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

Lot 24: Professional Washing Machines, Dryers and Dishwashers

Tender No. TREN/D3/91-2007

May 2011

Final Report, Part:
Washing Machines and Dryers

Task 7: Improvement Potential

Öko-Institut e.V.
Institute for Applied Ecology, Germany
Kathrin Graulich
Markus Blepp
Eva Brommer
Carl-Otto Gensch
Ina Rüdenauer

BIO Intelligence Service, France
Shailendra Mudgal
Raul Cervantes
Thibault Faninger
Lorcan Lyons

Öko-Institut e.V.
Freiburg Head Office
P.O. Box 17 71
79017 Freiburg, Germany
Street Address
Merzhauser Str. 173
79100 Freiburg, Germany
Tel. +49 (0) 761 – 4 52 95-0
Fax +49 (0) 761 – 4 52 95-88

Darmstadt Office
Rheinstr. 95
64295 Darmstadt, Germany
Tel. +49 (0) 6151 – 81 91-0
Fax +49 (0) 6151 – 81 91-33

Berlin Office
Schicklerstr. 5-7
10179 Berlin, Germany
Tel. +49 (0) 30 – 40 50 85-0
Fax +49 (0) 30 – 40 50 85-388

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

The report at hand covers ***professional washing machines and dryers***.

The Task 7 report on *professional dishwashers*
is published separately.

Table of contents

List of figures **V**

List of tables **VII**

1 Introduction **1**

1.1 Objective of Task 7 **1**

2 Design options **1**

2.1 Description of individual design options **2**

2.1.1 Bill of materials 5

2.1.2 Volume 7

2.1.3 Energy consumption 8

2.1.4 Water and detergent consumption 10

2.1.5 Prices and costs 11

2.2 Combination of design options: Best available products **13**

3 Impacts analysis **16**

3.1 Base Case WM 1: Semi-professional washer extractor **16**

3.2 Base Case WM 2: Professional washer extractor <15kg **20**

3.3 Base Case WM 3: Professional washer extractor 15–40 kg **24**

3.4 Base Case WM 4: Professional washer extractor >40kg **28**

3.5 Base Case WM 5: Professional washer dryer **32**

3.6 Base Case WM 6: Professional Barrier Washer **36**

3.7 Base Case WM 7: Washing tunnel machine **40**

3.8 Base Case D 1: Semi-professional dryer, condenser **44**

3.9 Base Case D 2: Semi-professional dryer, air vented **48**

3.10 Base Case D 3: Professional cabinet dryer **52**

3.11 Base Case D 4: Professional tumble dryer (<15 kg) **56**

3.12 Base Case D 5: Professional tumble dryer (15–40 kg) **60**

3.13 Base Case D 6: Professional tumble dryer (>40 kg) **64**

3.14 Base Case D 7: pass-through (transfer) tumble dryer **68**

4 Costs analysis **72**

4.1 Base Case WM 1: Semi-professional washer extractor **72**

4.2 Base Case WM 2: Professional washer extractor <15kg **74**

4.3 Base Case WM 3: Professional washer extractor 15–40 kg **76**

4.4 Base Case WM 4: Professional washer extractor >40kg **78**

4.5 Base Case WM 5: Professional washer dryer **80**

4.6 Base Case WM 6: Professional Barrier Washer **82**

4.7 Base Case WM 7: Washing tunnel machine **84**

4.8 Base Case D 1: Semi-professional dryer, condenser 86
4.9 Base Case D 2: Semi-professional dryer, air vented 88
4.10 Base Case D 3: Professional Cabinet dryer 90
4.11 Base Case D 4: Professional tumble dryer (<15 kg) 92
4.12 Base Case D 5: Professional tumble dryer (15–40 kg) 94
4.13 Base Case D 6: Professional tumble dryer (>40 kg) 96
4.14 Base Case D 7: Industrial pass-through (transfer) tumble dryer 98
4.15 Payback periods 100
5 Analysis of LLCC and BAT 102
5.1 Base Case WM 1: Semi-professional washer extractor 103
5.2 Base Case WM 2: Professional washer extractor <15kg 104
5.3 Base Case WM 3: Professional washer extractor 15–40 kg 105
5.4 Base Case WM 4: Professional washer extractor >40kg 106
5.5 Base Case WM 5: Professional washer dryer 107
5.6 Base Case WM 6: Professional Barrier Washer 108
5.7 Base Case WM 7: Washing tunnel machine 109
5.8 Base Case D 1: Semi-professional dryer, condenser 110
5.9 Base Case D 2: Semi-professional dryer, air vented 111
5.10 Base Case D 3: Professional Cabinet dryer 112
5.11 Base Case D 4: Professional tumble dryer (<15 kg) 113
5.12 Base Case D 5: Professional tumble dryer (15–40 kg) 114
5.13 Base Case D 6: Professional tumble dryer (>40 kg) 115
5.14 Base Case D 7: Industrial pass-through (transfer) tumble dryer 116
5.15 Summary of the LLCC and BAT options identified 117
6 Long-term targets (BNAT) and systems analysis 118
7 Conclusions 119
8 Annex: Additional questionnaire to stakeholders 119

List of figures

Figure 1	Energy consumption by improvement option for Base Case WM 1	19
Figure 2	Improvement potential by improvement option for Base Case WM 1	20
Figure 3	Energy consumption by improvement option for Base Case WM 2	23
Figure 4	Improvement potential by improvement option for Base Case WM 2	24
Figure 5	Energy consumption by improvement option for Base Case WM 3	27
Figure 6	Improvement potential by improvement option for Base Case WM 3	28
Figure 7	Energy consumption by improvement option for Base Case WM 4	31
Figure 8	Improvement potential by improvement option for Base Case WM 4	32
Figure 9	Energy consumption by improvement option for Base Case WM 5	35
Figure 10	Improvement potential by improvement option for Base Case WM 5	36
Figure 11	Energy consumption by improvement option for Base Case WM 6	39
Figure 12	Improvement potential by improvement option for Base Case WM 6	40
Figure 13	Energy consumption by improvement option for Base Case WM 7	43
Figure 14	Improvement potential by improvement option for Base Case WM 7	44
Figure 15	Energy consumption by improvement option for Base Case D 1	47
Figure 16	Improvement potential by improvement option for Base Case D 1	48
Figure 17	Energy consumption by improvement option for Base Case D 2	51
Figure 18	Improvement potential by improvement option for Base Case D 2	52
Figure 19	Energy consumption by improvement option for Base Case D 3	55
Figure 20	Improvement potential by improvement option for Base Case D 3	55
Figure 21	Energy consumption by improvement option for Base Case D 4	59
Figure 22	Improvement potential by improvement option for Base Case D 4	60
Figure 23	Energy consumption by improvement option for Base Case D 5	63
Figure 24	Improvement potential by improvement option for Base Case D 5	64
Figure 25	Energy consumption by improvement option for Base Case D 6	67
Figure 26	Improvement potential by improvement option for Base Case D 6	68
Figure 27	Energy consumption by improvement option for Base Case D 7	71
Figure 28	Improvement potential by improvement option for Base Case D 7	72
Figure 29	Life cycle costs breakdown by improvement option for Base Case WM 1	74
Figure 30	Life cycle costs breakdown by improvement option for Base Case WM 2	76
Figure 31	Life cycle costs breakdown by improvement option for Base Case WM 3	78

Figure 32	Life cycle costs breakdown by improvement option for Base Case WM 4	80
Figure 33	Life cycle costs breakdown by improvement option for Base Case WM 5	82
Figure 34	Life cycle costs breakdown by improvement option for Base Case WM 6	84
Figure 35	Life cycle costs breakdown by improvement option for Base Case WM 7	86
Figure 36	Life cycle costs breakdown by improvement option for Base Case D 1	88
Figure 37	Life cycle costs breakdown by improvement option for Base Case D 2	90
Figure 38	Life cycle costs breakdown by improvement option for Base Case D 3	92
Figure 39	Life cycle costs breakdown by improvement option for Base Case D 4	94
Figure 40	Life cycle costs breakdown by improvement option for Base Case D 5	96
Figure 41	Life cycle costs breakdown by improvement option for Base Case D 6	98
Figure 42	Life cycle costs breakdown by improvement option for Base Case D 7	100
Figure 43	Economic and environmental analysis for Base Case WM 1	103
Figure 44	Economic and environmental analysis for Base Case WM 2	104
Figure 45	Economic and environmental analysis for Base Case WM 3	105
Figure 46	Economic and environmental analysis for Base Case WM 4	106
Figure 47	Economic and environmental analysis for Base Case WM 5	107
Figure 48	Economic and environmental analysis for Base Case WM 6	108
Figure 49	Economic and environmental analysis for Base Case WM 7	109
Figure 50	Economic and environmental analysis for Base Case D 1	110
Figure 51	Economic and environmental analysis for Base Case D 2	111
Figure 52	Economic and environmental analysis for Base Case D 3	112
Figure 53	Economic and environmental analysis for Base Case D 4	113
Figure 54	Economic and environmental analysis for Base Case D 5	114
Figure 55	Economic and environmental analysis for Base Case D 6	115
Figure 56	Economic and environmental analysis for Base Case D 7	116

List of tables

Table 1	Capacities, prices and consumption values of professional washing machines bases cases	4
Table 2	Capacities, prices and consumption values of professional dryers bases cases	5
Table 3	Material composition of the design options for washing machines	6
Table 4	Material composition of the design options for dryers	6
Table 5	Material composition of a heat pump, by dryer base case	6
Table 6	Relative volume by improvement option in comparison with the base case, for washing machines	7
Table 7	Relative volume by improvement option in comparison with the base case, for dryers	8
Table 8	Estimated energy savings potential by improvement option, for washing machines	9
Table 9	Estimated energy savings potential by improvement option, for dryers	9
Table 10	Relative water consumption by improvement option, in comparison with the base case, for professional washing machines	10
Table 11	Relative detergent consumption by improvement option, in comparison with the base case, for professional washing machines	11
Table 12	Purchase prices (and repair costs) by improvement option in comparison with the base case, for professional washing machines	12
Table 13	Purchase prices (and repair costs) by improvement option in comparison with the base case, for professional dryers	12
Table 14	Description of the best available products, for washing machines	13
Table 15	Description of the best available products, for dryers	14
Table 16	Changes in the volume, energy water and detergent consumption and of the purchase price for BA products, for professional washing machines	15
Table 17	Changes in the volume, energy and water consumption and of the purchase price for BA products, for professional dryers	15
Table 18	Environmental impacts by improvement option for Base Case WM 1	17
Table 19	Environmental impacts by improvement option for Base Case WM 2	21
Table 20	Environmental impacts by improvement option for Base Case WM 3	25
Table 21	Environmental impacts by improvement option for Base Case WM 4	29
Table 22	Environmental impacts by improvement option for Base Case WM 5	33
Table 23	Environmental impacts by improvement option for Base Case WM 6	37

Table 24	Environmental impacts by improvement option for Base Case WM 7	41
Table 25	Environmental impacts by improvement option for Base Case D 1	45
Table 26	Environmental impacts by improvement option for Base Case D 2	49
Table 27	Environmental impacts by improvement option for Base Case D 3	53
Table 28	Environmental impacts by improvement option for Base Case D 4	57
Table 29	Environmental impacts by improvement option for Base Case D 5	61
Table 30	Environmental impacts by improvement option for Base Case D 6	65
Table 31	Environmental impacts by improvement option for Base Case D 7	69
Table 32	Life cycle costs by improvement option for Base Case WM 1	73
Table 33	Life cycle costs by improvement option for Base Case WM 2	75
Table 34	Life cycle costs by improvement option for Base Case WM 3	77
Table 35	Life cycle costs by improvement option for Base Case WM 4	79
Table 36	Life cycle costs by improvement option for Base Case WM 5	81
Table 37	Life cycle costs by improvement option for Base Case WM 6	83
Table 38	Life cycle costs by improvement option for Base Case WM 7	85
Table 39	Life cycle costs by improvement option for Base Case D 1	87
Table 40	Life cycle costs by improvement option for Base Case D 2	89
Table 41	Life cycle costs by improvement option for Base Case D 3	91
Table 42	Life cycle costs by improvement option for Base Case D 4	93
Table 43	Life cycle costs by improvement option for Base Case D 5	95
Table 44	Life cycle costs by improvement option for Base Case D 6	97
Table 45	Life cycle costs by improvement option for Base Case D 7	99
Table 46	Payback periods (in years) of the improvement options for professional washing machines	101
Table 47	Payback periods (in years) of the improvement options for professional dryers	101
Table 48	LLCC and BAT options by base case	117

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 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 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.

2 Design options

The Technical Analysis of BAT (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.

NOTE: The following calculations only reflect technical design options. Transversely to all base cases, there is also **improvement potential at infrastructural level**, by changing the energy source for heating the water or air in professional washing machines and dryers from electricity to more efficient alternative heating (e.g. gas or steam). In Section 3.15 of Task 5, we exemplified calculations of such an infrastructural change for the base cases WM1 and D4. The results show that for both professional washing machines and dryers, the alternative heating product scores better for all environmental impacts. Furthermore, the better environmental performance of the alternative heated products goes along with important monetary savings for the customer and no additional costs for the manufacturer.

2.1 Description of individual design options

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 some options, fourteen 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 Task 5. The inquiry was sent out to manufacturers (see Annex 8). The following tables in Section 2 present the aggregated and averaged results of filled in questionnaires.[1] Against this background, we strongly point out again to the **important note about the assessment of data quality** (see Task 6, Section 1.2).

The improvement options are applicable to washing machines that will be analysed in this task (all options do not necessarily apply to all base cases; for detailed description, see 2.2.1 in Task 6):

- **M 1.1: Increased motor efficiency**: enhancing the efficiency of the motor would enable some energy savings within the professional washing machine. A three-phase system is more economical compared to a single- or two-phase system or a direct current motor at the same voltage.
- **M 1.2: Heat exchanger**: it enables energy savings by recovering partly the energy contained in the warm wastewater. Different technological alternatives of heat exchangers are available.

1 Responses received from five manufacturers.

- **M 1.3: Water recovery systems**: washing machines with a water recycling system collect the wash water from all previous rinse cycles for a re-use in the next prewash and main wash cycle, thus decreasing the amount of fresh water required.
- **M 1.4: Load control**: the machine is equipped with sensors that evaluate the load weight and the degree of soiling of the laundry, adapting consequently the amount of water and detergent needed as well as the programme duration.
- **M 1.5: Further control systems**: automated dosage systems are often used for dispensing the liquid detergents, powders, pastes or additives (bleach, alkali) for the prewash, main wash and the fabric softener for the final rinse.
- ***M 1.6: Ozone technology**: Ozone works as bleaching agent at low temperatures and furthermore shortens wash time cycles so that energy savings are possible. As we did not receive any data on the specific savings potential and costs, this option is not included in the following calculations.*
- **M 1.7: Drum construction:** in recent years, the drums of professional washing machines had cylindrical perforations resulting in an inter-fibre friction caused by the rough edges. Better drum design can be used to protect delicate textile fibres.
- ***M 1.8: Wash process with lower temperature**: Changing user behaviour by lowering the wash temperatures might result in energy savings. However, the possible application depends on the specific hygiene demands in the respective customer segments and might require reformulated detergents to receive same hygiene performance at lower temperatures. This option is not included in the following calculations.*
- Along with these seven 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).

For dryers, the possible options implemented will be (for detailed description, see 3.2.1 in Task 6):

- **M 2.1: Increased motor efficiency**: optimizing the motor control system (adaptive acceleration, speed, positional control, and agitation patterns) would provide possible improvements regarding the energy consumption, the uniformity of drying and a gentler treatment of the laundry.
- **M 2.2: Heat pump**: the energy consumption of a dryer with heat pump can be reduced by approximately 40 to 60% compared to a conventional condenser dryer. A heat pump consists of a refrigeration loop containing a refrigerant steam compressor, an evaporator heat exchanger, a condensing heat exchanger, and an expansion valve.
- **M 2.3: Heat recovery systems**: heat recovery systems are usually based on a heat exchange principle by using the warm exhaust air produced by the tumble dryer to

preheat the cold inlet air. This system leads to energy savings, especially when the incoming air is not exceeding 24°C.

- **M 2.4: Improved air flow system**: tumble dryers can be equipped with different air flow systems (axial, radial, mixed or others).
- **M 2.5: Load Control**: weight sensors directly measure the weight of the load and can adapt the drying process in case of partial load.
- **M 2.6: Residual Moisture Control (RMC)**: the residual moisture control system promotes an optimal end-point determination to avoid both still wet laundry as a result of too short drying and over-drying by extended drying.
- **M 2.7: Improved insulation**: improved geometry and materials for the casing, drum, tubing, etc. shall ensure that as little heat as possible is lost to the surroundings.
- Along with these seven 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 2.2).

The following subsections will summarise the changes in an improved product that would result from the implementation of the various single design options (and their combination) 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 1 and Table 2 first summarize 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 1 Capacities, prices and consumption values of professional washing machines bases cases

	WM 1	**WM 2**	**WM 3**	**WM 4**	**WM 5**	**WM 6**	**WM 7**
Parameters	**Semi-prof. washer extractor**	**Prof. washer extractor, <15 kg**	**Prof. washer extractor, 15–40 kg**	**Prof. washer extractor, > 40 kg**	**Prof. washer dryer**	**Prof. Barrier Washer**	**Washing tunnel machine**
Capacity per cycle (kg)	6	10	24	90	6	32	1 500 (kg/hour)
Typical market segment	Coin & Card, AHL	Coin & Card, AHL	Hospitality	Com-mercial Industrial Laundry	Hospitality	Healthcar e	Com-mercial Industrial Laundry
Nominal annual capacity (in kg laundry)	7 000	14 400	42 200	194 400	7 400	56 300	3 825 000
Main energy source to heat up the water	60% Electricity 40% Alternative	55% Electricity 45% Alternative	40% Electricity 60% Alternative	15% Electricity 85% Alternative	100% Electricity	25% Electricity 75% Alternative	100% Alternative

Parameters	WM 1 Semi-prof. washer extractor	WM 2 Prof. washer extractor, <15 kg	WM 3 Prof. washer extractor, 15–40 kg	WM 4 Prof. washer extractor, > 40 kg	WM 5 Prof. washer dryer	WM 6 Prof. Barrier Washer	WM 7 Washing tunnel machine
Purchase price (€)	2 670	5 000	15 250	58 750	8 000	38 250	390 000
Energy consumption (kWh/kg laundry)	0.15	0.17	0.21	0.35	0.8 (Wash and dry)	0.39	0.35
Water consumption (L/kg laundry)	9	12	13	14	10	16	6
Detergent consumption (g/kg laundry)	17	17	14	18	14	18	9

Table 2 Capacities, prices and consumption values of professional dryers bases cases

Parameters	D 1 Semi-prof. dryer, condenser	D 2 Semi-prof. dryer, air vented	D 3 Prof. Cabinet dryer	D 4 Prof. tumble dryer, <15 kg	D 5 Prof. tumble dryer, 15–40 kg	D 6 Prof. tumble dryer, >40 kg	D 7 Pass-through (transfer) tumble dryer
Capacity per cycle (kg)	6	6	8	10	23	70	400 (kg/hour)
Typical market segment	Coin & Card, AHL	Coin & Card, AHL	Coin & Card, AHL	Coin & Card, AHL	Hospitality	Commercial Industrial Laundry	Commercial Industrial Laundry
Nominal annual capacity (in kg laundry)	6 500	6 500	6 300	14 400	40 500	168 000	1 020 000
Main energy source to heat up the air	100 % Electricity	65% Electricity 35% Alternative	100 % Electricity	45% Electricity 55% Alternative	30% Electricity 70% Alternative	10% Electricity 90% Alternative	100 % Alternative heating
Purchase price (€)	1 970	1 680	3 500	4 000	7 125	21 500	62 500
Energy consumption (kWh/kg laundry)	0.6	0.56	0.75	0.55	0.65	0.85	0.80

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 laundry appliance. Tables 3, 4 and 5 list the additional materials required for each improvement option considered. The composition of heat pumps varies depending on the base case considered.

Table 3 Material composition of the design options for washing machines[2]

Design Option / Material category	M 1.1 Increased motor efficiency [g]	M 1.2 Heat exchanger [g]	M 1.3 Water recovery [g]	M 1.4 Load control [g]	M 1.5 Further control systems [g]	M 1.7 Drum construction [g]
PP					+ 200	
Stainless steel	- 100	+ 8 000	+ 15 000		+ 2 500	- 200
Aluminium diecast		+ 3 000			+ 750	
Electronics				+ 200	+ 250	
Misc.					+ 100	

Table 4 Material composition of the design options for dryers[3]

Design Option / Material category	M 2.1 Increased motor efficiency [g]	M 2.2 Heat pump [g]	M 2.3 Heat recovery from exhaust air [g]	M 2.4 Improved air flow system [g]	M 2.5 Load control [g]	M 2.6 Residual moisture control [g]	M 2.7 Improved insulation [g]
Bulk plastics		See Table below	+ 1 400				+ 200
PP				+ 500			
Stainless steel	- 200		+ 21 000	+ 500			
Copper wire			+ 850	+ 1 500			
Aluminium diecast			+4 700	+ 500			
Electronics				+ 100			
Misc.					+ 200	+ 100	

Table 5 Material composition of a heat pump, by dryer base case

Design Option / Material category	WM 1	WM 2	WM 3	WM 4	WM 5	WM 6
	M 2.2 Heat pump [g]					
Stainless steel	40 433	38 418	103 072	112 500	251 731	500 373
Copper wire	1 617	1 537	4 123	4 500	10 069	20 015
Aluminium diecast	9 165	8 708	23 363	25 500	57 059	113 418
Electronics	270	256	687	750	1 678	3 336
Refrigerant R-134a	431	410	1 099	1 200	2 685	5 337

[2] Sources: Task 6, Section 2.2.1.

[3] Sources: Task 6, Section 3.2.1

The additional weight of the heat pump was considered proportional to the weight of the base case dryer, and original data was obtained for base case WM 4. Data for the other base cases was then extrapolated by using the following composition within the heat pump: 75% stainless steel, 4.5% copper wire, 17% aluminium diecast, 1.2% electronics and 0.8% refrigerant (other materials were neglected).

According to manufacturers, the refrigerant R-134a is commonly used in laundry appliances heat pumps. Thus, this is 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[4]. Fugitive and dumped refrigerant of 15% over the whole lifecycle is assumed.

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 than the change in mass. These values were calculated from the bills of materials (see Table 3, Table 4, and Task 5) and are shown in Table 6 and Table 7. 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.

Table 6 Relative volume by improvement option in comparison with the base case, for washing machines[5]

	M 1.1 Increased motor efficiency	M 1.2 Heat ex-changer	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion
WM 1 Semi-professional washer extractor	1.00	1.14	1.20	1.00	1.05	1.00
WM 2 Professional washer extractor (<15kg)	1.00	1.05	1.07	1.00	1.02	1.00
WM 3 Professional washer extractor (15–40 kg)	1.00	1.02	1.02	1.00	1.00	1.00
WM 4 Professional washer extractor (>40kg)	1.00	1.00	1.01	1.00	1.00	n.a.
WM 5 Professional washer dryer	1.00	n.a.	n.a.	1.00	1.01	n.a.
WM 6 Professional barrier washer	1.00	1.01	1.01	1.00	1.00	n.a.
WM 7 Washing tunnel machine	1.00	1.00	n.a.	n.a.	n.a.	n.a.

4 IPCC Fourth Assessment Report (AR4), 2007

5 ‘n.a‘ means that the option cannot be implemented in the product category considered.

Table 7 Relative volume by improvement option in comparison with the base case, for dryers

	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual moisture control	M 2.7 Improved insulation
D 1 Semi-professional dryer, condenser	1.00	1.86	n.a.	1.05	1.00	1.00	1.00
D 2 Semi-professional dryer, air vented	1.00	1.86	1.49	1.05	1.00	1.00	1.00
D 3 Professional cabinet dryer	n.a.	1.86	1.18	1.02	n.a.	n.a.	1.00
D 4 Professional tumble dryer (<15 kg)	1.00	1.86	1.17	1.02	1.00	1.00	1.00
D 5 Professional tumble dryer (15 - 40 kg)	1.00	1.86	1.07	1.00	1.00	1.00	1.00
D 6 Professional tumble dryer (>40 kg)	1.00	1.86	1.04	1.00	1.00	1.00	1.00
D 7 Pass-through (transfer) tumble dryer	1.00	n.a	1.01	n.a	n.a	n.a	1.00

2.1.3 Energy consumption

The following tables (Table 8 and Table 9) show the overall energy performance improvement due to the single design options. Manufacturers' aggregated and averaged estimations on the changes in energy consumption are provided assuming the values of the base cases represent 100% each.

The savings are applied with the same proportions for electricity consumption and heat input than the split assumed in the definition of the base cases: for example, if the energy consumption is reduced to 95% of the base case consumption, both the electricity consumption value and the heat input value are reduced by 5%. The underlying reason is that the base cases are 'virtual' product and that manufacturers gave estimations on the overall energy savings, which cannot be directly linked to a specific part of the machine. Like in Task 5, the alternative heating option selected in EcoReport for the heat input is a gas boiler (non-condensed) with an efficiency of 90%[6].

[6] Lower Heating Value

Table 8 Estimated energy savings potential by improvement option, for washing machines [7]

	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion
WM 1 Semi-professional washer extractor	99%	90%	90%	85%	90%	99%
WM 2 Professional washer extractor, <15kg	99%	90%	90%	83%	93%	98%
WM 3 Professional wash-er extractor, 15-40 kg	99%	90%	90%	83%	95%	98%
WM 4 Professional washer extractor, >40kg	99%	77%	70%	90%	97%	n.a.
WM 5 Professional washer dryer	99%	n.a.	n.a.	80%	90%	n.a.
WM 6 Professional barrier Washer	99%	77%	70%	90%	97%	n.a.
WM 7 Washing tunnel machine	99%	70%	(incl. in base case)	(incl. in base case)	(incl. in base case)	n.a.

Table 9 Estimated energy savings potential by improvement option, for dryers [8]

	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Im-proved air flow system	M 2.5 Load control	M 2.6 Residual moisture control	M 2.7 Im-proved insula-tion
D 1 Semi-professional dryer, condenser	98%	45%	n.a.	90%	90%	90%	90%
D 2 Semi-professional dryer, air vented	98%	50%	90%	90%	90%	90%	90%
D 3 Professional cabinet dryer	n.a.	40%	90%	90%	n.a.	n.a.	90%
D 4 Professional tumble dryer, <15 kg	97%	40%	90%	92%	88%	88%	93%
D 5 Professional tumble dryer, 15-40 kg	98%	40%	91%	89%	90%	90%	94%
D 6 Professional tumble dryer´, >40 kg	99%	40%	92%	95%	95%	95%	98%
D 7 Pass-through (transfer) tumble dryer	99%	n.a.	88%	n.a.	(incl. in the tunnel washer associated)	n.a.	97%

7 Source: Manufacturers' questionnaires

8 Source: Manufacturers' questionnaires

2.1.4 Water and detergent consumption

In Table 10 and Table 11, manufacturers' aggregated and averaged estimations on the change in the water and detergent consumption are provided, assuming the values of the base cases represent 100% each.

Table 10 Relative water consumption by improvement option, in comparison with the base case, for professional washing machines[9]

	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construction
WM 1 Semi-professional washer extractor	100%	100%	70%	80%	90%	99%
WM 2 Professional washer extractor (<15kg)	100%	100%	70%	78%	93%	98%
WM 3 Professional washer extractor (15-40 kg)	100%	100%	70%	78%	95%	98%
WM 4 Professional washer extractor (>40kg)	100%	100%	63%	78%	97%	n.a.
WM 5 Professional washer dryer	100%	n.a.	n.a.	70%	90%	n.a.
WM 6 Professional barrier washer	100%	100%	63%	78%	97%	n.a.
WM 7 Washing tunnel machine	100%	100%	n.a.	n.a.	n.a.	n.a.

9 Source: Manufacturers' questionnaires

Table 11 Relative detergent consumption by improvement option, in comparison with the base case, for professional washing machines[10]

	M 1.1 Increased motor efficiency	M 1.2 Heat ex-changer	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion
WM 1 Semi-professional washer extractor	100%	100%	85%	80%	90%	99%
WM 2 Professional washer extractor (<15kg)	100%	100%	85%	80%	95%	98%
WM 3 Professional washer extractor (15-40 kg)	100%	100%	85%	80%	95%	98%
WM 4 Professional washer extractor (>40kg)	100%	100%	63%	78%	97%	n.a.
WM 5 Professional washer dryer	100%	n.a.	n.a.	70%	90%	n.a.
WM 6 Professional barrier washer	100%	100%	68%	78%	98%	n.a.
WM 7 Washing tunnel machine	100%	100%	n.a.	n.a.	n.a.	n.a.

2.1.5 Prices and costs

The changes in purchase prices are shown in Table 12 and Table 13. The maintenance and repair costs of improved products are assumed to represent the same share of the purchase price as for the base cases: 3% for WM 1-2-3-5 and D 1-2-3-4-5, 25% for WM 4-6-7 and 18% for D 6-7. As a result, they change in the same way as purchase prices. Manufacturers' aggregated and averaged estimations on the change in prices are provided assuming the values of the base cases represent 100% each.

Installation costs represent around 4% of the purchase price for most appliances, except for WM 7 and D 7 for which they account for 9%. These costs are considered to be constant in comparison with the base cases, except for options M 1.2, M 1.3, M 1.6, M 2.2 and M 2.3 which require the installation of additional modules. For these options, the installation costs will be assumed to follow the same variation than the purchase prices and repair costs, presented in the table below.

[10] Source: Manufacturers' questionnaires

Table 12 Purchase prices (and repair costs) by improvement option in comparison with the base case, for professional washing machines[11]

	M 1.1 Increased motor efficiency	M 1.2 Heat ex-changer*	M 1.3 Water recovery*	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion
WM 1 Semi-professional washer extractor	102%	105%	150%	116%	107%	103%
WM 2 Professional washer extractor (<15kg)	102%	105%	150%	116%	101%	102%
WM 3 Professional washer extractor (15-40 kg)	102%	105%	150%	116%	101%	102%
WM 4 Professional washer extractor (>40kg)	102%	120%	130%	112%	103%	n.a.
WM 5 Professional washer dryer	102%	n.a.	n.a.	102%	100%	n.a.
WM 6 Professional barrier washer	102%	120%	130%	112%	103%	n.a.
WM 7 Washing tunnel machine	105%	115%	n.a.	n.a.	n.a.	n.a.

Table 13 Purchase prices (and repair costs) by improvement option in comparison with the base case, for professional dryers[11]

	M 2.1 Increased motor efficiency	M 2.2 Heat pump*	M 2.3 Heat re-covery from exhaust air*	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual moisture control	M 2.7 Improved insulation
D 1 Semi-professional dryer, condenser	103%	180%	n.a.	108%	110%	110%	110%
D 2 Semi-professional dryer, air vented	103%	160%	130%	108%	110%	110%	110%
D 3 Professional cabinet dryer	n.a.	200%	130%	105%	n.a.	n.a.	110%
D 4 Professional tumble dryer (<15 kg)	102%	180%	123%	105%	115%	105%	105%
D 5 Professional tumble dryer (15-40 kg)	102%	180%	124%	106%	114%	109%	106%
D 6 Professional tumble dryer (>40 kg)	102%	180%	137%	108%	111%	115%	109%
D 7 Pass-through (transfer) tumble dryer	106%	n.a.	116%	n.a.	n.a.	n.a.	109%

[11] Source: Manufacturers' questionnaires. For options with *, the installation costs follow the evolutions given in the table. For other options, they are assumed constant (same value than for the base case product).

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 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. 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 14 for washing machines and Table 15 for dryers.

No BA product was taken into account for the BC WM 5 washer dryer as the variety of models currently offered for this product category is relatively low and already represented by the single improvement options.

Table 14 Description of the best available products, for washing machines[12]

	M 1.1 Increased motor efficiency	**M 1.2 Heat exchanger**	**M 1.3 Water recovery**	**M 1.4 Load control**	**M 1.5 Further control systems**	**M 1.7 Drum construc-tion**
WM 1 Semi-professional washer extractor	Yes	Yes	-	Yes	Yes	Yes
WM 2 Professional washer extractor (<15kg)	Yes	Yes	-	Yes	Yes	Yes
WM 3 Professional washer extractor (15-40 kg)	Yes	Yes	-	Yes	Yes	Yes
WM 4 Professional washer extractor (>40kg)	Yes	Yes	-	Yes	Yes	-
WM 6 Professional barrier washer	Yes	Yes	-	Yes	Yes	-
WM 7 Washing tunnel machine	Yes	Yes	Yes	Yes	Yes	-

[12] Source: Manufacturers questionnaires. 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.

Table 15 Description of the best available products, for dryers[13]

	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual moisture control	M 2.7 Improved insulation	Infrared control
D 1 Semi-professional dryer, condenser	Yes	Yes	-	Yes	Yes	Yes	Yes	-
D 2 Semi-professional dryer, air vented	Yes	-	Yes	Yes	Yes	Yes	Yes	-
D 3 Professional cabinet dryer	-	Yes	-	Yes	-	-	Yes	-
D 4 Professional tumble dryer (<15 kg)	Yes	Yes	-	Yes	Yes	Yes	Yes	-
D 5 Professional tumble dryer (15 - 40 kg)	Yes	Yes	-	-	Yes	Yes	Yes	-
D 6 Professional tumble dryer (>40 kg)	Yes	Yes	-	-	Yes	Yes	Yes	-
D 7 Pass-through (transfer) tumble dryer	Yes	-	Yes	-	Yes	-	Yes	Yes

The bills of materials of these BA products are directly derived from Table 3, by adding the indicated components of relevant options to the composition of the corresponding base case.

The energy and water consumption and price changes in comparison with the base cases were obtained from manufacturers' information and are summarised in Table 16 and Table 17. In terms of energy consumption, the base case WM 7 shows the highest improvement potential with the BA product consuming 65% of the initial consumption of the base case. The same situation happens for water and detergent consumption (50% reduction), while the purchase price increases by 30%. For dryers, the BA product of base case D3 has the highest reduction (68%, i.e. 32% of the base case consumption) in energy consumption while its price goes up to 250% of the base case purchase price. In general, the increase of the purchase price of the BA products is less important (in %) for large capacity machines (e.g. 130% for D7 but 250% for D1), as their purchase prices are larger in absolute values.

[13] Source: Manufacturers' questionnaires. 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.

Table 16 Changes in the volume, energy water and detergent consumption and of the purchase price for BA products, for professional washing machines [14]

	BA product of					
	WM 1	**WM 2**	**WM 3**	**WM 4**	**WM 6**	**WM 7**
Volume	**119%**	**106%**	**102%**	**106%**	**101%**	**100%**
Overall energy consumption	**72%**	**79%**	**81%**	**77%**	**77%**	**65%**
Overall water consumption	**63%**	**77%**	**78%**	**77%**	**78%**	**50%**
Overall detergent consumption	**63%**	**79%**	**80%**	**78%**	**78%**	**50%**
Purchase price (and repair and maintenance costs)	**200%**	**125%**	**130%**	**135%**	**135%**	**130%**

Table 17 Changes in the volume, energy and water consumption and of the purchase price for BA products, for professional dryers [14]

	BA product of						
	D 1	**D 2**	**D 3**	**D 4**	**D 5**	**D 6**	**D 7**
Volume	**192%**	**155%**	**188%**	**188%**	**186%**	**186%**	**101%**
Overall energy consumption	**33%**	**75%**	**32%**	**33%**	**40%**	**40%**	**75%**
Purchase price (and repair and maintenance costs)	**250%**	**150%**	**250%**	**180%**	**180%**	**180%**	**141%**

[14] Source: Manufacturers' answers through questionnaire. The change in volume was assessed from the change in mass in the Bills of Materials.

3 Impacts analysis

The aim of this sub-task is to quantify the environmental benefits and impacts of the different improvement options. All relevant design improvements are investigated to see how the design 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 Commission and experts.

3.1 Base Case WM 1: Semi-professional washer extractor

The results of the environmental analysis of the improvement options for Base Case WM 1 are shown below. The BA product provides the greatest energy savings (28%). This option has the greatest savings in most indicators, but emits more PAHs, heavy metals and particulate matter than the base case product, due to the additional metal content. Option M 1.4 Load control is the single option that provides the highest energy savings (16%).

Table 18 Environmental impacts by improvement option for Base Case WM 1

Life cycle indicators per unit	Unit	Base Case WM 1	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construction	BA product
Other resources and waste									
Total Energy (GER)	**GJ**	135.9	135.0	128.4	122.2	114.5	123.5	134.6	97.9
	% change with BC	0%	-1%	-5%	-10%	-16%	-9%	-1%	-28%
of which, electricity	**primary GJ**	74.2	73.5	67.1	67.2	63.3	67.1	73.5	54.2
	MWh	7.1	7.0	6.4	6.4	6.0	6.4	7.0	5.2
	% change with BC	0%	-1%	-10%	-9%	-15%	-10%	-1%	-27%
Water (process)	**kL**	688.1	688.0	688.2	484.5	551.2	619.8	681.2	435.6
	% change with BC	0%	0%	0%	-30%	-20%	-10%	-1%	-37%
Water (cooling)	**kL**	196.5	194.5	177.1	177.1	167.2	177.0	194.5	142.0
	% change with BC	0%	-1%	-10%	-10%	-15%	-10%	-1%	-28%
Waste, non-haz./ landfill	**kg**	203.0	202.1	215.9	204.4	181.1	196.2	201.5	189.3
	% change with BC	0%	0%	6%	1%	-11%	-3%	-1%	-7%
Waste, hazardous/ incinerated	**kg**	12.3	12.3	12.1	12.0	12.0	12.3	12.3	11.9
	% change with BC	0%	0%	-1%	-3%	-3%	0%	0%	-3%
Emissions (Air)									
Greenhouse Gases in GWP100	**t CO2 eq.**	6.2	6.2	5.9	5.7	5.3	5.7	6.2	4.6
	% change with BC	0%	-1%	-5%	-9%	-15%	-9%	-1%	-26%
Acidification, emissions	**kg SO2 eq.**	32.3	32.1	31.1	29.7	27.4	29.6	32.0	24.1
	% change with BC	0%	-1%	-4%	-8%	-15%	-8%	-1%	-25%
Volatile Organic Compounds (VOC)	**kg**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-1%	0%	0%	-9%	-3%	-1%	-9%
Persistent Organic Pollutants (POP)	**µg i-Teq**	1.1	1.1	1.1	1.1	0.9	1.0	1.1	0.9
	% change with BC	0%	-1%	4%	4%	-12%	-4%	-1%	-11%

Life cycle indicators per unit	Unit	Base Case WM 1	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construction	BA product
Heavy Metals	g Ni eq.	5.5	5.5	6.6	7.6	5.2	5.7	5.5	6.5
	% change with BC	0%	-1%	20%	37%	-6%	4%	-1%	18%
PAHs	g Ni eq.	0.6	0.6	0.9	0.6	0.6	0.7	0.6	1.0
	% change with BC	0%	0%	46%	-3%	-4%	11%	0%	53%
Particulate Matter (PM, dust)	kg	6.0	6.0	6.6	6.8	5.9	6.2	6.0	6.7
	% change with BC	0%	0%	10%	12%	-2%	3%	0%	11%
Emissions (Water)									
Heavy Metals	g Hg/20	2.6	2.6	3.4	3.9	2.6	2.9	2.6	3.7
	% change with BC	0%	-1%	29%	48%	0%	11%	-1%	40%
Eutrophication	kg PO4	69.1	69.1	69.1	58.8	55.3	62.2	68.4	43.6
	% change with BC	0%	0%	0%	-15%	-20%	-10%	-1%	-37%

Figure 1 shows the primary energy and electricity consumption (with the percentage of the primary energy that it represents) over the lifecycle. For all options, the share of electricity represents around 52-56% of the total energy consumption.

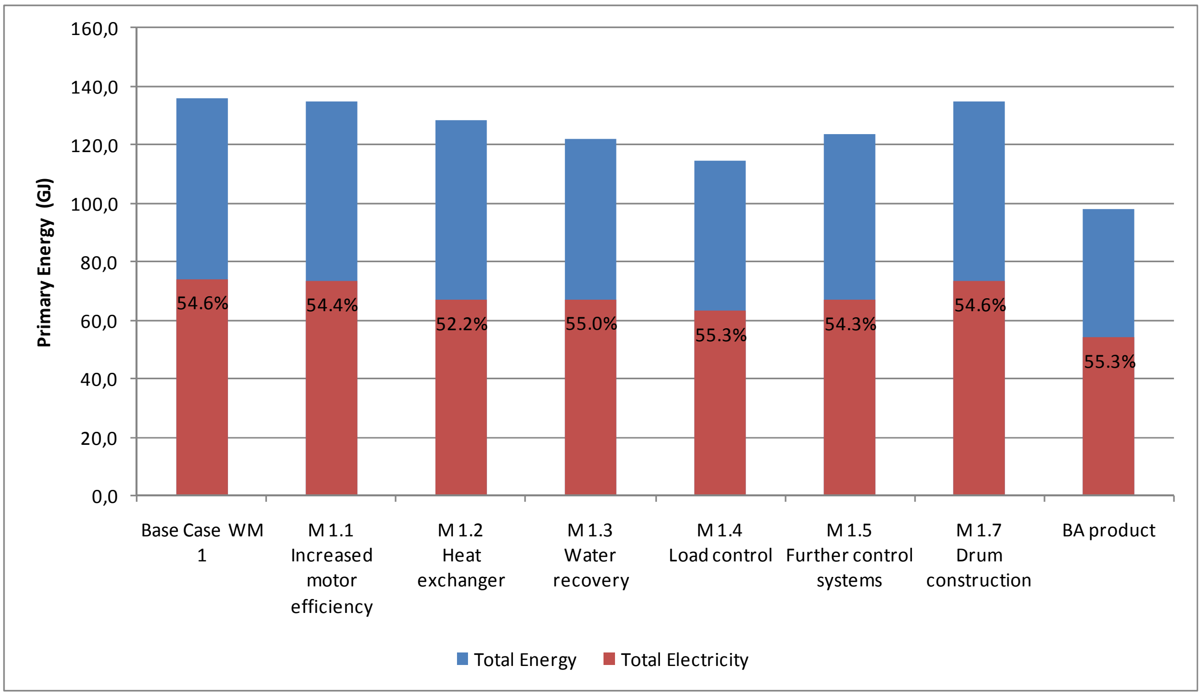


Figure 1 Energy consumption by improvement option for Base Case WM 1

The savings in other indicators are shown in Figure 2 below. Some options induce increase in PAHs emissions due to a larger metal content of the product.

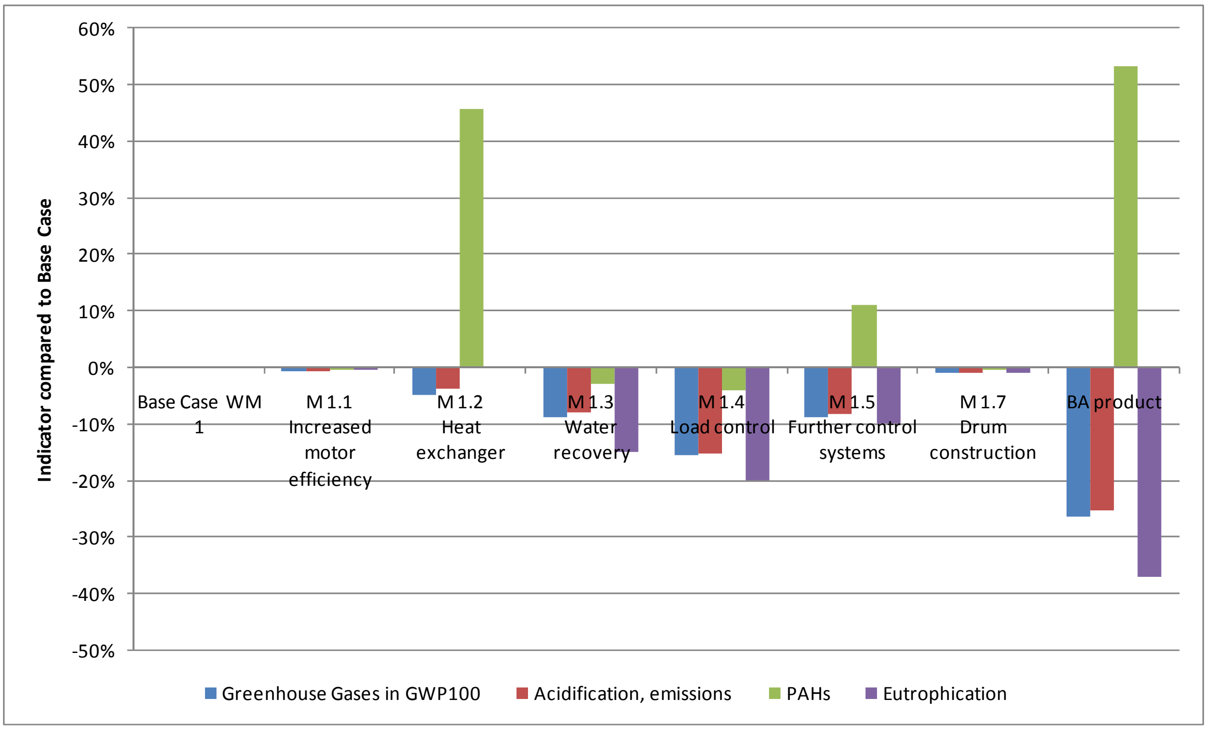


Figure 2 Improvement potential by improvement option for Base Case WM 1

3.2 Base Case WM 2: Professional washer extractor <15kg

The results of the environmental analysis of the improvement options for Base Case WM 2 are shown below.

The greatest energy savings are provided by the BA product. This savings are considered to be around 20%. The second greatest savings comes from option M 1.4 Load control (17%). This option also provides the greatest savings for many air emissions types (e.g. VOC, PAHs, heavy metals).

Table 19 Environmental impacts by improvement option for Base Case WM 2

Life cycle indicators per unit	Unit	Base Case WM 2	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion	BA product
Other resources and waste									
Total Energy (GER)	**GJ**	449.7	446.6	420.7	401.6	373.0	422.7	441.1	361.5
	% change with BC	0%	-1%	-6%	-11%	-17%	-6%	-2%	-20%
of which, electricity	**primary GJ**	254.7	252.2	230.0	230.1	212.4	237.5	249.7	202.8
	MWh	24.3	24.0	21.9	21.9	20.2	22.6	23.8	19.3
	% change with BC	0%	-1%	-10%	-10%	-17%	-7%	-2%	-20%
Water (process)	**kL**	2 825.5	2 825.4	2 824.5	1 984.8	2 206.4	2 628.6	2 769.2	2 178.6
	% change with BC	0%	0%	0%	-30%	-22%	-7%	-2%	-23%
Water (cooling)	**kL**	667.4	660.7	601.0	601.1	554.3	620.9	654.1	527.9
	% change with BC	0%	-1%	-10%	-10%	-17%	-7%	-2%	-21%
Waste, non-haz./ landfill	**kg**	797.3	794.3	789.6	763.3	719.1	776.0	788.3	733.3
	% change with BC	0%	0%	-1%	-4%	-10%	-3%	-1%	-8%
Waste, hazardous/ incinerated	**kg**	18.4	18.3	17.8	17.3	16.9	18.1	18.2	17.0
	% change with BC	0%	0%	-3%	-6%	-8%	-1%	-1%	-8%
Emissions (Air)									
Greenhouse Gases in GWP100	**t CO2 eq.**	20.8	20.6	19.5	18.7	17.3	19.6	20.4	16.8
	% change with BC	0%	-1%	-6%	-10%	-17%	-6%	-2%	-19%
Acidification, emissions	**kg SO2 eq.**	106.1	105.4	100.3	95.6	88.5	100.2	104.1	86.6
	% change with BC	0%	-1%	-5%	-10%	-17%	-6%	-2%	-18%
Volatile Organic Compounds (VOC)	**kg**	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2
	% change with BC	0%	-1%	-4%	-6%	-12%	-3%	-1%	-12%
Persistent Organic Pollutants (POP)	**µg i-Teq**	6.1	6.1	6.0	6.0	5.7	6.0	6.1	5.7
	% change with BC	0%	0%	-1%	-3%	-7%	-2%	-1%	-7%

Life cycle indicators per unit	Unit	Base Case WM 2	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion	BA product
Heavy Metals	**g Ni eq.**	15.9	15.8	16.7	17.4	14.7	15.9	15.7	16.2
	% change with BC	0%	0%	5%	10%	-7%	0%	-1%	2%
PAHs	**g Ni eq.**	2.5	2.5	2.7	2.4	2.4	2.5	2.5	2.7
	% change with BC	0%	0%	10%	-3%	-5%	2%	-1%	10%
Particulate Matter (PM, dust)	**kg**	9.7	9.6	9.9	9.8	9.3	9.6	9.6	9.7
	% change with BC	0%	0%	2%	2%	-4%	0%	0%	0%
Emissions (Water)									
Heavy Metals	**g Hg/20**	8.8	8.8	9.5	10.0	8.6	9.0	8.8	9.7
	% change with BC	0%	0%	7%	13%	-2%	2%	-1%	10%
Eutrophication	**kg PO4**	212.4	212.4	212.4	180.6	170.0	201.8	208.2	167.9
	% change with BC	0%	0%	0%	-15%	-20%	-5%	-2%	-21%

The total electricity consumption represents approximately 56% of the primary energy consumption for all options.

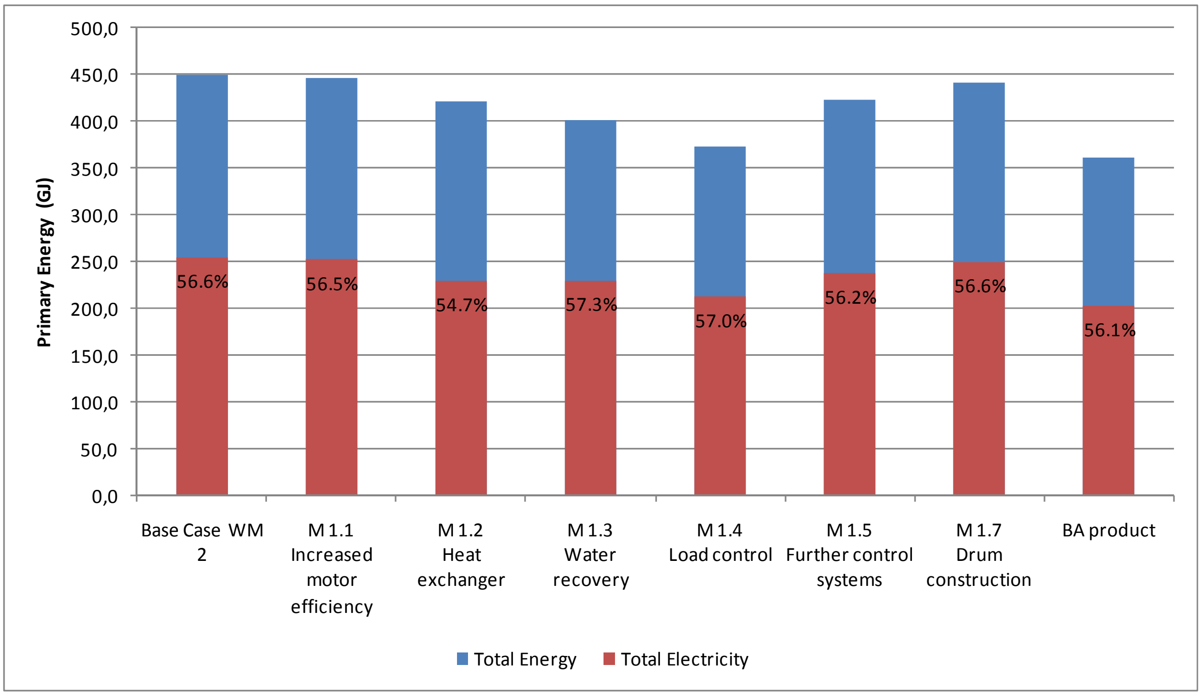


Figure 3 Energy consumption by improvement option for Base Case WM 2

The savings in other indicators are shown in the Figure 4 below. Some options induce increase in PAHs emissions due to a larger metal content of the product.

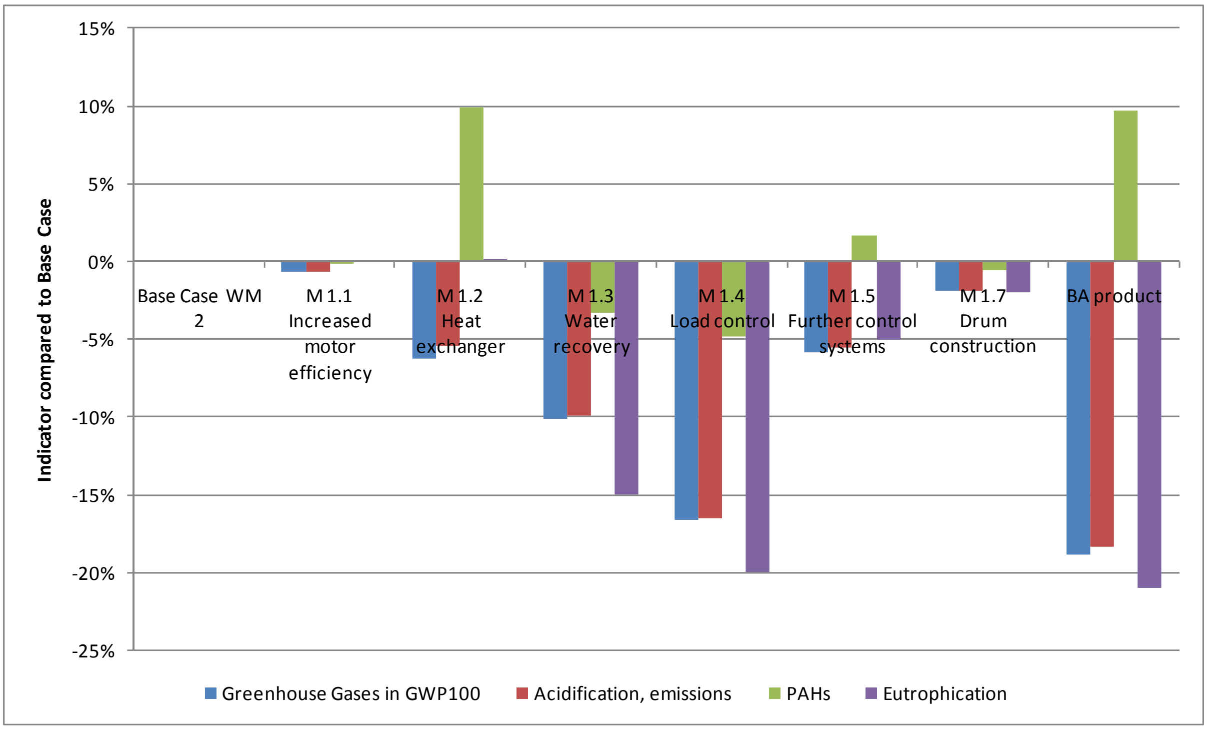


Figure 4 Improvement potential by improvement option for Base Case WM 2

3.3 Base Case WM 3: Professional washer extractor 15–40 kg

The results of the environmental analysis of the improvement options for Base Case WM 3 are shown below.

The BA product provides the greatest energy savings (19%), just before option M 1.4 Load control (17%). In terms of water used (process) and eutrophication, the option M 1.3 Water recovery reduces these impacts by 30% and 15 % respectively.

Table 20 Environmental impacts by improvement option for Base Case WM 3

Life cycle indicators per unit	Unit	Base Case WM 3	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion	BA product
Other resources and waste									
Total Energy (GER)	**GJ**	1 514.1	1 502.9	1 403.4	1 350.0	1 252.7	1 440.7	1 484.6	1 231.7
	% change with BC	0%	-1%	-7%	-11%	-17%	-5%	-2%	-19%
of which, electricity	**primary GJ**	783.3	775.5	705.9	706.0	651.4	744.6	767.8	636.2
	MWh	74.6	73.9	67.2	67.2	62.0	70.9	73.1	60.6
	% change with BC	0%	-1%	-10%	-10%	-17%	-5%	-2%	-19%
Water (process)	**kL**	10 441.9	10 441.4	10 437.4	7 326.0	8 150.3	9 920.6	10 233.3	8 150.1
	% change with BC	0%	0%	0%	-30%	-22%	-5%	-2%	-22%
Water (cooling)	**kL**	2 106.0	2 085.3	1 900.3	1 899.3	1 754.2	2 002.9	2 064.6	1 714.5
	% change with BC	0%	-1%	-10%	-10%	-17%	-5%	-2%	-19%
Waste, non-haz./ landfill	**kg**	1 720.8	1 711.7	1 641.3	1 585.6	1 485.0	1 658.4	1 694.3	1 480.4
	% change with BC	0%	-1%	-5%	-8%	-14%	-4%	-2%	-14%
Waste, hazardous/ incinerated	**kg**	47.9	47.7	46.1	44.8	43.2	46.7	47.3	43.0
	% change with BC	0%	0%	-4%	-6%	-10%	-2%	-1%	-10%
Emissions (Air)									
Greenhouse Gases in GWP100	**t CO2 eq.**	70.6	70.1	65.4	63.1	58.5	67.2	69.2	57.6
	% change with BC	0%	-1%	-7%	-11%	-17%	-5%	-2%	-18%
Acidification, emissions	**kg SO2 eq.**	313.0	311.0	293.1	279.5	259.6	298.4	307.1	256.3
	% change with BC	0%	-1%	-6%	-11%	-17%	-5%	-2%	-18%
Volatile Organic Compounds (VOC)	**kg**	0.8	0.8	0.7	0.7	0.7	0.8	0.8	0.7
	% change with BC	0%	-1%	-7%	-9%	-15%	-4%	-2%	-16%
Persistent Organic Pollutants (POP)	**µg i-Teq**	11.8	11.7	11.3	11.0	10.4	11.4	11.6	10.4
	% change with BC	0%	0%	-4%	-6%	-11%	-3%	-1%	-11%

Life cycle indicators per unit	Unit	Base Case WM 3	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion	BA product
Heavy Metals	**g Ni eq.**	41.5	41.3	41.4	41.5	38.0	40.9	41.1	39.3
	% change with BC	0%	0%	0%	0%	-8%	-1%	-1%	-5%
PAHs	**g Ni eq.**	2.8	2.8	2.7	2.6	2.4	2.7	2.8	2.4
	% change with BC	0%	-1%	-5%	-9%	-14%	-4%	-2%	-15%
Particulate Matter (PM, dust)	**kg**	26.4	26.3	26.2	26.0	25.2	26.2	26.2	25.5
	% change with BC	0%	0%	-1%	-1%	-4%	-1%	0%	-3%
Emissions (Water)									
Heavy Metals	**g Hg/20**	18.1	18.0	18.3	18.9	17.2	18.1	18.0	18.0
	% change with BC	0%	0%	1%	4%	-5%	0%	-1%	0%
Eutrophication	**kg PO4**	599.8	599.8	599.9	510.0	480.1	569.9	587.9	480.1
	% change with BC	0%	0%	0%	-15%	-20%	-5%	-2%	-20%

Figure 5 presents the proportions represented by electricity consumption amongst the total primary energy consumption.

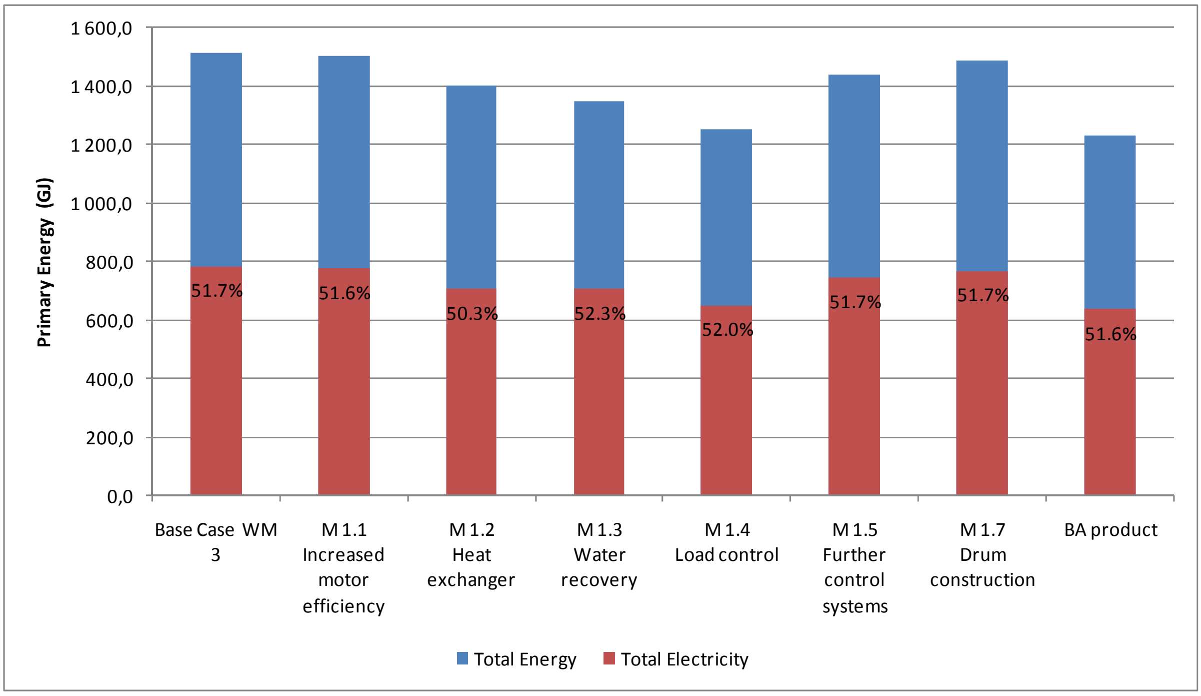


Figure 5 Energy consumption by improvement option for Base Case WM 3

The savings in other environmental indicators are shown in Figure 6 below.

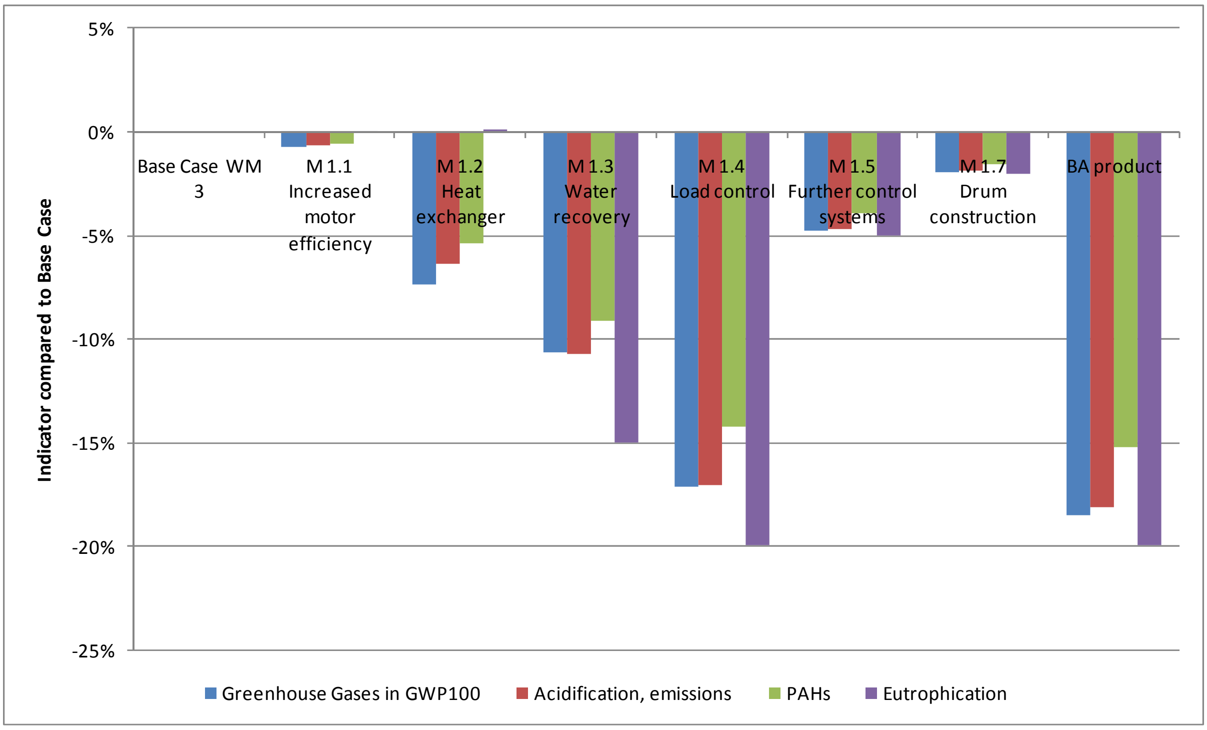


Figure 6 Improvement potential by improvement option for Base Case WM 3

3.4 Base Case WM 4: Professional washer extractor >40kg

The results of the environmental analysis of the improvement options for Base Case WM 4 are shown below.

In the case of the base case WM 4, option M 1.3 Water recovery provides the greatest reduction for all impacts. The savings in energy due to this option is 31%. The second greatest energy savings are due to the BA product (22%).

Table 21 Environmental impacts by improvement option for Base Case WM 4

Life cycle indicators per unit	Unit	Base Case WM 4	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	BA product
Other resources and waste								
Total Energy (GER)	**GJ**	10 193.4	10 113.4	8 354.0	7 047.8	8 949.6	9 893.3	7 910.9
	% change with BC	0%	-1%	-18%	-31%	-12%	-3%	-22%
of which, electricity	**primary GJ**	4 687.8	4 641.2	3 615.8	3 289.6	4 221.7	4 548.0	3 615.9
	MWh	446.5	442.0	344.4	313.3	402.1	433.1	344.4
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Water (process)	**kL**	49 390.3	49 387.2	49 319.4	31 154.6	38 571.1	47 910.0	38 041.6
	% change with BC	0%	0%	0%	-37%	-22%	-3%	-23%
Water (cooling)	**kL**	12 452.9	12 328.6	9 593.9	8 723.8	11 209.8	12 080.0	9 594.0
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Waste, non-haz./ landfill	**kg**	12 555.3	12 501.1	11 333.5	10 086.0	11 500.6	12 329.0	10 825.1
	% change with BC	0%	0%	-10%	-20%	-8%	-2%	-14%
Waste, hazardous/ incinerated	**kg**	230.3	229.2	205.6	180.9	209.3	225.8	195.5
	% change with BC	0%	0%	-11%	-21%	-9%	-2%	-15%
Emissions (Air)								
Greenhouse Gases in GWP100	**t CO2 eq.**	488.0	484.1	398.8	339.1	429.8	473.7	379.5
	% change with BC	0%	-1%	-18%	-31%	-12%	-3%	-22%
Acidification, emissions	**kg SO2 eq.**	1 866.0	1 853.5	1 578.3	1 297.4	1 625.7	1 813.0	1 463.6
	% change with BC	0%	-1%	-15%	-30%	-13%	-3%	-22%
Volatile Organic Compounds (VOC)	**kg**	5.4	5.4	4.5	3.9	4.8	5.3	4.3
	% change with BC	0%	-1%	-18%	-28%	-11%	-3%	-21%
Persistent Organic Pollutants (POP)	**µg i-Teq**	73.5	73.2	66.5	59.5	67.5	72.2	63.6
	% change with BC	0%	0%	-9%	-19%	-8%	-2%	-13%

Life cycle indicators per unit	Unit	Base Case WM 4	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	BA product
Heavy Metals	**g Ni eq.**	206.1	205.3	188.9	171.6	190.5	203.1	181.7
	% change with BC	0%	0%	-8%	-17%	-8%	-1%	-12%
PAHs	**g Ni eq.**	34.9	34.8	33.1	30.6	33.1	34.6	32.3
	% change with BC	0%	0%	-5%	-12%	-5%	-1%	-8%
Particulate Matter (PM, dust)	**kg**	104.5	104.2	98.6	92.7	99.4	103.5	96.3
	% change with BC	0%	0%	-6%	-11%	-5%	-1%	-8%
Emissions (Water)								
Heavy Metals	**g Hg/20**	95.0	94.7	88.9	87.3	92.0	94.3	89.1
	% change with BC	0%	0%	-6%	-8%	-3%	-1%	-6%
Eutrophication	**kg PO4**	3 377.8	3 377.7	3 377.7	2 128.6	2 635.0	3 276.5	2 635.0
	% change with BC	0%	0%	0%	-37%	-22%	-3%	-22%

Figure 7 presents the proportions represented by electricity consumption amongst the total primary energy consumption.

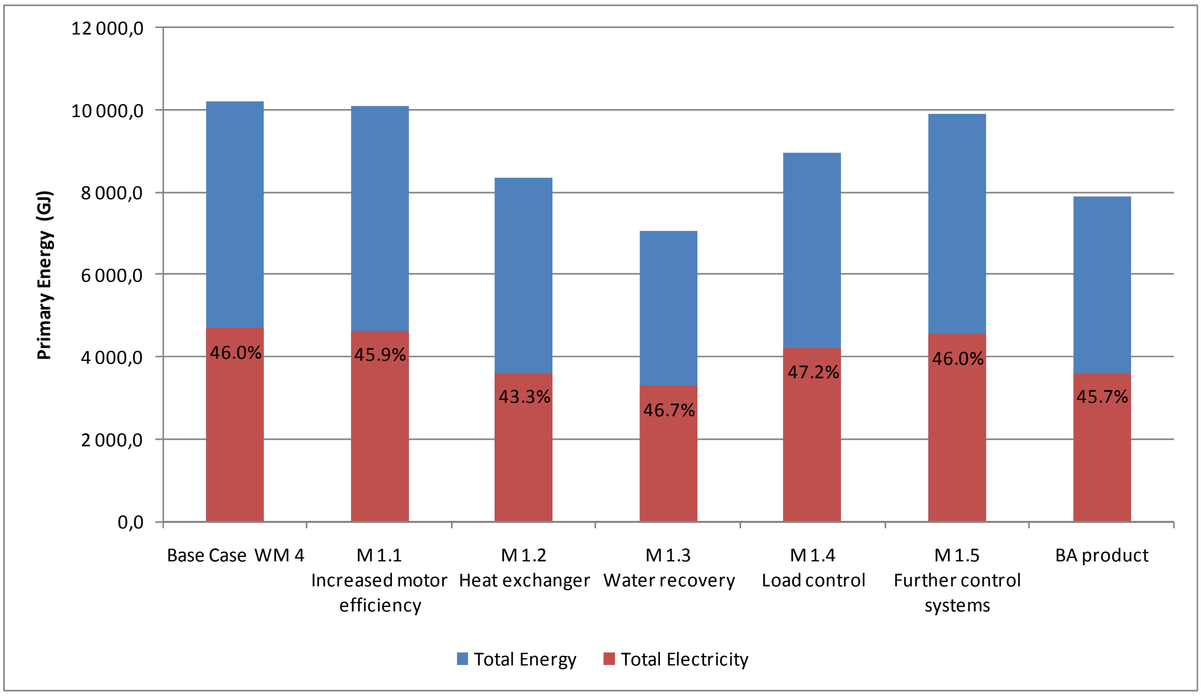


Figure 7 Energy consumption by improvement option for Base Case WM 4

The savings in other environmental indicators are shown in Figure 8 below.

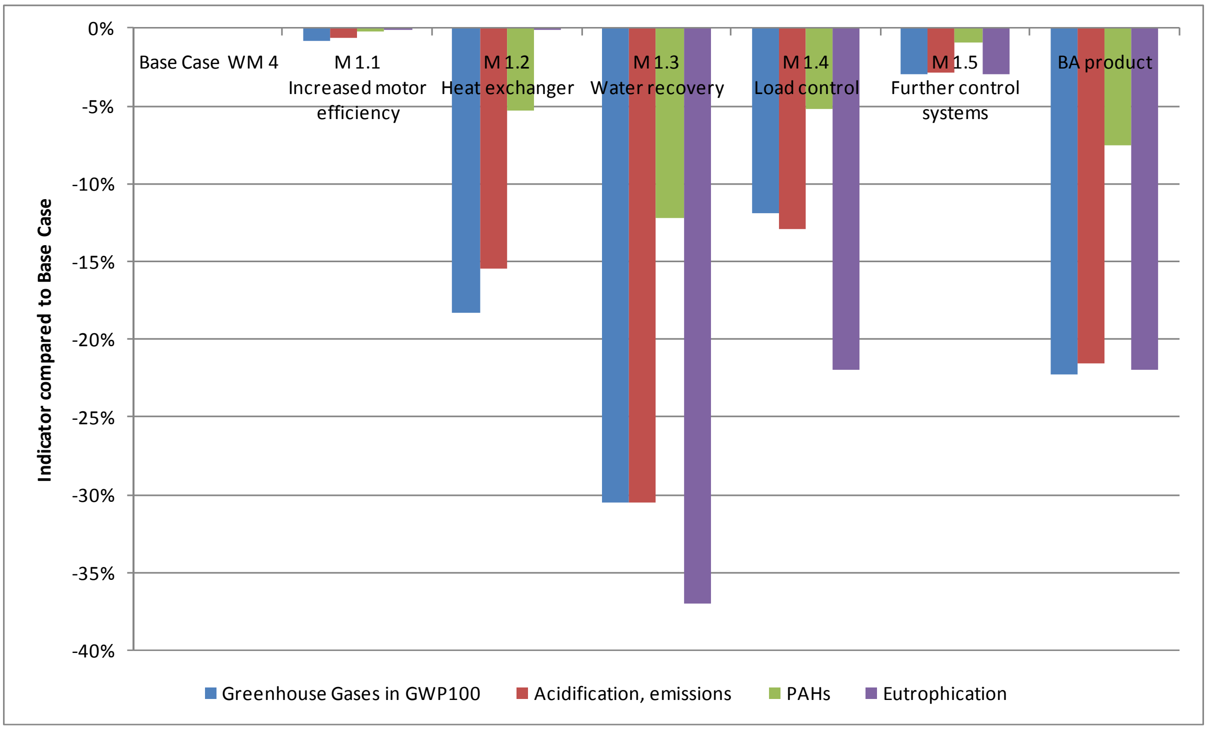


Figure 8 Improvement potential by improvement option for Base Case WM 4

3.5 Base Case WM 5: Professional washer dryer

The results of the environmental analysis of the improvement options for Base Case WM 5 are shown in Table 22. In terms of energy, the application of option M 1.4 Load control is the best option, reducing the energy consumption in about 20%. This option also represents the best improvement for all the other indicators, including water (process) and eutrophication.

Table 22 Environmental impacts by improvement option for Base Case WM 5

Life cycle indicators per unit	Unit	Base Case WM 5	M 1.1 Increased motor efficiency	M 1.4 Load control	M 1.5 Further control systems
Other resources and waste					
Total Energy (GER)	GJ	937.1	928.6	751.6	847.3
	% change with BC	0%	-1%	-20%	-10%
of which, electricity	primary GJ	865.4	856.8	694.6	780.1
	MWh	82.4	81.6	66.1	74.3
	% change with BC	0%	-1%	-20%	-10%
Water (process)	kL	1 165.3	1 164.8	824.0	1 050.0
	% change with BC	0%	0%	-29%	-10%
Water (cooling)	kL	2 282.7	2 260.0	1 826.9	2 054.9
	% change with BC	0%	-1%	-20%	-10%
Waste, non-haz./ landfill	kg	1 795.3	1 785.3	1 580.3	1 696.8
	% change with BC	0%	-1%	-12%	-5%
Waste, hazardous/ incinerated	kg	34.9	34.7	30.7	33.1
	% change with BC	0%	-1%	-12%	-5%
Emissions (Air)					
Greenhouse Gases in GWP100	t CO2 eq.	41.7	41.4	33.6	37.8
	% change with BC	0%	-1%	-19%	-9%
Acidification, emissions	kg SO2 eq.	245.1	242.9	197.3	222.1
	% change with BC	0%	-1%	-19%	-9%
Volatile Organic Compounds (VOC)	kg	0.5	0.5	0.4	0.5
	% change with BC	0%	-1%	-13%	-6%
Persistent Organic Pollutants (POP)	µg i-Teq	14.6	14.5	13.4	14.0
	% change with BC	0%	0%	-8%	-4%

Life cycle indicators per unit	Unit	Base Case WM 5	M 1.1 Increased motor efficiency	M 1.4 Load control	M 1.5 Further control systems
Heavy Metals	g Ni eq.	23.6	23.4	20.4	22.4
	% change with BC	0%	-1%	-13%	-5%
PAHs	g Ni eq.	3.6	3.6	3.3	3.6
	% change with BC	0%	0%	-10%	-2%
Particulate Matter (PM, dust)	kg	17.6	17.5	16.6	17.2
	% change with BC	0%	0%	-6%	-2%
Emissions (Water)					
Heavy Metals	g Hg/20	13.8	13.7	12.8	13.6
	% change with BC	0%	0%	-8%	-2%
Eutrophication	kg PO4	82.7	82.7	58.0	74.5
	% change with BC	0%	0%	-30%	-10%

Figure 9 presents the proportions represented by electricity consumption amongst the total primary energy consumption. From the figure it is clear that the electricity consumption of this base case is rather high (it is considered 100% electric heating, on the contrary to the other base cases). It represents more than 90% for all the options.

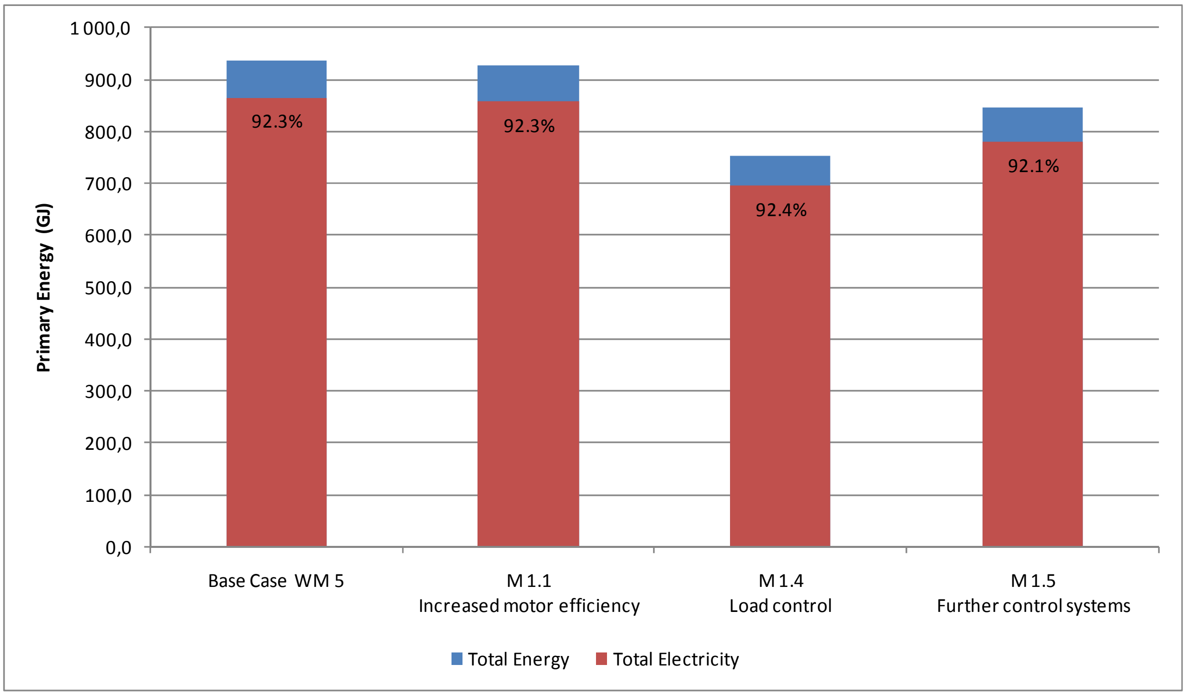


Figure 9 Energy consumption by improvement option for Base Case WM 5

Other environmental impacts are shown in Figure 10 below.

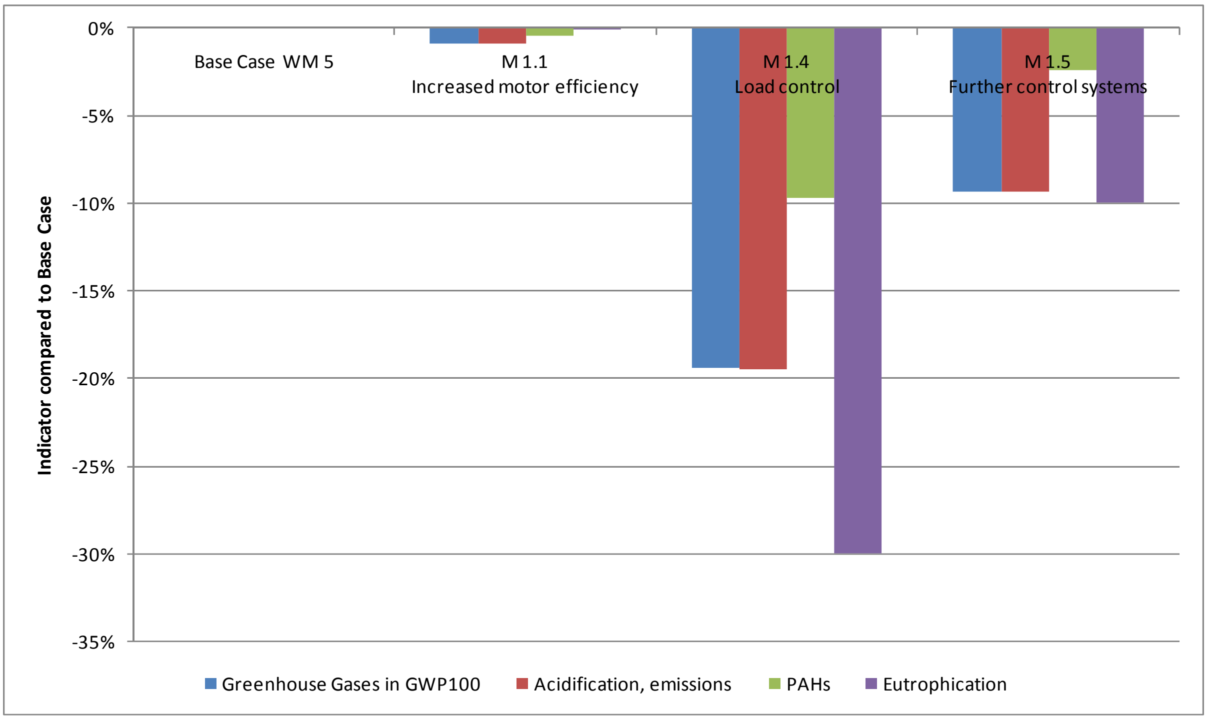


Figure 10 Improvement potential by improvement option for Base Case WM 5

3.6 Base Case WM 6: Professional Barrier Washer

The results of the environmental analysis of the improvement options for Base Case WM 6 are shown in Table 23. Most indicators considered are improved by option M 1.3 Water recovery. This option provides an efficient use of the resources. In terms of energy consumption, the reduction is around 30%. Option M 1.2 Heat exchanger is the single option that provides the third highest energy savings (18%), right behind the BA product (22%).

Table 23 Environmental impacts by improvement option for Base Case WM 6

Life cycle indicators per unit	Unit	Base Case WM 6	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	BA product
Other resources and waste								
Total Energy (GER)	**GJ**	2 998.9	2 975.2	2 453.4	2 085.3	2 641.3	2 917.1	2 333.9
	% change with BC	0%	-1%	-18%	-30%	-12%	-3%	-22%
of which, electricity	**primary GJ**	1 351.8	1 338.5	1 044.5	951.0	1 218.1	1 311.8	1 044.6
	MWh	128.7	127.5	99.5	90.6	116.0	124.9	99.5
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Water (process)	**kL**	15 271.4	15 270.5	15 251.5	9 641.6	11 930.3	14 814.7	11 919.5
	% change with BC	0%	0%	0%	-37%	-22%	-3%	-22%
Water (cooling)	**kL**	3 584.4	3 548.7	2 764.4	2 514.9	3 227.8	3 477.5	2 764.5
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Waste, non-haz./ landfill	**kg**	3 460.4	3 444.8	3 125.1	2 778.5	3 166.4	3 407.2	2 992.0
	% change with BC	0%	0%	-10%	-20%	-8%	-2%	-14%
Waste, hazardous/ incinerated	**kg**	109.6	109.3	102.5	95.7	103.8	108.6	99.9
	% change with BC	0%	0%	-6%	-13%	-5%	-1%	-9%
Emissions (Air)								
Greenhouse Gases in GWP100	**t CO2 eq.**	145.2	144.0	118.6	101.7	128.4	141.3	113.4
	% change with BC	0%	-1%	-18%	-30%	-12%	-3%	-22%
Acidification,	**kg SO2 eq.**	540.5	536.9	458.2	380.8	473.3	527.0	427.3

Life cycle indicators per unit	Unit	Base Case WM 6	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	BA product
emissions	**% change with BC**	0%	-1%	-15%	-30%	-12%	-2%	-21%
Volatile Organic Compounds (VOC)	**kg**	1.7	1.7	1.4	1.3	1.6	1.7	1.4
	% change with BC	0%	-1%	-17%	-26%	-10%	-2%	-19%
Persistent Organic Pollutants (POP)	**µg i-Teq**	22.6	22.5	20.7	18.8	20.9	22.3	19.9
	% change with BC	0%	0%	-9%	-17%	-7%	-1%	-12%
Heavy Metals	**g Ni eq.**	105.0	104.8	101.0	97.0	100.7	104.6	99.3
	% change with BC	0%	0%	-4%	-8%	-4%	0%	-5%
PAHs	**g Ni eq.**	7.9	7.9	7.6	6.7	7.4	7.9	7.5
	% change with BC	0%	0%	-4%	-15%	-6%	0%	-6%
Particulate Matter (PM, dust)	**kg**	52.2	52.1	50.8	49.2	50.7	52.0	50.2
	% change with BC	0%	0%	-3%	-6%	-3%	0%	-4%
Emissions (Water)								
Heavy Metals	**g Hg/20**	51.9	51.8	50.7	50.6	51.0	51.9	51.0
	% change with BC	0%	0%	-2%	-2%	-2%	0%	-2%
Eutrophication	**kg PO4**	913.7	913.7	913.7	576.1	713.0	895.5	713.0
	% change with BC	0%	0%	0%	-37%	-22%	-2%	-22%

The proportions total energy and total electricity remain constant for all options. Total electricity is around 45% of total primary energy for all options.

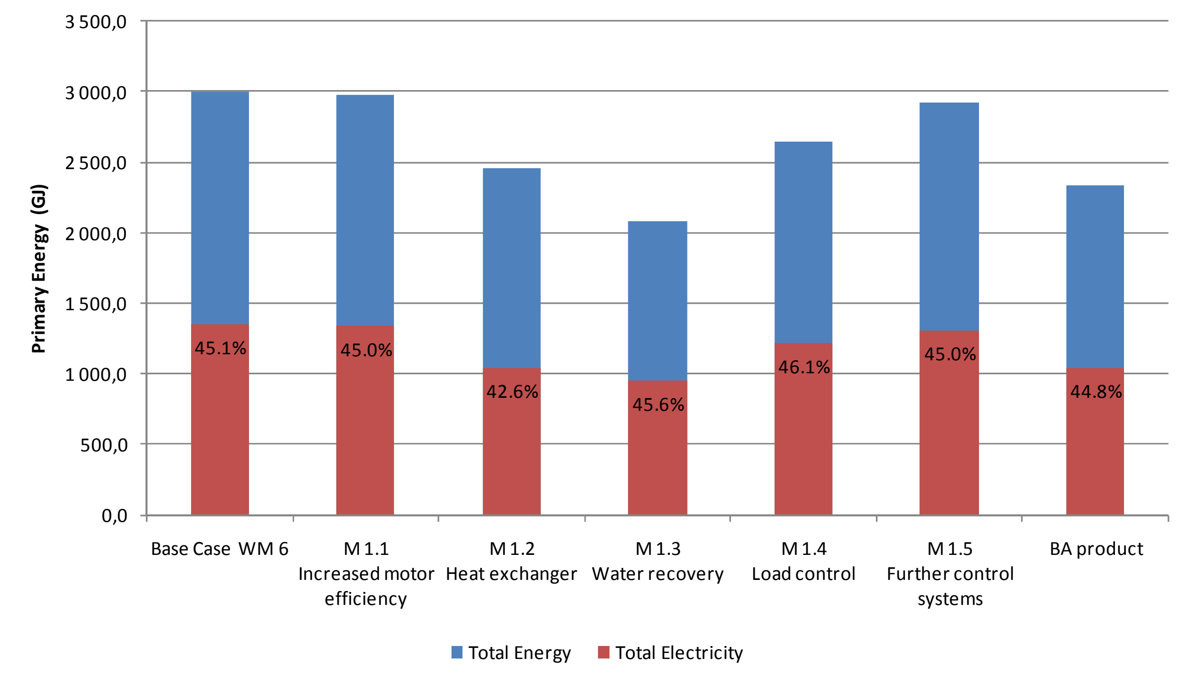


Figure 11 Energy consumption by improvement option for Base Case WM 6

The influence of each option on other impacts is shown in Figure 12 below.

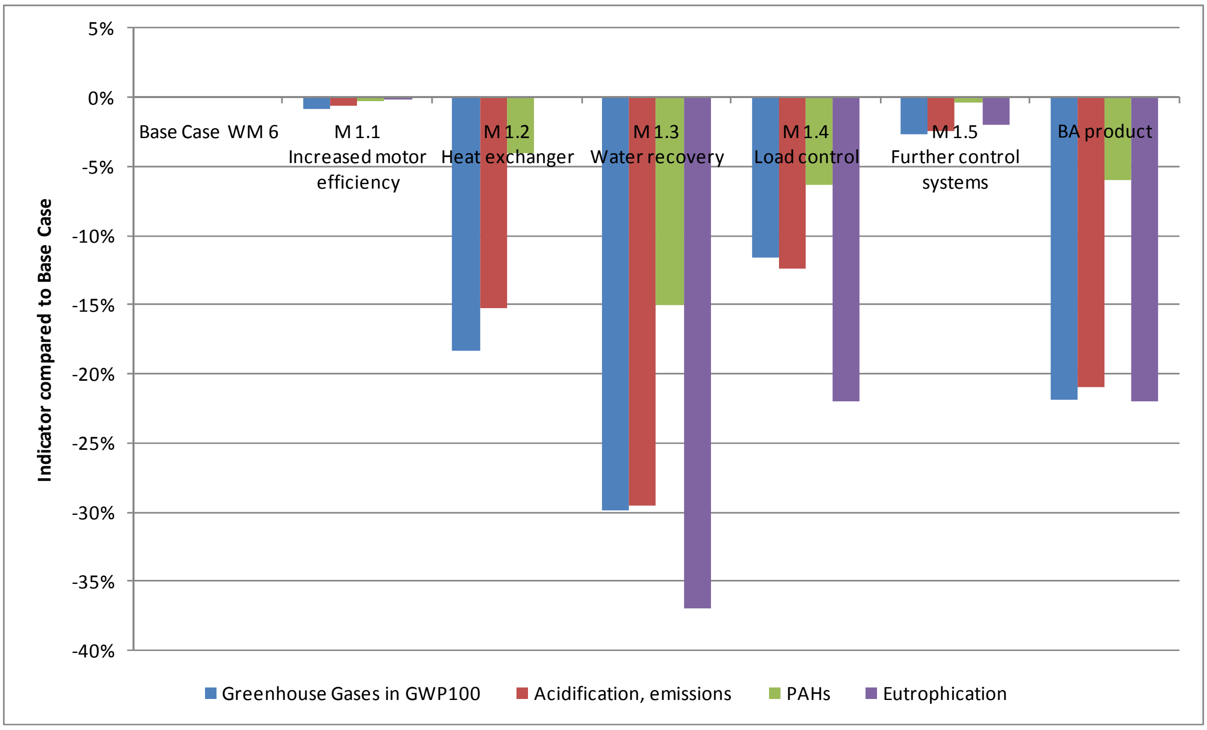


Figure 12 Improvement potential by improvement option for Base Case WM 6

3.7 Base Case WM 7: Washing tunnel machine

The results of the environmental analysis of the improvement options for Base Case WM 7 are shown in Table 24. The BA product leads to the greatest energy savings, around 37%, followed by option M 1.2 Heat exchanger (25%).

Table 24 Environmental impacts by improvement option for Base Case WM 7

Life cycle indicators per unit	Unit	Base Case WM 7	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	BA product
Other resources and waste					
Total Energy (GER)	**GJ**	114 095.0	113 136.2	85 330.7	71 942.6
	% change with BC	0%	-1%	-25%	-37%
of which, electricity	**primary GJ**	11 242.1	11 132.5	7 953.0	7 404.8
	MWh	1 070.7	1 060.2	757.4	705.2
	% change with BC	0%	-1%	-29%	-34%
Water (process)	**kL**	359 961.7	359 954.3	359 743.0	180 491.9
	% change with BC	0%	0%	0%	-50%
Water (cooling)	**kL**	29 406.3	29 113.9	20 634.9	19 173.0
	% change with BC	0%	-1%	-30%	-35%
Waste, non-haz./ landfill	**kg**	51 073.4	50 946.2	47 268.7	36 668.7
	% change with BC	0%	0%	-7%	-28%
Waste, hazardous/ incinerated	**kg**	895.0	892.5	819.2	608.6
	% change with BC	0%	0%	-8%	-32%
Emissions (Air)					
Greenhouse Gases in GWP100	**t CO2 eq.**	6 010.1	5 958.3	4 458.1	3 824.4
	% change with BC	0%	-1%	-26%	-36%
Acidification, emissions	**kg SO2 eq.**	9 380.2	9 338.3	8 123.5	5 686.5
	% change with BC	0%	0%	-13%	-39%
Volatile Organic Compounds (VOC)	**kg**	75.7	75.0	55.9	49.4
	% change with BC	0%	-1%	-26%	-35%
Persistent Organic Pollutants (POP)	**µg i-Teq**	307.0	306.3	285.5	225.6
	% change with BC	0%	0%	-7%	-27%
Heavy Metals	**g Ni eq.**	1 982.0	1 980.1	1 926.8	1 769.9
	% change with BC	0%	0%	-3%	-11%

Life cycle indicators per unit	Unit	Base Case WM 7	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	BA product
PAHs	g Ni eq.	76.5	76.2	69.3	51.2
	% change with BC	0%	0%	-9%	-33%
Particulate Matter (PM, dust)	kg	472.7	471.9	447.7	396.2
	% change with BC	0%	0%	-5%	-16%
Emissions (Water)					
Heavy Metals	g Hg/20	980.8	980.1	960.3	956.7
	% change with BC	0%	0%	-2%	-2%
Eutrophication	kg PO4	28 809.3	28 809.3	28 809.2	14 416.5
	% change with BC	0%	0%	0%	-50%

Figure 13 presents the proportions represented by electricity consumption amongst the total primary energy consumption. This proportion is constant for all options (only 10% approximately, due to high use of gas as energy source for this kind of product).

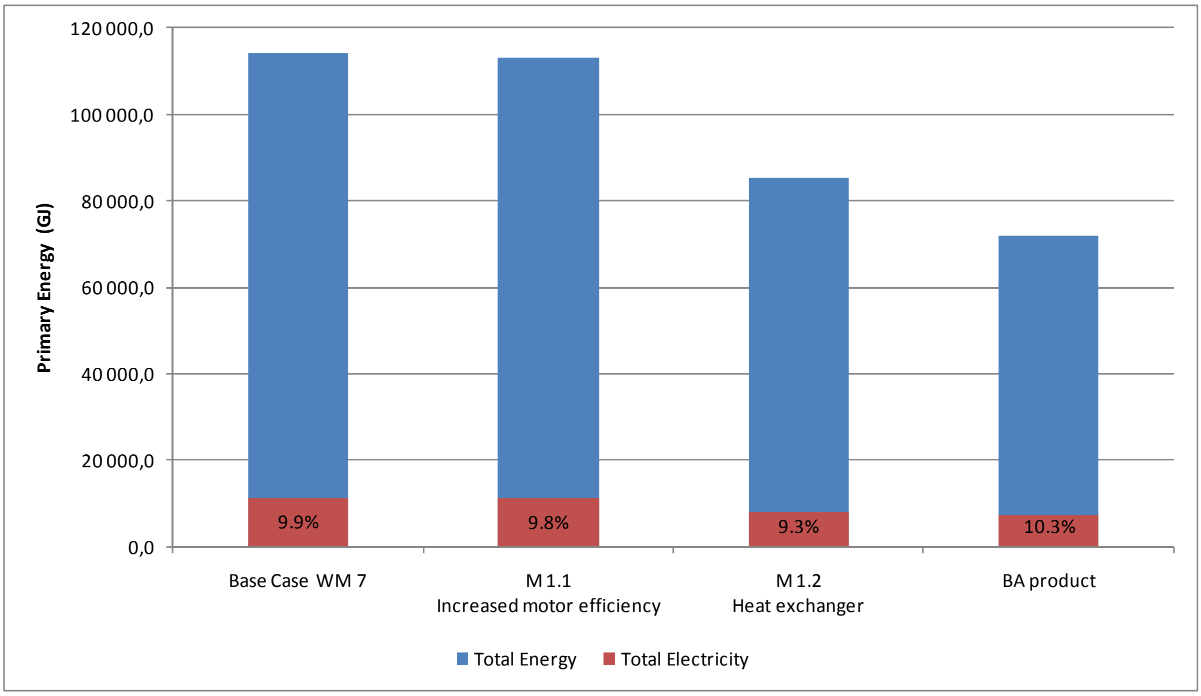


Figure 13 Energy consumption by improvement option for Base Case WM 7

Other impacts are represented in Figure 14 below.

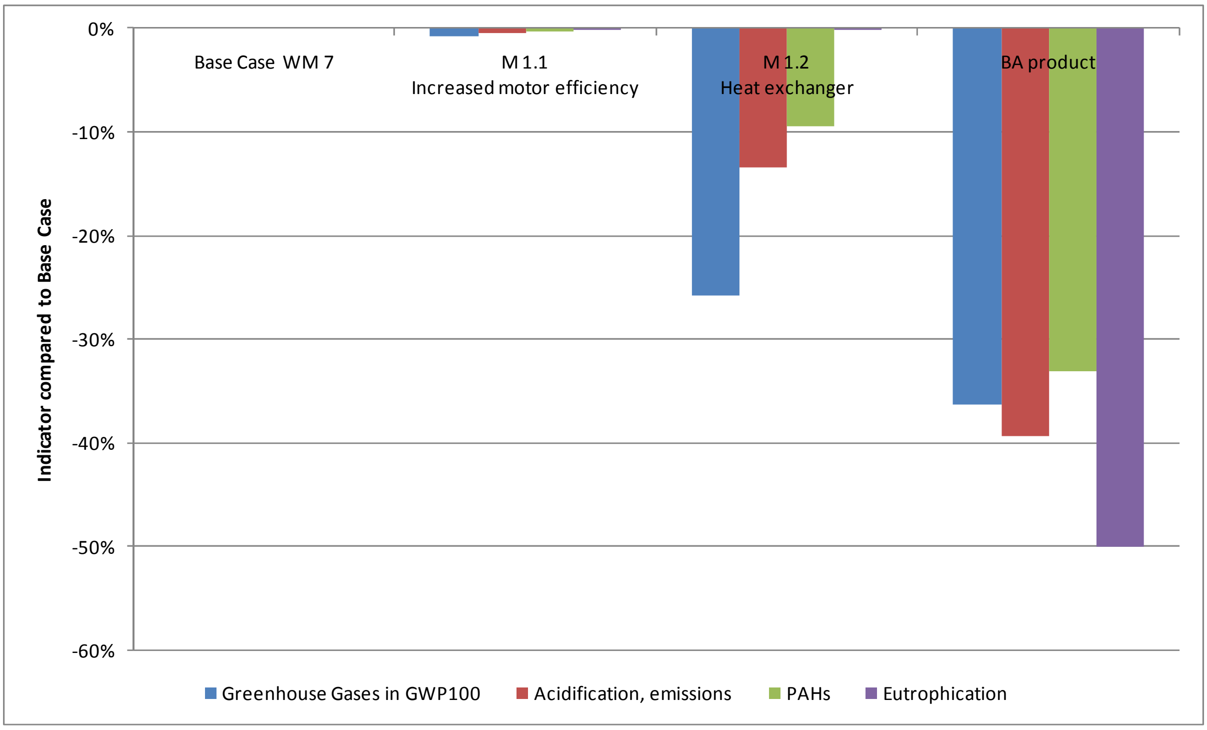


Figure 14 Improvement potential by improvement option for Base Case WM 7

3.8 Base Case D 1: Semi-professional dryer, condenser

The results of the environmental analysis of the improvement options for Base Case D 1 are shown in Table 25. The BA product leads to the best improvement of all indicators. In particular, it leads to 64% of primary energy reduction. Option M 2.2 Heat pump is the single option that provides the second highest energy savings (53%).

Table 25 Environmental impacts by improvement option for Base Case D 1

Life cycle indicators per unit	Unit	Base Case D 1	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Other resources and waste									
Total Energy (GER)	GJ	417.1	408.9	197.8	376.6	376.3	376.2	376.1	149.4
	% change with BC	0%	-2%	-53%	-10%	-10%	-10%	-10%	-64%
of which, electricity	primary GJ	411.9	403.7	187.6	371.1	371.1	371.0	371.0	138.7
	MWh	39.2	38.5	17.9	35.3	35.3	35.3	35.3	13.2
	% change with BC	0%	-2%	-54%	-10%	-10%	-10%	-10%	-66%
Water (process)	kL	31.0	30.5	19.3	28.4	28.4	28.4	28.3	16.2
	% change with BC	0%	-2%	-38%	-8%	-8%	-9%	-9%	-48%
Water (cooling)	kL	1 094.2	1 072.4	494.0	985.0	985.0	985.0	985.0	362.9
	% change with BC	0%	-2%	-55%	-10%	-10%	-10%	-10%	-67%
Waste, non-haz./ landfill	kg	584.6	574.9	439.7	570.4	537.5	537.3	537.1	416.3
	% change with BC	0%	-2%	-25%	-2%	-8%	-8%	-8%	-29%
Waste, hazardous/ incinerated	kg	20.3	20.2	15.3	19.8	19.5	19.5	19.5	15.0
	% change with BC	0%	-1%	-25%	-3%	-4%	-4%	-4%	-26%
Emissions (Air)									
Greenhouse Gases in GWP100	t CO2 eq.	18.4	18.0	9.1	16.6	16.6	16.6	16.6	7.0
	% change with BC	0%	-2%	-50%	-10%	-10%	-10%	-10%	-62%
Acidification, emissions	kg SO2 eq.	109.8	107.6	55.5	99.8	99.3	99.3	99.2	43.6
	% change with BC	0%	-2%	-49%	-9%	-10%	-10%	-10%	-60%
Volatile Organic Compounds (VOC)	kg	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.1
	% change with BC	0%	-2%	-35%	-7%	-7%	-8%	-8%	-43%
Persistent Organic Pollutants (POP)	µg i-Teq	3.1	3.1	2.1	2.9	2.9	2.9	2.9	1.8

Life cycle indicators per unit	Unit	Base Case D 1	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
	% change with BC	0%	-2%	-34%	-8%	-9%	-9%	-9%	-44%
Heavy Metals	g Ni eq.	12.8	12.7	15.3	12.3	12.2	12.2	12.1	14.6
	% change with BC	0%	-1%	19%	-4%	-5%	-5%	-5%	14%
PAHs	g Ni eq.	1.3	1.2	1.8	1.2	1.2	1.2	1.2	1.8
	% change with BC	0%	-1%	39%	-1%	-5%	-6%	-6%	38%
Particulate Matter (PM, dust)	kg	6.1	6.1	7.2	6.1	5.9	5.9	5.9	7.1
	% change with BC	0%	-1%	18%	-1%	-3%	-4%	-3%	16%
Emissions (Water)									
Heavy Metals	g Hg/20	6.7	6.6	9.3	6.7	6.5	6.5	6.4	9.4
	% change with BC	0%	-1%	40%	0%	-3%	-3%	-4%	40%
Eutrophication	kg PO4	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2
	% change with BC	0%	-1%	82%	1%	0%	-1%	-1%	84%

Total electricity represents over 92% of total primary energy for all improvement options (the base case is considered 100% electric heating). This proportion is shown in Figure 15.

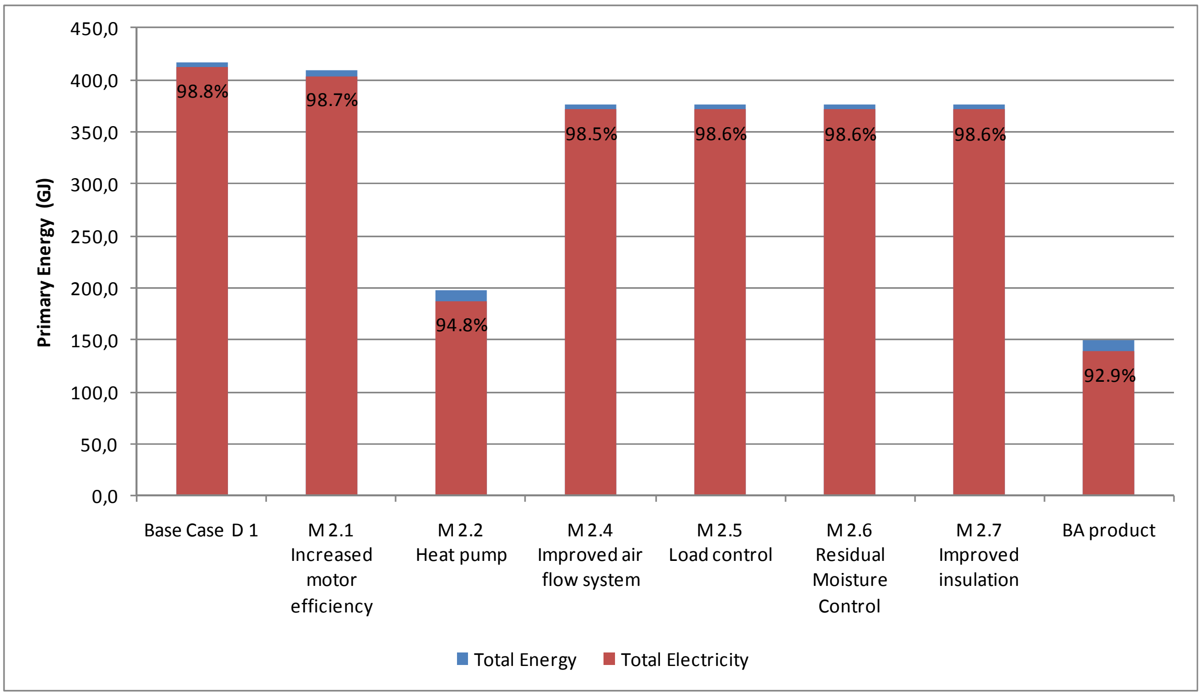


Figure 15 Energy consumption by improvement option for Base Case D 1

Impacts for other environmental indicators are shown below. The heat pump option and the BA product show the largest reduction in greenhouse gases and acidification emissions but also the largest increase in PAHs and eutrophication.

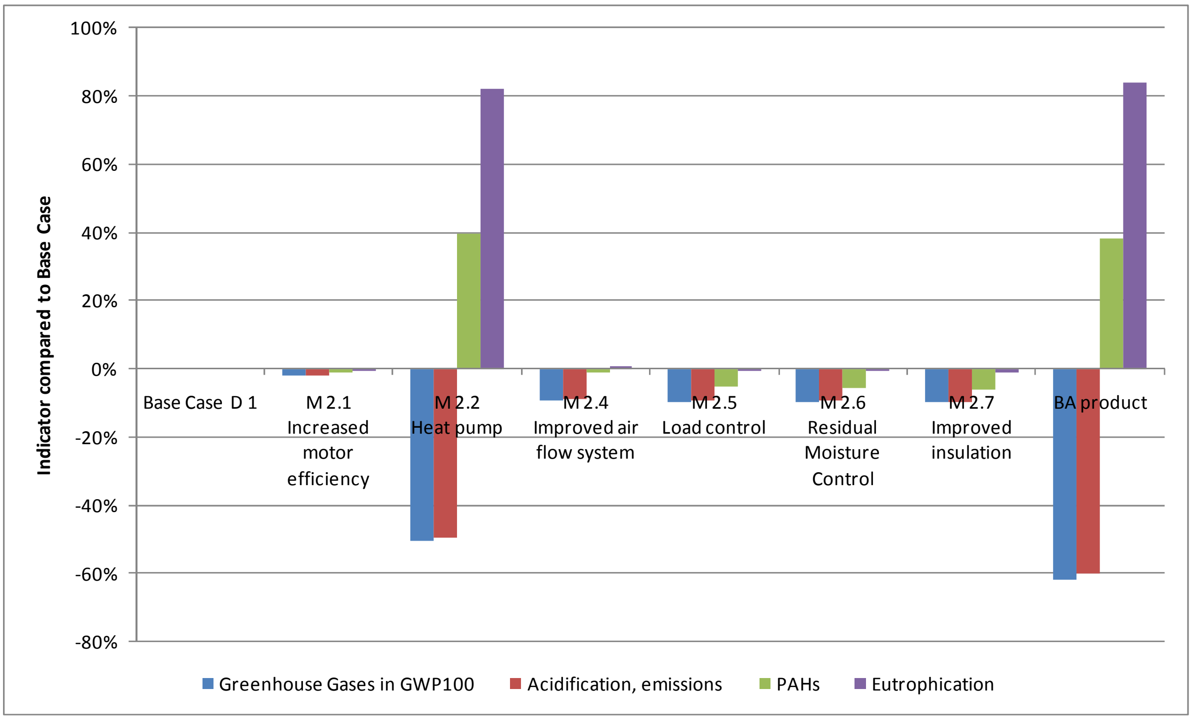


Figure 16 Improvement potential by improvement option for Base Case D 1

3.9 Base Case D 2: Semi-professional dryer, air vented

The results of the environmental analysis of the improvement options for Base Case D 2 are shown below. The greatest energy reduction is due to the heat pump option (47%). This option also leads to increases in other indicators such as heavy metals, PAHs and eutrophication. Presumably this is a consequence of the extra material and refrigerant use.

Table 26 Environmental impacts by improvement option for Base Case D 2

Life cycle indicators per unit	Unit	Base Case D 2	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Other resources and waste										
Total Energy (GER)	**GJ**	314.0	307.9	166.3	286.6	283.8	283.5	283.4	283.4	241.3
	% change with BC	0%	-2%	-47%	-9%	-10%	-10%	-10%	-10%	-23%
of which, electricity	**primary GJ**	257.4	252.2	130.7	232.3	231.9	231.9	231.9	231.8	194.3
	MWh	24.5	24.0	12.4	22.1	22.1	22.1	22.1	22.1	18.5
	% change with BC	0%	-2%	-49%	-10%	-10%	-10%	-10%	-10%	-24%
Water (process)	**kL**	20.6	20.2	15.1	20.5	18.9	19.0	18.9	18.9	18.1
	% change with BC	0%	-2%	-26%	0%	-8%	-8%	-8%	-8%	-12%
Water (cooling)	**kL**	682.3	668.7	342.5	614.6	614.3	614.2	614.2	614.2	512.6
	% change with BC	0%	-2%	-50%	-10%	-10%	-10%	-10%	-10%	-25%
Waste, non-haz./ landfill	**kg**	403.2	397.0	365.8	434.1	406.9	373.9	373.7	373.6	423.4
	% change with BC	0%	-2%	-9%	8%	1%	-7%	-7%	-7%	5%
Waste, hazardous/ incinerated	**kg**	15.7	15.5	12.9	16.1	15.5	15.2	15.1	15.2	15.9
	% change with BC	0%	-1%	-18%	3%	-1%	-3%	-3%	-3%	2%
Emissions (Air)										
Greenhouse Gases in GWP100	**t CO2 eq.**	14.5	14.2	8.0	13.3	13.1	13.1	13.1	13.1	11.3
	% change with BC	0%	-2%	-45%	-8%	-9%	-10%	-10%	-10%	-22%
Acidification, emissions	**kg SO2 eq.**	70.6	69.3	41.0	65.9	64.6	64.1	64.0	64.0	56.6
	% change with BC	0%	-2%	-42%	-7%	-9%	-9%	-9%	-9%	-20%
Volatile Organic Compounds (VOC)	**kg**	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.1
	% change with BC	0%	-2%	-30%	-2%	-7%	-7%	-8%	-8%	-12%

Life cycle indicators per unit	Unit	Base Case D 2	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Persistent Organic Pollutants (POP)	**µg i-Teq**	2.1	2.1	1.7	2.2	2.0	1.9	1.9	1.9	1.9
	% change with BC	0%	-2%	-21%	2%	-7%	-8%	-8%	-8%	-9%
Heavy Metals	**g Ni eq.**	9.9	9.8	13.7	12.7	9.6	9.5	9.5	9.5	12.3
	% change with BC	0%	-1%	39%	29%	-3%	-4%	-4%	-4%	24%
PAHs	**g Ni eq.**	1.0	0.9	1.6	1.4	1.0	0.9	0.9	0.9	1.4
	% change with BC	0%	-1%	67%	45%	1%	-4%	-5%	-5%	45%
Particulate Matter (PM, dust)	**kg**	5.1	5.1	6.7	6.4	5.1	5.0	5.0	5.0	6.3
	% change with BC	0%	-1%	31%	24%	0%	-3%	-3%	-2%	24%
Emissions (Water)										
Heavy Metals	**g Hg/20**	5.5	5.4	8.6	7.4	5.6	5.4	5.4	5.3	7.5
	% change with BC	0%	-1%	56%	35%	1%	-2%	-2%	-3%	37%
Eutrophication	**kg PO4**	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.2
	% change with BC	0%	-1%	89%	49%	1%	0%	0%	-1%	51%

Total electricity represents over 78% of total primary energy for all improvement options.

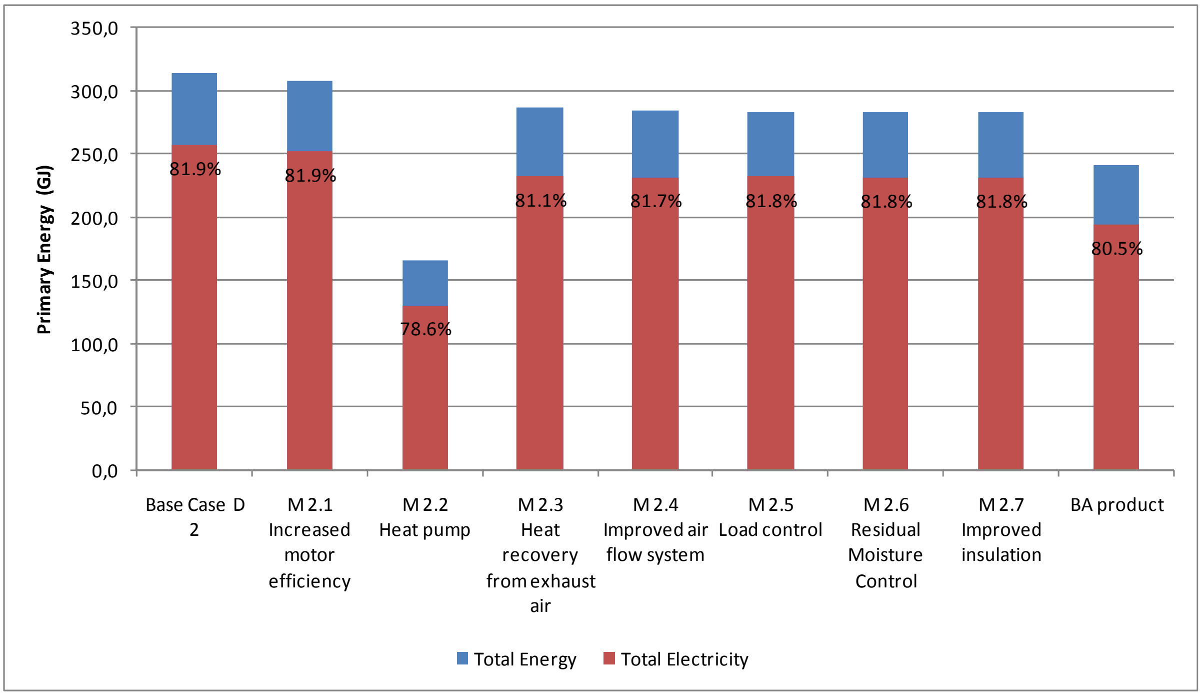


Figure 17 Energy consumption by improvement option for Base Case D 2

Other impacts are shown below. The Figure 18 shows how some of the options increase eutrophication instead of reducing it.

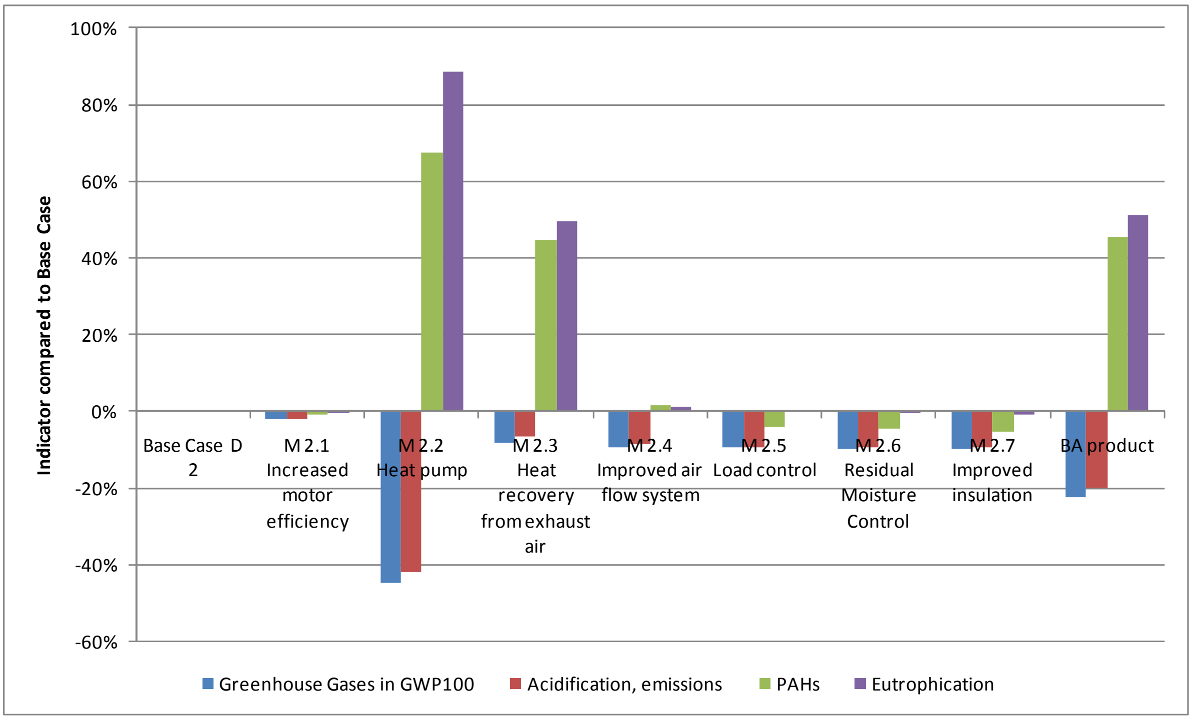


Figure 18 Improvement potential by improvement option for Base Case D 2

3.10 Base Case D 3: Professional cabinet dryer

The results of the environmental analysis of the improvement options for Base Case D 3 are shown below. In this case, the best option corresponds to the BA product. The energy reduction is around 65%. Option M 2.2 Heat pump is the single option that provides the second highest energy savings (57%).

Table 27 Environmental impacts by improvement option for Base Case D 3

Life cycle indicators per unit	Unit	Base Case D 3	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.7 Improved insulation	BA product
Other resources and waste							
Total Energy (GER)	**GJ**	949.1	405.0	859.1	856.3	855.9	330.8
	% change with BC	0%	-57%	-9%	-10%	-10%	-65%
of which, electricity	**primary GJ**	936.6	379.5	843.8	843.4	843.3	304.9
	MWh	89.2	36.1	80.4	80.3	80.3	29.0
	% change with BC	0%	-59%	-10%	-10%	-10%	-67%
Water (process)	**kL**	64.3	35.2	59.7	58.1	58.0	30.3
	% change with BC	0%	-45%	-7%	-10%	-10%	-53%
Water (cooling)	**kL**	2 489.3	998.0	2 240.9	2 240.5	2 240.5	799.0
	% change with BC	0%	-60%	-10%	-10%	-10%	-68%
Waste, non-haz./ landfill	**kg**	1 391.8	990.0	1 333.9	1 298.8	1 283.7	918.7
	% change with BC	0%	-29%	-4%	-7%	-8%	-34%
Waste, hazardous/ incinerated	**kg**	27.4	15.0	26.3	25.7	25.4	13.9
	% change with BC	0%	-45%	-4%	-6%	-7%	-50%
Emissions (Air)							
Greenhouse Gases in GWP100	**t CO2 eq.**	41.8	18.7	37.9	37.7	37.7	15.5
	% change with BC	0%	-55%	-9%	-10%	-10%	-63%
Acidification, emissions	**kg SO2 eq.**	245.2	109.9	223.0	221.4	221.2	90.9
	% change with BC	0%	-55%	-9%	-10%	-10%	-63%
Volatile Organic Compounds (VOC)	**kg**	0.4	0.3	0.4	0.4	0.4	0.2
	% change with BC	0%	-36%	-6%	-8%	-8%	-42%
Persistent Organic Pollutants (POP)	**µg i-Teq**	9.3	6.7	8.9	8.7	8.7	6.2
	% change with BC	0%	-28%	-4%	-6%	-7%	-33%

Life cycle indicators per unit	Unit	Base Case D 3	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.7 Improved insulation	BA product
Heavy Metals	g Ni eq.	17.9	24.3	19.6	16.4	16.3	23.2
	% change with BC	0%	36%	9%	-8%	-9%	30%
PAHs	g Ni eq.	4.1	5.5	4.4	4.0	4.0	5.4
	% change with BC	0%	32%	7%	-3%	-4%	30%
Particulate Matter (PM, dust)	kg	13.8	17.8	14.9	13.5	13.3	17.6
	% change with BC	0%	29%	8%	-2%	-4%	28%
Emissions (Water)							
Heavy Metals	g Hg/20	8.7	15.3	10.1	8.2	8.1	15.0
	% change with BC	0%	77%	17%	-5%	-7%	73%
Eutrophication	kg PO4	0.1	0.3	0.1	0.1	0.1	0.3
	% change with BC	0%	349%	72%	-1%	-4%	349%

Total electricity consumption is more than 92% of primary energy.

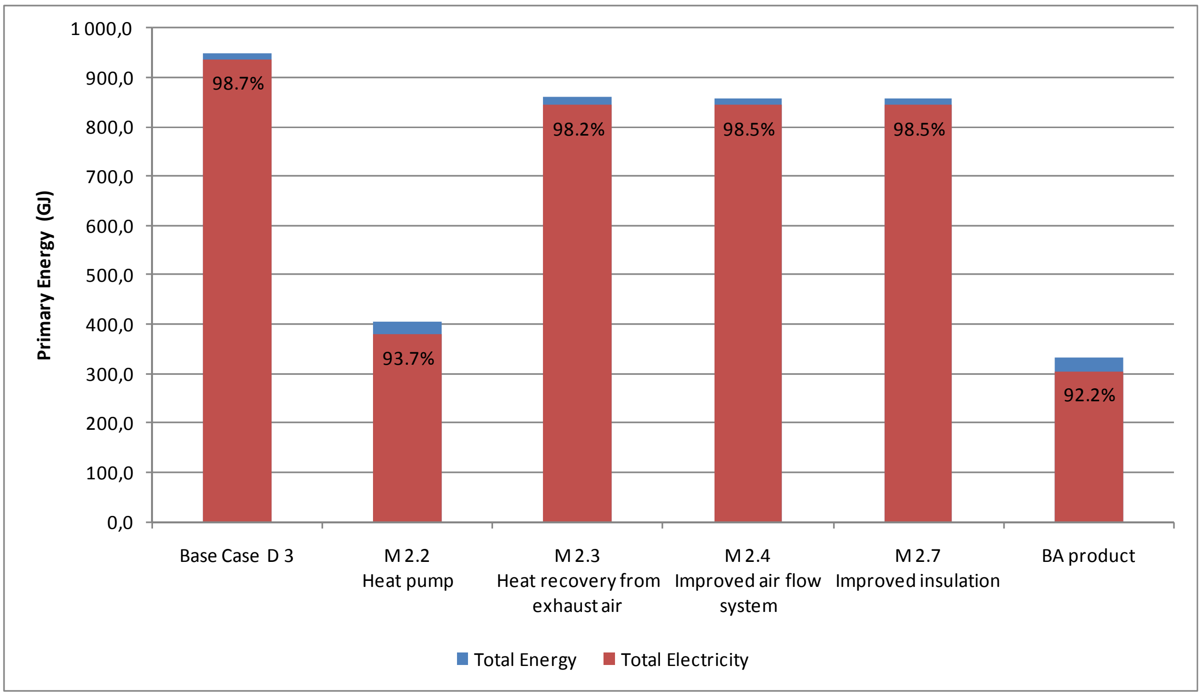


Figure 19 Energy consumption by improvement option for Base Case D 3

Other indicators are shown in Figure 20 below.

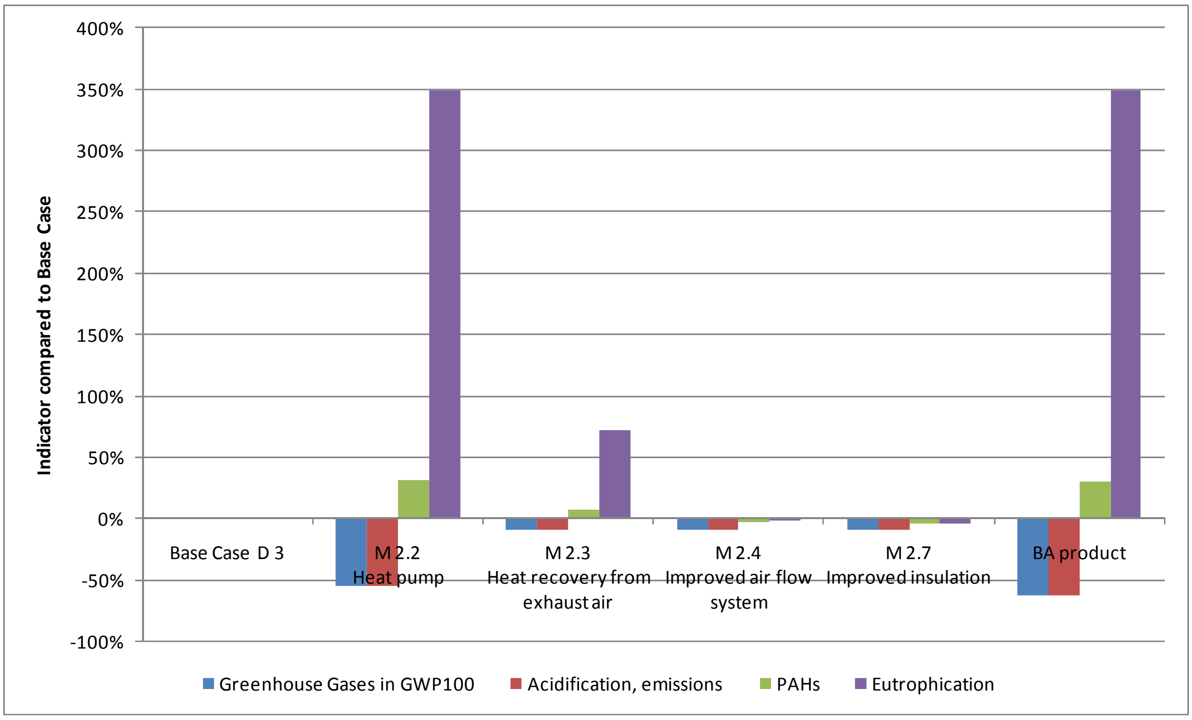


Figure 20 Improvement potential by improvement option for Base Case D 3

3.11 Base Case D 4: Professional tumble dryer (<15 kg)

The results of the environmental analysis of the improvement options for Base Case D 4 are shown below. The BA product results in the greatest reduction of energy consumption (65%) but also leads to increasing emissions (e.g. PAHs, particulate matter) due the additional materials required and the refrigerant.

Table 28 Environmental impacts by improvement option for Base Case D 4

Life cycle indicators per unit	Unit	Base Case D 4	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Other resources and waste										
Total Energy (GER)	**GJ**	960.4	931.9	402.6	867.8	884.7	846.4	846.4	893.9	336.4
	% change with BC	0%	-3%	-58%	-10%	-8%	-12%	-12%	-7%	-65%
of which, electricity	**primary GJ**	671.8	651.7	272.1	605.3	618.3	591.4	591.4	624.9	225.3
	MWh	64.0	62.1	25.9	57.6	58.9	56.3	56.3	59.5	21.5
	% change with BC	0%	-3%	-59%	-10%	-8%	-12%	-12%	-7%	-66%
Water (process)	**kL**	45.9	44.5	27.9	43.1	42.4	40.5	40.5	42.8	24.8
	% change with BC	0%	-3%	-39%	-6%	-8%	-12%	-12%	-7%	-46%
Water (cooling)	**kL**	1 789.5	1 735.9	724.3	1 612.1	1 646.9	1 575.1	1 575.1	1 664.4	599.6
	% change with BC	0%	-3%	-60%	-10%	-8%	-12%	-12%	-7%	-66%
Waste, non-haz./ landfill	**kg**	1 003.9	980.4	668.7	951.0	942.8	910.7	910.7	949.6	615.2
	% change with BC	0%	-2%	-33%	-5%	-6%	-9%	-9%	-5%	-39%
Waste, hazardous/ incinerated	**kg**	18.9	18.4	9.7	18.3	18.0	17.0	17.0	17.9	9.1
	% change with BC	0%	-2%	-49%	-3%	-5%	-10%	-10%	-5%	-52%
Emissions (Air)										
Greenhouse Gases in GWP100	**t CO2 eq.**	45.4	44.1	19.7	41.1	41.8	40.0	40.0	42.3	16.6
	% change with BC	0%	-3%	-57%	-9%	-8%	-12%	-12%	-7%	-63%
Acidification, emissions	**kg SO2 eq.**	179.8	174.4	81.1	163.5	165.7	158.5	158.5	167.4	68.8
	% change with BC	0%	-3%	-55%	-9%	-8%	-12%	-12%	-7%	-62%
Volatile Organic Compounds (VOC)	**kg**	0.5	0.5	0.3	0.5	0.5	0.5	0.5	0.5	0.3
	% change with BC	0%	-3%	-45%	-7%	-7%	-11%	-11%	-6%	-51%
Persistent Organic	**µg i-Teq**	7.6	7.4	5.9	7.3	7.2	7.0	7.0	7.3	5.6

Life cycle indicators per unit	Unit	Base Case D 4	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Pollutants (POP)	**% change with BC**	0%	-2%	-22%	-3%	-5%	-7%	-7%	-4%	-26%
Heavy Metals	**g Ni eq.**	14.2	13.8	24.5	16.3	13.4	12.8	12.8	13.4	23.7
	% change with BC	0%	-3%	72%	15%	-6%	-10%	-10%	-6%	67%
PAHs	**g Ni eq.**	1.7	1.7	2.5	1.9	1.6	1.5	1.5	1.6	2.5
	% change with BC	0%	-2%	50%	10%	-4%	-9%	-9%	-5%	46%
Particulate Matter (PM, dust)	**kg**	11.5	11.4	15.4	12.4	11.4	11.1	11.1	11.3	15.3
	% change with BC	0%	-1%	34%	8%	-1%	-4%	-4%	-2%	33%
Emissions (Water)										
Heavy Metals	**g Hg/20**	5.9	5.7	13.2	7.3	5.6	5.4	5.4	5.6	12.9
	% change with BC	0%	-3%	124%	24%	-5%	-9%	-9%	-5%	119%
Eutrophication	**kg PO4**	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.3
	% change with BC	0%	-2%	378%	72%	1%	-3%	-4%	-2%	380%

The shares of total electricity are constant for all improvement options (around 70% of primary energy consumption).

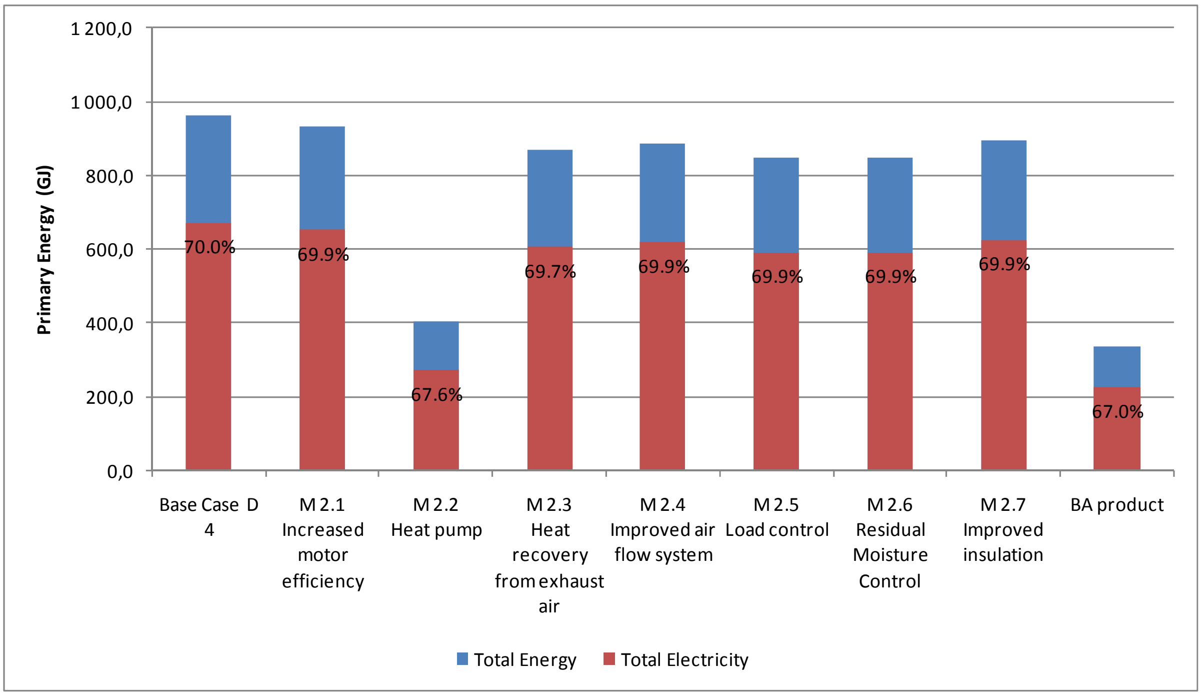


Figure 21 Energy consumption by improvement option for Base Case D 4

The impact on other indicators is shown in Figure 22 below. The impact of the heat pump and the BA product is particularly important in terms of PAHs emissions (almost +400%).

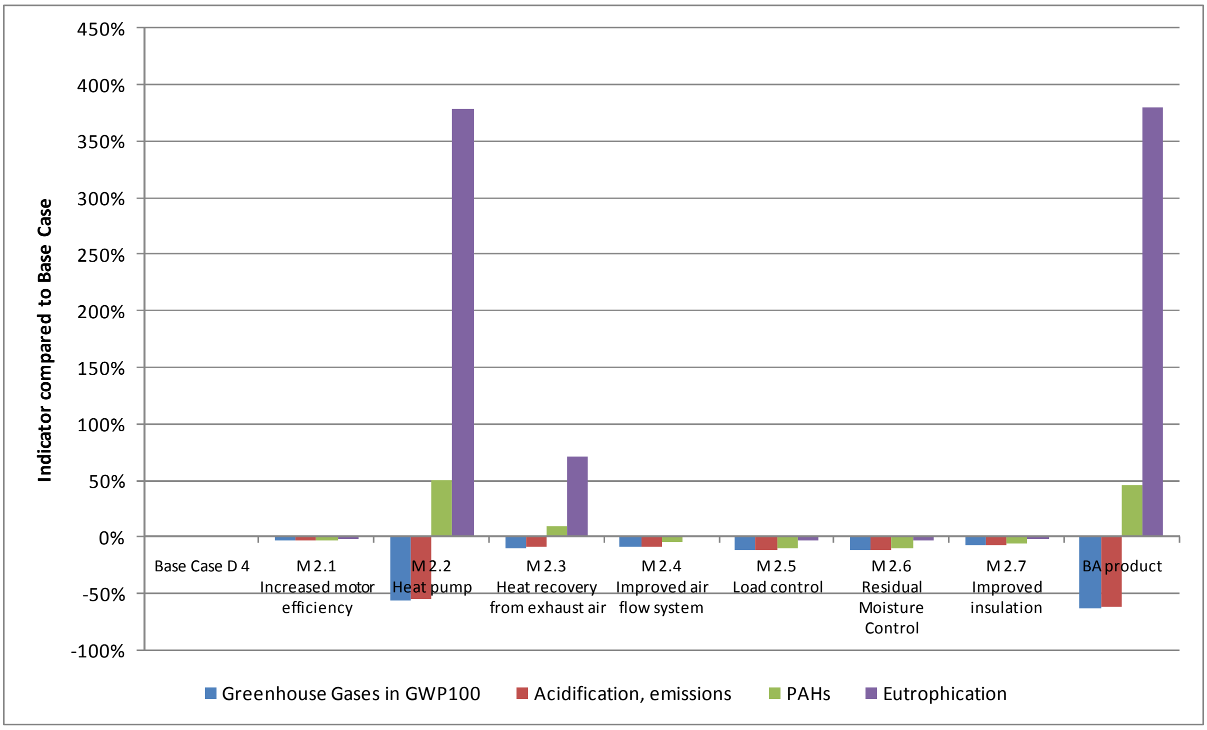


Figure 22 Improvement potential by improvement option for Base Case D 4

3.12 Base Case D 5: Professional tumble dryer (15–40 kg)

The results of the environmental analysis of the improvement options for Base Case D 5 are shown below. The option M 2.2 Heat pump provides the best improvement for most of the indicators, especially 58% for energy consumption. The BA product shows a very similar performance, and increases the emissions of PAHs and particulate matter due to the higher metal content.

Table 29 Environmental impacts by improvement option for Base Case D 5

Life cycle indicators per unit	Unit	Base Case D 5	M 2.1 In-creased motor efficien-cy	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insula-tion	BA product
Other resources and waste										
Total Energy (GER)	**GJ**	3 014.5	2 954.8	1 261.5	2 749.2	2 686.8	2 716.4	2 716.3	2 835.6	1 261.8
	% change with BC	0%	-2%	-58%	-9%	-11%	-10%	-10%	-6%	-58%
of which, electricity	**primary GJ**	1 727.0	1 692.7	703.4	1 573.0	1 538.3	1 555.5	1 555.4	1 624.0	703.6
	MWh	164.5	161.2	67.0	149.8	146.5	148.1	148.1	154.7	67.0
	% change with BC	0%	-2%	-59%	-9%	-11%	-10%	-10%	-6%	-59%
Water (process)	**kL**	122.2	119.9	73.7	113.5	109.7	110.8	110.8	115.3	73.8
	% change with BC	0%	-2%	-40%	-7%	-10%	-9%	-9%	-6%	-40%
Water (cooling)	**kL**	4 581.3	4 489.7	1 838.2	4 169.6	4 077.8	4 123.5	4 123.5	4 306.6	1 838.2
	% change with BC	0%	-2%	-60%	-9%	-11%	-10%	-10%	-6%	-60%
Waste, non-haz./ landfill	**kg**	2 659.2	2 619.2	2 067.4	2 530.3	2 455.5	2 460.5	2 460.3	2 539.8	2 067.8
	% change with BC	0%	-2%	-22%	-5%	-8%	-7%	-7%	-4%	-22%
Waste, hazardous/ incinerated	**kg**	56.2	55.4	33.6	53.7	52.3	52.4	52.3	54.0	34.0
	% change with BC	0%	-1%	-40%	-5%	-7%	-7%	-7%	-4%	-40%
Emissions (Air)										
Greenhouse Gases in GWP100	**t CO2 eq.**	147.1	144.2	63.4	134.3	131.2	132.6	132.6	138.4	63.4
	% change with BC	0%	-2%	-57%	-9%	-11%	-10%	-10%	-6%	-57%
Acidification, emissions	**kg SO2 eq.**	473.9	464.6	217.6	434.0	423.2	427.7	427.7	446.1	217.8
	% change with BC	0%	-2%	-54%	-8%	-11%	-10%	-10%	-6%	-54%
Volatile Organic Compounds (VOC)	**kg**	1.7	1.7	0.9	1.6	1.6	1.6	1.6	1.7	0.9
	% change with BC	0%	-2%	-48%	-8%	-10%	-9%	-9%	-5%	-48%
Persistent Organic	**µg i-Teq**	18.7	18.5	14.6	17.9	17.5	17.6	17.6	18.0	14.6

Life cycle indicators per unit	Unit	Base Case D 5	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Pollutants (POP)	**% change with BC**	0%	-1%	-22%	-4%	-6%	-6%	-6%	-4%	-22%
Heavy Metals	**g Ni eq.**	36.4	35.8	57.9	37.0	33.3	33.5	33.5	34.6	57.9
	% change with BC	0%	-2%	59%	2%	-8%	-8%	-8%	-5%	59%
PAHs	**g Ni eq.**	5.0	5.0	8.8	5.2	4.7	4.7	4.7	4.8	8.8
	% change with BC	0%	-1%	75%	3%	-6%	-7%	-7%	-4%	75%
Particulate Matter (PM, dust)	**kg**	24.4	24.2	30.8	24.7	23.5	23.5	23.5	23.9	30.8
	% change with BC	0%	-1%	26%	1%	-4%	-4%	-4%	-2%	26%
Emissions (Water)										
Heavy Metals	**g Hg/20**	18.6	18.3	36.9	19.6	17.5	17.5	17.5	17.9	37.0
	% change with BC	0%	-1%	99%	6%	-6%	-6%	-6%	-4%	99%
Eutrophication	**kg PO4**	0.2	0.2	0.8	0.2	0.2	0.2	0.2	0.2	0.8
	% change with BC	0%	-1%	298%	24%	-2%	-2%	-2%	-2%	299%

Figure 23 presents the proportions represented by electricity consumption amongst the total primary energy consumption. It is around 57% for all improvement options.

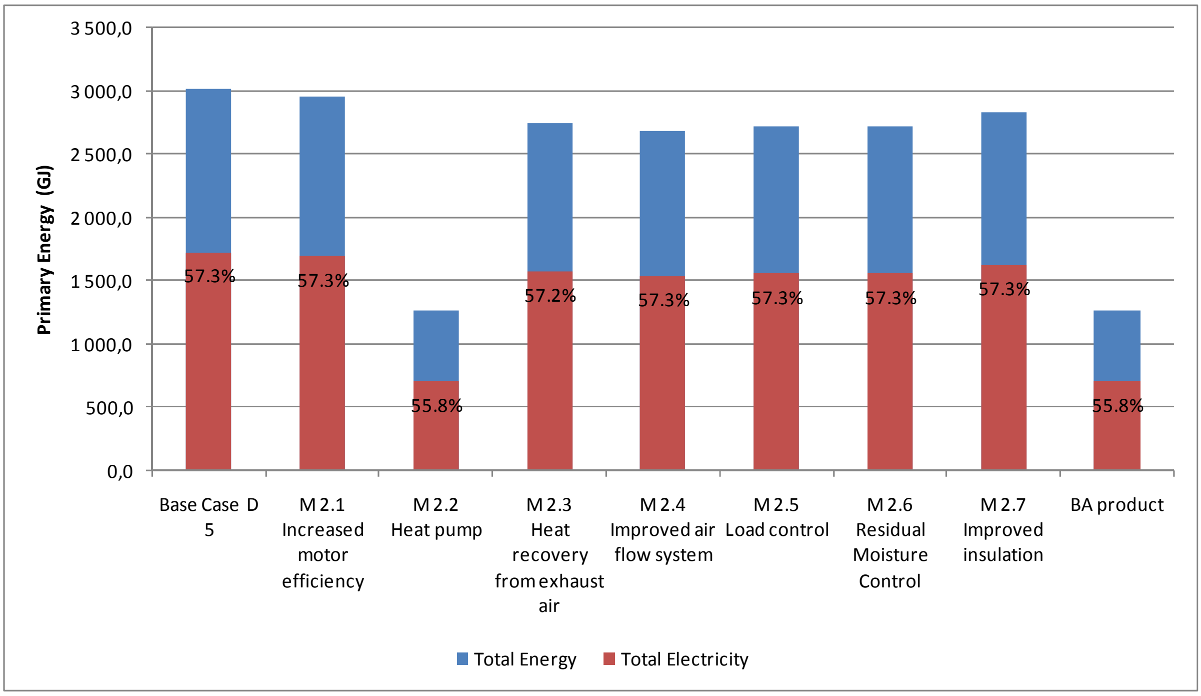


Figure 23 Energy consumption by improvement option for Base Case D 5

The impact of these options on other indicators is shown in Figure 24 below.

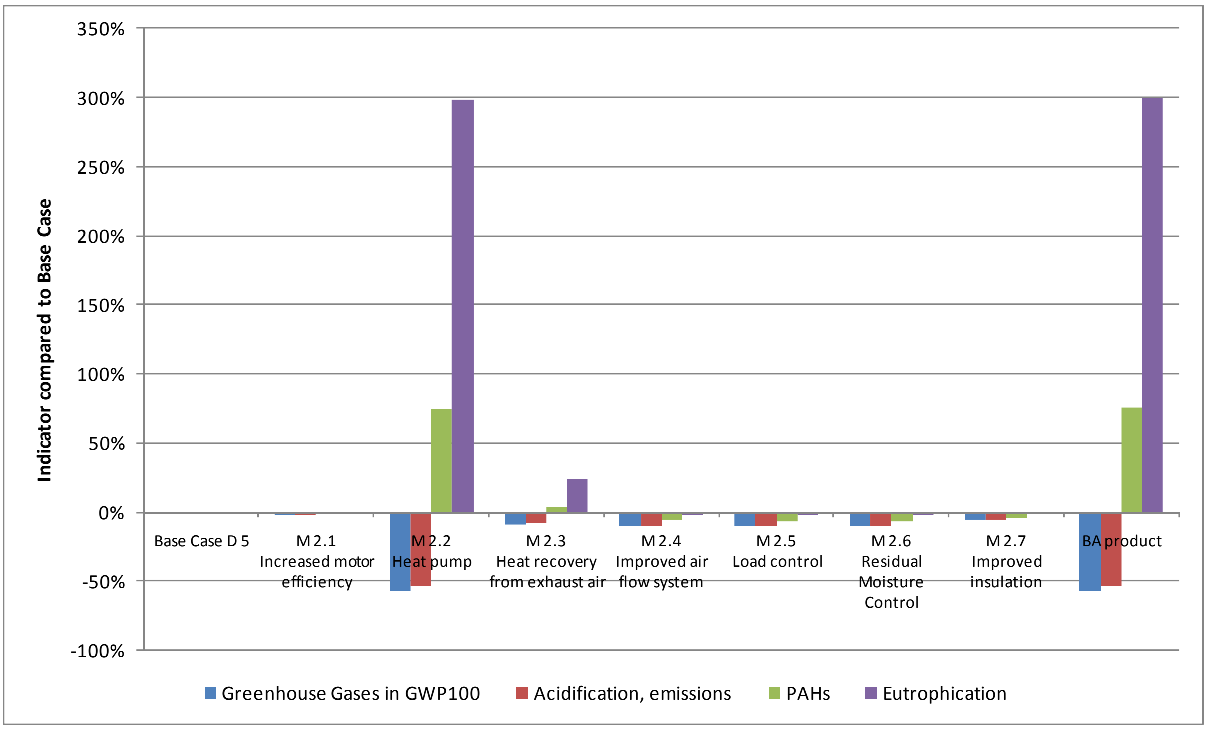


Figure 24 Improvement potential by improvement option for Base Case D 5

3.13 Base Case D 6: Professional tumble dryer (>40 kg)

The results of the environmental analysis of the improvement options for Base Case D 6 are shown below. Option M 2.2 Heat pump represents the greatest savings for many indicators. The reduction of the total energy is around 59%, while the reduction of electricity is about 60%. However, emissions of heavy metals, PAHs and particulate matter are again more important than for the base case because of the higher metal content.

Table 30 Environmental impacts by improvement option for Base Case D 6

Life cycle indicators per unit	Unit	Base Case D 6	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Other resources and waste										
Total Energy (GER)	**GJ**	12 858.0	12 730.1	5 256.8	11 837.8	12 218.9	12 218.6	12 218.5	12 602.2	5 257.0
	% change with BC	0%	-1%	-59%	-8%	-5%	-5%	-5%	-2%	-59%
of which, electricity	**primary GJ**	5 518.5	5 463.6	2 233.3	5 079.3	5 243.8	5 243.8	5 243.8	5 408.6	2 233.5
	MWh	525.6	520.3	212.7	483.7	499.4	499.4	499.4	515.1	212.7
	% change with BC	0%	-1%	-60%	-8%	-5%	-5%	-5%	-2%	-60%
Water (process)	**kL**	382.6	379.0	202.9	354.9	364.4	364.4	364.4	375.3	203.0
	% change with BC	0%	-1%	-47%	-7%	-5%	-5%	-5%	-2%	-47%
Water (cooling)	**kL**	14 665.2	14 518.7	5 877.7	13 492.9	13 932.4	13 932.4	13 932.3	14 372.1	5 877.8
	% change with BC	0%	-1%	-60%	-8%	-5%	-5%	-5%	-2%	-60%
Waste, non-haz./ landfill	**kg**	7 780.6	7 716.6	5 155.5	7 320.9	7 477.1	7 462.3	7 462.1	7 653.1	5 155.8
	% change with BC	0%	-1%	-34%	-6%	-4%	-4%	-4%	-2%	-34%
Waste, hazardous/ incinerated	**kg**	160.9	159.6	87.1	151.7	155.0	154.7	154.6	158.5	87.5
	% change with BC	0%	-1%	-46%	-6%	-4%	-4%	-4%	-1%	-46%
Emissions (Air)										
Greenhouse Gases in GWP100	**t CO2 eq.**	647.8	641.4	268.4	596.6	615.7	615.6	615.6	634.9	268.4
	% change with BC	0%	-1%	-59%	-8%	-5%	-5%	-5%	-2%	-59%
Acidification, emissions	**kg SO2 eq.**	1 557.3	1 542.0	679.9	1 436.4	1 480.9	1 480.8	1 480.7	1 526.7	680.0
	% change with BC	0%	-1%	-56%	-8%	-5%	-5%	-5%	-2%	-56%

Life cycle indicators per unit	Unit	Base Case D 6	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Volatile Organic Compounds (VOC)	kg	7.8	7.7	3.6	7.2	7.4	7.4	7.4	7.6	3.6
	% change with BC	0%	-1%	-54%	-7%	-5%	-5%	-5%	-2%	-54%
Persistent Organic Pollutants (POP)	µg i-Teq	51.7	51.4	35.4	49.1	50.0	49.9	49.9	51.0	35.4
	% change with BC	0%	-1%	-32%	-5%	-3%	-3%	-3%	-1%	-32%
Heavy Metals	g Ni eq.	109.1	108.2	130.3	104.9	104.6	104.4	104.4	107.2	130.3
	% change with BC	0%	-1%	19%	-4%	-4%	-4%	-4%	-2%	19%
PAHs	g Ni eq.	14.6	14.5	19.6	14.2	14.1	14.0	14.0	14.4	19.6
	% change with BC	0%	-1%	34%	-3%	-3%	-4%	-4%	-2%	34%
Particulate Matter (PM, dust)	kg	65.6	65.3	72.2	64.3	64.2	64.0	64.0	65.0	72.2
	% change with BC	0%	-1%	10%	-2%	-2%	-2%	-2%	-1%	10%
Emissions (Water)										
Heavy Metals	g Hg/20	51.4	51.1	79.9	50.6	49.8	49.7	49.7	50.7	80.0
	% change with BC	0%	-1%	55%	-2%	-3%	-3%	-3%	-1%	55%
Eutrophication	kg PO4	0.5	0.5	1.6	0.5	0.5	0.5	0.5	0.5	1.6
	% change with BC	0%	0%	239%	8%	-1%	-2%	-2%	-1%	239%

The share of total electricity is constant at 43% for almost all options and the base case.

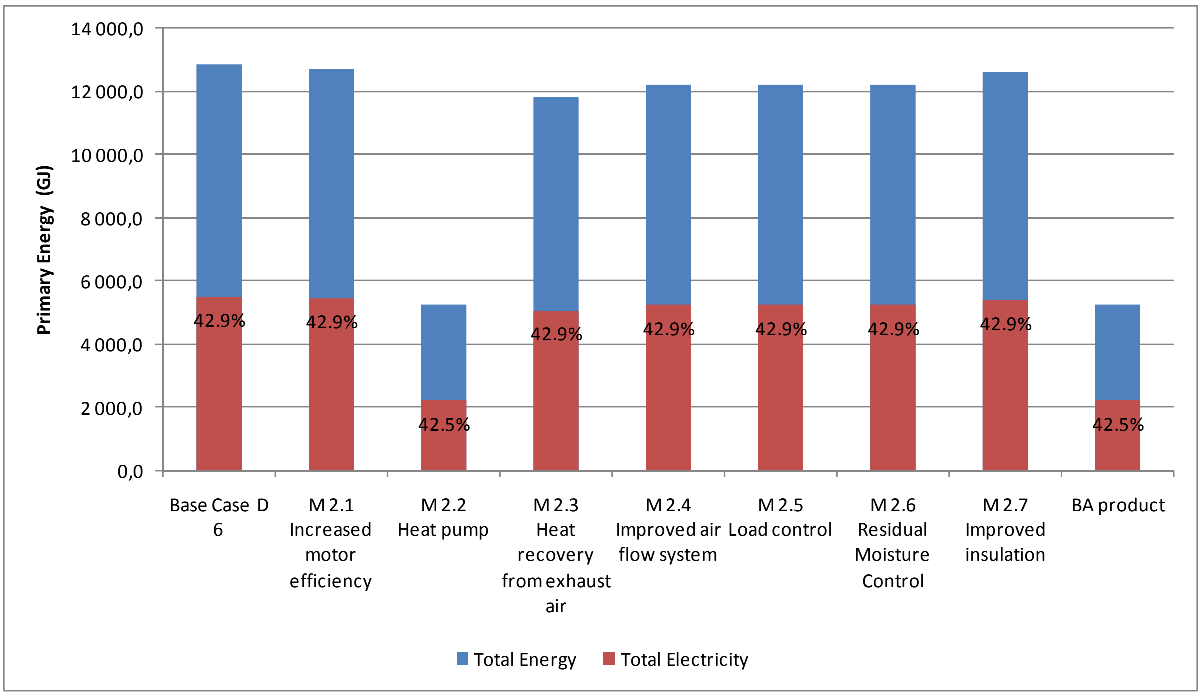


Figure 25 Energy consumption by improvement option for Base Case D 6

The impact of the options on other indicators is shown in Figure 26 below.

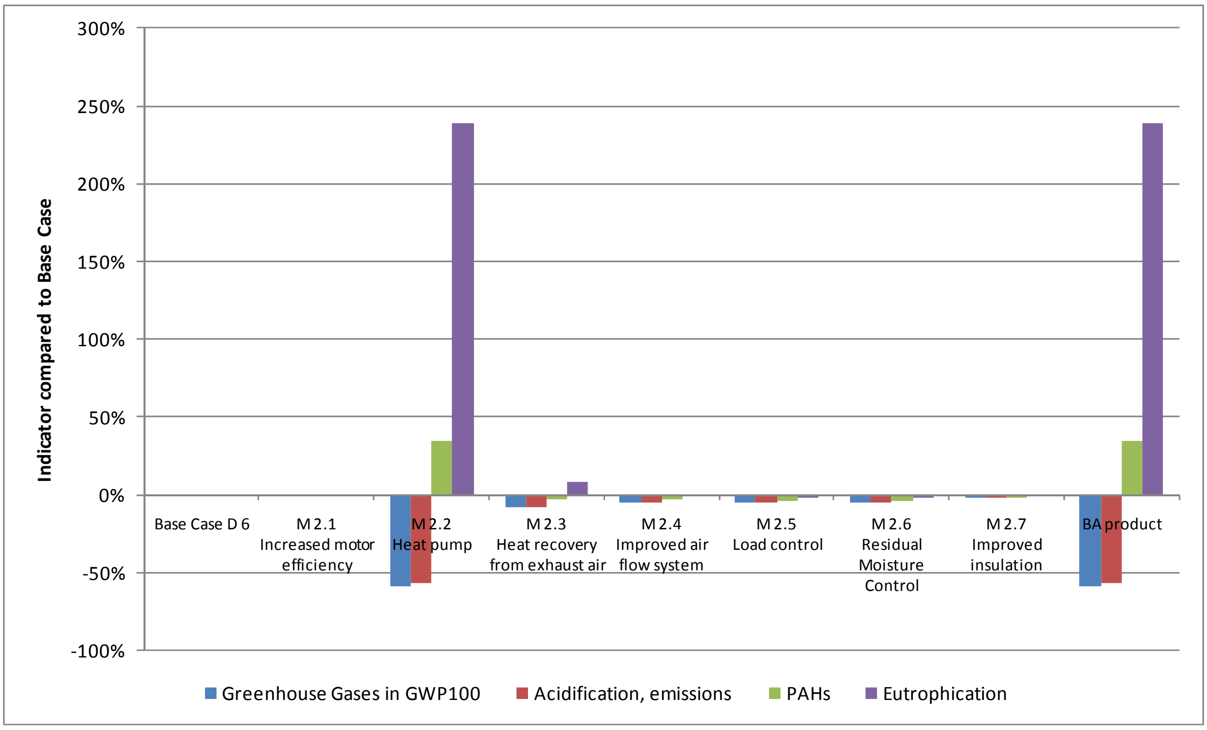


Figure 26 Improvement potential by improvement option for Base Case D 6

3.14 Base Case D 7: pass-through (transfer) tumble dryer

The results of the environmental analysis of the improvement options for Base Case D 7 are shown below. The BA product represents the highest reduction for all indicators, with 25% less total energy consumption and electricity consumption. The heat recovery option reduces energy consumption as well, by 12%.

Table 31 Environmental impacts by improvement option for Base Case D 7

Life cycle indicators per unit	Unit	Base Case D 7	M 2.1 Increased motor concept	M 2.3 Heat recovery from exhaust air	M 2.7 Improved insulation	BA product
Other resources and waste						
Total Energy (GER)	GJ	63 369.1	62 737.2	55 788.0	61 473.3	47 572.8
	% change with BC	0%	-1%	-12%	-3%	-25%
of which, electricity	primary GJ	14 738.6	14 591.6	12 974.7	14 297.5	11 063.4
	MWh	1 403.7	1 389.7	1 235.7	1 361.7	1 053.7
	% change with BC	0%	-1%	-12%	-3%	-25%
Water (process)	kL	983.7	973.9	867.7	954.3	740.2
	% change with BC	0%	-1%	-12%	-3%	-25%
Water (cooling)	kL	39 221.1	38 829.0	34 516.8	38 044.9	29 419.9
	% change with BC	0%	-1%	-12%	-3%	-25%
Waste, non-haz./ landfill	kg	22 386.0	22 215.3	20 373.3	21 874.7	18 157.0
	% change with BC	0%	-1%	-9%	-2%	-19%
Waste, hazardous/ incinerated	kg	348.1	344.7	308.4	338.1	264.5
	% change with BC	0%	-1%	-11%	-3%	-24%
Emissions (Air)						
Greenhouse Gases in GWP100	t CO2 eq.	3 335.4	3 302.2	2 936.9	3 235.7	2 504.9
	% change with BC	0%	-1%	-12%	-3%	-25%
Acidification, emissions	kg SO2 eq.	4 606.4	4 560.7	4 059.8	4 469.4	3 466.1
	% change with BC	0%	-1%	-12%	-3%	-25%
Volatile Organic Compounds (VOC)	kg	41.6	41.2	36.8	40.4	31.4
	% change with BC	0%	-1%	-12%	-3%	-25%
Persistent Organic Pollutants (POP)	µg i-Teq	173.7	172.7	162.3	170.8	149.8
	% change with BC	0%	-1%	-7%	-2%	-14%
Heavy Metals	g Ni eq.	273.1	270.5	246.1	265.5	213.2

Life cycle indicators per unit	Unit	Base Case D 7	M 2.1 Increased motor concept	M 2.3 Heat recovery from exhaust air	M 2.7 Improved insulation	BA product
	% change with BC	0%	-1%	-10%	-3%	-22%
PAHs	g Ni eq.	32.4	32.0	28.8	31.5	24.9
	% change with BC	0%	-1%	-11%	-3%	-23%
Particulate Matter (PM, dust)	kg	175.9	174.9	165.4	173.0	153.2
	% change with BC	0%	-1%	-6%	-2%	-13%
Emissions (Water)						
Heavy Metals	g Hg/20	108.6	107.7	99.1	105.8	86.8
	% change with BC	0%	-1%	-9%	-3%	-20%
Eutrophication	kg PO4	0.8	0.8	0.8	0.7	0.7
	% change with BC	0%	-1%	0%	-2%	-8%

Figure 27 presents the proportions represented by electricity consumption amongst the total primary energy consumption: 23.3% for all options.

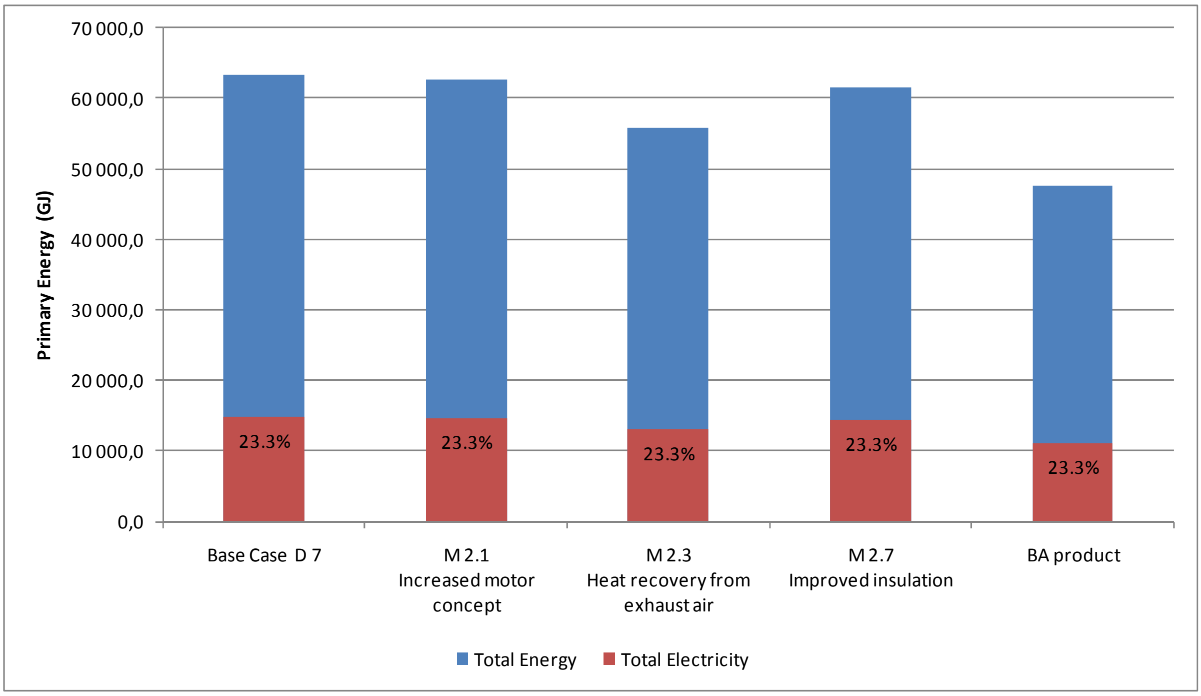


Figure 27 Energy consumption by improvement option for Base Case D 7

The impact of the heat recovery impact is positive with respect to GHG emissions. In general, the BA product is the best option, as it reduces the impact on all the indicators as shown below.

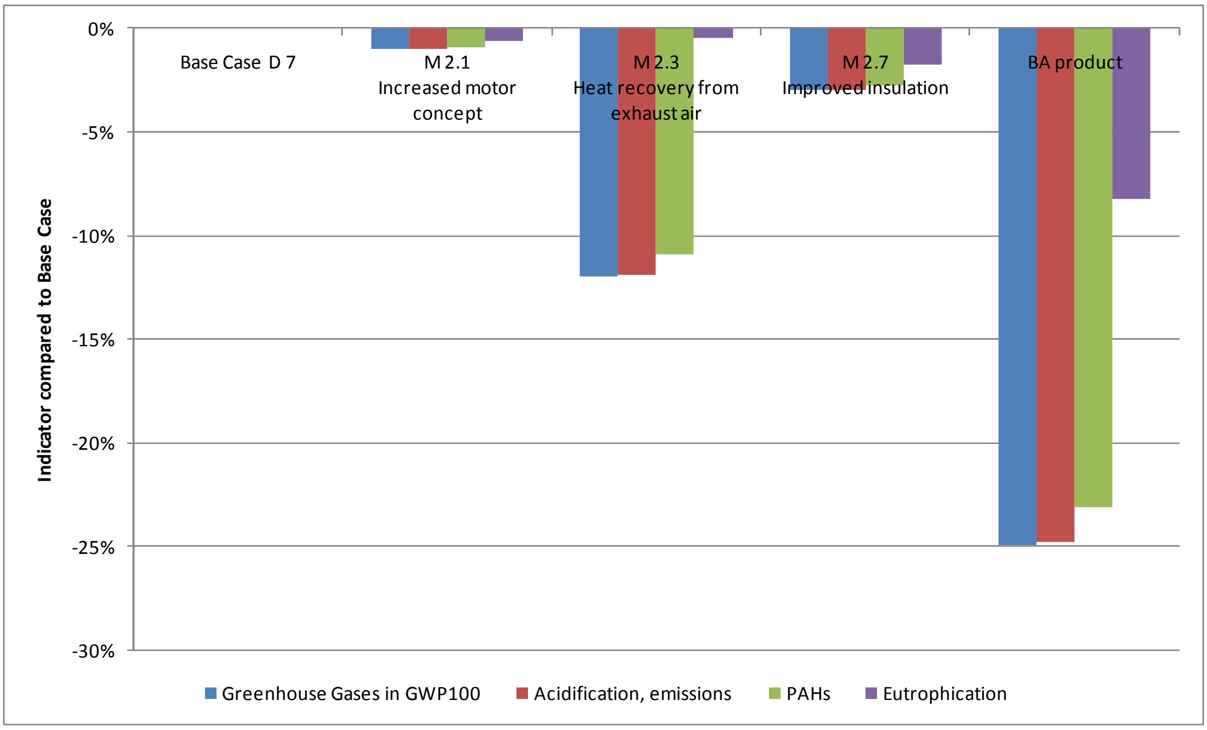


Figure 28 Improvement potential by improvement option for Base Case D 7

4 Costs analysis

The aim of this sub-task is to assess the LCC of each of the 14 individual improvement options (and their combination) considered. In doing so the quantification will cover both the PP (purchasing price) and the OE (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 WM 1: Semi-professional washer extractor

Table 32 shows that the LCC is related to option M 1.4 Load control, reducing it around 6%. The BA product does not appear beneficial over the lifetime (+16%), and neither does option M 1.3 (Water recovery), even if the operating costs are highly reduced (-37% for water and detergent costs for the BA product, -28% for energy costs).

Table 32 Life cycle costs by improvement option for Base Case WM 1

Life cycle indicators per unit	Unit	Base Case WM 1	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construction	BA product
Economic indicators									
Purchase price	€	2 670	2 723	2 804	4 005	3 097	2 857	2 750	5 340
	% change with BC	0%	2%	5%	50%	16%	7%	3%	100%
Installation costs	€	107	107	112	160	107	107	107	214
	% change with BC	0%	0%	5%	50%	0%	0%	0%	100%
Electricity costs	€	809	801	728	728	688	728	801	583
	% change with BC	0%	-1%	-10%	-10%	-15%	-10%	-1%	-28%
Gas costs	€	139	138	125	125	118	125	138	100
	% change with BC	0%	-1%	-10%	-10%	-15%	-10%	-1%	-28%
Water costs	€	1 512	1 512	1 512	1 058	1 209	1 361	1 497	952
	% change with BC	0%	0%	0%	-30%	-20%	-10%	-1%	-37%
Detergents costs	€	2 168	2 168	2 168	1 843	1 734	1 951	2 146	1 366
	% change with BC	0%	0%	0%	-15%	-20%	-10%	-1%	-37%
Maintenance and repair costs	€	67	69	71	101	78	72	69	135
	% change with BC	0%	2%	5%	50%	16%	7%	3%	100%
Life cycle cost	€	7 472	7 518	7 520	8 021	7 032	7 201	7 508	8 690
	% change with BC	0%	1%	1%	7%	-6%	-4%	0%	16%

Figure 29 presents the breakdown of the LCC for the base case and all improvement options. The purchase price of the BA product represents a very important share of the total life cycle costs (61.5%).

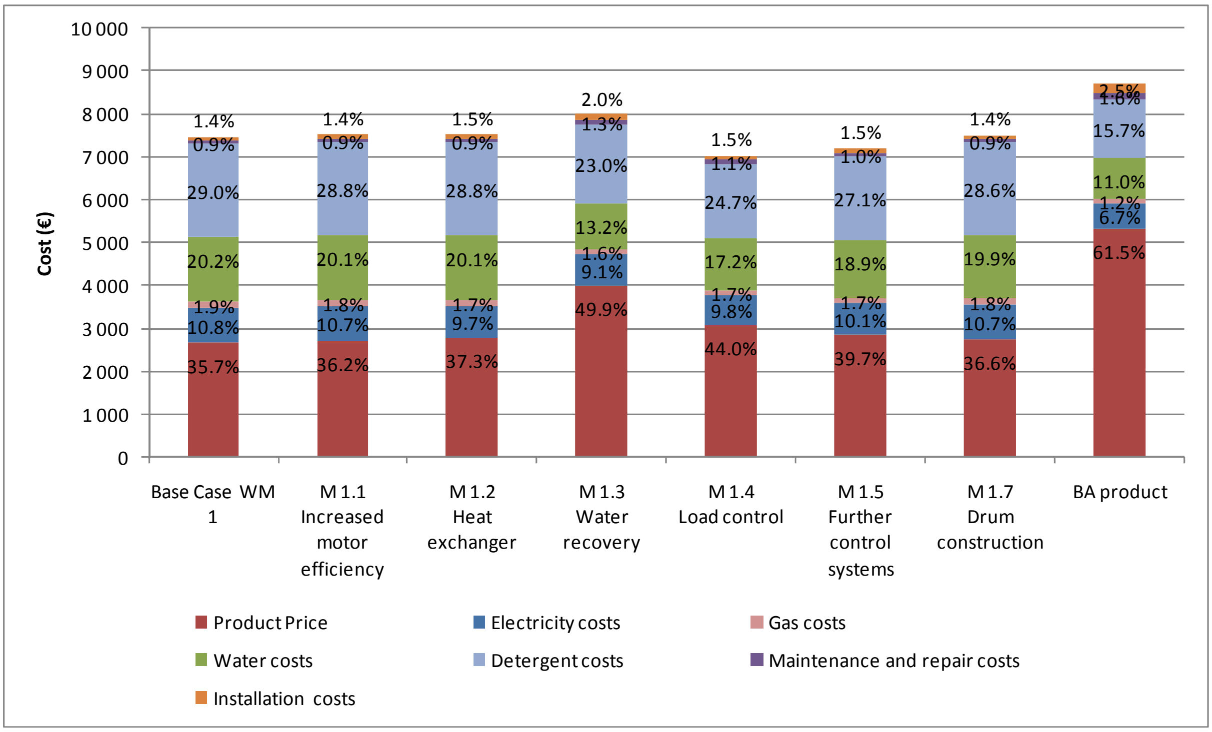


Figure 29 Life cycle costs breakdown by improvement option for Base Case WM 1

4.2 Base Case WM 2: Professional washer extractor <15kg

Again, option M 1.4 load control leads to the LLCC, reducing the LCC in 11% as shown in the Table 33. However, most options are now beneficial and reducing the LCC compared to the base case: -10% for the BA product, -4% for option M 1.5 Further control systems, -2% for option M 1.3 Water recovery.

Table 33 Life cycle costs by improvement option for Base Case WM 2

Life cycle indicators per unit	Unit	Base Case WM 2	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion	BA product
Economic indicators									
Purchase price	**€**	5 000	5 100	5 250	7 500	5 800	5 050	5 100	6 250
	% change with BC	0%	2%	5%	50%	16%	1%	2%	25%
Installation costs	**€**	200	200	210	300	200	200	200	250
	% change with BC	0%	0%	5%	50%	0%	0%	0%	25%
Electricity costs	**€**	2 563	2 537	2 307	2 307	2 127	2 384	2 512	2 025
	% change with BC	0%	-1%	-10%	-10%	-17%	-7%	-2%	-21%
Gas costs	**€**	441	436	397	397	366	410	432	348
	% change with BC	0%	-1%	-10%	-10%	-17%	-7%	-2%	-21%
Water costs	**€**	5 780	5 780	5 780	4 046	4 508	5 375	5 664	4 451
	% change with BC	0%	0%	0%	-30%	-22%	-7%	-2%	-23%
Detergents costs	**€**	6 194	6 194	6 194	5 265	4 955	5 884	6 070	4 893
	% change with BC	0%	0%	0%	-15%	-20%	-5%	-2%	-21%
Maintenance and repair costs	**€**	117	120	123	176	136	118	120	147
	% change with BC	0%	2%	5%	50%	16%	1%	2%	25%
Life cycle cost	**€**	20 295	20 367	20 261	19 990	18 093	19 422	20 098	18 364
	% change with BC	0%	0%	0%	-2%	-11%	-4%	-1%	-10%

Figure 30 presents the breakdown of the LCC for the base case and all improvement options. Although the share of the product price is more important for M 1.4 Load control (322.1%), the investment reduces the shares of the water and detergent costs which results in a beneficial LCC.

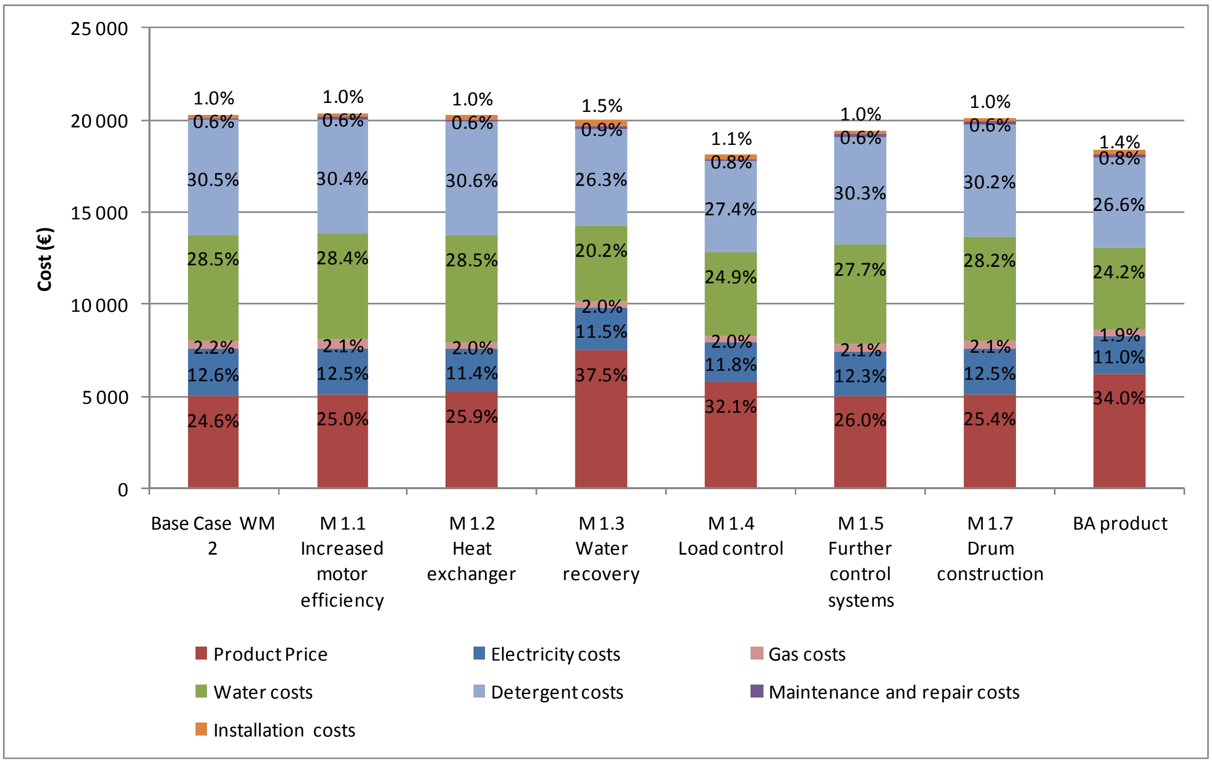


Figure 30 Life cycle costs breakdown by improvement option for Base Case WM 2

4.3 Base Case WM 3: Professional washer extractor 15–40 kg

The option M 1.4 Load control leads to the LLCC. The reduction in the expenses is reduced by 11%. The situation is similar to WM 2 where most improvement options lead to a reduction of the LCC.

Table 34 Life cycle costs by improvement option for Base Case WM 3

Life cycle indicators per unit	Unit	Base Case WM 3	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construc-tion	BA product
Economic indicators									
Purchase price	**€**	15 250	15 555	16 013	22 875	17 690	15 403	15 555	19 825
	% change with BC	0%	2%	5%	50%	16%	1%	2%	30%
Installation costs	**€**	610	610	641	915	610	610	641	793
	% change with BC	0%	0%	5%	50%	0%	0%	5%	30%
Electricity costs	**€**	5 854	5 795	5 269	5 269	4 859	5 561	5 737	4 742
	% change with BC	0%	-1%	-10%	-10%	-17%	-5%	-2%	-19%
Gas costs	**€**	2 409	2 385	2 168	2 168	1 999	2 288	2 361	1 951
	% change with BC	0%	-1%	-10%	-10%	-17%	-5%	-2%	-19%
Water costs	**€**	20 653	20 653	20 653	14 457	16 109	19 620	20 240	16 109
	% change with BC	0%	0%	0%	-30%	-22%	-5%	-2%	-22%
Detergents costs	**€**	16 859	16 859	16 859	14 330	13 487	16 016	16 522	13 487
	% change with BC	0%	0%	0%	-15%	-20%	-5%	-2%	-20%
Maintenance and repair costs	**€**	345	352	362	518	400	349	352	449
	% change with BC	0%	2%	5%	50%	16%	1%	2%	30%
Life cycle cost	**€**	61 980	62 209	61 964	60 531	55 155	59 847	61 407	57 356
	% change with BC	0%	0%	0%	-2%	-11%	-3%	-1%	-7%

Figure 31 presents the breakdown of the LCC for the base case and all improvement options. The higher purchase prices are generally counterbalanced by reduced energy, water and detergent costs. Gas costs always represent a low share of the LCC (around 3-4%).

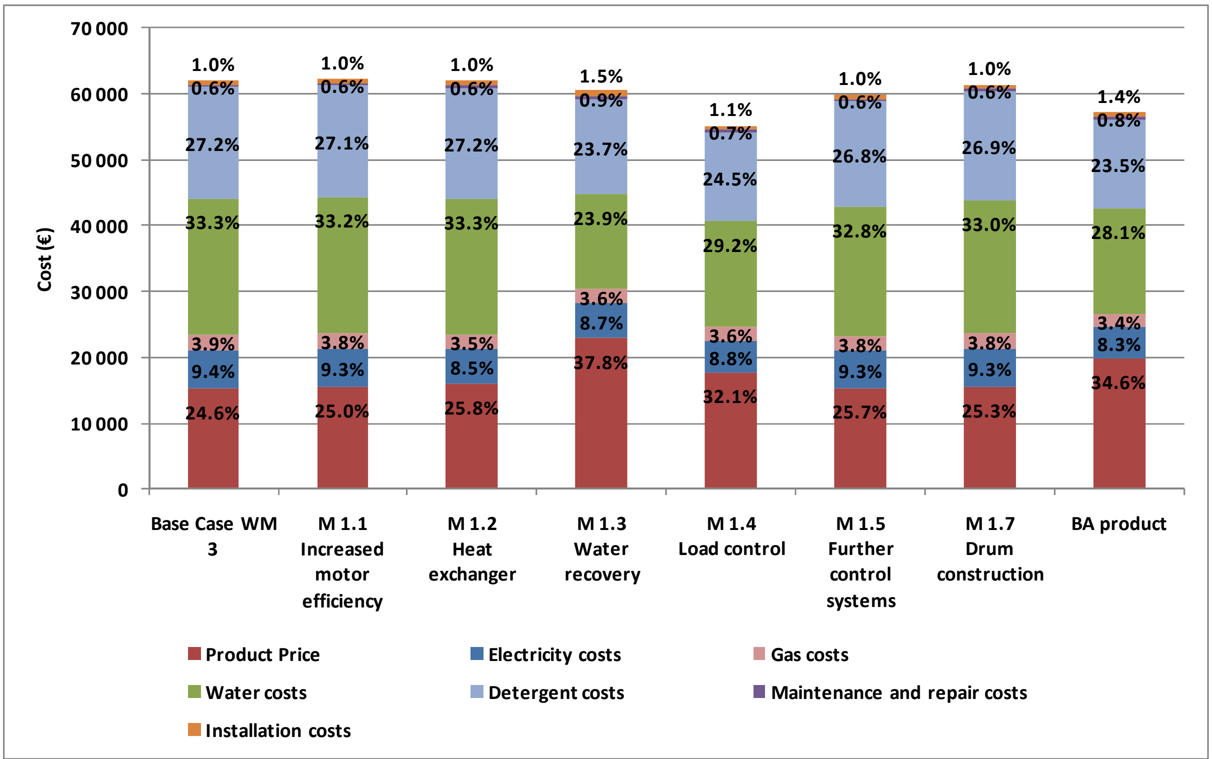


Figure 31 Life cycle costs breakdown by improvement option for Base Case WM 3

4.4 Base Case WM 4: Professional washer extractor >40kg

Option M 1.3 Water recovery leads to the LLCC with a reduction of 20% on the LCC. Option M 1.4 Load control and the BA product always result in important reduction of the LCC, respectively 12% and 9%. This is particularly due to the reduction of the water costs for these three options. Other options having no influence on the water and detergent consumption (M 1.1 Increased motor efficiency and M 1.2 Heat exchanger) do not reduce the LCC.

Table 35 Life cycle costs by improvement option for Base Case WM 4

Life cycle indicators per unit	Unit	Base Case WM 4	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	BA product
Economic indicators								
Purchase price	**€**	58 750	59 925	70 500	76 375	65 800	60 513	79 313
	% change with BC	0%	2%	20%	30%	12%	3%	35%
Installation costs	**€**	2 350	2 350	2 820	3 055	2 350	2 350	3 173
	% change with BC	0%	0%	20%	30%	0%	0%	35%
Electricity costs	**€**	29 617	29 321	22 805	20 732	26 655	28 728	22 805
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Gas costs	**€**	20 353	20 150	15 672	14 247	18 318	19 743	15 672
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Water costs	**€**	95 863	95 863	95 863	60 394	74 773	92 987	73 815
	% change with BC	0%	0%	0%	-37%	-22%	-3%	-23%
Detergents costs	**€**	93 372	93 372	93 372	58 824	72 830	90 571	72 830
	% change with BC	0%	0%	0%	-37%	-22%	-3%	-22%
Maintenance and repair costs	**€**	10 887	11 104	13 064	14 153	12 193	11 213	14 697
	% change with BC	0%	2%	20%	30%	12%	3%	35%
Life cycle cost	**€**	311 192	312 085	314 096	247 780	272 920	306 105	282 304
	% change with BC	0%	0%	1%	-20%	-12%	-2%	-9%

Figure 32 presents the breakdown of the LCC for the base case and all improvement options.

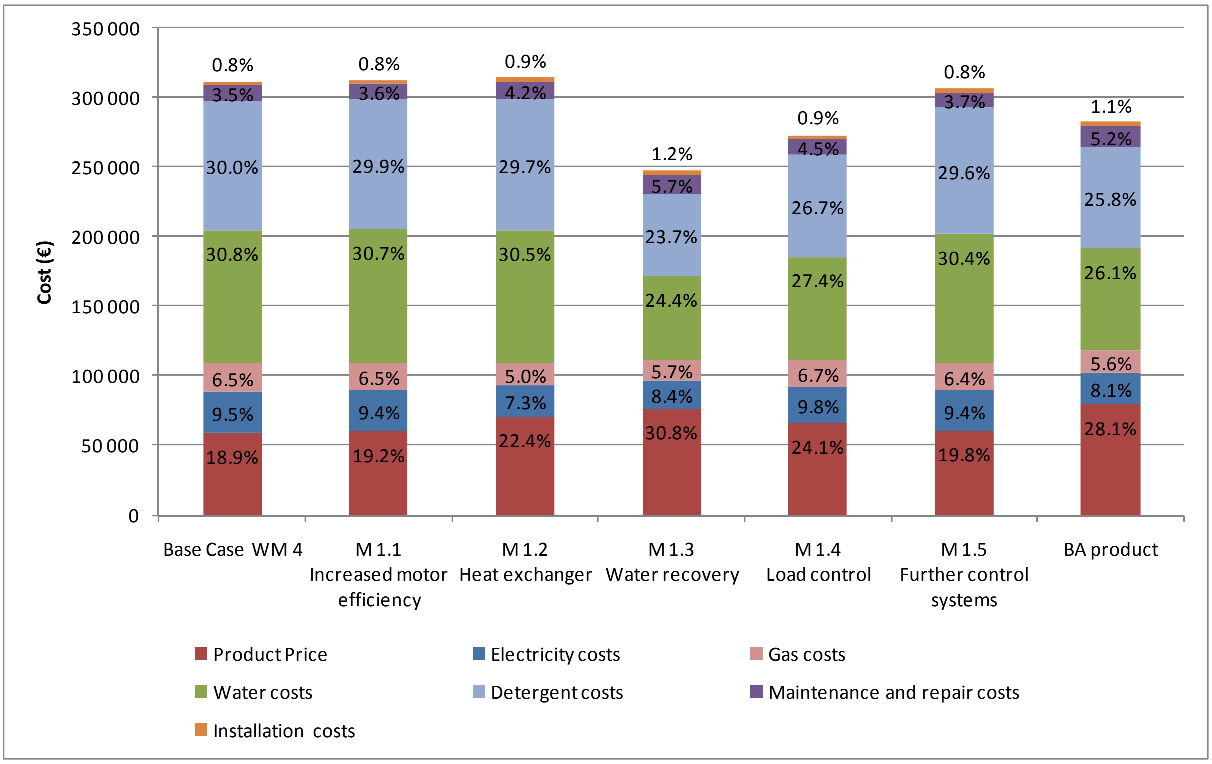


Figure 32 Life cycle costs breakdown by improvement option for Base Case WM 4

4.5 Base Case WM 5: Professional washer dryer

In this case, the improvement option M 1.4 load control leads to the LLCC. The reduction of the LCC is about 13%. Both energy and water and detergent costs are importantly reduced. Option M 1.5 Further control systems also leads to a LCC reduction (-6%), but this is not the case of option M 1.1 Increased motor efficiency.

Table 36 Life cycle costs by improvement option for Base Case WM 5

Life cycle indicators per unit	Unit	Base Case WM 5	M 1.1 Increased motor efficiency	M 1.4 Load control	M 1.5 Further control systems
Economic indicators					
Purchase price	**€**	8 000	8 160	8 160	8 000
	% change with BC	0%	2%	2%	0%
Installation costs	**€**	320	320	320	320
	% change with BC	0%	0%	0%	0%
Electricity costs	**€**	6 807	6 739	5 446	6 126
	% change with BC	0%	-1%	-20%	-10%
Water costs	**€**	2 310	2 310	1 617	2 079
	% change with BC	0%	0%	-30%	-10%
Detergents costs	**€**	2 453	2 453	1 717	2 208
	% change with BC	0%	0%	-30%	-10%
Maintenance and repair costs	**€**	191	195	195	191
	% change with BC	0%	2%	2%	0%
Life cycle cost	**€**	20 081	20 177	17 455	18 924
	% change with BC	0%	0%	-13%	-6%

Figure 33 presents the breakdown of the LCC for the base case and all improvement options. Electricity costs represent an important share (32-33%) of the LCC for all options, in comparison with other base cases.

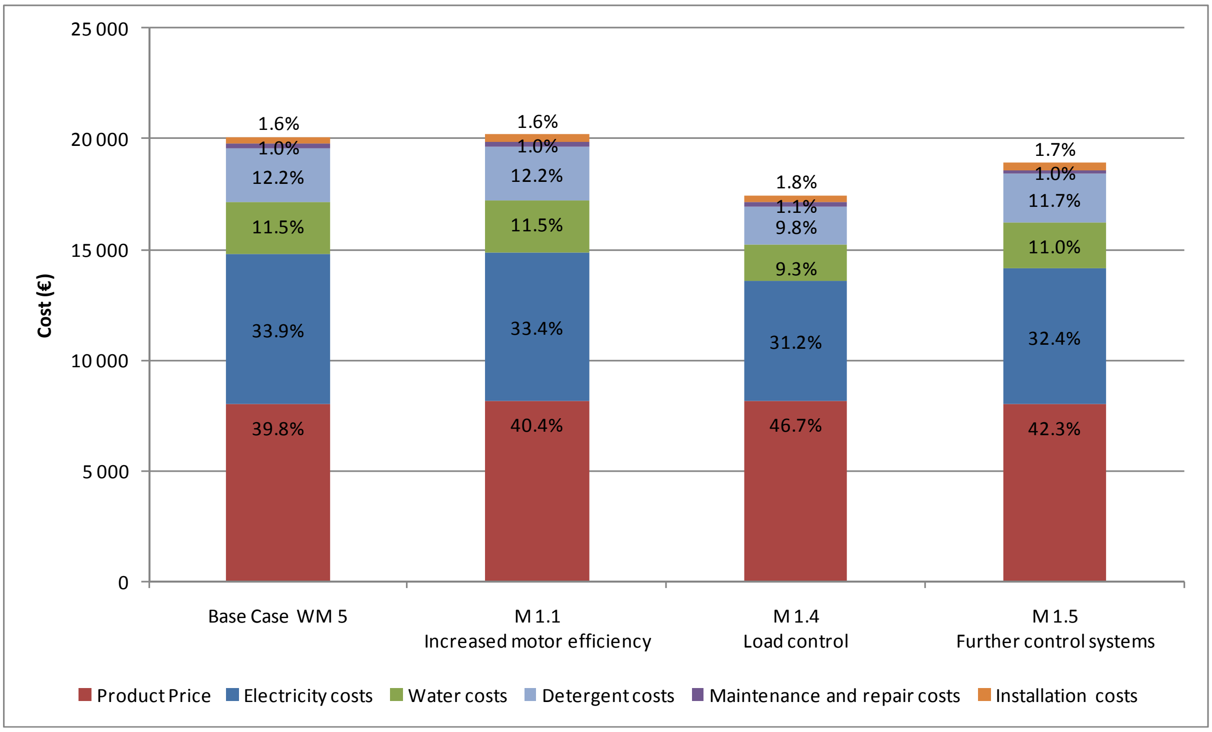


Figure 33 Life cycle costs breakdown by improvement option for Base Case WM 5

4.6 Base Case WM 6: Professional Barrier Washer

Option M 1.3 Water recovery leads to the LLCC, it reduces 10% of the LCC. Option M 1.4 Load control is also beneficial (4% reduction), also thanks to the reduction of water and detergent costs. The BA product has a similar LCC than the base case, which means that its improved environmental performance would be justified, even if not providing economic benefits.

Table 37 Life cycle costs by improvement option for Base Case WM 6

Life cycle indicators per unit	Unit	Base Case WM 6	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	BA product
			Economic indicators					
Purchase price	**€**	38 250	39 015	45 900	49 725	42 840	39 398	51 638
	% change with BC	0%	2%	20%	30%	12%	3%	35%
Installation costs	**€**	1 530	1 530	1 836	1 989	1 530	1 530	2 066
	% change with BC	0%	0%	20%	30%	0%	0%	35%
Electricity costs	**€**	10 089	9 988	7 768	7 062	9 080	9 786	7 768
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Gas costs	**€**	7 344	7 271	5 655	5 141	6 610	7 124	5 655
	% change with BC	0%	-1%	-23%	-30%	-10%	-3%	-23%
Water costs	**€**	30 144	30 144	30 144	18 991	23 513	29 240	23 513
	% change with BC	0%	0%	0%	-37%	-22%	-3%	-22%
Detergents costs	**€**	25 690	25 690	25 690	16 184	20 038	25 176	20 038
	% change with BC	0%	0%	0%	-37%	-22%	-2%	-22%
Maintenance and repair costs	**€**	7 215	7 359	8 658	9 379	8 081	7 431	9 740
	% change with BC	0%	2%	20%	30%	12%	3%	35%
Life cycle cost	**€**	120 262	120 997	125 651	108 472	111 691	119 685	120 417
	% change with BC	0%	1%	4%	-10%	-7%	0%	0%

Figure 34 presents the breakdown of the LCC for the base case and all improvement options. The purchase price represents 45.8% of the LCC in the case of option M 1.3 Water recovery, while all the other costs are highly reduced, especially for water and detergent. The additional investment of M 1.2 Heat exchanger does not appear beneficial as the energy costs (gas and electricity) which are reduced do not represent a high enough share of the total LCC.

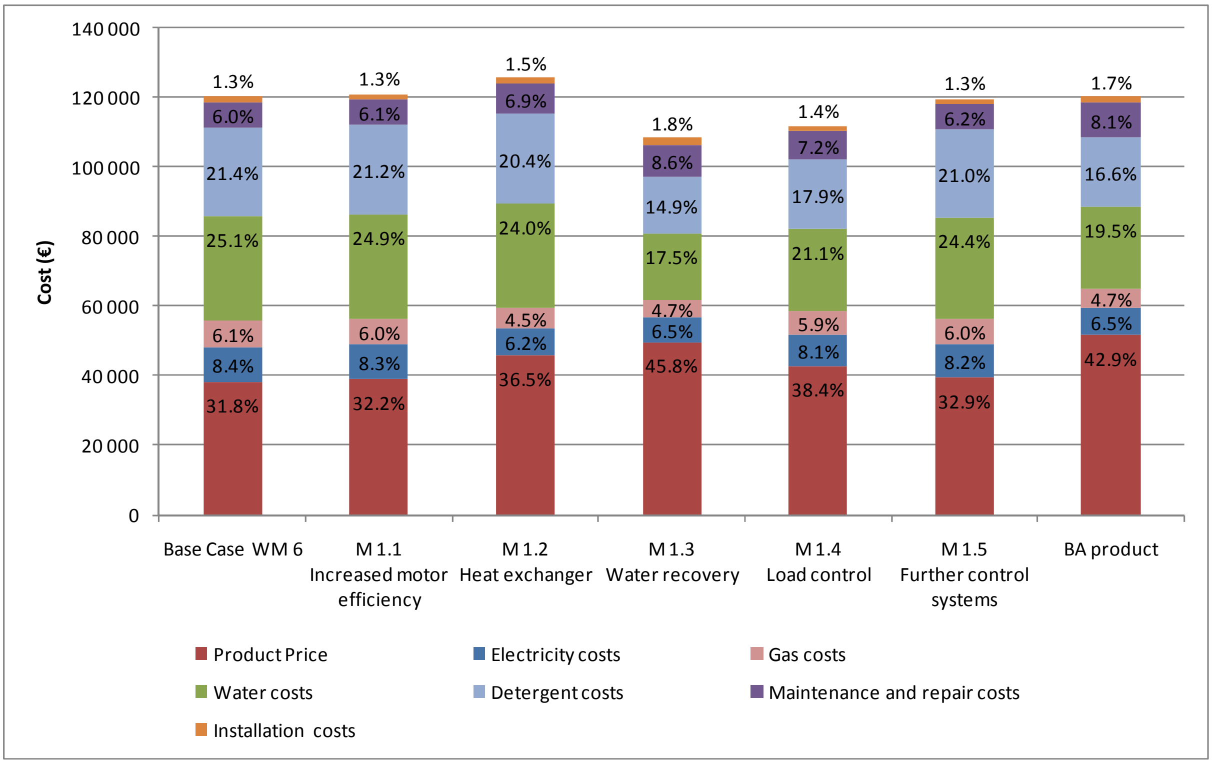


Figure 34 Life cycle costs breakdown by improvement option for Base Case WM 6

4.7 Base Case WM 7: Washing tunnel machine

The BA product represents the LLCC for this base case. It reduces the LCC by 32%, thanks to 50% reduction of the water and detergent costs. Therefore, the additional investment of 30% (purchase price, installation and maintenance), is quickly counterbalanced. Option M 1.2 Heat exchanger also appear significantly beneficial for the first time (-4%), amongst the different washing machine base cases.

Table 38 Life cycle costs by improvement option for Base Case WM 7

Life cycle indicators per unit	Unit	Base Case WM 7	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	BA product
Economic indicators					
Purchase price	€	390 000	409 500	448 500	507 000
	% change with BC	0%	5%	15%	30%
Installation costs	€	35 100	35 100	40 365	45 630
	% change with BC	0%	0%	15%	30%
Electricity costs	€	72 189	71 467	50 532	46 923
	% change with BC	0%	-1%	-30%	-35%
Water costs	€	726 013	726 013	726 013	363 006
	% change with BC	0%	0%	0%	-50%
Detergents costs	€	825 014	825 014	825 014	412 507
	% change with BC	0%	0%	0%	-50%
Maintenance and repair costs	€	74 892	78 637	86 126	97 360
	% change with BC	0%	5%	15%	30%
Gas costs	€	535 976	530 616	375 183	348 384
	% change with BC	0%	-1%	-30%	-35%
Life cycle cost	€	2 659 184	2 676 347	2 551 733	1 820 811
	% change with BC	0%	1%	-4%	-32%

Figure 35 presents the breakdown of the LCC for the base case and all improvement options. Detergent and water costs almost account for 60% of the LCC for all options and the base case, except the BA product.

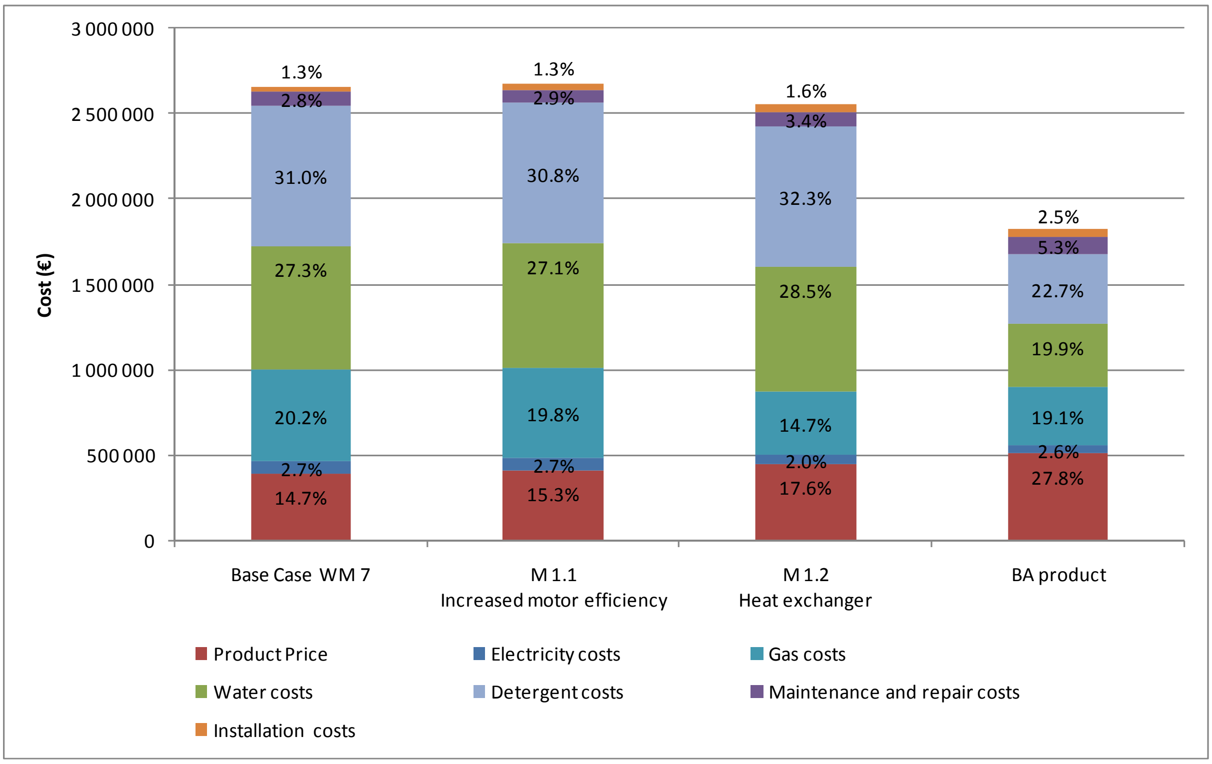


Figure 35 Life cycle costs breakdown by improvement option for Base Case WM 7

4.8 Base Case D 1: Semi-professional dryer, condenser

The option M 2.2 heat pump leads to the LLCC. It reduces 12% the LCC. All the other single improvement options reduce the LCC too, but the BA product does not (+2%) because of the higher purchase price (+150%). Electricity costs are nonetheless reduced by 67%.

Table 39 Life cycle costs by improvement option for Base Case D 1

Life cycle indicators per unit	Unit	Base Case D 1	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Economic indicators									
Purchase price	**€**	1 970	2 029	3 546	2 128	2 167	2 167	2 167	4 925
	% change with BC	0%	3%	80%	8%	10%	10%	10%	150%
Installation costs	**€**	79	81	142	79	79	79	79	197
	% change with BC	0%	3%	80%	0%	0%	0%	0%	150%
Electricity costs	**€**	4 531	4 441	2 039	4 078	4 078	4 078	4 078	1 495
	% change with BC	0%	-2%	-55%	-10%	-10%	-10%	-10%	-67%
Maintenance and repair costs	**€**	50	51	90	54	55	55	55	124
	% change with BC	0%	3%	80%	8%	10%	10%	10%	150%
Life cycle cost	**€**	6 630	6 602	5 816	6 338	6 379	6 379	6 379	6 742
	% change with BC	0%	0%	-12%	-4%	-4%	-4%	-4%	2%

Figure 36 presents the breakdown of the LCC for the base case and all improvement options. The electricity cost represents the highest proportion of expenditure for all options except the heat pump and the BA product. In this case, the purchase price is much higher.

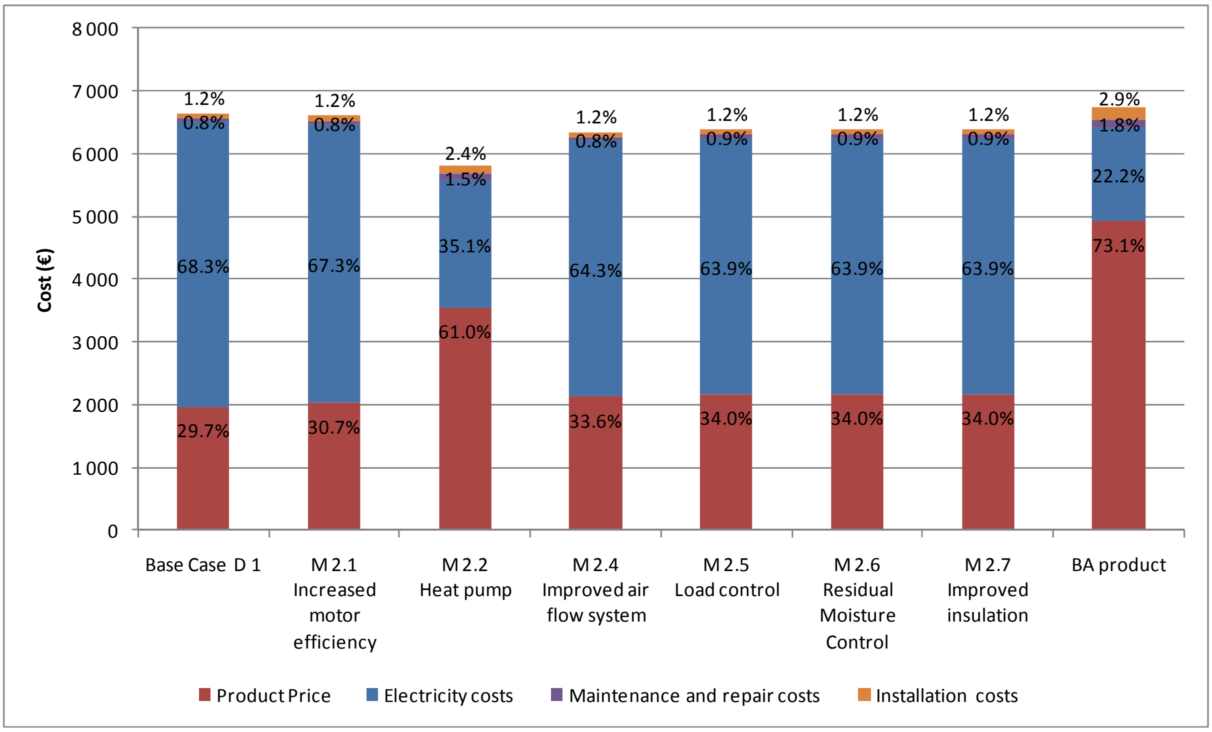


Figure 36 Life cycle costs breakdown by improvement option for Base Case D 1

4.9 Base Case D 2: Semi-professional dryer, air vented

The option M 2.2 Heat pump has the highest reduction of the LCC. It is around 11% of the total LCC. The BA product and option M 2.3 Heat recovery from exhaust air are the only two options which are not reducing the LCC (respectively +1% and +4%).

Table 40 Life cycle costs by improvement option for Base Case D 2

Life cycle indicators per unit	Unit	Base Case D 2	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Economic indicators										
Purchase price	**€**	1 680	1 730	2 688	2 184	1 814	1 848	1 848	1 848	2 520
	% change with BC	0%	3%	60%	30%	8%	10%	10%	10%	50%
Installation costs	**€**	67	67	108	87	67	67	67	67	101
	% change with BC	0%	0%	60%	30%	0%	0%	0%	0%	50%
Electricity costs	**€**	2 823	2 767	1 412	2 541	2 541	2 541	2 541	2 541	2 117
	% change with BC	0%	-2%	-50%	-10%	-10%	-10%	-10%	-10%	-25%
Maintenance and repair costs	**€**	42	44	68	55	46	47	47	47	64
	% change with BC	0%	3%	60%	30%	8%	10%	10%	10%	50%
Gas costs	**€**	457	448	229	411	411	411	411	411	343
	% change with BC	0%	-2%	-50%	-10%	-10%	-10%	-10%	-10%	-25%
Life cycle costs	**€**	5 070	5 056	4 503	5 279	4 879	4 914	4 914	4 914	5 144
	% change with BC	0%	0%	-11%	4%	-4%	-3%	-3%	-3%	1%

Figure 37 presents the breakdown of the LCC for the base case and all improvement options. Gas costs represent a very low share in comparison with the electricity costs. For option M 2.2 Heat pump, the purchase price represents 60% of the LCC but the energy costs are so importantly reduced that this option ends up being the LLCC.

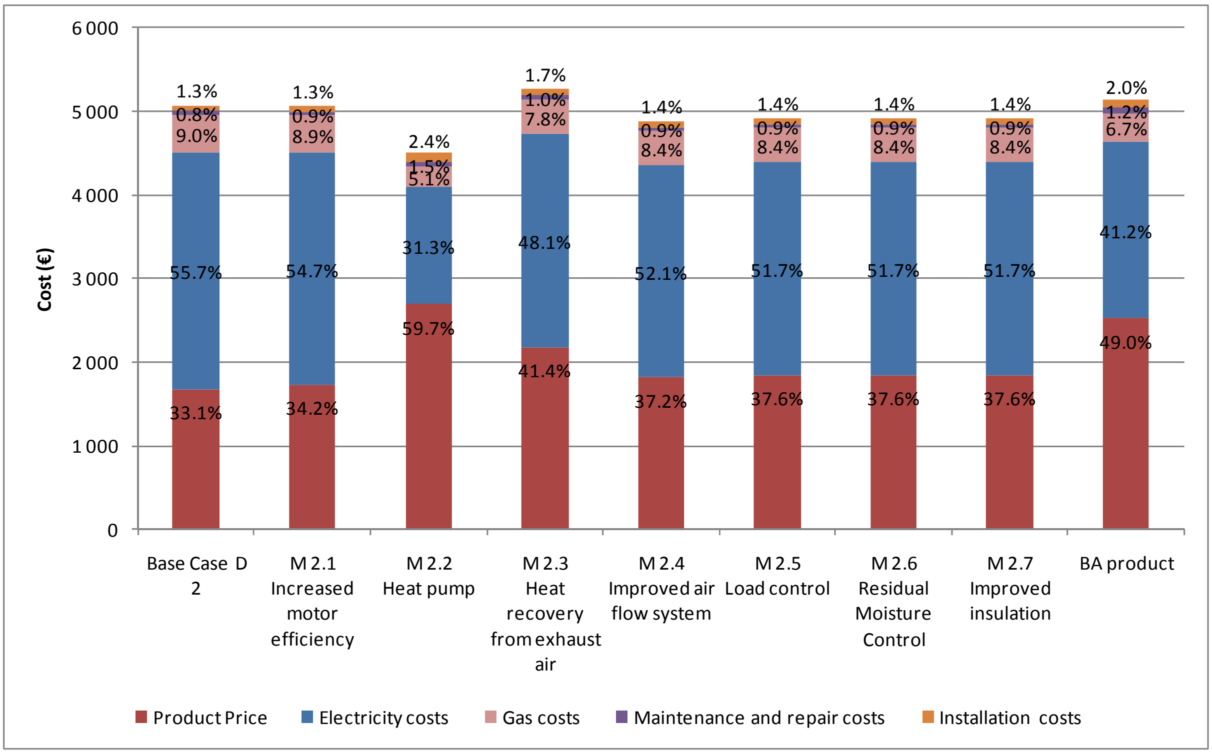


Figure 37 Life cycle costs breakdown by improvement option for Base Case D 2

4.10 Base Case D 3: Professional Cabinet dryer

The option M 2.2 heat pump leads to the LLCC. It reduces 14% the LCC, thanks to a 60% reduction of the energy costs. Again, all the other options except option M 2.3 Heat recovery from exhaust air reduce the LCC (between 4% and 6%). The BA product reduces the most the electricity costs (-68%) but also has the higher purchase price (+150%).

Table 41 Life cycle costs by improvement option for Base Case D 3

Life cycle indicators per unit	Unit	Base Case D 3	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.7 Improved insulation	BA product
Economic indicators							
Purchase price	**€**	3 500	7 000	4 550	3 675	3 850	8 750
	% change with BC	0%	100%	30%	5%	10%	150%
Installation costs	**€**	140	280	182	140	140	350
	% change with BC	0%	100%	30%	0%	0%	150%
Electricity costs	**€**	9 089	3 636	8 180	8 180	8 180	2 909
	% change with BC	0%	-60%	-10%	-10%	-10%	-68%
Maintenance and repair costs	**€**	78	156	101	82	86	195
	% change with BC	0%	100%	30%	5%	10%	150%
Life cycle cost	**€**	12 807	11 071	13 014	12 077	12 256	12 203
	% change with BC	0%	-14%	2%	-6%	-4%	-5%

The purchase share for M 2.2 and BA product are the highest among all the options and the base case. In particular for the case of the BA product option this is the result of having reduced energy costs as shown in the figure below.

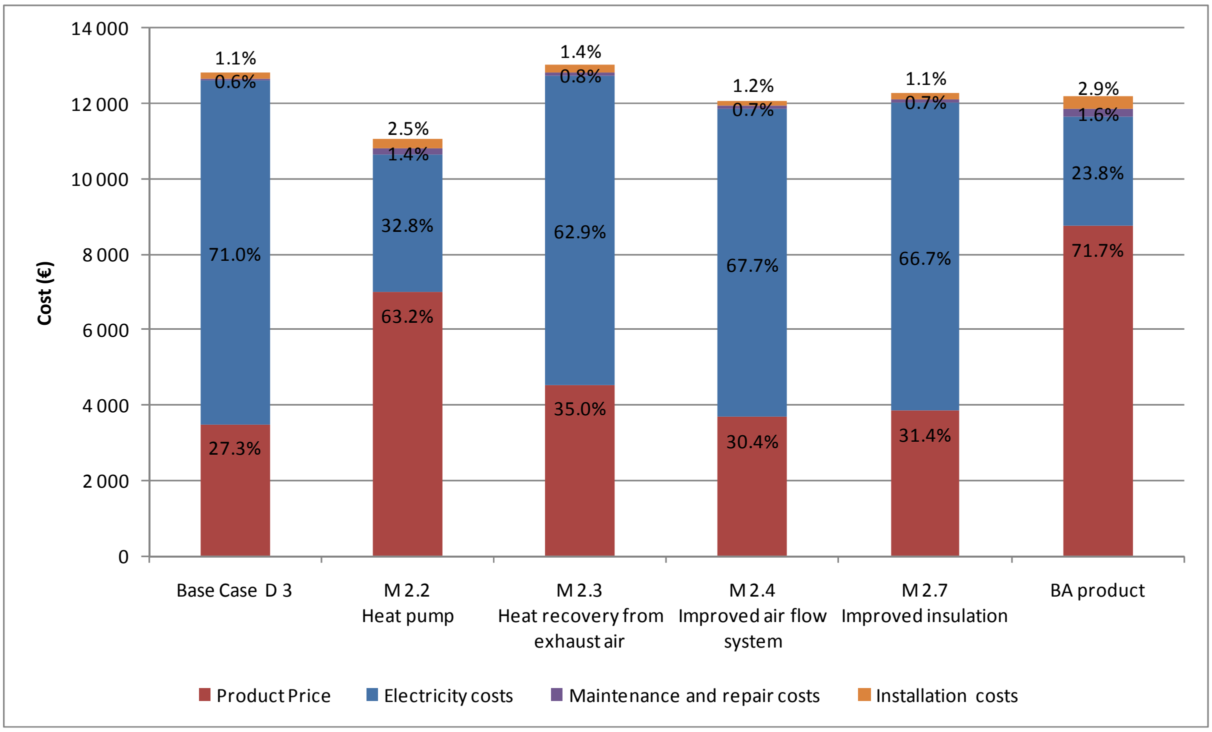


Figure 38 Life cycle costs breakdown by improvement option for Base Case D 3

4.11 Base Case D 4: Professional tumble dryer (<15 kg)

The BA product leads to the LLCC. It reduces 20% the LCC. Option M 2.2 heat pump also reduces the LCC by 15% thanks to reduced gas and electricity costs (-60%). Option M 2.3 Heat recovery from exhaust air is still not economically beneficial over the lifetime but all other improvement options are.

Table 42 Life cycle costs by improvement option for Base Case D 4

Life cycle indicators per unit	Unit	Base Case D 4	M 2.1 In-creased motor effici-ency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insula-tion	BA product
Economic indicators										
Purchase price	**€**	4 000	4 080	7 200	4 920	4 200	4 600	4 200	4 200	7 200
	% change with BC	0%	2%	80%	23%	5%	15%	5%	5%	80%
Installation costs	**€**	160	160	288	197	160	160	160	160	288
	% change with BC	0%	0%	80%	23%	0%	0%	0%	0%	80%
Electricity costs	**€**	6 764	6 561	2 706	6 087	6 223	5 952	5 952	6 290	2 232
	% change with BC	0%	-3%	-60%	-10%	-8%	-12%	-12%	-7%	-67%
Maintenance and repair costs	**€**	92	94	166	113	97	106	97	97	166
	% change with BC	0%	2%	80%	23%	5%	15%	5%	5%	80%
Gas costs	**€**	2 252	2 184	901	2 026	2 071	1 981	1 981	2 094	743
	% change with BC	0%	-3%	-60%	-10%	-8%	-12%	-12%	-7%	-67%
Life cycle cost	**€**	13 268	13 079	11 260	13 344	12 751	12 800	12 390	12 841	10 629
	% change with BC	0%	-1%	-15%	1%	-4%	-4%	-7%	-3%	-20%

The purchase shares for M 2.2 (63.9%) and the BA product (67.7%) are the highest among all the options and the base case and are in both cases counterbalanced by the reduction of the energy costs.

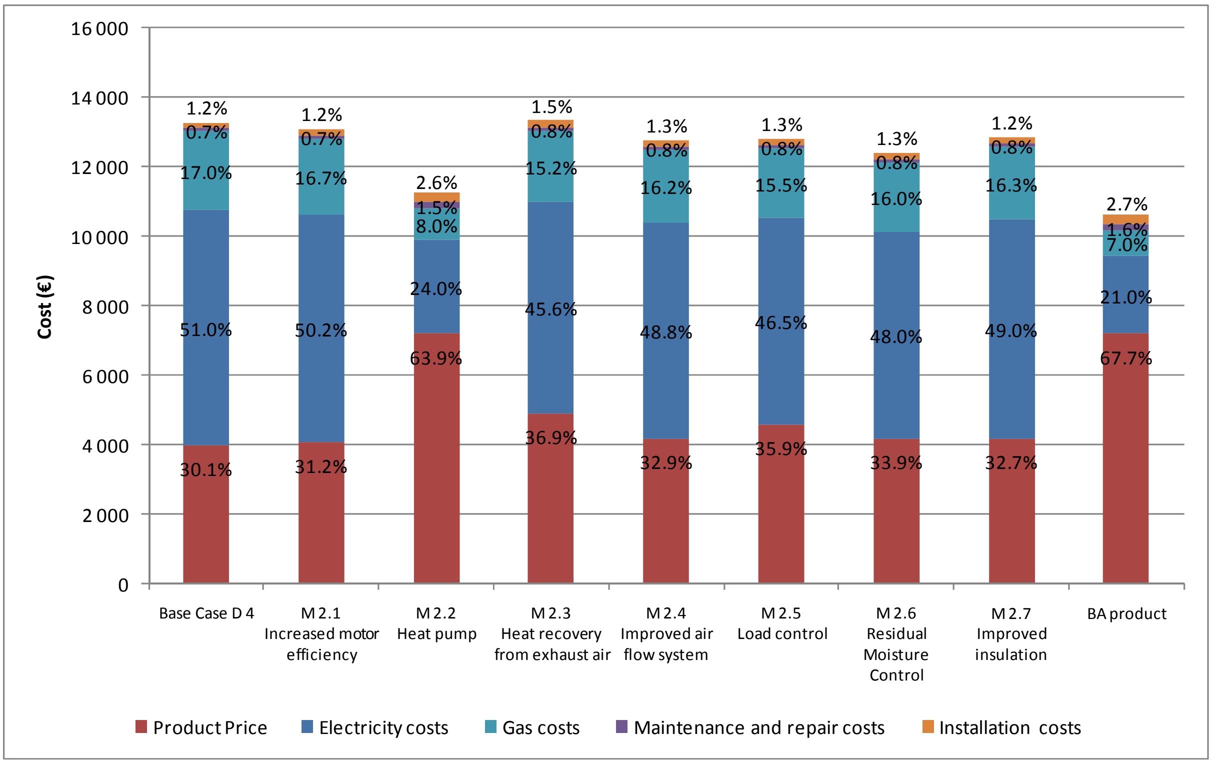


Figure 39 Life cycle costs breakdown by improvement option for Base Case D 4

4.12 Base Case D 5: Professional tumble dryer (15–40 kg)

The option M 2.2 heat pump and the BA product lead to the LLCC. They reduce 24% the LCC, and 60% the electricity and gas costs. All other options reduce the LCC as well, included option M 2.3 Heat recovery from exhaust air.

Table 43 Life cycle costs by improvement option for Base Case D 5

Life cycle indicators per unit	Unit	Base Case D 5	M 2.1 In-creased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insula-tion	BA product
Economic indicators										
Purchase price	**€**	7 125	7 268	12 825	8 835	7 553	8 123	7 766	7 553	12 825
	% change with BC	0%	2%	80%	24%	6%	14%	9%	6%	80%
Installation costs	**€**	285	285	513	353	302	285	285	285	513
	% change with BC	0%	0%	80%	24%	6%	0%	0%	0%	80%
Electricity costs	**€**	12 953	12 694	5 181	11 787	11 528	11 658	11 658	12 176	5 181
	% change with BC	0%	-2%	-60%	-9%	-11%	-10%	-10%	-6%	-60%
Maintenance and repair costs	**€**	161	165	290	200	171	184	176	171	290
	% change with BC	0%	2%	80%	24%	6%	14%	9%	6%	80%
Gas costs	**€**	8 935	8 757	3 574	8 131	7 952	8 042	8 042	8 399	3 574
	% change with BC	0%	-2%	-60%	-9%	-11%	-10%	-10%	-6%	-60%
Life cycle cost	**€**	29 460	29 168	22 384	29 307	27 506	28 291	27 927	28 584	22 384
	% change with BC	0%	-1%	-24%	-1%	-7%	-4%	-5%	-3%	-24%

Figure 40 presents the breakdown of the LCC for the base case and all improvement options.

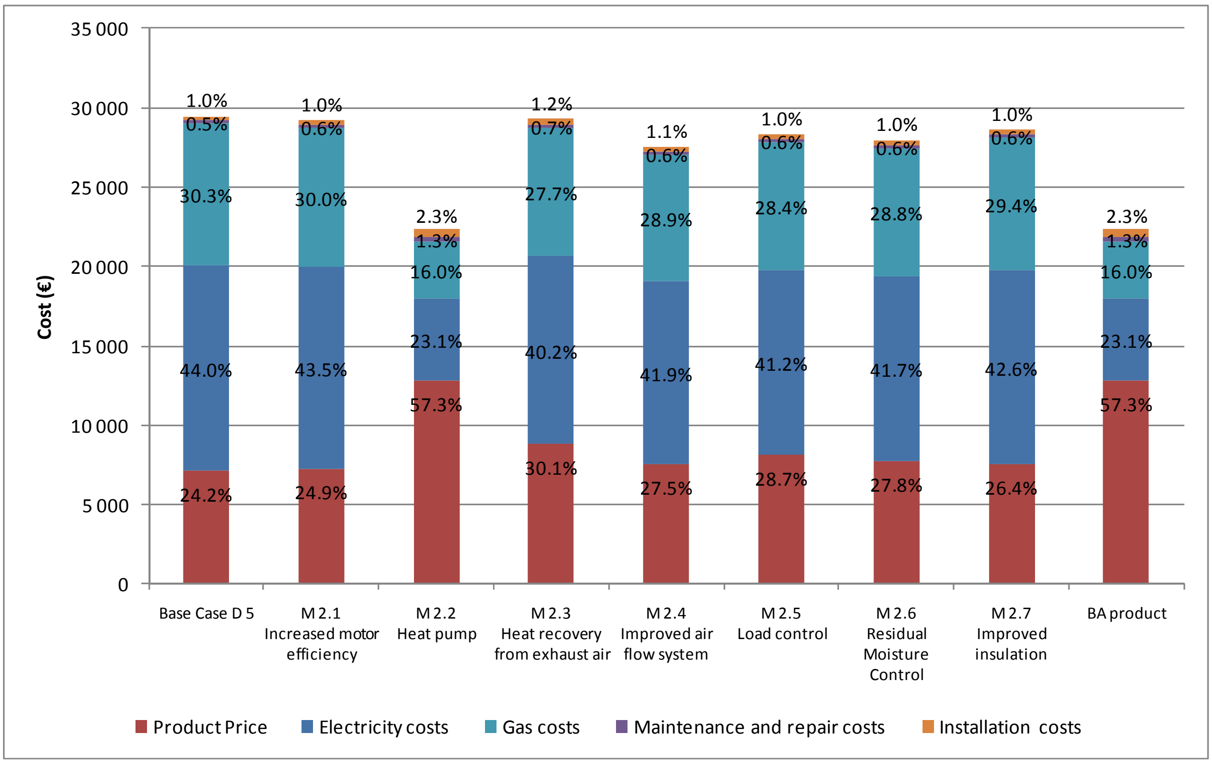


Figure 40 Life cycle costs breakdown by improvement option for Base Case D 5

4.13 Base Case D 6: Professional tumble dryer (>40 kg)

Option M 2.2 Heat pump and the BA product represent the LLCC for this base case. They reduce the LCC by 27% and the energy costs by 60% while the purchase costs increase by 80%. Option M 2.3 Heat recovery from exhaust air is the only improvement option not being economically beneficial (+3%).

Table 44 Life cycle costs by improvement option for Base Case D 6

Life cycle indicators per unit	Unit	Base Case D 6	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
Economic indicators										
Purchase price	€	21 500	21 930	38 700	29 455	23 220	23 865	24 725	23 435	38 700
	% change with BC	0%	2%	80%	37%	8%	11%	15%	9%	80%
Installation costs	€	860	860	1 548	1 178	860	860	860	860	1 548
	% change with BC	0%	0%	80%	37%	0%	0%	0%	0%	80%
Electricity costs	€	36 191	35 829	14 476	33 295	34 381	34 381	34 381	35 467	14 476
	% change with BC	0%	-1%	-60%	-8%	-5%	-5%	-5%	-2%	-60%
Maintenance and repair costs	€	2 973	3 032	5 351	4 073	3 210	3 300	3 419	3 240	5 351
	% change with BC	0%	2%	80%	37%	8%	11%	15%	9%	80%
Gas costs	€	46 038	45 577	18 415	42 355	43 736	43 736	43 736	45 117	18 415
	% change with BC	0%	-1%	-60%	-8%	-5%	-5%	-5%	-2%	-60%
Life cycle cost	€	107 561	107 228	78 490	110 356	105 407	106 141	107 120	108 119	78 490
	% change with BC	0%	0%	-27%	3%	-2%	-1%	0%	1%	-27%

Figure 41 presents the breakdown of the LCC for the base case and all improvement options. In comparison with the other base cases, gas costs now represent a substantial share of the LCC (between 23.5% for the BA product and 42.8% for the base case), which is larger than the electricity share.

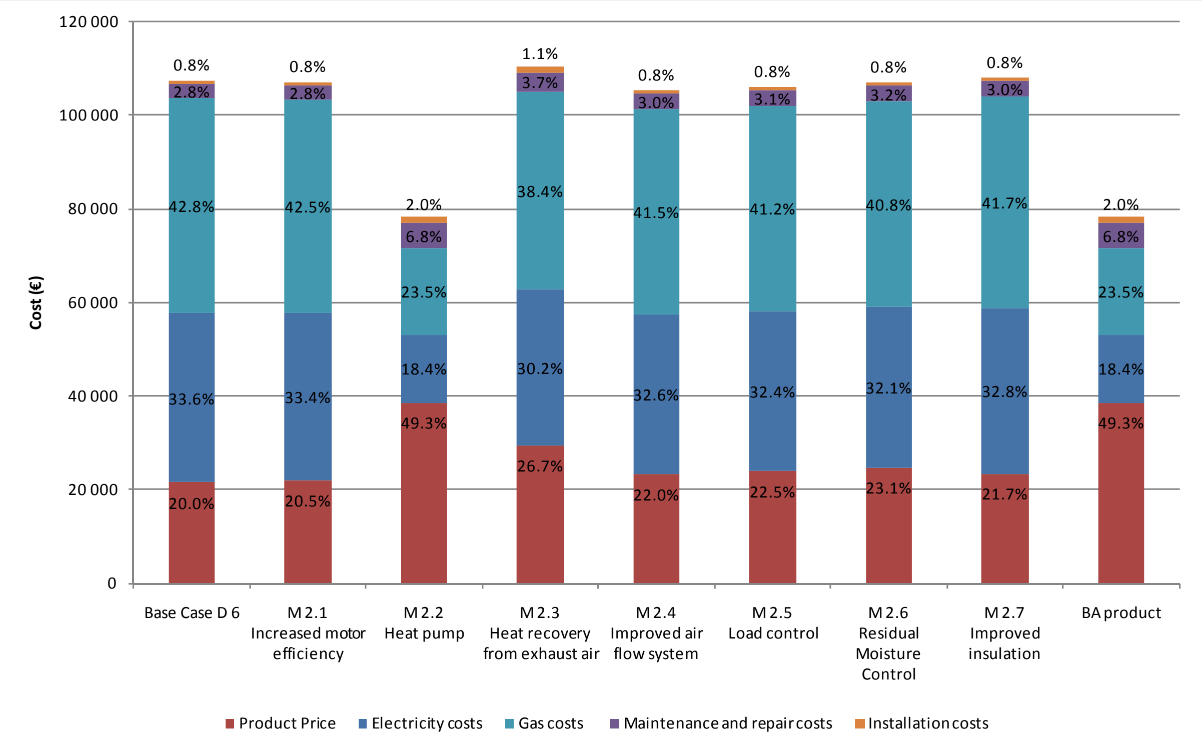


Figure 41 Life cycle costs breakdown by improvement option for Base Case D 6

4.14 Base Case D 7: Industrial pass-through (transfer) tumble dryer

The BA product option represents the LLCC for this base case. It reduces 14% the LCC and 25% the energy costs. Option M 2.1 Increased motor efficiency gives the highest LCC, while M 2.3 heat recovery from exhaust air reduces the LCC by 8% compared to the base case.

Table 45 Life cycle costs by improvement option for Base Case D 7

Life cycle indicators per unit	Unit	Base Case D 7	M 2.1 Increased motor concept	M 2.3 Heat recovery from exhaust air	M 2.7 Improved insulation	BA product
Economic indicators						
Purchase price	**€**	62 500	66 250	72 500	68 125	88 125
	% change with BC	0%	6%	16%	9%	41%
Installation costs	**€**	5 625	5 625	6 525	5 625	7 931
	% change with BC	0%	0%	16%	0%	41%
Electricity costs	**€**	96 802	95 834	85 185	93 898	72 601
	% change with BC	0%	-1%	-12%	-3%	-25%
Maintenance and repair costs	**€**	8 641	9 160	10 024	9 419	12 184
	% change with BC	0%	6%	16%	9%	41%
Gas costs	**€**	306 057	302 997	269 330	296 875	229 543
	% change with BC	0%	-1%	-12%	-3%	-25%
Life cycle cost	**€**	479 625	479 865	443 565	473 942	410 385
	% change with BC	0%	0%	-8%	-1%	-14%

Figure 42 presents the breakdown of the LCC for the base case and all improvement options. Gas costs are also particularly important for this base case which is considered with a 100% "alternative" heating (see Task 5).

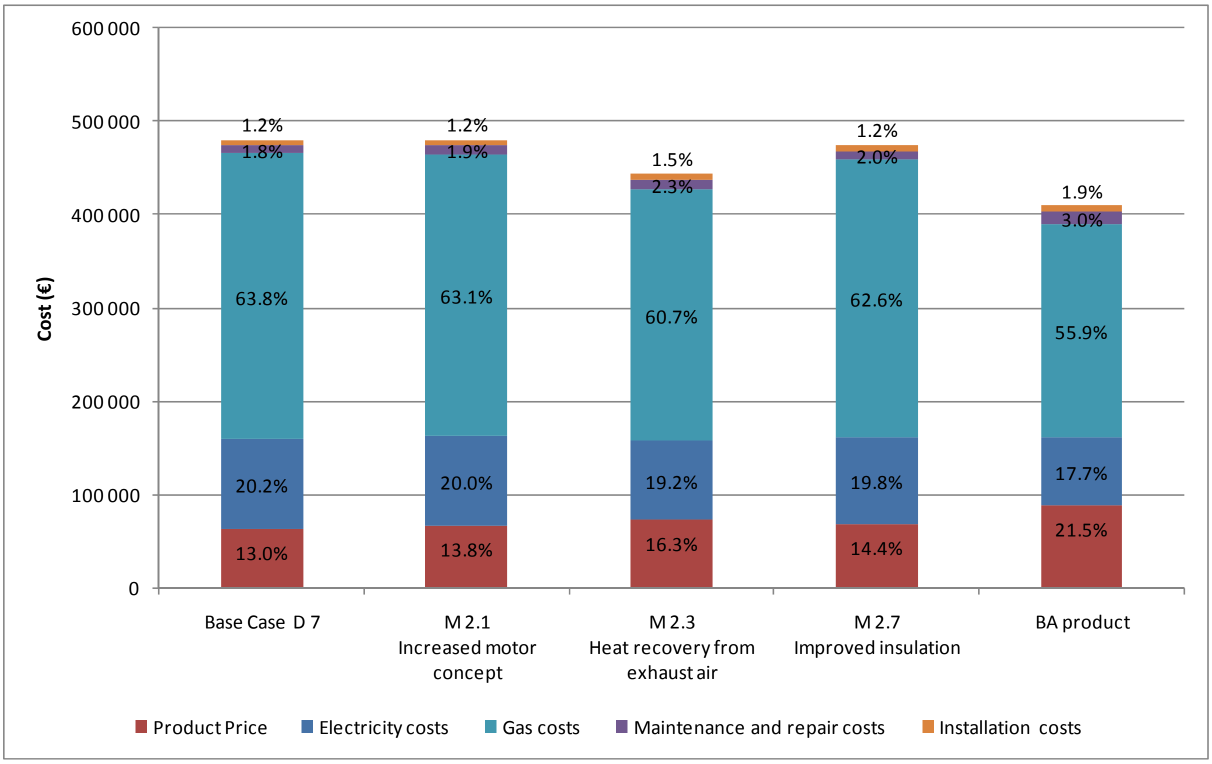


Figure 42 Life cycle costs breakdown by improvement option for Base Case D 7

4.15 Payback periods

Table 46 and Table 47 present the payback periods in years of the different improvement options implemented, for professional laundry appliances. In the estimation of these periods, maintenance and repair costs were kept constant in the calculations of the life cycle costs (and not proportional to the lifetime considered), since they were estimated by a percentage of the purchase price in Task 5, rather than on the basis of the product lifetime.

The payback period represents the year when the additional investment done when buying a more expensive appliance (all improvement options result in increases of the purchase price of the professional laundry appliances) is counterbalanced by the reduced operating costs of the appliance (in particular here, energy, water and detergent costs), when summing all costs in a life cycle approach.

Regarding professional washing machines, options M 1.4 Load control and M 1.5 Further control systems have quite low payback periods for all base cases. On the other hand, options M 1.1 Increased motor efficiency and M 1.2 heat exchanger present very long periods, except for base case WM 7 and the heat exchanger (one year). For the remaining options, the situation is intermediate and the period depends on the base case considered (from one to 17 years for the BA products, 7 to 15 years for M 1.3 Water recovery).

Table 46 Payback periods (in years) of the improvement options for professional washing machines

Base case	Lifetime considered in previous analysis	M 1.1 Increased motor efficiency	M 1.2 Heat exchanger	M 1.3 Water recovery	M 1.4 Load control	M 1.5 Further control systems	M 1.7 Drum construction	BA product
WM 1	8	>20	14	15	4	4	17	17
WM 2	12	>20	11	11	3	1	4	5
WM 3	14	>20	14	12	4	1	5	7
WM 4	15	>20	>20	4	3	4	-	6
WM 5	11	>20	-	-	1	1	-	-
WM 6	14	>20	>20	7	5	9	-	15
WM 7	13	>20	1	-	-	-	-	1

Regarding professional laundry dryers, the options generally present lower payback periods. Except for the heat recovery system which in similar situation as the heat exchanger for washing machine (all periods high except for base case D 7), all other options have payback times of less than 8 years for most of the base cases. Given the average estimated lifetimes (all under 8 years), most options are logically economically beneficial over the lifetime of the product, as shown in the previous costs analysis.

Table 47 Payback periods (in years) of the improvement options for professional dryers

Base case	Lifetime considered in prev. analysis	M 2.1 Increased motor efficiency	M 2.2 Heat pump	M 2.3 Heat recovery from exhaust air	M 2.4 Improved air flow system	M 2.5 Load control	M 2.6 Residual Moisture Control	M 2.7 Improved insulation	BA product
D1	8	6	6	-	3	4	4	4	9
D2	8	7	5	15	4	4	4	4	9
D3	15	-	10	>20	3	-	-	5	14
D4	13	4	8	15	4	7	3	4	7
D5	14	4	6	13	3	6	4	4	6
D6	13	7	5	>20	6	8	12	20	5
D7	13	15	-	3	-	-	-	7	4

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:

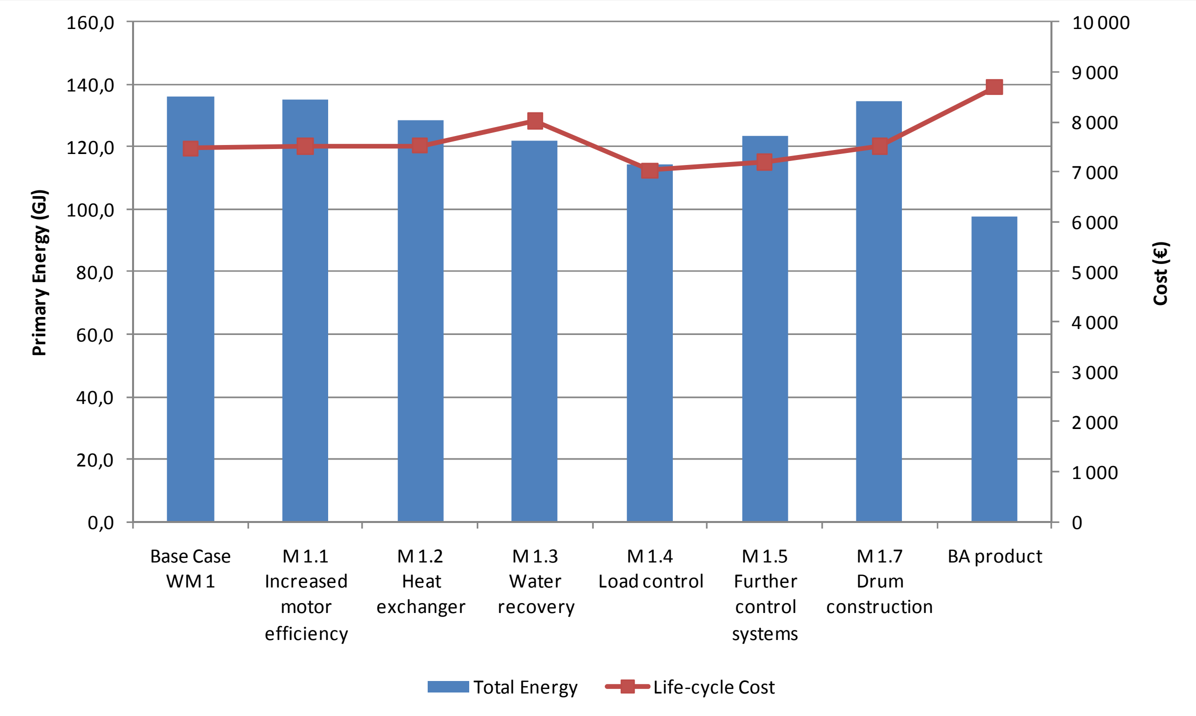
- Ranking the identified design options by LCC (e.g. option 1, option 2, option 3)
- Considering the possible trade-offs (positive or negative side effects of the envisaged options/individual design measures);
- Estimating the accumulative improvement and cost effects of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.);
- Ranking the cumulative design options, drawing an LCC-curve (Y1-axis = energy consumption, Y2-axis = LLCC, 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 improvement options often increases the quantity of waste generated (mostly non-hazardous), 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 change 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.

5.1 Base Case WM 1: Semi-professional washer extractor

Figure 43 shows that the LLCC for WM 1 is M 1.4 Load control, while energy consumption is reduced most with the BA product.



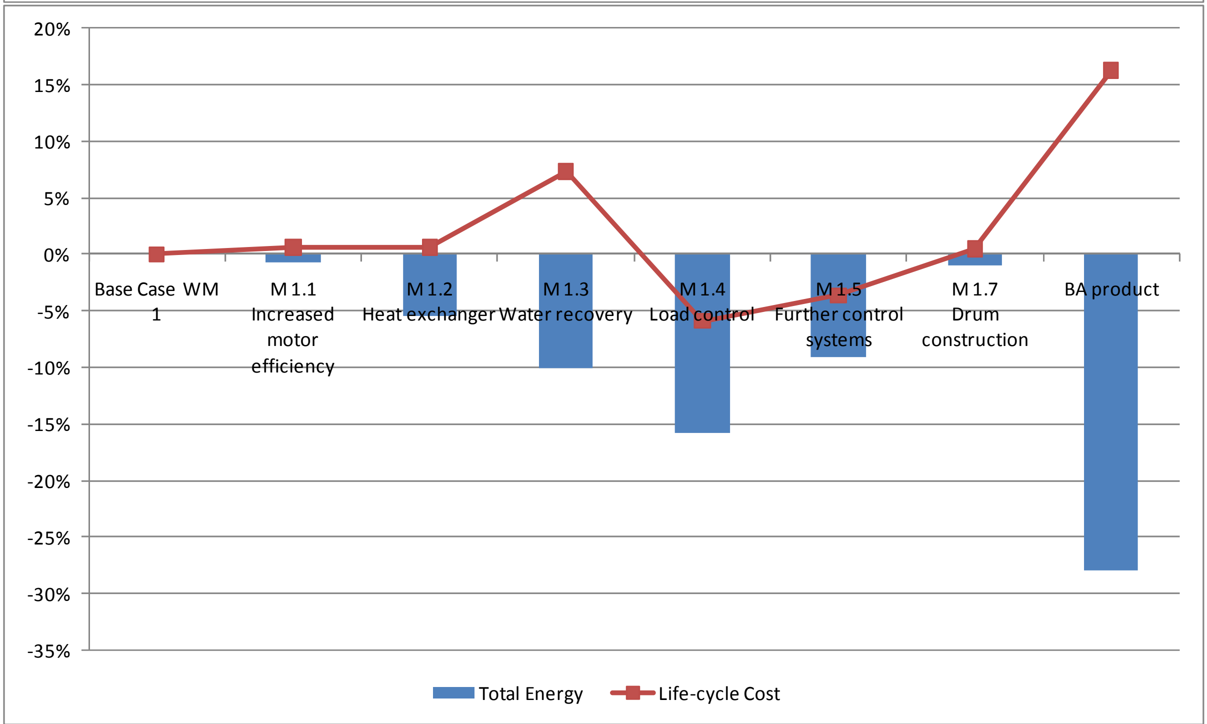


Figure 43 Economic and environmental analysis for Base Case WM 1

5.2 Base Case WM 2: Professional washer extractor <15kg

Figure 44 shows that the LLCC for WM 2 is M 1.4 Load control whereas the energy is reduced the most with the BA product.

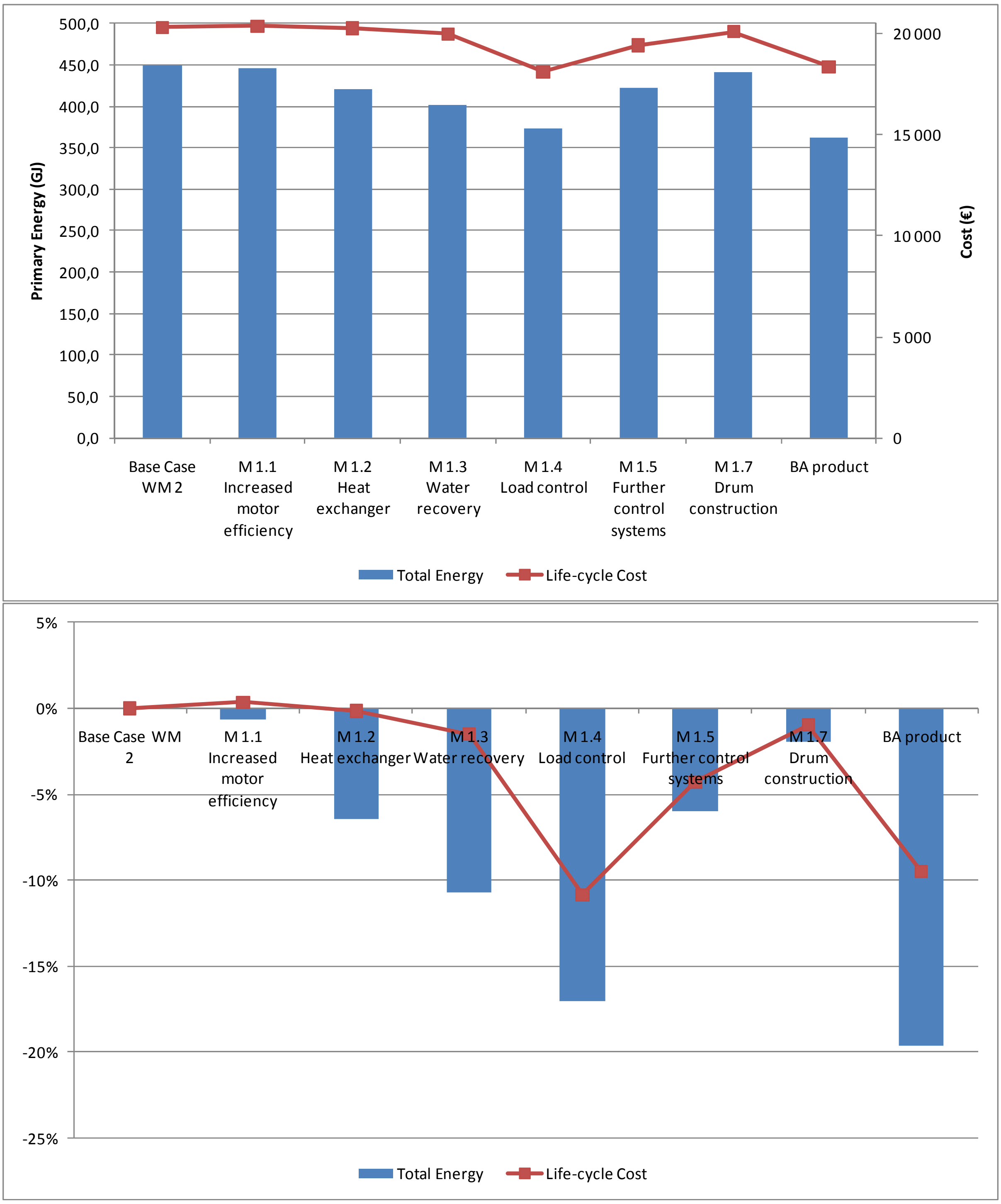
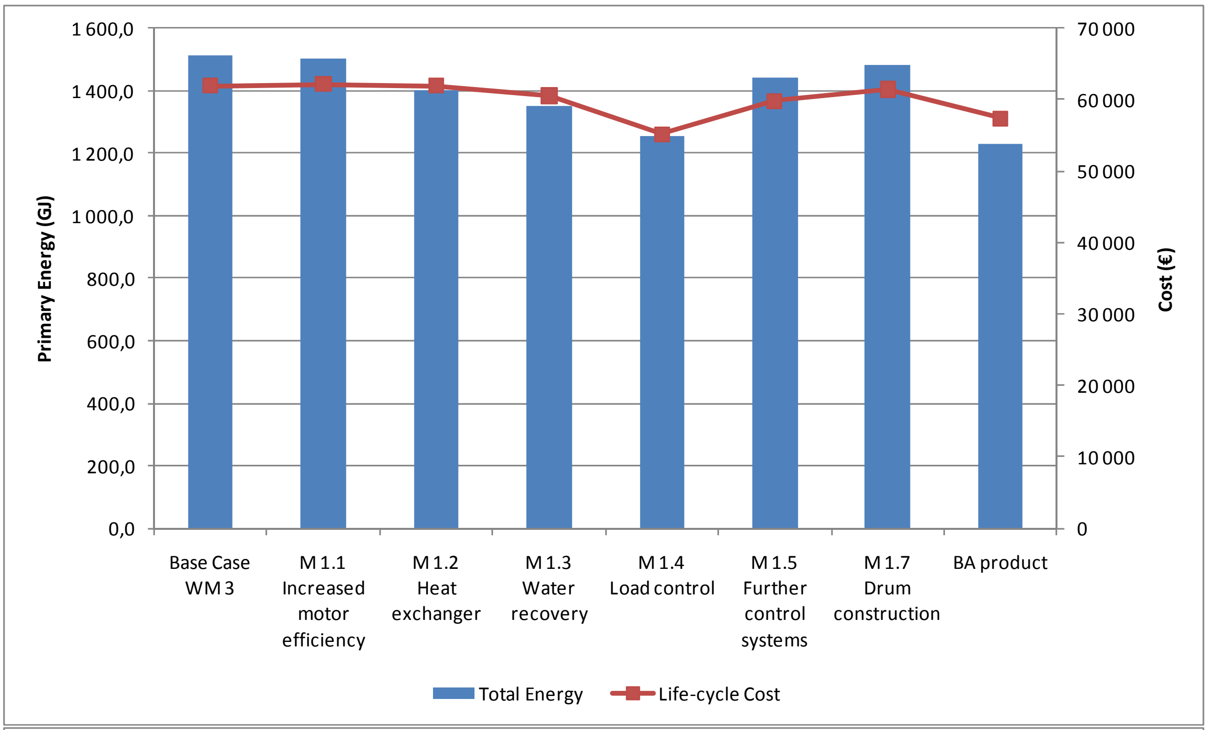


Figure 44 Economic and environmental analysis for Base Case WM 2

5.3 Base Case WM 3: Professional washer extractor 15–40 kg

Figure 45 shows that the LLCC for WM 3 is M 1.4 Load control whereas the maximum energy consumption is achieved with the BA product.



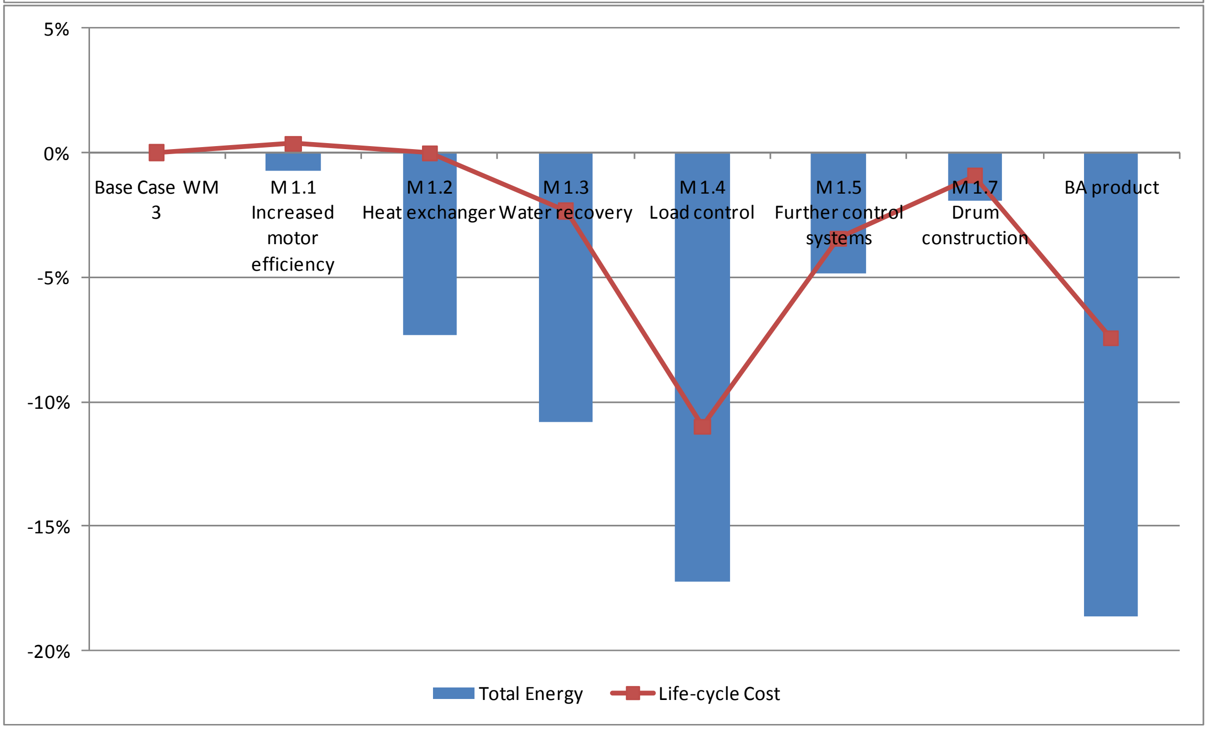
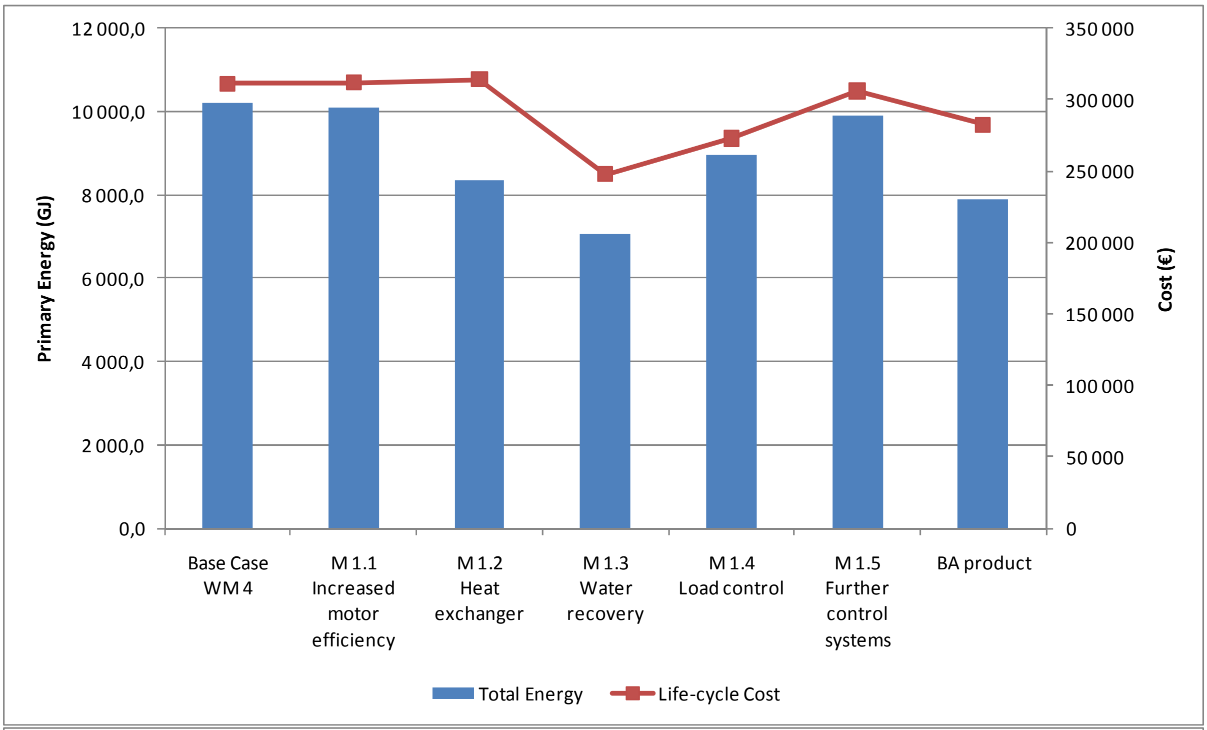


Figure 45 Economic and environmental analysis for Base Case WM 3

5.4 Base Case WM 4: Professional washer extractor >40kg

Figure 46 shows that the LLCC for WM 4 is M 1.3 Water recovery. This option also shows the highest reduction in the energy consumption (BAT).



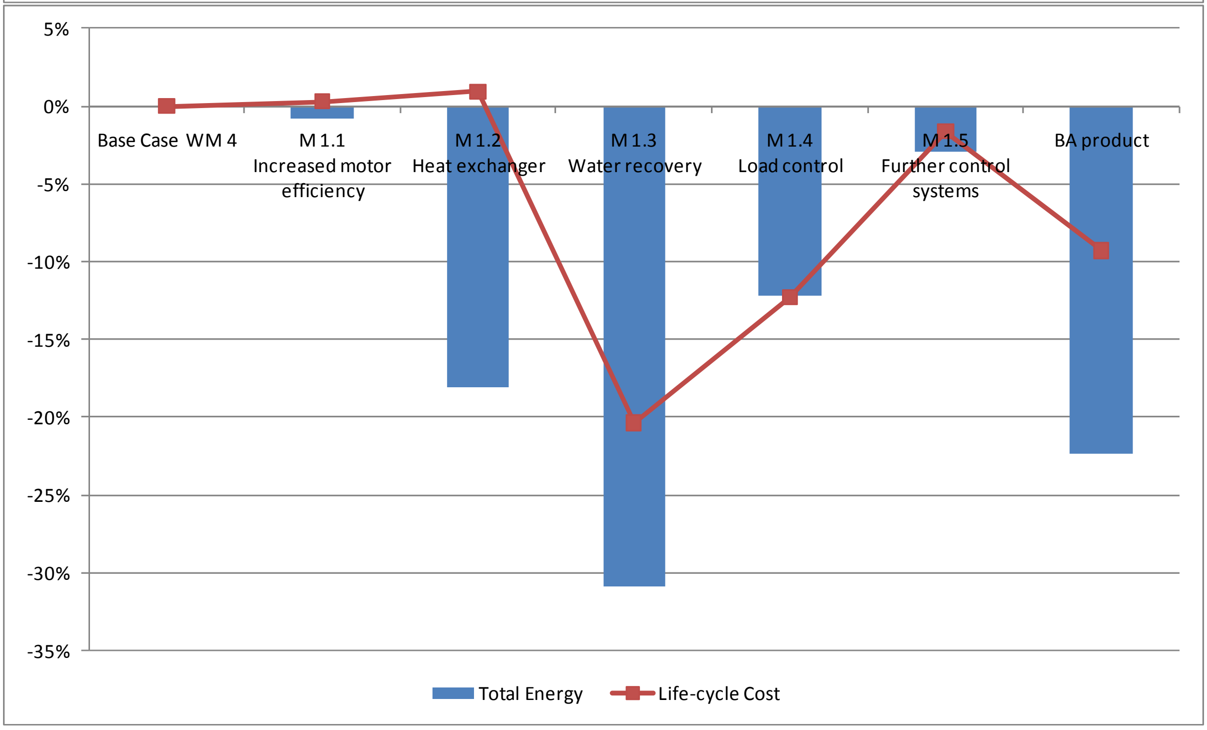
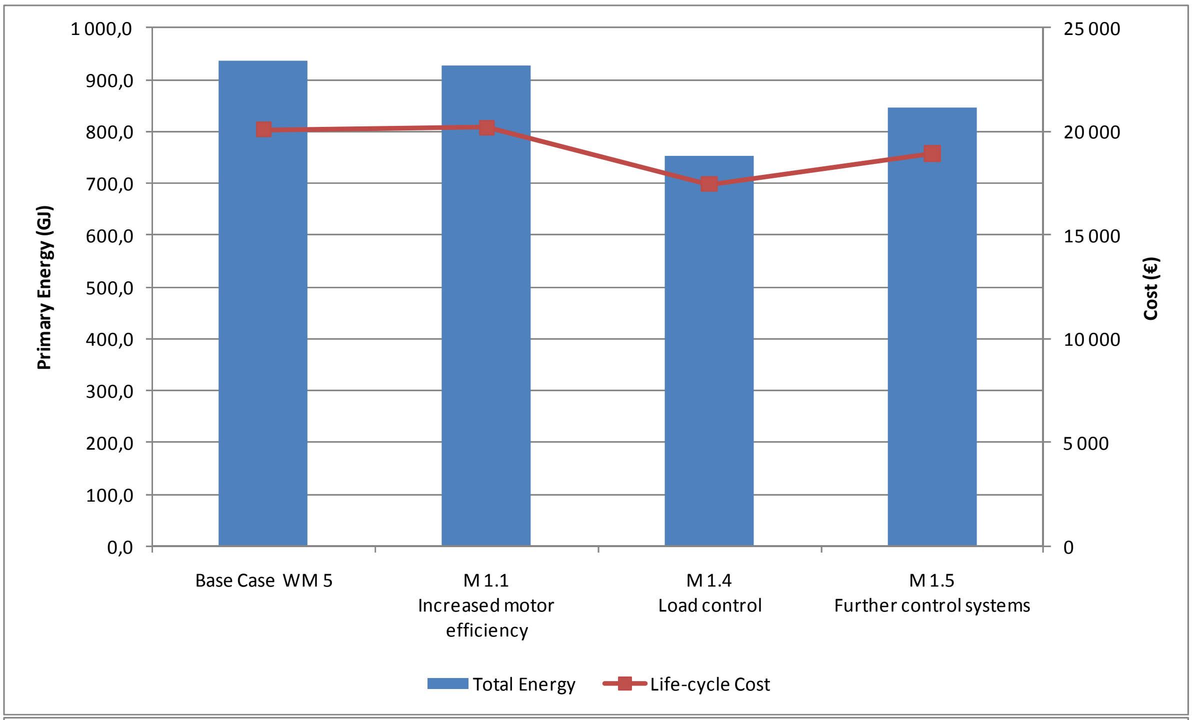


Figure 46 Economic and environmental analysis for Base Case WM 4

5.5 Base Case WM 5: Professional washer dryer

Figure 47 shows that the LLCC for WM 5 is M 1.4 Load control. This option also shows the highest reduction of the energy consumption (BAT).



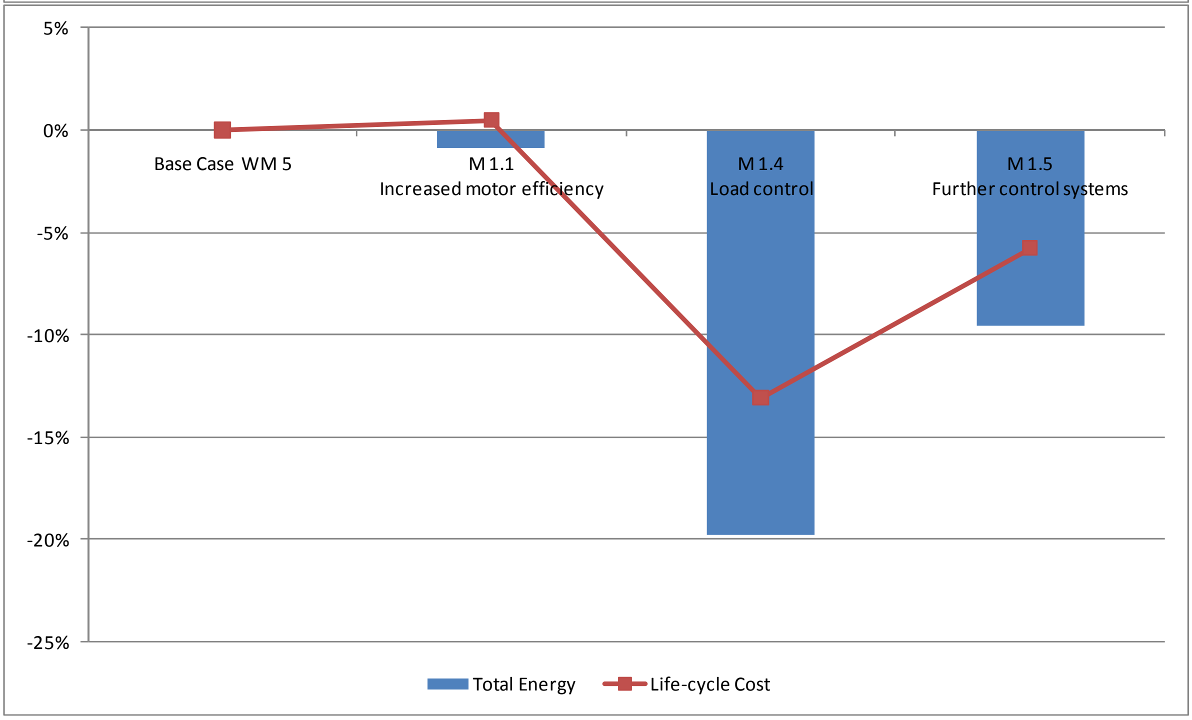
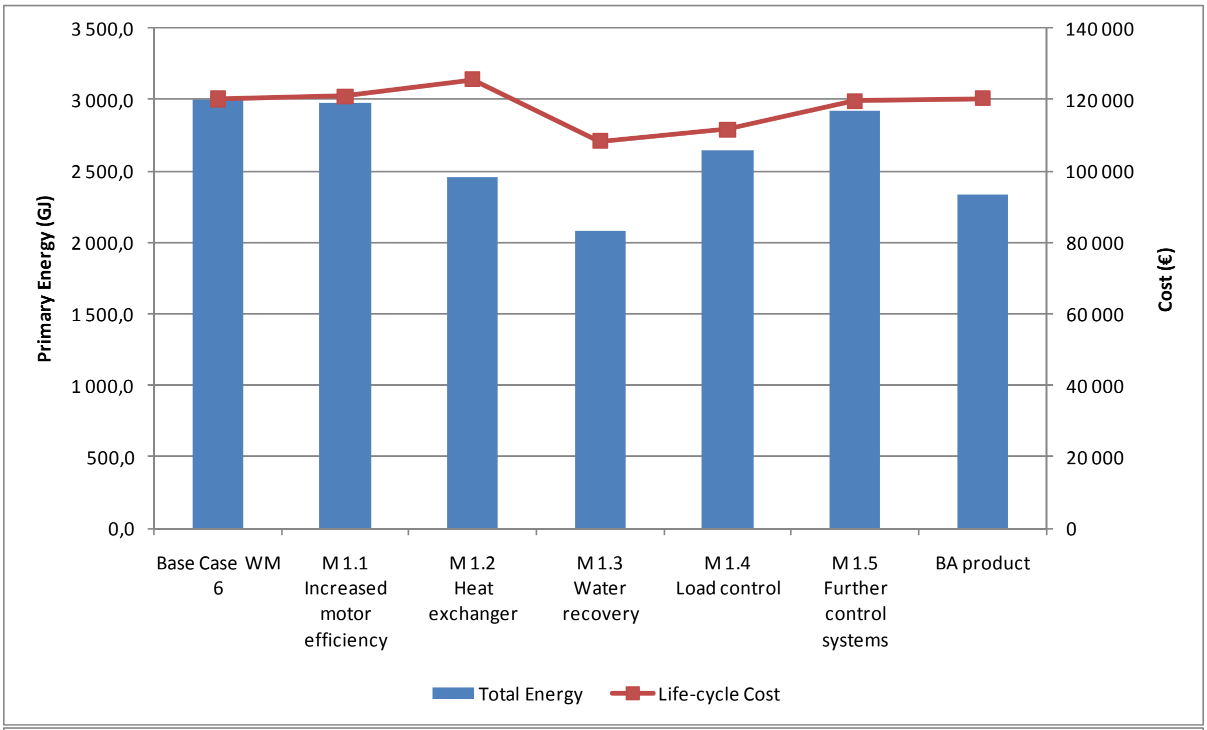


Figure 47 Economic and environmental analysis for Base Case WM 5

5.6 Base Case WM 6: Professional Barrier Washer

Figure 48 shows that the LLCC for WM 6 is M 1.3 Water recovery. This option also shows the highest reduction in the energy consumption (BAT).



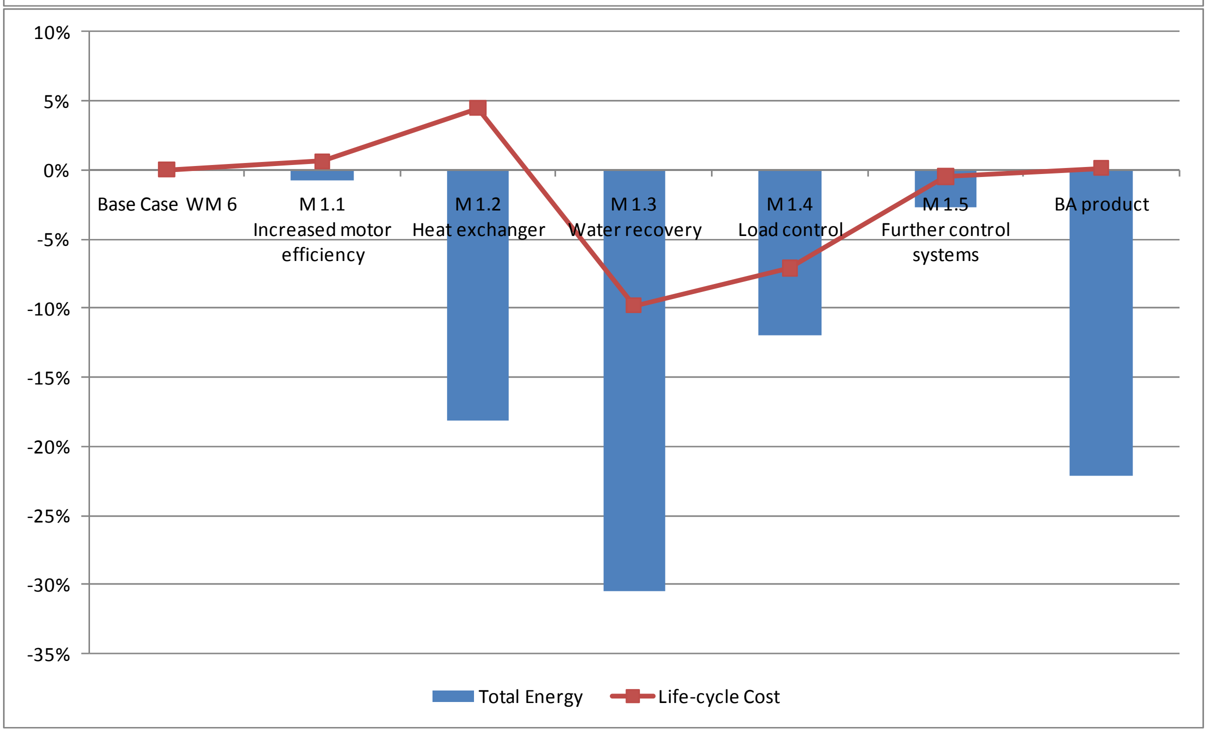
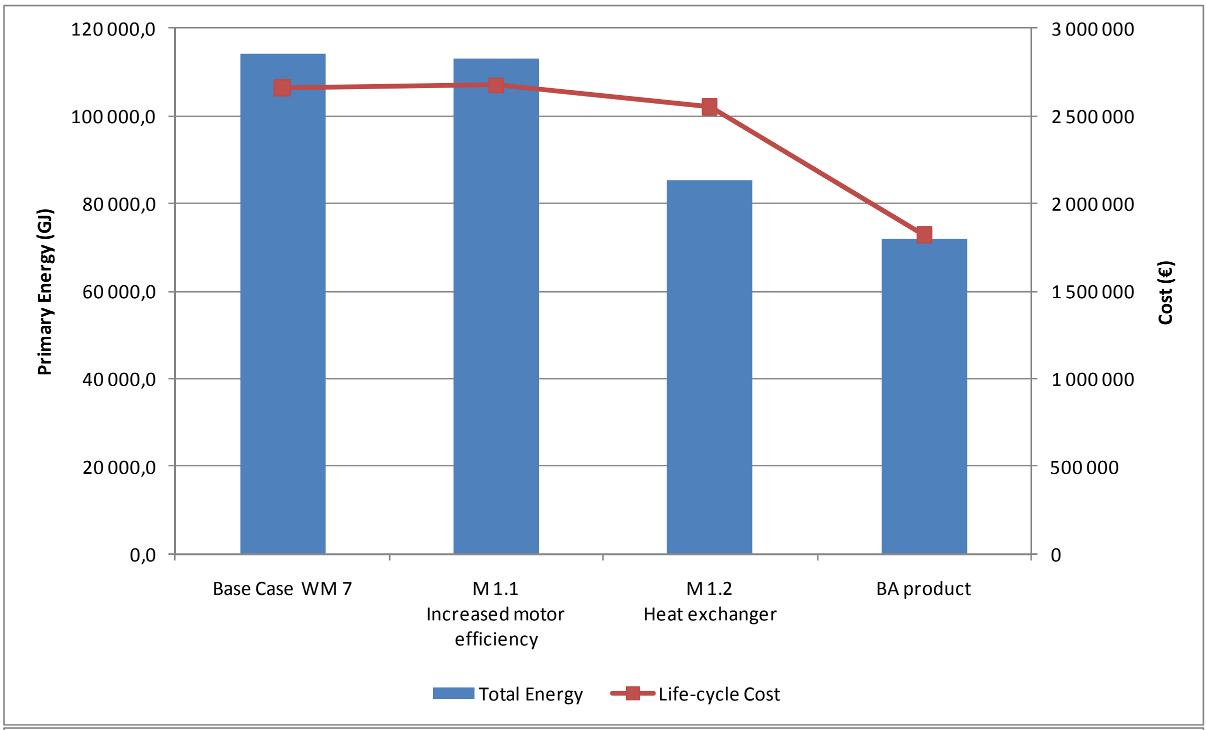


Figure 48 Economic and environmental analysis for Base Case WM 6

5.7 Base Case WM 7: Washing tunnel machine

The figure below shows that the LLCC for WM 7 is the BA product. This option also shows the highest reduction in the energy consumption (BAT).



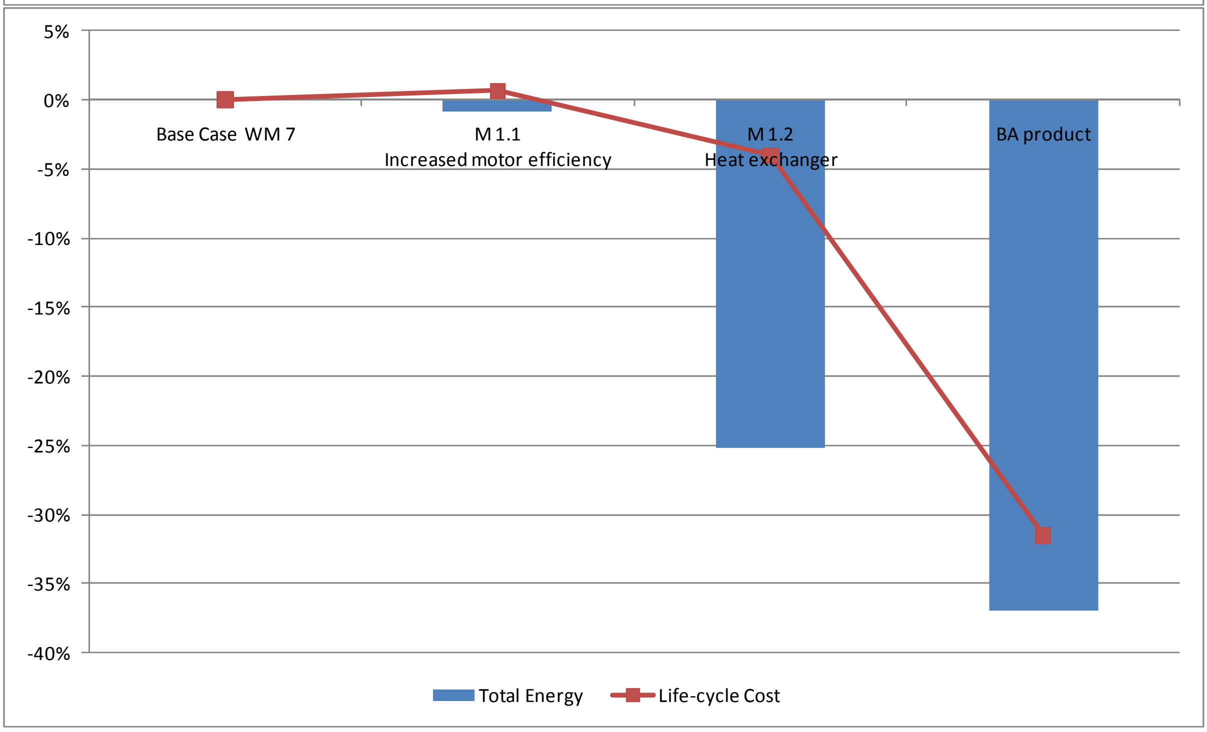
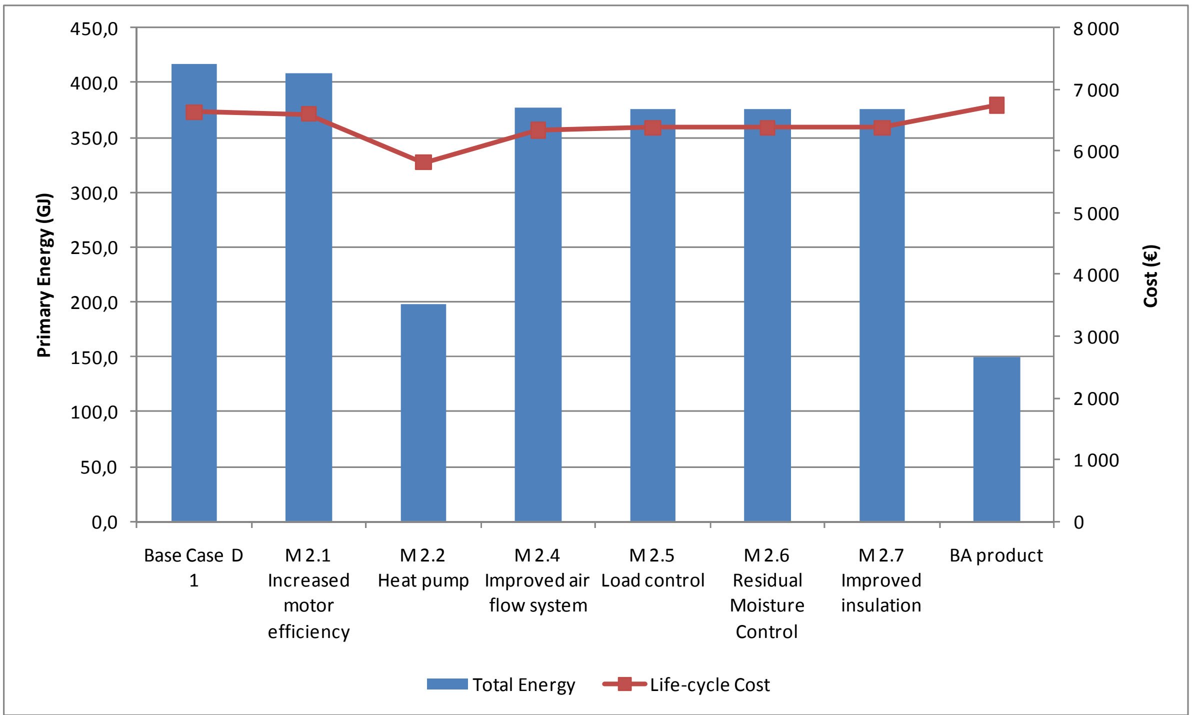


Figure 49 Economic and environmental analysis for Base Case WM 7

5.8 Base Case D 1: Semi-professional dryer, condenser

As shown in the figure below, the LLCC is the option M 2.2 Heat pump, while the BAT is the BA product.



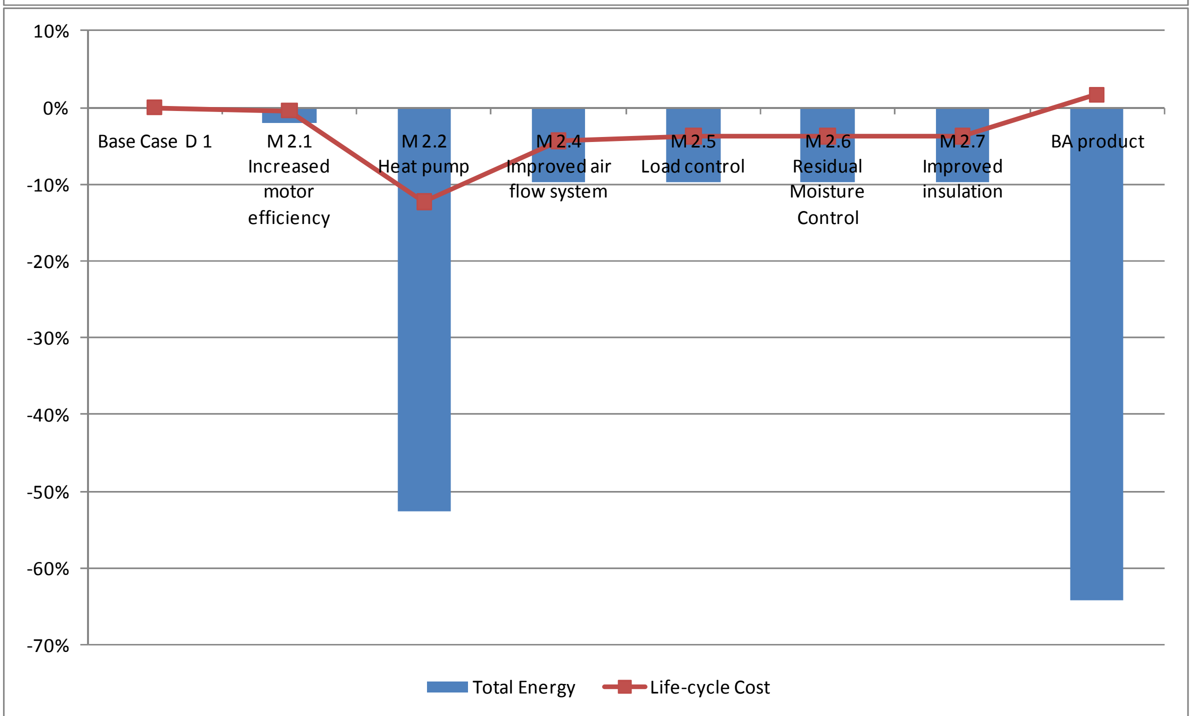


Figure 50 Economic and environmental analysis for Base Case D 1

5.9 Base Case D 2: Semi-professional dryer, air vented

As shown in the figure below, the option M 2.2 Heat pump represents both the LLCC and the BAT.

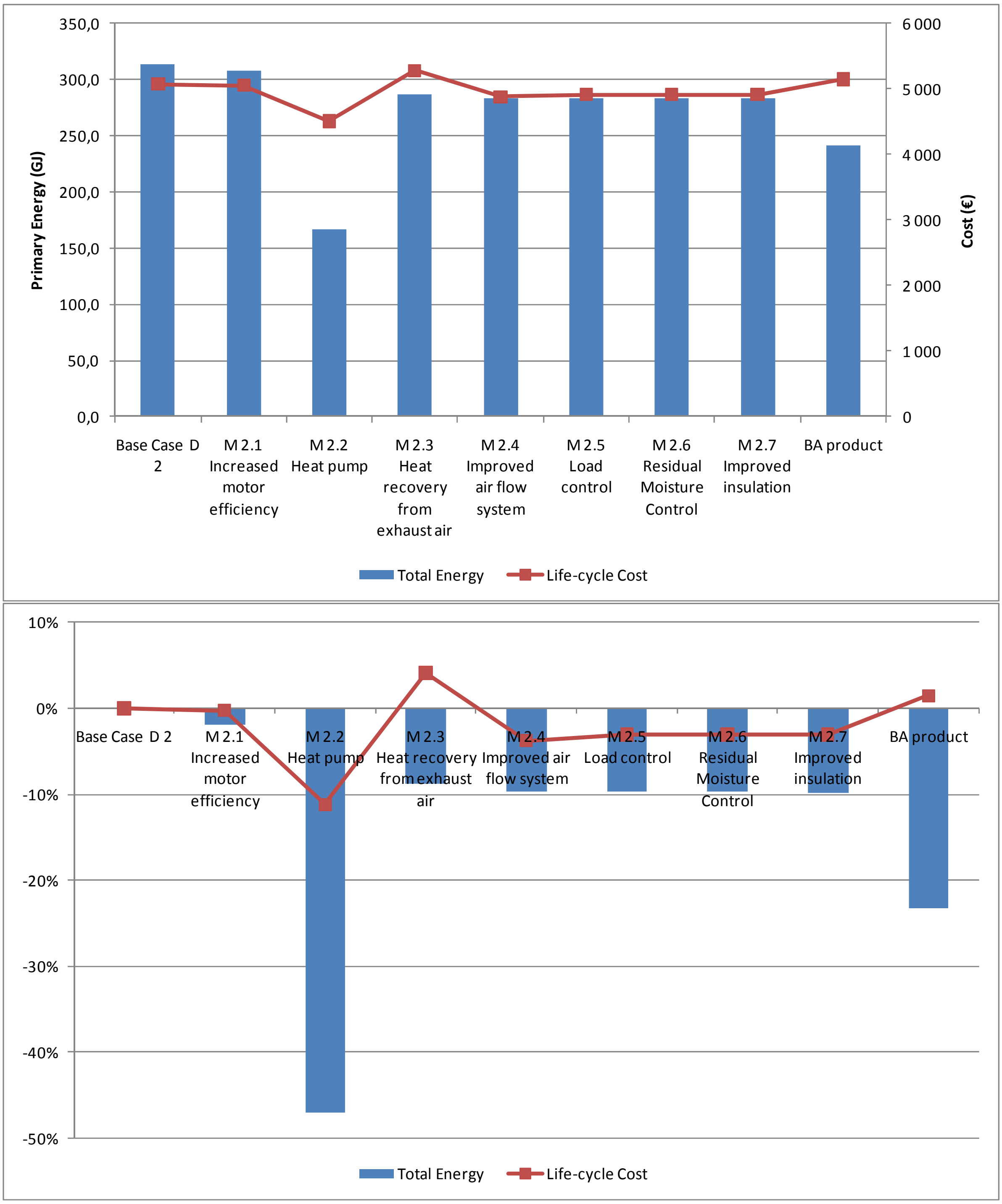


Figure 51 Economic and environmental analysis for Base Case D 2

5.10 Base Case D 3: Professional Cabinet dryer

As shown in the figure below, the LLCC is the option M 2.2 Heat pump, while the BAT is the BA product.

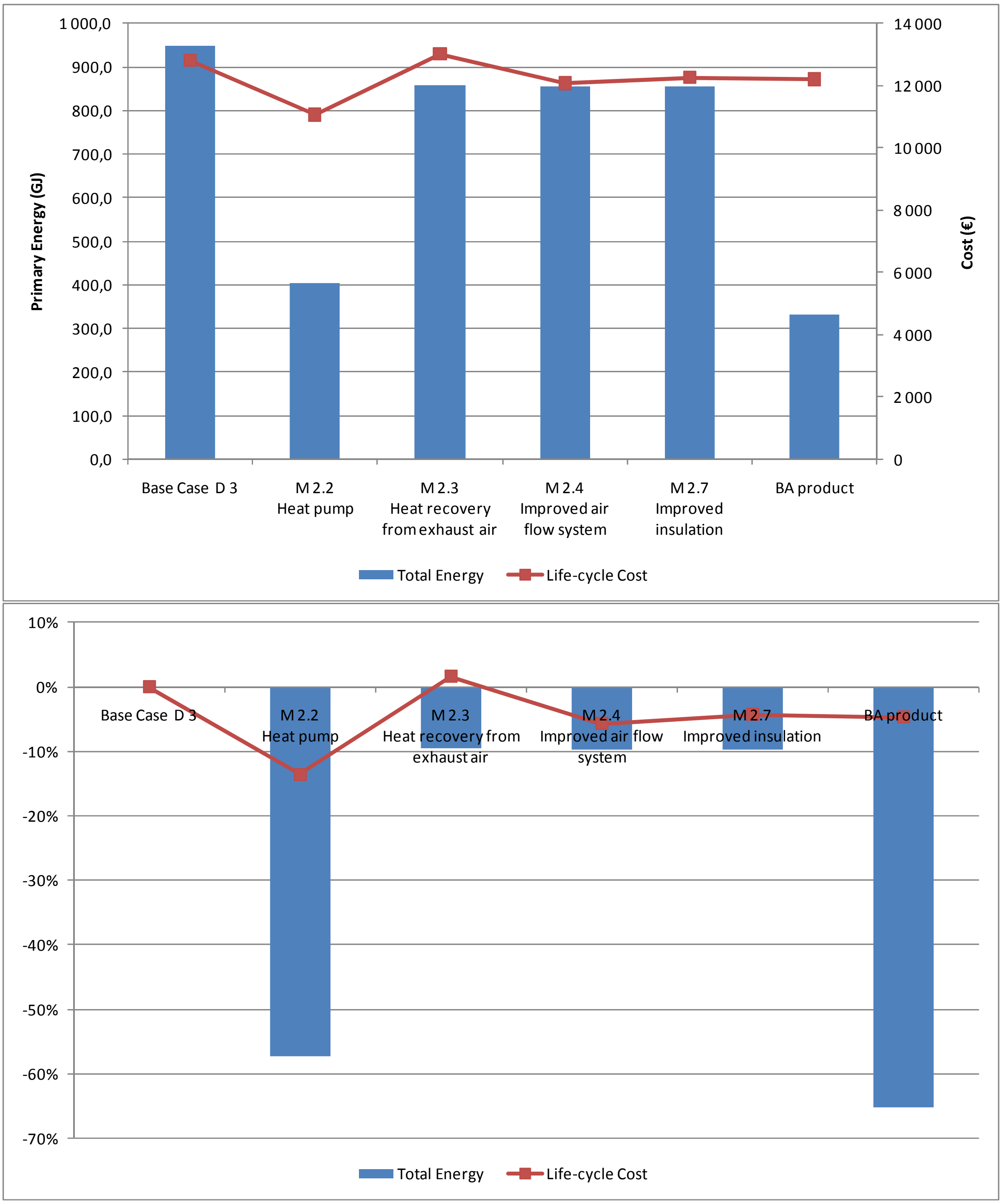
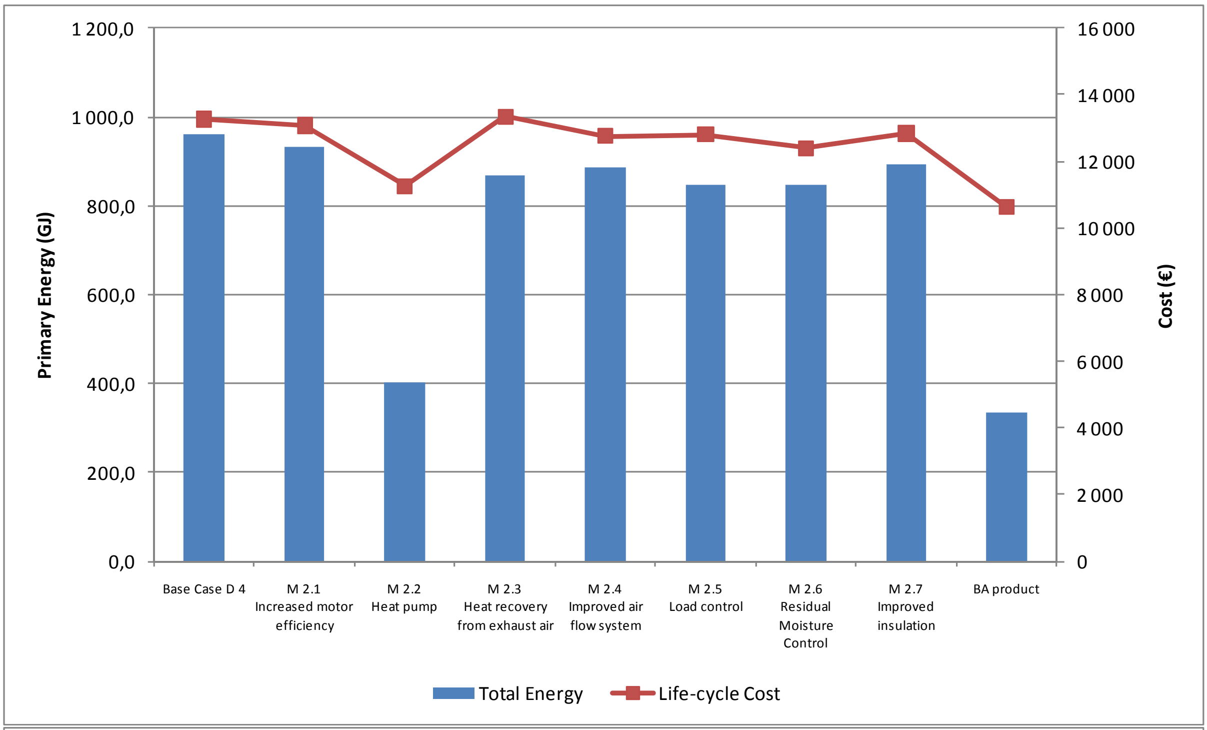


Figure 52 Economic and environmental analysis for Base Case D 3

5.11 Base Case D 4: Professional tumble dryer (<15 kg)

As shown in the figure below, the BA product represents both the LLCC and the BAT.



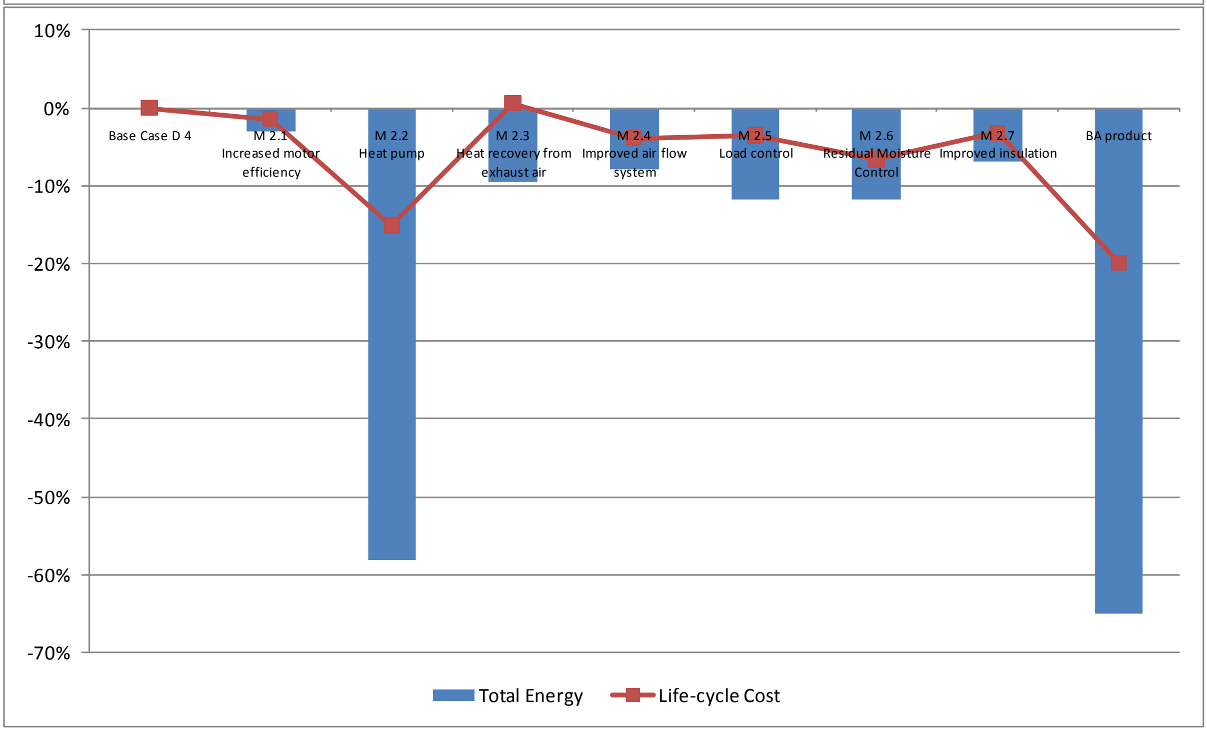
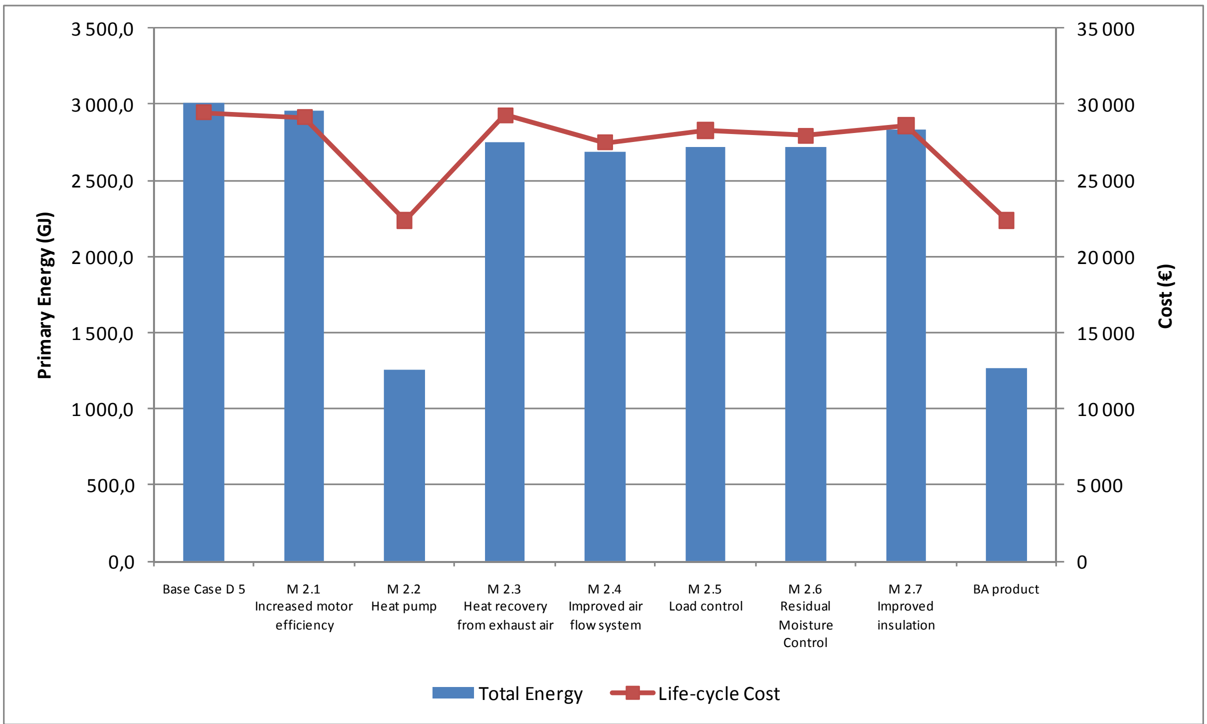


Figure 53 Economic and environmental analysis for Base Case D 4

5.12 Base Case D 5: Professional tumble dryer (15–40 kg)

As shown in the figure below, the option M 2.2 Heat pump represents both the LLCC (with the BA product) and the BAT.



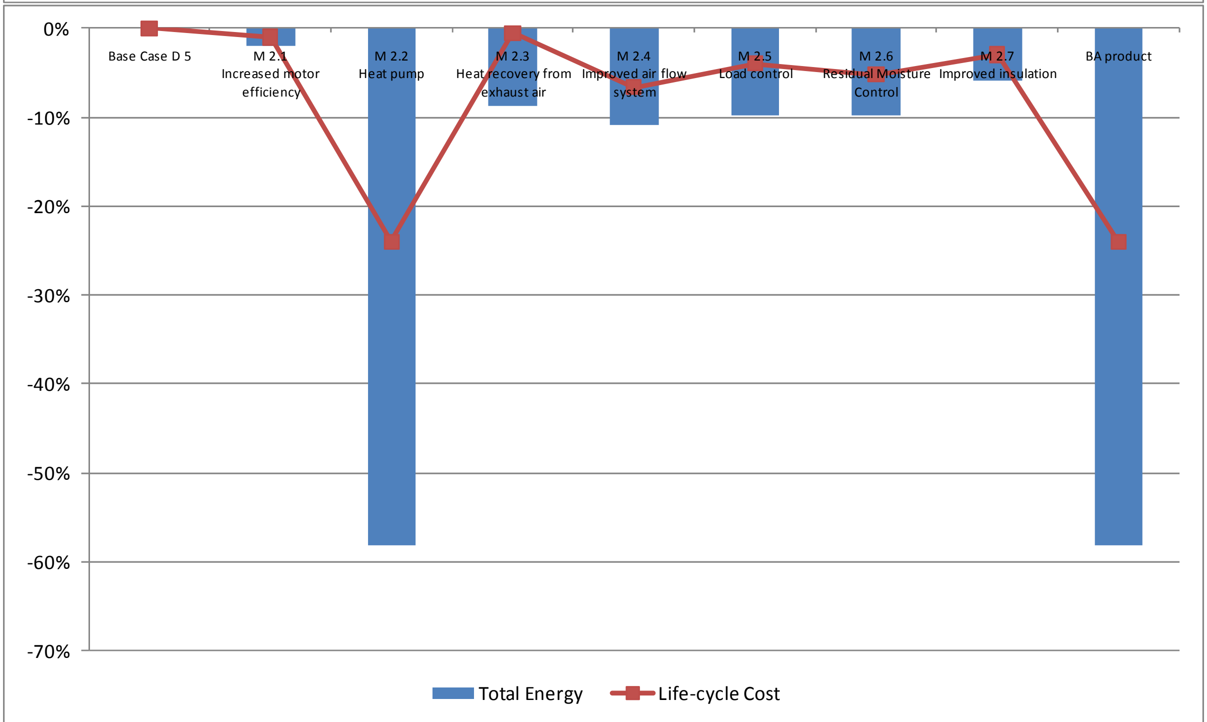
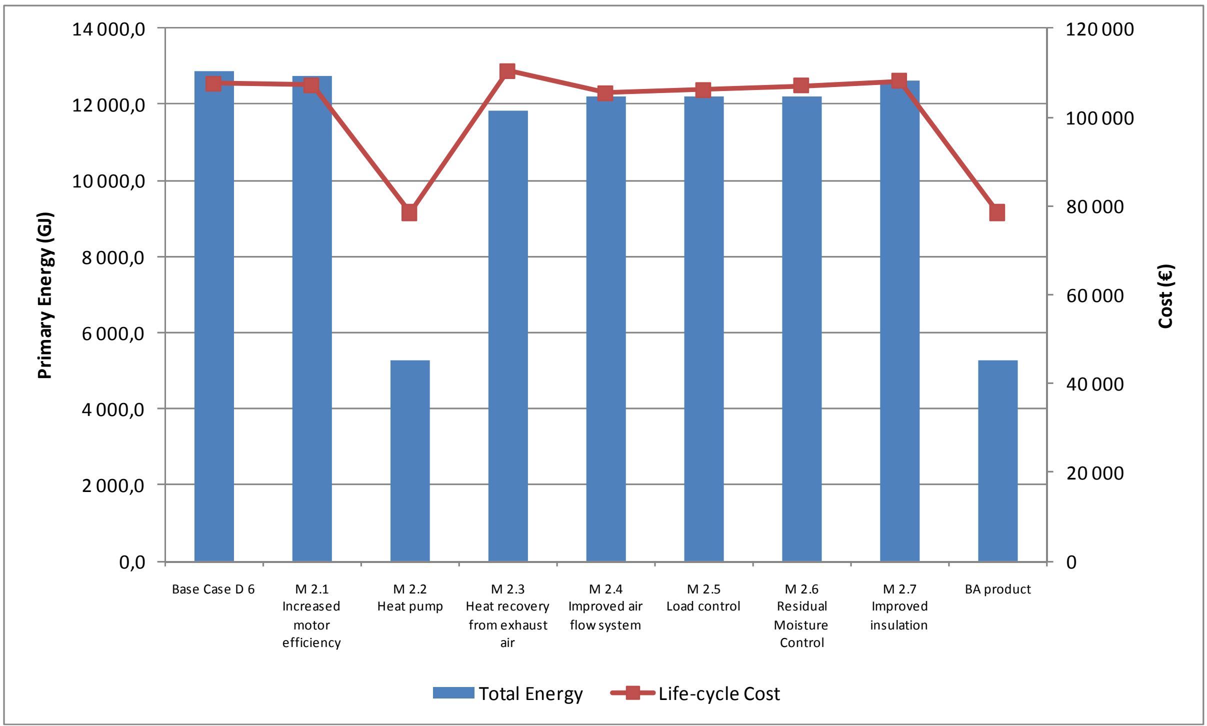


Figure 54 Economic and environmental analysis for Base Case D 5

5.13 Base Case D 6: Professional tumble dryer (>40 kg)

As shown in the figure below, the option M 2.2 Heat pump represents both the LLCC (with the BA product) and the BAT.



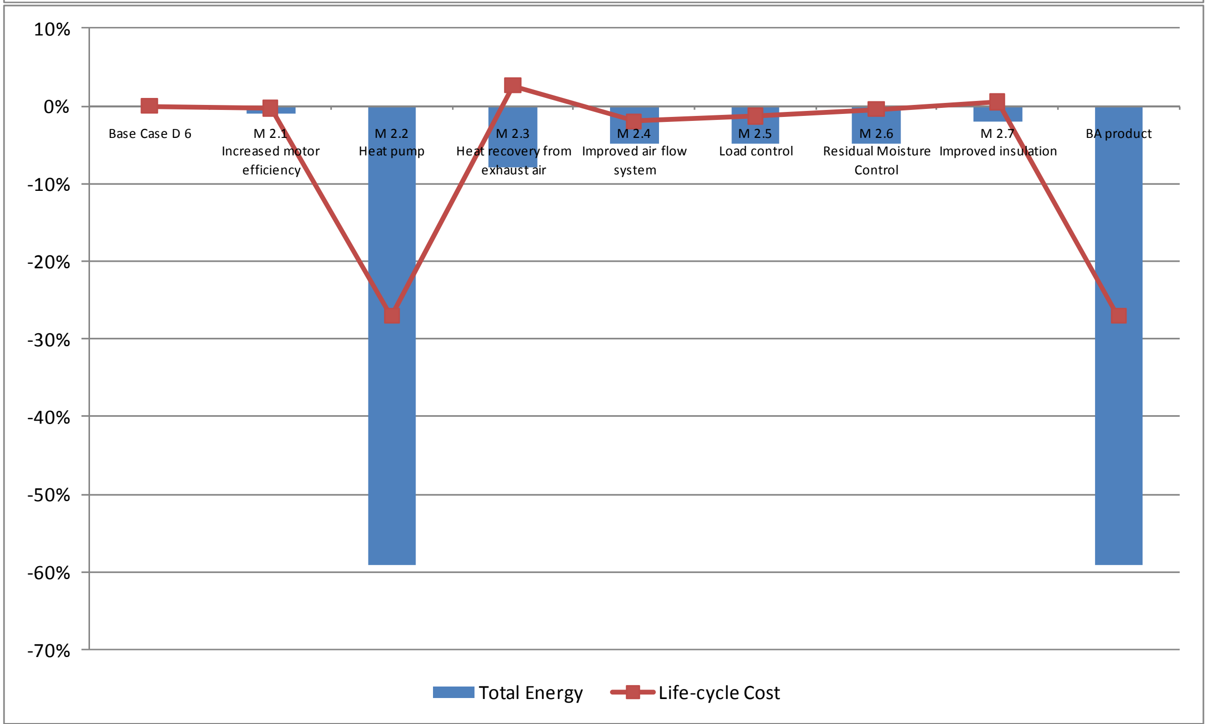


Figure 55 Economic and environmental analysis for Base Case D 6

5.14 Base Case D 7: Industrial pass-through (transfer) tumble dryer

In the case of this base case, the BAT and LLCC is represented by the BA product option.

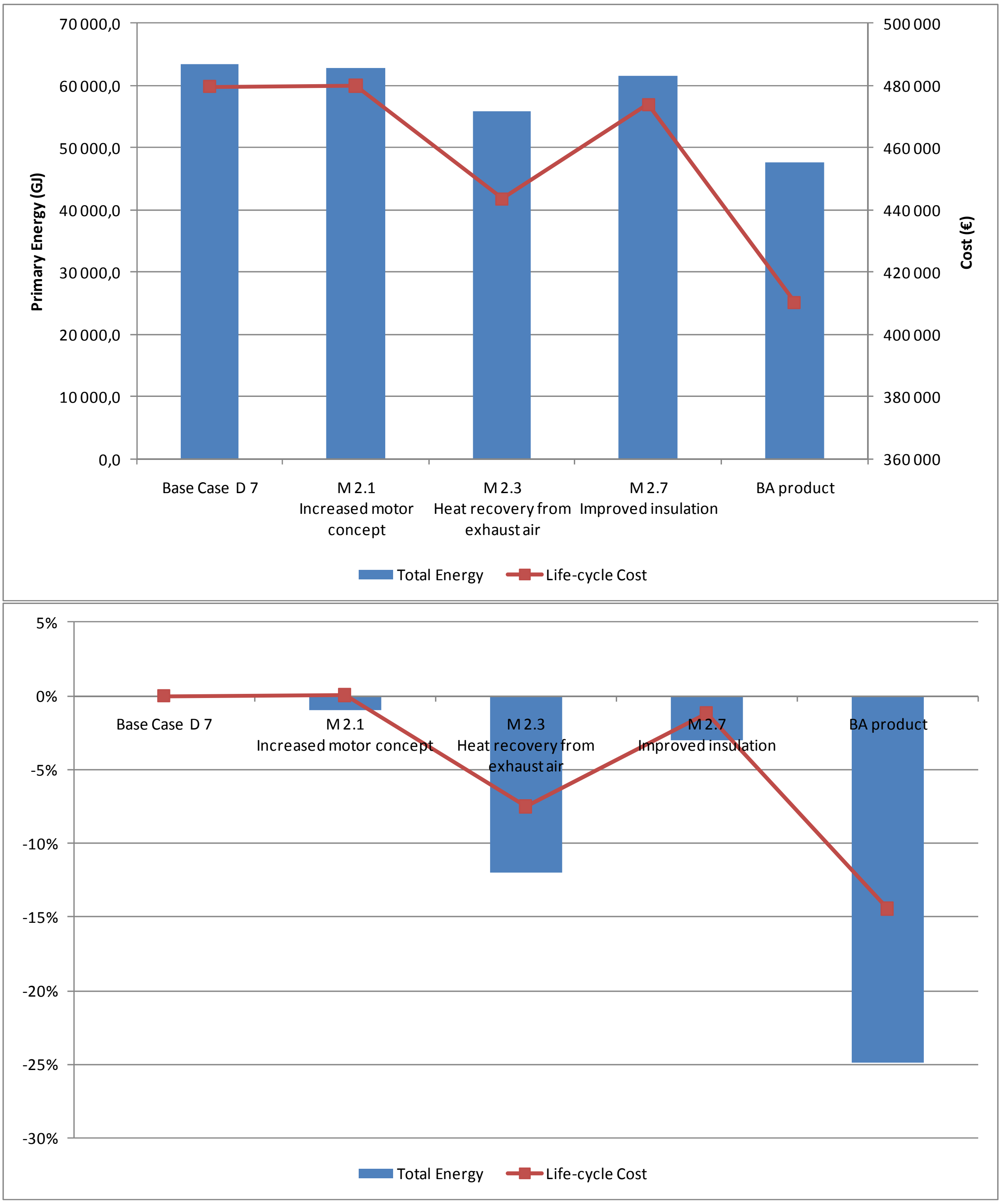


Figure 56 Economic and environmental analysis for Base Case D 7

5.15 Summary of the LLCC and BAT options identified

Table 48 summarises the results of the environmental and economic analysis of the improvement options by presenting the LLCC and BAT options identified for each base case.

Table 48 LLCC and BAT options by base case

	LLCC option	BAT option
WM 1 Semi-professional washer extractor	M 1.4 Load control	BA product
WM 2 Professional washer extractor (<15kg)	M 1.4 Load control	BA product
WM 3 Professional washer extractor (15 - 40 kg)	M 1.4 Load control	BA product
WM 4 Professional washer extractor (>40kg)	M 1.3 Water recovery	M 1.3 Water recovery
WM 5 Professional washer dryer	M 1.4 Load control	M 1.4 Load control
WM 6 Professional Barrier Washer	M 1.3 Water recovery	M 1.3 Water recovery
WM 7 Washing tunnel machine	BA product	BA product
D 1 Semi-professional dryer, condenser	M 2.2 Heat pump	BA product
D 2 Semi-professional dryer, air vented	M 2.2 Heat pump	M 2.2 Heat pump
D 3 Professional cabinet dryer	M 2.2 Heat pump	BA product
D 4 Professional tumble dryer (<15 kg)	BA Product	BA Product
D 5 Professional tumble dryer (15 - 40 kg)	M 2.2 Heat pump	M 2.2 Heat pump
D 6 Professional tumble dryer (>40 kg)	M 2.2 Heat pump	M 2.2 Heat pump
D 7 Pass-through (transfer) tumble dryer	BA product	BA product

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 as 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.

The BNAT identified in Task 6 are:

- Polymer beads: currently under development and expected to be introduced in the market in 2011/2012. By contact and friction of polymer beads introduced in a specific washing machine, the stains are more easily removed and this process can result in large savings in energy, water and detergent. It represents however a totally different washing approach than the conventional laundry.
- Microwave dryer: this technology is expected to be used in the future. It is based on the use of microwave to heat the remaining water.
- Vacuum dryer: by reducing pressure in the dryer drum, it is possible to evaporate the water at a lower temperature. As a drawback, energy reduction in the water evaporation process might be compensated by an increase in energy use to create the vacuum.
- Smart portal display (changes to appliances operation): the aim is to harmonise the available power on the grid with the demand. Therefore an energy demand manager starts the washing machine within a predefined time interval.[15]

It should be noted that, for competition reasons, manufacturers are rather reluctant to talk about inventions, ideas and strategies which are not yet available on the market. Competition between the manufacturers is quite fierce and the circle of leading manufacturers is rather small. For this reason the information received from manufacturers may not be complete.

[15] University of Bonn, Synergy Potential of Smart Domestic Appliances in Renewable Energy Systems, Prof.Dr. R. Stamminger (Stamminger 2009)

7 Conclusions

The most energy-demanding process in washing machines is water heating. Any action to improve or reduce the related energy consumption will have a significant impact. The environmental impacts and life cycle costs of these machines can also be significantly reduced by using alternative, more efficient energy sources such as gas, for heating the water or air of the washing machines or dryers which was illustrated in Task 5.

In terms of water pollution, any reduction in detergent used will reduce the eutrophication potential. Stronger chemical products are not seen as an alternative option in the EU.

Laundry dryers can also be improved by using alternative technological options, especially heat pumps, which seem economical for most base cases.

According to the analysis presented in this task, there is room for improvement that would not entail additional lifecycle costs to consumers. However, the options providing the highest improvement are often the ones with higher purchase costs. This could damage the competitiveness of these machines, in the case of customers not following a Life Cycle Cost approach for their purchasing decision. This issue should be considered during the development of any EU policy measure.

8 Annex: Additional questionnaire to stakeholders

The additional questionnaire for the final report is provided separately in the following document:

- EuP_Lot24_Wash_T2-T7_Questionnaire_for_Final_Report.xls