Designing Major Appliances: a Decision Support Model

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Abstract

Although competitors from low-cost countries are pushing manufacturers to lowering prices and replace the production [1] at the expense of quality, the definition of new scenarios through research and development seems the best way to succeed. This paper seeks to explain why companies should invest in the redesign of household appliances when there is a potential improvement in the sustainability of the product. This work considers home appliances investigating their disassembly, the updating of components and the management of end of life, combined with their connectivity and the communication with the final user. This research develops a multi-criteria model to select among the major appliances the most suitable to redesign, providing a ranking of alternatives. The analysis is based on the potential improvement on eco-design of products, determined on eight relevant criteria about sustainability and relationship between users and appliances. This study attempts to prove that business models based on Multi Criteria Decision Aid (MCDA) methodology, combined with two design approaches to sustainability, are able to move from linear to circular economy. Waste management and product refurbishment - through Design by Components focused on product maintenance and replacement of its parts - are, in fact, key aspects to achieve valuable results. The paper proposes an analysis of this decision process, synthesizing the most critical aspects and the result of a Multi Criteria Decision Aid intervention [2].

1 Introduction

Over the last decades competitors from low-cost countries have made considerable inroads into advanced economies. Until now, the entrance of a low-cost competitor is always followed by companies' differentiation of products, cutting of prices or both [1]. However, low-cost-country competition differs significantly to domestic low-cost competition and replicating the cost structure of a low-cost-country rival is in many cases impossible to achieve in high-cost countries. Moreover, there is certain ambiguity and lack of available information about new entrants. Companies that rely solely on cost reduction strategies in response to foreign competition lose market share and see their relative competitive position eroded [3]. Although competition from low-cost countries is a relevant issue, some big players tackle the problem by increasing investment in R&D, segmenting their products to reach the need of different regions and developing connected appliances [4]. However the majority of them still adopt economies of scale [5]. The market of household appliances remains remarkable. In 2014, the total turnover of the major appliances weighted USD 44 billions, representing 350 millions of units [6]. This analysis relied on 50 manufacturers and included refrigerators and freezers, washers and dryers, dishwashers, hoods and cooking appliances. For this reason, the attempt to develop innovative strategies in this area seems to be significant. This paper seeks to address this issue by suggesting an approach that is focused on the design phase, instead of price war, in order to provide an added value to products for both consumers and producers. On the one hand, consumers will benefit from a product designed on their needs, which also considers aspects such as ease of use, replacement of parts, product maintenance, accessibility and disassembly. On the other hand, manufacturers will come out from economies of scale in favour of product innovation. The work introduces a possible integration of Multi Criteria Decision Aid (MCDA) [7] together with two different approaches developed by Politecnico di Torino to perform product innovation: (i) Systemic Design (SD) [8] and (ii) Design by Components (DC) [9]. Starting from the idea that new scenarios should be investigated, the research team has been questioned about how to determine new appliances on a scientific basis, by determining some criteria to support the decisions phase. Environmental aspects and the role of the user have emerged as the two key aspects of the analysis.

2 Methodology

Multi Criteria Decision Aid is a flexible and integrated methodology to address a variety of real-world decision-making situations [10]. In this field, decision-making is a multidimensional and multi-actor process that can be facilitated by quantitative analysis techniques. The purpose of this paper is to explore how a

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multi-criteria model can be used to address the design phase of major appliances, which are divided into:

- cooking appliances: cooktop, oven and hood;
- cold appliances: refrigerator and freezer;
- wet appliances: dishwasher and washing machine.

Each new appliance can be considered alone, in a first step, and then combined with others, that have resulted complementary, in a new conceptual scenario. Each new appliance is considered a possible design decision and its specific characteristics can be evaluated in relation to some criteria. A criterion is a real function that connects a possible decision with its (quantitative or qualitative) performance in relation to a specific aspect. The application of a multi-criteria method, to the model and some preferential information on the criteria, activates a pair-wise comparison of the possible decisions (the major appliances in this study) on each criterion and synthesizes these elements in order to obtain a ranking of the design decisions. The application of the ELECTRE III method [11] [12], a well-known multi-criteria method, synthesizes the performances in an outranking relation and uses a distillation procedure to classify the possible decisions. The first and main task in this approach is the definition of some consistent criteria, in relation to this specific decision-making process, and to acquire relevant information about the evaluations of all the appliances in relation to all the criteria. In this study the criteria are determined and structured in a tree-like hierarchy from two broad aspects: (1) environmental sustainability and (2) relationship between user and product as it is shown in Figure 1.

1) Environmental sustainability:

- Resource Recovery: (i) wastewater and heat dispersion generated by household appliances can be prevented, reduced or optimized as valuable resources.
- End of life: it measures (ii) the difficulty of disassembling components and (iii) the potential loss in value of materials used in the manufacturing process, especially when they are combined in irreversible ways.

2) Relationship between user and product

- Operational issues: aspect related to (iv) operating costs, (v) maintenance and accessibility of the different components.
- Needs and inconveniences: it attempts to measure (vi) product and interface effectiveness, (vii) possible functional integrations and (viii) discomfort such as noise, smell and cleaning problems.

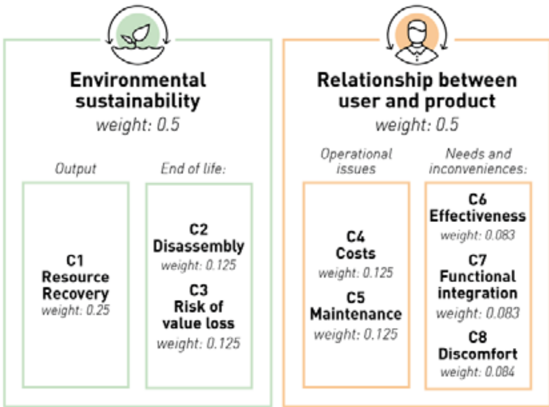

Figure 1: Criteria and weights structured in tree-like hierarchy.

At the same stage the criteria weights are estimated, according to the user assessment of their importance. This set of criteria is considered to be non-redundant and it provides only the absolutely necessary information for the evaluation of the alternatives.

2.1 Criterion 1 – Resource Recovery

This criterion evaluates the possible recovery of water and energy. Wastewater recovery creates an ordinal scale of 7 levels (Table 1) starting from data on water use and quality of recovery (Table 2).

WR	*VL*	*L*	*M*	*H*
L	1	2	3	4
M	2	3	4	5
H	3	4	5	6
VH	4	5	6	7

Table 1: Wastewater Recovery (WR): Combination of Quantity and Quality.

Alternatives	**Quantity[1] (litre/year)**	**Quality[2] recovery**	**(WR)**
Cooktop	540 *(M) Medium*	*(M) Medium*	4 *(M) Medium*
Oven	60 *(L) Low*	*(L) Low*	2 *(L) Low*
Hood	60 *(L) Low*	*(L) Low*	2 *(L) Low*
Fridge	60 *(L) Low*	*(M) Medium*	3 *(ML) Medium Low*
Dishwasher	4.400 *(H) High*	*(H) High*	6 *(H) High*
Washing m.	11.180 *(VH) Very High*	*(VL) Very Low*	4 *(M) Medium*

Table 2: Wastewater recovery.

[1](litres per hour*hours per day*days of use= litres per year)

[2](qualitative analysis)

Heat dissipation (see Figure 2) measures the energy inefficiency through the thermal dissipation, by combining frequency, duration and thermal dispersion temperature (Table 3).

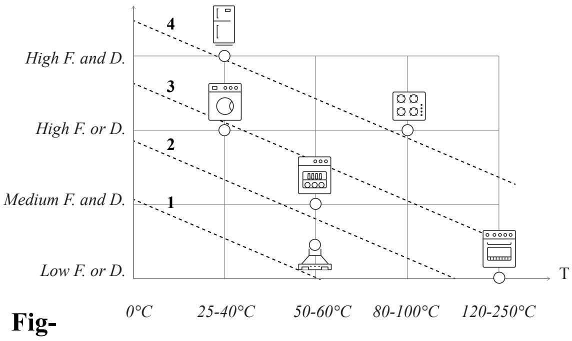

Figure 2: Heat Dissipation: combination of frequency and duration with temperature.

Alternat.	Frequency F (day/year)	Duration D (hour/day)	Temp. T (°C)
Cooktop	300 *(H) High*	2 *(M) Medium*	80-100
Oven	50 *(L) Low*	1 *(L) Low*	120-250
Hood	200 *(M) Medium*	1 *(L) Low*	40-60
Fridge	365 *(H) High*	24 *(H) High*	25-40
Dishwasher	220 *(M) Medium*	2 *(M) Medium*	50
Washing m.	250 *(H) High*	3*(M) Medium*	40

Table 3: Heat dissipation.

Alternatives	Wastewater Recovery (WR)	Heat Dissipation HD (Fig. 2)	C1
Cooktop	4 *(M) Medium*	4 *(H) High*	**5**
Oven	2 *(L) Low*	2.2 *(M) Medium*	**2**
Hood	2 *(L) Low*	1.6 *(L) Low*	**1**
Fridge	3 *(ML) Medium Low*	4 *(H) High*	**4**
Dishwasher	6 *(VH) Very High*	2.2 *(M) Medium*	**5**
Washing m.	4 *(M) Medium*	2.8 *(MH) Medium High*	**4**

Table 4: Criterion 1 – Recovery.

The criterion 1 (evaluations in Table 4 and combination of WR and HD in Table 5) establishes whether the recovery of these resources is convenient or not.

C1	*L*	*M*	*MH*	*H*
L /ML	1	2	3	4
M	2	3	4	5
H	3	4	5	6
VH	4	5	6	7

Table 5: Scale of C1 (Water and Heat Recovery).

Referring to Systemic Design Approach [8], the application of the concept of circular economy to the design field, flows of resources deriving from a system can be considered as input for another one, by exploiting their residual quality.

2.2 Criterion 2 – Disassembly

The Disassembly of Indesit appliances has been carried out during the course Design by Components held by Professor Luigi Bistagnino [8] in the Master Degree in Systemic Design at Politecnico di Torino (AY 2011-2012). The current method focuses on manual disassembly of household appliances in order to determine the number of components, the difficulty of the task (accessibility, positioning, force and time (Table 6 and 7) [14]) and the required tools recording the information in an exploded view (see Figure 3). Design weaknesses may then be identified through interpretation of the evaluation results [14].

Alternat.	Total n. of components	% of components difficult to disass.	C2
Cooktop	11 *(x<20) (L) Low*	27 (25<x<40) *(MH) Medium High*	**4**
Oven	21 (20<x<39) *(M)* Medium	19 (15<x<25) *(ML) Medium Low*	**3**
Hood	27 (20<x<39) *(M)* Medium	7 (x<15) *(L) Low*	**2**
Fridge	40 (x≥40) *(H) High*	43 (x≥40) *(H) High*	**7**
Dishw.	51(x≥40) *(H) High*	14 (x<15) *(L) Low*	**4**
Wash.	50 (x≥40) *(H) High*	12 (x<15) *(L) Low*	**4**

Table 6: Disassembly.

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C2	*L*	*ML*	*MH*	*H*
L	1	2	4	5
M	2	3	5	6
H	4	5	6	7

Table 7: Criterion 2: Combination of total number of components and the % of them, which are difficult to disassemble, according to Fig. 3.

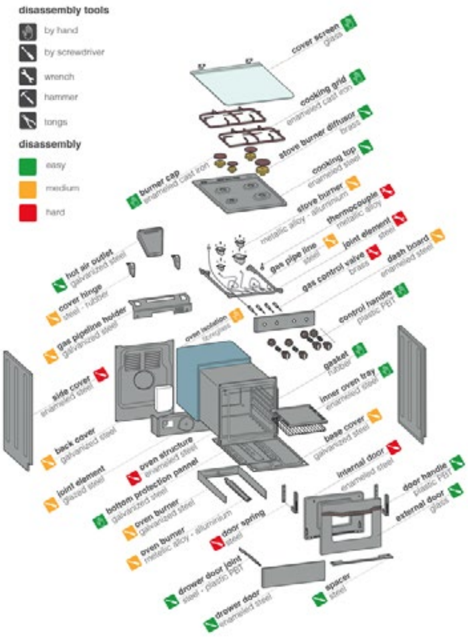

Figure 3: An example of appliances' disassembly: cooktop and oven.

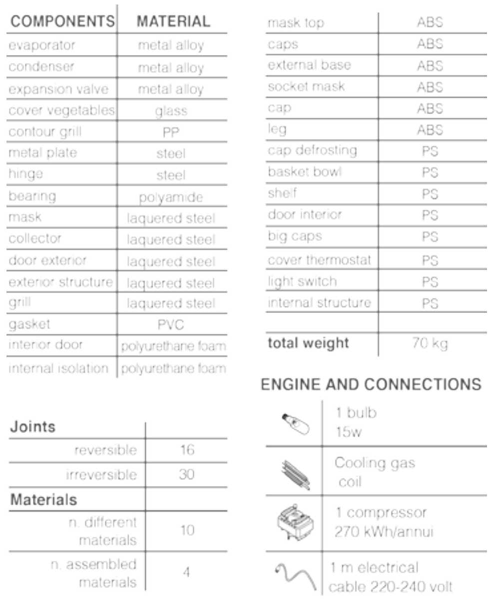

Figure 4: An example of material bill: washing machine.

2.3 Criterion 3 – Risk of value loss

During the above mentioned Master course, students recorded the data in a bill of materials (see Figure 4), pointing out different materials used, how are they assembled and the total weight. Thus, the emerging criterion represents the indirect risk assessment of the value loss, which occurs in the disposal of the household appliances, through the number of different materials. A cardinal scale uses the indicator "Number of different materials" (Table 8) as an indirect risk assessment.

Alternatives	C3
Cooktop	**6**
Oven	**12**
Hood	**7**
Fridge	**10**
Dishwasher	**13**
Washing m.	**12**

Table 8: Criterion 3: Risk of value loss

2.4 Criterion 4 - Costs

This criterion (Table 9) considers the operating costs (water and energy) and the cost of the appliance divided by its useful life, instead of the total cost of ownership (TCO). It was a choice carried out to have a control over the data, since reliable databases about TCO are currently missing.

Altern.	**Exp. useful life *(year)***	**Price *(€)***	**Price/ useful life *(€/year)***	**Oper. costs *(€/year)***	**C4 *(€)***
Cooktop	14	330	20	300	**320**
Oven	14	350	25	40	**65**
Hood	14	300	20	10	**30**
Fridge	13	800	60	120	**180**
Dishw.	9	400	45	90	**135**
Wash.	12	700	60	110	**170**

Table 9: Criterion 4: sum of depreciation and other cots.

2.5 Criterion 5 – Maintenance

This criterion combines maintenance costs (maintenance service cost and other costs for the replacement of parts) with the percentage of components difficult to access (Table 10 and 11), according to the same

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analysis made for criterion 2, which in turn evaluates the accessibility (see Figure 5).

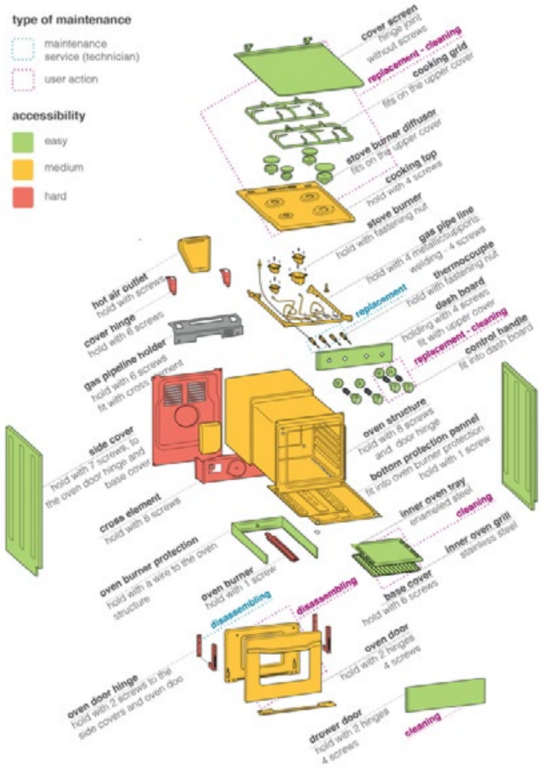

Figure 5: An example of maintenance analysis: cooktop and oven.

Alternat.	Maintenance costs *(€/year)*	% of comp. difficult to access	C5
Cooktop	0 (x<50) *(L)*	0 (x<15) *(L) Low*	**1**
Oven	0 (x<50) *(L) Low*	30 (25<x<40) *(MH) Medium High*	**4**
Hood	40 (x<50) *(L) Low*	80 (x≥40) *(H) High*	**5**
Fridge	30 (x<50) *(L) Low*	80 (x≥40) *(H) High*	**5**
Dishw.	80 (50<x<100) *(M) Medium*	15 (15≤x<25) *(ML) Medium Low*	**3**
Washing machine	140 (x>100) *(H) High*	10 (x<15) *(L) Low*	**4**

Table 10: Maintenance.

C5	*L*	*ML*	*MH*	*H*
L	1	2	4	5
M	2	3	5	6
H	4	5	6	7

Table 11: Criterion 5: Combination of costs and accessibility.

2.6 Criterion 6 – Effectiveness

This criterion evaluates product and interface use effectiveness (see Figure 6, Table 12 and 13).

Alternat.	**Interface effectiveness**	**Product effectiveness**	**C6**
Cooktop	Good (G)	Good (G)	**7**
Oven	Good (G)	Low (L)	**5**
Hood	Sufficient (S)	Good (G)	**6**
Fridge	Very Low (VL)	Sufficient (S)	**3**
Dishw.	Sufficient (S)	Low (L)	**4**
Wash.	Low (L)	Low (L)	**3**

Table 12: Effectiveness.

C6	*VL*	*L*	*S*	*G*
VL	1	1	2	3
L	1	2	3	4
S	2	3	4	5
G	3	4	5	6

Table 13: Criterion 6: Combination of interface and product effectiveness.

Figure 6: An example of effectiveness analysis: refrigerator.

2.7 Criterion 7 – Functional Integration

The criterion 7 evaluates the current and expected level of interaction and functional integration reachable by the appliance (Tables 14 and 15). It is estimated on the basis of current case studies (concept or marketed).

Alternatives	Type of interaction	Possibility to integrate functions	C7
Cooktop	Long (L)	High (H)	**7**
Oven	Short and repeated (SR)	Medium (M)	**5**
Hood	Short and occasional (SO)	Medium (M)	**4**
Fridge	Short and repeated (SR)	Low (L)	**3**
Dishwasher	Short and repeated (SR)	Very Low (VL)	**2**
Washing machine	Short and occasional (SO)	Very Low (VL)	**1**

Table 14: Functional Integration .

C7	*VL*	*L*	*M*	*H*
SO	1	2	4	5
SR	2	3	5	6
L	4	5	6	7

Table 15: Criterion 7: Combination of the type of interaction with the possibility to ingrate functions in the appliance.

2.8 Criterion 8 – Discomfort

The criterion evaluates some critical aspects that may cause discomfort such as noise and smell (see Figure 7, Table 16), first combined together (Table 17) and then combined with the accumulation of dirt (Tables 18 and 19). The criterion is based on the daily experience, except for the noise, because there are no reliable databases on smell and cleaning.

Alternat.	Smell	Noise (dB)	Sensory Discomfort
Cooktop	*(L)*	0 (<55) *(L)*	1 *(L) Low*
Oven	*(MH)*	55 (55≤x<60) *(ML)*	4 *(MH) Medium High*
Hood	*(ML)*	70 (≥65) *(H)*	5 *(H) High*
Fridge	*(MH)*	50 (<55)*(L)*	3 *(ML) Medium Low*
Dishwasher	*(MH)*	60 (60≤x<65) *(MH)*	5 *(H) High*
Wash.	*(ML)*	70 (≥65) *(H)*	5 *(H) High*

Table 16: Sensory Discomfort SeD.

SeD	*L*	*ML*	*MH*	*H*
L	1	2	3	4
ML	2	3	4	5
MH	3	4	5	6
H	4	5	6	7

Table 17: Combination of noise and smell .

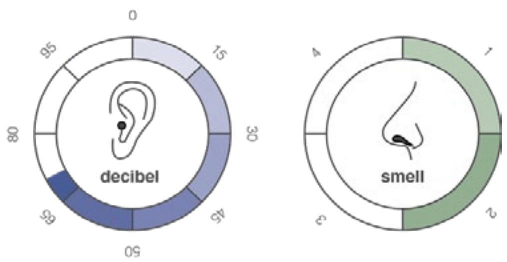

Figure 7: Noise and smell analysis: kitchen hood

Alternat.	(SeD)	Dirt Accumul.	C8
Cooktop	*(L) Low*	*(ML) Medium Low*	**2**
Oven	*(MH) Medium High*	*(H) High*	**6**
Hood	*(H) High*	*(H) High*	**7**
Fridge	*(ML) Medium Low*	*(ML) Medium Low*	**3**
Dishwasher	*(H) High*	*(L) Low*	**4**
Wash.	*(H) High*	*(L) Low*	**4**

Table 18: Discomfort.

C8	*L*	*ML*	*MH*	*H*
L	1	2	3	4
ML	2	3	4	5
MH	3	4	5	6
H	4	5	6	7

Table 19: Criterion 8: Combination of sensory discomfort and dirt accumulation.

An overview about performances related to different criteria is provided in Table 20.

Altern.	C1	C2	C3	C4	C5	C6	C7	C8
Cooktop	5	4	6	320	1	7	7	2
Oven	2	3	12	65	4	5	5	6
Hood	1	2	7	30	5	6	4	7
Fridge	4	7	10	180	5	3	3	3
Dishw.	5	4	13	135	3	4	2	4
Wash.	4	4	12	170	4	3	1	4

Table 20: Performances.

The model and its evaluations are based on the present scenario (average data about the appliances currently available in the Italian houses). It is already known that the latest products, according to EU Directive 92/75/EC, have been improved in terms of consumption and dispersions and some innovative case studies of appliances are already on the market to answer to new needs and requirements. The model can be easily updated to include in its comprehensive and holistic approach the new parameters consistent with the on-going scenarios.

3 Results and discussion

The construction of an outranking relation is based on two major concepts:

1. Concordance. A sufficient majority of criteria should be in favour of the statement “alternative *a* is equal or preferred to alterative *b*”. The weights associated to the criteria are essential to determine the concordance principle.
2. Non-discordance. None of the criteria in the minority should oppose too strongly to the previous assertion “alternative *a* outranks *b*” [13]. A veto threshold is used to express the power attributed to a given criterion to be against the assertion “*a* outranks *b*”, when the difference between the evaluations of b and a is greater than this threshold [13].

Weights, veto thresholds and other two parameters (indifference and preference thresholds) were specified for each criterion. These last thresholds are used to control the negative effect on the results of the possible uncertainty (in relation to the available information and the preference system) associated to a specific criterion. Table 21 presents the results of the thresholds estimation process for the design decision. The weights, associated to the logical structure of the multi-criteria model are proposed in Figure 1.

Criteria	Indifference Threshold		Preference Threshold		Veto Thres.	
	α	ß	α	ß	α	ß
C1 Recovery	0	0	0	0	6	0
C2 Disassem.	0	0	0	0	5	0
C3 Value Loss	0.5	0	2	0	7	0
C4 Costs	40	0	80	0	300	0
C5 Mainten.	0	0	0	0	5	0
C6 Effectiven.	0	0	0	0	5	0
C7 F. Integrat.	0	0	0	0	8	0
C8 Discomfort	0	0	0	0	6	0

Table 21: Indifference, preference and veto thresholds.

The final goal of the study is to construct a ranking of the major appliances from the best to worst. To this end, ELECTRE III employs two (ascending and descending) distillation procedures and synthesizes them in a final rank (see Figure 8).

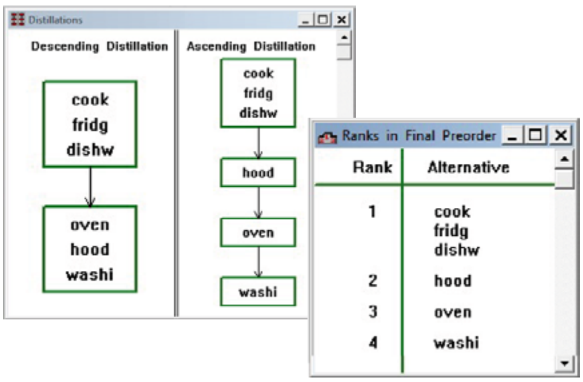

Figure 8: Distillations of results and ranks in final pre-order

ELECTRE III assigns the alternatives cooktop, refrigerator and dishwasher, together, as the top ranked, thus widening the scenario towards the need for an integrated design of the food system, that manages storage, cooking and washing (food and dishes). This result matches with the concept of circular economy applied to the domestic environment in a systemic way. In Italy, the kitchen environment is the area of the house in which the user is standing actively close to a major appliance for a substantial time, giving the possibility of providing some added functionality. The alternatives hood, oven and washing machine are ordered. The bottom rank of the washing machine is due to several aspects, such as the quality of wastewater that precludes the possible reuse and the lack of user interaction with the appliances. The appliance can be designed considering the almost complete automation, but it is unlikely to provide much added value to the user. In fact, many studies foresee the sharing of this good.

4 Conclusions

The MCDA methodology applied to the design field is apparently unexploited, nevertheless it offers a range of possibilities to solve problems such as making a choice among different product to be designed (this paper provide an example), choosing among different methodologies, concepts and technologies during the design phase or as a tool to compare different products on the market. In particular, this decision-making study attempted to address the following tasks:

- Provide a methodology and an alternative strategy to manufacturers;
- Improve the environmental sustainability of major appliances;
- Involve the user and face his needs;
- Lead to product innovation [15].

This analysis should allow the designer to focus on the redesign considering different criteria. Thus each subsequent project should consider also the feasibility with cost-benefit analysis (CBA) and include other evaluations such as LCA and LCC analysis. LCA analysis depends on the choices made by the designer and the manufacturing company (e.g. materials, volumes, technology integration) while LCC should consider real costs. Both of them cannot be performed in advance.

5 Literature

[1] Bernard, A. B., & Koerte, P. (2007), Strategic responses to multiple dimensions of low-cost country competition. Tuck School of Business Working Paper.

[2] Norese, M.F., Toso, F., (2004), Group Decision and Distributed Technical Support. International Transactions in Operational Research, 11(4), 395-417.

[3] Spanos, Y.E., Zaralis, G., Lioukas S. (2004), Strategy and Industry Effects on Profitability: Evidence from Greece. Strategic Management Journal 25(2): 139-165.

[4] Electrolux (2015) Innovation - Electrolux Annual Report 2015 Available at: http://www.electroluxgroup.com/annualreports/2015/en/strategic-development/innovation/ accessed on 10 July 2016.

[5] Shyam, S., (2008) Globalization in Appliance Industry: A Case Study of India and China. Chapter 48: Flexible Enterprise for Global Business.

[6] Volpe, A., (2015), Profiles of 50 major appliance manufacturers worldwide, No AP17, CSIL reports, CSIL Centre for Industrial Studies.

[7] Roy, B., (1996), Multicriteria Methodology for Decision Aiding. Kluwer Academic Publishers, Dordrecht.

[8] Bistagnino, L., (2008), The outside shell seen from the inside. CEA, Milano.

[9] Bistagnino, L., (2011), Systemic design: designing the productive and environmental sustainability, Slow Food Editore, Bra (Cuneo).

[10] Doumpos, M. and Zopounidis, C. (2002), Multicriteria Decision Aid Classification Methods, Kluwer Academic Publishers, Dordrecht.

[11] Roy, B. (1978), Electre III: Un algorithme de classements fondé sur une représentation floue en présence de critères multiples. Cahier du CERO, 20, 3-24.

[12] Roy, B. (1990), The outranking approach and the foundations of ELECTRE methods. In: Bana CA, ed. Readings in Multiple Criteria Decision Aid. Springer-Verlag, Heidelberg115-184

[13] Figueira J., Mousseau, V., Roy, B., (2005), ELECTRE methods. In J. Figueira, S. Greco, and M. Ehrgott, editors, Multiple Criteria Decision Analysis: State of the Art Surveys, (pp. 133-162) Springer, Berlin.

[14] Hanft, T.A., Kroll, E., (1996), Ease-of-disassembly evaluation in design for recycling. In: Design for X: Concurrent Engineering Imperatives. London: Champman Hail, cap. 15, p.318-334, 1996

[15] Tamborrini, P. (2009), Sustainable design – objects, systems and behaviour. Electa, Milano.