Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 29– Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under Lot 11) – Task 7: Improvement potential

Final report to the European Commission, DG ENER
28 March 2014

European Commission

Developed by:
bio by Deloitte.
ATKINS

Document information

CLIENT	European Commission, DG ENER
CONTRACT NUMBER	ENER/C3/403/2010
REPORT TITLE	ENER Lot 29– Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under Lot 11) – Task 7: Improvement potential
PROJECT NAME	Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC
PROJECT CODE	ENER Lot 28
PROJECT TEAM	BIO Intelligence Service, Atkins
DATE	28 March 2014
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Please cite this publication as:
BIO Intelligence Service (2014), Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC, ENER Lot 29– Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under Lot 11) – Task 7: Improvement potential prepared for. European Commission, DG ENER

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Task 7 Improvement Potential

Task 7 quantitatively analyses design improvement options, based on the Best Available Technologies (BATs) described in Task 6 for each of the product Base-Cases. The environmental impacts of each of these options are calculated by using the MEEuP EcoReport tool. The economic impacts of each design are assessed in terms of Life Cycle Cost (LCC). The assessment of LCC is relevant as it indicates whether the design solutions may impact the cost to users over the total lifetime of the product (purchase, operating, end-of-life costs, etc.). The assessment of both environmental and economic impacts allows the identification of the design improvement with the Least Life Cycle Costs (LLCC) and that results in the most significant reductions in environmental impacts. The Best Not yet Available Technologies (BNAT) are also discussed, assessing long-term improvement potential of the products.

7.1 Identification of design options

This section presents the different improvement options applicable to each Base-Case. The design option(s) should:

- Do not result in significant variation in the functionality and the performance parameter of the pumps compared to the Base-Cases
- Have a significant potential for improvement in the environmental performance
- Not entail excessive costs and impacts on the manufacturer.

For each of the improvement options, the modifications implied by their implementation in the Base-Case are quantified by the change in energy consumption. The potential of a particular improvement option or a combination of them is evaluated by using the MEEuP EcoReport tool. The cost effectiveness of an improvement option is expressed in terms of payback time in years, defined as a ratio between:

$$\frac{\Delta(\text{investment})}{\Delta(\text{annual running costs})}$$

Where "investment" includes the purchase and installation costs and "annual running costs" include the cost of the energy consumed and the costs of repair and maintenance. In the case of annual running costs higher than the original product, the return of the investment would not be possible. In some cases the payback time is longer than the lifetime of the product, which would prevent the implementation of the improvement option.

The following sections show the possible energy savings and cost increase of each of the improvement options presented in Task 6 for the pumps in Lot 29. The energy savings and costs estimated in Task 6 serve to calculate the payback time as per the formula shown above. The environmental impacts and the economic impacts of each of the improvement options are then calculated by using the EcoReport tool presented in Task 5.

7.1.1 Base-Case 1: Domestic swimming pool pump with built-in strainer up to 2.2 kW

Task 5 identified that reducing total energy consumption during use would be an effective way to also reduce the overall environmental impacts of a domestic swimming pool pump. Task 6 identified the improvement options that aim to reduce the total energy consumption. Each of the improvement options applicable to domestic swimming pool pumps are presented here with their relative impact of their implementation on a real product in the market. These savings are however contested by some EU pumps manufacturers.

Table 7-1 presents the summary of the selected improvement options.

Option 3 and option 4 provide the highest electricity savings of all the individual improvement options compared to the base-case, but also very long payback times. These options involve using Variable Speed Drives (VSD) in order to achieve energy savings via the reduction in friction losses in the system. It also allows finer controls which make the heating, filter backwashing, disinfection and general circulation all to have different operating flow speeds. This has the effect of reducing pump power consumption and improving filtration efficiency. These savings are however contested by some EU pumps manufacturers.

Table 7-1: Identified energy savings potentials for BC-1: Domestic swimming pool pumps with built-in strainer up to 2.2 kW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-22	7	0	0	2.9
Option 2 (OP2)	Motor improvements	-7	7	0	0	9.1
Option 3 (OP3)	VSD	-144	660	50	0	44.8
Options 4 (OP1+OP2+OP3)	Pump/hydraulic, motor and VSD improvements	-173	674	50	0	38.0

7.1.2 Base-Case 2: Domestic/Commercial swimming pool pumps with built-in strainer over 2.2 kW

The selected improvement options for domestic/commercial swimming pool pumps with built-in strainer over 2.2 kW do not differ from those analysed in the previous section for domestic swimming pool pumps. The use of VSD is also in this case the option that offers the biggest savings in energy consumption of all the other options. In this case, the energy savings are higher and therefore the payback time is lower. Another possible alteration is the inclusion of two speed controllers, which operate the pumps at half-speed when there is not a demand for full speed operation from the heating or filter backwash systems. However, some systems running pumps at half speed do not provide sufficient head to overcome the system losses, resulting to very low flow conditions. Table 7-2 shows the potential electricity savings, price increase and payback times for each of the design options selected.

Table 7-2: Identified energy savings potentials for BC-2: Domestic/commercial swimming pool pumps with built-in strainer over 2.2 kW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulics improvements	-304	30	0	-1	0.9
Option 2 (OP2)	Motor improvements	-101	30	0	-1	2.5
Option 3 (OP3)	VSD	-8 100	1500	50	3	1.7
Option 4 (OP1+OP2+OP3)	Pump/hydraulic, motor and VSD improvements	-8 505	1560	50	1	1.7

7.1.3 Base-Case 3: Fountain and pond pumps up to 1 kW

The summary of potential design improvements for Fountain and Pond pumps up to 1kW can be seen in Table 7-3. As seen in the table, the option that provides the highest savings in energy consumption within a feasible payback time is option 1. The pumps with integral filters have a higher efficiency as they avoid losses associated with the connector hose. However, as with swimming pool pumps, the losses associated with the filter will depend on the size of the filter being used; being those with the largest open area the most efficient This has to be balanced against the fact that strainers with larger open areas, may not be able to filter smaller solids or may be structurally weaker.

Table 7-3: Identified energy savings potentials for BC-3: Fountain and pond pump up to 1 kW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulics improvements	-2.2	2	0	0	8.3
Option 2 (OP2)	Motor improvements	-0.7	2	0	0	26.0
Option 3 (OP1+OP2)	Pump/hydraulic and Motor improvements	-2.9	4	0	0	12.5

7.1.4 Base-Case 4&5: Aquarium pumps (domestic/small aquarium non-commercial) up to 120 W and aquarium pumps power head to 120 W

Looking at the improvement potentials of the various options for aquarium pumps in Table 7-4, the pump/hydraulic improvements seem to give the highest savings in energy consumption of all the other not-combined options. The pump/filter plays a vital role in the aquarium ecosystem and must operate continuously 24/7, which means that improvement modifications made to this component will result in reducing energy consumption. However, the payback time of the improvement options for aquarium pumps are long.

Over the last decade, there have been great efforts to optimise the hydraulic design with the view to improving the performance and get further reduction of energy consumption. These modifications are able to guarantee the correct direction of rotation without using electronics that controls the start-up phase of the pump.

Table 7-4: Identified energy savings potentials for BC-4&5: Aquarium pumps (domestic/small aquarium non-commercial) up to 120 W and aquarium power head to 120 W

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-0.8	1	0	0	11.4
Option 2 (OP2)	Motor improvements	-0.3	1	0	0	30.3
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	-1.1	2	0	0	16.5

7.1.5 Base-Case 6: Spa pumps for domestic & commercial spas

Looking at the improvement potentials of the various options for spa pumps in Table 7-5, similar performance enhancements to the hydraulic performance could be achieved as those for swimming pool pumps. These pumps are generally smaller than the pumps used for domestic swimming pools and therefore, have a slightly lower overall efficiency. As in swimming pool pumps, spa pumps have good hydraulic performance as the body is made from plastic materials, which are smooth and can be made with tight tolerances. Improvements on the motor would entail an increase of the maintenance costs without much energy savings, which means that it would not be possible to get a return of the investment.

Table 7-5: Identified energy savings potentials for BC-6: Spa pumps for domestic and commercial spas

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-4.6	0	0	0	0.0
Option 2 (OP2)	Motor improvements	-4.6	6	0	1	No return of investment possible
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	-9.2	6	0	1	25.9

7.1.6 Base-Case 7: Counter-current pumps

The selected improvement options for counter-current pumps do functions in the same way as those analysed in the previous section on spa pumps. As said before, counter-current pumps work as swimming pool pumps and have the same hydraulic performance. However, they are generally not provided with an inlet filter basket, but they do have strainers on the upstream end of the water inlet pipe-work, which does reduce the overall efficiency of the pumps.

Table 7-6 shows the potential electricity savings, price increase and payback times for each of the design options selected. The improvements achieved are insignificant and would not justify the cost increase.

Table 7-6: Identified energy savings potentials for BC-7: Counter-current pumps

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Pump/hydraulic improvements	-1	0	0	0	0.0
Option 2 (OP2)	Motor improvements	-1	27	125	1	No return of investment possible
Option 3 (OP1+OP2)	Pump/hydraulic and motor improvements	-2	27	125	1	No return of investment possible

7.1.7 Base-Case 8: End-Suction Close Coupled pumps from 150 kW to 1 MW

The summary of potential design improvements for End-Suction close coupled pumps from 150 kW to 1 MW pumps can be seen in Table 7-7.

As can be seen in the table, the VSD option offers the highest energy savings but the improvements of the hydraulic efficiency offers the shortest payback time. For example, modifications in the geometry of the impeller and the casing will increase the efficiency and will result in electricity savings but the head stability would have to be sacrificed. Nevertheless, it is expected that the increase in sales due to the higher efficiency will balance out the decrease in sales, due to the lower performance in other areas.

Apart from positive effects such as electricity savings and efficiency improvements, design options can have negative effects, which would have to be considered. For example, reducing the surface friction may result in high costs and time-consuming operations and reducing leakages will lead to an increase in costs and require tighter manufacturing tolerances.

Table 7-7: Identified energy savings potentials for BC-8: End-Suction Close Coupled pumps from 150 kW to 1 MW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-6 480	200	0	-10	0.3
Option 2 (OP2)	VSD	-81 000	16 000	2 000	0	2.0
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-87 480	16 200	2 000	-10	1.9

7.1.8 Base-Case 9: End-Suction Close Coupled Inline from 150 kW to 1 MW

The selected improvement options for End-Suction close coupled inline from 150 kW to 1 MW pumps do not differ from those analysed in the previous section. As mentioned before, for example, modifications in the geometry of the impeller and the casing will increase the efficiency and will result in electricity savings. As in end-suction close-coupled pumps, design options can have negative effects, which would have to be considered. For example, reducing the surface friction may result in high costs and time-consuming operations and reducing leakages will lead to an increase in costs and require tighter manufacturing tolerances.

Table 7-8: Identified energy savings potentials for BC-9: End-Suction Close Coupled Inline from 150 kW to 1 MW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-6 480	200	0	0	0.3
Option 2 (OP2)	VSD	-81 000	16 000	2 000	0	2.0
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-87 480	16 200	2 000	0	1.9

7.1.9 Base-Case 10: End-suction own bearing water pumps from 150 kW to 1 MW

The summary of potential design improvements for End-Suction own bearing water pumps from 150 kW to 1 MW can be seen in Table 7-9. As can be seen in the table, the VSD option offers the largest potential energy savings.

In terms of surface friction reduction, the inner surfaces should be as smooth as possible, but the mechanical, methods of smoothing the rough cast interiors of impellers in iron or bronze are time-consuming and not entirely effective due to inaccessibility. Where good access is possible, a cast iron impeller can be coated with a smooth resin, although this is costly and rarely implemented.

Table 7-9: Identified energy savings potentials for BC-10: End-Suction Own Bearing from 150 kW to 1 MW

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-11 700	250	0	0	0.2
Option 2 (OP2)	VSD	-146 250	17 500	2 000	0	1.2
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-157 950	17 750	2 000	0	1.1

7.1.10 Base-Case 11: Submersible borehole pumps

The summary of potential design improvements for submersible borehole pumps can be seen in Table 7-10.

As can be seen in the table, the VSD option is the largest potential energy saving option, but the longest payback time. Option 1 offers the possibility of improving the hydraulics, this way, by increasing the number of stages and increasing the stage width it would be possible to increase the stage efficiency and in many cases, increase the pump efficiency for a given duty. Another example is the use of plastic and sheet metal hydraulic components to reduce the surface friction and this way to improve the efficiency of the pump.

Table 7-10: Identified energy savings potentials for BC-11: Submersible borehole pumps

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-2 108	109	0	0	0.5
Option 2 (OP2)	VSD	-42 168	5 835	972	0	1.5
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-44 276	5 944	972	0	1.4

7.1.11 Base-Case 12: Vertical multistage pumps

The summary of potential design improvements for vertical multistage pumps can be seen in Table 7-11.

As can be seen in the table and the section before, the VSD option offers the largest potential energy savings but the longer payback time. Option 1 achieves improvement modification in the Hydraulic design. This modification requires for a given duty that the number of pump stages is minimised and the stage length reduced. Another way to improve the efficiency would be by using outward flow diffusers (pumps use inward flow diffusers, usually). The pump diameter would increase and, in some cases, so would the stage length. However, if the pumps become taller they may need to be made sturdier.

Table 7-11: Identified energy savings potentials for BC-12: Vertical multistage pumps

Improvement Options	Description	Energy consumption change at product level [kWh/year]	Purchase price change at product level [€]	Installation price change at product level[€]	Repair & maintenance costs change at product level [€/year]	Payback time at product level (years)
Option 1 (OP1)	Improved hydraulics	-2 461	302	0	0	1.1
Option 2 (OP2)	VSD	-49 212	6 762	960	0	1.4
Option 3 (OP1+OP2)	Pump/hydraulic improvements and VSD	-51 673	7 064	960	0	1.4

7.2 Analysis BAT and LLCC

The design option(s) identified in the technical, environmental and economic analyses in Task 6 are ranked to identify the design improvement option with the least cycle environmental impacts and the least Life Cycle Costs (LLCC). Constructing an energy-LCC-curve (Y-axis= energy consumed and LCC, X-axis=options) allows the LLCC and BATs to be identified[1].

The performance of each improvement option will be compared using the Base-Case presented in Task 5 as reference. The comparison is made in terms of primary energy consumption and LCC.

LLC is the sum of the product price, costs of energy, and the costs of installation and maintenance as described in Task 5 and Task 6.

7.2.1 Base-Case 1: Domestic swimming pool pump with built-in strainer up to 2.2 kW

An environmental and economic assessment was carried out for each improvement option relevant for Domestic swimming pool pumps with built-in strainers up to 2.2 kW using the EcoReport tool. Outcomes of this, taking into account the whole life cycle, are provided in Table 7-12 with absolute values (in units) and variations (in %) compared with the Base-Case.

Design improvement options

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

[1] This is usually the last data point of the curve showing the product design with the lowest environmental impact, irrespective of the price.

Table 7-12: Environmental impacts of the BC-1 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 1	Option 1	Option 2	Option 3	Option 4
Total Energy (GER)	GJ	303.9	299.3	302.5	273.7	264.6
	% change with BC	0%	-2%	0%	-10%	-13%
Of which, electricity	Primary GJ	302.6	298.0	301.2	272.4	263.3
	Final MWh	28.8	28.4	28.7	25.9	25.1
	% change with BC	0%	-2%	0%	-10%	-13%
Water (process)	kL	20.2	19.9	20.1	18.2	17.6
	% change with BC	0%	-2%	0%	-10%	-13%
Water (cooling)	kL	806.6	794.3	802.7	726.0	701.8
	% change with BC	0%	-2%	0%	-10%	-13%
Waste, non-haz./ landfill	kg	401.1	395.8	399.4	366.1	355.5
	% change with BC	0%	-1%	0%	-9%	-11%
Waste, hazardous/ incinerated	kg	11.1	11.0	11.1	10.4	10.2
	% change with BC	0%	-1%	0%	-6%	-8%
Greenhouse Gases in GWP100	t CO_2 eq.	13.3	13.1	13.2	12.0	11.6
	% change with BC	0%	-2%	0%	-10%	-13%
Acidification, emissions	Kg SO_2 eq.	78.6	77.5	78.3	70.9	68.5
	% change with BC	0%	-2%	0%	-10%	-13%
Volatile Organic Compounds (VOC)	kg	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-10%	-12%
Persistent Organic Pollutants (POP)	µg i-Teq	2.2	2.2	2.2	2.0	2.0
	% change with BC	0%	-1%	0%	-9%	-12%
Heavy Metals to air	g Ni eq.	5.5	5.4	5.4	4.9	4.8
	% change with BC	0%	-1%	0%	-10%	-12%
PAHs	g Ni eq.	0.6	0.6	0.6	0.6	0.6
	% change with BC	0%	-1%	0%	-9%	-12%
Particulate Matter (PM, dust)	kg	2.5	2.5	2.5	2.4	2.3
	% change with BC	0%	-1%	0%	-7%	-9%
Heavy Metals to water	g Hg/20	2.0	2.0	2.0	1.8	1.8
	% change with BC	0%	-1%	0%	-10%	-13%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-8%	-10%
Life-cycle cost	€	2,732.7	2,713.6	2,736.0	3,234.2	2,671.4
	% change with BC	0%	-1%	0%	18%	-2%

The analysis of these figures shows that option 4 achieves the lowest environmental impacts when compared to the Base-Case. This option achieves the lowest primary consumption of all the options presented. Options 3 is the second to achieve the highest energy consumption reduction.

The share of LCC for the Base-Case and the improvements options is shown in Figure 7-1. The electricity costs are the highest share of the LCC, and the second greatest expenses are the purchase price of the pump.

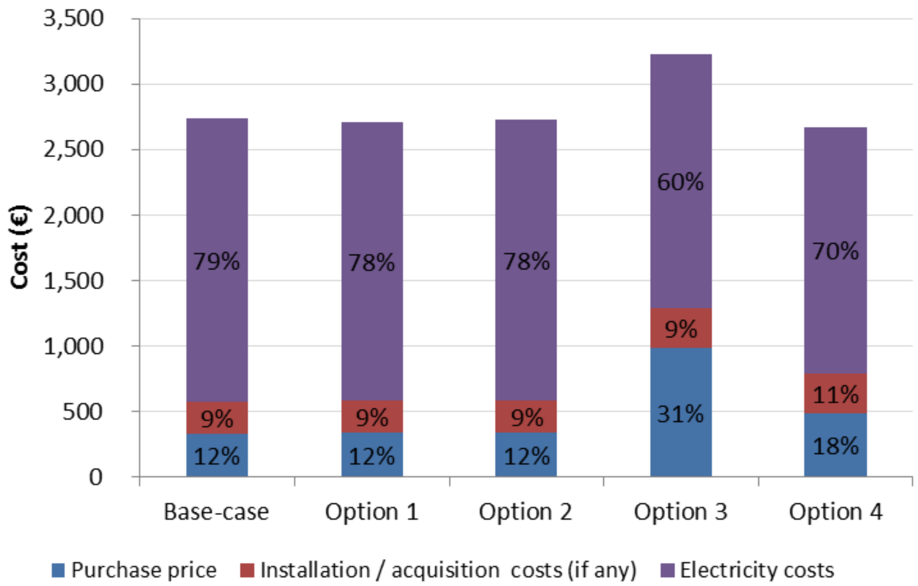

Figure 7-1: Life cycle costs of the improvement options for BC-1

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

Figure 7-2 presents the comparison between primary energy consumption and life cycle costs of the Base-Case and its design options. The least cycle cost option is option 4, which is also the BAT option. This option allows 12% of energy savings.

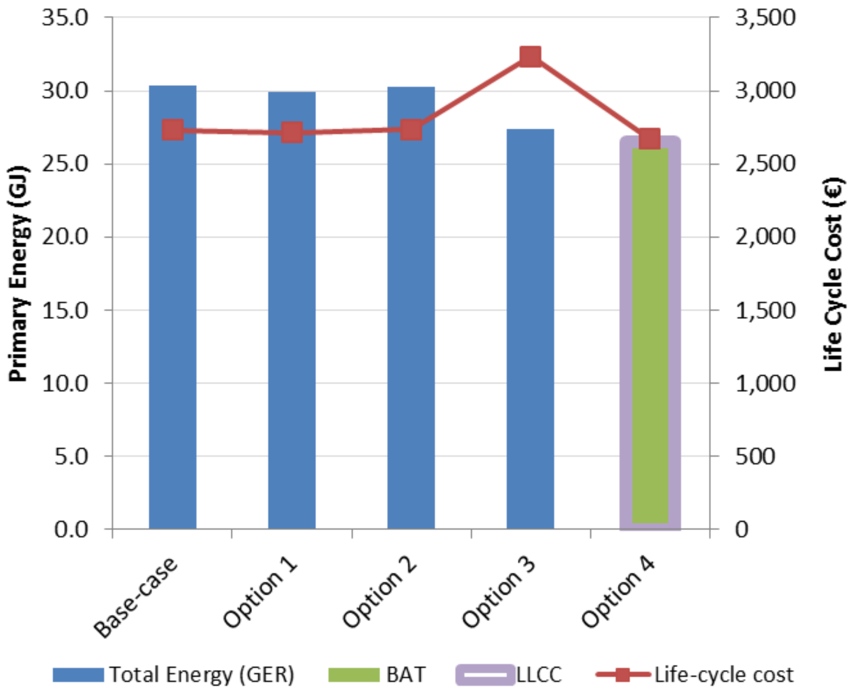

Figure 7-2: Identification of design improvement options with the least energy consumption and LLCC for BC-1

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

7.2.2 Base-Case 2: Domestic/Commercial swimming pool pumps with built-in strainer over 2.2 kW

Table 7-13 shows the environmental and economic impacts of the improvement options selected for BC2. Option 3 achieves a significant reduction in primary energy consumption, but is the Option 4 (i.e. the combination of options 1+2+3), which achieves the highest reduction in environmental impacts related to the Base-Case. The option with lower environmental impacts is option 2. The lowest life cycle cost is also achieved with the combination of options 1 to 3.

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

Table 7-13: Environmental impacts of the BC-2 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 2	Option 1	Option 2	Option 3	Option 4
Total Energy (GER)	GJ	4,254.5	4,190.6	4,233.3	2,553.5	2,043.2
	% change with BC	0%	-2%	0%	-40%	-52%
Of which, electricity	Primary GJ	4,252.8	4,188.9	4,231.6	2,551.8	2,041.5
	Final MWh	405.0	398.9	403.0	243.0	1,94.4
	% change with BC	0%	-2%	0%	-40%	-52%
Water (process)	kL	283.6	279.3	282.1	170.2	136.1
	% change with BC	0%	-2%	0%	-40%	-52%
Water (cooling)	kL	11,340.2	11,170.0	11,283.6	6,804.2	5,443.4
	% change with BC	0%	-2%	0%	-40%	-52%
Waste, non-haz./ landfill	kg	5,000.8	4,926.7	4,976.2	3,028.5	2,436.9
	% change with BC	0%	-1%	0%	-39%	-51%
Waste, hazardous/ incinerated	kg	100.4	99.0	100.0	61.3	49.5
	% change with BC	0%	-1%	0%	-39%	-51%
Greenhouse Gases in GWP100	t CO2 eq.	185.7	182.9	184.8	111.5	89.2
	% change with BC	0%	-2%	0%	-40%	-52%
Acidification, emissions	Kg SO2 eq.	1,096.0	1,079.5	1,090.5	658.0	526.6
	% change with BC	0%	-1%	0%	-40%	-52%
Volatile Organic Compounds (VOC)	kg	1.6	1.6	1.6	1.0	0.8
	% change with BC	0%	-1%	0%	-40%	-52%
Persistent Organic Pollutants (POP)	µg i-Teq	28.4	27.9	28.2	17.2	13.9
	% change with BC	0%	-1%	0%	-39%	-51%
Heavy Metals to air	g Ni eq.	73.3	72.2	72.9	44.1	35.4
	% change with BC	0%	-1%	0%	-40%	-52%
PAHs	g Ni eq.	8.4	8.3	8.4	5.1	4.1
	% change with BC	0%	-1%	0%	-40%	-52%
Particulate Matter (PM, dust)	kg	24.6	24.3	24.5	15.3	12.5
	% change with BC	0%	-1%	0%	-38%	-49%
Heavy Metals to water	g Hg/20	27.5	27.1	27.4	16.6	13.3
	% change with BC	0%	-1%	0%	-40%	-52%
Eutrophication	Kg PO4	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-39%	-51%
Life-cycle cost	€	32,952.0	32,526.8	32,830.3	22,395.0	17,633.9
	% change with BC	0%	-1%	0%	-32%	-46%

Figure 7-3 shows the different shares of consumer expenditure throughout the life cycle of BC2 and the design options. For all the cases, the electricity costs have the highest share (between 81% and 92% of the total).

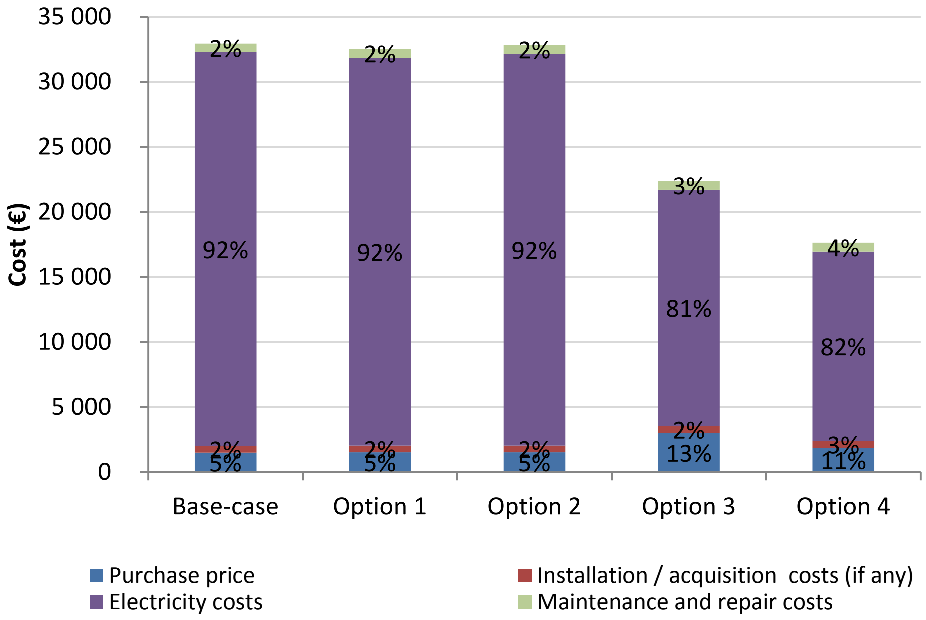

Figure 7-3: Life cycle costs of the improvement options for BC-2

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

Figure 7-4 presents the comparison between LCC and primary energy consumption of BC2 and its design options. The Option 4 is the option with the lowest energy consumption and LLCC. This combination of options presents the LCC 44% lower than the Base-Case and the primary energy consumption as 52% lower than the Base-Case.

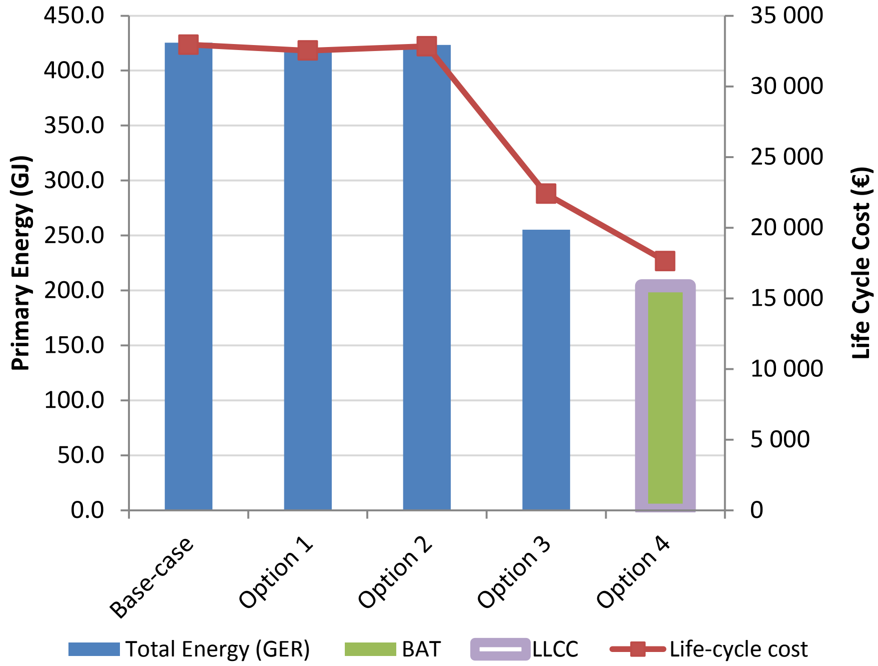

Figure 7-4: Identification of design improvement options with the least energy consumption and LLCC for BC-2

Option 1	Option 2	Option 3	Option 4
Pump/hydraulic improvements	Motor improvements	VSD	Pump/hydraulic, motor and VSD improvements

7.2.3 Base-Case 3: Fountain and pond pumps up to 1 kW

The results of the environmental analysis of the different designs options for BC3 are presented in Table 7-14. Option 1 shows to have reductions in the environmental impacts compare to the Base-Case but is the combination option 3 that shows the most optimal results regarding environmental impacts.

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Table 7-14: Environmental impacts of the BC-3 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 3	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	14.0	13.8	13.9	13.7
	% change with BC	0%	-1%	0%	-2%
Of which, electricity	Primary GJ	13.7	13.5	13.6	13.4
	Final MWh	1.3	1.3	1.3	1.3
	% change with BC	0%	-2%	0%	-2%
Water (process)	kL	0.9	0.9	0.9	0.9
	% change with BC	0%	-1%	0%	-2%
Water (cooling)	kL	36.4	35.8	36.2	35.6
	% change with BC	0%	-2%	0%	-2%
Waste, non-haz./ landfill	kg	27.0	26.8	27.0	26.7
	% change with BC	0%	-1%	0%	-1%
Waste, hazardous/ incinerated	kg	1.1	1.1	1.1	1.1
	% change with BC	0%	0%	0%	-1%
Greenhouse Gases in GWP100	t CO2 eq.	0.6	0.6	0.6	0.6
	% change with BC	0%	-1%	0%	-2%
Acidification, emissions	Kg SO2 eq.	3.7	3.7	3.7	3.6
	% change with BC	0%	-1%	0%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-2%
Persistent Organic Pollutants (POP)	µg i-Teq	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-1%
Heavy Metals to air	g Ni eq.	0.3	0.3	0.3	0.3
	% change with BC	0%	-1%	0%	-2%
PAHs	g Ni eq.	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Particulate Matter (PM, dust)	kg	0.3	0.3	0.3	0.3
	% change with BC	0%	0%	0%	-1%
Heavy Metals to water	g Hg/20	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-2%
Eutrophication	Kg PO4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	-1%
Life-cycle cost	€	217.9	218.1	219.3	219.6
	% change with BC	0%	0%	1%	1%

Figure 7-5 shows the different shares of life cycle costs throughout the life cycle of BC3 and the design options. For all the cases, the electricity costs have the highest share (between 53% and 54% of the total). The purchase price has the second highest share (between 46% and 47% of the total).

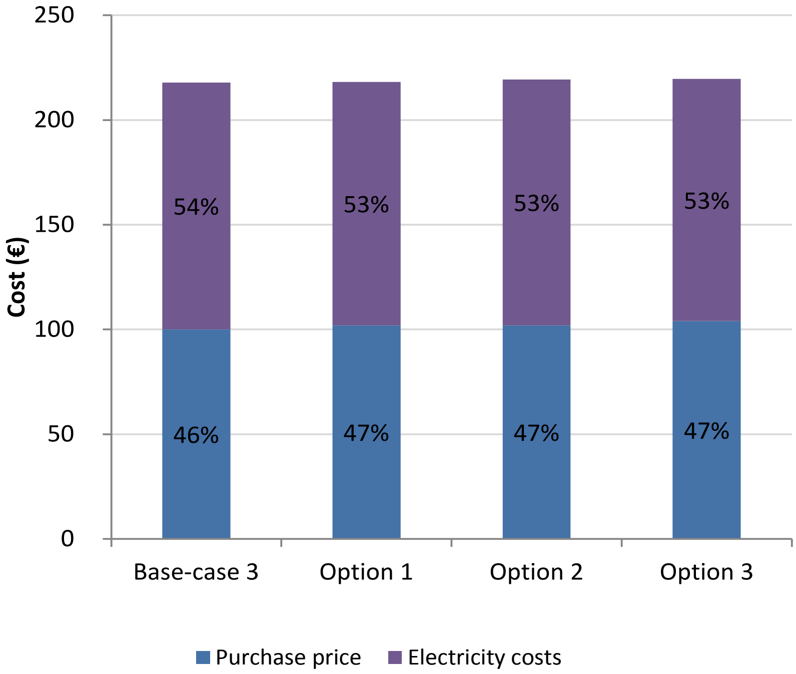

Figure 7-5: Life cycle costs of the improvement options for BC-3

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Figure 7-6 presents the comparison between LCC and the primary energy consumption for BC3 and the design options. For this Base-Case, the Option 3 (i.e. combination of options 1+2) is the BAT, achieving 2% energy savings but has an increase of 1% in life cycle costs. The LLCC is the base case although the cost savings are only 1%.

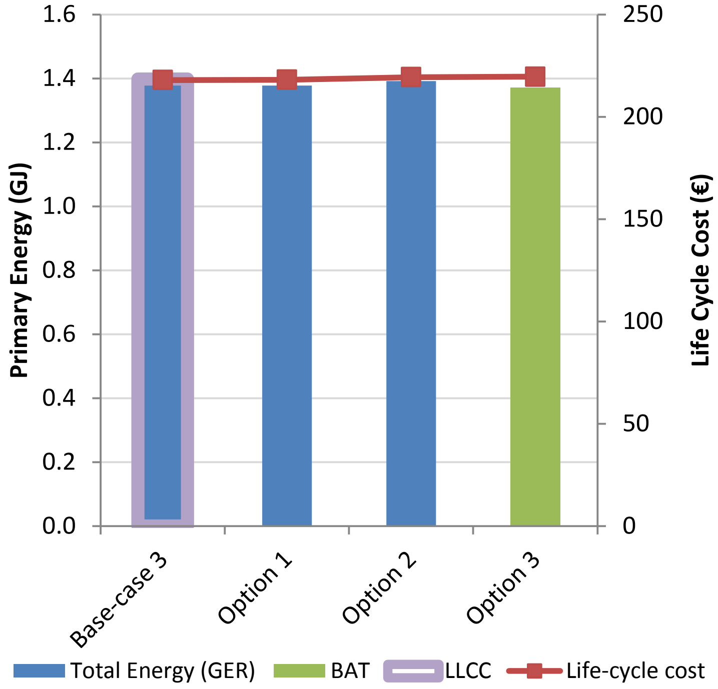

Figure 7-6: Identification of design improvement options with the least energy consumption and LLCC for BC-3

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

7.2.4 Base-Case 4&5: Aquarium pumps (domestic/small aquarium non-commercial) up to 120 W and aquarium pumps power head to 120 W

The results of the environmental analysis of the different designs options for BC4&5 are presented in Table 7-15. Option 1 shows to have reductions in the environmental impacts compared to the Base-Case but is the combination of options 1+2 that shows the most optimal results regarding environmental impacts.

As in BC3, the combination of options 1+2 allows primary energy reductions of 2% and a decrease of 3% on the LCC. On the other hand, the contributions of options 1 and 3 to the reduction of energy consumption and LCC reductions are non-existent.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Table 7-15: Environmental impacts of the BC-4&5 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 4&5	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	4.0	3.9	4.0	3.9
	% change with BC	0%	-1%	0%	-2%
Of which, electricity	Primary GJ	3.8	3.8	3.8	3.8
	Final MWh	0.4	0.4	0.4	0.4
	% change with BC	0%	-1%	0%	-2%
Water (process)	kL	0.3	0.3	0.3	0.3
	% change with BC	0%	-1%	0%	-2%
Water (cooling)	kL	10.2	10.1	10.2	10.0
	% change with BC	0%	-1%	0%	-2%
Waste, non-haz./ landfill	kg	7.1	7.0	7.1	7.0
	% change with BC	0%	-1%	0%	-1%
Waste, hazardous/ incinerated	kg	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-1%
Greenhouse Gases in GWP100	t CO_2 eq.	0.2	0.2	0.2	0.2
	% change with BC	0%	-1%	0%	-2%
Acidification, emissions	Kg SO_2 eq.	1.0	1.0	1.0	1.0
	% change with BC	0%	-1%	0%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-2%
Heavy Metals to air	g Ni eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	-2%
PAHs	g Ni eq.	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Particulate Matter (PM, dust)	kg	0.1	0.1	0.1	0.1
	% change with BC	0%	0%	0%	0%
Heavy Metals to water	g Hg/20	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-2%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	0%	-1%
Life-cycle cost	€	84.1	84.6	85.0	85.4
	% change with BC	0%	1%	1%	2%

In Figure 7-7 we can see the different shares of life cycle costs throughout the life cycle of BC4&5 and the design options. For all the cases, the purchase price has the highest share (between 59% and 61% of the total). The electricity costs have the second highest share of the life cycle costs (between 39% and 41% of the total).

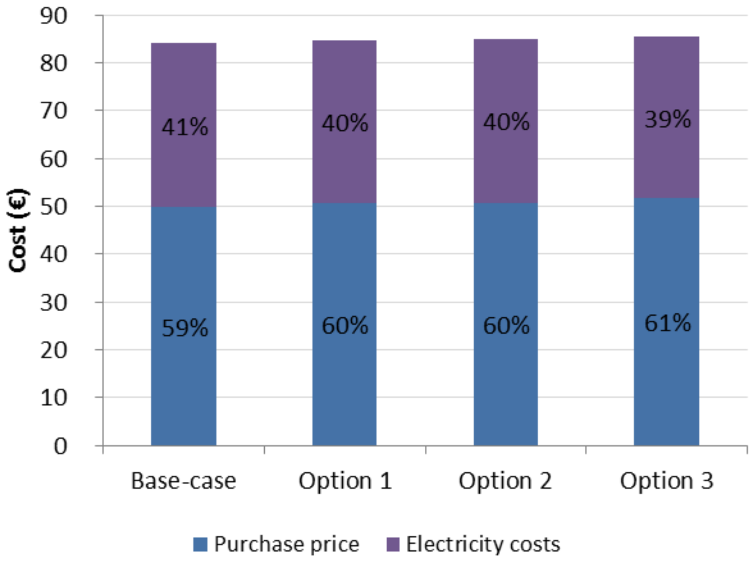

Figure 7-7: Life cycle costs of the improvement options for BC-4&5

Option 1	Option 2	Option 3
Pump/hydraulic Improvements	Motor improvements	Pump/hydraulic and Motor improvements

Figure 7-8 shows the comparison between LCC and the primary energy consumption for BC4&5 and the design options. For this Base-Case, the combination of options 1+2 is the BAT, achieving 2% energy savings but has an increase of 2% in life cycle costs. The LLCC is the Base-Case.

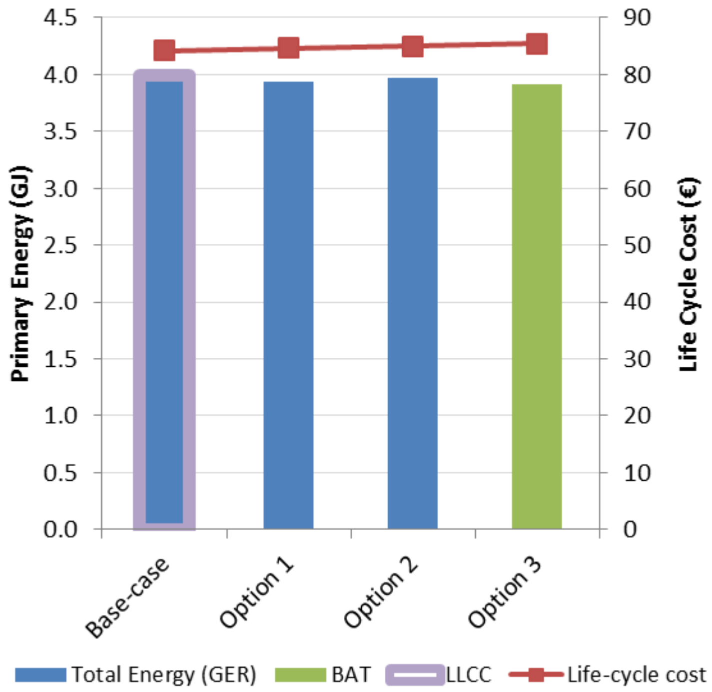

Figure 7-8: Identification of design improvement options with the least energy consumption and LLCC for BC-4&5

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

7.2.5 Base-Case 6: Spa pumps for domestic & commercial spas

The results of the environmental analysis of the different designs options for BC6 are presented in Table 7-16. Options 1 and 2 show to have reductions in the environmental impacts compare to the Base-Case and a primary energy reduction of 1% but it is the combination of these two options that allows the highest reduction of environmental impacts and consumer expenditure over the life cycle.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Table 7-16: Environmental impacts of the BC-6 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 6	Option 1	Option 2	Options 1+2
Total Energy (GER)	GJ	99.7	98.8	98.8	97.8
	% change with BC	0%	-1%	-1%	-2%
Of which, electricity	Primary GJ	97.4	96.5	96.5	95.5
	Final MWh	9.3	9.2	9.2	9.1
	% change with BC	0%	-1%	-1%	-2%
Water (process)	kL	6.6	6.5	6.5	6.5
	% change with BC	0%	-1%	-1%	-2%
Water (cooling)	kL	259.1	256.5	256.5	253.9
	% change with BC	0%	-1%	-1%	-2%
Waste, non-haz./ landfill	kg	213.0	211.9	211.9	210.8
	% change with BC	0%	-1%	-1%	-1%
Waste, hazardous/ incinerated	kg	8.4	8.4	8.4	8.4
	% change with BC	0%	0%	0%	-1%
Greenhouse Gases in GWP100	t CO2 eq.	4.4	4.3	4.3	4.3
	% change with BC	0%	-1%	-1%	-2%
Acidification, emissions	Kg SO2 eq.	26.5	26.3	26.3	26.0
	% change with BC	0%	-1%	-1%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	-1%	-2%
Persistent Organic Pollutants (POP)	µg i-Teq	1.1	1.1	1.1	1.1
	% change with BC	0%	-1%	-1%	-1%
Heavy Metals to air	g Ni eq.	2.2	2.1	2.1	2.1
	% change with BC	0%	-1%	-1%	-2%
PAHs	g Ni eq.	0.3	0.3	0.3	0.3
	% change with BC	0%	-1%	-1%	-1%
Particulate Matter (PM, dust)	kg	2.1	2.1	2.1	2.1
	% change with BC	0%	0%	0%	-1%
Heavy Metals to water	g Hg/20	0.8	0.8	0.8	0.7
	% change with BC	0%	-1%	-1%	-2%
Eutrophication	Kg PO4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%
Life-cycle cost	€	1,415.7	1,408.8	1,414.3	1,407.3
	% change with BC	0%	0%	0%	-1%

In Figure 7-9 it can be seen the different shares of life cycle costs throughout the life cycle of BC6 and the design options. For all the cases, the electricity costs have the highest share (between 48% and 49% of the total). The installation costs are the second contributor to the LCC. Purchase prices is the third contributor to the LCC

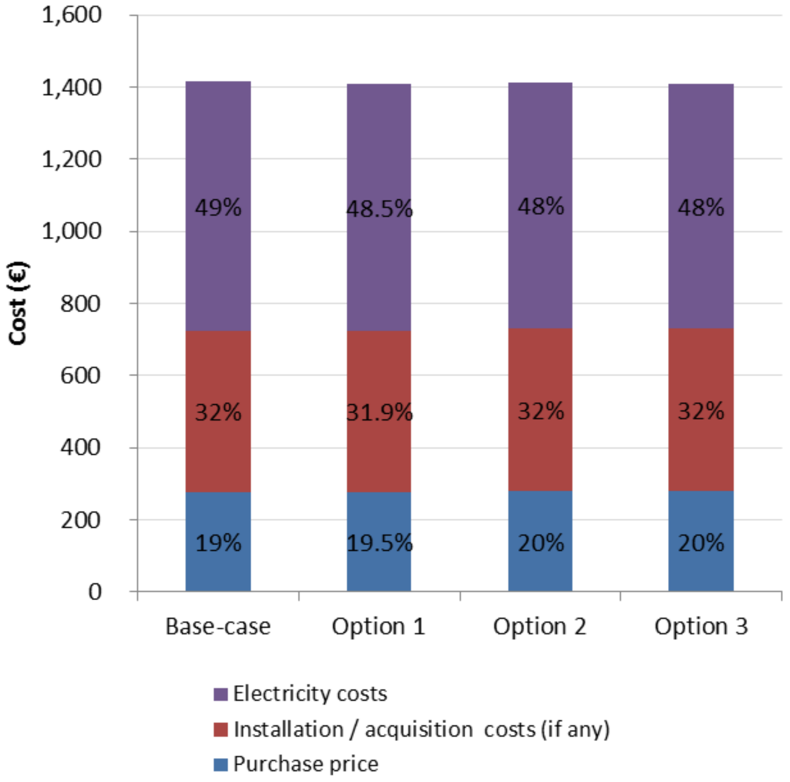

Figure 7-9: Life cycle costs of the improvement options for BC-6

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Figure 7-10 shows the comparison between LCC and the primary energy consumption for BC6 and the design options. For this Base-Case, the combination of options 1+2 is the BAT as well as the LLCC, achieving 2% energy savings and a reduction of 1% in life cycle costs.

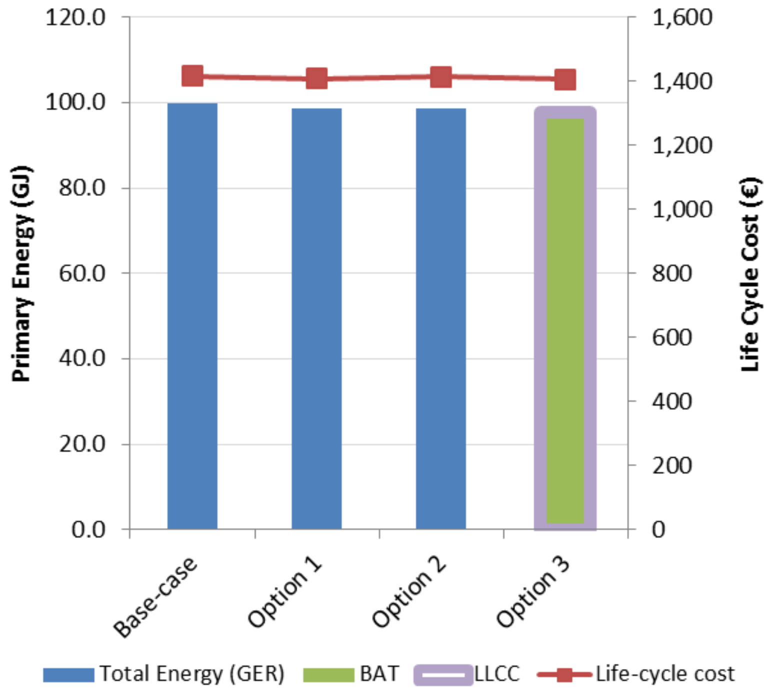

Figure 7-10: Identification of design improvement options with the least energy consumption and LLCC for BC-6

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

7.2.6 Base-Case 7: Counter-current pumps

The results of the environmental analysis of the different designs options for BC7 are presented in Table 7-17. Options 1 and 2 show to have reductions in the environmental impacts compared to the Base-Case and a primary energy reduction of 1% but it is the combination of these options that allows the highest reduction of environmental impacts, but the lowest consumer expenditure over the life cycle is achieved through option 1.
Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Table 7-17: Environmental impacts of the BC-7 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 7	Option 1	Option 2	Options 1+2
Total Energy (GER)	GJ	17.5	17.2	17.2	17.2
	% change with BC	0%	-1%	-1%	-2%
Of which, electricity	Primary GJ	15.5	15.3	15.3	15.2
	Final MWh	1.5	1.5	1.5	1.4
	% change with BC	0%	-1%	-1%	-2%
Water (process)	kL	1.1	1.1	1.1	1.1
	% change with BC	0%	-1%	-1%	-2%
Water (cooling)	kL	40.6	40.0	40.0	39.8
	% change with BC	0%	-1%	-1%	-2%
Waste, non-haz./ landfill	kg	97.0	96.8	96.8	96.7
	% change with BC	0%	0%	0%	0%
Waste, hazardous/ incinerated	kg	4.4	4.4	4.4	4.4
	% change with BC	0%	0%	0%	0%
Greenhouse Gases in GWP100	t CO_2 eq.	0.8	0.8	0.8	0.8
	% change with BC	0%	-1%	-1%	-2%
Acidification, emissions	Kg SO_2 eq.	5.0	4.9	4.9	4.9
	% change with BC	0%	-1%	-1%	-2%
Volatile Organic Compounds (VOC)	kg	0.0	0.0	0.0	0.0
	% change with BC	0%	-1%	-1%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	0.6	0.6	0.6	0.6
	% change with BC	0%	0%	0%	0%
Heavy Metals to air	g Ni eq.	0.7	0.7	0.7	0.7
	% change with BC	0%	-1%	-1%	-1%
PAHs	g Ni eq.	0.1	0.1	0.1	0.1
	% change with BC	0%	0%	0%	-1%
Particulate Matter (PM, dust)	kg	1.5	1.5	1.5	1.5
	% change with BC	0%	0%	0%	0%
Heavy Metals to water	g Hg/20	0.2	0.2	0.2	0.2
	% change with BC	0%	-1%	-1%	-1%
Eutrophication	Kg PO_4	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%
Life-cycle cost	€	1,932.6	1,931.1	2,083.7	2,082.0
	% change with BC	0%	0%	8%	8%

Figure 7-11 shows the different shares of life cycle costs throughout the life cycle of BC7 and the design options. For all the cases, purchase price have the highest share (69% of the total). The installation costs are the second contributors to the LCC. Both electricity and maintenance costs have little impacts throughout the life cycle of BC7 and the design options.

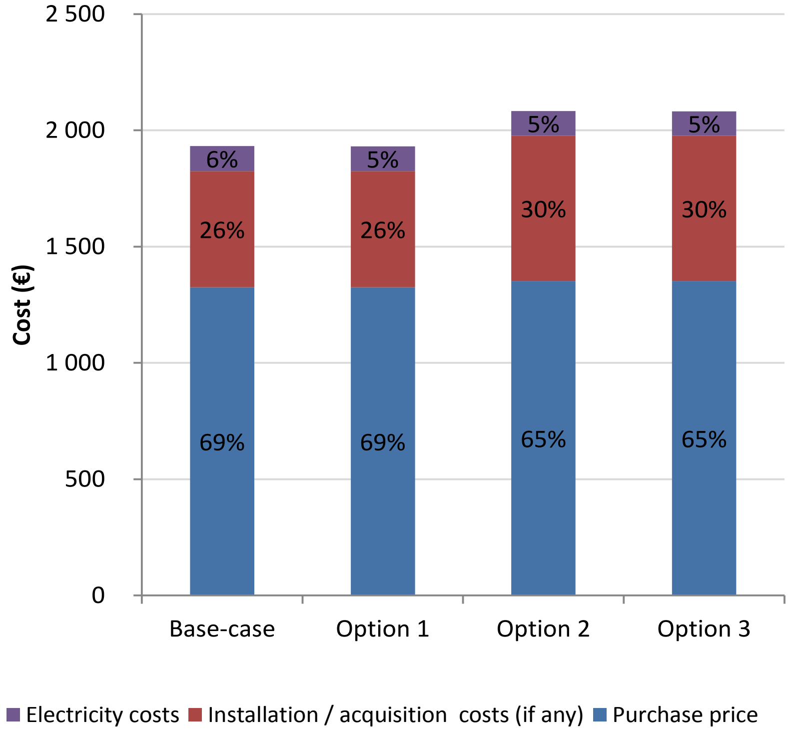

Figure 7-11: Life cycle costs of the improvement options for BC-7

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

Figure 7-12 presents the comparison between LCC and the primary energy consumption for BC7 and the design options. Combination of options 1+2 is the BAT and option 2 is the LLCC, achieving 1% energy savings and a reduction of 1% in life cycle costs.

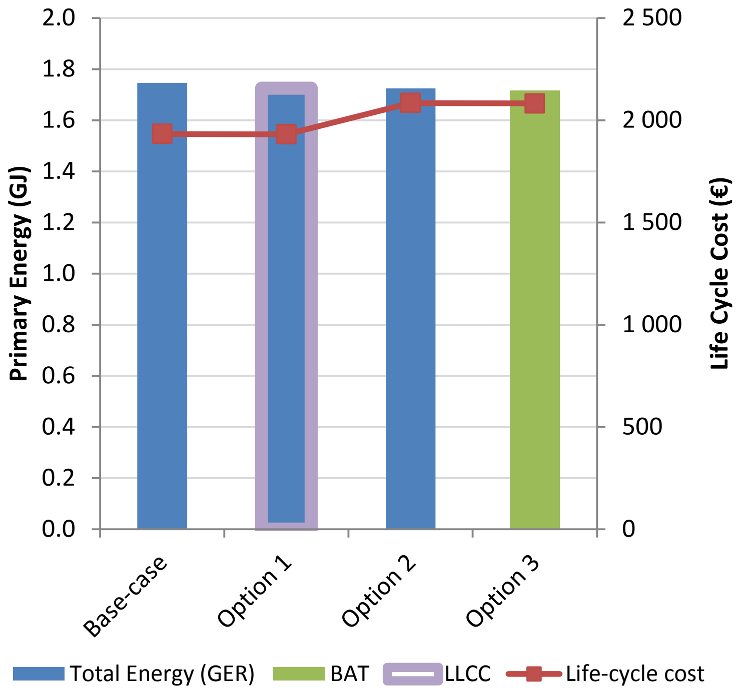

Figure 7-12: Identification of design improvement options with the least energy consumption and LLCC for BC-7

Option 1	Option 2	Option 3
Pump/hydraulic improvements	Motor improvements	Pump/hydraulic and motor improvements

7.2.7 Base-Case 8: End-Suction Close Coupled pumps from 150 kW to 1 MW

The results of the environmental analysis of the different designs options for BC8 are presented in Table 7-18. The combination of options 1+2 shows the highest reductions in the environmental impacts and primary energy consumption, compared to the Base-Case. However, it is option 2 has a significantly higher energy savings potential than option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-18: Environmental impacts of the BC-8 and its improvement options

Life-Cycle indicators per unit	Unit	Base-Case 8	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	136,097.4	134,736.6	119,087.4	117,726.6
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	136,082.0	134,721.2	119,072.0	117,711.2
	Final MWh	12,960.2	12,830.6	11,340.2	11,210.6
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	9,072.8	8,982.1	7,938.8	7,848.1
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	362,882.9	359,254.1	317,522.9	313,894.1
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	158,314.2	156,736.4	138,592.1	137,014.3
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	3,138.4	3,107.1	2,746.5	2,715.1
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	5,939.8	5,880.5	5,197.5	5,138.2
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	35,046.5	34,696.1	30,666.5	30,316.1
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	kg	51.4	50.8	45.0	44.4
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	898.4	889.5	786.9	778.0
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	2,338.1	2,314.7	2,046.2	2,022.9
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	268.3	265.6	234.8	232.1
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	763.6	756.1	670.1	662.6
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	878.6	869.8	768.9	760.2
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	4.2	4.2	3.7	3.7
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	985,513.6	976,019.6	882,423.8	860,200.7
	% change with BC	0%	-1%	-10%	-13%

Figure 7-13 shows the different shares of life cycle costs throughout the life cycle of BC-8 and the design options. For all the cases, the electricity costs have the highest share of almost 100%. The purchase prices, installations and maintenance costs show very little impacts throughout the life cycle of BC8 and the design options.

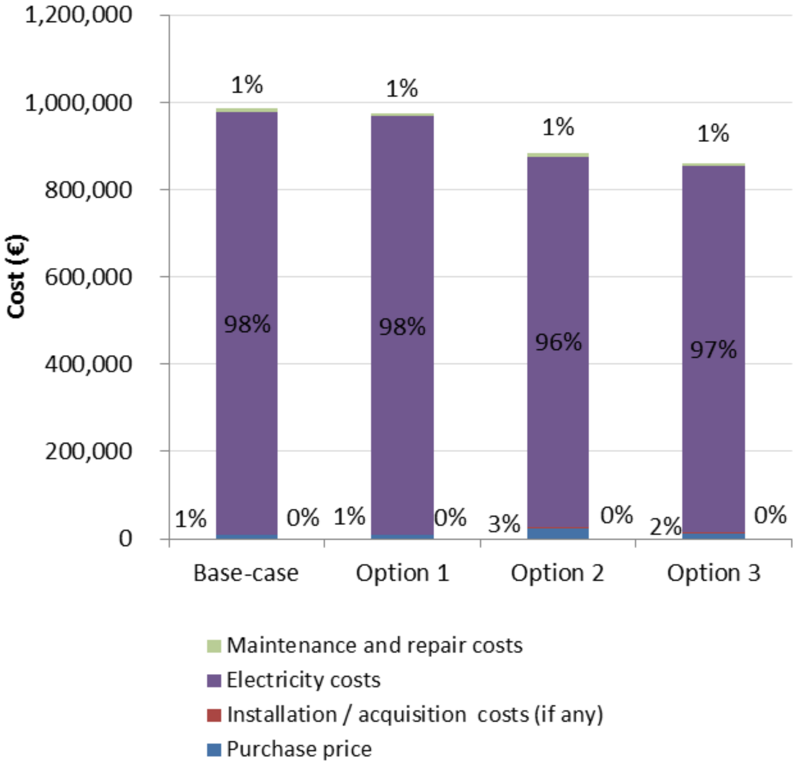

Figure 7-13: Life cycle costs of the improvement options for BC-8

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-14 presents the comparison between LCC and the primary energy consumption for BC8 and the design options. The combination of option 1+2 appears as the BAT and the LLCC, with energy savings of 13% and reduction of the LLC of 13%.

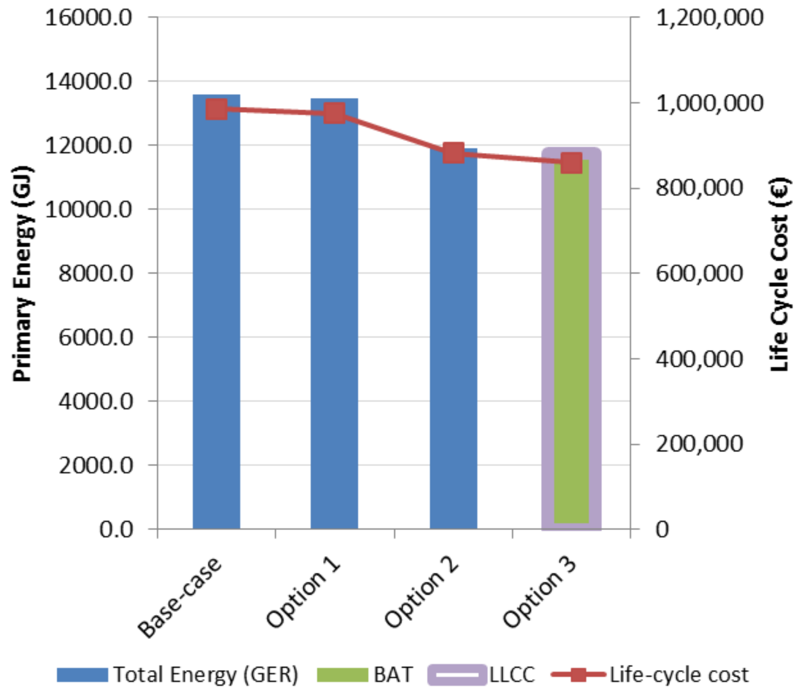

Figure 7-14: Identification of design improvement options with the least energy consumption and LLCC for BC-8

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.8 Base-Case 9: End-Suction Close Coupled Inline from 150 kW to 1 MW

The results of the environmental analysis of the different designs options for BC9 are presented in Table 7-19. As seen with BC8, the combination of options 1+2 shows to have the highest reductions in environmental impacts compared to the Base-Case. However, it is option 2 has a significantly higher energy savings potential than option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-19: Environmental impacts of the BC-9 End-Suction Close Coupled Inline from 150 kW to 1 MW

Life-Cycle indicators per unit	Unit	Base-Case 9	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	136,097.4	134,736.6	119,087.4	117,726.6
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	136,082.0	134,721.2	119,072.0	117,711.2
	Final MWh	12,960.2	12,830.6	11,340.2	11,210.6
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	9,072.8	8,982.1	7,938.8	7,848.1
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	362,882.9	359,254.1	317,522.9	313,894.1
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	158,314.2	156,736.4	138,592.1	137,014.3
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	3,138.4	3,107.1	2,746.5	2,715.1
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	5,939.8	5,880.5	5,197.5	5,138.2
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	35,046.5	34,696.1	30,666.5	30,316.1
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	Kg	51.4	50.8	45.0	44.4
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	898.4	889.5	786.9	778.0
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	2,338.1	2,314.7	2,046.2	2,022.9
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	268.3	265.6	234.8	232.1
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	763.6	756.1	670.1	662.6
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	878.6	869.8	768.9	760.2
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	4.2	4.2	3.7	3.7
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	985,513.6	976,026.4	882,423.8	860,436.6
	% change with BC	0%	-1%	-10%	-13%

Figure 7-15 shows the different shares of life cycle costs throughout the life cycle of BC-9 and the design options. For all the cases, the electricity costs have the highest share of almost a 100%. Purchase prices, installations and maintenance show very little impacts throughout the life cycle of BC9 and the design options.

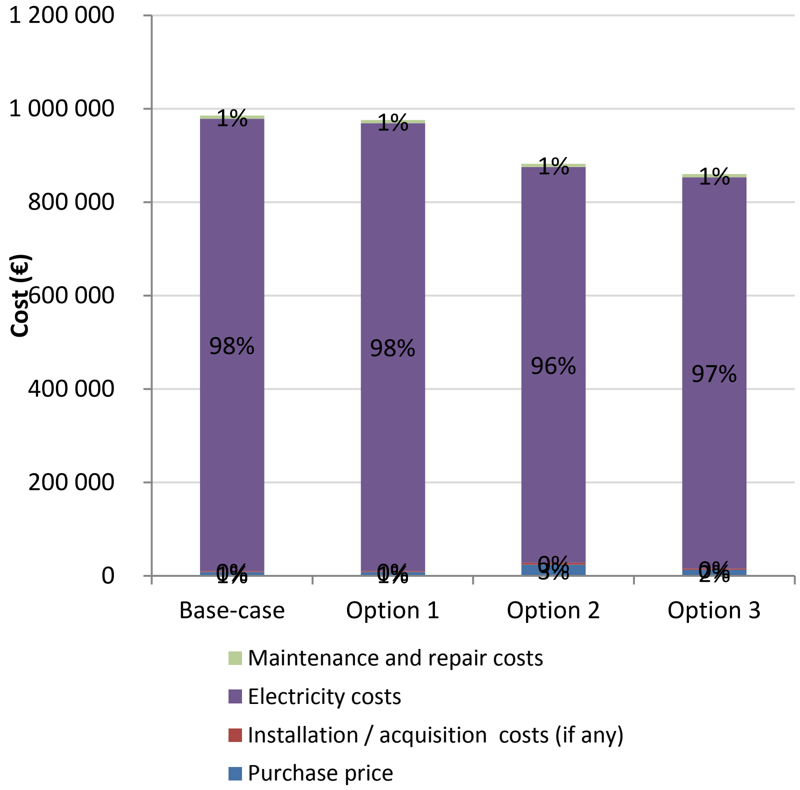

Figure 7-15: Life cycle costs of the improvement options for BC-9

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-16 presents the comparison between LCC and the primary energy consumption for BC-9 and the design options. The combination of option 1+2 appears as the BAT and the LLCC, with energy savings of 13% and reduction of the LLC of 13%.

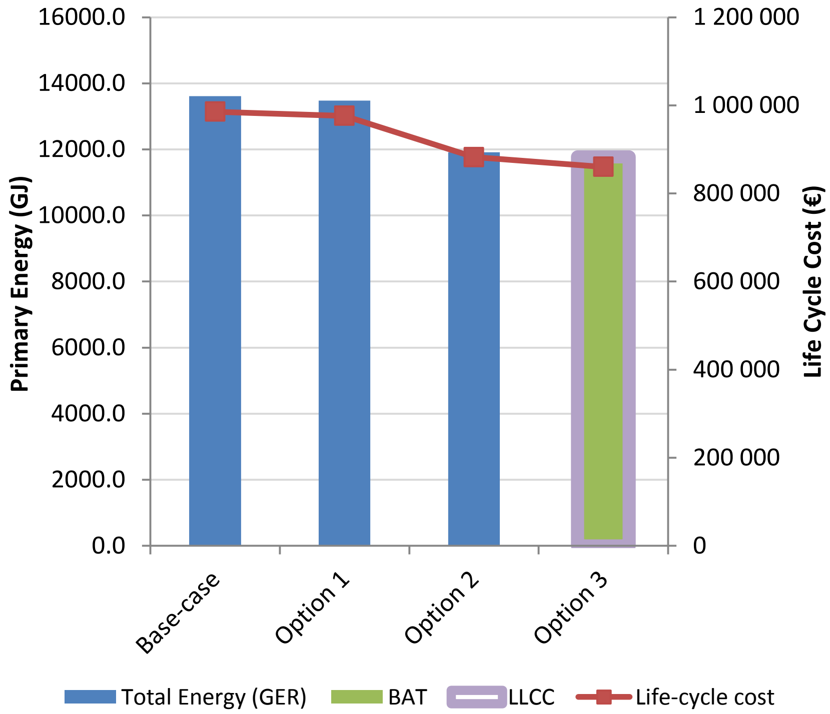

Figure 7-16: Identification of design improvement options with the least energy consumption and LLCC for BC-9

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.9 Base-Case 10: End-Suction Own Bearing from 150 kW to 1 MW

The results of the environmental analysis of the different designs options for BC10 are presented in Table 7-20. As seen with BC8 and BC9, the combination of options 1+2 shows to have the highest reductions in environmental impacts compared to the Base-Case. However, it is option 2 has a significantly higher energy savings potential than option 1.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-20: Environmental impacts of BC10: End-Suction Own Bearing from 150 kW to 1 MW

Life-Cycle indicators per unit	Unit	Base-Case 10	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	245,717.2	243,260.2	215,004.7	212,547.7
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	245,702.0	243,245.0	214,989.5	212,532.5
	Final MWh	23,400.2	23,166.2	20,475.2	20,241.2
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	16,380.8	16,217.0	14,333.3	14,169.5
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	655,202.8	648,650.8	573,302.8	566,750.8
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	285,411.9	282,563.1	249,802.4	246,953.7
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	5,662.6	5,606.0	4,954.9	4,898.2
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	10,723.6	10,616.4	9,383.3	9,276.1
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	63,273.7	62,641.0	55,365.2	54,732.5
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	Kg	92.6	91.7	81.1	80.2
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	1,616.9	1,600.8	1,415.6	1,399.5
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	4,218.7	4,176.5	3,691.8	3,649.6
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	484.2	479.4	423.7	418.9
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	1,366.4	1,352.8	1,197.4	1,183.9
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	1,585.4	1,569.6	1,387.4	1,371.5
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	7.6	7.5	6.7	6.6
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	1,765,870.2	1,748,579.4	1,557,235.8	1,538,945.0
	% change with BC	0%	-1%	-12%	-13%

Figure 7-17 shows the different shares of life cycle costs throughout the life cycle of BC-10 and the design options. For all the cases, the electricity costs have the highest share of almost a 100%. Purchase prices, installations and maintenance show very little impacts throughout the life cycle of BC10 and the design options.

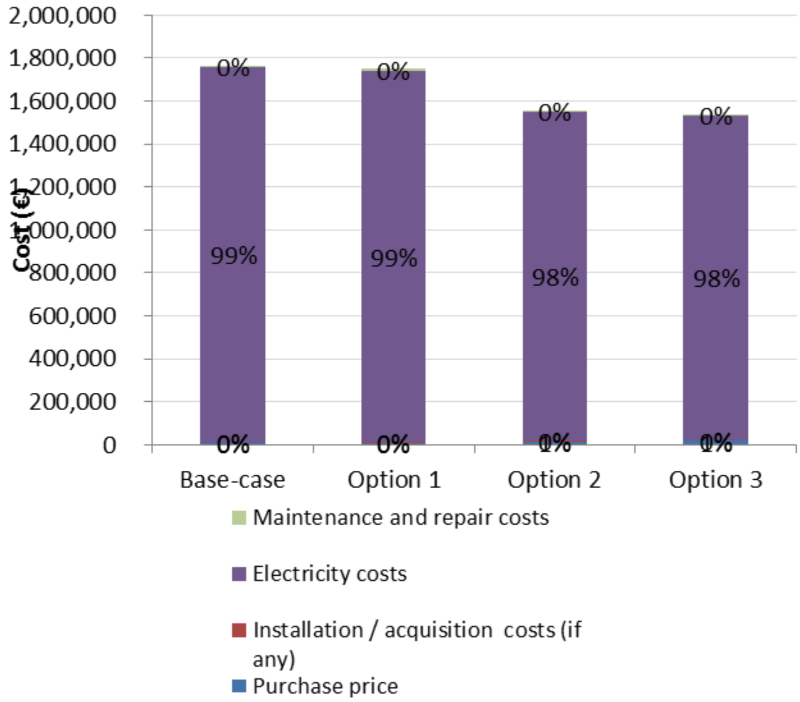

Figure 7-17: Life cycle costs of the improvement options for BC-10

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-18 presents the comparison between LCC and the primary energy consumption for BC10 and the design options. The combination of option 1+2 appears as the BAT the LLCC with a reduction of 13% of the Life cycle cost and a 13% reduction of primary energy consumption .

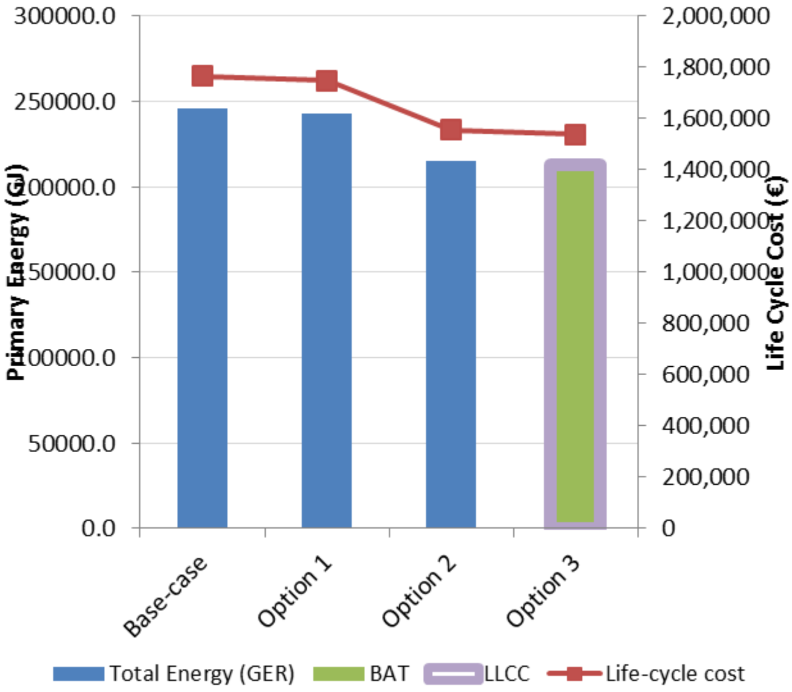

Figure 7-18: Identification of design improvement options with the least energy consumption and LLCC for BC-10

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.10 Base-Case 11: Submersible bore-hole pumps

The results of the environmental analysis of the different designs options for BC11 are presented in Table 7-21. As seen with BC8, BC9 and BC10 the combination of options 1+2 shows to have the highest reductions in environmental impacts compared to the Base-Case.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-21: Environmental impacts of the BC-11 Submersible bore-hole pumps

Life-Cycle indicators per unit	Unit	Base-Case 11	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	24,368.4	24,125.0	21,324.4	21,080.9
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	24,355.2	24,111.7	21,311.2	21,067.6
	Final MWh	2,319.5	2,296.4	2,029.6	2,006.4
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	1,624.1	1,607.9	1,421.2	1,404.9
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	64,941.2	64,292.0	56,823.9	56,174.4
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	28,677.9	28,395.6	25,148.5	24,866.1
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	566.9	561.3	496.8	491.2
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	1,063.9	1,053.3	931.0	920.4
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	6,274.2	6,211.5	5,490.4	5,427.6
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	Kg	9.2	9.2	8.1	8.0
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	μg i-Teq	166.4	164.8	146.4	144.8
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	420.8	416.6	368.6	364.4
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	48.0	47.5	42.0	41.5
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	Kg	142.2	140.8	125.4	124.1
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	158.1	156.5	138.4	136.9
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	0.8	0.8	0.7	0.7
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	231,878.1	229,955.7	210,735.3	208,463.1
	% change with BC	0%	-1%	-9%	-10%

Figure 7-19 shows the different shares of life cycle costs throughout the life cycle of BC-11 and the design options. For all the cases, the electricity costs have the highest share (between 84% and 88% of the total). The maintenance and repair are the second contributors to the LCC with 8%-9% of the total. The installation and purchase costs represent 1%-4% of the LCC throughout the life cycle of BC-11 and the design options.

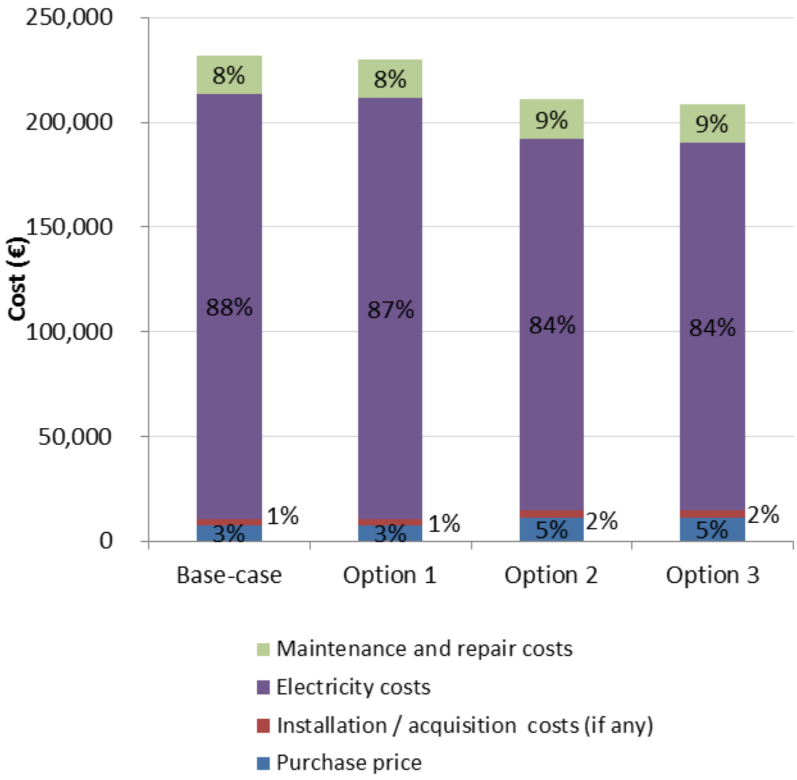

Figure 7-19: Life cycle costs of the improvement options for BC-11

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-20 presents the comparison between LCC and the primary energy consumption for BC-11 and the design options. The option 3 appears as the LLCC with a reduction of 18% of the Life cycle cost. The BAT is alsto option 3 with a 13% reduction in energy consumption.

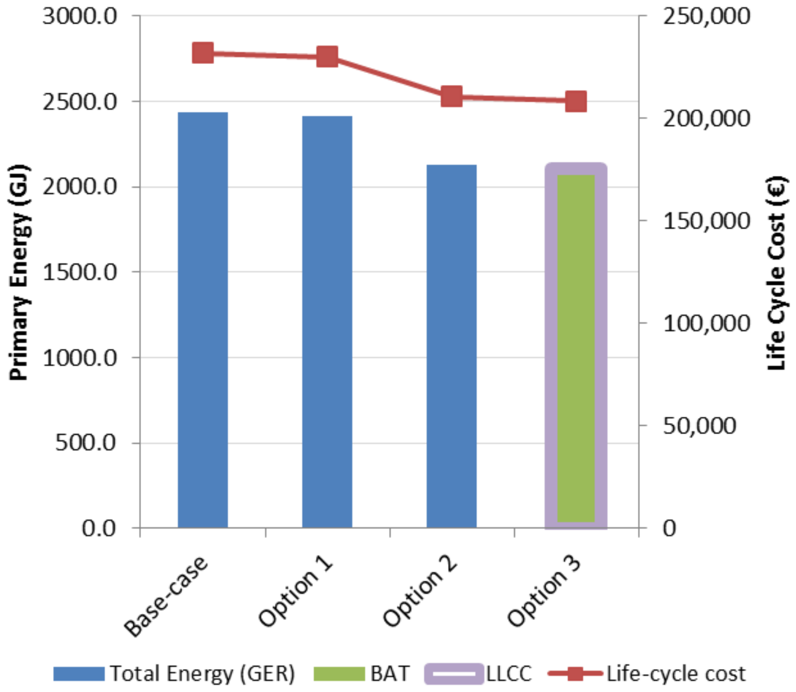

Figure 7-20: Identification of design improvement options with the least energy consumption and LLCC for BC-11

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.2.11 Base-Case 12: Vertical multi-stage pumps

The results of the environmental analysis of the different design options for BC12 are presented in Table 7-22. As seen with BC11, the combination of options 1+2 shows to have the highest reductions in the environmental impacts compared to the Base-Case and a primary energy reduction of 13%.

Design improvement options

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Table 7-22: Environmental impacts of the BC-12 Vertical multi-stage pumps

Life-Cycle indicators per unit	Unit	Base-Case 12	Option 1	Option 2	Option 3
Total Energy (GER)	GJ	31,016.2	30,706.2	27,140.7	26,830.7
	% change with BC	0%	-1%	-12%	-13%
Of which, electricity	Primary GJ	31,005.3	30,695.3	27,129.9	26,819.9
	Final MWh	2,952.9	2,923.4	2,583.8	2,554.3
	% change with BC	0%	-1%	-12%	-13%
Water (process)	kL	2,067.5	2,046.9	1,809.2	1,788.5
	% change with BC	0%	-1%	-12%	-13%
Water (cooling)	kL	82,677.8	81,851.1	72,343.3	71,516.5
	% change with BC	0%	-1%	-12%	-13%
Waste, non-haz./ landfill	kg	36,324.2	35,964.7	31,830.8	31,471.3
	% change with BC	0%	-1%	-12%	-13%
Waste, hazardous/ incinerated	kg	717.6	710.4	628.3	621.1
	% change with BC	0%	-1%	-12%	-13%
Greenhouse Gases in GWP100	t CO_2 eq.	1,353.9	1,340.4	1,184.8	1,171.2
	% change with BC	0%	-1%	-12%	-13%
Acidification, emissions	Kg SO_2 eq.	7,987.2	7,907.4	6,989.3	6,909.5
	% change with BC	0%	-1%	-12%	-13%
Volatile Organic Compounds (VOC)	kg	11.7	11.6	10.3	10.2
	% change with BC	0%	-1%	-12%	-13%
Persistent Organic Pollutants (POP)	µg i-Teq	207.9	205.9	182.5	180.5
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to air	g Ni eq.	534.3	529.0	467.8	462.5
	% change with BC	0%	-1%	-12%	-13%
PAHs	g Ni eq.	61.2	60.6	53.6	53.0
	% change with BC	0%	-1%	-12%	-13%
Particulate Matter (PM, dust)	kg	179.3	177.6	158.0	156.3
	% change with BC	0%	-1%	-12%	-13%
Heavy Metals to water	g Hg/20	200.7	198.7	175.7	173.7
	% change with BC	0%	-1%	-12%	-13%
Eutrophication	Kg PO_4	1.0	1.0	0.9	0.9
	% change with BC	0%	-1%	-12%	-13%
Life-cycle cost	€	277,399.1	275,158.7	250,443.6	247,964.9
	% change with BC	0%	-1%	-10%	-11%

Figure 7-21 shows the different shares of life cycle costs throughout the life cycle of BC-12 and the design options. For all the cases, the electricity costs have the highest share (between 89% and 92% of the total). The purchase prices are the second contributors to the LCC with 4% -6% of the total. The installation and maintenance costs represent 1% and 3% respectively of the LCC throughout the life cycle of BC-12 and the design options

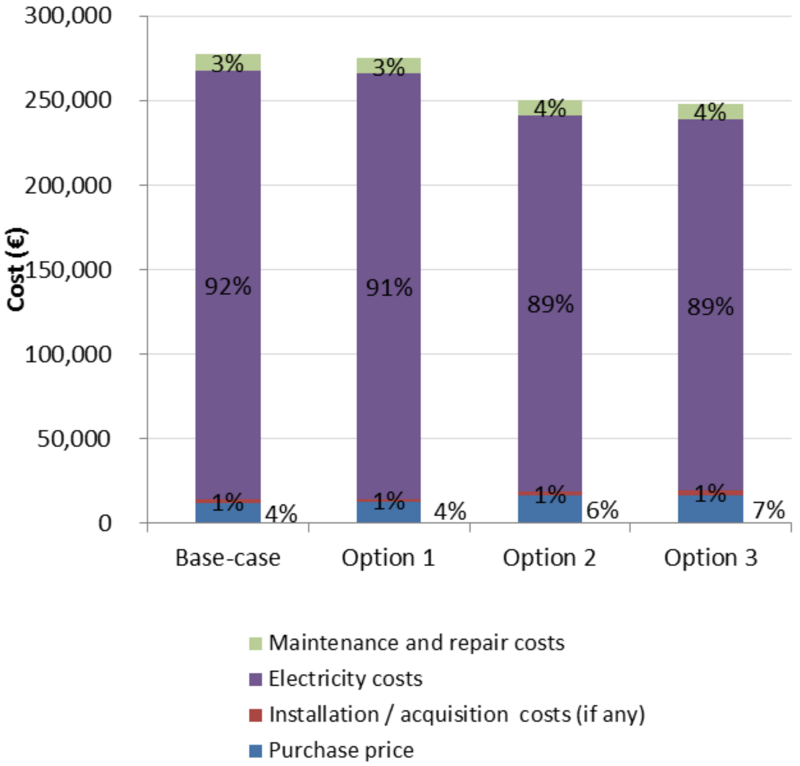

Figure 7-21: Life cycle costs of the improvement options for BC-12

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

Figure 7-22 presents the comparison between LCC and the primary energy consumption for BC11 and the design options. The combination of option 1+2 appears as the LLCC with a reduction of 12% of the Life cycle cost, as well as the BAT with 13% reduction of primary energy consumption.

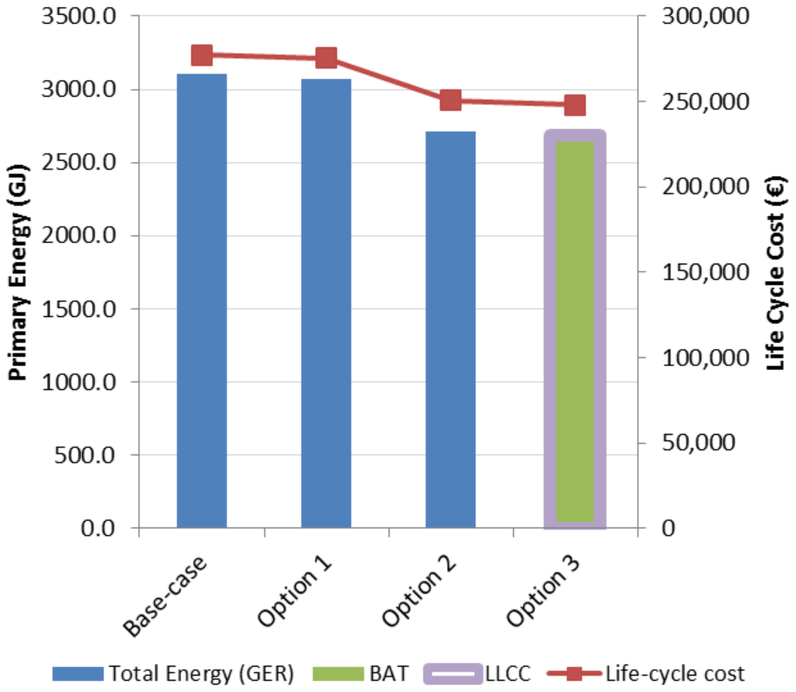

Figure 7-22: Identification of design improvement options with the least energy consumption and LLCC for BC-12

Option 1	Option 2	Option 3
Pump/hydraulic improvements	VSD	Pump/hydraulic improvements and VSD

7.3 BNAT and long-term systems analysis

Pumps are a very well established technology that has been refined for several years, and therefore there is very little in terms of BNAT appearing on the horizon. There will inevitably be small improvements in efficiency as computational fluid dynamics allows more experimentation and refinement to take place in the design process, and as closer manufacturing tolerances become feasible.

An area where savings are likely to be realised in the future is in optimum control of swimming pool pumps. This is already seen to a limited fashion at the moment through variable speed drives, however in the future the potential exists to combine the pump operation with a greater level of intelligence regarding the water quality, such as through the use of turbidity monitors to detect the suspended solids, or chemical analysis to control the chemical dosing requirements. With more intelligence, the VSD and other control units can be used largely and the savings made will be more significant.

7.4 Conclusions

Several improvement options are available for each Base-Case, with different payback periods and in some cases a few constraints. Combinations of these improvement options provide potential for some energy savings, leading to reduction of negative environmental impacts.

In terms of potential energy savings, the option offering the most significant potential savings is VSD. Where applicable, VSD seems to offer the biggest potential energy consumption savings that varies between 10% and 40%. This is the case for swimming pool pumps (BC-1, BC-2), End-suction closed coupled pumps (BC-8, BC-9, BC- 10) and for submersible and vertical pumps (BC-11, BC-12). However, the VSD technology only provides a benefit in applications where variable speed is needed. Some pump applications would not benefit from this option if they only operate at full speed.

There are some improvement options that stand out in terms of payback time due to their requirement of little to no investment. As discussed before, VSD is the option that offers the biggest energy savings but also has higher associated costs. The results show that throughout all the Base-Cases, the BAT is always a combination of the different improvement options.

Only in counter-current pumps (BC 7) the option with LLCC is one of the improvement non-combined options. For aquarium pumps the Base-case itself is the LLCC (BC4&5). For the remaining Base-Cases, the LLCC is a combination of all the different improvement options, which is at the same time the BAT. Currently, no available improvement options have a potential to become more affordable over the coming years.

Hence, some increase in the energy efficiency of pumps could be achieved without significant additional environmental impacts, but this varies significantly between pumps types. Fountain, pond, aquarium, spa and counter-current pumps do not present high potential for energy efficiency improvement, and some of the improvement options have long payback times.

Swimming pool pumps, end-suction pumps, submersible borehole pumps and vertical multistage pumps present some potential for energy efficiency improvement, mainly due to VSD. This technology is already implemented in part of end-suction pumps and vertical multistage pumps installed in the EU. However, as discussed above, VSD would not be beneficial for all the pump applications. These results will be further discussed in context of policy options in Task 8.

28 March 2014

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