a blade system equipped with SSDs

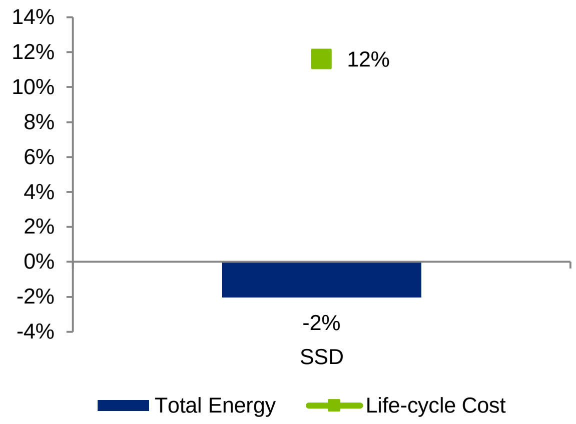


Figure 33: Primary energy consumption and life-cycle costs as compared to the BC (in %)

As in the first BC, the energy savings remain low (-2%). Since the overall product is more expensive than a rack server, the relative price increase is lower. Here again, the benefits do not overweigh the overall costs.

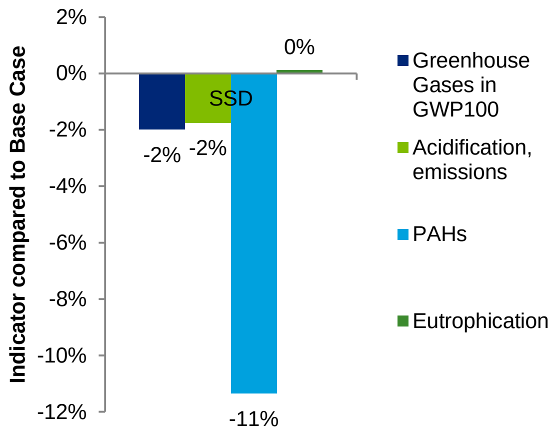


Figure 34: Environmental indicators for the SSD design option

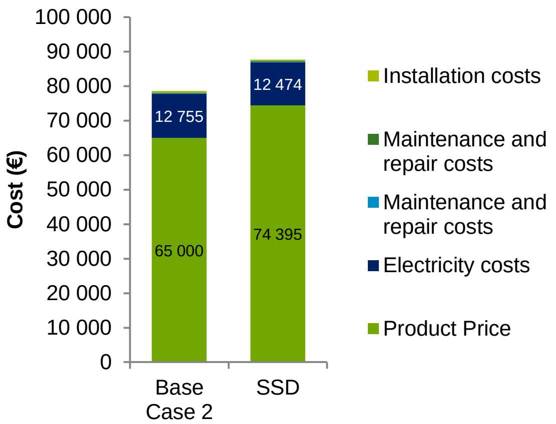


Figure 35: Different cost components of SSD design option

2.2.3. Design Option 3 and 4: ASHRAE A1 and A2

The following figures show the EcoReport results for the ASHRAE A1 and A2 design options.

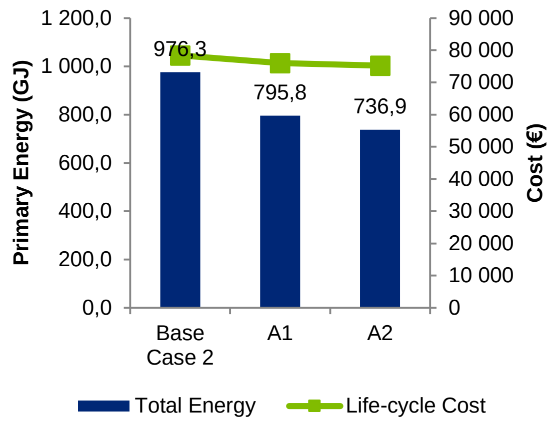


Figure 36: Primary energy consumption and life-cycle costs of a blade system under the A1 and A2 option

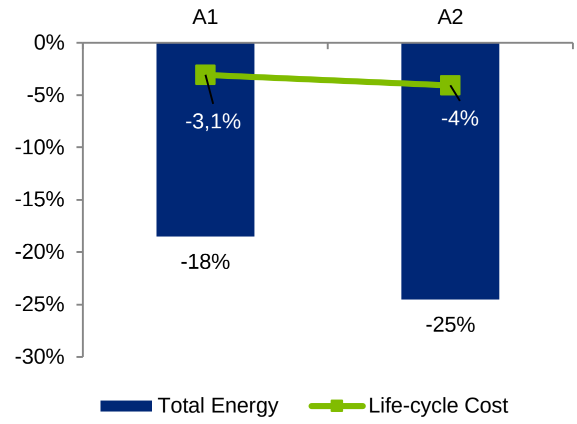


Figure 37: Primary energy consumption and life-cycle costs (in % of BC) for the A1 and A2 option

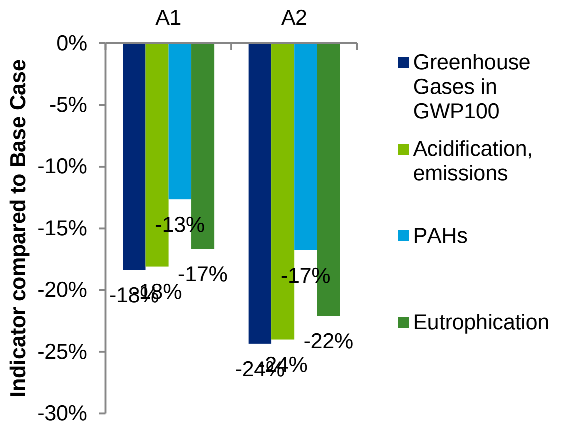


Figure 38: Environmental indicators for the A1 and A2 design option

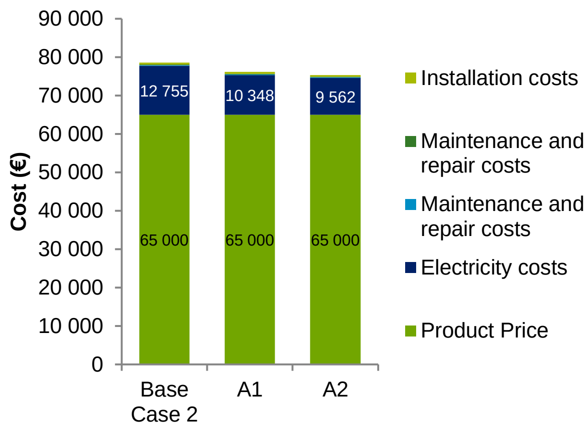


Figure 39: Cost structure of the A1 and A2 design option

2.2.4. Design Option 5: Advanced processor power management (APPM)

Below figures show the EcoReport outcomes of the design option related to advanced processor power management.

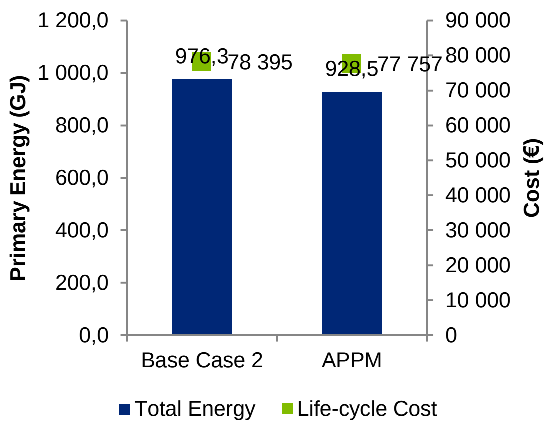


Figure 40: Primary energy consumption and life-cycle costs of a blade system under the APPM option

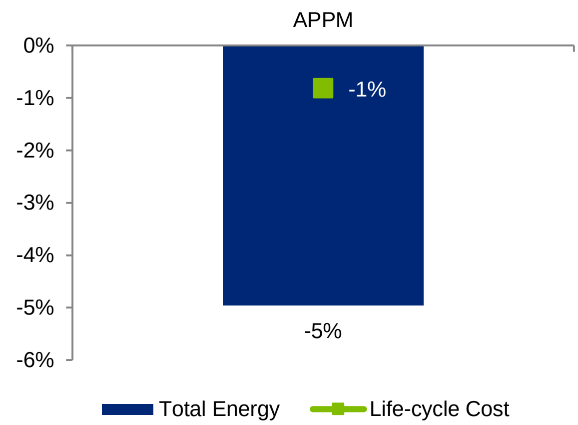


Figure 41: Primary energy consumption and life-cycle costs (in % of BC) for the APPM option

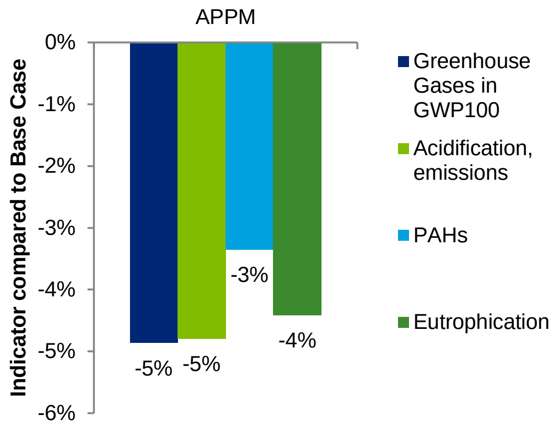


Figure 42: Environmental indicators for the APPM design option

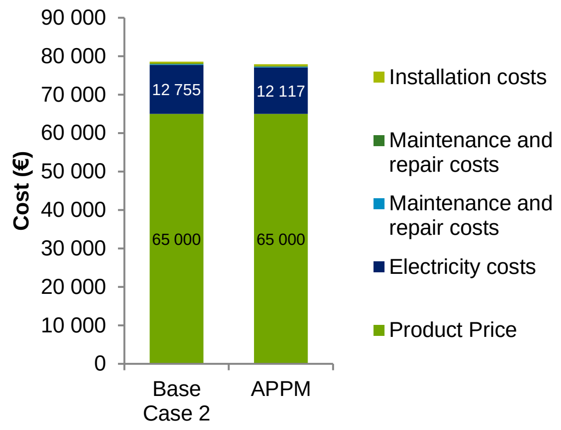


Figure 43: Cost structure of the APPM design option

2.2.5. Design Option 6: Full configuration vs. reduced configuration

This improvement option is a theoretical case study which intends to show how important a fuller configuration (consolidation of hardware resources) is. This is no real design option, but puts the advantages of blade systems (modularity) into perspective.

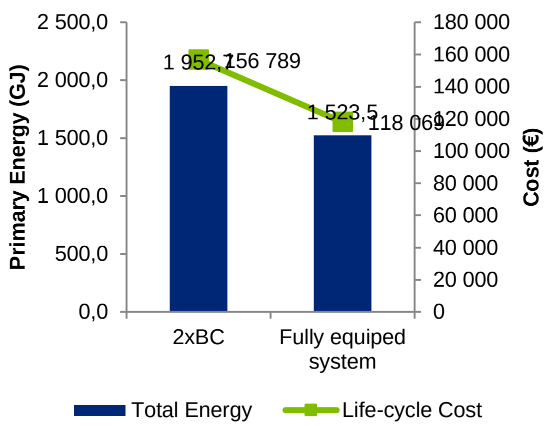


Figure 44: Primary energy consumption and life-cycle costs of two BC vs one fully configured system

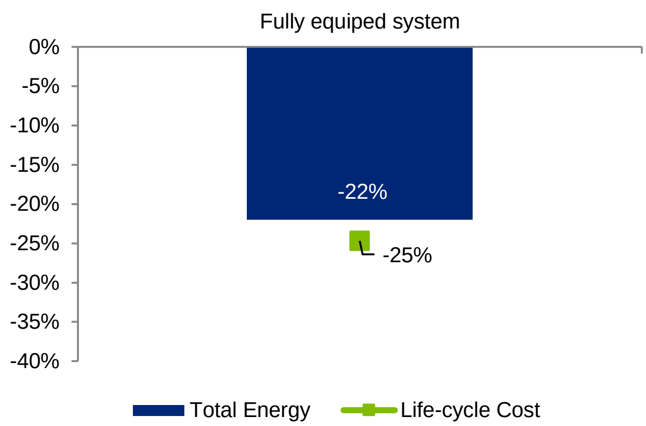


Figure 45: Primary energy consumption and life-cycle costs of a fully configured system compared to two BC

This exercise shows that a full configured system can reduce the total energy consumption by up to 22% and lead to life-cycle cost savings of 25% as compared to two half configures systems (2xBC).

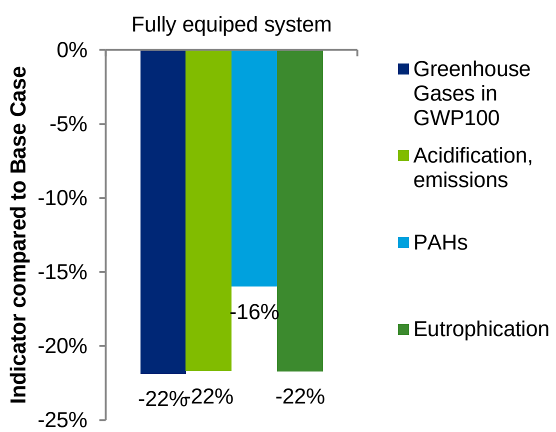


Figure 46: Environmental indicators for the fully configured system against two BC

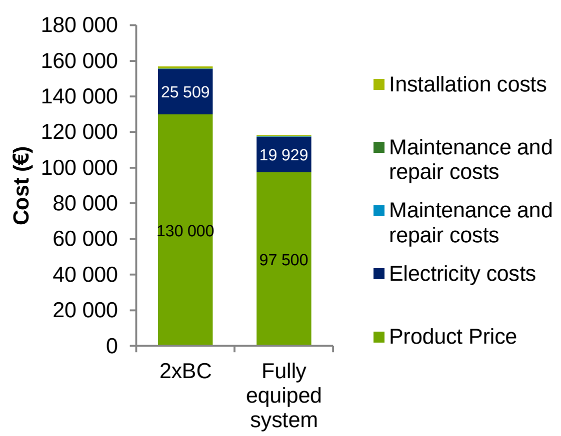


Figure 47: Cost structures of fully configured system against two BC

2.2.6. Best available (BA) product

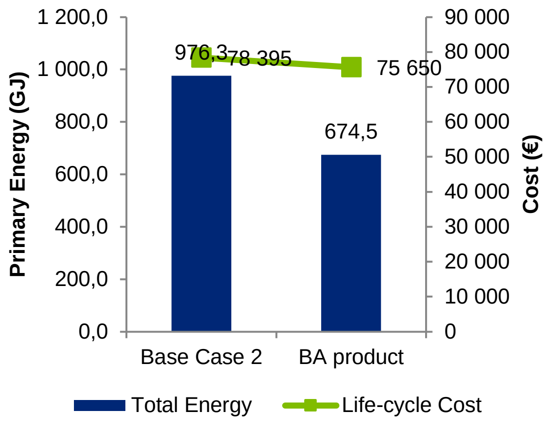


Figure 48: Primary energy consumption and life-cycle costs of a blade system under the BA option

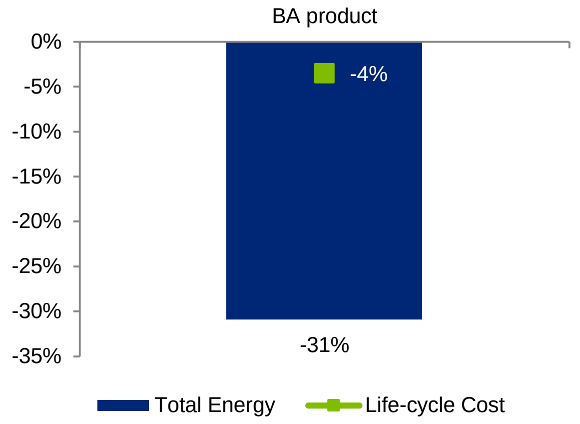


Figure 49: Primary energy consumption and life-cycle costs (in % of BC) for the BA option

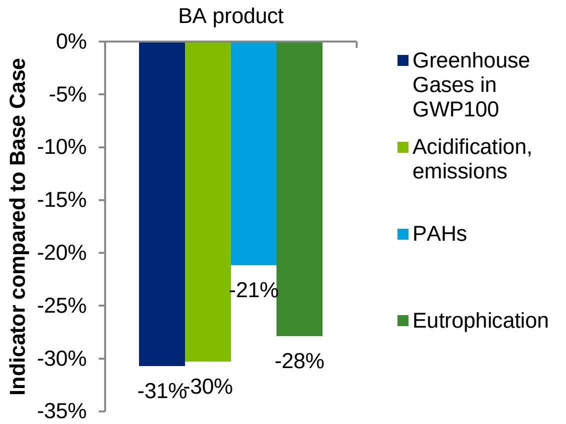


Figure 50: Environmental indicators for the fully configured system for the BA option

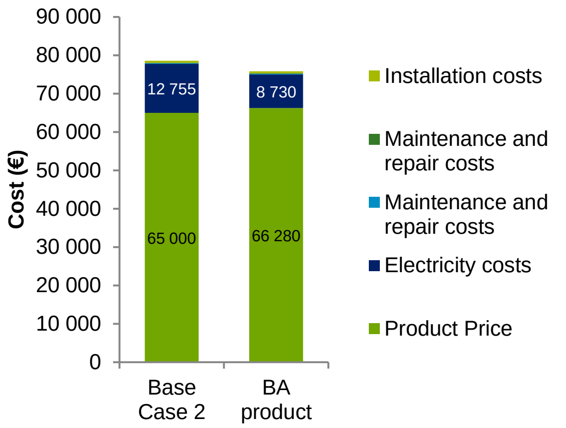


Figure 51: Cost structures of fully configured system against the BC

2.2.7. Summary of the Design Option impacts for a blade system (BC 2)

This subchapter shows a summary of above mentioned design options and adds a “Best Available” product, which is a combination of an On/Sb Mode Titanium PSU (DO-1.7), ASHRAE A2 (DO-4) and advanced processor power management (DO-5). The “fully equipped” design option was scaled down to the functional unit (FU).

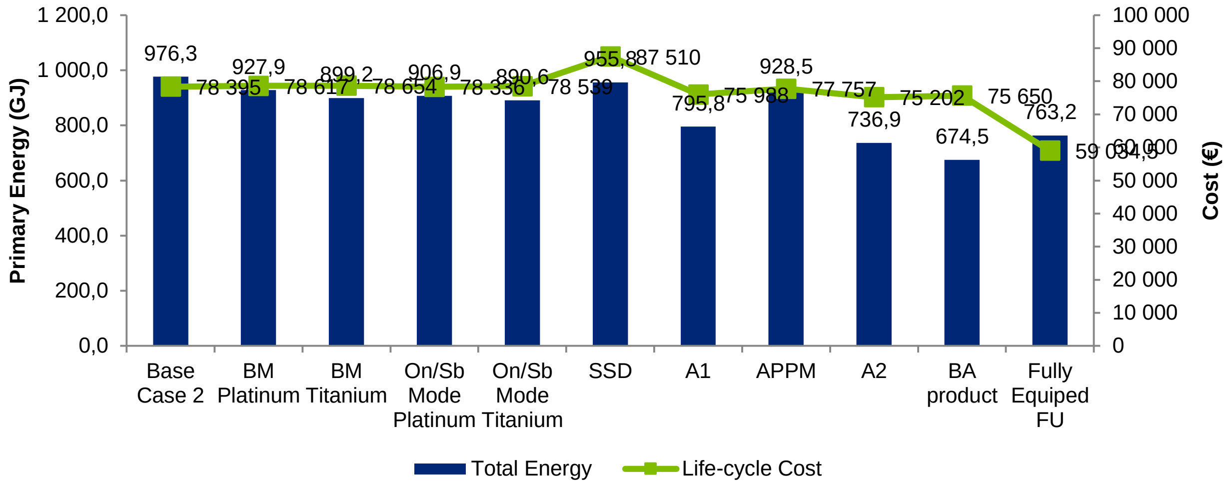


Figure 52: Summary of primary energy consumption versus life-cycle costs for the different design options

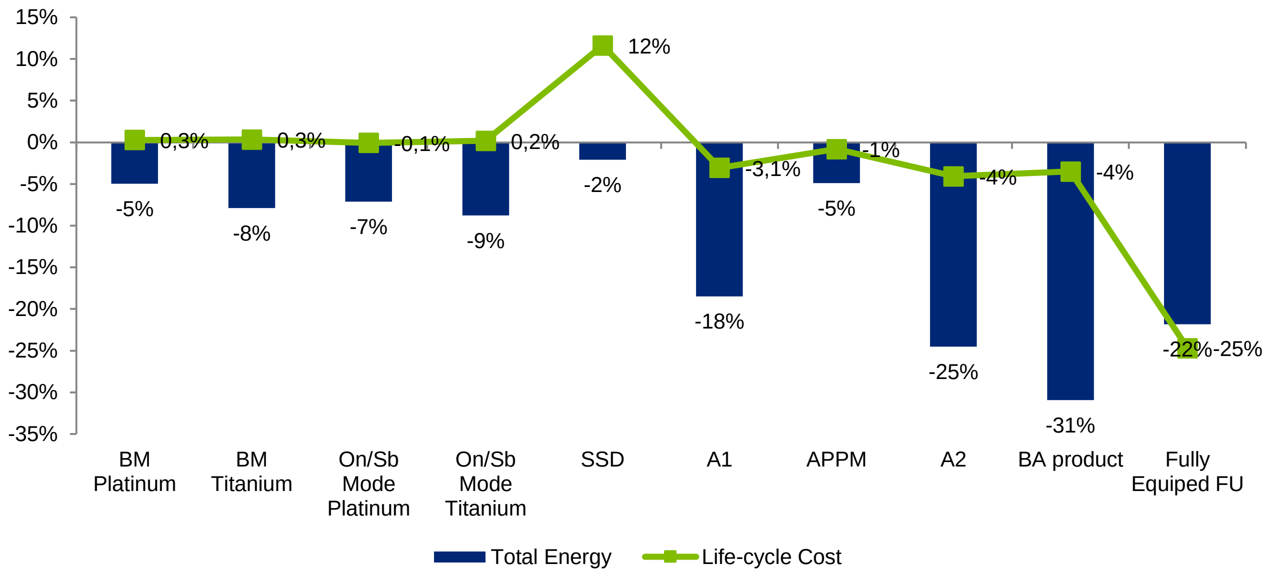


Figure 53: Primary energy consumption and life-cycle costs of different options as compared to the BC (in %)

These figures on life-cycle costs and total energy consumption show that as in the previous case the ASHRAE A1/A2 and advanced processor power management options can lead to significant energy savings of 18%/25% and 5% respectively. The SSD option is again not viable from an economic point of view, even though the relative price increase is lower than for BC 1. The Best Available product which in this case combines an on/sb mode titanium PSU under ASHRAE A2 conditions and additional advanced processor power management shows that savings up to 31% of total energy seem to be possible, accompanied by 4% of life-cycle cost savings.

The following figure shows the environmental impacts as compared to the BC.

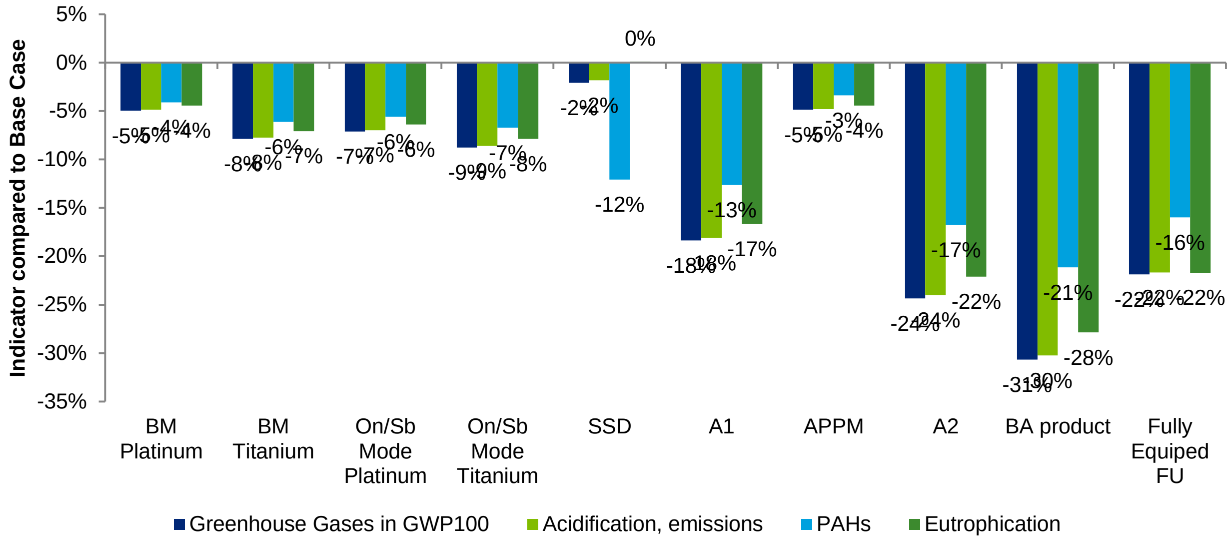


Figure 54: Environmental indicators for the different design options

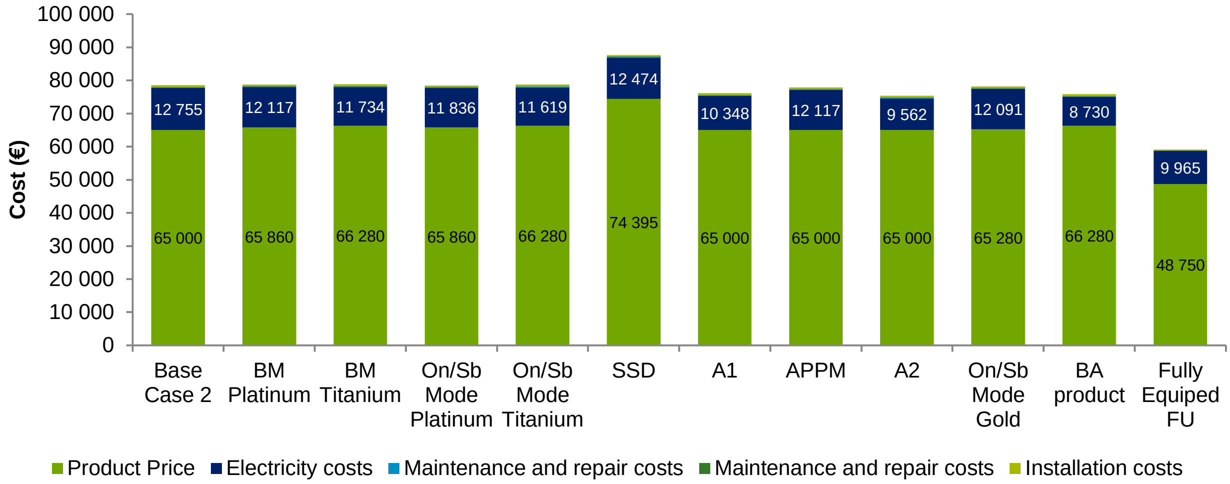


Figure 55: Cost structures of different design options

A closer look at the cost structure of the different design options reveals that significant monetary savings can be achieved through reduced electricity consumption (in particular via A1, A2 and highly efficient PSUs).

2.3. Base-Case 3: Storage System

2.3.1. Design Option 1: Power Supply Unit (PSU)

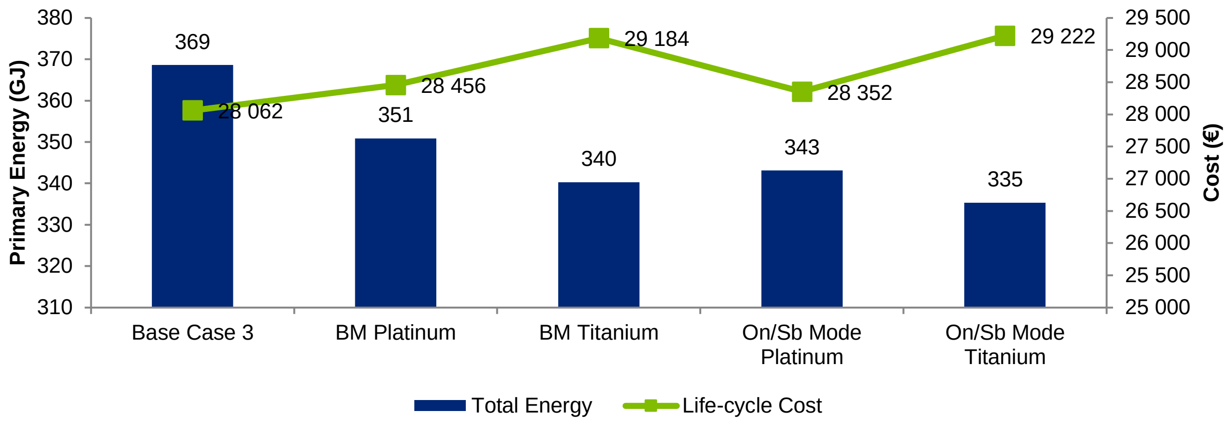


Figure 56: Primary energy consumption versus life-cycle costs for different PSUs

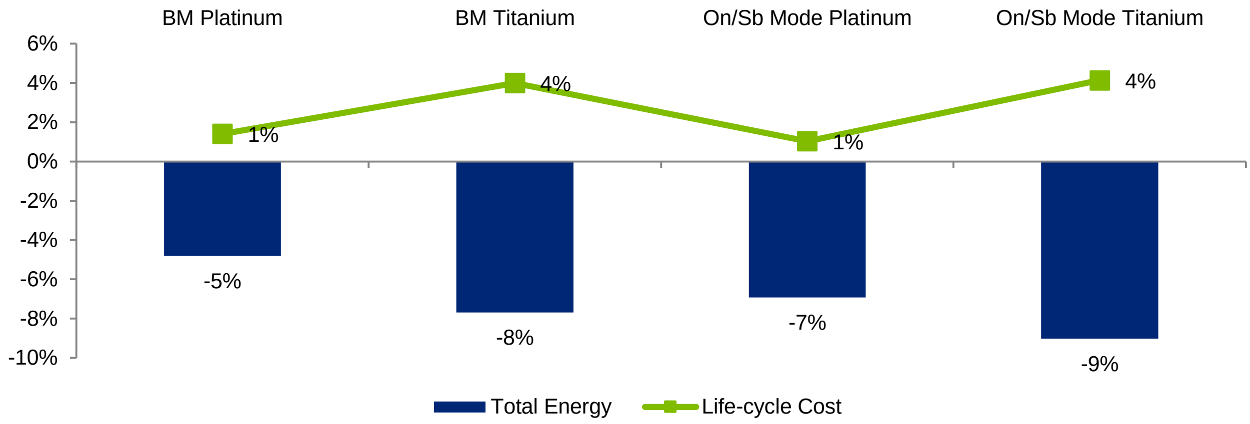


Figure 57: Primary energy consumption and life-cycle costs of PSUs as compared to the BC (in %)

When applied to the third base case, Design Option 1 shows that energy savings up to 9% can be realised when replacing an 80 PLUS Silver PSU by an 80 PLUS Titanium PSU (on/sb mode). However, life-cycle costs can increase by 4%. The relative savings of the 80 Plus Gold category can be compared to those in Base Case 1 and are therefore omitted in the presentation.

Below figures provide the EcoReport outcomes for four environmental indicators as well as the respective cost structures of different PSU design options.

Industry representatives mentioned that storage products often use a multi-voltage power supply and that storage is running 2 to 3 years behind server systems with regards to use of a given 80 plus power supply (or equivalent) efficiency level. Storage products typically require a larger output energy because of the fact that spinning drives have a consistent power use with little variation between maximum and idle power use. The on/standby mode for redundant power supplies might be more difficult to apply to storage products.

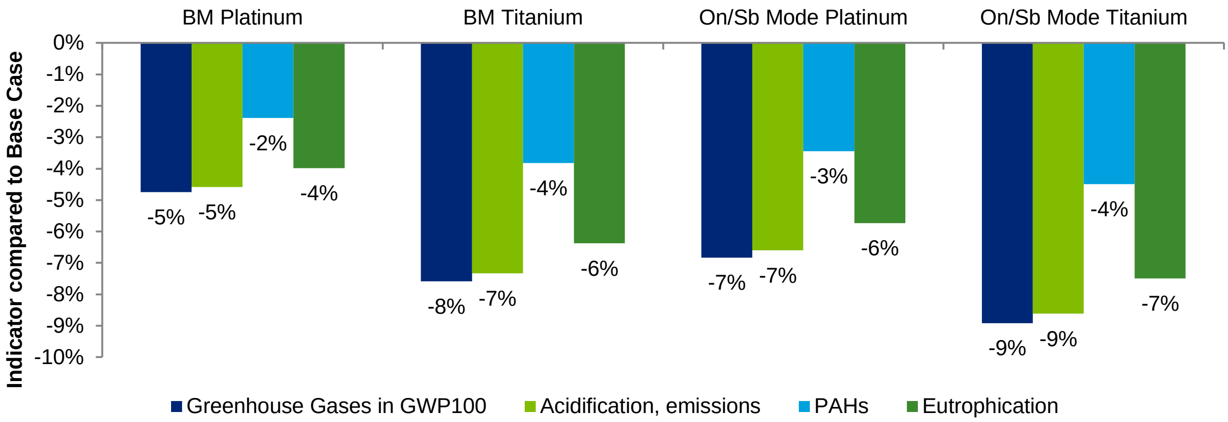


Figure 58: Environmental indicators for the different PSU design options

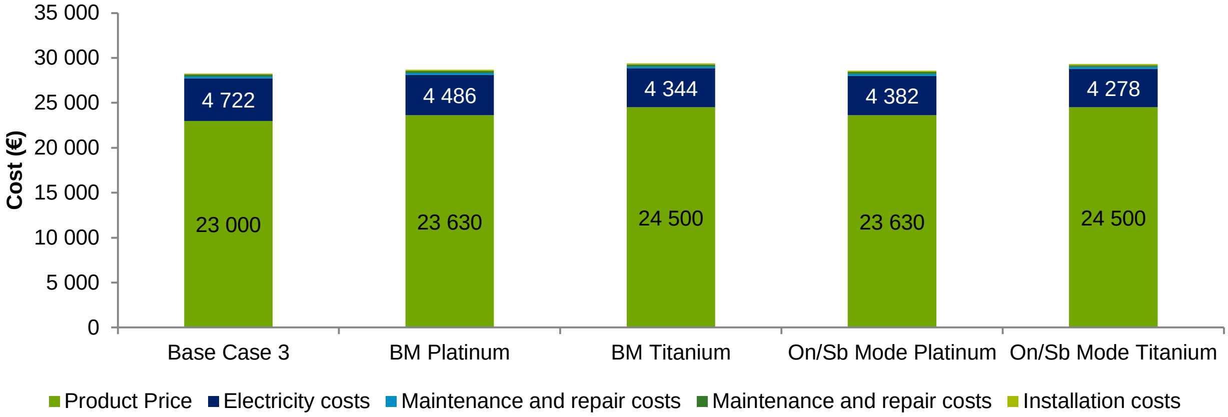


Figure 59: Cost structures of different PSU design options

2.3.2. Design Option 7: Storage Capacity Optimization (COMS)

This design option is only considered for the storage base case and follows the hypothesis that Capacity Optimisation Methods Software (COMS) reduces the capacity required to store a particular data set. It is assumed that 25% of capacity can be saved in suitable products (Online 3 +), leading to life-cycle cost savings and total energy savings described in below figures.

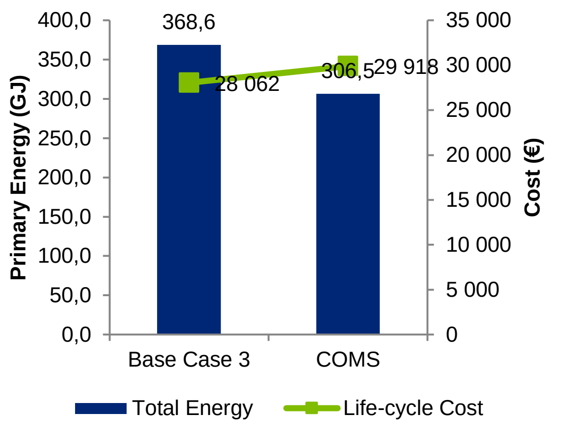


Figure 60: Primary energy consumption and life-cycle costs of a COMS design option

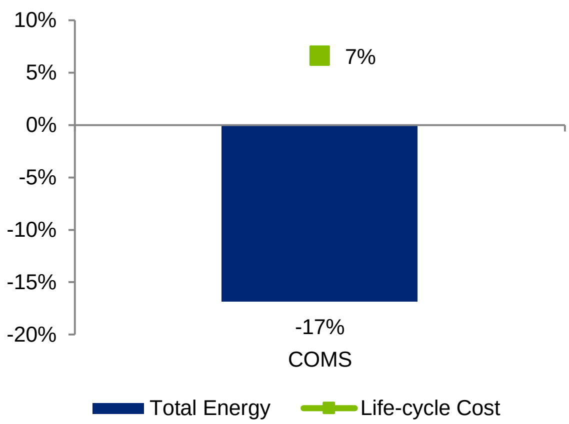
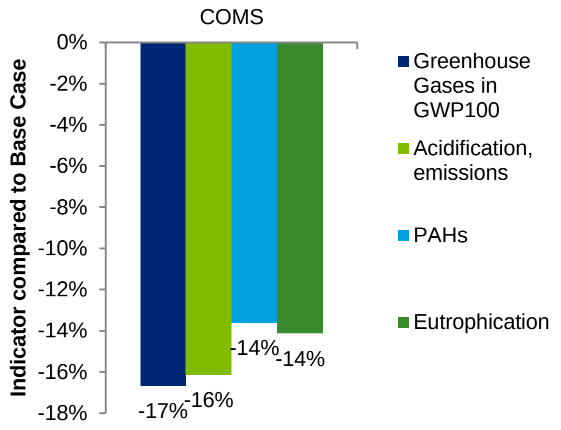


Figure 61: Primary energy consumption and life-cycle costs of a COMS design option (% BC)



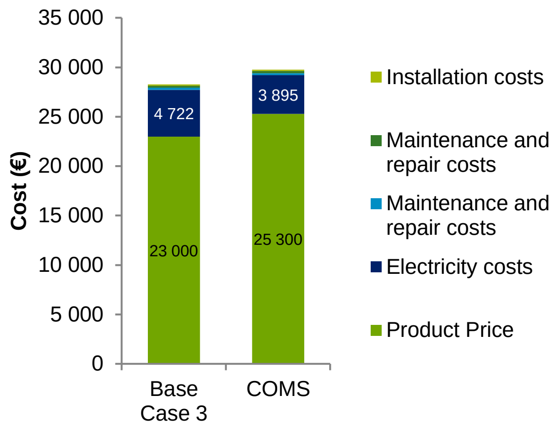
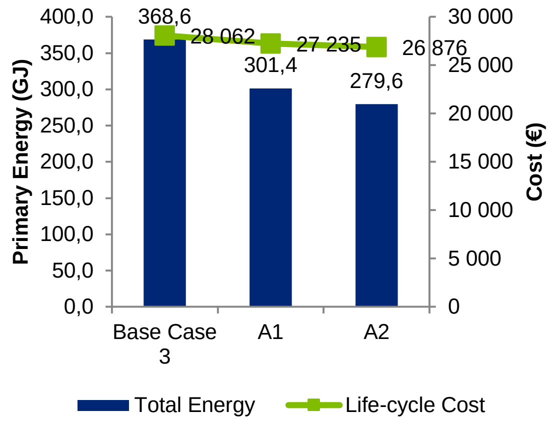


Figure 62: Environmental indicators for the COMS design option

Figure 63: Cost structure of the COMS design option

Results from the EcoReport indicate that under this scenario 17% of GHG can be saved.

2.3.3. Design Options 3 and 4: ASHRAE A1 and A2



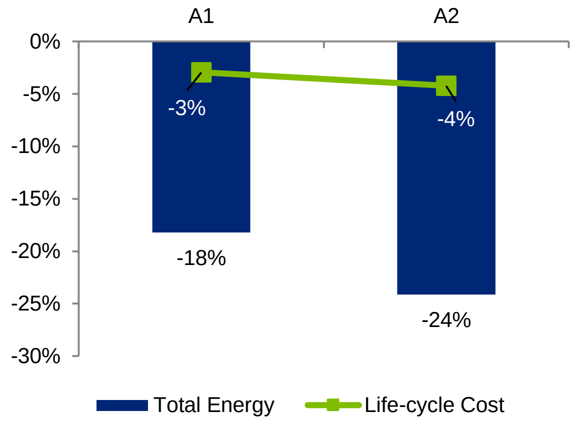
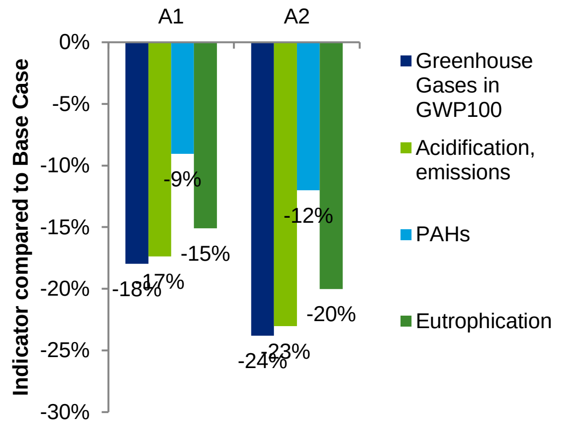


Figure 64: Primary energy consumption and life-cycle costs of the A1 and A2 design option

Figure 65: Primary energy consumption and life-cycle costs of the A1 and A2 design option (% BC)



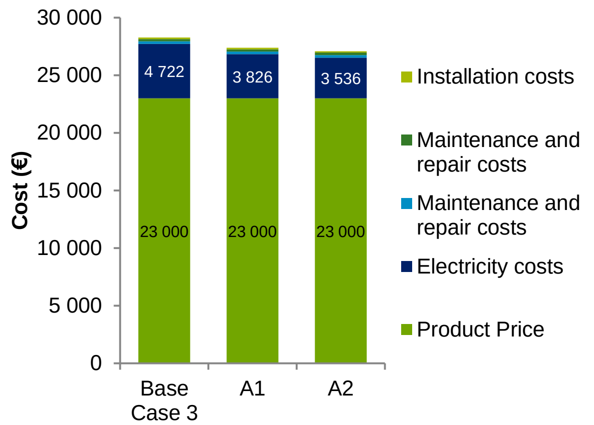


Figure 66: Environmental indicators for the A1 and A2 design option

Figure 67: Cost structure of the A1 and A2 design option

2.3.4. Design Option 7: Reuse

This design option follows the assumption that the reuse rate of the storage system is increased from 25% to 50%. As can be seen from below results, the overall impact is relatively low. The only significant environmental improvement concerns the PAHs, which decrease by 9%.

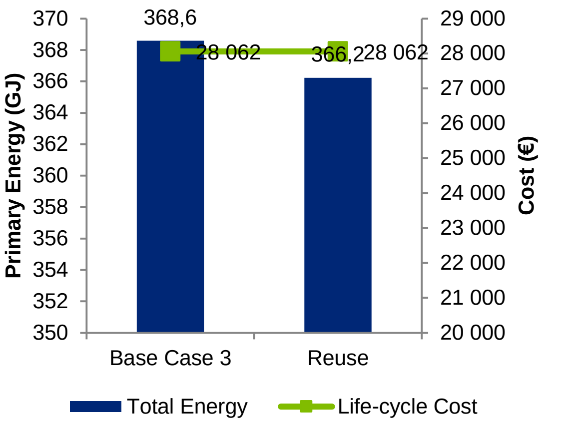


Figure 68: Primary energy consumption and life-cycle costs of the Reuse design option

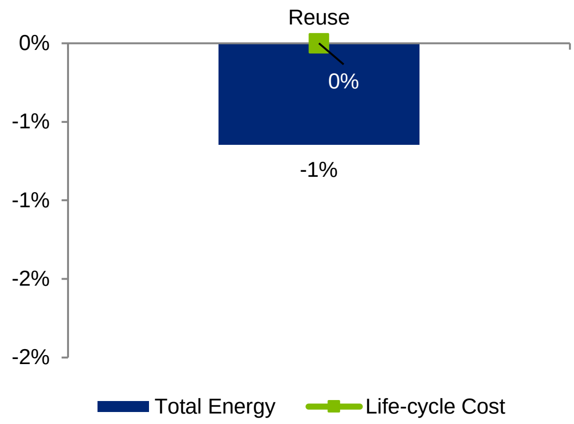


Figure 69: Primary energy consumption and life-cycle costs of the Reuse design option (% BC)

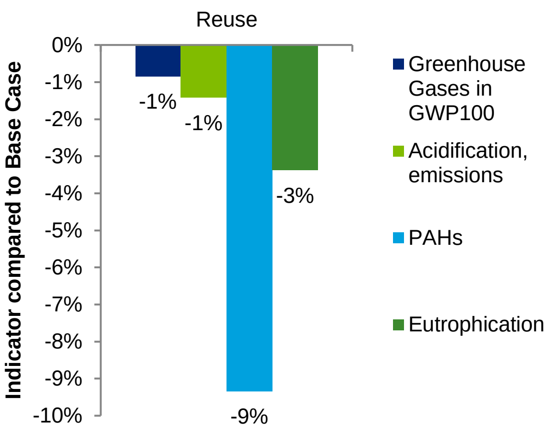


Figure 70: Environmental indicators for the Reuse design option

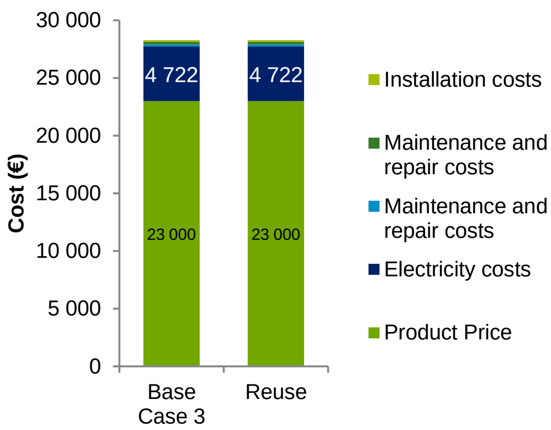


Figure 71: Cost structure of the Reuse design option

Since an increase of the reuse rate by 25% did not show significant changes of the EcoReport results, this design option was not implemented for the other base cases.

However, one has to emphasize that the modelling of reuse is has limitations in the Ecoreport tool. The tool credits an amount of 75% of the impact for material production, while impacts due to manufacturing are not considered. This point is very important, since when reusing a component, the benefits should not only account for the materials but also for the manufacturing part (i.e. the benefit of reusing a printed circuit board, is the avoided production of a new board).

In the methodology, the 75% value is justified in the following way: "For re-use the credit is 75% of all the plastics production impacts, because it is assumed that collection and cleaning will take its toll" (MEErP Methodology Part 2 Final, p.27). However, this rate this is also applied to other non-plastic materials without further specifications. Another problem is also that the Ecoreport tool uses a reuse rate for all the parts, while the reuse of servers is mainly focused on some components (e.g. HDD or memory cards which are less affected by technological obsolescence).

The JRC-IES study could show in their results that the reuse of components into remanufactured servers implies significant environmental benefits in terms of avoided production of new components[9].

2.3.5. Summary of the Design Option impacts for a storage system (BC 3)

This subchapter presents a summary of above mentioned design options and adds a “Best Available” product, which is a combination of an On/Sb Mode Titanium PSU (DO-1.7), COMS and ASHRAE A1 (DO-3).

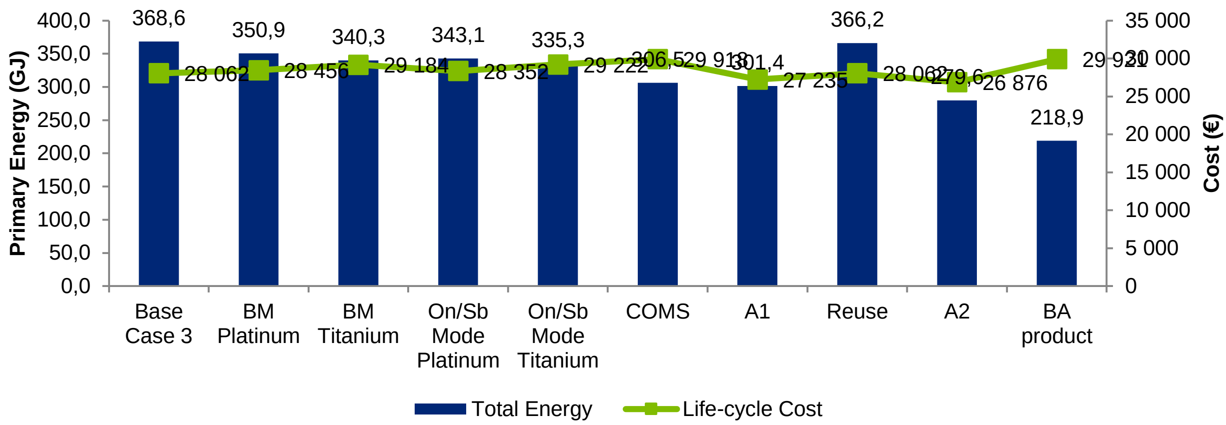


Figure 72: Summary of primary energy consumption versus life-cycle costs for the different design options

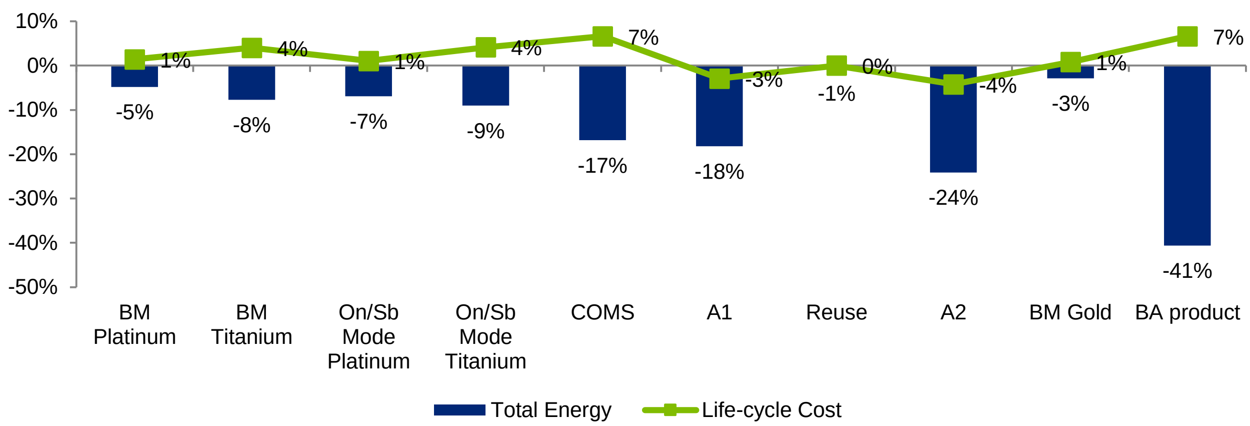


Figure 73: Primary energy consumption and life-cycle costs of different options as compared to the BC (in %)

Above figures on life-cycle costs and total energy consumption indicate that the COMS design option and the ASHRAE A1 and A2 options can lead to significant energy savings of 17%, 18% and 24% respectively. The SSD option has not been considered for this base case, since it would be not viable from an economic point of view. The Best Available product which in this case combines an on/sb mode titanium PSU under ASHRAE A2 conditions and with COMS shows that maximal savings up to 41% of total energy seem to be theoretically achievable. This however might come with increased life-cycle costs (+7%).

The following figure shows the environmental impacts as compared to the BC.

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

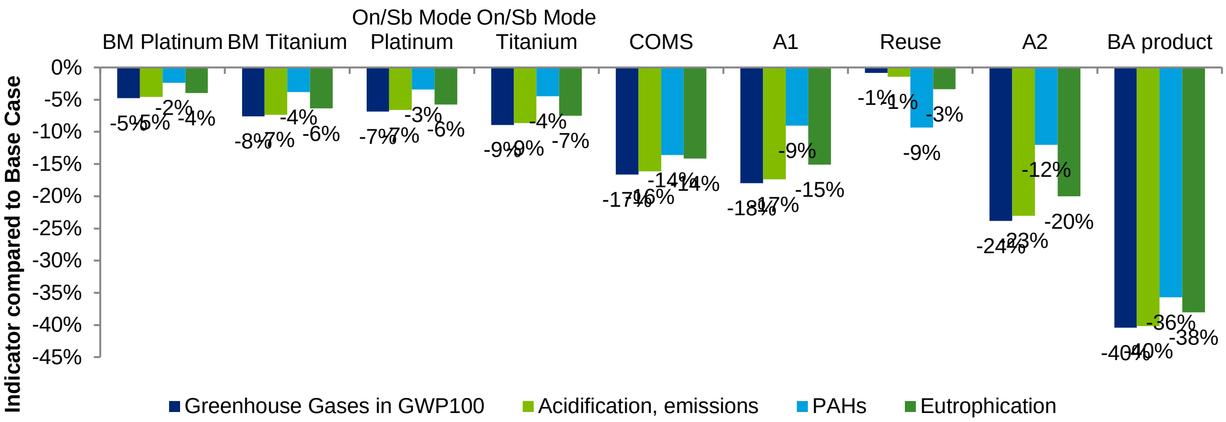


Figure 74: Summary of environmental indicators for the different design options

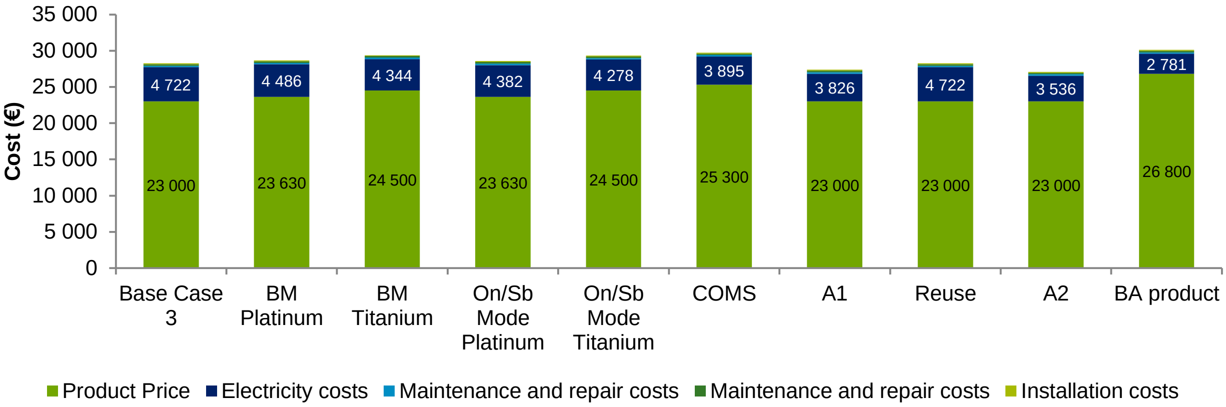


Figure 75: Summary of the cost structures of the different design options

The comparison of the cost structures shows that COMS and the A1 and A2 design option can lead to significant savings on the electricity cost side. The Best Available option comes with an increase the product price but can decrease electricity costs by more than 40%.

3.Analysis BAT and LLCC

The design options identified in the technical, environmental and economic analyses are ranked to identify the design improvement option with the least cycle environmental impacts (BAT) and the Least Life Cycle Costs (LLCC). Building an energy-LCC curve (Y-axis= energy consumed and LCC, X-axis=options) allows the LLCC and BATs to be identified.

The performance of each improvement option is compared using the base-case. The comparison is made in terms of primary energy consumption and LCC. LCC is the sum of the product price, costs of energy and the costs of installation and maintenance as described in Task 5.

The individual design options usually have very different effects: Some of them can generate big savings on running costs at hardly any extra production costs, others may be very expensive, deliver only small environmental improvements and give little reduction on running costs. This phenomenon is the basis for ranking the individual design options in terms of Life Cycle Costs versus environmental benefits.

According to the EcoReport, the quantitative basis for the ranking of options, when they result in monetary savings (e.g. lower energy costs for the consumer) is the payback period. It is defined as the time period it takes for an investor to recuperate the extra investment in purchase price *dPP* through the reduction in annual operating expense *dOE*. Since in our case discount and escalation rate are equal, the Simple Payback Period SPP can be used. The equation for comparing two alternatives ‘A’ and ‘B’ is then:

$$SPP_{AB} = dPP_{AB}/dOE_{AB} \ (in\ years)$$

The following abbreviations are used in the comparison tables and figures:

Table 16: Abbreviations used in BAT and LLCC analysis

Abbreviation	Description
APPM	Advanced Processor Power Management
A1	ASHRAE A1 design option
A2	ASHRAE A2 design option
BA product	Best available product
On/Sb Mode (Gold, Platinum, Titanium)	On/Stand-by mode for different PSU efficiency levels (80 PLUS)
BM (Gold, Platinum, Titanium)	Balanced mode for different PSU efficiency levels (80 PLUS)
SSD	Storage Media design option (SSD)
Reuse	Reuse design option (storage)
COMS	Capacity Optimisation Methods Software (storage)

3.1.Base-Case 1: Rack Server

The following table shows the simple payback period for different design options of BC-1:

Table 17: Simple Payback Period for design options of BC-1

	APPM	A1	A2	BA product	On/Sb Mode Gold	On/Sb Mode Platinum	BM Gold	BM Platinum	SSD
dPP (EUR)	0	0	0	124	54	124	54	124	2 350
dOE (EUR, per year)	20	75	100	131	21	29	12	20	18,88
SPP (years)	0	0	0	0.9	2.6	4,3	4,5	6,2	124,5

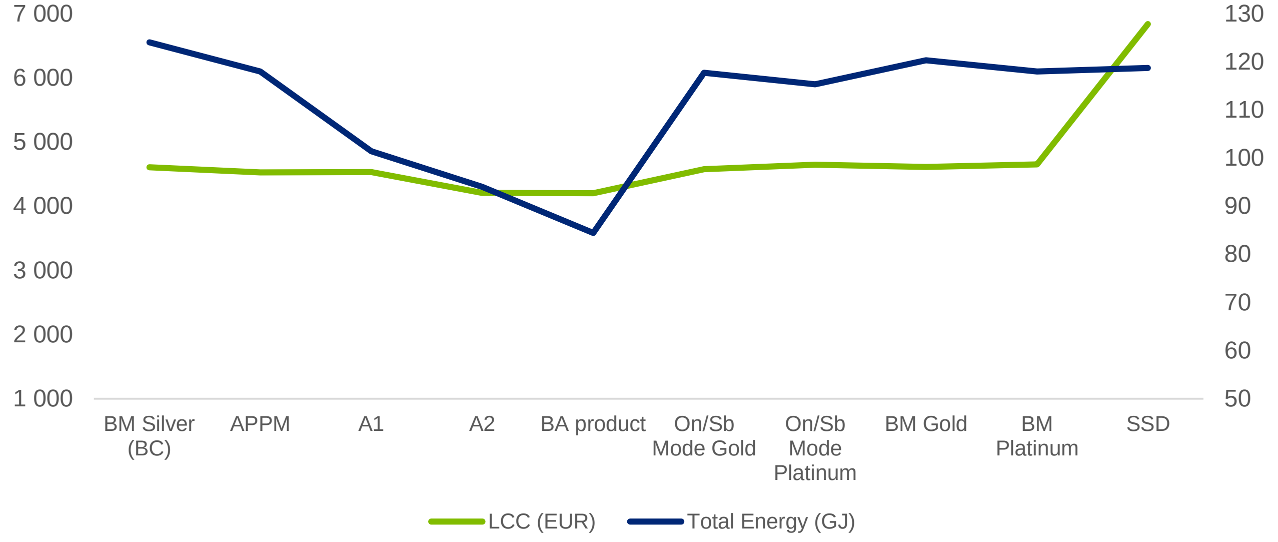


Figure 76: LCC curve for Base-Case 1

Above figure shows the LCC curve for the rack base case. The BA product, which is a combination of on/sb Mode Platinum PSU (DO-1.6), ASHRAE A2 (DO-4) and advanced processor power management (DO-5) is situated between the A2 design option and the on/sb mode Gold PSU. The SSD option takes the last place because of its high costs.

3.2.Base-Case 2: Blade System

The following table shows the simple payback period for different design options of BC-2:

Table 18: Simple Payback Period for design options of BC-2

	APPM	A1	A2	BA product	On/Sb Mode Gold	On/Sb Mode Platinum	On/Sb Mode Titanium	BM Titanium	BM Platinum	SSD
dPP (EUR)	0	0	0	1 280	280	860	1 280	1 280	860	9 395
dOE (EUR, per year)	159	602	798	1006	166	230	284	255	230	70
SPP (years)	0,0	0,0	0	1,2	1,7	3,7	4,5	5,0	3.7	134,1

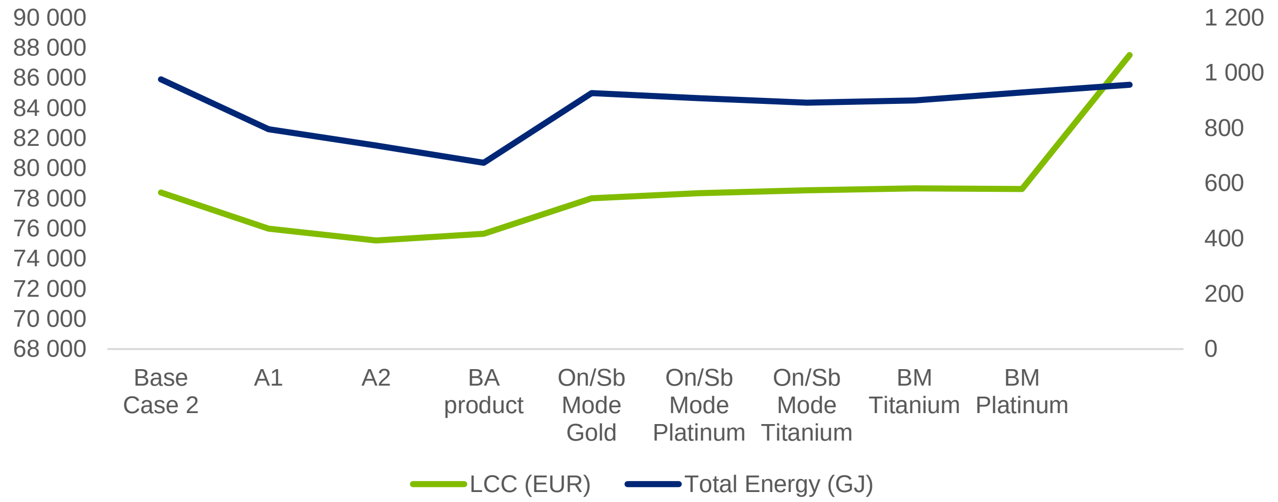


Figure 77: LCC curve for Base-Case 2

This figure shows the LCC curve for the second base case, a blade system with 8 blades. The Best Available product option, which in this case combines an on/sb mode titanium PSU under ASHRAE A2 conditions and additional advanced processor power management, finds itself embedded between the A2 option and the on/sb mode Gold PSU option. The SSD option is again economically not viable.

3.3.Base-Case 3 : Storage System

The following table shows the simple payback period for different design options of BC-3:

Table 19: Simple Payback Period for design options of BC-3

	Reuse	A1	A2	On/Sb Mode Platinum	BA product	BM Gold	BM Platinum	COMS	On/Sb Mode Titanium	BM Titanium
dPP (EUR)	0	0	0	630	3 800	360	630	2 300	1 500	1 500
dOE (EUR, per year)	0	149	198	57	324	24	39	137	73,97	62,96
SPP (years)	NA	0	0	11	12	15	16	17	20	24

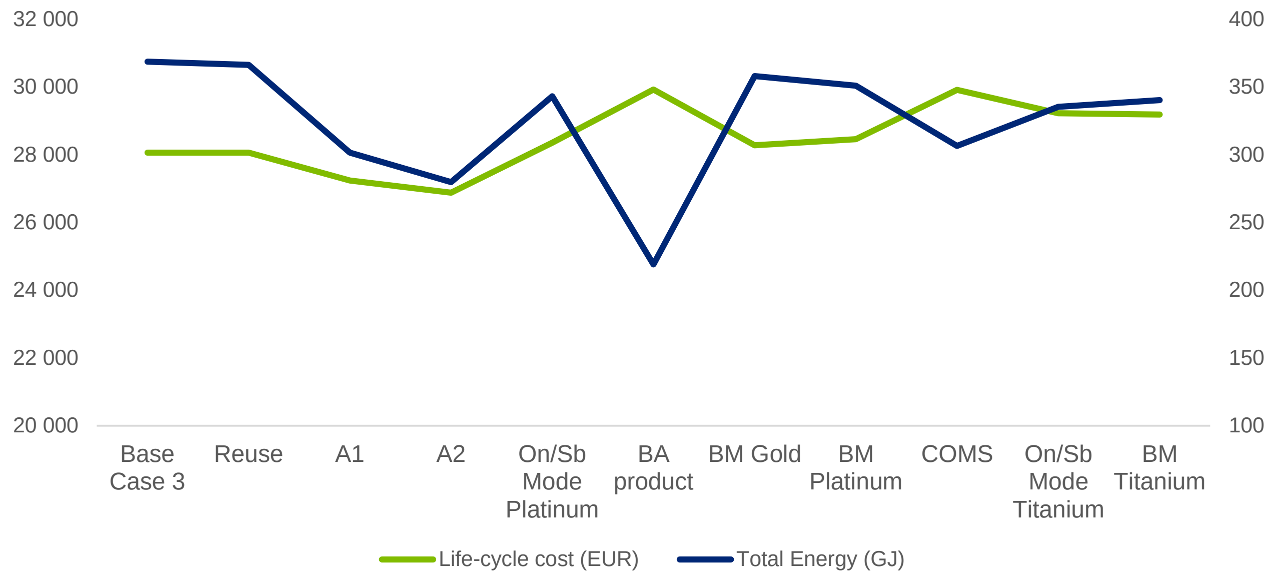


Figure 78: LCC curve for Base-Case 3

Above figure describes the LCC curve for the third base case, a storage system. The Best Available product is in this case an on/sb mode titanium PSU under ASHRAE A2 conditions and equipped with COMS. It finds itself between the on/sb mode platinum PSU option and the BM Gold PSU option. Because of the longer life-time, the SPP value is in general higher for the storage system as compared to the server base cases.

4. Long-term potential (BNAT) & systems analysis

The IT sector is changing at a very fast pace and Moore's Law keeps contributing strongly to periodical performance increases and related energy efficiency improvements. For this and other reasons the clear distinction between already implemented technology, BAT or BNAT is difficult to make and can change quickly. As mentioned in Task 4, some of BNAT candidates could be e.g. memory resistor technologies, 3D Memory RRAM, Heat Assisted Magnetic Recording (HAMR), Bit Patterned Media (BPM), optical I/O and mainboards, as well as long-term quantum computing, . However, it is far from clear with what kind of environmental performances and costs these products might enter the market and when. When it comes to the environmental footprint and energy consumption of a data centre, the improvement will not necessarily be made on a product level, but on a system level.

5.Conclusion

This task had the goal to quantitatively assess improvement options for each of the product Base-Cases, based on the improvement design described in Task 4. Several improvement options have been shown and quantified for each Base-Case. Combinations of these improvement options provide potential for significant energy savings, leading to a reduction of negative environmental impacts.

Throughout the study it has become clear that it is not enough to only concentrate on the environmental impact of a single physical product, but that within a data centre all the equipment is closely linked and interdependent. For this reason a slightly wider approach for the design options was chosen, taking into account options such as ASHRAE A1 and A2 or Capacity Optimisation Methods Software (COMS) for storage equipment. These two general options demonstrated a substantial improvement potential.

The EcoReport results show that from a life-cycle cost assessment point of view it is often worth to opt for a better 80 PLUS PSU category and that a lower PUE due to an allowance of somewhat higher inlet temperature conditions can lead to significant energy savings. Furthermore, advanced processor power management and COMS can decrease the environmental footprint and save costs. However, all options are highly specific and need to be assessed individually for the specific application.

We also demonstrated theoretically the positive energy saving effects of more completely configured products as well as a higher average utilization. Modular systems have considerable environmental benefits due to better performance scalability, maintenance, and platform refurbishment including the reuse of valuable components such storage drives.

SSDs are in general more energy efficient than HDDs but cannot substitute the latter due to different functionality and much higher costs for the time being. A reuse of storage devices might reduce increasing storage costs in future and improves the overall environmental impact.

Using the Ecoreport tool, it was not possible to show that an increase the reuse rate has significant impacts on the environmental indicators. However, this is most likely related to limitations of the applied methodology, which are explained in section 2.3.4. A parallel study conducted by the JRC-IES could show that the reuse of components into remanufactured servers implies significant environmental benefits in terms of avoided production of new components.

6.Annex

Outputs of the different design options for the three Base Cases

Base Case 1

Life-cycle indicators per unit	Unit	Base Case 1	BM Gold	BM Platinum	On/Sb Mode Gold	On/Sb Mode Platinum	SSD	A1	APPM	A2	BA product
Other resources and waste											
Total Energy (GER)	GJ	124,0	120,3	118,0	117,7	115,3	118,7	101,4	118,0	94,0	84,4
	Δ change with BC	0,0	-3,7	-6,1	-6,3	-8,7	-5,4	-22,7	-6,1	-30,1	-39,6
	% change with BC	0%	-3%	-5%	-5%	-7%	-4%	-18%	-5%	-24%	-32%
of which, electricity	primary GJ	122,4	118,7	116,3	116,1	113,7	117,1	99,7	116,3	92,4	82,9
	MWh	11,7	11,3	11,1	11,1	10,8	11,1	9,5	11,1	8,8	7,9
	Δ change with BC (MWh)	0,0	-0,4	-0,6	-0,6	-0,8	-0,5	-2,2	-0,6	-2,9	-3,8
	% change with BC	0%	-3%	-5%	-5%	-7%	-4%	-19%	-5%	-25%	-32%
Water (process)	kL	0,7	0,7	0,8	0,8	0,8	1,0	0,8	0,8	0,8	0,8
	% change with BC	0%	0%	10%	10%	10%	36%	10%	10%	9%	10%
Water (cooling)	kL	5,8	5,6	5,5	5,5	5,4	5,6	4,8	5,5	4,5	4,0
	% change with BC	0%	-3%	-5%	-5%	-7%	-4%	-17%	-5%	-23%	-30%
Waste, non-haz./ landfill	kg	79,7	77,5	76,9	76,8	75,5	78,4	68,3	76,9	64,8	59,6
	% change with BC	0%	-3%	-4%	-4%	-5%	-2%	-14%	-4%	-19%	-25%
Waste, hazardous/ incinerated	kg	2,6	2,5	2,8	2,8	2,8	3,2	2,5	2,8	2,4	2,3
	% change with BC	0%	-2%	8%	8%	6%	24%	-2%	8%	-7%	-13%
Emissions (Air)											
Greenhouse Gases in GWP100	t CO2 eq.	5,4	5,2	5,1	5,1	5,0	5,1	4,4	5,1	4,1	3,7
	% change with BC	0%	-3%	-5%	-5%	-7%	-4%	-18%	-5%	-24%	-32%
Acidification, emissions	kg SO2 eq.	24,4	23,7	23,3	23,2	22,8	23,6	20,2	23,3	18,7	16,9
	% change with BC	0%	-3%	-5%	-5%	-7%	-3%	-17%	-5%	-23%	-31%

Volatile Organic Compounds (VOC)	**kg**	2,7	2,6	2,5	2,5	2,5	2,6	2,2	2,5	2,0	1,8
	% change with BC	0%	-3%	-5%	-5%	-7%	-5%	-19%	-5%	-25%	-33%
Persistent Organic Pollutants (POP)	**µg i-Teq**	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,4
	% change with BC	0%	-3%	-3%	-4%	-5%	-5%	-11%	-3%	-13%	-18%
Heavy Metals	**g Ni eq.**	2,0	1,9	1,9	1,9	1,9	2,0	1,7	1,9	1,7	1,6
	% change with BC	0%	-2%	-3%	-3%	-4%	1%	-12%	-3%	-16%	-20%
PAHs	**g Ni eq.**	0,6	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
	% change with BC	0%	-1%	-2%	-2%	-3%	-14%	-9%	-2%	-13%	-17%
Particulate Matter (PM, dust)	**kg**	1,8	1,8	1,8	1,8	1,7	1,9	1,7	1,8	1,7	1,5
	% change with BC	0%	-1%	-1%	-1%	-2%	7%	-5%	-1%	-7%	-16%
Emissions (Water)											
Heavy Metals	**g Hg/20**	0,8	0,8	0,8	0,8	0,8	0,8	0,7	0,8	0,7	0,6
	% change with BC	0%	-10%	-9%	-9%	-10%	-4%	-17%	-9%	-21%	-26%
Eutrophication	**kg PO4**	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	% change with BC	0%	-4%	-4%	-4%	-6%	1%	-15%	-4%	-20%	-26%

Base Case 2

Life-cycle indicators per unit	Unit	Base Case 2	BM Platinum	BM Titanium	On/Sb Mode Platinum	On/Sb Mode Titanium	SSD	A1	APPM	A2	On/Sb Mode Gold	BA product
Other resources and waste												
Total Energy (GER)	**GJ**	976,3	928,5	899,8	907,5	891,2	956,4	795,8	928,5	736,9	926,6	674,5
	Δ change with BC	0,0	-47,8	-76,5	-68,9	-85,1	-19,9	-180,5	-47,8	-239,5	-49,7	-301,8
	% change with BC	0%	-5%	-8%	-7%	-9%	-2%	-18%	-5%	-25%	-5%	-31%
of which, electricity	**primary GJ**	968,3	920,5	891,8	899,4	883,2	948,6	787,8	920,5	728,9	918,6	666,5
	MWh	92,2	87,7	84,9	85,7	84,1	90,3	75,0	87,7	69,4	87,5	63,5
	Δ change with BC (MWh)	0,0	-4,6	-7,3	-6,6	-8,1	-1,9	-17,2	-4,6	-22,8	-4,7	-28,7
	% change with BC	0%	-5%	-8%	-7%	-9%	-2%	-19%	-5%	-25%	-5%	-31%
Water (process)	**kL**	3,1	3,1	3,1	3,1	3,1	3,8	3,1	3,1	3,1	3,1	3,1

	% change with BC	0%	0%	0%	0%	0%	22%	0%	0%	0%	0%	0%
Water (cooling)	**kL**	44,4	42,2	41,0	41,3	40,6	43,5	36,3	42,2	33,7	42,2	30,9
	% change with BC	0%	-5%	-8%	-7%	-9%	-2%	-18%	-5%	-24%	-5%	-30%
Waste, non-haz./ landfill	**kg**	629,6	604,9	590,1	594,1	585,7	623,3	536,5	604,9	506,2	603,9	474,0
	% change with BC	0%	-4%	-6%	-6%	-7%	-1%	-15%	-4%	-20%	-4%	-25%
Waste, hazardous/ incinerated	**kg**	18,4	17,7	17,2	17,3	17,1	19,7	15,6	17,7	14,6	17,6	13,7
	% change with BC	0%	-4%	-7%	-6%	-7%	7%	-15%	-4%	-21%	-4%	-26%
Emissions (Air)												
Greenhouse Gases in GWP100	**t CO2 eq.**	42,0	39,9	38,7	39,0	38,3	41,1	34,3	39,9	31,8	39,9	29,1
	% change with BC	0%	-5%	-8%	-7%	-9%	-2%	-18%	-5%	-24%	-5%	-31%
Acidification, emissions	**kg SO2 eq.**	188,4	179,4	174,0	175,4	172,3	185,1	154,3	179,4	143,2	179,0	131,4
	% change with BC	0%	-5%	-8%	-7%	-9%	-2%	-18%	-5%	-24%	-5%	-30%
Volatile Organic Compounds (VOC)	**kg**	21,4	20,4	19,7	19,9	19,5	21,0	17,4	20,4	16,1	20,3	14,7
	% change with BC	0%	-5%	-8%	-7%	-9%	-2%	-19%	-5%	-25%	-5%	-31%
Persistent Organic Pollutants (POP)	**µg i-Teq**	4,2	4,1	4,0	4,1	4,0	4,2	3,8	4,1	3,7	4,1	3,5
	% change with BC	0%	-3%	-4%	-4%	-5%	-2%	-10%	-3%	-13%	-3%	-17%
Heavy Metals	**g Ni eq.**	13,2	12,7	12,4	12,5	12,4	13,3	11,4	12,7	10,8	12,7	10,2
	% change with BC	0%	-4%	-6%	-5%	-7%	0%	-14%	-4%	-18%	-4%	-23%
PAHs	**g Ni eq.**	3,3	3,2	3,2	3,2	3,1	3,0	2,9	3,2	2,8	3,2	2,6
	% change with BC	0%	-3%	-5%	-5%	-6%	-11%	-13%	-3%	-17%	-3%	-21%
Particulate Matter (PM, dust)	**kg**	10,4	10,2	10,1	10,1	10,1	10,8	9,7	10,2	9,4	10,2	9,2
	% change with BC	0%	-2%	-3%	-3%	-3%	4%	-7%	-2%	-9%	-2%	-12%
Emissions (Water)												
Heavy Metals	**g Hg/20**	5,3	5,1	5,0	5,0	4,9	5,2	4,5	5,1	4,3	5,1	4,0
	% change with BC	0%	-4%	-6%	-6%	-7%	-2%	-15%	-4%	-19%	-4%	-24%
Eutrophication	**kg PO4**	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,1
	% change with BC	0%	-4%	-7%	-6%	-8%	0%	-17%	-4%	-22%	-5%	-28%

Base Case 3

Life-cycle indicators per unit	Unit	Base Case 3	BM Platinum	BM Titanium	On/Sb Mode Platinum	On/Sb Mode Titanium	COMS	A1	Reuse	A2	BM Gold	BA product
Other resources and waste												
Total Energy (GER)	**GJ**	368,6	350,9	340,3	343,1	335,3	306,5	301,4	366,2	279,6	358,0	218,9
	Δ change with BC	0,0	-17,7	-28,3	-25,5	-33,3	-62,1	-67,1	-2,4	-88,9	-10,6	-149,7
	% change with BC	0%	-5%	-8%	-7%	-9%	-17%	-18%	-1%	-24%	-3%	-41%
of which, electricity	**primary GJ**	363,8	346,1	335,5	338,3	330,5	301,9	296,7	362,2	274,9	353,2	215,3
	MWh	34,7	33,0	32,0	32,2	31,5	28,8	28,3	34,5	26,2	33,6	20,5
	Δ change with BC (MWh)	0,0	-1,7	-2,7	-2,4	-3,2	-5,9	-6,4	-0,2	-8,5	-1,0	-14,1
	% change with BC	0%	-5%	-8%	-7%	-9%	-17%	-18%	0%	-24%	-3%	-41%
Water (process)	**kL**	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,0	2,5	2,5	1,7
	% change with BC	0%	0%	0%	0%	0%	-1%	0%	-18%	0%	0%	-31%
Water (cooling)	**kL**	16,6	15,8	15,3	15,5	15,1	13,8	13,6	16,5	12,6	16,1	9,9
	% change with BC	0%	-5%	-8%	-7%	-9%	-17%	-18%	-1%	-24%	-3%	-40%
Waste, non-haz./ landfill	**kg**	231,8	222,7	217,2	218,6	214,6	199,5	197,2	224,4	186,0	226,3	148,0
	% change with BC	0%	-4%	-6%	-6%	-7%	-14%	-15%	-3%	-20%	-2%	-36%
Waste, hazardous/ incinerated	**kg**	7,2	6,9	6,7	6,7	6,6	6,1	6,1	6,9	5,7	7,0	4,3
	% change with BC	0%	-4%	-6%	-6%	-7%	-15%	-15%	-4%	-20%	-2%	-39%
Emissions (Air)												
Greenhouse Gases in GWP100	**t CO2 eq.**	15,9	15,2	14,7	14,9	14,5	13,3	13,1	15,8	12,1	15,5	9,5
	% change with BC	0%	-5%	-8%	-7%	-9%	-17%	-18%	-1%	-24%	-3%	-40%
Acidification, emissions	**kg SO2 eq.**	73,0	69,6	67,6	68,2	66,7	61,2	60,3	71,9	56,2	71,0	43,7
	% change with BC	0%	-5%	-7%	-7%	-9%	-16%	-17%	-1%	-23%	-3%	-40%
Volatile Organic Compounds (VOC)	**kg**	7,9	7,5	7,3	7,4	7,2	6,6	6,4	7,9	6,0	7,7	4,7
	% change with BC	0%	-5%	-8%	-7%	-9%	-17%	-19%	0%	-25%	-3%	-41%
Persistent Organic Pollutants (POP)	**µg i-Teq**	1,5	1,4	1,4	1,4	1,4	1,3	1,3	1,4	1,3	1,4	1,0
	% change with BC	0%	-3%	-4%	-4%	-5%	-10%	-11%	-6%	-14%	-2%	-29%
Heavy Metals	**g Ni eq.**	6,2	6,1	6,0	6,0	5,9	5,6	5,6	5,8	5,3	6,1	4,0

	% change with BC	0%	-3%	-5%	-4%	-5%	-10%	-11%	-7%	-14%	-2%	-35%
PAHs	**g Ni eq.**	1,7	1,7	1,7	1,7	1,7	1,5	1,6	1,6	1,5	1,7	1,1
	% change with BC	0%	-2%	-4%	-3%	-4%	-14%	-9%	-9%	-12%	-1%	-36%
Particulate Matter (PM, dust)	**kg**	6,0	5,9	5,9	5,9	5,8	5,7	5,7	5,2	5,6	5,9	4,0
	% change with BC	0%	-1%	-2%	-2%	-2%	-4%	-5%	-13%	-6%	-1%	-32%
Emissions (Water)												
Heavy Metals	**g Hg/20**	2,5	2,4	2,4	2,4	2,3	2,2	2,2	2,3	2,1	2,4	1,6
	% change with BC	0%	-3%	-5%	-4%	-6%	-12%	-12%	-7%	-15%	-2%	-36%
Eutrophication	**kg PO4**	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
	% change with BC	0%	-4%	-6%	-6%	-7%	-14%	-15%	-3%	-20%	-2%	-38%