Preparatory Studies for Eco-design Requirements of Energy-using Products

Lot 24: Professional Washing Machines, Dryers and Dishwashers

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Task 7: Improvement Potential

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For reasons of better readability, two Task 7 reports were prepared.

The report at hand covers ***professional dishwashers***.

The Task 7 report on *professional washing machines and dryers*
is published separately.

Part: Professional Dishwashers

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1 Introduction

1.1 Objective of Task 7

The objective of Task 7 is to assess the environmental and economic impacts of the base cases (BC) with the improvement options identified in Task 6. Impacts include the monetary consequences in terms of Life Cycle Cost (LCC) for the user, environmental costs and benefits, economic and social impacts. The solution with the Least Life Cycle Cost (LLCC) and the Best Available Technology (BAT) will be highlighted. The available design options are investigated by assessing the environmental impact and LCC of each against the base case using the MEEuP EcoReport, as in Task 5.

The assessment of LCC is relevant to indicate how design solutions might affect total user expenditure over the total product lifetime (purchase, operating and end-of-life costs). The gap between the LLCC option and the BAT one indicates the remaining room for product-differentiation (competition), in cases where the LLCC option is set as a minimum target. The BAT represents a short- to medium-term target, for which promotional measures would probably be more appropriate than restrictions. The Best Not yet Available Technology (BNAT) gives an idea of long-term possibilities and helps to define the exact scope and definition of any possible measures.

1.2 Methodology and assessment of data quality

Based on the currently applied BAT design options, the general constraints with regard to implementation and combination possibilities, and the infeasibility to quantify the improvement potential of most of the options (see Task 6), six design options were chosen for further proceedings.

For these selected design options, manufacturers were asked to quantify the concrete saving potential and price differences compared to the base case products as defined in Tasks 3, 4 and 5. The inquiry was sent out to seven manufacturers (see Annex). The following tables in section 2 present the aggregated and averaged results of four filled in questionnaires.

Important note: Assessment of data quality throughout Task 6 report

It is important to note that all information with regard to the saving potential of improvement options should be seen in the following context:

- There are no standard measurement methods for quantifying the energy and water consumption of professional dishwashers, and there are likewise no standards requiring manufacturers to define the measurement procedure for potential savings (see Task 1).

- Energy and water savings depend on many different factors such as: ambient air temperature, inlet water temperature, temperature and humidity of exhaust air, temperature of waste water, type of machine and, last but not least, the reference case to which savings are compared.
- Quantification based on information from independent side is not possible as there is no scientific literature about the results of BAT and the potential saving impacts of improvement options in the professional dishwashing sector published.
- Within the study we also tried to collect usage data from different categories of end-users (e.g. large canteens). But it was not possible to get data which enable us to quantify the impact of BAT on water- and energy-savings.
- Manufacturers assess their innovative systems in different ways to their competitors.
- The figures in sales brochures are usually used for marketing purposes and therefore might over-estimate the actual savings.
- Quantitative data provided by manufacturers with regard to the savings potentials are only rough estimations.
- Due to the above reasons, estimations and quantitative data of the different manufacturers diverge considerably.
- The data presented in the Task report at hand are average values of the responses.

2 Design options

The Technical Analysis of BAT (see Task 6) identified and described individual design options for environmental improvement according to the usual criteria:

- The design option(s) should not change significantly the functionality or performance parameters compared to the base case.
- The design option(s) should have a significant potential for improvement regarding at least one of the following eco-design parameters without deteriorating others: consumption of energy, water and other resources, use of hazardous substances, emissions to air, water or soil, weight and volume of the product, use of recycled material, quantity and nature of consumables needed for proper use and maintenance, ease of reuse and recycling, extension of lifetime or amount of waste generated.
- The design option(s) should not entail excessive costs. Redesign, testing, investment and/or production costs should be investigated, taking into account economies of scale, sector-specific margins and market structure, and the time required for market penetration of the new design option(s) and replacement of the existing products. Assessment of the costs includes an estimation of possible price increase due to

implementation of the design option either by looking at product prices on the market and/or by applying a production cost model with sector-specific margins.

In the following section, the influence of the implementation of the improvement options on base case products is assessed in more detail.

2.1 Description of individual design options

The improvement options that will be analysed in this task are (all options do not necessarily apply to all base cases):

- **M 1.5 Auxiliary rinsing** (see 3.1.1.5 in Task 6): for conveyor-type dishwashers, lower fresh-water consumption can be achieved thanks to a two or three-step rinsing zone.
- **M 2.1.1 Exhaust air heat exchanger** (see 3.2.1.1 in Task 6): the heat from the exhaust air can be used to preheat the incoming water of the machine through a counter-flow exchanger.
- **M 2.1.2 Exhaust air heat pump** (see 3.2.1.1 in Task 6): thanks to a heat pump, an electric device with cooling and heating capabilities, the energy contained in the exhaust air can be recovered more efficiently than with a heat exchanger.
- **M 3.1.1 Waste water heat exchanger** (see 3.3.1.1 in Task 6): the process is the same as for an exhaust air heat exchanger except that the heat is extracted from the waste water.
- **M 4.1 Insulation**, closed bottom (see 3.4.1.1 in Task 6): the wash tank and other parts of the dishwasher can be thermally insulated to reduce convection losses in the operating and ready-to-use modes.
- **M 4.2 High efficiency pumps and motors** (see 3.4.1.2 in Task 6): the efficiency of the whole hydraulic system (including pumps, motors and pipes) can be optimised, thus reducing energy losses.

- Along with these six individual design options, one overall combination of design options will be added for each base case. This option will be labelled **Best Available (BA) product** (see section 2.2).
- Finally, the **warm water supply** will also be studied, in comparison with the base case, but in an indicative way only (see section 2.3). This option will not be identified as the LLCC or BAT option as its implementation highly depends on the available building infrastructure.

The following subsections will summarise the changes in an improved product that would result from the implementation of the various single design options in each base case.

The parameters of the analysis that are kept constant are the same which were used for the base case analysis (see Task 5). Table 2-1 first summarizes the capacities, prices and consumption values of the base cases as defined in Tasks 3, 4 and 5. These values represent the 100% baseline for the assessment of the design options as provided in the following subsections.

Table 2-1 Capacities, prices and consumption values of bases cases

Parameters	Base case					
	1	**2**	**3**	**4**	**5**	**6**
	Under-counter water-change	**Under-counter one-tank**	**Hood-type**	**Utensil/ Pot**	**Conveyor-type one-tank**	**Conveyor-type multi-tank**
Capacity (dishes/hour)	200	550	860	20 cycles/hour	1 750	3 600
Purchase price (Euro)	3 200	3 500	4 700	10 500	15 000	45 000
Continuous operation						
Specific energy consumption (kWh/100 dishes)	4.3	1.6	1.7	0.5 (per cycle)	2.0	2.0
Specific water consumption (l/100 dishes)	80	16	16	5.2 (per cycle)	13	12
Standby consumption (kWh/hour)						
Left-on mode (BC 1), ready-to-use-mode (BC 2-6)	0.01	0.25	0.35	1.00	0.80	2.00

2.1.1 Bill of materials

The implementation of improvement options can involve the addition of components to enhance product performance (e.g. heat pump). These components increase the quantity of raw materials required to manufacture the product, the weight and volume, as well as the quantity of materials discarded at the end-of-life of the dishwasher. Table 2-2 lists the additional materials required for each improvement option considered.

Table 2-2 Material composition of the design options

Materials	Additional bill of materials due to the improvement options (g)					
	M 2.1.1 Exhaust air heat exchanger	**M 2.1.2** Exhaust air heat pump	**M 3.1.1** Waste water heat exchanger	**M 4.1** Insulation, closed bottom	**M 4.2** High efficient pumps and motors	**M 1.5** Auxiliary rinsing
Stainless steel	+ 5 000	+ 35 000	+ 10 000	n.a.	n.a.	+ 10 000
Copper sheet/tube	+ 5 000	+ 55 000				
Copper wire						+ 1 500
Aluminium diecast						+ 500
Polypropylene		+ 500				+ 500
Electronics		+ 500				+ 100
Refrigerant R-134a		+ 2500				

(Sources: Task 6, Tables 1, 2, and 3, and section 3.4.2)
Note: empty fields = not applicable or no response by manufacturers

The option M 2.1.2 (exhaust air heat pump) results in the presence of refrigerant in the product bill of materials. According to manufacturers, the refrigerant R-134a is commonly used in dishwashers' heat pumps and is thus the type of refrigerant used as an input in EcoReport. This refrigerant has a negligible ozone depletion potential and a 100-year Global Warming Potential of 1 430.[1]

Stakeholders[2] mentioned that the percentage of refrigerant lost during the life cycle of the product was comprised between 5% and 15%. In practice, it is common that a limited number of machines (newly installed ones) lose the total amount of refrigerant due to a defect, which increases significantly the loss rate of the stock. One or several partial refill(s) of the refrigerant can be done over the lifetime. Therefore, the fugitive and dumped refrigerant percentage will be set at 10% over the whole lifecycle in EcoReport.

2.1.2 Volume

It was assumed that the density of the complete product remains the same. Thus the change in volume of the packaged product between the base case and the product with the improvement option is the same as the change in mass. These values were calculated from the bills of materials (see Table 2-2 and Task 5) and are shown in Table 2-3. Given the results of Task 5, this input has a very low influence on the final outcomes of the environmental analysis, and no influence at all on the economic analysis.

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1 IPCC Fourth Assessment Report (AR4), 2007

2 Feedback from Miele and GDF-Suez

Table 2-3 Relative volume by improvement option in comparison with the base case

	M 2.1.1 Exhaust air heat exchanger	**M 2.1.2 Exhaust air heat pump**	**M 3.1.1 Waste water heat exchanger**	**M 4.1 Insulation, closed bottom**	**M 4.2 High efficiency pumps and motors**	**M 1.5 Auxiliary rinsing**
BC 1 Undercounter water-change	120%	-	-	100%	100%	-
BC 2 Undercounter one-tank	113%	218%	113%	100%	100%	-
BC 3 Hood-type	107%	169%	107%	100%	100%	-
BC 4 Utensil/pot	104%	141%	104%	100%	100%	-
BC 5 Conveyor-type one-tank	101%	109%	101%	100%	100%	101%
BC 6 Conveyor-type multi-tank	101%	106%	101%	100%	100%	101%

'-' means that the option cannot be implemented in the product category considered

2.1.3 Energy consumption

The following tables (Table 2-4 to Table 2-9) show the energy performance improvement enabled by the single design options, both for continuous operation and for the left-on/ready-to-use mode and calculate the overall energy performance improvement by taking into account the annual energy consumption breakdown presented in Task 4.

Manufacturers' aggregated and averaged estimations on the evolution of energy consumption are provided assuming the values of the base cases represent 100% each. As can be seen, the main differences occur in the energy consumption during the operating mode. The energy demand in the ready-to-use mode mainly influenced through improved insulation and a reduction in vaporisation losses of the wash tanks (M 4.1), only accounts for a minor part of the overall energy demand, leading only to limited overall saving potential.

Table 2-4 Estimated energy savings potential by improvement option for base case 1 (undercounter water-change)

	Annual energy consumption of the base case (kWh)	Relative consumption by improvement option, in comparison with the base case 1					
		M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficiency pumps & motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing
Continuous operation	1 249	97%	not considered[3]	not considered[4]	97%	98%	-
Standby consumption (Left-on mode)	5	100%	-	-	100%	100%	-
Overall energy consumption	1 254	**97%**	-	-	**97%**	**98%**	-

(Source: Manufacturers answers through questionnaire)

Table 2-5 Estimated energy savings potential by improvement option for base case 2 (undercounter one-tank)

	Annual energy consumption of the base case (kWh)	Relative consumption by improvement option, in comparison with the base case 2					
		M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficiency pumps & motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing
Continuous operation	4 391	90%	90%	90%	92%	100%	-
Initial filling	236	-	-	-	-	-	-
Standby consumption (Ready-to-use mode)	626	100%	100%	100%	100%	99%	-
Overall energy consumption[5]	5 253	**91.6%**	**91.6%**	**91.6%**	**93.3%**	**99.9%**	-

(Source: Manufacturers answers through questionnaire)

[3] Actually, the technical realisation within the available space seems not possible. Further, heat pumps in a temperature range of about 90°C seem to be not realisable with commercially available compressors.

[4] This design option is within the available space not realisable.

[5] Composed of continuous operation, standby consumption and initial filling (not displayed in the table)

Table 2-6 Estimated energy savings potential by improvement option for base case 3 (hood-type)

	Annual energy consumption of the base case (kWh)	Relative consumption by improvement option, in comparison with the base case 3					
		M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficiency pumps & motors	M 4.1 Insula-tion, closed bottom	M 1.5 Auxiliary rinsing
Continuous operation	6 845	88%	90%	85%	92%	100%	-
Initial filling	629	-	-	-	-	-	-
Standby consumption (Ready-to-use mode)	784	100%	100%	100%	100%	99%	-
Overall energy consumption[5]	8 258	**90.1%**	**91.7%**	**87.6%**	**93.4%**	**99.9%**	-

(Source: Manufacturers answers through questionnaire)

Table 2-7 Estimated energy savings potential by improvement option for base case 4 (utensil/pot)

	Annual energy consumption of the base case (kWh)	Relative consumption by improvement option, in comparison with the base case 4					
		M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficiency pumps & motors	M 4.1 Insula-tion, closed bottom	M 1.5 Auxiliary rinsing
Continuous operation	5 423	85%	90%	85%	92%	100%	-
Initial filling	1 257	-	-	-	-	-	-
Standby consumption (Ready-to-use mode)	2 233	100%	100%	100%	100%	99%	-
Overall energy consumption[5]	8 913	**90.9%**	**93.9%**	**90.9%**	**95.1%**	**99.7%**	-

(Source: Manufacturers answers through questionnaire)

Table 2-8 Estimated energy savings potential by improvement option for base case 5 (conveyor-type one-tank)

	Annual energy consumption of the base case (kWh)	Relative consumption by improvement option, in comparison with the base case 5					
		M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficiency pumps & motors	M 4.1 Insula-tion, closed bottom	M 1.5 Auxiliary rinsing
Continuous operation	34 259	80%	78%	85%	93%	100%	88%
Initial filling	1 728	-	-	-	-	-	-
Standby consumption (Ready-to-use mode)	1 716	100%	100%	100%	100%	98%	100%
Overall energy consumption[5]	37 703	**81.8%**	**80.0%**	**86.4%**	**93.6%**	**99.9%**	**89.1%**

(Source: Manufacturers answers through questionnaire)

Table 2-9 Estimated energy savings potential by improvement option for base case 6 (conveyor-type multi-tank)

	Annual energy consumption of the base case (kWh)	Relative consumption by improvement option, in comparison with the base case 6					
		M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficiency pumps & motors	M 4.1 Insula-tion, closed bottom	M 1.5 Auxiliary rinsing
Continuous operation	94 624	82%	75%	85%	88%	100%	88%
Initial filling	3 975	-	-	-	-	-	-
Standby consumption (Ready-to-use mode)	3 630	100%	100%	100%	100%	98%	99%
Overall energy consumption[5]	102 229	**83.3%**	**76.9%**	**86.1%**	**88.9%**	**99.9%**	**88.9%**

(Source: Manufacturers answers through questionnaire)

2.1.4 Water and detergent consumption

Assuming the detergent concentration is kept constant whatever quantity of water is required during the dishwashing operation, the change in detergent consumption is the same to the change in water consumption when implementing improvement options (in terms of percentage). In Table 2-10, manufacturers' aggregated and averaged estimations on the evolution of the water consumption are provided, assuming the values of the base cases represent 100% each.

Table 2-10 Relative water and detergent consumption by improvement option, in comparison with the base case[6]

	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps and motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing
BC 1 Undercounter water-change	100%	-	-	95%	100%	-
BC 2 Undercounter one-tank	100%	100%	100%	93%	100%	-
BC 3 Hood-type	100%	100%	100%	93%	100%	-
BC 4 Utensil/Pot	100%	100%	100%	93%	100%	-
BC 5 Conveyor-type one-tank	100%	100%	100%	90%	100%	88%
BC 6 Conveyor-type multi-tank	100%	100%	100%	85%	100%	88%

2.1.5 Prices and costs

The changes in purchase prices are shown in Table 2-11. The maintenance and repair costs of improved products are assumed to represent the same share of the purchase price as for the base cases: 37.5% for BC 1 and 44% for all other BCs (see Task 2). As a result, they change in the same way as purchase prices. Manufacturers' aggregated and averaged estimations on the evolution of the prices are provided assuming the values of the base cases represent 100% each.

Table 2-11 Purchase prices (and repair costs) by improvement option in comparison with the base case[7]

	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing
BC 1 Undercounter water-change	105%	-	-	108%	103%	-
BC 2 Undercounter one-tank	118%	200%	115%	113%	103%	-
BC 3 Hood-type	120%	200%	118%	115%	103%	-
BC 4 Utensil/Pot	117%	160%	109%	110%	101%	-
BC 5 Conveyor-type one-tank	115%	160%	120%	110%	108%	113%
BC 6 Conveyor-type multi-tank	108%	132%	115%	115%	106%	113%

[6] Source: Manufacturers answers through questionnaire

[7] Source: Manufacturers answers through questionnaire

2.2 Combination of design options: Best Available products

Most of the improvement options presented can be implemented at the same time in a single product but the marginal savings decrease with the number of options implemented.

The objective of this section was to find out the lowest, technically achievable energy and water consumption in the six categories by using all available and technically feasible improvement options and best available technology components. Because carrying out a thorough analysis of the marginal savings for each combination of improvement options would not be realistic and because the data obtained through the Tasks 6-7 questionnaire was not substantially completed by all manufacturers, only the overall combination of improvement options for each BC is presented in this task (the sum of all options, not all possible combinations). This corresponds to the best available product (BA product) on the market and the results are based on existing products produced by manufacturers. The individual design options that are implemented in the BA product for each BC are presented in Table 2-12.

Table 2-12 Description of the BA products, by base case[8,9]

	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing
BC 1 Undercounter water-change[10]	Yes	-	-	Yes	Yes	-
BC 2 Undercounter one-tank	Yes	-	Yes	Yes	Yes	-
BC 3 Hood-type	Yes	-	Yes	Yes	Yes	-
BC 4 **U**tensil/Pot	Yes	-	Yes	Yes	Yes	-
BC 5 Conveyor-type one-tank	Yes	Yes	(Yes)	Yes	Yes	Yes
BC 6 Conveyor-type multi-tank	Yes	Yes	(Yes)	Yes	Yes	Yes

The bills of materials of these BA products are directly derived from Table 2-2, by adding the indicated components to the composition of the corresponding base case.

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8 Source: Manufacturers answers through questionnaire

9 This is an "average" Bill of Materials for the product as the best available products of different manufacturers do not necessarily implement the same technical improvement features. Given the low importance of the production phase in the overall environmental impacts, this approximation is estimated reasonable.

10 The measures "exhaust air heat pump" and "waste water heat exchanger" have not been considered under BC 1 because of the restricted available space of this machine type.

The energy consumption and price evolutions in comparison with the base cases were obtained from manufacturers' information and are summarised in Table 2-13.

Table 2-13 Evolution of the volume, energy and water consumption and of the purchase price for BA products

	BA product of					
	BC 1	**BC 2**	**BC 3**	**BC 4**	**BC 5**	**BC 6**
Volume	**120%**	**125%**	**115%**	**109%**	**113%**	**109%**
Continuous operation	92%	86%	79%	78%	68%	60%
Standby consumption (Left-on/Ready-to-use mode)	100%	99.3%	99.3%	99.3%	98.7%	98.7%
Overall energy consumption	**92.0%**	**88.2%**	**82.5%**	**86.4%**	**70.9%**	**62.9%**
Overall water consumption	**95%**	**95%**	**95%**	**95%**	**85%**	**75%**
Purchase price (and repair and maintenance costs)	**116%**	**160%**	**177%**	**151%**	**181%**	**168%**

(Source: Manufacturers answers through questionnaire. The change in volume was assessed from the change in mass in the Bills of Materials. The overall energy consumption is a balanced average of the continuous and standby operation modes, like in section 2.1.3.)

2.3 Warm water input option

In Task 3, the fact that warm water can be used as a direct input to professional dishwashers is described. This can be considered as a sort of improvement option because the process of external water heating is normally more efficient when done at the building level than with electric resistance inside the appliance: the final energy required by the machine is exactly the same but the efficiency of the heating process is higher if warm water is used and the operating costs may be different depending on the source of primary energy (gas, wood, etc.). However, this alternative depends on the infrastructure available to the dishwasher's owner and it might not be possible to implement it in every situation. Furthermore, the objective of the European Commission is not to impose one or several type(s) of energy source to the end users. **Therefore, the option will be analysed from the environmental and economic perspectives like the other improvement options, but will however not be identified as the LLCC or BAT option when scoring best.**

From a technical point of view, the machine is considered to be exactly the same product as the base case (the number of inlet valves does not impose the use of cold or warm water): same bill of materials, same volume, same (final) energy, water and detergent consumption, same purchase price and repair and maintenance costs. The only two differences reside in the breakdown of the energy consumption, where a certain percentage will be brought to the system in the form of 'heat' via warm water (instead of electricity), and in the operating energy costs due to indirect primary energy consumption to heat the water externally.

To calculate the heat contained in the warm water consumed annually (see Table 2-14), the cold water temperature was assessed at 15°C and the warm water temperature at 60°C. The heat capacity of water considered is 4.19 kJ/(kg.K). The annual power input due to warm water is the direct result of the multiplication of the annual quantity of warm water consumed by the heat capacity of water and the temperature gap (45°C in this case).

The calculation of primary energy consumption necessary for the initial heating of the warm water is done automatically and taken into account in the environmental and economic analysis in EcoReport. The most common central heating boiler was estimated to be a gas boiler (non-condensing) with an efficiency of 90%.[11,12]

In the life cycle assessment, the production, distribution and end-of-life impacts of the boiler are not taken into account in the environmental impacts (only direct emissions and energy use are accounted for). First, these impacts are expected to be negligible in comparison with the impacts of the primary energy consumed during the use phase of the boiler. Besides, it would be very tricky to estimate what the percentage of the boiler operation dedicated to the dishwasher warm water is, on average in the EU-27. This share can indeed be very variable depending on the building considered. Boilers were already considered in an eco-design preparatory study (Lot 1 for DG ENER, eco-design requirements are expected to be defined in 2011 for this product category), as well as central heating products (Lot 21 for DG ENER).

Regarding the costs, it could be argued that the use of the external boiler generates additional installation, purchase and maintenance costs. However, it is believed that the investment for a central heating gas boiler would not be made just in order to supply a commercial dishwasher with warm water. The most common case is that the customer benefits from the infrastructure available and goes for a 100% electric product if it is not. As a result, the costs for the external boiler are already allocated to other processes and would exist anyway. Costs that could have possibly been taken into account in the analysis are the installation costs for the specific connection and pipes from the boiler to the dishwasher. However, given that the analysis of the warm water supply option will not be considered as BAT or LLCC option, this level of detail was not estimated necessary.

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11 Efficiency values in EcoReport relate to net calorific value (lower heating value).

12 Feedback from GDF-Suez.

Table 2-14 Warm water consumption and heat power inputs[13]

	Annual quantity of warm water consumed (m^3) Description of the technical characteristics of the machine	Annual heat power input due to warm water (kWh)[14]	Total annual energy consumption[15] (kWh)
BC 1 Undercounter water-change	12.96 Machine with two valves, using cold and warm water in continuous operation **Assumption:** 50% of the water input is warm water and the remaining share is cold water.	679	1 254
BC 2 Undercounter one-tank	55.82 Machine with one single valve using only warm water (for initial filling and final rinse)	2 926	5 253
BC 3 Hood-type	86.65 Machine with one single valve using only warm water (for initial filling and final rinse)	4 542	8 258
BC 4 Utensil/pot	89.52 Machine with one single valve using only warm water (for initial filling and final rinse)	4 692	8 913
BC 5 Conveyor-type one-tank	33.00 Machine with two or more valves using warm water for the initial filling and cold water for the final rinse	1 730	37 703
BC 6 Conveyor-type multi-tank	75.90 Machine with two or more valves using warm water for the initial filling and cold water for the final rinse	3 978	102 229

Due to the lack of data and the minor importance of alternative heating processes possible within the dishwashers (low pressure steam and hot water heating, see Table 13 in Task 3), the analysis of such appliances has not been done in this context. The environmental and economic results for this alternative internal heating option are however expected to be similar to the ones that will be presented for the warm water supply option, as these two options rely on the same principle: replace some share of the electricity consumption with a more efficient heating process based on gas water heating.

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[13] Source: Tasks 4 and 5 and own calculations

[14] Additional heat input in comparison with the base case situation, where only cold water is supplied. These figures result from direct calculations.

[15] This energy consumption is exactly the same as the total annual energy consumption of the base cases (see Task 5)

3 Impacts analysis

The aim of this sub-task is to quantify the environmental benefits and impacts of the improvement options. All relevant design improvements are investigated to see how the option affects the output values of the EcoReport. It is likely that the impact assessment will reveal trade-offs between some impact categories for a given option. For example, an option with less greenhouse gas emissions might result in increased non-renewable material consumption or waste generation. An appropriate weighting of the different impact categories is not easy to establish, and this matter merits further discussion with the European Commission and experts.

3.1 Base case 1: Undercounter water-change

The results of the environmental analysis of the improvement options for BC 1 are seen below. Excluding the warm water supply option, the BA product provides the greatest improvement for most of the impacts (up to 8% improvement in electricity consumption and water cooling) (Table 3-1). Then comes option M 4.2 (high efficient pumps and motors), reducing the electricity consumption by 3% and the eutrophication potential by 5%.

Regarding option M 2.1.1, its implementation is detrimental for many environmental indicators (e.g. +37% for non hazardous waste generation, +13% for heavy metals emissions in air, +2% for POP, +3% for PAHs and +5% PM emissions), which tends to show that the addition of material required for this option is not counterbalanced by the energy savings that it enables during the use phase.

Table 3-1 Environmental impacts by improvement option for base case 1

life-cycle indicators per unit	unit	Base Case 1	M 2.1.1 Exhaust air heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Other resources and waste							
Total Energy (GER)	GJ	196.5	192.9	190.1	193.4	183.3	145.8
	% change with BC	0%	-2%	-3%	-2%	-7%	-26%
of which, electricity	primary GJ	159.1	154.4	154.3	155.9	146.6	73.5
	MWh	15.1	14.7	14.7	14.8	14.0	7.0
	% change with BC	0%	-3%	-3%	-2%	-8%	-54%
Water (process)	kL	324.6	324.7	308.7	324.4	308.6	318.9
	% change with BC	0%	0%	-5%	0%	-5%	-2%
Water (cooling)	kL	422.7	410.2	410.1	414.3	389.2	194.6
	% change with BC	0%	-3%	-3%	-2%	-8%	-54%
Waste, non-haz./ landfill	kg	277.3	378.8	269.9	273.6	367.8	178.1
	% change with BC	0%	37%	-3%	-1%	33%	-36%
Waste, hazardous/ incinerated	kg	11.4	11.3	11.3	11.4	11.1	9.5
	% change with BC	0%	-1%	-1%	-1%	-3%	-17%
Emissions (Air)							
Greenhouse Gases in GWP100	t CO2 eq.	8.7	8.6	8.4	8.6	8.1	6.9
	% change with BC	0%	-2%	-3%	-2%	-6%	-21%
Acidification, emissions	kg SO2 eq.	51.8	52.4	50.1	51.0	49.9	30.3
	% change with BC	0%	1%	-3%	-2%	-4%	-41%
Volatile Organic Compounds (VOC)	kg	0.1	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	1%	-2%	-1%	-2%	-5%
Persistent Organic Pollutants (POP)	µg i-Teq	1.5	1.5	1.5	1.5	1.5	1.0
	% change with BC	0%	2%	-3%	-1%	-2%	-37%
Heavy Metals	g Ni eq.	7.4	8.4	7.3	7.4	8.2	6.0
	% change with BC	0%	13%	-1%	-1%	11%	-20%
PAHs	g Ni eq.	0.7	0.7	0.7	0.7	0.7	0.5
	% change with BC	0%	3%	-2%	-1%	0%	-25%
Particulate Matter (PM, dust)	kg	6.8	7.1	6.8	6.8	7.1	6.3
	% change with BC	0%	5%	-1%	0%	4%	-7%
Emissions (Water)							
Heavy Metals	g Hg/20	3.5	4.4	3.5	3.5	4.4	3.0
	% change with BC	0%	25%	-1%	-1%	24%	-16%
Eutrophication	kg PO4	56.0	56.1	53.2	56.0	53.3	56.0
	% change with BC	0%	0%	-5%	0%	-5%	0%

Figure 3-1 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the life cycle. For all improvement options excluding warm water supply, the share of electricity remains approximately the same (80-81% of the total primary energy) because of the important electricity consumption during the use phase. A significant difference can be observed for the “warm water”, where electricity represents only 50% of the total primary energy, due to the fact that a share of the energy heating the water comes from the external heating system (gas boiler in our model).

Figure 3-2 shows the evolution of some environmental indicators (GWP, acidification, PAHs and Eutrophication) for each design option.

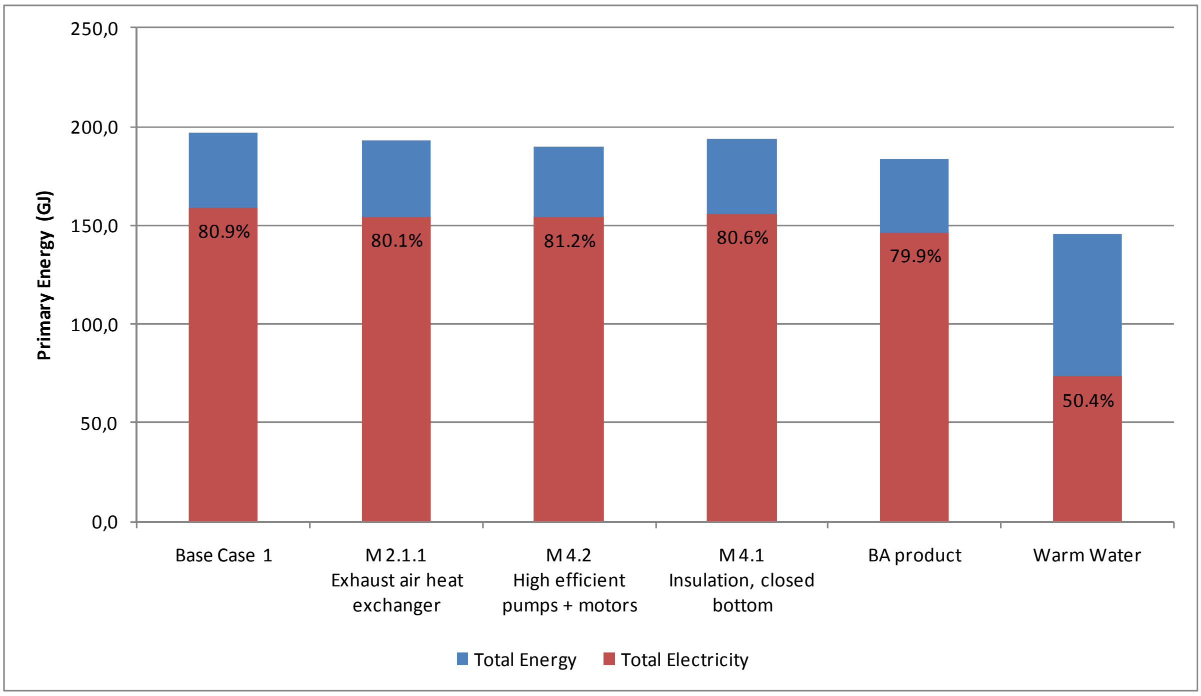

Figure 3-1 Energy consumption by improvement option for base case 1

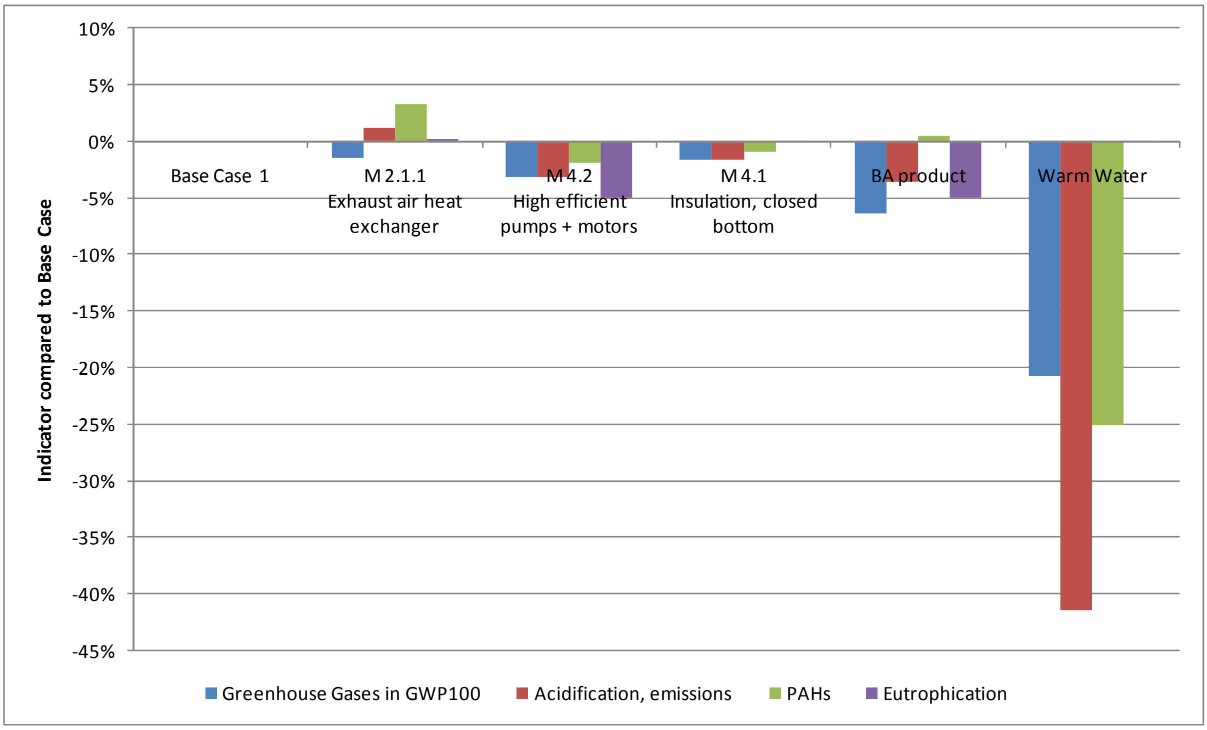

Figure 3-2 Improvement potential by improvement option for base case 1

3.2 Base case 2: Undercounter one-tank

The results of the environmental analysis of the improvement options for BC 2 are seen below. The BA product provides the greatest improvement for most of the impacts (up to 12% improvement in electricity consumption and water cooling) (Table 3-2), when warm water supply is not considered as a suitable option. Then come the single options M 2.1.1, M 3.1.1 and M 4.2 which have a similar overall influence on the environmental impacts. The option M 2.1.2 is detrimental for several environmental indicators (+66% for non-hazardous waste, +18% for PAHs, +20% for POP) despite reducing the electricity consumption by 8%. The option M 4.1 Insulation has a negligible influence on the environmental performance of the dishwasher.

Figure 3-3 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the life cycle. A significant difference can be observed for the breakdown of “warm water”. For other design options, the share of electricity remains approximately the same. Figure 3-4 shows the evolution of some environmental indicators for each design option. In particular, only option 4.2 and the BA product reduce the eutrophication potential, as these are the only options reducing the water consumption (and thus the detergent consumption as well).

Table 3-2 Environmental impacts by improvement option for base case 2

life-cycle indicators per unit	unit	Base Case 2	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Other resources and waste									
Total Energy (GER)	GJ	497.2	461.2	468.1	461.2	464.3	496.7	444.5	351.6
	% change with BC	0%	-7%	-6%	-7%	-7%	0%	-11%	-29%
of which, electricity	primary GJ	443.0	406.2	407.6	406.3	413.4	442.4	391.3	197.2
	MWh	42.2	38.7	38.8	38.7	39.4	42.1	37.3	18.8
	% change with BC	0%	-8%	-8%	-8%	-7%	0%	-12%	-55%
Water (process)	kL	481.5	479.4	482.0	479.8	448.2	481.5	456.8	465.1
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	-3%
Water (cooling)	kL	1 178.4	1 080.1	1 080.8	1 080.2	1 099.7	1 177.0	1 039.9	523.0
	% change with BC	0%	-8%	-8%	-8%	-7%	0%	-12%	-56%
Waste, non-haz./ landfill	kg	685.0	689.0	1 134.7	653.6	646.9	684.4	680.0	400.0
	% change with BC	0%	1%	66%	-5%	-6%	0%	-1%	-42%
Waste, hazardous/ incinerated	kg	18.4	17.5	18.2	17.5	17.6	18.4	17.1	12.7
	% change with BC	0%	-5%	-1%	-5%	-4%	0%	-7%	-31%
Emissions (Air)									
Greenhouse Gases in GWP100	t CO2 eq.	21.9	20.4	21.2	20.4	20.5	21.9	19.7	16.8
	% change with BC	0%	-7%	-3%	-7%	-7%	0%	-10%	-24%
Acidification, emissions	kg SO2 eq.	130.6	121.7	127.2	121.7	122.1	130.4	117.8	68.9
	% change with BC	0%	-7%	-3%	-7%	-6%	0%	-10%	-47%
Volatile Organic Compounds (VOC)	kg	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	% change with BC	0%	-5%	4%	-5%	-6%	0%	-7%	-9%
Persistent Organic Pollutants (POP)	µg i-Teq	3.8	3.6	4.4	3.6	3.5	3.7	3.6	2.1
	% change with BC	0%	-4%	18%	-4%	-6%	0%	-4%	-43%
Heavy Metals	g Ni eq.	16.8	17.1	23.5	17.7	16.2	16.8	18.3	12.6
	% change with BC	0%	2%	40%	5%	-3%	0%	9%	-25%
PAHs	g Ni eq.	1.4	1.4	1.7	1.4	1.4	1.4	1.4	0.9
	% change with BC	0%	-3%	20%	-5%	-5%	0%	-5%	-34%
Particulate Matter (PM, dust)	kg	7.7	7.8	10.3	7.8	7.5	7.6	8.0	6.3
	% change with BC	0%	1%	34%	2%	-2%	0%	4%	-17%
Emissions (Water)									
Heavy Metals	g Hg/20	7.9	8.3	13.0	8.6	7.7	7.9	9.1	6.3
	% change with BC	0%	5%	64%	8%	-2%	0%	15%	-20%
Eutrophication	kg PO4	80.8	80.8	80.9	80.8	75.1	80.8	76.8	80.8
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	0%

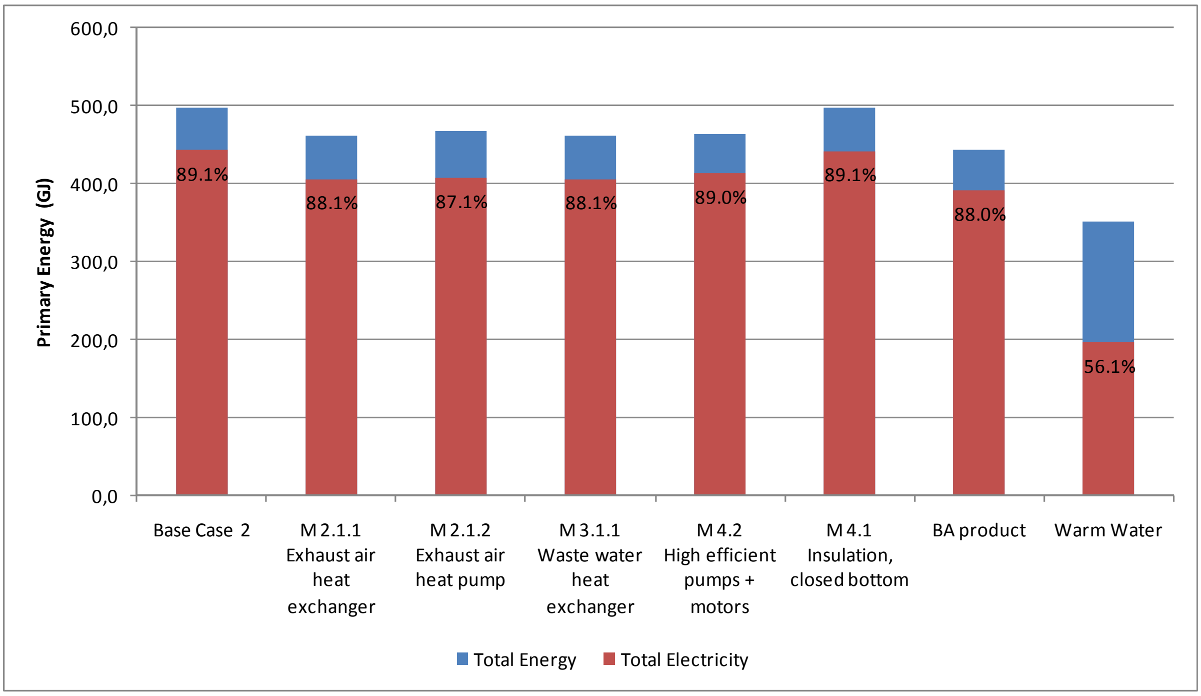

Figure 3-3 Energy consumption by improvement option for base case 2

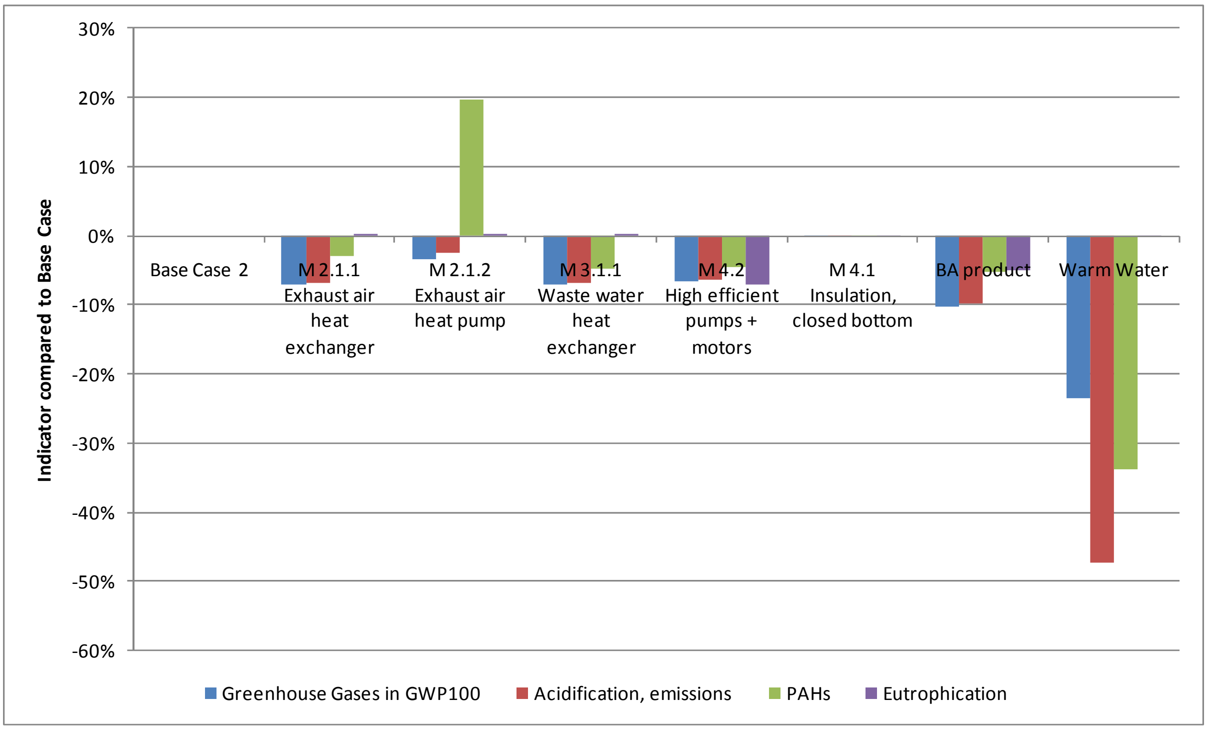

Figure 3-4 Improvement potential by improvement option for base case 2

3.3 Base case 3: Hood-type dishwashers

The results of the environmental analysis of the improvement options for BC 3 are seen below. The BA product provides the greatest improvement for most of the impacts (up to 17% improvement in electricity consumption and water cooling) (Table 3-3), when warm water supply is not considered as a suitable option. Then comes option M 3.1.1 Waste water heat exchanger, reducing the electricity consumption by 12% and the PAHs and POP emissions by 8%. Again, the option M 2.1.2 Exhaust air heat pump is detrimental for several environmental indicators.

Figure 3-5 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the life cycle. A significant difference can be observed for the “warm water supply”. For other design options, the share of electricity remains approximately the same (88-89%). Figure 3-6 shows the evolution of some environmental indicators for each design option, showing in particular that the heat pump increases the PAHs emissions in comparison with BC 3.

Table 3-3 Environmental impacts by improvement option for base case 3

life-cycle indicators per unit	unit	Base Case 3	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Other resources and waste									
Total Energy (GER)	GJ	781.2	713.1	731.6	695.9	730.0	780.6	658.0	555.2
	% change with BC	0%	-9%	-6%	-11%	-7%	0%	-16%	-29%
of which, electricity	primary GJ	696.4	627.5	640.4	610.3	650.4	695.7	575.5	314.8
	MWh	66.3	59.8	61.0	58.1	61.9	66.3	54.8	30.0
	% change with BC	0%	-10%	-8%	-12%	-7%	0%	-17%	-55%
Water (process)	kL	749.1	744.8	748.2	744.1	697.3	749.0	707.4	723.6
	% change with BC	0%	-1%	0%	-1%	-7%	0%	-6%	-3%
Water (cooling)	kL	1 852.2	1 668.3	1 699.6	1 622.3	1 729.5	1 850.5	1 529.2	834.8
	% change with BC	0%	-10%	-8%	-12%	-7%	0%	-17%	-55%
Waste, non-haz./ landfill	kg	1 079.2	1 046.0	1 505.1	990.6	1 019.8	1 078.5	992.4	636.9
	% change with BC	0%	-3%	39%	-8%	-6%	0%	-8%	-41%
Waste, hazardous/ incinerated	kg	26.1	24.5	25.4	24.1	24.9	26.1	23.2	17.3
	% change with BC	0%	-6%	-2%	-8%	-5%	0%	-11%	-34%
Emissions (Air)									
Greenhouse Gases in GWP100	t CO2 eq.	34.5	31.6	32.9	30.8	32.3	34.5	29.2	26.5
	% change with BC	0%	-9%	-5%	-11%	-6%	0%	-15%	-23%
Acidification, emissions	kg SO2 eq.	205.6	188.5	197.0	184.0	192.4	205.4	174.7	109.8
	% change with BC	0%	-8%	-4%	-11%	-6%	0%	-15%	-47%
Volatile Organic Compounds (VOC)	kg	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	% change with BC	0%	-7%	1%	-9%	-6%	0%	-12%	-9%
Persistent Organic Pollutants (POP)	µg i-Teq	6.0	5.6	6.5	5.5	5.7	6.0	5.4	3.5
	% change with BC	0%	-6%	9%	-8%	-6%	0%	-11%	-42%
Heavy Metals	g Ni eq.	28.3	28.1	34.7	28.4	27.5	28.3	28.7	21.8
	% change with BC	0%	-1%	22%	0%	-3%	0%	1%	-23%
PAHs	g Ni eq.	2.1	2.0	2.4	2.0	2.0	2.1	1.9	1.4
	% change with BC	0%	-5%	12%	-8%	-5%	0%	-10%	-35%
Particulate Matter (PM, dust)	kg	12.4	12.4	15.4	12.4	12.2	12.4	12.5	10.4
	% change with BC	0%	0%	24%	-1%	-2%	0%	0%	-17%
Emissions (Water)									
Heavy Metals	g Hg/20	13.5	13.7	18.5	13.9	13.2	13.5	14.3	11.1
	% change with BC	0%	1%	37%	2%	-2%	0%	5%	-18%
Eutrophication	kg PO4	125.5	125.5	125.6	125.5	116.7	125.5	119.3	125.5
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	0%

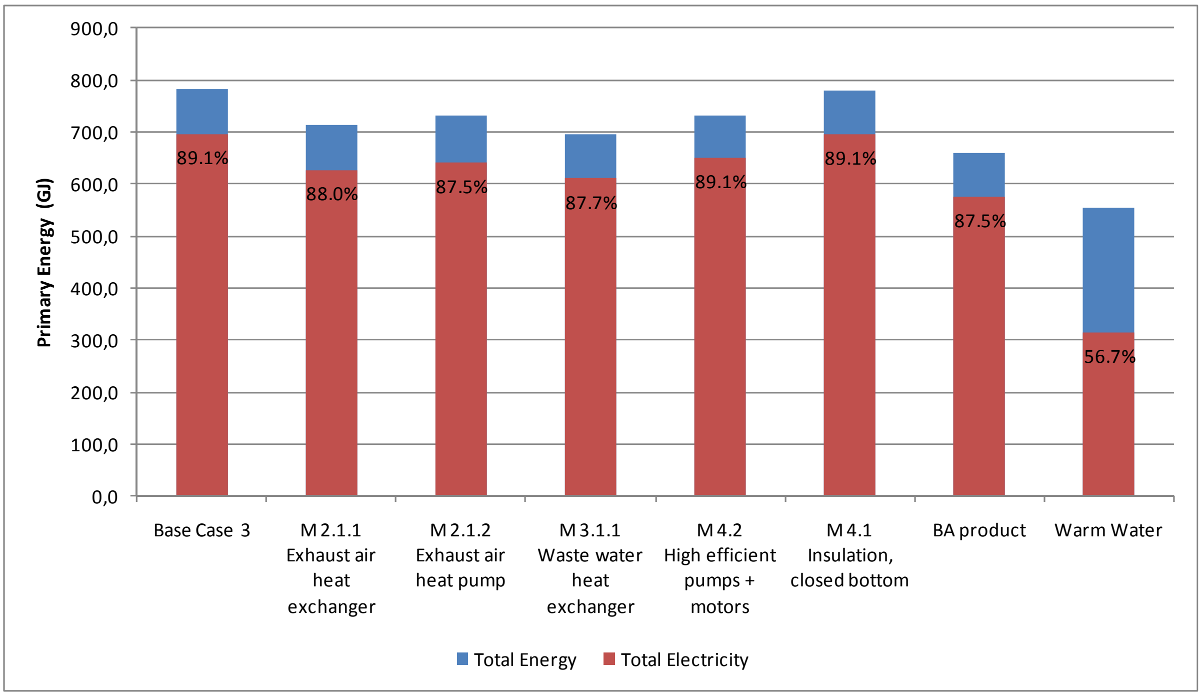

Figure 3-5 Energy consumption by improvement option for base case 3

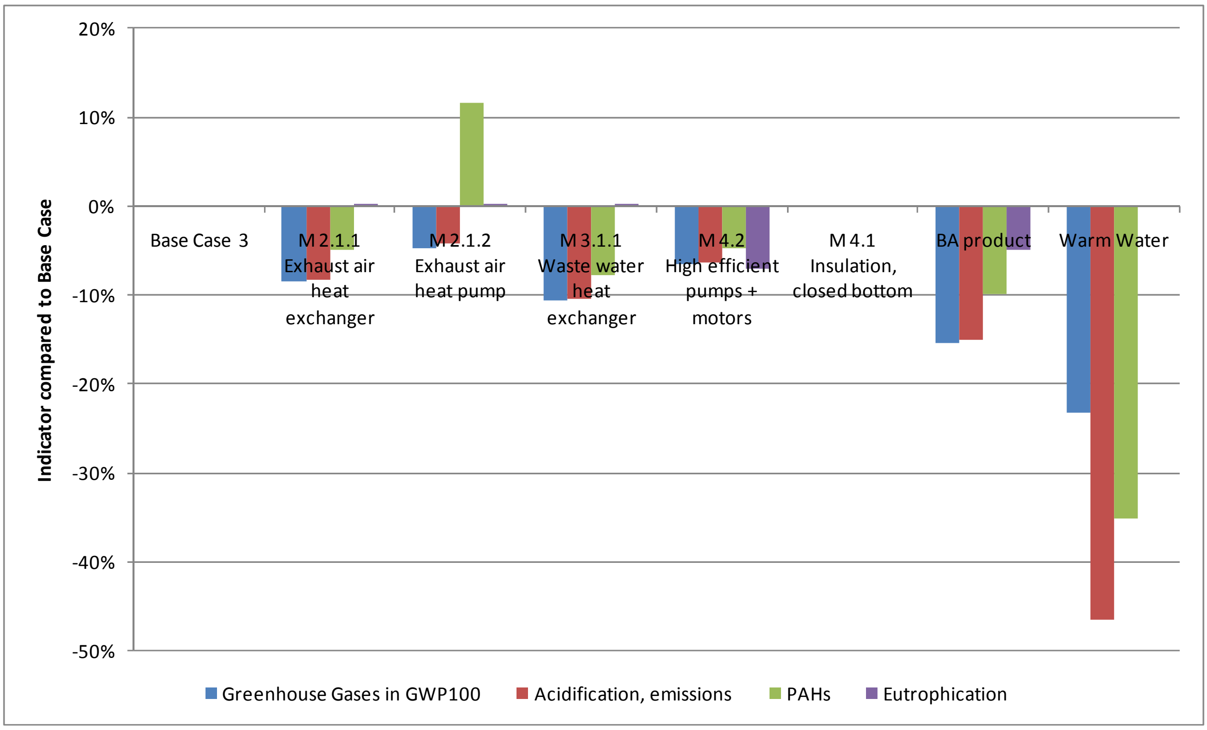

Figure 3-6 Improvement potential by improvement option for base case 3

3.4 Base case 4: Utensil/pot dishwashers

The results of the environmental analysis of the improvement options for BC 4 are seen below. The BA product provides the greatest improvement for most of the impacts (up to 13% improvement in electricity consumption) (Table 3-4), when warm water supply is not considered as a suitable option. Then come the single improvement options M 2.1.1 Exhaust air heat exchanger and M 3.1.1 Waste water heat exchanger with approximately the same environmental results. Again, the option M 2.1.2 Heat pump is detrimental for several environmental indicators.

Figure 3-7 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the life cycle. A significant difference can be observed for the “warm water” supply but for other design options, the share of electricity remains approximately the same (87-88%). Figure 3-8 shows changes in environmental indicators for each design option.

Table 3-4 Environmental impacts by improvement option for base case 4

life-cycle indicators per unit	unit	Base Case 4	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Other resources and waste									
Total Energy (GER)	GJ	850.7	783.4	814.6	783.4	809.0	848.8	747.5	617.3
	% change with BC	0%	-8%	-4%	-8%	-5%	0%	-12%	-27%
of which, electricity	primary GJ	754.0	685.9	710.0	685.9	717.6	752.2	652.9	359.9
	MWh	71.8	65.3	67.6	65.3	68.3	71.6	62.2	34.3
	% change with BC	0%	-9%	-6%	-9%	-5%	0%	-13%	-52%
Water (process)	kL	782.1	777.9	782.0	778.3	729.4	782.0	740.6	755.8
	% change with BC	0%	-1%	0%	0%	-7%	0%	-5%	-3%
Water (cooling)	kL	2 000.7	1 818.6	1 880.0	1 818.7	1 903.6	1 995.7	1 730.2	949.7
	% change with BC	0%	-9%	-6%	-9%	-5%	0%	-14%	-53%
Waste, non-haz./ landfill	kg	1 271.8	1 239.4	1 712.1	1 204.0	1 223.5	1 269.7	1 207.9	814.9
	% change with BC	0%	-3%	35%	-5%	-4%	0%	-5%	-36%
Waste, hazardous/ incinerated	kg	34.6	33.0	34.2	33.0	33.6	34.5	32.1	25.5
	% change with BC	0%	-5%	-1%	-5%	-3%	0%	-7%	-26%
Emissions (Air)									
Greenhouse Gases in GWP100	t CO2 eq.	38.0	35.0	36.9	35.1	36.1	37.9	33.5	29.6
	% change with BC	0%	-8%	-3%	-8%	-5%	0%	-12%	-22%
Acidification, emissions	kg SO2 eq.	226.5	209.6	221.3	209.6	215.8	226.1	200.7	127.6
	% change with BC	0%	-7%	-2%	-7%	-5%	0%	-11%	-44%
Volatile Organic Compounds (VOC)	kg	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	% change with BC	0%	-4%	7%	-4%	-3%	0%	-6%	-6%
Persistent Organic Pollutants (POP)	µg i-Teq	7.1	6.7	7.7	6.7	6.8	7.0	6.6	4.5
	% change with BC	0%	-5%	9%	-5%	-4%	0%	-7%	-37%
Heavy Metals	g Ni eq.	40.9	40.7	47.5	41.3	40.2	40.9	41.6	34.2
	% change with BC	0%	-1%	16%	1%	-2%	0%	2%	-17%
PAHs	g Ni eq.	2.9	2.8	3.2	2.8	2.8	2.9	2.7	2.1
	% change with BC	0%	-3%	11%	-4%	-3%	0%	-6%	-27%
Particulate Matter (PM, dust)	kg	30.8	31.3	38.4	31.3	30.6	30.8	31.9	28.7
	% change with BC	0%	2%	25%	2%	-1%	0%	4%	-7%
Emissions (Water)									
Heavy Metals	g Hg/20	21.1	21.3	26.2	21.6	20.9	21.1	22.0	18.6
	% change with BC	0%	1%	24%	2%	-1%	0%	4%	-12%
Eutrophication	kg PO4	126.5	126.5	126.6	126.5	117.7	126.5	120.2	126.5
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	0%

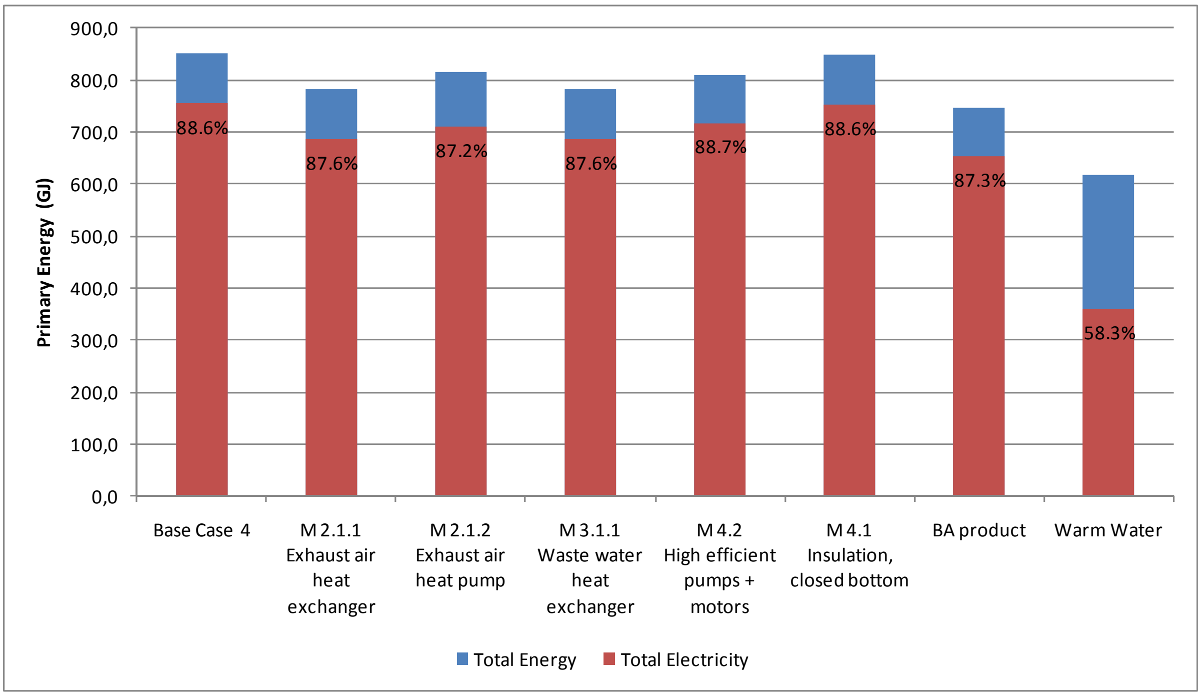

Figure 3-7 Energy consumption by improvement option for base case 4

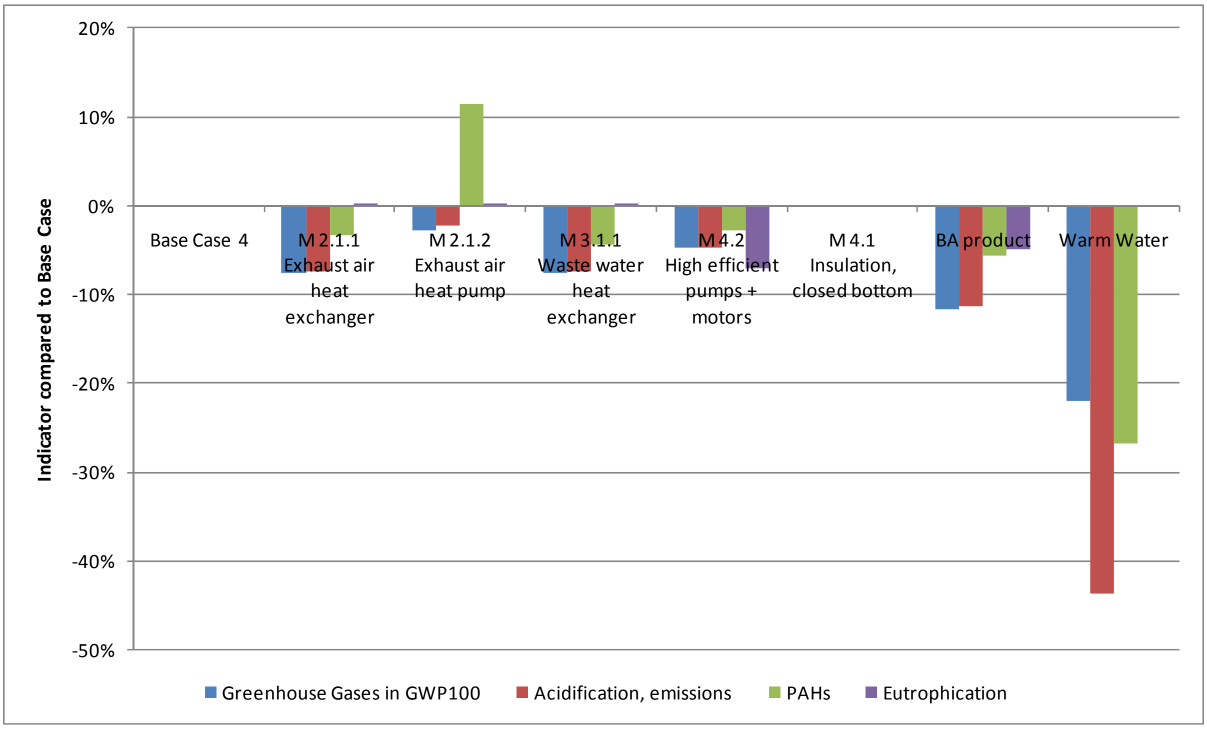

Figure 3-8 Improvement potential by improvement option for base case 4

3.5 Base case 5: Conveyor-type one-tank

The results of the environmental analysis of the improvement options for base case 5 are shown below. The “BA product” provides the greatest improvement for most of the impacts (up to 29% improvement in electricity consumption and water cooling) (Table 3-5), even when warm water is considered as a suitable option. The “warm water” is by far not as beneficial as it was for the previous base cases and the implementation of the heat pump (M 2.1.2) is now reducing substantially all the environmental impacts. For this product category, the base case is scoring worst for every environmental indicator considered.

Figure 3-9 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the life cycle. Important differences can be observed in terms of energy consumption between the design options but the share of electricity is always around 90-92% of the total primary energy consumed. Figure 3-10 shows the evolution of some environmental indicators for each design option. In particular, we notice that the GWP, acidification and PAHs emission indicators are correlated to the energy efficiency while the eutrophication is linked to the water efficiency (options M 1.5, M 4.2 and BA product).

Table 3-5 Environmental impacts by improvement option for base case 5

life-cycle indicators per unit	unit	Base Case 5	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing	BA product	Warm Water
Other resources and waste										
Total Energy (GER)	GJ	5 188.2	4 325.7	4 246.9	4 541.6	4 852.8	5 183.8	4 631.7	3 765.8	5 059.0
	% change with BC	0%	-17%	-18%	-12%	-6%	0%	-11%	-27%	-2%
of which, electricity	primary GJ	4 773.4	3 910.2	3 825.2	4 126.1	4 471.2	4 769.1	4 255.7	3 391.4	4 555.4
	MWh	454.6	372.4	364.3	393.0	425.8	454.2	405.3	323.0	433.8
	% change with BC	0%	-18%	-20%	-14%	-6%	0%	-11%	-29%	-5%
Water (process)	kL	3 449.4	3 392.2	3 389.0	3 407.0	3 121.6	3 449.1	3 046.5	2 900.6	3 434.8
	% change with BC	0%	-2%	-2%	-1%	-10%	0%	-12%	-16%	0%
Water (cooling)	kL	12 686.0	10 383.9	10 154.4	10 959.5	11 880.2	12 674.5	11 304.9	8 996.1	12 104.7
	% change with BC	0%	-18%	-20%	-14%	-6%	0%	-11%	-29%	-5%
Waste, non-haz./ landfill	kg	7 733.8	6 779.6	7 125.4	6 994.4	7 344.9	7 728.8	7 131.1	6 666.1	7 481.0
	% change with BC	0%	-12%	-8%	-10%	-5%	0%	-8%	-14%	-3%
Waste, hazardous/ incinerated	kg	197.9	178.0	176.7	182.9	190.1	197.8	185.4	165.9	192.8
	% change with BC	0%	-10%	-11%	-8%	-4%	0%	-6%	-16%	-3%
Emissions (Air)										
Greenhouse Gases in GWP100	t CO2 eq.	229.5	191.9	188.9	201.3	214.9	229.3	205.2	168.1	224.9
	% change with BC	0%	-16%	-18%	-12%	-6%	0%	-11%	-27%	-2%
Acidification, emissions	kg SO2 eq.	1 372.3	1 150.6	1 134.1	1 206.2	1 285.9	1 371.2	1 229.7	1 011.7	1 317.6
	% change with BC	0%	-16%	-17%	-12%	-6%	0%	-10%	-26%	-4%
Volatile Organic Compounds (VOC)	kg	2.4	2.1	2.1	2.2	2.3	2.4	2.2	1.9	2.4
	% change with BC	0%	-13%	-14%	-10%	-5%	0%	-9%	-21%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	40.2	34.7	34.9	36.1	38.0	40.2	36.7	32.1	38.8
	% change with BC	0%	-14%	-13%	-10%	-5%	0%	-9%	-20%	-4%
Heavy Metals	g Ni eq.	193.0	179.1	184.0	183.4	187.2	192.9	185.0	179.8	189.2
	% change with BC	0%	-7%	-5%	-5%	-3%	0%	-4%	-7%	-2%
PAHs	g Ni eq.	17.2	15.5	15.7	15.9	16.5	17.1	16.1	14.8	16.7
	% change with BC	0%	-10%	-9%	-7%	-4%	0%	-6%	-14%	-2%
Particulate Matter (PM, dust)	kg	96.0	91.8	95.7	93.0	94.1	96.0	93.7	94.8	94.8
	% change with BC	0%	-4%	0%	-3%	-2%	0%	-2%	-1%	-1%
Emissions (Water)										
Heavy Metals	g Hg/20	97.6	92.7	96.9	94.3	95.7	97.6	95.4	96.6	96.2
	% change with BC	0%	-5%	-1%	-3%	-2%	0%	-2%	-1%	-1%
Eutrophication	kg PO4	558.2	558.2	558.3	558.2	502.6	558.2	491.4	474.8	558.2
	% change with BC	0%	0%	0%	0%	-10%	0%	-12%	-15%	0%

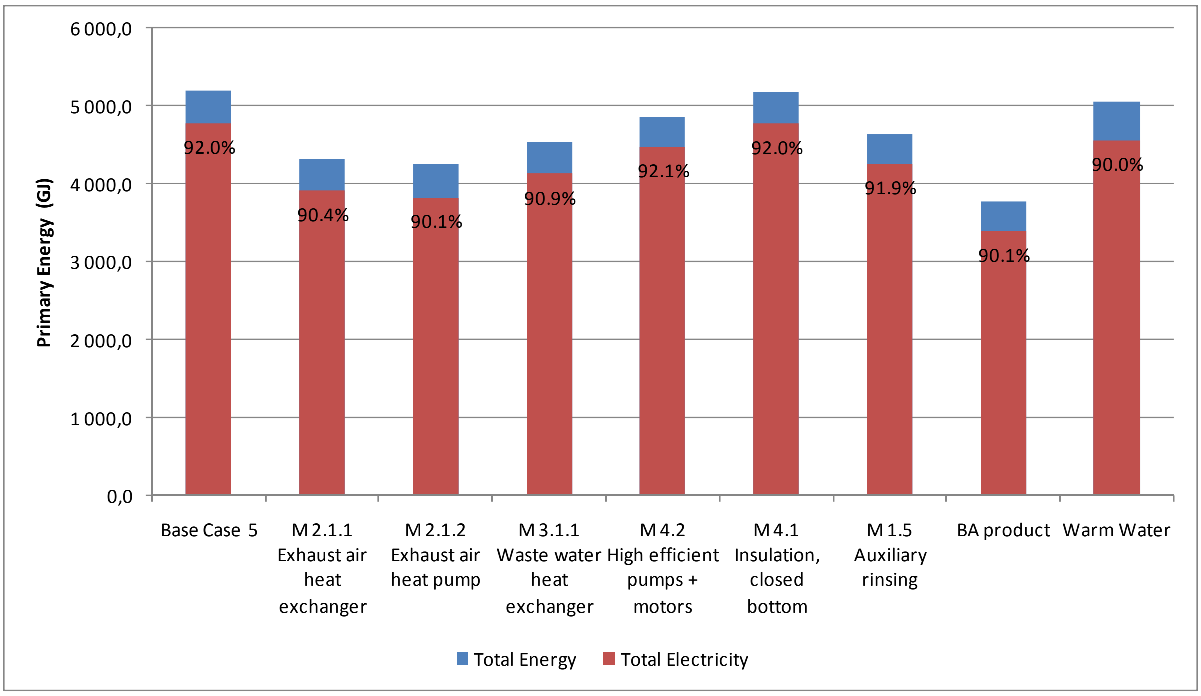

Figure 3-9 Energy consumption by improvement option for base case 5

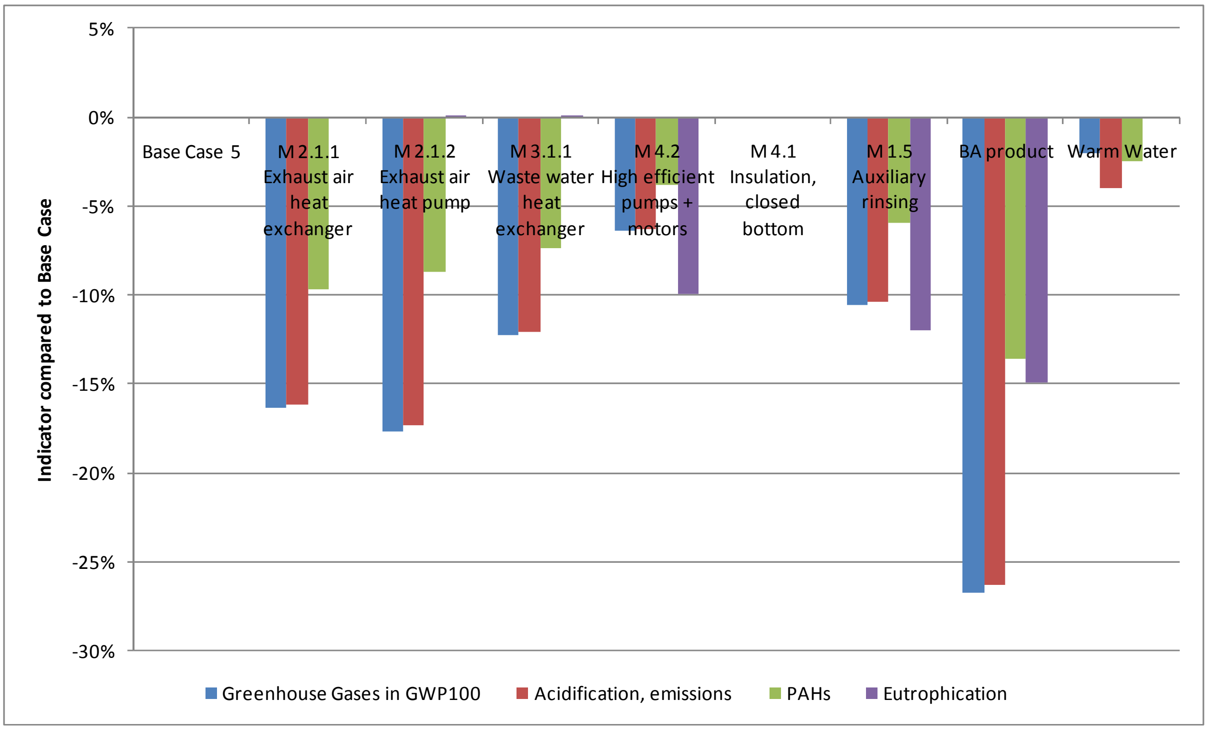

Figure 3-10 Improvement potential by improvement option for base case 5

3.6 Base case 6: Conveyor-type multi-tank

The results of the environmental analysis of the improvement options for BC 6 are seen below. The BA product provides the greatest improvement for most of the impacts (up to 37% improvement in electricity consumption and water cooling) (Table 3-6), even when warm water is considered as a suitable option. Similarly to base case 5, the “warm water” is by far not as beneficial as it was for the base cases 1 to 4 and the implementation of the heat pump (M 2.1.2) is also reducing substantially all the environmental impacts. The base case is scoring worst for every environmental indicator considered.

Figure 3-11 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the life cycle. Important differences can be observed in terms of energy consumption between the design options. Figure 3-12 shows the evolution of some environmental indicators for each design option.

Table 3-6 Environmental impacts by improvement option for base case 6

life-cycle indicators per unit	unit	Base Case 6	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing	BA product	Warm Water
Other resources and waste										
Total Energy (GER)	GJ	19 567.1	16 527.7	15 352.8	17 034.5	17 365.2	19 554.2	17 395.1	12 522.1	19 146.5
	% change with BC	0%	-16%	-22%	-13%	-11%	0%	-11%	-36%	-2%
of which, electricity	primary GJ	18 282.0	15 241.9	14 060.9	15 748.6	16 255.1	18 269.0	16 248.9	11 519.5	17 571.9
	MWh	1 741.1	1 451.6	1 339.1	1 499.9	1 548.1	1 739.9	1 547.5	1 097.1	1 673.5
	% change with BC	0%	-17%	-23%	-14%	-11%	0%	-11%	-37%	-4%
Water (process)	kL	12 273.5	12 071.2	11 995.0	12 105.4	10 492.9	12 272.7	10 822.4	9 085.0	12 226.2
	% change with BC	0%	-2%	-2%	-1%	-15%	0%	-12%	-26%	0%
Water (cooling)	kL	48 686.4	40 579.1	37 426.9	41 930.4	43 281.5	48 651.8	43 264.4	30 648.7	46 792.9
	% change with BC	0%	-17%	-23%	-14%	-11%	0%	-11%	-37%	-4%
Waste, non-haz./ landfill	kg	24 668.6	21 190.4	20 265.4	21 742.4	22 115.6	24 653.6	22 192.7	17 081.9	23 845.3
	% change with BC	0%	-14%	-18%	-12%	-10%	0%	-10%	-31%	-3%
Waste, hazardous/ incinerated	kg	548.6	478.5	452.0	490.2	497.8	548.3	498.9	387.1	532.2
	% change with BC	0%	-13%	-18%	-11%	-9%	0%	-9%	-29%	-3%
Emissions (Air)										
Greenhouse Gases in GWP100	t CO2 eq.	858.6	726.0	675.2	748.1	762.5	858.0	763.8	551.8	843.6
	% change with BC	0%	-15%	-21%	-13%	-11%	0%	-11%	-36%	-2%
Acidification, emissions	kg SO2 eq.	5 088.4	4 306.2	4 007.4	4 436.6	4 521.1	5 085.1	4 529.7	3 279.6	4 910.2
	% change with BC	0%	-15%	-21%	-13%	-11%	0%	-11%	-36%	-4%
Volatile Organic Compounds (VOC)	kg	8.1	6.9	6.5	7.1	7.2	8.0	7.2	5.4	8.0
	% change with BC	0%	-14%	-19%	-12%	-10%	0%	-10%	-32%	-1%
Persistent Organic Pollutants (POP)	µg i-Teq	137.6	117.8	110.9	121.1	123.2	137.5	123.4	92.6	132.9
	% change with BC	0%	-14%	-19%	-12%	-10%	0%	-10%	-33%	-3%
Heavy Metals	g Ni eq.	493.8	442.5	428.7	451.8	456.0	493.5	458.1	384.1	481.6
	% change with BC	0%	-10%	-13%	-8%	-8%	0%	-7%	-22%	-2%
PAHs	g Ni eq.	46.7	40.7	38.7	41.7	42.3	46.6	42.4	33.2	45.3
	% change with BC	0%	-13%	-17%	-11%	-9%	0%	-9%	-29%	-3%
Particulate Matter (PM, dust)	kg	211.8	195.6	193.0	198.4	199.7	211.7	200.5	179.1	208.0
	% change with BC	0%	-8%	-9%	-6%	-6%	0%	-5%	-15%	-2%
Emissions (Water)										
Heavy Metals	g Hg/20	217.5	198.5	195.6	202.0	204.4	217.4	205.4	181.8	212.9
	% change with BC	0%	-9%	-10%	-7%	-6%	0%	-6%	-16%	-2%
Eutrophication	kg PO4	1 958.6	1 958.5	1 958.6	1 958.5	1 665.2	1 958.6	1 723.9	1 469.7	1 958.6
	% change with BC	0%	0%	0%	0%	-15%	0%	-12%	-25%	0%

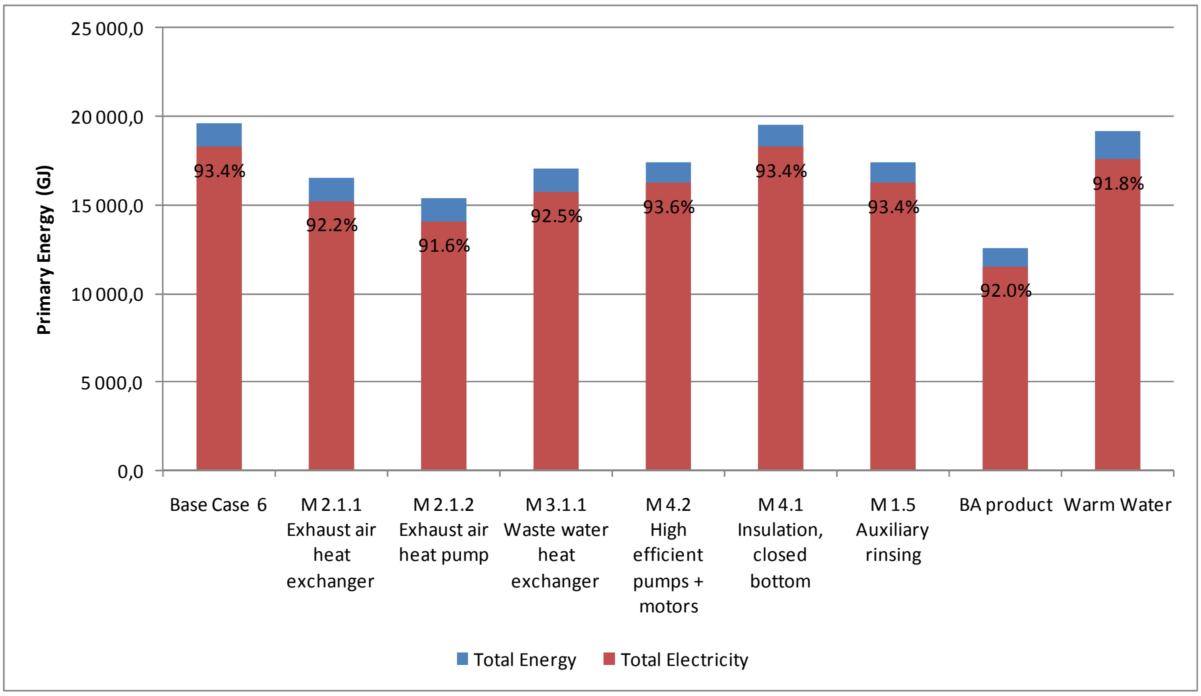

Figure 3-11 Energy consumption by improvement option for base case 6

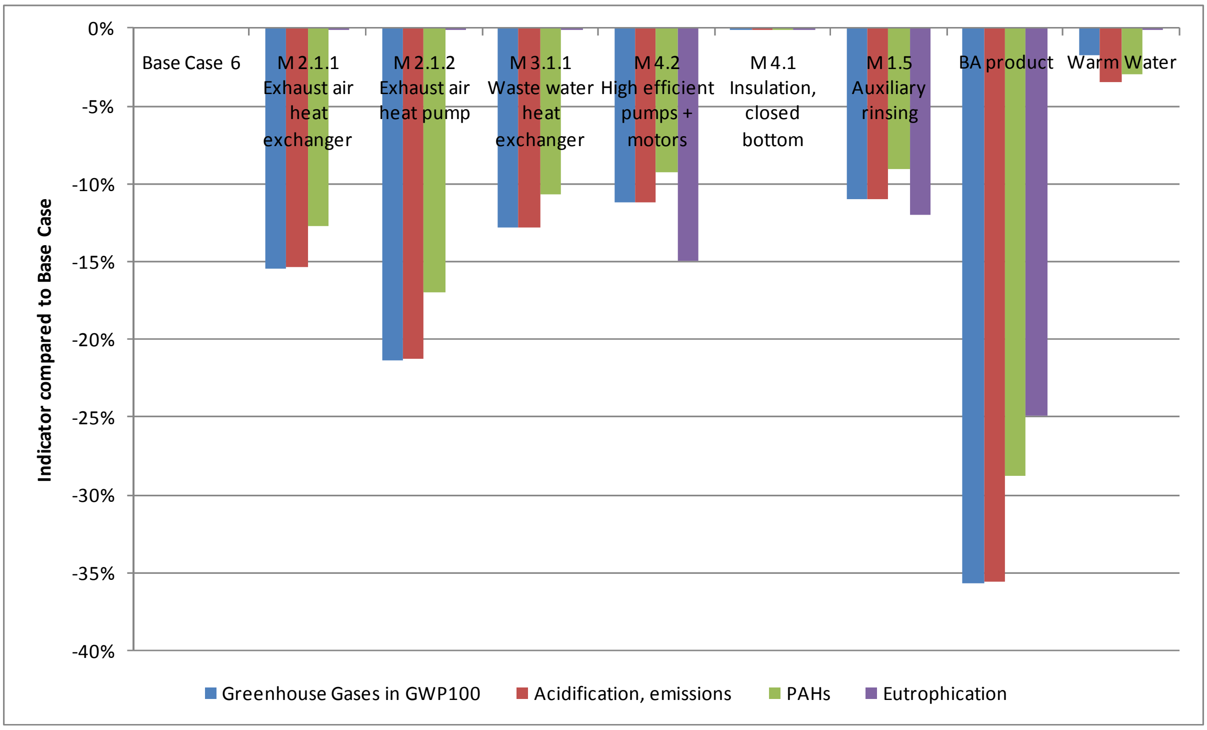

Figure 3-12 Improvement potential by improvement option for base case 6

4 Costs analysis

The aim of this sub-task is to assess the LCC of each of the design options (and their combination) considered. In doing so, the quantification will cover both the purchase prices and the operating expenses by consumers, as in Task 5.

The approach chosen, and deemed to be the most relevant for the type of options selected, is to consider the marginal costs due to the improvement options. The extent to which the various costs are expected to change from the LCC established for the base cases in Task 5 is analysed. This approach is relevant here because the options considered constitute more an evolution or additional features than a complete technological revolution of the products.

4.1 Base case 1: Undercounter water-change

The three individual improvement options analysed would result in an increase in the purchase price of BC 1, meaning that the BA product would result in an increase of 16% (Table 4-1). On the other hand, electricity costs are only slightly reduced (8% for the BA product) and do not overbalance the higher purchase price, resulting in LCC increases (1-2% for individual improvement options, or 4% for the BA product).

As previously assumed, the warm water supply does not affect the purchase price. LCC of the warm water option is 7% lower than the base case and electricity costs are reduced significantly, though the option does imply gas costs.

Table 4-1 Life cycle costs by improvement option for base case 1

life-cycle indicators per unit	unit	Base Case 1	M 2.1.1 Exhaust air heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
		Economic indicators					
Purchase price	€	3 200	3 360	3 456	3 296	3 712	3 200
	% change with BC	0%	5%	8%	3%	16%	0%
Electricity costs	€	1 624	1 576	1 576	1 592	1 495	745
	% change with BC	0%	-3%	-3%	-2%	-8%	-54%
Water and detergent costs	€	3 092	3 092	2 937	3 092	2 937	3 092
	% change with BC	0%	0%	-5%	0%	-5%	0%
Maintenance and repair costs	€	939	985	1 014	967	1 089	939
	% change with BC	0%	5%	8%	3%	16%	0%
Gas costs	€	0	0	0	0	0	286
	% change with BC	-	-	-	-	-	-
Life-cycle cost	€	8 854	9 013	8 982	8 946	9 232	8 261
	% change with BC	0%	2%	1%	1%	4%	-7%

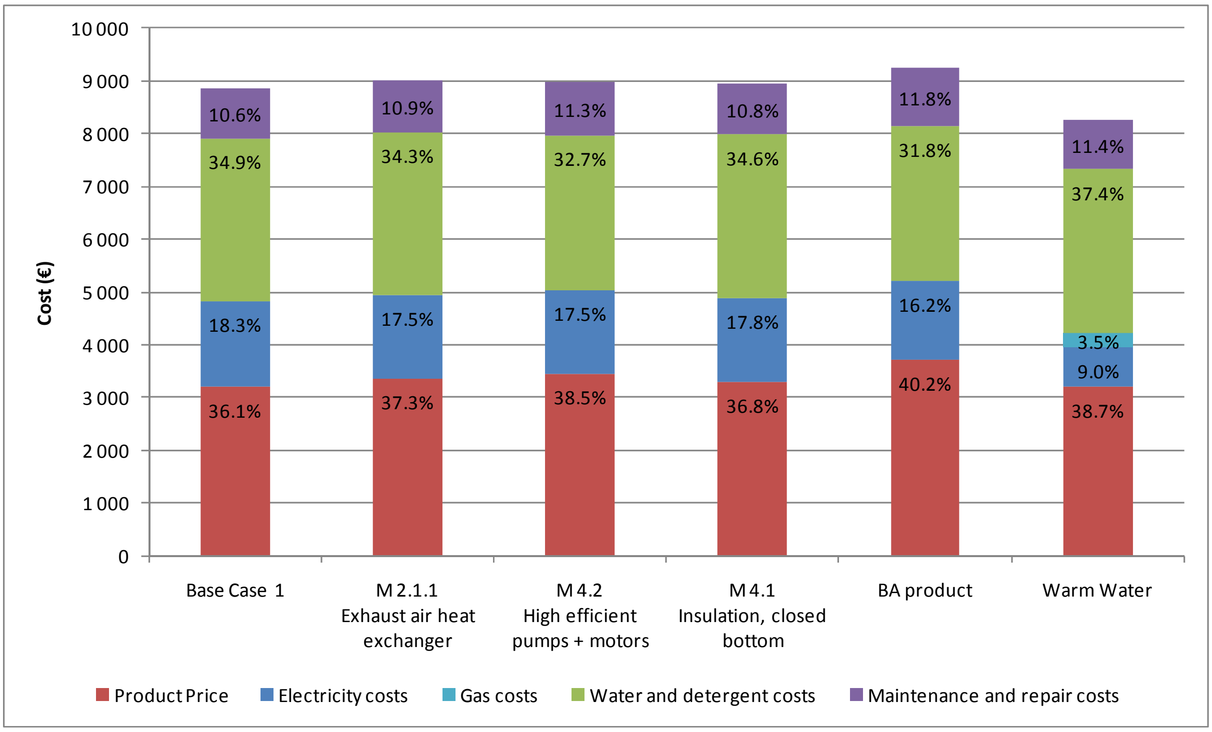

Figure 4-1 Life cycle costs breakdown by improvement option for base case 1

4.2 Base case 2: Undercounter one-tank

For BC 2, the exhaust air heat pump option would double the purchase price to 7 000 Euro and increase LCC by 30%. Implementation of high efficiency pumps and motors would slightly reduce the LCC and increase the purchase price by 13%.

Again the warm water supply option results in an important decrease of the LCC of 13%. As for the other base cases it reduces electricity costs but implies additional gas costs, of 884 Euro this time.

Table 4-2 Life cycle costs by improvement option for base case 2

life-cycle indicators per unit	unit	Base Case 2	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Economic indicators									
Purchase price	€	3 500	4 130	7 000	4 025	3 955	3 605	5 600	3 500
	% change with BC	0%	18%	100%	15%	13%	3%	60%	0%
Electricity costs	€	4 881	4 473	4 473	4 473	4 554	4 875	4 305	2 162
	% change with BC	0%	-8%	-8%	-8%	-7%	0%	-12%	-56%
Water and detergent costs	€	4 789	4 789	4 789	4 789	4 454	4 789	4 550	4 789
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	0%
Maintenance and repair costs	€	1 296	1 529	2 592	1 490	1 465	1 335	2 074	1 296
	% change with BC	0%	18%	100%	15%	13%	3%	60%	0%
Gas costs	€	0	0	0	0	0	0	0	884
	% change with BC	-	-	-	-	-	-	-	-
Life-cycle cost	€	14 466	14 922	18 854	14 778	14 428	14 604	16 529	12 632
	% change with BC	0%	3%	30%	2%	0%	1%	14%	-13%

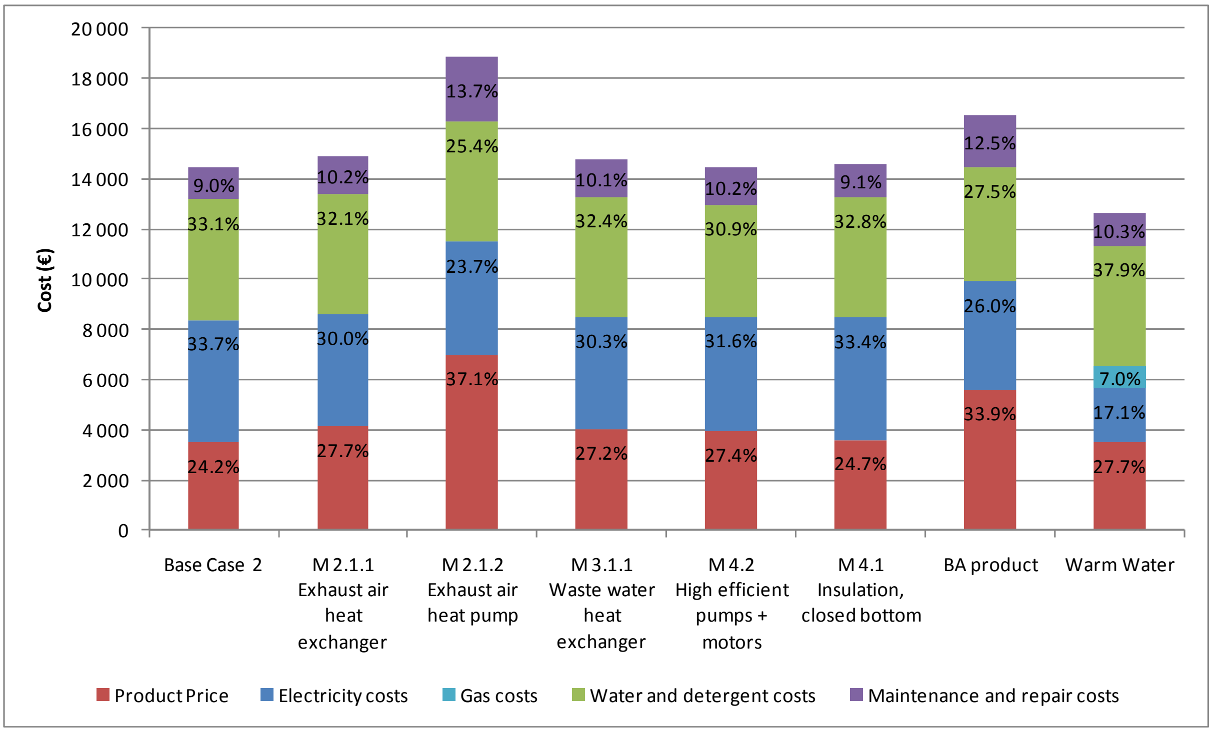

Figure 4-2 Life cycle costs breakdown by improvement option for base case 2

4.3 Base case 3: Hood-type dishwashers

For hood-type dishwashers, again the exhaust air heat pump option doubles the purchase price and increases LCC by a similar percentage (30%). And again, high efficiency pumps and motors would leave the LCC almost unchanged (by reducing water and detergent costs by 7%) and increase the purchase price, by 15%. Here, the warm water option reduces LCC by 10%, with gas costs of 1 226 Euro.

Table 4-3 Life cycle costs by improvement option for base case 3

life-cycle indicators per unit	unit	Base Case 3	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Economic indicators									
Purchase price	**€**	4 700	5 640	9 400	5 546	5 405	4 841	8 319	4 700
	% change with BC	0%	20%	100%	18%	15%	3%	77%	0%
Electricity costs	**€**	5 838	5 257	5 354	5 112	5 451	5 832	4 818	2 627
	% change with BC	0%	-10%	-8%	-12%	-7%	0%	-17%	-55%
Water and detergent costs	**€**	7 438	7 438	7 438	7 438	6 917	7 438	7 066	7 438
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	0%
Maintenance and repair costs	**€**	1 740	2 088	3 481	2 054	2 001	1 793	3 081	1 740
	% change with BC	0%	20%	100%	18%	15%	3%	77%	0%
Gas costs	**€**	0	0	0	0	0	0	0	1 226
	% change with BC	-	-	-	-	-	-	-	-
Life-cycle cost	**€**	19 716	20 424	25 673	20 150	19 775	19 904	23 283	17 731
	% change with BC	0%	4%	30%	2%	0%	1%	18%	-10%

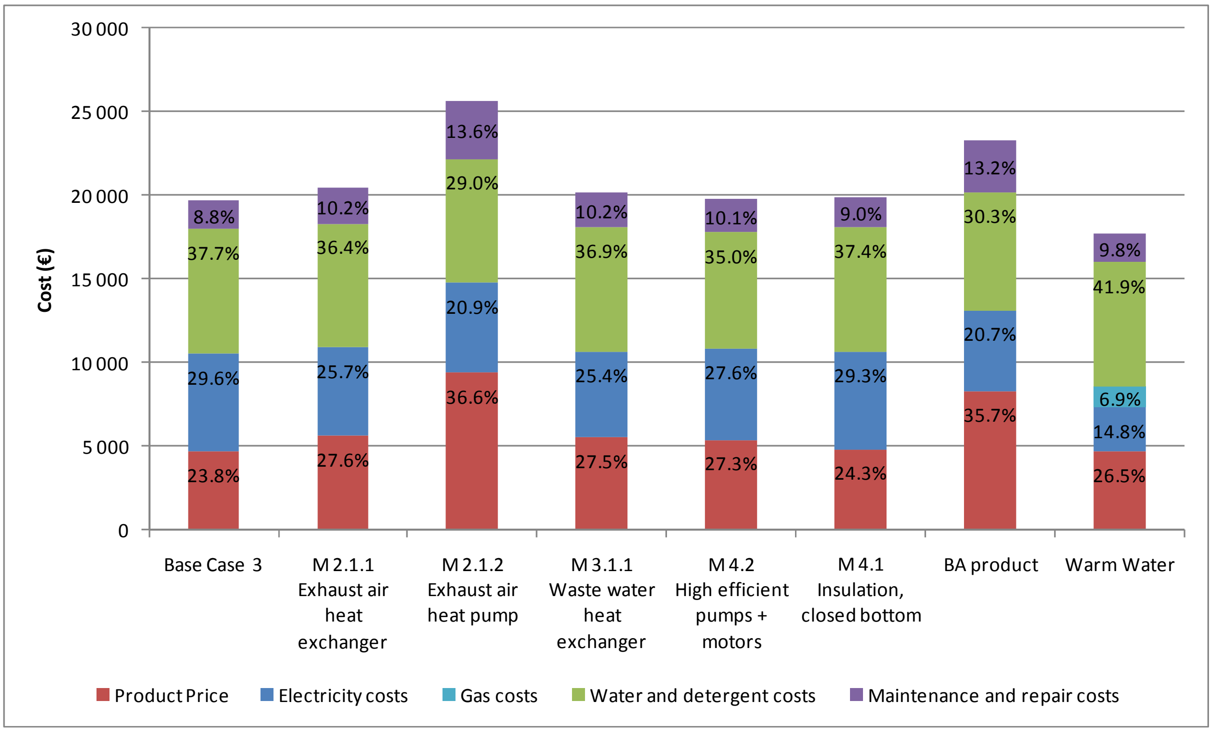

Figure 4-3 Life cycle costs breakdown by improvement option for base case 3

4.4 Base case 4: Utensil/pot dishwashers

The BA product in base case 4 costs 77% more to purchase, and is 35% more expensive on a life cycle basis. The insulation option has a negligible effect on costs. Otherwise, the trends are similar to the previous base cases.

Over the lifecycle of the dishwasher, the warm water supply results in monetary savings of 7% compared to the base case LCC.

Table 4-4 Life cycle costs by improvement option for base case 4

life-cycle indicators per unit	unit	Base Case 4	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	BA product	Warm Water
Economic indicators									
Purchase price	**€**	10 500	12 285	16 800	11 445	11 550	10 605	18 585	10 500
	% change with BC	0%	17%	60%	9%	10%	1%	77%	0%
Electricity costs	**€**	6 301	5 726	5 918	5 726	5 994	6 285	5 446	2 984
	% change with BC	0%	-9%	-6%	-9%	-5%	0%	-14%	-53%
Water and detergent costs	**€**	7 529	7 529	7 529	7 529	7 002	7 529	7 153	7 529
	% change with BC	0%	0%	0%	0%	-7%	0%	-5%	0%
Maintenance and repair costs	**€**	3 888	4 549	6 221	4 238	4 277	3 927	6 882	3 888
	% change with BC	0%	17%	60%	9%	10%	1%	77%	0%
Gas costs	**€**	0	0	0	0	0	0	0	1 266
	% change with BC	-	-	-	-	-	-	-	-
Life-cycle cost	**€**	28 219	30 089	36 468	28 938	28 824	28 347	38 066	26 168
	% change with BC	0%	7%	29%	3%	2%	0%	35%	-7%

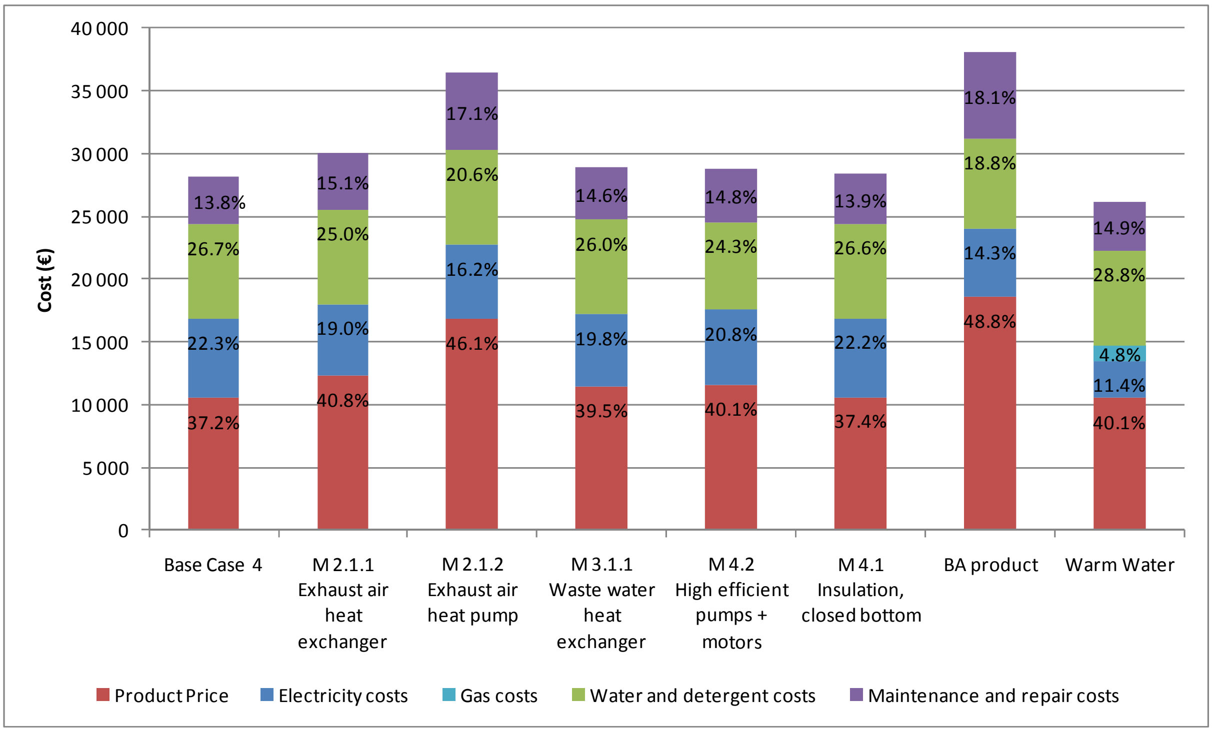

Figure 4-4 Life cycle costs breakdown by improvement option for base case 4

4.5 Base case 5: Conveyor-type one-tank

For conveyor-type one-tanks, the warm water option only reduces electricity costs by 5%, and LCC by 1%. In this case, the option M 1.5 Auxiliary rinsing is the most beneficial option from a LCC point of view –5%), but an exhaust air heat exchanger or high efficiency pumps and motors would also reduce LCC for a relatively small increase in purchase price.

Table 4-5 Life cycle costs by improvement option for base case 5

life-cycle indicators per unit	unit	Base Case 5	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing	BA product	Warm Water
Economic indicators										
Purchase price	**€**	15 000	17 250	24 000	18 000	16 500	16 200	16 950	27 150	15 000
	% change with BC	0%	15%	60%	20%	10%	8%	13%	81%	0%
Electricity costs	**€**	31 846	26 059	25 480	27 506	29 820	31 817	28 374	22 567	30 385
	% change with BC	0%	-18%	-20%	-14%	-6%	0%	-11%	-29%	-5%
Water and detergent costs	**€**	30 689	30 689	30 689	30 689	27 620	30 689	27 007	26 086	30 689
	% change with BC	0%	0%	0%	0%	-10%	0%	-12%	-15%	0%
Maintenance and repair costs	**€**	5 162	5 936	8 259	6 194	5 678	5 575	5 833	9 343	5 162
	% change with BC	0%	15%	60%	20%	10%	8%	13%	81%	0%
Gas costs	**€**	0	0	0	0	0	0	0	0	571
	% change with BC	-	-	-	-	-	-	-	-	-
Life-cycle cost	**€**	82 697	79 934	88 428	82 389	79 619	84 281	78 163	85 146	81 807
	% change with BC	0%	-3%	7%	0%	-4%	2%	-5%	3%	-1%

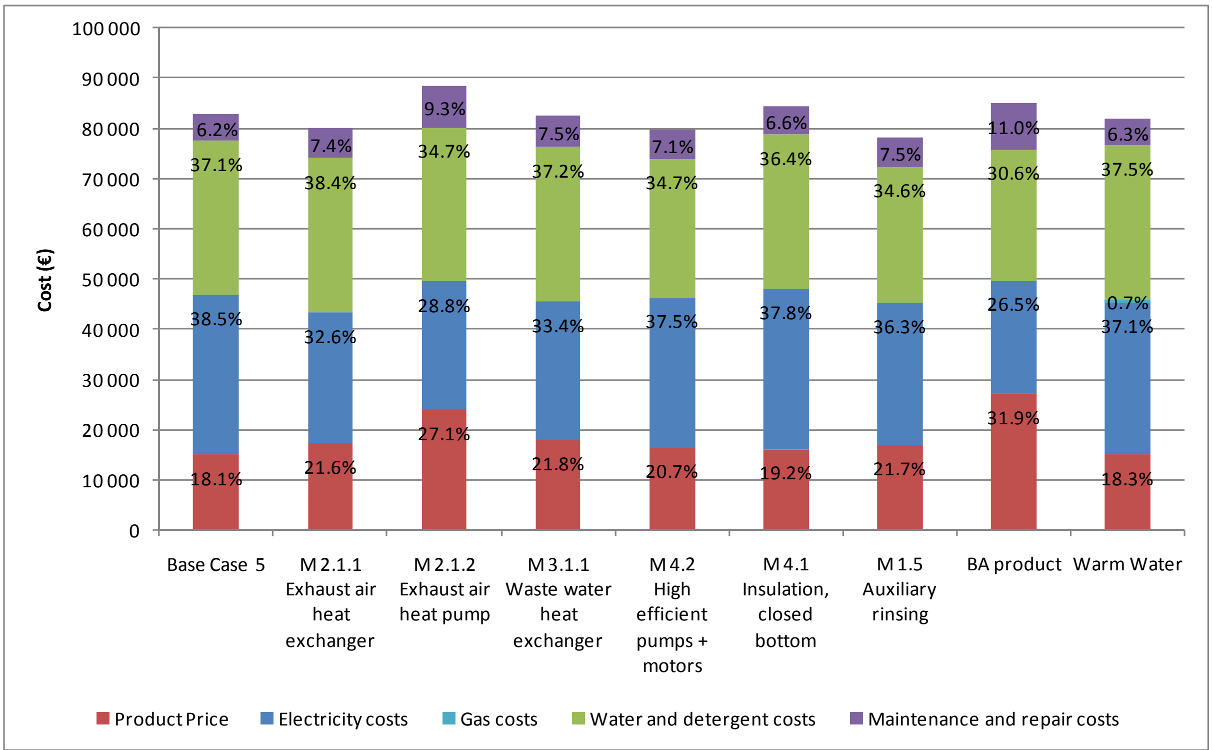

Figure 4-5 Life cycle costs breakdown by improvement option for base case 5

4.6 Base case 6: Conveyor-type multi-tank

Finally, for conveyor-type multi-tank machines, the BA product increases the purchase price by 68% but results in economic savings over the lifetime. All single improvement options reduce the LCC with the exception of M 4.1 Insulation, which would only increase LCC by 1%. Warm water has only a negligible effect.

Table 4-6 Life cycle costs by improvement option for base case 6

life-cycle indicators per unit	unit	Base Case 6	M 2.1.1 Exhaust air heat exchanger	M 2.1.2 Exhaust air heat pump	M 3.1.1 Waste water heat exchanger	M 4.2 High efficient pumps + motors	M 4.1 Insulation, closed bottom	M 1.5 Auxiliary rinsing	BA product	Warm Water
Economic indicators										
Purchase price	€	45 000	48 600	59 400	51 750	51 750	47 700	50 850	75 600	45 000
	% change with BC	0%	8%	32%	15%	15%	6%	13%	68%	0%
Electricity costs	€	111 932	93 283	86 030	96 391	99 499	111 852	99 459	70 438	107 576
	% change with BC	0%	-17%	-23%	-14%	-11%	0%	-11%	-37%	-4%
Water and detergent costs	€	98 995	98 995	98 995	98 995	84 146	98 995	87 115	74 246	98 995
	% change with BC	0%	0%	0%	0%	-15%	0%	-12%	-25%	0%
Maintenance and repair costs	€	14 169	15 303	18 704	16 295	16 295	15 020	16 011	23 805	14 169
	% change with BC	0%	8%	32%	15%	15%	6%	13%	68%	0%
Gas costs	€	0	0	0	0	0	0	0	0	1 703
	% change with BC	-	-	-	-	-	-	-	-	-
Life-cycle cost	€	270 096	256 180	263 129	263 430	251 689	273 566	253 436	244 089	267 443
	% change with BC	0%	-5%	-3%	-2%	-7%	1%	-6%	-10%	-1%

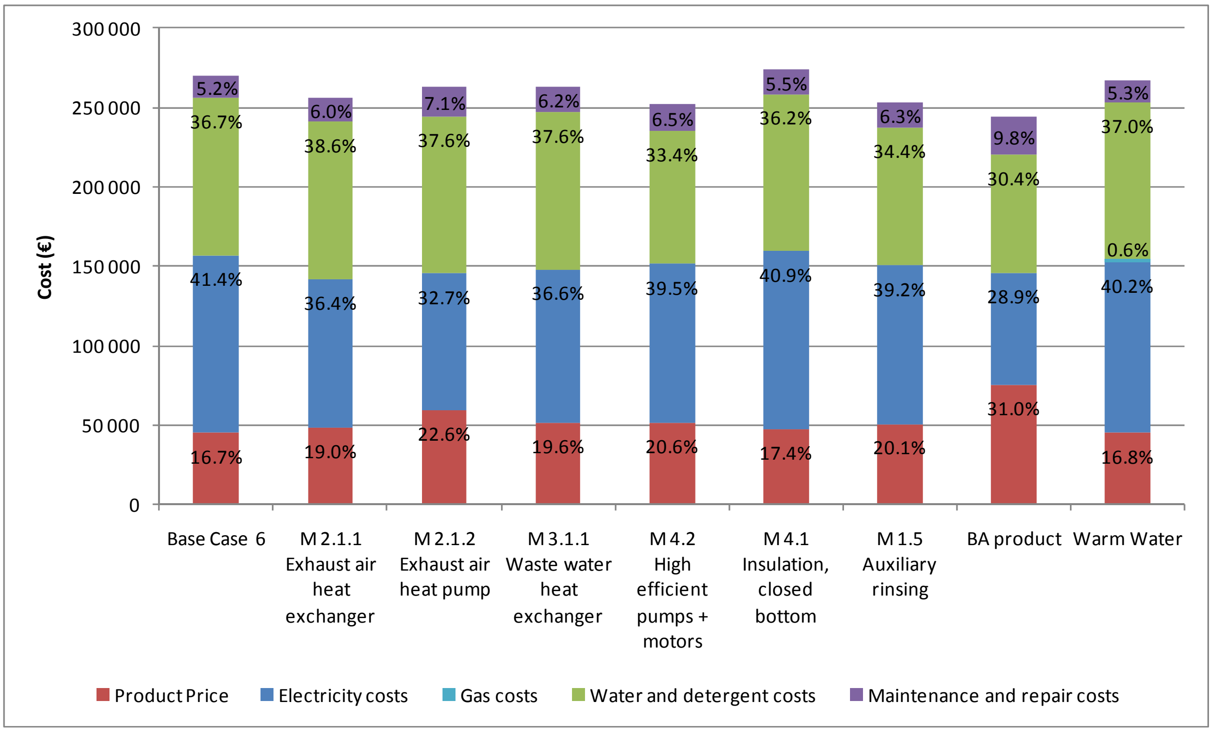

Figure 4-6 Life cycle costs breakdown by improvement option for base case 6

5 Analysis of LLCC and BAT

In this sub-task we will combine environmental impacts and costs. The objective is to identify, amongst the options analysed, the Least Life Cycle Cost (LLCC) option and the Best Available Technology (BAT). This task will include:

- Ranking the identified design options by LCC (e.g. option 1, option 2, option 3)
- Considering the possible trade-offs (positive or negative side effects of the envisaged options/individual design measures);
- Estimating the accumulative improvement and cost effects of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account 'rebound' side effects of the individual design measures;
- Ranking the cumulative design options, drawing an LCC-curve (Y1-axis = Energy consumption, Y2-axis = LCC, X-axis = options) and identifying the Least Life Cycle Cost (LLCC) point and the BAT point. The improvement potential resulting from the ranking will be discussed, such as the appropriateness of setting minimum requirements at the LLCC point, to use the environmental performance of the BAT point or benchmarks set in other countries as a benchmark or if manufacturers will make use of this ranking to evaluate alternative design solutions and the achieved environmental performance of the product.

The figures in the following subsection show on the one hand the total primary energy consumed over the whole life cycle of the products and the life cycle costs on the other hand. Primary energy was chosen here as the most important and representative environmental indicator, given the importance of the use phase and the electricity consumption during this phase:

- Although implementing the design options often increases the quantity of waste generated (mostly non-hazardous in the case of professional dishwashers), this impact category is directly related to the quantity of material that is contained in the product and the major environmental impacts that are due to this waste management (e.g. incineration) are also accounted for in other emissions impact categories. Thus, this category gives an interesting indicator but should not be considered as a priority. Besides, the implementation of some features (heat pumps, heat exchangers, etc.) requires the manufacture of additional materials resulting in higher PAH (especially aluminium), POP and heavy metal emissions (especially stainless steel). However, because of the high recycling rates of the metals, it is estimated that the higher emissions they may cause are not of primary importance in these life cycle assessments.
- Acidification is another important environmental indicator and an overview of the environmental results tables shows that its evolution is very similar (almost the same) as that of Global Warming Potential. Primary energy consumption is estimated to be representative and in line with these two indicators.
- Eutrophication is almost entirely due to detergent consumption, which in this study is linked to water consumption (based on the assumption that the detergent concentration is constant). Given the large amount of water consumed during the use phase, this environmental indicator is also considered important.

As explained earlier, the warm water supply option will not be identified as the LLCC or BAT option if scoring best from the environmental or economic point of view.

5.1 Base case 1: Undercounter water-change

Figure 5-1 shows that the LLCC for BC1 is actually the base case product. Option M 4.1 Insulation comes second, before the individual design options M 4.2, and then M 2.1.1. The BA product is last from an economic point of view: the implementation of all design options does not seem beneficial over the lifetime of the dishwasher.

The BA product is the BAT option (taking primary energy as the reference indicator, as specified earlier). The option M 4.2 'High efficient motor and pumps' scores second, just ahead of M 2.1.1 and M 4.1. The base case logically has the highest primary energy consumption.

Besides, the warm water supply is clearly worth being implemented whenever possible as it is the option having the least life cycle cost and the lowest primary energy consumption of all actual improvement options.

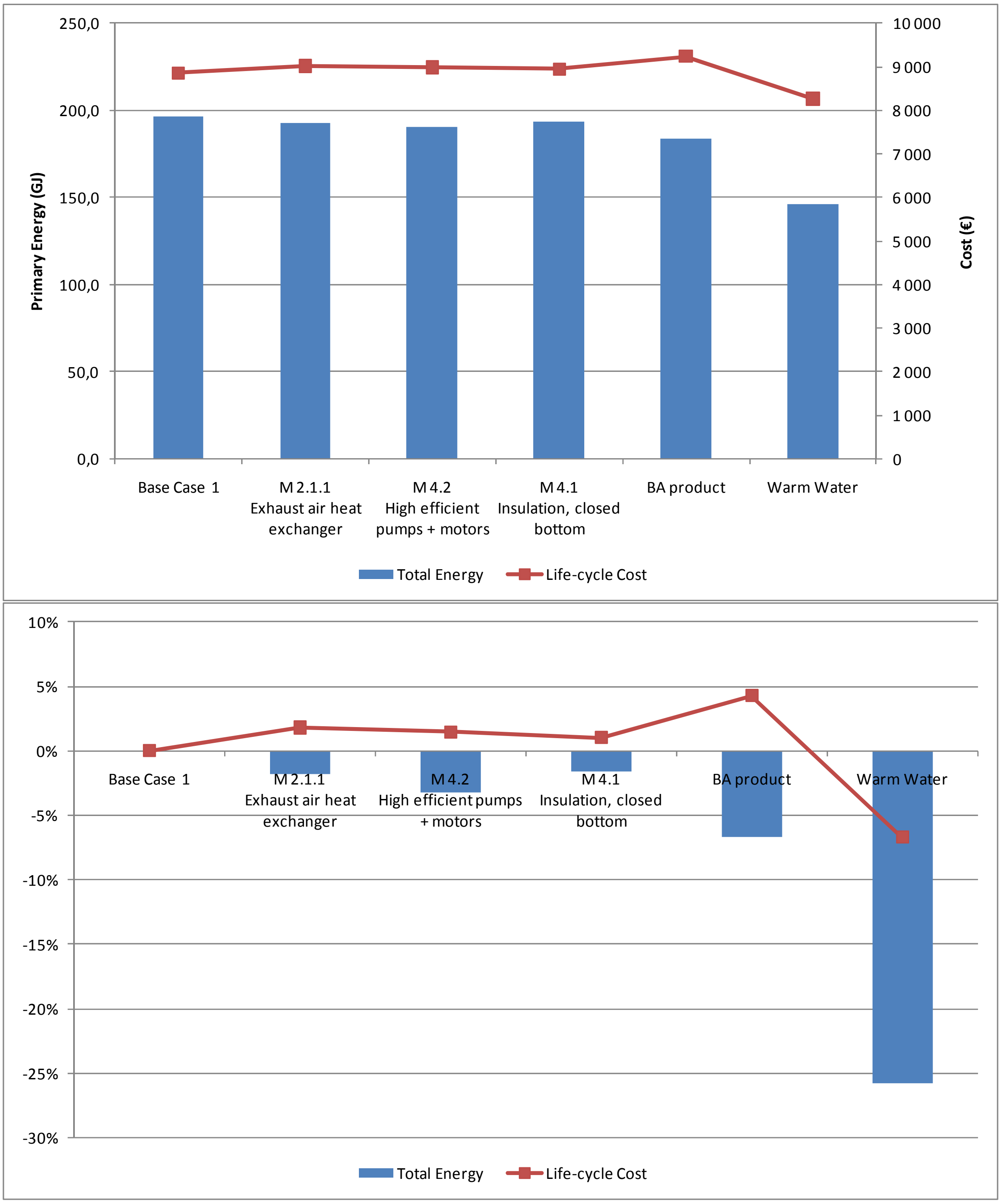

Figure 5-1 Economic and environmental analysis for base case 1

5.2 Base case 2: Undercounter one-tank

Figure 5-2 shows that the LLCC for BC2 is the single option M 4.2 High efficient pumps and motors. The base case comes second, very close to the following single design options: M 4.1, M 3.1.1, M 2.1.1. Then comes the BA product and last is the exhaust air heat pump (M 2.1.2).

Regarding primary energy consumption, the BA product is the BAT option. Options M 2.1.1 Exhaust air heat exchanger and M 3.1.1 Waste water heat exchanger score second, just in front of the individual design options M 4.2 High efficient pumps and motors and M 2.1.2 Heat pump (M 4.1 better insulation almost makes no difference in comparison with the base case). The base case logically has the highest primary energy consumption.

Regarding the combined environmental and economic analysis, warm water is clearly worth being implemented as it scores better than the base case both environmentally and economically (it is a virtual BAT and LLCC option). Other single design options could be considered (M 4.2, M 3.1.1, M 2.1.1) as improving the environmental footprint without (major) additional investment. Again, the BA product is not beneficial from an economic point of view.

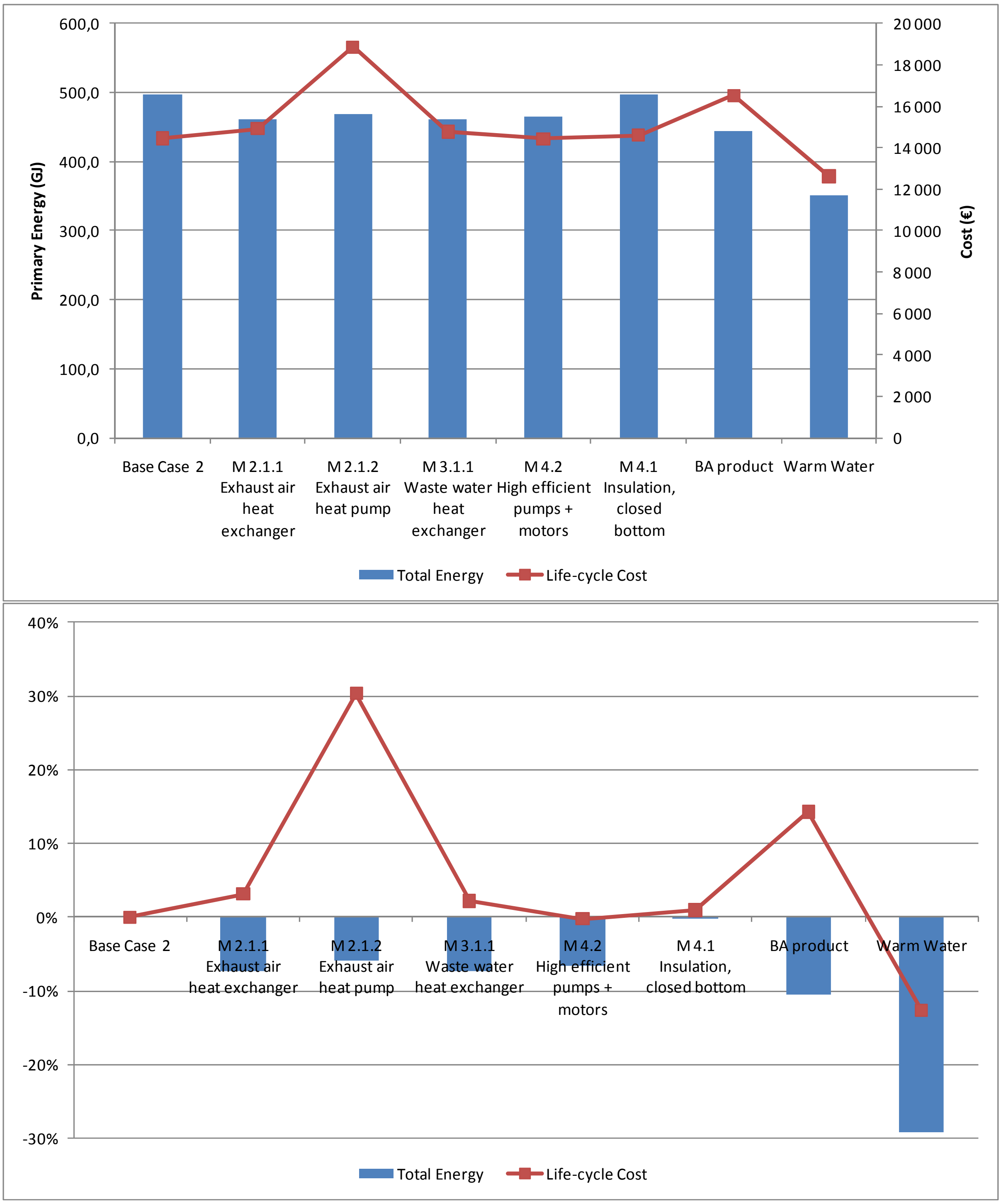

Figure 5-2 Economic and environmental analysis for base case 2

5.3 Base case 3: Hood-type dishwashers

Figure 5-3 shows that the LLCC for BC3 is the base case product, very close to the following single design options: M 4.2, M 4.1, M 3.1.1, M 2.1.1. Then comes the BA product and last is the exhaust air heat pump (M 2.1.2). This profile is very similar to the BC 2 analysis.

Regarding the primary energy consumption, the BA product is the BAT option. It scores just in front of the individual design options (M 3.1.1, then M 2.1.1, M 4.2, M 2.1.2, and lastly M 4.1). The base case logically has the highest primary energy consumption.

Regarding the combined environmental and economic analysis, warm water is clearly worth implementing as it scores better than the base case both environmentally and economically (it is again a virtual LLCC and BAT option). Other single design options could be considered (M 4.2, M 3.1.1, M 2.1.1) as improving the environmental footprint without major additional investment. Again, the BA product is not beneficial from the economic point of view but the reduction in primary energy it achieves is nonetheless important.

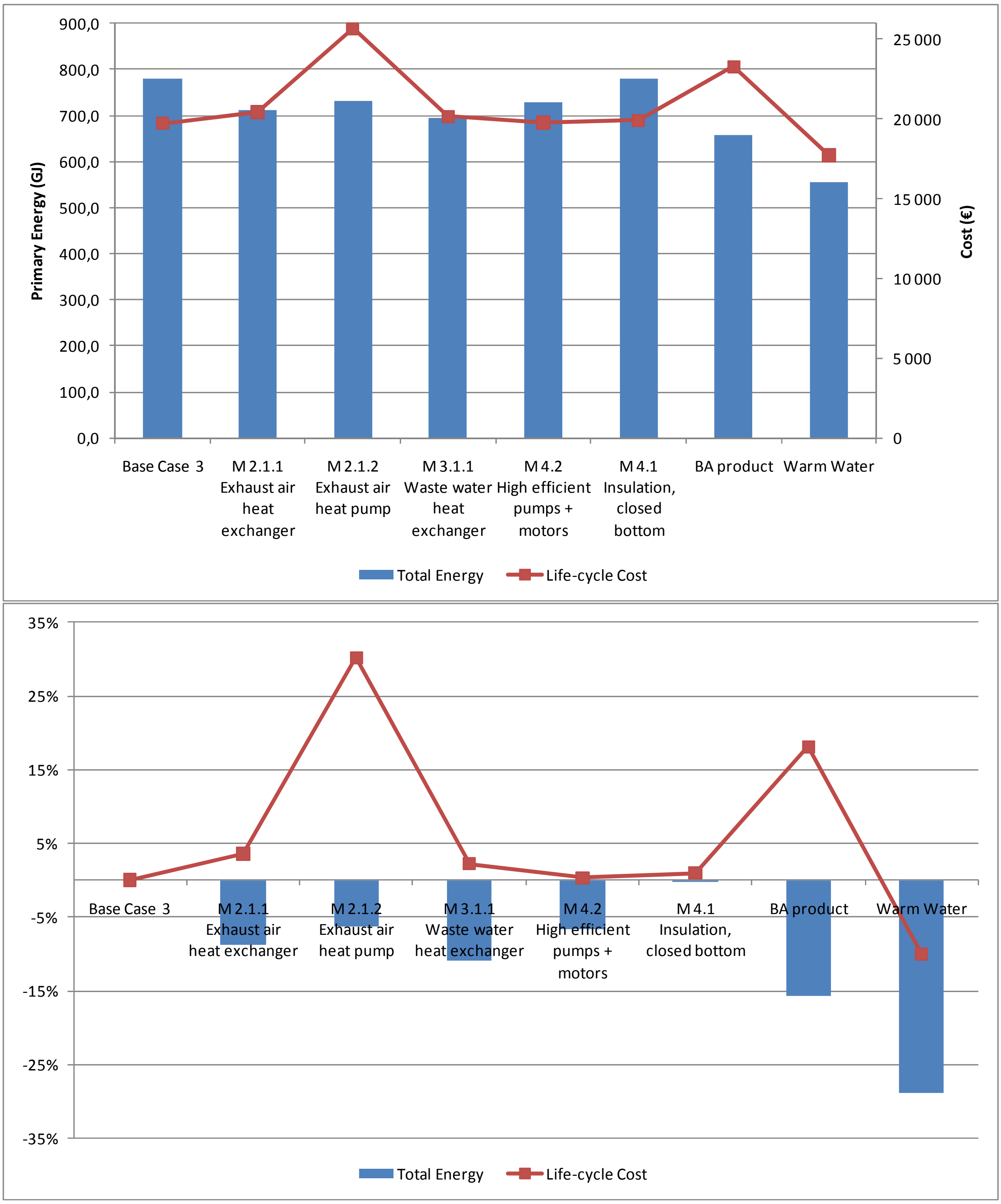

Figure 5-3 Economic and environmental analysis for base case 3

5.4 Base case 4: Utensil/pot dishwashers

Figure 5-4 shows that the LLCC for BC4 is the base case product. The following single design options have close but slightly larger LCC: M 4.1, M 4.2, M 3.1.1, M 2.1.1. Then comes the exhaust air heat pump option (M 2.1.2) with a much higher LCC (+30%), and last is the BA product.

Regarding primary energy consumption, the BA product represents the BAT option. The waste water or exhaust air heat exchangers (M 3.1.1 and M 2.1.1) score second, just in front of the remaining individual design options (M 4.2, M 2.1.2, and lastly M 4.1 which induces a limited improvement). The base case logically has the highest primary energy consumption.

Regarding the combined environmental and economic analysis, the warm water supply is clearly worth being implemented as it scores better than the base case both environmentally and economically (it is a virtual LLCC and BAT option). Other single design options could be considered (M 3.1.1, M 4.2 or even M 2.1.1) as improving the environmental footprint without major additional investment. The BA product and the exhaust air heat pump are not beneficial from the economic point of view because their LCC are much higher than the base case LCC: the operating expenses of the use phase do not counterbalance the initial investment in the product price.

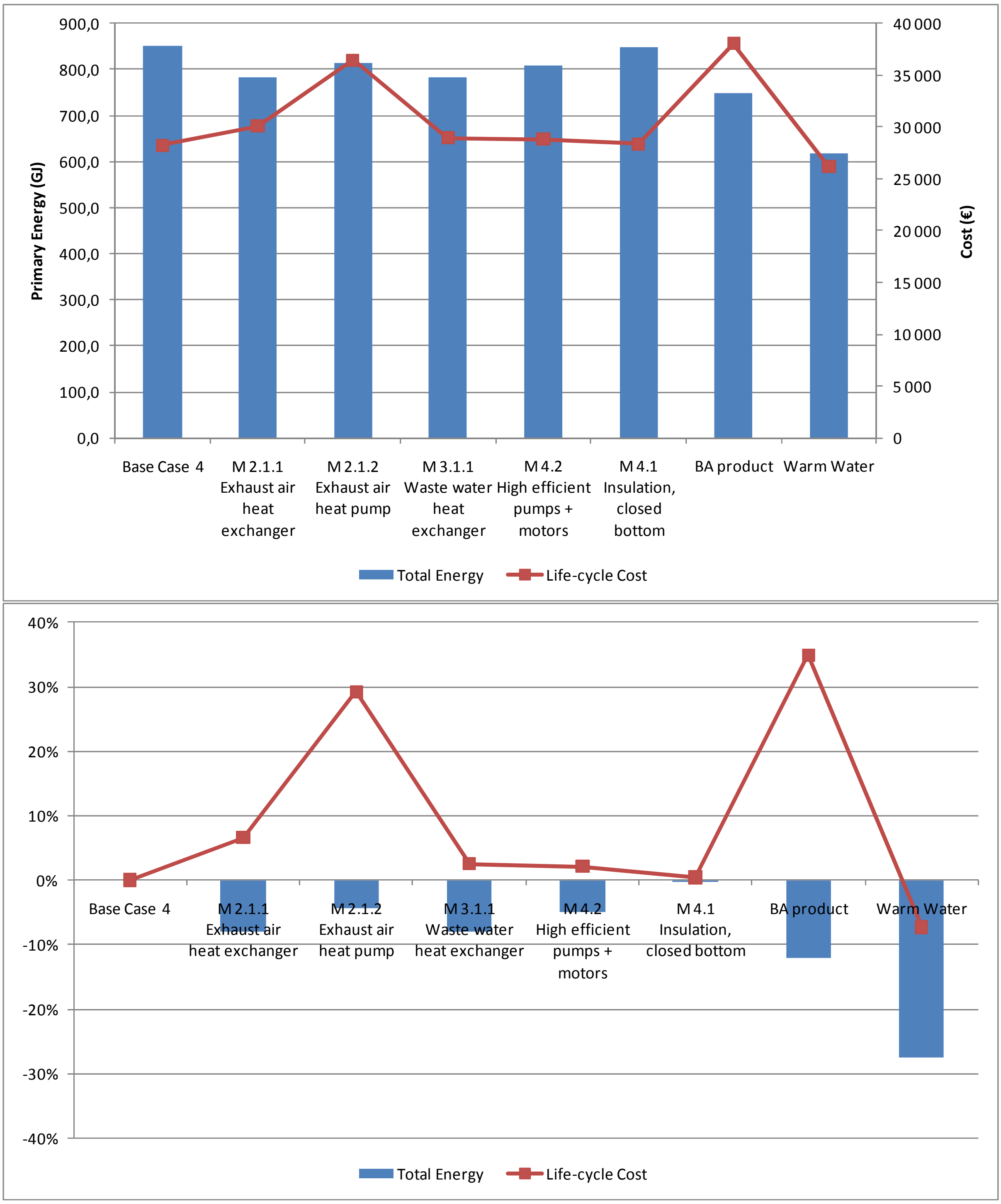

Figure 5-4 Economic and environmental analysis for base case 4

5.5 Base case 5: Conveyor-type one-tank

Significant changes appear for BC5 in comparison with the four previous base cases (see Figure 5-5). The LLCC for BC5 is not the base case product anymore, but the auxiliary rinsing option (M 1.5). Then come the other single improvement options: M 4.2 High efficient pumps and motors, M 2.1.1 Exhaust air heat exchanger, and M 3.1.1 Waste water heat exchanger, which are less expensive on a whole life cycle basis than the base case. M 4.1, the BA product and M 2.1.2 Heat pump have, on the other hand, higher LCCs.

The BA product is again the BAT option. The heat pump (M 2.1.2) scores second, ahead of the other individual design options. The base case unsurprisingly has the highest primary energy consumption.

Regarding the combined environmental and economic analysis, some options are clearly worth implementing as they score better than the base case both environmentally and economically: M 2.1.1 Exhaust air heat exchanger, M 1.5 Auxiliary rinsing, M 3.1.1 Waste water heat exchanger, M 4.2 High efficient pumps and motors. Despite the important decreases in energy consumption, the BA product and the exhaust air heat pump are still not beneficial from an economic point of view, but their LCCs are quite close to the base case LCC (respectively +3% and +7%).

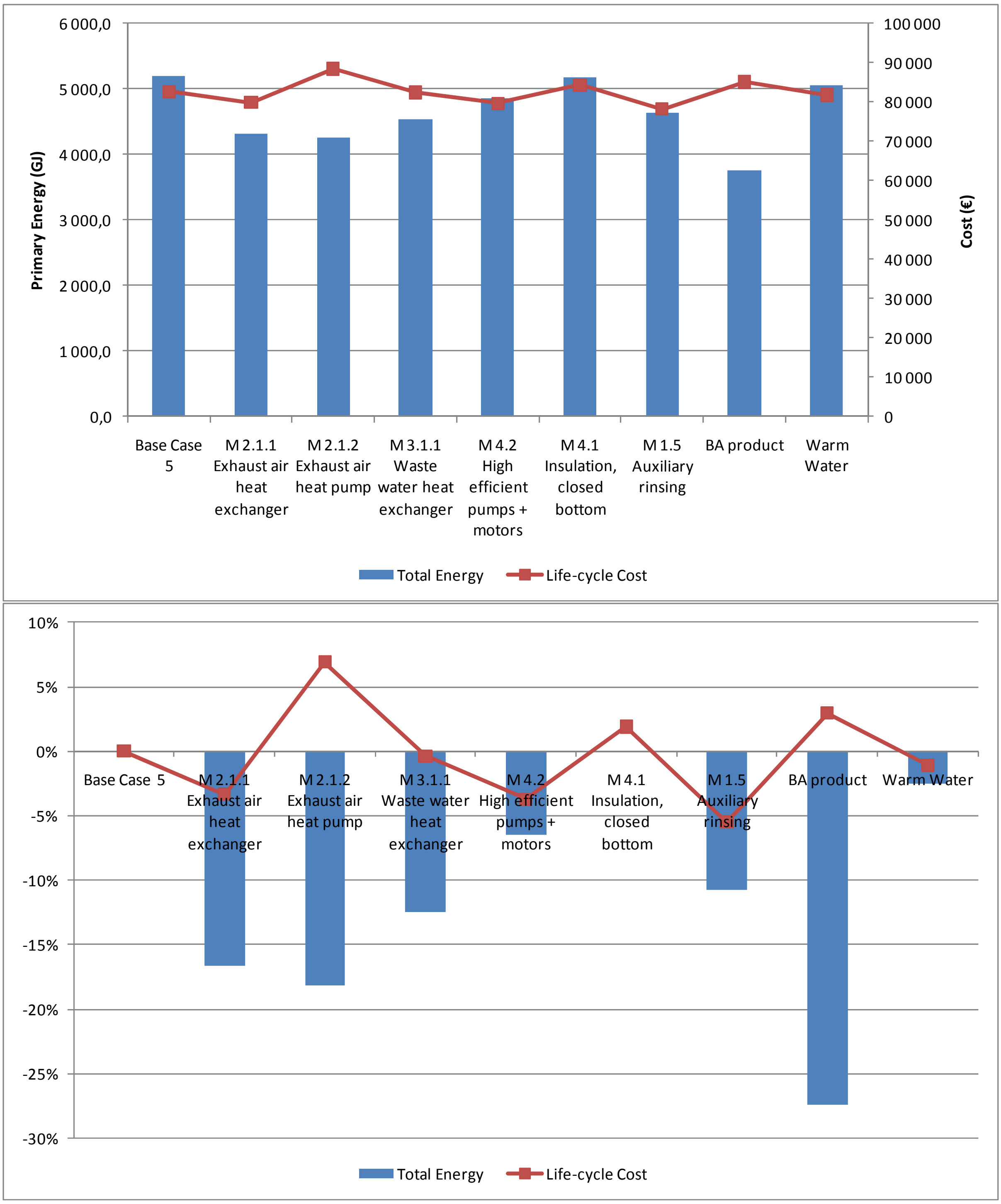

Figure 5-5 Economic and environmental analysis for base case 5

5.6 Base case 6: Conveyor-type multi-tank

The LLCC for BC 6 is the BA product (see Figure 5-6). Then come the following single improvement options: M 4.2 High efficient motors and pumps, M 1.5 Auxiliary rinsing, M 2.1.1 Exhaust air heat exchanger, M 2.1.2 Heat pump and M 3.1.1 Waste water heat exchanger. Warm water is also slightly beneficial economically and better insulation (M 4.1) is the only option for which this is not the case.

Regarding the primary energy consumption, the BA product is also the BAT option. The heat pump (M 2.1.2) scores second, ahead of the other individual design options. The reduction in primary energy consumption due to warm water and M 4.1 is very low. The base case logically has the highest primary energy consumption.

Regarding the combined environmental and economic analysis, the situation is very different: for the first time, the BA product and the heat pump have lower LCCs than the base cases and are certainly worth implementing. The BA product is even the LLCC and the BAT option. All other options, except M 4.1 (higher LCC), also appear environmentally and economically beneficial.

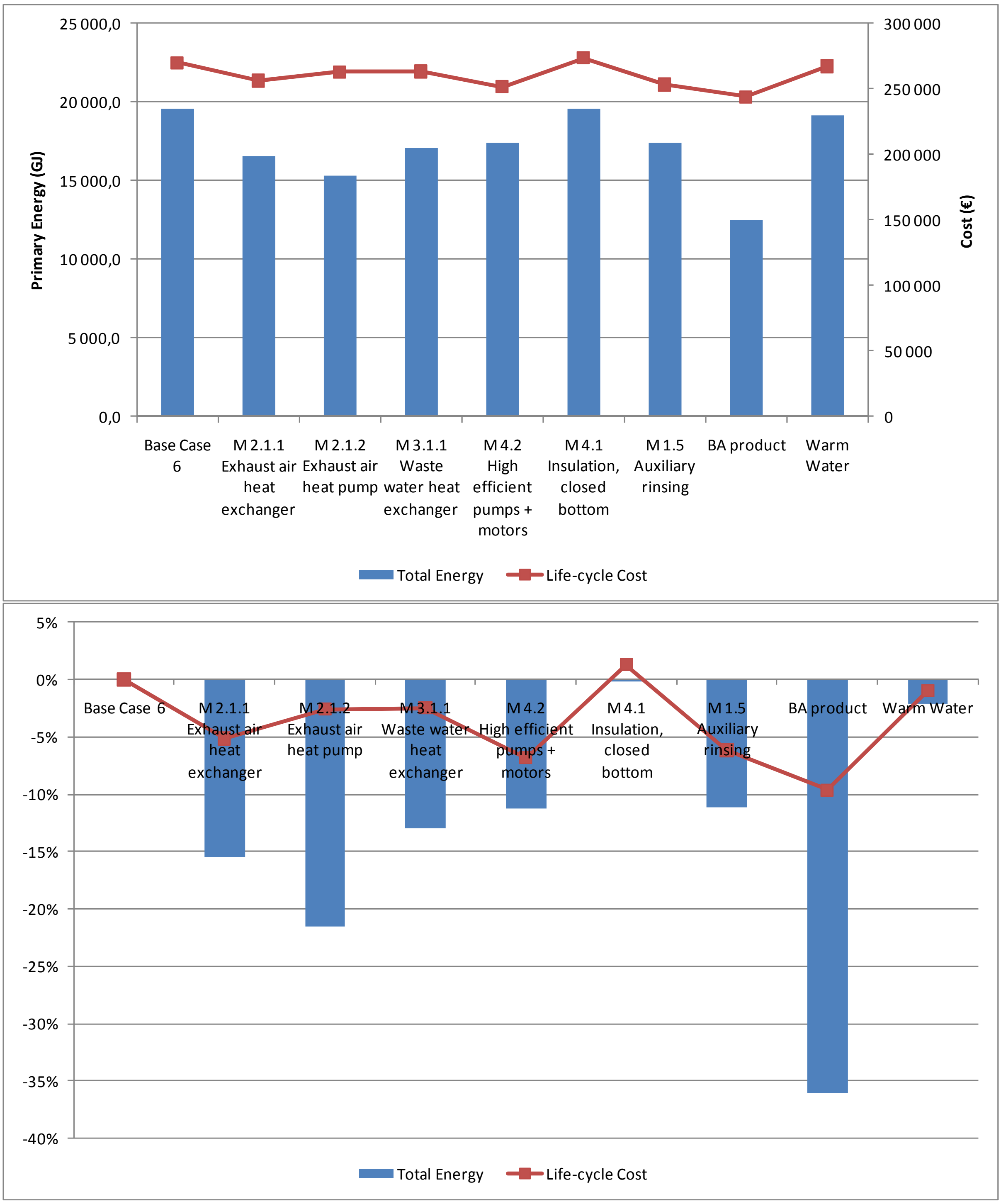

Figure 5-6 Economic and environmental analysis for base case 6

6 Long-term targets (BNAT) and systems analysis

Not all possible improvement options were considered in the preceding sections. Some are still prohibitively expensive or not yet widely available. Such options can be described as BNAT and considered long-term targets. The term BNAT indicates long-term possibilities and helps to define the exact scope and nature of any potential eco-design measures.

Predicting the technological status over such a long period (a horizon of 2020/2025) in a very innovative sector is not possible with a high level of accuracy. Technology roadmaps tend to have a time horizon of 10-12 years at most, describing mid-term targets but often without specifying which particular technologies will be used to achieve those targets.

Some BNAT options are likely to become less costly to manufacturers in coming years, and would thus become applicable to products on the market. Some improvement options or available technologies mentioned by manufacturers that have not yet been applied to professional dishwashers are:

- latent heat storage (through phase-change materials),
- thermo-chemical heat storage (e.g. similar to the zeolite technology introduced as BAT in dishwashers for domestic use in 2010),[16]
- heat pipe,
- detergent re-use (water treatment of waste water and detergent recovery),
- microwave technology (water heating through microwave),
- peltier technology (electric heat pump),
- high-temperature heat pumps capable of reaching a temperature that can heat up the final rinse to 85°C.

None of the technologies was mentioned to be introduced within the next two or three years. Further, the savings potential of these technologies could not be quantified by the manufacturers.

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16 The dishwashers feature a special container of zeolite, a mineral with the ability to store moisture and energy. It dries the dishes after the cleaning cycle by absorbing the moisture from the air in the dishwasher's interior. During the next cleaning cycle, the zeolite is heated up and the moisture released so that it is ready for the next drying cycle. Zeolite speeds up the drying process, so that the dishwashers need 20 percent less electricity than the most energy efficient household dishwashers to date. However, the regeneration (heating up) of the zeolite currently needs 25 minutes; as for professional dishwashers the whole cleaning cycle is considerably shorter, zeolite technology is not applicable to date in professional DW. According to manufacturer's feedback, a reduction of the regeneration time of zeolite is not possible for the present state of technology. Theoretically the technology could be applied in category 1 to 4 dishwashers that are not so frequently used. For category 5 and 6 dishwashers the technology could only be used to transfer the heat from the wash tanks from one to another day.

At market level, Task 2 identified that environmental awareness is increasing; consumers also have economic motivation to reduce energy and water use. These trends drive changes in use patterns and machine sales over time.

However, a full discussion of these issues is not yet possible. Because the professional dishwasher sector is very competitive, manufacturers are reluctant to disclose information about research and development activities.

7 Conclusion

As a conclusion, Task 7 makes the environmental and economic comparison of the improvement options introduced in Task 6 and quantified thanks to a questionnaire, with the base case assessment done in Task 5.

For base cases 1 to 4, it appears that the improvement options, despite introducing some environmental benefits (e.g. electricity savings), do not seem economical over the lifetime of the dishwashers. The savings during the use phase (less energy and water costs) are not sufficient to counterbalance the higher investment for the purchase price. Some options have nevertheless Life Cycle Costs that are very close to the base results and could be implemented in case of financial incentives.

However; for base cases 5 and 6, which are larger appliances, several options appear as beneficial in the LCC analysis: auxiliary rinsing, exhaust air heat exchanger, high efficient pumps and motors or exhaust air heat pump (for base case 6). In parallel, these options enable to achieve important energy savings because of the high use rate of these heavy-duty machines.

The results of this analysis are highly dependent on the inputs and a sensitivity analysis in Task 8 will complement the current results to highlight the influence of the most important parameters of the study on the environmental and financial outcomes.

8 Annex

8.1 Enquiry for stakeholders

"Saving potential and additional costs of single improvement options"

<u>Guidance</u>

The objective of the enquiry is to obtain the concrete saving potential and price differences between standard products (as defined in Task 3 and 4) and these products including the mentioned design options to reduce water and energy consumption.
As we are aware that filling this enquiry may represent a substantial amount of work, please fill in XYZ first if your time and resources are not sufficient to fill in the whole spreadsheet.

This enquiry contains information request on all the base-cases. Please provide information for as many as you can, depending on the products manufactured by your company.

None of the information you will provide will be published as such. The data will be aggregated and averaged to be representative of the EU market. If you wish, a Non-Disclosure Agreement can be signed between Büro Ö-Quadrat/Oeko-Institut and your company.

Definition of the base-cases:
BC 1: Under-counter water-change dishwashers (capacity: 200 dishes/hour)
BC 2: Under-counter one-tank dishwashers (capacity: 550 dishes/hour)
BC 3: Pass-through (hood-type) dishwashers (capacity: 860 dishes/hour)
BC 4: Utensil/Pot dishwashers (capacity: 0.42 m2, 20 cycles/hour)
BC 5: One-tank conveyor-dishwashers (capacity: 1750 dishes/hour)
BC 6: Multi-tank conveyor-dishwashers (with one pump pre wash zone, one cleaning zone and one fi
capacity: 3600 dishes/hour)

Please contact Dieter Seifried, Kathrin Graulich or Eva Brommer in case of any question at:

seifried@oe2.de
k.graulich@oeko.de
e.brommer@oeko.de

Saving potential and additional costs of single improvement options

Introduction

From previous enquiries the following design options were identified as options where the saving potential can be quantified at all and which therefore need to be analysed in more detail:
option 1: exhaust air heat exchanger
option 2: exhaust air heat pump
option 3: waste water heat exchanger
option 4: high efficienc hydraulic system and motors
option 5: Insulation of dishwasher, closed bottom
option 6: auxiliary rinsing system

Please indicate in the following tables what would be the saving potential of each option and the additional costs of a product with such a feature compared to a standard product without this feature. The reference values of the bas case products as defined in tasks 2, 3 and 4 are listed in the first table.

It is possible to give minimum values (e.g. at least 20% higher purchase price) or ranges (e.g. energy saving between 5 and 15%). Any information is highly appreciated.

Please don't fill in the grey shaded cells.

I. Reference values of standard product (see task 2 and 3 reports)

	Base Cases					
	BC 1	BC 2	BC 3	BC 4	BC 5	BC 6
	Under-counter water-change	Under-counter one-tank	Pass-through (hood-type)	Utensil/Pot	One-tank conveyor-type	Multi-tank conveyor-type
Reference price	3.200 €	3.500 €	4.700 €	10.500 €	15.000 €	45.000 €
Continuous operation						
Specific energy consumption (kWh/100 dishes)	4,3	1,6	1,7	0,5 (per cycle)	2	2
Specific water consumption (l/100 dishes)	80	16	16	5,2 (per cycle)	13	12
Standby consumption						
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	0,01	0,25	0,35	1,00	0,80	2,00
Do you agree with the reference values? (yes/no)						
If no, please provide reference values that you would suggest:						

II. Saving potential

In the following section, please provide information on the evolution of the prices, energy and water consumption within the tables, in %, assuming the values of the base-case represent 100% each (for instance, multi-tank conveyor-type dishwasher with an exhaust air heat pump has a price of 115% of the reference price of the base-case). If you have suggested other values for the base-cases than the ones given above (corresponding to those of Task 2 and 3 reports), please give this evolution based on your suggested values. The green cells correspond to the base-cases dishwashers.
Please do not fill in the grey cells.

		Improvement options					
Base Case 1 Under-counter water-change		Option 1: Exhaust air heat exchanger	Option 2: Exhaust air heat pump	Option 3: Waste water heat exchanger	Option 4: High efficient hydraulic system + motors	Option 5: Insulation, closed bottom	Option 6: Auxiliary rinsing
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						

		Improvement options					
Base Case 2 Under-counter one-tank		Option 1: Exhaust air heat exchanger	Option 2: Exhaust air heat pump	Option 3: Waste water heat exchanger	Option 4: High efficient hydraulic system + motors	Option 5: Insulation, closed bottom	Option 6: Auxiliary rinsing
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						

Base Case 3 Pass-through (hood-type)		Improvement options					
		Option 1: Exhaust air heat exchanger	Option 2: Exhaust air heat pump	Option 3: Waste water heat exchanger	Option 4: High efficient hydraulic system + motors	Option 5: Insulation, closed bottom	Option 6: Auxiliary rinsing
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						

Base Case 4 Utensil/Pot		Improvement options					
		Option 1: Exhaust air heat exchanger	Option 2: Exhaust air heat pump	Option 3: Waste water heat exchanger	Option 4: High efficient hydraulic system + motors	Option 5: Insulation, closed bottom	Option 6: Auxiliary rinsing
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						

Base Case 5 One-tank conveyor-type		Improvement options Option 1: Exhaust air heat exchanger	Option 2: Exhaust air heat pump	Option 3: Waste water heat exchanger	Option 4: High efficient hydraulic system + motors	Option 5: Insulation, closed bottom	Option 6: Auxiliary rinsing
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						

Base Case 6 Multi-tank conveyor-type		Improvement options Option 1: Exhaust air heat exchanger	Option 2: Exhaust air heat pump	Option 3: Waste water heat exchanger	Option 4: High efficient hydraulic system + motors	Option 5: Insulation, closed bottom	Option 6: Auxiliary rinsing
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						

Combination of quantifiable design options

Introduction

The following table shows that in principle all options can technically be combined. Please comment on the table if you do not agree with the assumption.

Please indicate in the second table, which options influence the energy / water saving potential of each other, if options are combined. Please quantify this influence if possible. For instance, the saving potential of an exhaust air heat pump is 10%, that of a waste water heat exchanger 10%, when installed as single option. If both options are built into one dishwasher the overall saving potential might be only 15%.

Finally please indicate in the third table the saving potential of products including all mentioned improvement options. The reference values shown in the "savings_and_costs" spreadsheet are considered as "100%" for each Base Case. If for example Base Case 2 (under-counter one-tank dishwasher) contains all possible improvement options then the energy consumption during operation might be 60%. You are also invited to include any comments (last line).

Please don't fill in the grey shaded cells.

I. Combinations of improvement options

Design option	Exhaust air heat exchanger	Exhaust air heat pump	Waste water heat exchanger	High efficient hydraulic systems and motors	insulation, closed bottom	Auxiliary rinsing system
Exhaust air heat exchanger	-					
Exhaust air heat pump	x	-				
Waste water heat exchanger	(x)	(x)	-			
High efficient hydraulic systems and motors	x	x	x	-		
Insulation, closed bottom	x	x	x	x	-	
Auxiliary rinsing system	x	x	x	x	x	-
Your comments						

x = possible combination
(x) combination limited

II. Influence of combination on saving potential

Design option	Exhaust air heat exchanger	Exhaust air heat pump	Waste water heat exchanger	High efficient hydraulic systems and motors	insulation, closed bottom	Auxiliary rinsing system
Exhaust air heat exchanger	-					
Exhaust air heat pump		-				
Waste water heat exchanger			-			
High efficient hydraulic systems and motors				-		
Insulation, closed bottom					-	
Auxiliary rinsing system						-

III. Relative purchase price and consumption of dishwashers with all improvement options

		Product including all possible improvement options					
		BC 1	BC 2	BC 3	BC 4	BC 5	BC 6
	Base Case value	Under-counter water-change	Under-counter one-tank	Pass-through (hood-type)	Utensil/Pot	One-tank conveyor-type	Multi-tank conveyor-type
Purchase price	100%						
Continuous operation							
Specific energy consumption (kWh/100 dishes)	100%						
Specific water consumption (l/100 dishes)	100%						
Standby consumption							
Left-on mode (BC 1), ready-to-use-mode (BC 2-6) (kWh/h)	100%						
Your comments							

8.2 Stakeholder feedback to draft versions of Task 7

Please note that the feedback refers to draft versions of Task 7 report; thus, the indicated numerations of chapters, tables, figures or pages might have changed.

Feedback		Comment
Hobart		
Section 4.5 and 4.6	The LCC values for machines with exhaust heat recovery and exhaust heat pump seem to be unrealistically high in relation to the base case.	The project team was also surprised by these preliminary results. This comment was discussed during the final stakeholder meeting and cost information on heat pumps has been double checked.
CECED Italia		
Section 2.3	We have several doubts that warm water input should be considered as an improvement option and included in the LLCC analysis. It is not clear how the cost of this option is evaluated in the LLCC analysis; in fact as it is written in Task 3 "the overall environmental and economic advantage of the connection to warm water supply strongly depends on the type of water heating outside the appliance and other infrastructural parameters, like length of the stub water line". Moreover in our opinion other costs should be taken into account as the maintenance of the heating system, the actions undertaken to prevent legionella and, most relevant, costs for the system installation where possible ("this additional improvement option depends on the infrastructure available to the dishwasher's owner and it might not be possible to implement it in every situation ")	Modified: the warm water supply has been excluded from the formal BAT and LLCC analysis
2.3	We do not have any specific data to present on boiler and external infrastructure but we would like to remark that the situation presented in the study in our opinion is a marginal situation that cannot be considered as representative of general conditions.	It is mentioned in the report (tasks 7 and 8) that this warm water input option should not be considered as a typical option
	We have some doubts on average lifetime data used in task 7 that seem to be not coherent with data used in lot 2. Is it correct?	This was checked but no error was found.
JRC IPTS		
	With regard to Part 2 entitled 'Professional Dishwashers', the report structure of the Draft Task 7: 'Improvement Potential' is generally in line with MEEUP methodology as applied in other DG ENER preparatory studies. However, we would like to draw attention to the fact that the part of the report regarding the identification of BAT options which are subject of the investigation in the improvement potential calculation has been shifted from Draft Task 7 to Draft Task 6. This shift is not justified. Despite the fact that this shift is less important if one studies the whole document, we consider it better to follow the MEEUP methodology as applied in all other preparatory studies as this eases the cross-checking of horizontal issues and enhances readability for policymakers.	Has been corrected in the final version of the report

Feedback		Comment
	In general the Draft Task 7 report gives a good impression. It is well structured and clearly presented. However, in some points, we consider that the draft report could be improved. In general, we consider that the study though consistent and transparent does not reach a significant level of detail. In the previous Draft Task 6 the analysis of the BAT products was kept on a rather generic level (please see also our comments on Draft Task 6 report) and now in Draft Task 7 the followed improvement potentials seem to be –inevitably– based strongly on stakeholder estimations (e.g. Table 3–11 of Draft Task 7 are based on stakeholders' rough estimations as presented in Draft Task 6). We consider that instead of a rather perfunctory approach, a more in depth investigation is needed and is appropriate for achieving the set goals of the Preparatory Study.	Thank you. The analysis made in Task 7 is indeed based mostly on parameters presented in Task 6. The data limitations regarding the BAT options were already presented in the responses to the comments on Task 6.
	In that respect we refer as an example to the relevant study regarding domestic appliances, in particular domestic dishwashers found in the respective documents of the finalised Preparatory Study of Lot 14 'Domestic Washing Machines and Dishwashers'. In this case technical parameters and models (e.g. the method for calculating the energy efficiency index, the cleaning efficiency index and the drying efficiency index) were determined and developed. The implementing measures on household dishwashers later used these models for the determination of benchmarks (please see also Regulation (EU) No 1016/2010). There are undeniable differences between domestic and professional dishwashers. However, there are many similarities between these two product groups and we consider a more precise determination of the technical parameters to still be feasible. This would allow the investigation of the improvement potential to be more precise and reliable.	The main difference between household and professional appliances is that there are much more variations in the programmes and types of machines available. Manufacturers insist that they should be the ones developing a harmonised testing methodology, and this work will begin in January 2011 within CENELEC working groups.
	Furthermore, it appears to be very helpful to handle the two product groups, domestic and professional dishwashers in more consistent and fair way especially when implementing measures are proposed and undertaken. Demanding precise eco-design goals for domestic devices via the implementing measurements whereas leaving the professional devices with rather roughly determined options does not seem to be a coherent approach.	We understand and agree with this point but the lack of standards/ harmonised test method is the reason why proposing specific eco-design goals does not seem feasible yet, but remains an objective for the next 2-3 years.
	Furthermore we would like to draw attention to a specific point regarding the investigation of one improvement option. In particular, in Section 2.3 'Warm water Input' of Draft Task 7 the improvement option of using warm water as input in the dishwasher is investigated. This option, based on the presented findings in Section 3.1-3.4 shows the highest environmental improvement in 4 out of 6 investigated product base cases. Thus, it gains special importance for the study. However, some important assumptions undertaken in the calculation of this option are not presented clearly and/or need to be further substantiated. In particular, it is not clear if in this improvement option in the assessment of the environmental performance of the dishwashers the product system is expanded. If it is expanded, does it include additionally the life cycle of the gas boiler (which is used for warming the water) and the consumption of gas? Are the emissions during the use phase of the gas boiler as well as the ones associated with the other life cycle stages included in the environmental assessment? How are the system boundaries of the two compared product systems, base case and improvement option set? Are they comparable? These are questions which should be clearly answered. If comparability of the options is not ensured, then instead of environmental savings a shift from environmental burdens between the two product systems can be	See answer below.

Feedback		Comment
	expected (e.g. from product life cycle of dishwashers to product life cycle of gas boilers).	
	Moreover, the assumption that water is warmed using a gas boiler is rather restricted. In some areas in Europe it might be more realistic to assume that the water is warmed using different means. Therefore and so far as this improvement option is regarded as the most beneficial in the majority of the investigated base cases, we consider it necessary to broaden and extend the investigation to other water heating systems.	See answer below.
2.1	The design options as named in the given bullets on page 2 should be extensively presented and described (see also general comments above). Furthermore, cross reference to the respective sections of Task 6 should be added. The improvement options should be re-numbered in a continuous manner because using the coding given in Draft Task 6 (e.g. M 2.1.1 for exhaust air heat exchanger and M 1.5 for auxiliary rinsing) is confusing.	Have been added. We did not re-number the improvement options to keep consistency with Task 6 report.
2.1	Where the presented tables are based on information found in the draft Task 6, they should be given exact cross-references. The source of information should be traceable (e.g. in which table, in which section and from which source the data is found). Moreover, when the tables are based on information of stakeholders this should be clearly stated in the text and in the table title. Calculations based on rough stakeholders' estimations should be differentiated from calculations relied on a stronger evidence basis.	Has been added.
2.2	It is reasonable to start investigating with only one combination of options for each product category. However, based on the first findings especially for base case 5 and 6 the improvement potentials seem to also be significant for different combinations of options. Thus, we consider it supportive especially in the impact analysis of these base cases in Section 3.5 and 3.6 and respectively later in Section 4.5 and 4.6 to extend the investigation to include different combinations of options.	As explained in the task 6 comments, the data was limited regarding all the possible combinations of options.
2.3	It is not clear if in the environmental performance calculation is the investigated product system expanded including the life cycle and the operation of a gas boiler (see also general comments above). Moreover, the investigation of different water heating systems is considered necessary in order to make this improvement option more realistic.	The way the boiler is taken into account in the environmental and economic analysis has been explained more clearly. The study is supposed to reflect an average situation which is why a “common” boiler was defined.
5.7	It would be desirable to provide additional figures similar to Figures 19–23 presenting the results in percentages instead of absolute values as that way some important aspects and differences among the numerous options could be better reflected. In addition, the 'y axis as given in Figures 19–23 regarding the costs should be re-scaled in such way as to allow for obtaining a clear picture among the different options and comparing the different base cases.	Has been added.
5	A final conclusion section summing up the findings given in Sections 5.1–5.6 is missing. This conclusion section should provide in short a clear overview of the ranking of the different improvement options for each investigated base case.	Has been added.