applied sciences

MDPI

Article

A Soft Computing Framework to Support Consumers in Obtaining Sustainable Appliances from the Market

Ricardo Santos [1,2,*], António Abreu [1,3], José Soares [4], Fernanda Mendes [5] and João M.F. Calado [1,6]

[1] Instituto Superior de Engenharia de Lisboa (ISEL), Instituto Politécnico de Lisboa, 1959-007 Lisboa, Portugal; ajfa@dem.isel.ipl.pt (A.A.); jcalado@dem.isel.ipl.pt (J.M.F.C.)
[2] GOVCOPP-Universidade de Aveiro, 3810-193 Aveiro, Portugal
[3] CTS Uninova, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Lisboa, Portugal; ajfa@dem.isel.ipl.pt
[4] ADVANCE - Instituto Superior de Economia e Gestão (ISEG), Universidade de Lisboa, 1200-109 Lisboa, Portugal; josesoares@iseg.ulisboa.pt
[5] Universidade Europeia, 1500-210 Lisboa, Portugal; fernanda.mendes6@gmail.com
[6] IDMEC-IST, Universidade de Lisboa, 1049-001 Lisboa, Portugal; jcalado@dem.isel.ipl.pt (J.M.F.C.)
* Correspondence: ricardosimoessantos84@ua.pt

Received: 1 April 2020; Accepted: 28 April 2020; Published: 4 May 2020

Abstract: Currently, sustainability is considered a priority by society, with the household appliances being one of the economic sectors involved in achieving sustainability. However, the existence of several issues (e.g., energy and water consumption, reliability, initial cost, and illuminance, among others) together with the diversity of brands and models on the market, make the consumer's decisions regarding sustainable options difficult, according to their concerns and related to each sustainability dimension (economic, environmental, and social). By combining evolutionary algorithms (EA) with multicriteria techniques, it is possible to achieve sustainable solutions for the consumer based on their requirements. In this paper, a method is presented to support the consumer by obtaining a set of sustainable household appliances on the market that suit their preferences, concerns, and needs. By using a case study to apply the approach developed here, a set of sustainable appliances from the market is obtained, where several benefits are achieved (e.g., energy and water consumption savings, avoidance of CO_2 emissions) during the lifecycle of each appliance, chosen from the appliance's industry.

Keywords: sustainability; energy efficiency; cyberphysical system; decision support systems; lifecycle cost analysis (LCCA); multi-attribute value theory (MAVT); multi-objective optimization; soft computing; evolutionary algorithm

1. Introduction

According to [1–4], the consumption of energy should be reduced in order to achieve sustainability. Approximately 38% of the final energy consumption is related to the building sector, and from that percentage, approximately 18% is related to the residential sector [4], which thereby represents a relevant sector for which to achieve sustainability.

With regard to household appliances, some measures have been made not only in Europe but in other world regions as well, in order to promote sustainability in this sector.

One of such measures, adopted in this context, is mandatory labeling [5–8], which allows informing the consumers about information related to each electrical appliance, such as heat capacity (air conditioner), water and energy consumption (dryer machine), and initial investment (lighting), among others. The goal of such a measure is to adjust each available solution to the consumer's needs [6–8].

Besides energy labeling, there are also eco-design policies, with both acting as essential tools to drive the shift from a "linear economy" to a more "circular" one that also promotes sustainable development [9,10].

Furthermore, and by including eco-design and energy labeling measures, the European Union has changed the way that our products are designed, bringing substantial reductions in terms of greenhouse gas (GHG) emissions and the corresponding consumption costs [4,5].

By 2020, and based on [9], the European Commission estimates that the energy consumption costs for each household in Europe will be approximately reduced by €300 per year, due to the adoption of such policies, with GHG emissions also seeing a reduction of approximately 319 megatons of CO_2 (equivalent) per year.

According to some studies, which include the EU's recommendations, increasing the durability, reparability, and recyclability of the products and, in particular, electrical appliances, represents an opportunity to improve eco-design and energy labeling measures with respect to the promotion of a circular economy [3–6].

Although sustainability is a goal to be achieved, the circular economy is a way to achieve such an end, therefore being a road map that should lead society to reach sustainability [4]. However, some studies argue that the circular economy will not be enough to achieve sustainability [4,8], since it only focuses on technological progress to solve economic and environmental problems, making it a "weaker" sustainability approach [9,10].

On the other hand, the rise of new developments resulting from the combination of information technologies with decision support systems, together with new business models of product service systems as well, could also help to satisfy the need for cultural change in order to reach a "stronger" sustainability approach [5,8,9].

The circular economy is a means to achieve sustainability since it helps (directly and indirectly) meeting targets of the Sustainable Development Goals defined by the United Nations [11].

As mentioned before, energy labeling policies, as well as eco-design, are essential tools to drive the shift to a circular economy [12].

Several studies regarding the circular economy and sustainable development issues have been developed by considering several contexts (e.g., market surveillance of resource efficiency [9], energy renewables [13], circular economy performance indicators [12,13]).

In recent years, several entities, including governments, associations, and manufactures, have also used measures in an attempt to sensitize the population to the problem of energy efficiency in the residential sector [14–16].

Despite the existence of such measures, it becomes difficult for a decision-agent (consumer) to acquire the best solution adjusted to its needs and preferences, given the diversity of options from the market (brands and models) as well as the diversity of the appliance's own features [14–16].

In this sense, the use of multicriteria techniques can support the consumer in making sustainable choices that not only address the consumer's preferences, but also their concerns and needs according to three dimensions of sustainability, namely economic, environmental, and social wellbeing. In addition, the use of multi-attribute value theory (MAVT), combined with optimization techniques, could also help to define the consumer's decision space and the corresponding objective functions in order to maximize the three objective functions mentioned above.

Based on previous work, evolutionary algorithms (EA) and, more specifically, the non-dominated sorting genetic algorithm II (NSGAII) have been successfully deployed to solve optimization problems with more efficiency than other methods by providing different and feasible solutions, given their stochastic nature [17–22].

Therefore, this work presents an integrated method, based on NSGAII and MAVT, with the aim of supporting the decision-agent (consumer) in finding sustainable solutions from the market based on different needs and concerns.

The method proposed here can also provide other sustainable (optimal) and alternative solutions to the consumer.

The applicability of the proposed approach will be demonstrated through a case study, where a set of sustainable (and alternative) solutions is obtained, given the consumer's issues, which include preferences and needs, on behalf of their economic, social, and environmental wellbeing.

The presented approach also includes economic (e.g., budget), social (e.g., minimum value of air conditioner heat capacity), and environmental (e.g., CO_2 emissions) constraints, related to each energy service (household appliance) considered in this work.

This paper is organized as follows: Section 2 contains the literature review and the paper's contribution. Section 3 contains the research method used, namely the adopted criteria regarding the three dimensions considered in this approach, the problem formulation, the strengths, weaknesses, and limitations of the work, and ending with a brief presentation of NSGAII. Section 4 presents and discusses the obtained results. Section 5 presents the conclusions and further work.

2. Literature Review and Paper's Contribution

2.1. Literature Review

Methods based on simulation (e.g., [23]) are commonly applied to simulate a restricted set of alternatives.

Other approaches are mainly economic, allowing consumers therefore to acquire the highest energy savings for the same initial investment (e.g., [17,18]), while others exploit issues based on the building's thermal performance by using evolutionary algorithms to optimize the building's parameters, thereby achieving GHG emission savings, among other perceived benefits (e.g., [22,23]), with some of them being also integrated with technologies (e.g., [24,25])

However, such approaches can be considered somehow limited because they do not consider other important issues (e.g., environment, energy labeling, and consumer's satisfaction, among others) to achieve solutions suitable for the consumer's needs. They also do not account for the criteria regarding each household appliance existing on the market, which can differ based on the number of household building occupants.

Presently, some works have created multicriteria decision-making (MCDM) approaches to support consumers with measures regarding buildings by accounting for energy efficiency and comfort in buildings (e.g., [6,26]), while other approaches were performed by ranking the different available options (e.g., [23]).

Some approaches promote sustainable measures by using the game theory model to maximize environmental and utility objectives with respect to the energy production sector (e.g., [21]), while other works promote sustainability measures by using fuzzy logic applied to the transportation sector while considering not only environmental issues (pollution), but also customer satisfaction (e.g., [21]).

In the literature, other MCDM models can be found as well as multiple-attribute value theory (MAVT) methods that allow combining optimization with multicriteria methods in order to obtain feasible solutions through according to a set of criteria (e.g., [18–20]).

However, these methods do not account for the different criteria regarding each household appliance, from the market, suitable for the consumer's needs.

Optimization methods based on metaheuristics have been also considered to solve energy problems by providing feasible solutions, such as genetic algorithms (GAs) (e.g., [20,22]) and particle swarm optimization (PSO) (e.g., [19,24]), among others.

However, such methods are not integrated as a combined approach to enable selection, from the market, of a set of sustainable appliances for the consumer (decision-agent) that are based on a set of criteria.

2.2. Paper's Contribution

Based on the literature discussed above, there is a gap regarding sustainable measures for buildings, involving household appliances, that allow supporting a household consumer in choosing a set of sustainable solutions from the market.

Therefore, the main contribution of this paper is the design of an approach to support a consumer to identify sustainable options for household appliances that exist on the market that attends to their needs, as well as a set of requirements, namely:

1) Maximization of a consumer's economic wellbeing (water and energy consumption savings, investment savings, etc.);
2) Maximization of a consumer's social wellbeing through their preferences (e.g., design, quality perceived, noise, and number of functions, among others);
3) Maximizing the consumer's environmental wellbeing (avoidance of CO_2 emissions, water savings);
4) Providing a methodology that allows obtaining several alternative sustainable solutions, which allow tackling some contingencies that eventually may occur (e.g., an out-of-stock electrical appliance initially recommended by the method).

In order to fulfill the previously identified gap, this work presents a decision support approach that provides the consumer (decision-agent) with a set of household appliances obtained from the market according to their preferences and needs.

The method presented here also promotes the circular economy by promoting sustainable options that exist on the market.

The presented approach also includes economic (e.g., budget), social (e.g., minimum value of air conditioner heat capacity), and environmental (e.g., CO_2) restrictions related to each energy service (household appliance type) considered in this study.

3. Material & Research Method

3.1. Problem Statement and Case Study

The problem presented in this work considers a household consumer (decision-agent) who wants to acquire different electrical appliances, existing in the market, for their household.

Thus, and regarding the case study used in this work, seven different energy services/electrical appliances to be acquired by the consumer were considered, namely dryer machine, lighting, air conditioner, dishwasher machine, electric oven, washing machine, and refrigerator.

The same consumer had a restricted budget of €2500, to acquire seven types of household appliances, with the goal of achieving a set of sustainable equipment that maximized their social, environment, and economic wellbeing according to a set of three relative importance weights, respectively ω_A (economics), ω_B (social), and ω_C (environment). In this case study, these were considered using values of 0.65, 0.25, and 0.1, respectively.

In total, the building has four occupants. Given the consumer's intention to buy an air conditioner, the corresponding cooling and heating needs were calculated based on the corresponding room area (living room).

Regarding the remaining assumptions, they are presented on Table 1, with the emission factor obtained from [27], while the consumer's usage profile is presented on Table 2, based on a Portuguese study [7].

Such a profile was adopted and based on a typical consumer's profile, considering the work in [7] and regarding the use of each household appliance type to be acquired.

However, the consumer can also create their own usage profile based on their needs or using the profile shown in this work by default.

Table 1. Emission factor and other assumptions considered in this work.

Emission Factor (gCO_2/kWh)	**675.00**	**Discount Factor (%)**	**7.00**
Lifecycle (usage phase) (years):	10.00	Annual Factor	7.03

Electrical Energy tariff ($\tau_{Elect.}$) (€/kWh)	0.16	Water tariff (τ_{H_2O}) (€/m^3)	1.19

Table 2. Consumer usage profile (considered).

Energy Service	Hours			
	Day	Week	Month	Year
Dryer machine	1.5	4.0	15.0	183.0
Washing machine	1.2	4.3	16.0	189.0
Fridge/freezer	11.0	76.3	329.1	4007.0
Oven (electric)	1.1	1.9	8.0	97.0
Dishwasher machine	1.0	4.1	16.0	193.0
Air conditioning	2.1	12.1	47.0	587.0
Lighting	5.0	35.2	150.1	1823.0
Energy Service	**Usage Frequency**			
	Day	**Week**	**Month**	**Year**
Dryer machine	1	3	14	185
Washing machine	1	2	14	181
Fridge/freezer	1	6	28	359
Oven (electric)	1	2	7	94
Dishwasher machine	1	3	14	189
Air conditioning	1	4	22	276
Lighting	1	6	28	359

Both set of assumptions shown on Tables 1 and 2, were considered when performing a lifecycle cost assessment (LCCA) related to each individual solution/appliance, which is described on next section.

3.2. Dataset

Based on the data presented before, namely the consumer's profile presented in Table 2, as well as the remaining assumptions, it was some calculations were performed using an LCCA approach in order to achieve savings for each appliance, regarding energy and water consumption, for each appliance considered in the decision space (Figure 1). The lifecycle period was also considered in this study (10 years). This was done by using the consumer profile, as considered in Table 2, and by comparing the consumption from each candidate solution (regarding each energy service) with the corresponding less-efficient one in terms of energy consumption, considered here as a "standard solution".

Data from the appliance's market was also considered, such as initial investment, brand and model, power, and noise, among other appliance issues regarding each appliance, and based on the criteria, as presented in Table 3.

In Appendix A, the adopted attributes regarding each obtained solution are presented.

In Appendix B, the final attribute values based on MAVT are presented.

3.3. Proposed Approach

The method presented in this work has been designed to support a consumer who intends to purchase, from the market, a set of appliances for their household (Figure 1).

This set is formed by individual solutions regarding each energy service to be acquired and is obtained from a group of candidate solutions previously selected using MAVT according to the consumer's preferences, needs and concerns, and regarding each sustainability dimension (Figure 1).

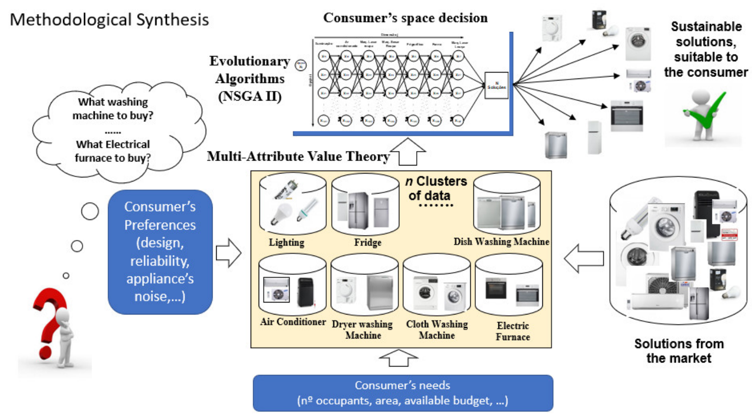

Figure 1. Proposed method.

Such an approach can be better described through a detailed view, as presented in Figure 2. The first phase starts with pre-selection of a set of potential solutions (x_{ij}) from the market and based on specific criteria. Although the corresponding attributes/criteria remain the same, the corresponding values vary according to the number of occupants.

The adopted criteria used here allows for the pre-selection of household appliances available in the market, so the decision space can be reduced by considering only these options that are adjusted to the consumer needs as well as through increasing the efficiency of NSGAII by acquiring optimal and feasible solutions within less time.

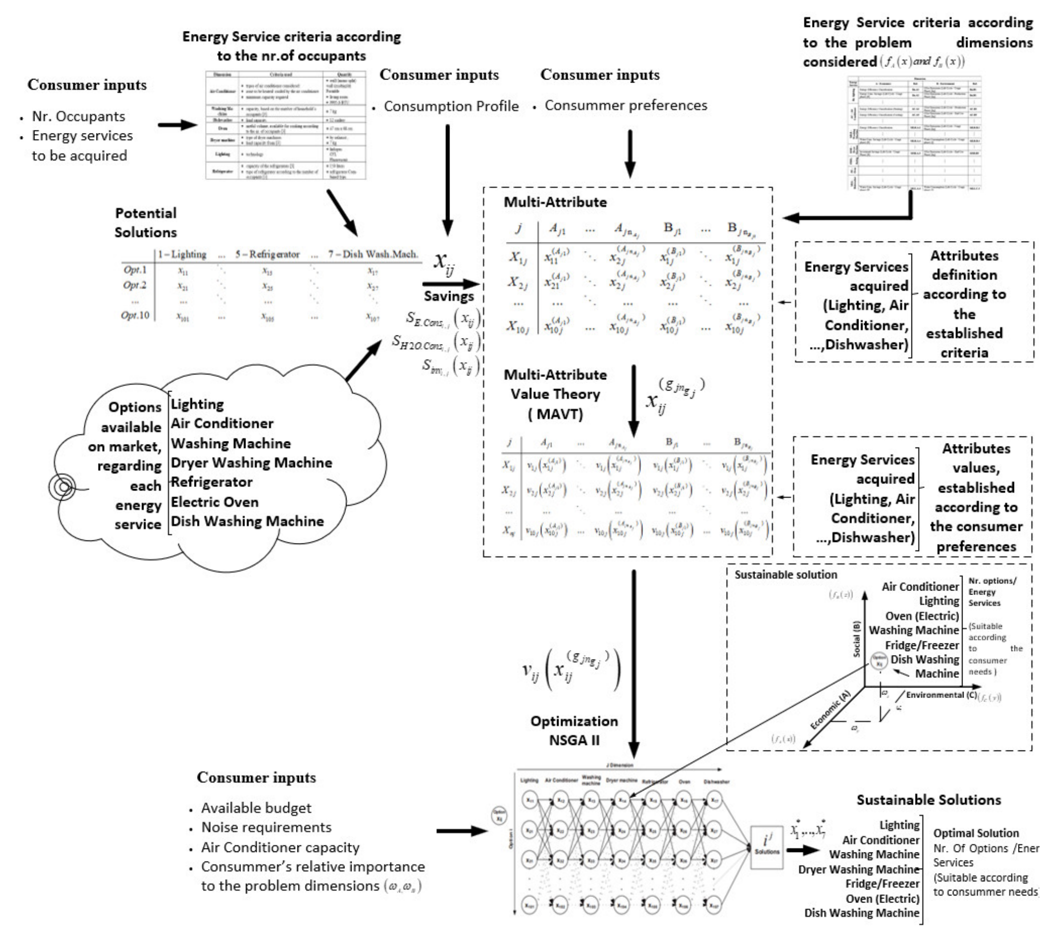

Figure 2. Model proposed (detailed view).

According to Figure 2, the first stage starts with the pre-selection of a set of candidate solutions (x_{ij}), existing in the market, which are based on specific criteria and according to the number of occupants of the building. Regarding the adopted criteria, it is the same, with the corresponding attribute' values varying based on the occupant number. An example of such criteria, considering the case studied in this work, is shown on Table 1.

Therefore, each candidate solution (x_{ij}) is then considered as an option *i* related to household appliance type *j*, to be bought from the market by the consumer.

By considering a consumer's profile, (e.g., Table 2), the approach involves performing a lifecycle cost assessment (LCCA) regarding each household appliance in order to calculate the respective savings as regarding energy consumption ($S_{E.Cons_{i,j}}(x_{ij})$), water consumption ($S_{H2O.Cons_{i,j}}(x_{ij})$), and the initial investment ($S_{inv_{i,j}}(x_{ij})$). The equivalent CO_2 emissions were then calculated according to [26].

All of the parameters mentioned above, are savings, and they result from the comparison of the efficient and the related standard solution (less sustainable one).

Through the diversity of issues related to each energy service and household appliance, together with the consumer's economic, environmental, and social concerns, a set of attributes was defined based on the consumer's preferences and related to each appliance type/energy service for the three problem dimensions considered, i.e., A—Economics, B—Social, and C—Environment. Such attributes are shown in Table 3.

Table 3. Adopted criteria to define problem dimensions according to the household appliance (energy service) type.

Household Appliance Type	Dimension A—Economics	Ref.	Dimension B—Social	Ref.	Dimension C—Environment	Ref.
Ilu—light	**Energy Efficiency Labeling**	**Ilu.A1**	Durability [h]	Ilu.B1	CO_2e (Avoided) emissions during the usage phase	Ilu.C1
					Percentage of recycling material [%]	Ilu.C2
	Energy Cons. Savings (Lifecycle—Usage Phase) [€]	Ilu.A5	Color Rendering Index (CRI) [%]	Ilu.B5	CO_2e (Avoided) emissions during the production phase	Ilu.C3
AC—Air Conditioning	Energy Efficiency Labeling (Heating)	AC.A1	Noise (Indoor) [dB]	AC.B1	CO_2e (Avoided) emissions during the production phase	AC.C1
					Products can be repaired by other professionals	AC.C2

	Energy Efficiency Labeling (Cooling)	AC.A6	Customer Service (Warranty)	AC.B9	CO_2e (Avoided) emissions during the usage phase	AC.C3
FE—Oven (Electric)	Energy Efficiency Labeling	FE.A.1	Design	FE.B1	CO_2e (Avoided) emissions during the usage phase	FE.C.1
					Accessibility (Product repaired by other people)	FEC2
	Investment cost[€)	FE.A.5	Perceived Satisfaction (by other clients)	FE.B.5	CO_2e (Avoided) emissions during the end use phase	FE.C.3
MLL—Dishwasher	Energy Efficiency Labeling	MLL.A.1	Design	MLL.B.1	CO_2e (Avoided) emissions during the usage phase	MLL.C.1
					CO_2e (Avoided) emissions during the end use phase	MLL.C2
					Durability	MLL.C3
	Water Cons. Savings (Lifecycle—Usage phase) [€)	MLL.A.6	Perceived Satisfaction (by other clients)	MLL.B.6	Water Consumption (Lifecycle—Usage phase)	MLL.C.4

The preferences regarding the social dimension were based on previous works from [20,28], as well as the ones from the economics dimension. The ones from the environmental dimension were chosen based on the works of [29].

Besides the energy efficiency classification label implicit in the attributes presented on Table 3 and referring to each energy service/appliance type considered, all the adopted attributes can be applied into other regions. In this case, the European Union's Energy Labelling Framework regulation (2017/1369) was adopted, considering previous research from [20,28,29]. However, with the corresponding adjustments mentioned before, it can be applied into other regions around the world.

The consumption profile was derived by making a set of assumptions based on the hours, which was then extrapolated to a weekly and year base. However, the consumer can also establish their own usage profile based on their needs, or even by using the profile considered in this case study as default values.

As mentioned before, MAVT is employed to support the consumer by assessing a set of alternative solutions based on a set of attributes. These attributes were established on behalf of the three considered dimensions of sustainability (Table 3). Based on Figures 1 and 2, a mathematical model was then defined to obtain the objective functions to be further optimized using NSGAII.

Through these attributes (Table 3), it a decision variable $x_{ij}^{(g_{jt})}$ was established that is related to each alternative solution/appliance i regarding a certain appliance type/energy service j. This variable is defined based on criteria t, associated with the energy service/appliance type j and problem dimension g considered (A–Economics, B–Social, and C–Environmental), i.e.,

$$g_{jt} \in \left\{ \left\{ A_{j1}, A_{j2}, ..A_{jn_{A_j}} \right\} \cup \left\{ B_{j1}, B_{j2}, ..B_{jn_{B_j}} \right\} \cup \left\{ C_{j1}, C_{j2}, ..C_{jn_{C_j}} \right\} \right\} \quad (1)$$

with

$$g = \{A, B, C\} \wedge j = \{1, 2, .., 7\} \wedge t = \left\{ \left\{1, 2, ..n_{A_j}\right\} \cup \left\{1, 2, ..n_{B_j}\right\} \cup \left\{1, 2, ..n_{C_j}\right\} \right\} \wedge n_{g_j}, \mathrm{t}, j \in \mathbb{N} \quad (2)$$

.

The numbers n_{A_j}, n_{B_j}, and n_{C_j} are regarded with respect to index *t* as the number of the last criteria t associated to energy service/appliance type *j* and problem dimension g.

Following the notation presented above and according to the criteria established before (Table 3) as well as the assumptions shown in Tables 1 and 2, regarding the case study considered here, the corresponding decision variable regarding each considered attribute $\left(x_{ij}^{(g_{jt})}\right)$ can be aggregated and framed into a set of pay-off/behavior tables regarding each energy service *j*. An example of this table is shown in Figure 3**a** regarding the energy service/appliance type "Air Conditioning". The corresponding table, regarding the corresponding decision values $\left(v_{ij}(x_{ij}^{(g_{jt})})\right)$, can be achieved using MAVT, and the following relation:

$$x_{ij}^{(g_{jt})} \longrightarrow v_{ij}(x_{ij}^{(g_{jt})}) \quad w/\ x_{ij}^{(g_{jt})}, v_{ij}(x_{ij}^{(g_{jt})}) \in \mathbb{R} \wedge i, j \in \mathbb{N} \setminus \{0\} \quad (3)$$

where

$$v_{ij}(x_{ij}^{(g_{jt})}) = \left(\frac{\left| x_{ij}^{(g_{jt})} - x_{ij(worst)}^{(g_{jt})} \right|}{\left| x_{ij(best)}^{(g_{jt})} - x_{ij(worst)}^{(g_{jt})} \right|} \right). \quad (4)$$

Since each decision value $\left(v_{ij}(x_{ij}^{(g_{jt})})\right)$ works with different scales and units, an expression was used to define the relation between the new and the previous value of $x_{ij}^{(g_{jt})}$, respectively $v_{ij}^{(2)}\left(x_{ij}^{(g_{jt})}\right)$ and $v_{ij}^{(1)}\left(x_{ij}^{(g_{jt})}\right)$ $\left(i.e., v_{ij}(x_{ij}^{(g_{jt})}) = v_{ij}^{(1)}(x_{ij}^{(g_{jt})})\right)$, by also using the corresponding worst and best results for a given criterion g_{jt}, i.e.,

$$v_{ij}^{(1)}(x_{ij}^{(g_{jt})}) \longrightarrow v_{ij}^{(2)}(x_{ij}^{(g_{jt})}) \quad w/\ v_{ij}^{(1)}(x_{ij}^{(g_{jt})}), v_{ij}^{(2)}(x_{ij}^{(g_{jt})}) \in \mathbb{R} \wedge i, j \in \mathbb{N} \setminus \{0\} \quad (5)$$

where

$$v_{ij}^{(2)}(x_{ij}^{(g_{jt})}) = \left(\frac{\left| v_{ij}^{(1)}\left(x_{ij}^{(g_{jt})}\right) - v_{worst_{ij}}\left(x_{ij}^{(g_{jt})}\right) \right|}{\left| v_{better_{ij}}\left(x_{ij}^{(g_{jt})}\right) - v_{worst_{ij}}\left(x_{ij}^{(g_{jt})}\right) \right|} \right). \quad (6)$$

The new values of $v_{ij}(x_{ij}^{(g_{jt})})$ $\left(i.e.\ v_{ij}(x_{ij}^{(g_{jt})}) = v_{ij}^{(2)}(x_{ij}^{(g_{jt})})\right)$ fill a new evaluation table belonging to each energy service *j*. On Figure 3**b**, an example is shown of a table regarding the energy service "Lighting".

A.C.	A.1.$_2$	A.2.$_2$	...	A.n$_2$	B.1.$_2$	B.2.$_2$	...	B.n.$_2$	C.1.$_2$	C.2.$_2$	...	C.n.$_2$
X_{12}	$v_{12}(x_{12}^{(A.2.1.)})$	$v_{12}(x_{12}^{(A.2.2.)})$	...	$v_{12}(x_{12}^{(A.2.n.)})$	$v_{12}(x_{12}^{(B.2.1.)})$	$v_{12}(x_{12}^{(B.2.2.)})$	...	$v_{12}(x_{12}^{(B.2.n)})$	$v_{12}(x_{12}^{(C.2.1)})$	$v_{12}(x_{12}^{(C.2.2)})$	...	$v_{12}(x_{12}^{(C.2.n)})$
X_{22}	$v_{22}(x_{22}^{(A.2.1)})$	$v_{22}(x_{22}^{(A.2.2)})$	...	$v_{22}(x_{22}^{(A.2.n.)})$	$v_{22}(x_{22}^{(B.2.1)})$	$v_{22}(x_{22}^{(B.2.2)})$	...	$v_{22}(x_{22}^{(B.2.n)})$	$v_{22}(x_{22}^{(C.2.1)})$	$v_{22}(x_{22}^{(C.2.2)})$	...	$v_{22}(x_{22}^{(C.2.n)})$
...	...	...	$\ddots$	...	...	...	...	...	...	...	...	...
X_{102}	$v_{102}(x_{102}^{(A.2.1.)})$	$v_{102}(x_{102}^{(A.2.2)})$	...	$v_{102}(x_{102}^{(A.2.n.)})$	$v_{102}(x_{102}^{(B.2.1.)})$	$v_{102}(x_{102}^{(B.2.2)})$	...	$v_{102}(x_{102}^{(B.2.n)})$	$v_{102}(x_{102}^{(C.2.1.)})$	$v_{102}(x_{102}^{(C.2.2)})$	...	$v_{102}(x_{102}^{(C.2.n)})$

a)

A.C.	A.1.$_2$	A.2.$_2$	...	An.$_2$	B.1.$_2$	B.2.$_2$	...	B.n.$_2$	C.1.$_2$	C.2.$_2$	...	C.n.$_2$
X_{12}	$v_{12}(x_{12}^{(A.2.1)})$	$v_{12}(x_{12}^{(A.2.2)})$	...	$v_{12}(x_{12}^{(A.2.n.)})$	$v_{12}(x_{12}^{(B.2.1)})$	$v_{12}(x_{12}^{(B.2.2)})$	...	$v_{12}(x_{12}^{(B.2.n)})$	$v_{12}(x_{12}^{(C.2.1.)})$	$v_{12}(x_{12}^{(C.2.2)})$	...	$v_{12}(x_{12}^{(C.2.n)})$
X_{22}	$v_{22}(x_{22}^{(A.2.1.)})$	$v_{22}(x_{22}^{(A.2.2.)})$	...	$v_{22}(x_{22}^{(A.2.n.)})$	$v_{22}(x_{22}^{(B.2.1.)})$	$v_{22}(x_{22}^{(B.2.2)})$	...	$v_{22}(x_{22}^{(B.2.n.)})$	$v_{22}(x_{22}^{(C.2.1)})$	$v_{22}(x_{22}^{(C.2.2)})$	...	$v_{22}(x_{22}^{(C.2.n)})$
...	...	...	$\ddots$	...	...	...	...	...	...	...	...	...
X_{102}	$v_{102}(x_{102}^{(A.2.1.)})$	$v_{102}(x_{102}^{(A.2.2)})$	...	$v_{102}(x_{102}^{(A.2.n.)})$	$v_{102}(x_{102}^{(B.2.1.)})$	$v_{102}(x_{102}^{(B.2.2.)})$	...	$v_{102}(x_{102}^{(B.2.n.)})$	$v_{102}(x_{102}^{(C.2.1)})$	$v_{102}(x_{102}^{(C.2.2)})$	...	$v_{102}(x_{102}^{(C.2.n)})$

b)

Figure 3. Example of evaluation table (Air Conditioner energy service)): (**a**) $x_j^{(g_{jt})}$; (**b**) $v_{ij}\left(x_j^{(g_{jt})}\right)$.

Through the value attributes mentioned before, and by using an additive model to aggregate them, a unique model was obtained, represented by an aggregated objective function which was further optimized using the NSGAII algorithm.

As it referred to earlier, the nature of this problem is combinatorial, with the number of combinations being dependent on the size of the sample (22 million combinations considered in this case study).

Additionally, there is a set of constraints that will be considered here to adjust the consumer needs and obtain feasible solutions. These constraints are presented below.

Thus, the problem p here can be presented as follows:

$$\begin{aligned} &\max \quad V_m(x), && c/m = A,B,C \\ &\textit{subject to } x \in X && c/V_m(x) = \left[V_A(x), V_B(x), V_C(x)\right]^T \end{aligned} \tag{7}$$

with x being the decision variable vector, which is defined as

$$x \in X : x \in \left\{ x_{ij}^{(A_{jt})}, x_{ij}^{(\mathrm{B}_{jt})}, x_{ij}^{(C_{jt})} \right\} \wedge \mathrm{t}, \mathrm{i}, j \in \mathbb{N} \tag{8}$$

where

$$j = \{1,..,10\} \wedge j = \{1,2,..,7\} \wedge t = \left\{ \left\{1,..,n_{A_j}\right\} \cup \left\{1,..,n_{B_j}\right\} \cup \left\{1,..,n_{C_j}\right\} \right\} \wedge n_{A_j}, n_{B_j}, n_{C_j} \in \mathbb{N} \tag{9}$$

with $V_A(x)$, $V_B(x)$, and $V_C(x)$ being the objective functions related to each considered sustainability dimension, i.e., A—Economics, B—Social, and C—Environment.

Each aggregate objective function is given by

$$V_g(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{g_j}} v_j(x_j^{(g_{jt})}) \ \ w/\, g = \{A,B,C\} \wedge v_j(x_j^{(g_{jt})}) \wedge n_j, n_{g_j}, \mathrm{t}, j \in \mathbb{N} \tag{10}$$

Thus, and through (10), the corresponding objective functions regarding each sustainability dimension can be defined as

$$\textit{Economic Well-being}: \max V_A(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{A_j}} v_j(x_j^{(A_{jt})}) \tag{11}$$

$$\textit{Social Well-being}: \max V_B(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{B_j}} v_j(x_j^{(\mathrm{B}_{jt})}) \tag{12}$$

$$Environment\ Well-being : \max V_B(x) = \sum_{j=1}^{n_j}\sum_{t=1}^{n_{B_j}}\left(1 - v_j(x_j^{(C_{jt})})\right) \quad (13)$$

The first and third objective functions are based on the works from [21] and [29] respectively. The second objective function (Social Wellbeing), is defined based on the attributes established in this work.

Through the use of an additive model developed using MAVT, we have combined the value functions $V_A(x)$, $V_B(x)$, and $V_C(x)$ into a unique aggregated expression which will be the model's objective function. This objective function will be pondered by a weigh factor (ω_g), expressing, therefore, the relative importance given by the consumer to each sustainability dimension, thus resulting in

$$V_{Total}(x) = V\left(V_A(x), V_B(x), V_C(x)\right) = \omega_A . V_A(x) + \omega_B . V_B(x) + \omega_C . V_C(x) \quad . \quad)(14)$$

Therefore, and based on Expression (3), Expression (13) can be described as

$$V_{Total}(x) = \sum_{j=1}^{n_j}\left\{\omega_A . \sum_{t=1}^{n_{A_j}}\left(\frac{\left(x_{efect.j}^{(A_{jt})} - x_{pior.j}^{(A_{jt})}\right)}{\left(x_{\text{melhor}.j}^{(A_{jt})} - x_{pior.j}^{(A_{jt})}\right)}\right) + \omega_B . \sum_{t=1}^{n_{B_j}}\left(\frac{\left(x_{efect.j}^{(\mathrm{B}_{jt})} - x_{pior.j}^{(\mathrm{B}_{jt})}\right)}{\left(x_{\text{melhor}.j}^{(\mathrm{B}_{jt})} - x_{pior.j}^{(\mathrm{B}_{jt})}\right)}\right) + \omega_C . \sum_{t=1}^{n_{C_j}}\left(1 - \left(\frac{\left(x_{efect.j}^{(\mathrm{C}_{jt})} - x_{pior.j}^{(\mathrm{C}_{jt})}\right)}{\left(x_{\text{melhor}.j}^{(\mathrm{C}_{jt})} - x_{pior.j}^{(\mathrm{C}_{jt})}\right)}\right)\right)\right. \quad (15)$$

which is subject to a set of constraints regarding economic, social, and environment wellbeing dimensions, namely

Economic—Budget

$$r_1 : \sum_{j=1}^{n_{\dim}} I_j\left(x_j\right) \le available\,budget\,(\eta_{disp.}) \Leftrightarrow \sum_{\substack{j=1 \\ j\neq 2}}^{n_j} x_{ij}^{(A_{j4})} + x_{i2}^{(A_{25})} \le \eta_{disp.} \quad (16)$$

Lighting Comfort (minimum illuminance)

$$r_2 : \frac{x_1^{(B_{15})}}{A} K_1 \ge E_{\min} \quad (17)$$

Heating/Cooling Requirements

$$r_3 : x_2^{(B_{23})} \ge Q_{th.Aquec.(proj.)} \quad (18)$$

$$r_4 : x_2^{(B_{24})} \ge Q_{th.Arref.(proj.)} \quad (19)$$

Environment—Noise

$$\begin{cases} r_{51} : x_{i1}^{(B_{11})} \le Noise_{def.1} \\ r_{52} : x_{i2}^{(B_{21})} \le Noise_{def.2} \\ \quad\vdots \qquad\qquad c/i = 5\ e\ j = \{2,3,4,5,7\} \\ r_{56} : x_{i6}^{(B_{61})} \le Noise_{def.6} \\ r_{57} : x_{i7}^{(B_{71})} \le Noise_{def.7} \end{cases} \quad (20)$$

Water Consumption

$$\begin{cases} r_{61} : x_{i3}^{(A.3.6.)} \times 1/\tau_{H_2O} \le C_{MLR} \\ r_{62} : x_{i7}^{(A.7.5.)} \times 1/\tau_{H_2O} \le C_{MLL} \end{cases} \quad (21)$$

3.4. Strengths, Weakness, and Limitations of the Work

The approach presented here uses a lifecycle cost assessment (LCCA) method to predict the cost regarding each solution during its usage phase and according to the consumer's profile.

However, the LCCA calculations only accounts for the cost in terms of water and CO_2 emissions involved, and do not consider the materials involved in the production and final phase of the product itself. Further developments regarding this issue should be accounted for in future.

Issues such as the minimal lighting illuminance requirements, the dishwasher capacity, and the air conditioner thermal power (among others) are also accounted for in order to support the consumer with suitable appliances from the market and according to their needs.

Besides the economic and environmental concerns, the consumer's social preferences, such as comfort requirements related to different dimensions (thermal, acoustic, and visual) are also considered here together with different preferences regarding such issues as the (perceived) quality of the product and reliability, among others. The consumer's relative importance, regarding each dimension (economics, social, and environment) are also accounted for here.

Another advantage from the use of this approach is the diversity (although still optimal) of solutions from the market, which allows facing a contingency problem with the availability regarding a specific appliance (e.g., when it is out of stock).

However, the model to calculate the consumer's needs in terms of the air conditioner capacity needs to account not only for the dimensions of the divisions to be climatized but also other issues (e.g., wall materials, the windows, the façade orientation) to increase the precision in obtaining the results by using the model.

Still regarding the lack of precision in the estimation of air conditioner capacity, the model should also account for the dynamics in terms of interdependence between air conditioner and the new lighting system, since that a new lighting system could impact the requirements in terms of building's thermal needs.

Regarding the weakness and strengths already discussed here, there were some limitations within this work. One had to do with dimensions of the database (and, therefore, the sample) that was used, and by considering only the Portuguese market, although the main purpose here was (as an initial phase) to validate the proposed model.

Some attributes used here are only adjusted to the European Union context (e.g., the use of European Union's Energy Labelling Framework as an energy label classification framework), which brings about the requirement to make necessary (and future) adjustments of the method to account for other contexts with respect to the countries or regions involved.

The lack of previous research studies on this topic, given the issues referred to before, also represents a limitation, due to the lack of other approaches to be used as a mean to compare the obtained results for example. Therefore, such limitations have allowed for the identification of new gaps in the literature, which point to the need for further developments.

3.5. The Optimization Method Non-Dominated Sorting Genetic Algorithm II (NSGAII)

As it mentioned before, NSGAII was used in this work as a multiobjective optimization method based on evolutionary algorithms. The motivation for its use is based on its success in other approaches, which are related to problems of the same nature, in addition with its perceived advantages [19,29].

Thus, the method presented in this work uses NSGAII to deal with a set of candidate solutions, which are assessed by using an approach of multicriteria analysis integrated with MAVT.

Regarding NSGAII and the individual's codification, the adopted was realistic given the nature of the decision variables used in this work.

The corresponding individual's framework is presented as follows in Figure 4.

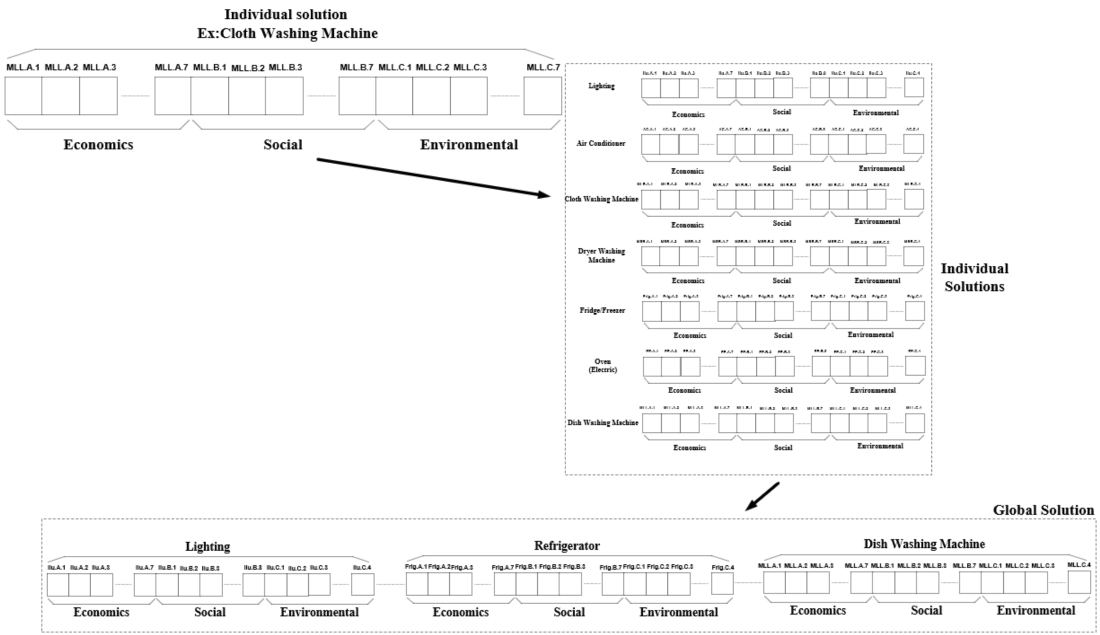

Figure 4. Individual framework.

According to [21,29], the NSGA's iteration process, applied here, uses several steps (Figure 5) consisting of initialization, crossover, and selection. Parameters such as the size of population, the iteration size, and crossover rate were determined empirically through a robustness analysis together with statistical analysis.

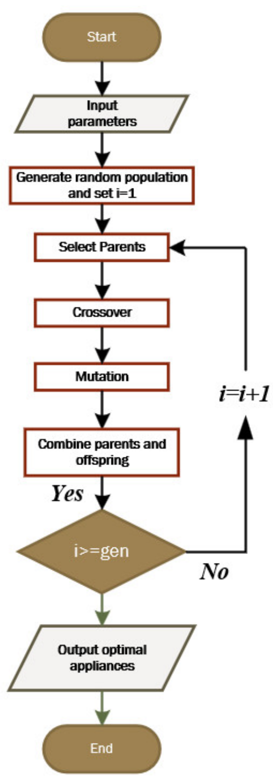

Figure 5. Non-dominated sorting genetic algorithm II (NSGAII) flowchart.

Based on Figure 5, the stopping criterion is defined by the variable "gen" regarding the maximum number of generations of NSGAII.

After the achievement of the feasible solutions/individuals, regarding each generation, they are selected from the parents and offspring. The last solution, results from the application of crossover and mutation. The process is finished, whenever the maximum number of iterations (defined by the user as a stop criteria) is surpassed.

The corresponding Pareto frontier is then obtained when we are dealing with a NSGAII with two objective functions, while a Pareto surface is found when we are dealing with a NSGAII with three objective functions.

4. Results and Discussion

The proposed model was then applied to the case study considered here. After defining the calculations according to LCCA, and regarding each individual solution as well as the corresponding attributes according to MAVT (Appendix A and B), the optimization process took place using the NSGAII algorithm. The corresponding algorithm was then coded on MATLAB software, by accounting for the following parameters:

- Selection method: tournament
- Crossover method: double point
- Mutation method: random mutation (one point)

The remaining parameters, namely the initial population, crossover, and mutation rate, were established after several trials.

The first parameter to be tested was the stopping criterion "max number of generations", where several runs were performed considering the corresponding values of 80 and 90 (Figure 6**a**,**b** respectively).

A maximum number of iterations (generations) of 80 was also defined, which was achieved given the neglectable difference obtained between the corresponding Pareto fronts (Figure 6**a**,**b**) regarding both scenarios, i.e.,; Economics & Environment (ω_A = 0.65, ω_B = 0.00, and ω_C = 0.35) and Economics & Social (ω_A = 0.65, ω_B = 0.35, and ω_C = 0.00),

Other parameters were also determined, such as the size of population (150 individuals), the size of tournament (10), the rate of crossover (0.75), and the rate of mutation (0.25).

In order to better analyze the fitness behavior considering different values of mutation and the crossover rate, a robustness test was performed considering two scenarios and regarding the considered case study, i,e., Economics & Environment (ω_A = 0.65, ω_B = 0.00, and ω_C = 0.35) and Economics & Social (ω_A = 0.65, ω_B = 0.35, and ω_C = 0.00)). The fixed parameters were the size of population (100 individuals) and the size of the tournament (12 individuals).

The rates regarding the mutation and crossover operators were then changed by performing several trials of crossover and mutation values (Table 4).

Table 4. Crossover's and mutation values considered.

Trial	Crossover Value	Mutation Value
1	0.75	0.15
2	0.75	0.25
3	0.85	0.15
4	0.85	0.25

All the trials shown in Table 4, were executed by setting a maximum number of iterations (90).

The respective results are shown on Figure 7**a**,7**b**, for each considered scenario. It is noted that a small change in the value of each parameter, has a negligible effect in the obtained results, considering both scenarios.

Therefore, the parameters NSGAII that were used to show the sustainable results obtained in this case study, were tournament size (10), max iteration (90), population size (100), mutation rate (0.1) and crossover rate (0.9).

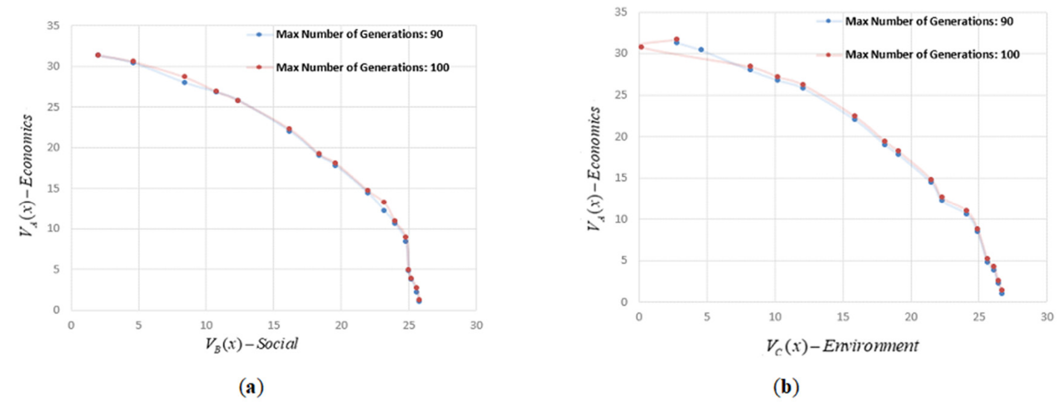

Figure 6. Pareto frontier regarding the 80th and 90th generations. (**a**) (ω_A = 0.65; ω_B = 0.35; ω_C = 0.00); (**b**) (ω_A = 0.65; ω_B = 0.00; ω_C = 0.35).

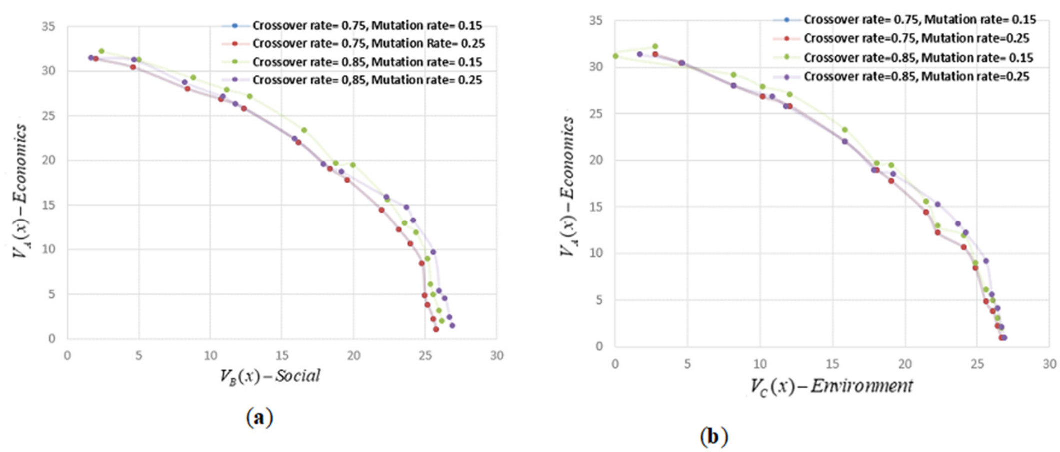

Figure 7. Pareto frontier considering different values of crossover and mutation rate. (**a**) (ω_A = 0.65; ω_B = 0.35; ω_C = 0.00); (**b**) (ω_A = 0.65; ω_B = 0.00; ω_C = 0.35),

After performing NSGAII calculations, a Pareto frontier is obtained by accounting for the scenarios described above for Economics vs, Social (ω_A = 0.65, ω_B = 0.35, and ω_C = 0.00) and Economics vs, Environment (ω_A = 0.65, ω_B = 0.00, and ω_C = 0.35) (Figure 8**a**,**b** respectively).

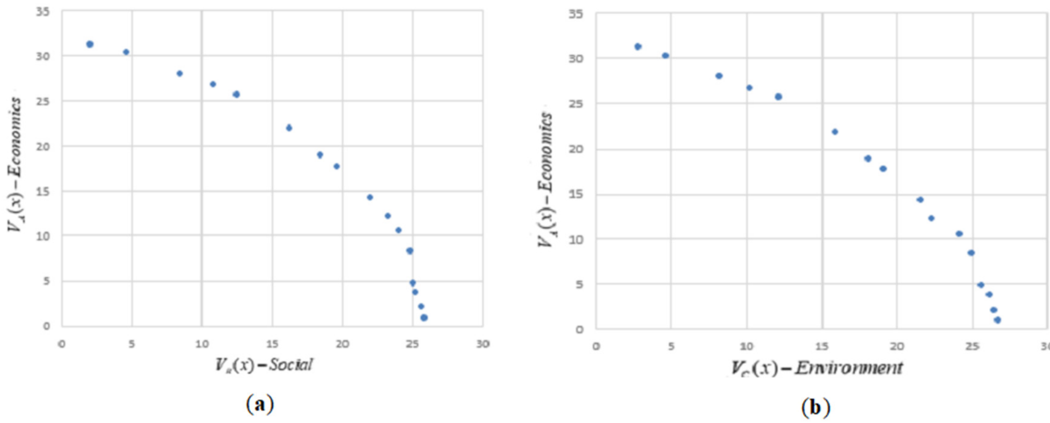

Figure 8. Pareto frontier: (**a**) (ω_A = 0.65; ω_B = 0.35; ω_C = 0.00); (**b**) (ω_A = 0.65; ω_B = 0.00; ω_C = 0.35).

Each point (or node) represents a global sustainable solution of the problem formed by a set of sustainable (and individual) solutions (household appliances) regarding each appliance type to be acquired by the consumer.

Although the Economic wellbeing decreases, the Social one increases (Figure 8**a**), with the same trade-off, being observed in Figure 8**b**, by considering only Economic and Environmental wellbeing dimensions.

Regarding the case study considered here and based on both trade-offs presented above, a scenario was considered with three dimensions and their corresponding consumer's relative importance, represented by the corresponding weights, i.e., ω_A = 0.65, ω_B = 0.25, and ω_C = 0.10.

The corresponding Pareto surface is obtained in Figure 9.

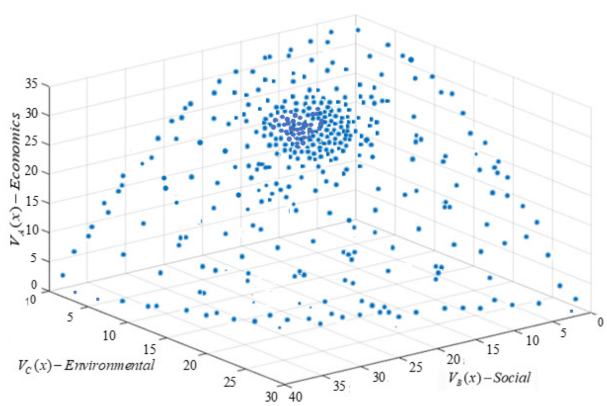

Figure 9. Pareto surface (ω_A = 0.65; ω_B = 0.25; ω_C = 0.10).

Based on the obtained Pareto surface (Figure 9), the crowding distance that resulted from each individual solution is higher in the region where the Economic dimension has more dominance, followed by the Social and, at last, the Environmental one. Such an order of dominance between each dimension of sustainability is somehow expected, given the relative importance values (weight) considered in this case for each dimension (ω_A = 0.65, ω_B = 0.25, and ω_C = 0.10).

One of the nodes from that region is shown on Table 5, regarding a sustainable solution obtained by considering a budget constraint of €2500 and a consumer lifecycle of 10 years.

Table 5. One of sustainable solutions achieved from the Pareto surface (ω_A = 0.65, ω_B = 0.25, and ω_C = 0.10).

Electrical Household Appliance	Standard Solution Total Invest, (€)	Sust. sol. Total Invest (€)	Inv. Saving (€)	Energy Consump. Savings (€)	Water Consump. (avoided) (l)	CO_2 Emissions (avoided) (kg)	Manuf.	Model Type
Light	16.88	49.04	5.35	62.20	-	27.60	Phillips	LEDspo
Air conditioning	352.00	279.00	69.00	1319.50	-	1322.60	Samsung	AQV09
Refrigerator	234.00	399.00	−265.00	709.30	-	9.72	Becken	Bc2016 I
Washing machine	272.20	249,90	−33,00	5.60	322.10	95.10	INDESIT	EWE71
Dishwasher machine	310.00	349.00	−39.00	3.20	423.00	6.90	LG	DF212F
Oven	171.00	701.00	−28.30	2.82	-	2.33	Electrolux	EZC243
Clothes dryer	368.00	449.00	−68.00	10.20	-	1.82	Bosch	WTE841
Total	1724.80	2475.94	−262.65	2112.30	745.10	1458.90	-	-

The avoided CO_2 emissions for each appliance are also shown, and they result from the comparison between the "sustainable" solution achieved and the "less sustainable" one, i.e., the standard solution.

The investment as well as the consumption savings were also obtained based on the difference between the "sustainable" solution achieved and the "less sustainable" one, and by also considering the lifecycle period regarding each energy service. Therefore, the corresponding monetary flows were then discounted to the present period in order to calculate the present value of each investment as well as each consumption value regarding the sustainable and less sustainable solutions.

Considering the results presented on Table 5, the consumer can achieve energy savings of around €2112.30 regarding the considered lifecycle.

Based on this value, we can estimate a consumption average value of 211.23 €/year (previous result divided by the considered lifecycle), which is lower than the average value of 300 in [9], although still significant, thus highlighting the importance of achieving energy savings during the lifecycle of each equipment.

During the considered lifecycle, the consumer can also avoid 1458.90 kg of CO_2 emissions and avoid consumption of approximately 745.10 liters of water, with both resulting in savings.

5. Conclusions & Future Work

In this paper, a decision support method was presented to provide sustainable household appliances from the market to a consumer by considering three dimensions of sustainability, namely, economics, social, and environmental wellbeing.

The proposed approach has made use of a set of established criteria, in order to pre-select a set of candidate solutions from the market, and by following the consumer requirements. The use of such criteria (adjustable to each consumer's requirements), allows for definition of the decision space, composed by a set of candidate solutions according to each type of appliance to be considered by the consumer.

Additional criteria were used and integrated with MAVT in order to model the consumer preferences according to the three problem dimensions presented here. The main purpose of these procedures was to maximize consumer wellbeing by acting on the three problem dimensions referred to above, and according to the relative importance given by the consumer.

After modeling the preferences of the consumer, where the ecological impact (e.g., CO_2 and water savings) and economic issues (energy consumption and initial investment savings) based on the lifecycle cost assessment (LCCA) of each household appliance were also taken into account, NSGAII was then applied to maximize the three objective functions referred to earlier.

The method presented in this work allows for maximizing all three dimensions of sustainability by acquiring a set of sustainable (and alternative) appliances from the market suitable for each consumer's preferences and concerns. This also allows the consumer to achieve a set of savings regarding energy consumption, CO_2 emissions, and water consumption.

There are some limitations, as pointed out earlier, as well as weaknesses that could be improved in the model in future, in order to make it more precise and suitable for the consumer.

Thus, and based on the limitations mentioned before, all of the adopted attributes can be used in other regions, although with necessary adjustments, given the existence of some differences regarding the region or country involved (e.g., energy labeling classification frameworks).

Besides the limitations identified earlier, which can be used as a basis to develop future work, the approach developed here can also be extended into other energy services with a relevant impact in terms of sustainable development, such as regarding information technology equipment (e.g., computers, printers, among others).

Furthermore, the use of indicators, such as the European Smart Readiness Indicator (SRI), can also be considered here as a future development by integrating the method developed in this paper into the SRI framework in order to better adjust each building (and it units) to each consumer's needs.

Author Contributions: R.S. and A.A., conceived and designed the experiments; F.M. and A.A., performed the experiments; J.M.C. and J.S., analyzed the data; J.S. and J.M.F.C., contributed analysis tools; R.S., wrote the paper.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Critérios utilizados

		Solução			Critério Economico							
		Marca	Modelo/Ref:	Tipo	Classe Ef.Ener.	Poup. Cons.Energia Horz.Temp.[€]	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]
Iluminação	Sol.Ref.	Lexman	Ref: 3782637	Halogenio	D	-	-	9.95	69.65	2.1492	21.492	0.3482	2.45
	Sol.Eficientes	OSRAM	Ref: 3316242	Halogenio	C	-1.84	20.79	6.98	48.86	3.7692	37.692	0.6106	4.29
		Phillips	Softone	Fluor. Compacta	A	-3.85	8.21	20.48	61.44	5.5296	55.296	0.8958	6.29
		Lexman	Ref: 3829536	Led	A+	0.00	-31.84	33.83	101.49	2.1492	21.492	0.3482	2.45
		GE	EFL23W	Fluor. Compacta	B	-1.50	37.55	16.05	32.10	3.4668	34.668	0.5616	3.94
		LED	G45	Led	A+	-0.37	42.17	13.74	27.48	2.4732	24.732	0.4007	2.81
		Phillips	ND 7	Led	A++	-5.09	20.61	24.52	49.04	6.6204	66.204	1.0725	7.53
		OSRAM	Facility	Fluorescente	A	-3.98	27.81	20.92	41.84	5.6484	56.484	0.9150	6.43
		GE	72379 OT	Fluor. Compacta	A	-1.00	52.85	5.6	16.80	3.024	30.24	0.4899	3.44
		OSRAM	Dulux Circolux	Fluorescente	A	-12.94	-80.59	50.08	150.24	13.5216	135.216	2.1905	15.39
		WIVA	OPAL	Led	A+	-9.88	9.47	20.06	60.18	10.8324	108.324	1.7548	12.33

		Marca	Modelo	Tipo	Classe Ef.Ener.	Classe Ef.Ener.Arref.	Classe Ef.Ener.Aque	Poup. Cons.Energia Horz.Temp.[€]	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]
Ar Condicionado	Sol.Ref.	GENERAL ELECTRIC	AIR 112	Spliter	C	C	C	-	-	368.00	368.00	1.64	16.40	0.2656	1.87
	Sol.Efic.	SAMSUNG	AR12FSSYAWTN	Multi Spliter	A++	A+	A++	1.87	-181.00	549.00	549.00	0.00	0.00	0.0000	0.00
		SAMSUNG	AQV09PSBN	Multi Spliter	A	A	A	0.84	89.00	279.00	279.00	0.90	9.00	0.1458	1.02
		OBERGOZO	FKDR 350 9KBTU	Multi Spliter	B	B	B	0.81	-431.00	799.00	799.00	0.93	9.30	0.1507	1.06
		SAMSUNG	FB	Multi Spliter	A++	A++	A++	0.84	-61.99	429.99	429.99	0.91	9.05	0.1466	1.03
		WHIRLPOOL	PACW 9HP	Portatil	A+	A	A+	0.93	-160.99	528.99	528.99	0.83	8.26	0.1339	0.94
		LG	9BTUS PM09SP 1X1	Spliter	A++	A+	A++	0.97	-561.99	929.99	929.99	0.79	7.85	0.1272	0.89
		HISENSE	AST-	Spliter	A++	A+	A++	1.05	-61.99	429.99	429.99	0.72	7.15	0.1158	0.81
		BECKEN	9btus Bac2321 1x1	Spliter	A++	A	A++	1.02	58.01	309.99	309.99	0.75	7.45	0.1207	0.85
		Inverter	Ase9ui Ek	Spliter	A+	A+++	A++	1.02	48.01	319.99	319.99	0.75	7.45	0.1207	0.85
		MITSUBISHI	DXK09Z5 1X1	Spliter	A	A	A+	0.16	-181.99	549.99	549.99	1.50	15.00	0.2430	1.71

		Marca	Modelo	Classe Ef.Ener.	Eficiência de Lavagem	Eficiência de Centrifugação	Poup. Cons.Energia	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]	Poup. Cons.Agua	Cons. Agua [€/ano]	Cons. Agua [€/horz.temp.]
Maquina Lavar Roupa	Sol.Ref.	INDESIT	WI 52	C	C	E			262.00	262.00	2.10	21.00	0.3402	2.39	-	12.14	85.29
	Sol.Efic.	WHIRLPOOL	AWOD 053	B	A	B	-0.23	-17.00	279.00	279.00	2.30	23.00	0.3726	2.62	2.59	11.78	82.70
		WHIRLPOOL	FWG 71284 W	A++	A	B	-0.23	-67.00	329.00	329.00	2.30	23.00	0.3726	2.62	-5.26	12.89	90.56
		ZANUSSI	ZWF71050W	B	A	C	-0.11	-57.00	319.00	319.00	2.20	22.00	0.3564	2.50	18.88	9.46	66.41
		SIEMENS	WI12A222ES	A++	A++	C	-0.11	-368.99	630.99	630.99	2.20	22.00	0.3564	2.50	-1.09	12.30	86.38
		INDESIT	EWE 71252 WEU/1	A+++	A	B	0.28	12.01	249.99	249.99	1.85	18.50	0.2997	2.10	-3.51	12.64	88.80
		KUNFT	7kg Kwm3485	A+++	A	C	0.28	6.00	256.00	256.00	1.85	18.50	0.2997	2.10	-1.06	12.30	86.35
		SAMSUNG	WW70J5355MW	A++	A	B	1.23	-127.00	389.00	389.00	1.02	10.20	0.1652	1.16	23.47	8.80	61.82
		AEG	L74272TL	A+++	A	B	1.23	-267.99	529.99	529.99	1.02	10.20	0.1652	1.16	13.37	10.24	71.93
		BECKEN	Bwm3215	A+++	A	B	-0.11	-57.99	319.99	319.99	2.20	22.00	0.3564	2.50	16.79	9.75	68.50
		HOTPOINT	FMG723MB	A+++	A	B	-0.11	-77.90	339.90	339.90	2.20	22.00	0.3564	2.50	12.03	10.43	73.26

		Solução			Critério Economico							
		Marca	Modelo	Tipo	Classe Ef.Ener.	Poup. Cons.Energia Horz.Temp.[€]	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]
Maquina Secar Roupa	Sol.Ref.	HOOVER	HNC 180	p/condensação	C			349.00	349.00	5.17	51.70	0.8375	5.88
	Sol.Eficientes	INDESIT	IDV 75	exaustão	B	5.88	129.01	219.99	219.99	0.00	0.00	0.0000	0.00
		KUNFT	Kdm2739 Av	exaustão	C	2.92	149.01	199.99	199.99	2.60	26.00	0.4212	2.96
		BALAY	3SB975B	exaustão	A++	3.61	-350.99	699.99	699.99	2.00	20.00	0.3240	2.28
		WHIRLPOOL	DDLX 70112	p/condensação	B	4.74	-80.99	429.99	429.99	1.00	10.00	0.1620	1.14
		ZANUSSI	ZDP7202PZ	p/condensação	A	3.72	-50.99	399.99	399.99	1.90	19.00	0.3078	2.16
		ELECTROLU	EDP2074PDW	p/condensação	B	2.70	-110.99	459.99	459.99	2.80	28.00	0.4536	3.19
		BOSCH	WTE84107EE	p/condensação	A	2.70	-100.00	449.00	449.00	2.80	28.00	0.4536	3.19
		SMEG	DHT83LIN	Bomba de Calor	A+++	2.92	-450.99	799.99	799.99	2.60	26.00	0.4212	2.96
		ELECTROLU	EDH3685TDW	Bomba de Calor	A++	4.97	-400.99	749.99	749.99	0.80	8.00	0.1296	0.91
		ZANUSSI	ZDH8333W	Bomba de Calor	A+	2.92	-280.99	629.99	629.99	2.60	26.00	0.4212	2.96

		Solução		Critério Economico							
		Marca	Modelo	Classe Ef.Ener.	Poup. Cons.Energia Horz.Temp.[€]	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]
Frigorifico	Sol.Ref.	WHIRLPOOL	ART867-G	C			250.00	250.00	0.53	5.29	0.0857	0.60
	Sol.Eficientes	CANDY	CFET 6184 XPU	A++	0.35	-399.99	649.99	649.99	0.23	2.25	0.0365	0.26
		CANDY	CFET 6182 W	B	0.29	-199.99	449.99	449.99	0.27	2.73	0.0442	0.31
		BECKEN	Bc2016 lx	A+	0.25	-149.99	399.99	399.99	0.31	3.07	0.0497	0.35
			EN3390MOW	A++	0.23	-452.99	702.99	702.99	0.33	3.29	0.0532	0.37
		BALAY	3KSB5410	A++	0.22	-209.99	459.99	459.99	0.34	3.39	0.0549	0.39
		BOSCH	KGV33VL31S	A++	0.22	-298.99	548.99	548.99	0.34	3.39	0.0548	0.39
		INDESIT	LI70 FF1 X	A+	0.25	-219.99	469.99	469.99	0.31	3.10	0.0502	0.35
		HOOVER	HDCF 184 WD/1	A++	0.35	-339.99	589.99	589.99	0.23	2.25	0.0365	0.26
		SAMSUNG	RB29FSRNDSA	A+	0.03	-279.99	529.99	529.99	0.50	5.02	0.0813	0.57
		CANDY	CF 18 S WIFI/1	A+	0.29	-499.99	749.99	749.99	0.27	2.73	0.0442	0.31

		Solução			Criterio Economico							
		Marca	Modelo	Tipo	Classe Ef.Ener.	Poup. Cons.Energia Horz.Temp.[€]	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]
Forno Electrico	Sol.Ref.	Miele	H399B		C			170.00	170.00	3.1	31.00	0.5022	3.53
	Sol.Eficientes	X	EZB3430AOX		A	0.7	-107.99	277.99	277.99	2.5	25.00	0.4050	2.84
		X	EZC2430AOX		A+	0.7	-531.98	701.98	701.98	2.5	25.15	0.4074	2.86
		BOSCH HBA43S360	HBA43S360E		A++	-0.3	-255.99	425.99	425.99	3.4	33.80	0.5476	3.85
		CATA	Cme 7007 X		A	0.6	-109.99	279.99	279.99	2.6	26.00	0.4212	2.96
		ZANUSSI	ZZB21601XV		B	0.4	-34.99	204.99	204.99	2.7	27.25	0.4415	3.10
		BOSCH	HBA21B250E		A	0.7	-144.99	314.99	314.99	2.5	24.80	0.4018	2.82
		BOSCH	HBA42R350E		A+	-0.5	-221.99	391.99	391.99	3.6	35.80	0.5800	4.07
		BALAY	3HB557XM		A	-0.1	-261.99	431.99	431.99	3.2	32.00	0.5184	3.64
		SIEMENS	HB22AR521E		A	0.3	-154.99	324.99	324.99	2.8	28.00	0.4536	3.19
		SIEMENS	HB42AR555E		A	-0.5	-259.99	429.99	429.99	3.6	35.80	0.5800	4.07

	Solução	Solução		Criterio Economico										
		Marca	Modelo	Classe Ef.Ener.	Poup. Cons.Energia Horz.Temp.[€]	Poupança Inv. Horz Temp. [€]	Invest. Inic. [€]	Invest. Inic. Tot. Act [€]	Cons.Energ.Anual. [kWh]	Cons.Energ.Tot. [kWh]	Cons.Energ. Anual. [€]	Cons.Energ. Tot. Act. [€]	Poup. Cons.Agua Horz Temp.[€]	Cons. Agua [€/ano]	Cons. Agua [€/horz.temp.]
Maquina Lavar Louça	Sol.Ref.	ZANUSSI	DW683	D			310.00	310.00	5.17	51.70	0.8375	5.88		3.69	25.90
	Sol.Eficientes	BOSCH	SMS46GW01E	A++	2.92	-95.99	405.99	405.99	2.60	26.00	0.4212	2.96	3.68	3.16	22.22
		DAEWOO	DDW-MQ1214S	A++	2.92	-89.99	399.99	399.99	2.60	26.00	0.4212	2.96	8.52	2.47	17.38
		SIEMENS	iSensoric	A++	4.74	-194.99	504.99	504.99	1.00	10.00	0.1620	1.14	3.68	3.16	22.22
		BOSCH	SMS25AI00E	A++	4.74	-120.99	430.99	430.99	1.00	10.00	0.1620	1.14	-1.67	3.93	27.57
		BOSCH	SMS24AW02E	A+	2.70	-79.99	389.99	389.99	2.80	28.00	0.4536	3.19	-1.67	3.93	27.57
		BALAY	3VS303IP	A+	2.70	-41.99	351.99	351.99	2.80	28.00	0.4536	3.19	-2.17	4.00	28.07
		SIEMENS	iSensoric	A+	2.92	-185.99	495.99	495.99	2.60	26.00	0.4212	2.96	3.68	3.16	22.22
		BALAY	3VS303BP	A+	2.92	-27.99	337.99	337.99	2.60	26.00	0.4212	2.96	3.84	3.14	22.05
		ELECTROLU	ESL7344RO	A++	2.92	-319.99	629.99	629.99	2.60	26.00	0.4212	2.96	1.34	3.50	24.56
		X	ESF5206LOX	A+	2.92	-103.99	413.99	413.99	2.60	26.00	0.4212	2.96	0.17	3.66	25.73

		Solução			Critério Social (Conforto, Gostos, Percepções)				
		Marca	Modelo/Ref:	Tipo	Durabilidade (hrs)	IRC	Frequ.Subst. Lampadas	Qualidade (Fiabilidade)	Fluxo Luminoso
Iluminação	Sol.Ref.	Lexman	Ref: 3782637	Halogenio	1900	100	6	7	1200
Iluminação	Sol.Eficientes	OSRAM	Ref: 3316242	Halogenio	2000	100	6	9	1230
		Phillips	Softone	Fluor. Compacta	10000	85	2	10	1200
		Lexman	Ref: 3829536	Led	10000	80	2	7	1400
		GE	EFL23W	Fluor. Compacta	15000	85	1	8	1258
		LED	G45	Led	25000	80	1	4	1258
		Phillips	ND 7	Led	15000	80	1	10	1000
		OSRAM	Facility	Fluorescente	11000	75	1	9	1450
		GE	72379 OT	Fluor. Compacta	10000	85	2	8	1238
		OSRAM	Dulux Circolux	Fluorescente	10000	85	2	10	1200
		WIVA	OPAL	Led	10000	85	2	4	1400

		Marca	Modelo	Tipo	Pot. Son. (Int.)[dB]	Pot. Son. (Ext.)[dB]	Capac. Nominal (Arref.) [kW]	Capac. Nominal (Aquec.) [kW]	Função desum.	Filtro Ar	Qualidade (Fiabilidade)	Nr. Funcionalidades	Design	Assistencia Pos-venda (Garantia)
Ar Condicionado	Sol.Ref.	GENERAL ELECTRIC	AIR 112	Spliter	42.00	42.00	3.15	11.93	Não	Sim	92.12	88.92	36.00	93.00
Ar Condicionado	Sol.Efic.	SAMSUNG	AR12FSSYAWTN	Multi Spliter	60.00	59.00	3.52	0.00	Sim	Sim	92.12	88.92	38.00	85.00
		SAMSUNG	AQV09PSBN	Multi Spliter	36.00	36.00	2.49	12.00	Sim	Sim	92.12	88.92	38.00	85.00
		OBERGOZO	FKDR 350 9KBTU	Multi Spliter	56.00	55.00	5.28	11.30	Não	Não	96.26	92.92	3.00	94.00
		SAMSUNG	FB	Multi Spliter	57.00	56.00	3.30	18.00	Sim	Sim	97.30	93.92	38.00	85.00
		WHIRLPOOL	PACW 9HP	Portatil	64.00	63.00	3.00	9.90	Não	Não	92.12	88.92	27.00	95.00
		LG	9BTUS PM09SP 1X1	Spliter	57.00	56.00	2.50	9.99	Sim	Sim	87.98	84.92	35.00	89.00
		HISENSE	AST-	Spliter	62.00	60.00	2.64	9.78	Sim	Sim	90.05	86.92	16.00	41.00
		BECKEN	9btus Bac2321 1x1	Spliter	54.00	50.00	2.50	9.10	Não	Não	96.26	92.92	19.00	87.00
		Inverter	Ase9ui Ek	Spliter	52.00	52.00	2.70	9.12	Sim	Sim	86.95	83.92	20.00	85.00
		MITSUBISHI	DXK09Z5 1X1	Spliter	27.00	27.00	2.64	9.00	Não	Sim	89.02	85.92	40.00	88.00

		Marca	Modelo		Ruido (dB)	Capacidade Nominal [kgs]					Qualidade (Fiabilidade)	Nr. Funcionalidades	Design	Assistencia Pos-venda (Garantia)
Maquina Lavar Roupa	Sol.Ref.	INDESIT	WI 52		56.00	7.00				INDESIT	89.00	86.33	87	98
Maquina Lavar Roupa	Sol.Efic.	WHIRLPOOL	AWOD 053		46.00	7.00				WHIRLPOOL	89.00	86.33	89.89	95
		WHIRLPOOL	FWG 71284 W		49.00	7.00				WHIRLPOOL	89.00	86.33	89.89	87
		ZANUSSI	ZWF71050W		48.00	6.00				ZANUSSI	93.00	90.21	93.93	84
		SIEMENS	WI12A222ES		48.00	7.00				SIEMENS	94.00	91.18	94.94	92
		INDESIT	EWE 71252 WEU/1		60.00	7.00				INDESIT	89.00	86.33	89.89	87
		KUNFT	7kg Kwm3485		58.00	6.00				KUNFT	85.00	82.45	85.85	94
		SAMSUNG	WW70J5355MW		62.00	7.00				SAMSUNG	87.00	84.39	87.87	95
		AEG	L74272TL		57.00	7.00				AEG	93.00	90.21	93.93	99
		BECKEN	Bwm3215		58.00	7.00				BECKEN	84.00	81.48	84.84	97
		HOTPOINT	FMG723MB		62.00	7.00				HOTPOINT	86.00	83.42	86.86	89

		Solução			Critério Social (Conforto, Gostos, Percepções)				
		Marca	Modelo	Tipo	Pot.Son.Sec. [dB]	Capacidade Nominal [kgs]	Qualidade (Fiabilidade)	Nr. Funcionalidades	Design	Assistencia Pos-venda (Garantia)
Maquina Secar Roupa	Sol.Ref.	HOOVER	HNC 180	p/condensação	60.00	6.00	95.00	86.45	89	91.00
Maquina Secar Roupa	Sol.Eficientes	INDESIT	IDV 75	exaustão	69.00	6.00	94.00	85.54	87	87.00
		KUNFT	Kdm2739 Av	exaustão	69.00	7.00	95.00	86.45	85	94.00
		BALAY	3SB975B	exaustão	65.00	6.00	95.00	86.45	84	90.00
		WHIRLPOOL	DDLX 70112	p/condensação	70.00	7.00	95.00	86.45	89	95.00
		ZANUSSI	ZDP7202PZ	p/condensação	65.00	7.00	95.00	89.30	87	94.00
		ELECTROLU	EDP2074PDW	p/condensação	64.00	7.00	95.00	89.30	82	93.00
		BOSCH	WTE84107EE	p/condensação	64.00	5.00	97.00	91.18	83	99.00
		SMEG	DHT83LIN	Bomba de Calor	65.00	7.00	89.00	88.11	96	98.00
		ELECTROLU	EDH3685TDW	Bomba de Calor	66.00	6.00	95.00	89.30	92	93.00
		ZANUSSI	ZDH8333W	Bomba de Calor	63.00	7.00	95.00	89.30	97	94.00

		Solução		Critério Social (Conforto, Gostos, Percepções)							
		Marca	Modelo	Ruido (dB)	Vol. util (>-6ºC) [l]	Vol. util (<-6ºC) [l]	Autonomia Corte Energia (horas)	Qualidade (Fiabilidade)	Nr. Funcionalidades	Design	Assistencia Pos-venda (Garantia)
Frigorífico	Sol.Ref.	WHIRLPOOL	ART867-G	43.00	203.00	102.00	4.00	92.00	89.24	54.00	5.2
Frigorífico	Sol.Eficientes	CANDY	CFET 6184 XPU	43.00	218.00	74.00	14.00	90.00	87.30	82.00	83
		CANDY	CFET 6182 W	42.00	227.00	84.00	14.00	90.00	87.30	82.00	84
		BECKEN	Bc2016 lx	43.00	222.00	95.00	14.00	99.00	96.03	84.00	98
			EN3390MOW	43.00	192.00	91.00	20.00	91.00	88.27	88.00	78
		BALAY	3KSB5410	39.00	194.00	94.00	19.00	95.00	92.15	86.00	90
		BOSCH	KGV33VL31S	39.00	192.00	94.00	23.00	95.00	92.15	97.00	97
		INDESIT	LI70 FF1 X	45.00	188.00	86.00	17.00	91.00	88.27	83.00	87
		HOOVER	HDCF 184 WD/1	43.00	218.00	74.00	18.00	88.00	85.36	93.00	92
		SAMSUNG	RB29FSRNDSA	39.00	192.00	98.00	17.00	95.00	92.15	99.00	85
		CANDY	CF 18 S WIFI/1	43.00	218.00	74.00	14.00	90.00	87.30	92.00	96

		Solução			Critério Social (Conforto, Gostos, Percepções)				
		Marca	Modelo	Tipo	Vol. util comp. (l)	Qualidade (Fiabilidade)	Nr. Funcionalidades	Design	Assistencia Pos-venda (Garantia)
Forno Electrico	Sol.Ref.	Miele	H399B		60	92.00	94.76	67	82
Forno Electrico	Sol.Eficientes	X	EZB3430AOX		60	87.30	89.92	86	83
		X	EZC2430AOX		57	87.30	89.92	66	83
		BOSCH HBA43S360	HBA43S360E		61	96.03	98.91	70	97
		CATA	Cme 7007 X		60	88.27	90.92	88	78
		ZANUSSI	ZZB21601XV		60	92.15	94.91	84	54
		BOSCH	HBA21B250E		61	92.15	94.91	70	85
		BOSCH	HBA42R350E		61	88.27	90.92	70	97
		BALAY	3HB557XM		60	85.36	87.92	86	82
		SIEMENS	HB22AR521E		61	94.72	97.56	83	82
		SIEMENS	HB42AR555E		61	89.73	92.42	83	82

	Solução	Solução		Critério Social (Conforto, Gostos, Percepções)					
		Marca	Modelo	Ruido (dB)	Capacidade [serviços-louça]	Qualidade (Fiabilidade)	Nr. Funcionalidades	Design	Assistencia Pos-venda (Garantia)
Maquina Lavar Louça	Sol.Ref.	ZANUSSI	DW683	56.00	12.00	94.00	95.88	83	84.66
Maquina Lavar Louça	Sol.Eficientes	BOSCH	SMS46GW01E	46.00	12.00	97.00	98.94	85	86.7
		DAEWOO	DDW-MQ1214S	49.00	11.00	89.00	90.78	87	88.74
		SIEMENS	iSensoric	48.00	12.00	95.00	96.9	96	97.92
		BOSCH	SMS25AI00E	48.00	12.00	97.00	98.94	98	99.96
		BOSCH	SMS24AW02E	50.00	10.00	97.00	98.94	88	89.76
		BALAY	3VS303IP	50.00	12.00	96.00	97.92	98	99.96
		SIEMENS	iSensoric	46.00	10.00	95.00	96.9	86	87.72
		BALAY	3VS303BP	50.00	11.00	96.00	97.92	87	88.74
		ELECTROLU	ESL7344RO	46.00	12.00	96.00	97.92	89	90.78
		X	ESF5206LOX	49.00	12.00	96.00	97.92	89	90.78

	Solução				Critério Ambiental			
		Marca	Modelo/Ref:	Tipo	Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Iluminação	Sol.Ref.	Lexman	Ref: 3782637	Halogenio	14.51	145.07	23625	23625
	Sol.Eficientes	OSRAM	Ref: 3316242	Halogenio	25.44	254.42	23569	23569
		Phillips	Softone	Fluor. Compacta	37.32	373.25	21025	21025
		Lexman	Ref: 3829536	Led	14.51	145.07	27589	27589
		GE	EFL23W	Fluor. Compacta	23.40	234.01	21456	21456
		LED	G45	Led	16.69	166.94	23466	23466
		Phillips	ND 7	Led	44.69	446.88	23488.5	23488.5
		OSRAM	Facility	Fluorescente	38.13	381.27	23511	23511
		GE	72379 OT	Fluor. Compacta	20.41	204.12	23533.5	23533.5
		OSRAM	Dulux Circolux	Fluorescente	91.27	912.71	23556	23556
		WIVA	OPAL	Led	73.12	731.19	23578.5	23578.5
		Marca	Modelo	Tipo	Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Ar Condicionado	Sol.Ref.	GENERAL ELECTRIC	AIR 112	Spliter	11.07	110.67	23625.00	23625.00
	Sol.Efic.	SAMSUNG	AR12FSSYAWTN	Multi Spliter	0.00	0.00	23569.00	23569.00
		SAMSUNG	AQV09PSBN	Multi Spliter	6.08	60.75	21025.00	21025.00
		OBERGOZO	FKDR 350 9KBTU	Multi Spliter	6.28	62.78	27589.00	27589.00
		SAMSUNG	FB	Multi Spliter	6.11	61.09	21456.00	21456.00
		WHIRLPOOL	PACW 9HP	Portatil	5.58	55.77	23466.00	23466.00
		LG	9BTUS PM09SP 1X1	Spliter	5.30	52.99	23488.50	23488.50
		HISENSE	AST-	Spliter	4.83	48.26	23511.00	23511.00
		BECKEN	9btus Bac2321 1x1	Spliter	5.03	50.29	23533.50	23533.50
		Inverter	Ase9ui Ek	Spliter	5.03	50.29	23556.00	23556.00
		MITSUBISHI	DXK09Z5 1X1	Spliter	10.13	101.25	23578.50	23578.50
		Marca	Modelo		Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Maquina Lavar Roupa	Sol.Ref.	INDESIT	WI 52		14.18	141.75	0.25	0.06
	Sol.Efic.	WHIRLPOOL	AWOD 053		15.53	155.25	0.29	0.07
		WHIRLPOOL	FWG 71284 W		15.53	155.25	0.29	0.07
		ZANUSSI	ZWF71050W		14.85	148.50	0.25	0.06
		SIEMENS	WI12A222ES		14.85	148.50	0.29	0.07
		INDESIT	EWE 71252 WEU/1		12.49	124.88	0.29	0.07
		KUNFT	7kg Kwm3485		12.49	124.88	0.25	0.06
		SAMSUNG	WW70J5355MW		6.89	68.85	0.29	0.07
		AEG	L74272TL		6.89	68.85	0.29	0.07
		BECKEN	Bwm3215		14.85	148.50	0.29	0.07
		HOTPOINT	FMG723MB		14.85	148.50	0.29	0.07
		Solução			Critério Ambiental			
		Marca	Modelo	Tipo	Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Maquina Secar Roupa	Sol.Ref.	HOOVER	HNC 180	p/condensação	34.90	348.98	0.25	0.06
	Sol.Eficientes	INDESIT	IDV 75	exaustão	0.00	0.00	0.25	0.06
		KUNFT	Kdm2739 Av	exaustão	17.55	175.50	0.29	0.07
		BALAY	3SB975B	exaustão	13.50	135.00	0.25	0.06
		WHIRLPOOL	DDLX 70112	p/condensação	6.75	67.50	0.29	0.07
		ZANUSSI	ZDP7202PZ	p/condensação	12.83	128.25	0.29	0.07
		ELECTROLU	EDP2074PDW	p/condensação	18.90	189.00	0.29	0.07
		BOSCH	WTE84107EE	p/condensação	18.90	189.00	0.21	0.05
		SMEG	DHT83LIN	Bomba de Calor	17.55	175.50	0.29	0.07
		ELECTROLU	EDH3685TDW	Bomba de Calor	5.40	54.00	0.25	0.06
		ZANUSSI	ZDH8333W	Bomba de Calor	17.55	175.50	0.29	0.07
		Solução			Critério Ambiental			
		Marca	Modelo		Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Frigorifico	Sol.Ref.	WHIRLPOOL	ART867-G		168.75	1687.50	23625.00	23625.00
	Sol.Eficientes	CANDY	CFET 6184 XPU		438.74	4387.43	23569.00	23569.00
		CANDY	CFET 6182 W		303.74	3037.43	21025.00	21025.00
		BECKEN	Bc2016 Ix		269.99	2699.93	27589.00	27589.00
			EN3390MOW		474.52	4745.18	21456.00	21456.00
		BALAY	3KSB5410		310.49	3104.93	23466.00	23466.00
		BOSCH	KGV33VL31S		370.57	3705.68	23488.50	23488.50
		INDESIT	LI70 FF1 X		317.24	3172.43	23511.00	23511.00
		HOOVER	HDCF 184 WD/1		398.24	3982.43	23533.50	23533.50
		SAMSUNG	RB29FSRNDSA		357.74	3577.43	23556.00	23556.00
		CANDY	CF 18 S WIFI/1		506.24	5062.43	23578.50	23578.50
		Solução			Critério Ambiental			
		Marca	Modelo	Tipo	Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Forno Electrico	Sol.Ref.	Miele	H399B		2.09	20.93	23625.00	23625.00
	Sol.Eficientes	X	EZB3430AOX		1.69	16.88	23569.00	23569.00
		X	EZC2430AOX		1.70	16.98	21025.00	21025.00
		BOSCH HBA43S360	HBA43S360E		2.28	22.82	27589.00	27589.00
		CATA	Cme 7007 X		1.76	17.55	21456.00	21456.00
		ZANUSSI	ZZB21601XV		1.84	18.39	23466.00	23466.00
		BOSCH	HBA21B250E		1.67	16.74	23488.50	23488.50
		BOSCH	HBA42R350E		2.42	24.17	23511.00	23511.00
		BALAY	3HB557XM		2.16	21.60	23533.50	23533.50
		SIEMENS	HB22AR521E		1.89	18.90	23556.00	23556.00
		SIEMENS	HB42AR555E		2.42	24.17	23578.50	23578.50
	Solução	Solução			Critério Ambiental			
		Marca	Modelo		Emissões CO2 equiv. (v.anuais)[kg]	Uso - Emissões CO2e (horz.temp.)[kg]	Fabrico - Emissões CO2e [kg]	Final - Emissões CO2e [kg]
Maquina Lavar Louça	Sol.Ref.	ZANUSSI	DW683		34.90	348.98	23625.00	23625.00
	Sol.Eficientes	BOSCH	SMS46GW01E		17.55	175.50	23569.00	23569.00
		DAEWOO	DDW-MQ1214S		17.55	175.50	21025.00	21025.00
		SIEMENS	iSensoric		6.75	67.50	27589.00	27589.00
		BOSCH	SMS25AI00E		6.75	67.50	21456.00	21456.00
		BOSCH	SMS24AW02E		18.90	189.00	23466.00	23466.00
		BALAY	3VS303IP		18.90	189.00	23488.50	23488.50
		SIEMENS	iSensoric		17.55	175.50	23511.00	23511.00
		BALAY	3VS303BP		17.55	175.50	23533.50	23533.50
		ELECTROLU	ESL7344RO		17.55	175.50	23556.00	23556.00
		X	ESF5206LOX		17.55	175.50	23578.50	23578.50

Figure A1. Definition of the attribute table associated with the options available in the market, considered in this work.

Appendix B

Solução				Tipo	A - Critério Economico							B - Critério Social											C - Critério Ambiental					
Iluminação - Subcritérios					Ilu.A.1	Ilu.A.2	Ilu.A.3	Ilu.A.4	Ilu.A.5		ViA(x)	Ilu.B.1	Ilu.B.2	Ilu.B.3	Ilu.B.4	Ilu.B.5						ViB(x)	Ilu.C.1	Ilu.C.2	Ilu.C.3		ViC(x)	V(x)
Ilu. - Iluminação	Sol.Re	Lexman	Ref: 3782637	Halogenio	-	-	-	-	-		-	-	-	-	-	-						-	-	-	-		-	-
	Sol.Efic.	OSRAM	Ref: 3316242	Halogenio	0,70	0,86	0,76	0,24	0,14		2,70	0,00	1,00	1,00	0,83	0,51						3,34	0,14	-3,20	-3,16		-6,22	-0,18
		Phillips	Softone	Fluor. Compacta	1,00	0,70	0,67	0,33	0,30		3,00	0,35	0,40	0,20	1,00	0,44						2,39	0,30	-3,20	-3,15		-6,05	-0,65
		Lexman	Ref: 3829536	Led	0,90	1,00	0,37	0,63	0,00		2,90	0,35	0,20	0,20	0,50	0,89						2,14	0,00	-3,20	-3,18		-6,38	-1,35
		GE	EFL23W	Fluor. Compacta	1,00	0,88	0,89	0,11	0,12		3,00	0,57	0,40	0,00	0,67	0,57						2,21	0,12	-3,20	-3,17		-6,25	-1,05
		LED	G45	Led	0,90	0,97	0,92	0,08	0,03		2,90	1,00	0,20	0,00	0,00	0,57						1,77	0,03	-3,20	-3,18		-6,35	-1,68
		Phillips	CorePro LEDspotMV ND 7	Led	0,90	0,61	0,76	0,24	0,39		2,90	0,57	0,20	0,00	1,00	0,00						1,77	0,39	-3,20	-3,13		-5,94	-1,27
		OSRAM	Dulux Intelligent Facility	Fluorescente	0,90	0,69	0,81	0,19	0,31		2,90	0,39	0,00	0,00	0,83	1,00						2,22	0,31	-3,20	-3,14		-6,03	-0,91
		GE	72379 OT FLE20TBX	Fluor. Compacta	0,90	0,92	1,00	0,00	0,08		2,90	0,35	0,40	0,20	0,67	0,53						2,14	0,08	-3,20	-3,17		-6,30	-1,25
		Phillips	Softone	Fluor. Compacta	0,90	0,00	0,00	1,00	1,00		2,90	0,35	0,40	0,20	1,00	0,44						2,39	1,00	-3,19	-3,06		-5,25	0,04
		FALSE	ML SPIRAL	Fluor. Compacta	0,90	0,24	0,67	0,33	0,76		2,90	0,35	0,40	0,20	0,00	0,89						1,84	0,76	-3,19	-3,09		-5,52	-0,78
Ar Condicionado - Subcritérios					AC.A.1	AC.A.2	AC.A.3	AC.A.4	AC.A.5	AC.A.6	ViA(x)	AC.B.1	AC.B.2	AC.B.3	AC.B.4	AC.B.5	AC.B.6	AC.B.7	AC.B.8	AC.B.9	AC.B.10	ViB(x)	AC.C.1	AC.C.2	AC.C.3		ViC(x)	V(x)
AC - Ar Condicionado	Sol.Re	GENERAL ELECTR	AIR 112	Spliter	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
	Sol.Efic.	SAMSUNG	AR12FSSYAWTN Serie Y	Multi Spliter	0,90	1,00	1,00	0,59	0,41	0,00	3,90	0,89	0,89	0,37	0,00	1,00	1,00	0,50	0,50	0,95	0,81	4,65	0,00	0,39	0,39		0,78	9,32
		SAMSUNG	AQV09PSBN	Multi Spliter	0,80	0,80	0,40	1,00	0,00	0,24	3,24	0,24	0,25	0,00	0,67	1,00	1,00	0,50	0,50	0,95	0,81	3,66	0,60	0,00	0,00		0,60	7,50
		OBERGOZO	FKDR 350 9KBTU	Multi Spliter	0,70	0,70	0,38	0,20	0,79	0,27	3,04	0,78	0,78	1,00	0,63	0,00	0,00	0,90	0,90	0,00	0,98	4,09	0,62	1,00	1,00		2,62	9,75
		SAMSUNG	FB AR09HSSFBWKNEU	Multi Spliter	1,00	0,80	0,40	0,77	0,25	0,14	3,35	0,81	0,81	0,29	1,00	1,00	1,00	1,00	1,00	0,31	0,77	5,91	0,60	0,07	0,07		0,73	9,99
		WHIRLPOOL	PACW 9HP	Portatil	0,80	0,90	0,45	0,62	0,40	0,07	3,24	1,00	1,00	0,18	0,55	0,00	0,00	0,56	0,56	0,15	0,95	3,29	0,55	0,37	0,37		1,29	7,82
		LG	9BTUS PM09SP 1X1	Spliter	0,90	1,00	0,48	0,00	1,00	0,04	3,42	0,81	0,81	0,00	0,55	1,00	1,00	0,11	0,11	0,26	0,84	4,29	0,52	0,38	0,38		1,27	8,98
		HISENSE	AST-09UW4SVETG10	Spliter	0,90	1,00	0,52	0,77	0,58	0,00	3,77	0,95	0,92	0,05	0,54	1,00	1,00	0,33	0,33	0,00	0,00	4,79	0,48	0,38	0,38		1,23	9,80
		BECKEN	9btus Bac2321 1x1	Spliter	0,80	1,00	0,50	0,95	0,13	0,00	3,39	0,73	0,64	0,00	0,51	0,00	0,00	1,00	1,00	0,00	0,21	2,88	0,50	0,38	0,38		1,26	7,52
		Inverter HIYASU	Ase9ui Ek	Spliter	1,00	1,00	0,50	0,94	0,18	0,00	3,62	0,68	0,69	0,07	0,51	1,00	1,00	0,00	0,00	0,00	0,07	3,95	0,50	0,39	0,39		1,27	8,84
		MITSUBISHI	DXK09Z5 1X1	Spliter	0,80	0,90	0,00	0,58	0,79	0,00	3,07	0,00	0,00	0,05	0,50	0,00	1,00	0,45	0,40	0,00	0,29	2,00	1,00	0,39	0,39		1,78	6,85
Maquina Lavar Roupa - Subcritérios					MLR.A.1	MLR.A.2	MLR.A.3	MLR.A.4	MLR.A.5	MLR.A.6	ViA(x)	MLR.B.1	MLR.B.2	MLR.B.3	MLR.B.4	MLR.B.5	MLR.B.6					ViB(x)	MLR.C.1	MLR.C.2	MLR.C.3	MLR.C.4	ViC(x)	V(x)
MLR - Maquina Lavar Roupa	Sol.Re	INDESIT	WI52	-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-
	Sol.Efic.	WHIRLPOOL	AWOD 053	-	0,60	0,00	0,92	0,08	0,08	1,00	2,68	0,00	1,00	0,50	0,50	0,63	0,73					3,36	1,00	0,73	1,00	0,73	3,45	9,49
		WHIRLPOOL	FWG 71284 W	-	0,90	0,00	0,79	0,21	0,21	1,00	3,11	0,19	1,00	0,50	0,50	1,00	0,20					3,39	1,00	1,00	1,00	1,00	4,00	10,49
		ZANUSSI	ZWF71050W	-	0,60	0,08	0,82	0,18	0,18	0,92	2,78	0,13	0,86	0,90	0,90	0,55	0,00					3,33	0,92	0,16	0,00	0,16	1,24	7,35
		SIEMENS	WI12A222ES	-	0,90	0,08	0,00	1,00	1,00	0,92	3,90	0,13	1,00	1,00	1,00	0,55	0,42					4,10	0,92	0,85	1,00	0,85	3,63	11,63
		INDESIT	EWE 71252 WEU/1	-	1,00	0,35	1,00	0,00	0,73	0,65	3,73	0,88	1,00	0,56	0,56	0,54	0,00					3,53	0,65	0,94	1,00	0,94	3,53	10,79
		KUNFT	Tkg Kwm3485	-	1,00	0,35	0,98	0,02	0,02	0,65	3,02	0,75	0,86	0,09	0,11	0,51	0,50					2,81	0,65	0,85	0,00	0,85	2,36	8,19
		SAMSUNG	WW70J5355MW	-	0,90	1,00	0,64	0,36	0,36	0,00	3,26	1,00	1,00	0,27	0,33	0,51	0,67					3,78	0,00	0,00	1,00	0,00	1,00	8,04
		AEG	L74272TL	-	1,00	1,00	0,27	0,73	0,73	0,00	3,73	0,69	1,00	0,82	1,00	0,50	1,00					5,01	0,00	0,35	1,00	0,35	1,70	10,44
		BECKEN	Bwm3215	-	1,00	0,08	0,82	0,18	0,18	0,92	3,18	0,75	1,00	0,00	0,00	0,63	1,00					3,38	0,92	0,23	1,00	0,23	2,39	8,95
		HOTPOINT	FMG723MB	-	1,00	0,08	0,76	0,24	0,24	0,92	3,24	1,00	1,00	0,00	0,00	1,00	0,25					3,25	0,92	0,40	1,00	0,40	2,72	9,20
Maquina Secar Roupa- Subcritérios					MSR.A.	MSR.A.2	MSR.A.3	MSR.A.4	MSR.A.5	MSR.A.6	ViA(x)	MSR.B.1	MSR.B.2	MSR.B.3	MSR.B.4	MSR.B.5	MSR.B.6					ViB(x)	MSR.C.1	MSR.C.2	MSR.C.3		ViC(x)	V(x)
MSR - Maquina Secar Roupa	Sol.Re	HOOVER	HNC 180	p/condensação	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-		-	-
	Sol.Eficientes	INDESIT	IDV 75	exaustão	0,70	1,00	0,37	0,03	0,03	0,00	2,13	0,86	0,50	0,63	0,00	0,63	0,00					2,61	0,00	0,50	0,50		1,00	6,34
		KUNFT	Kdm2739 Av	exaustão	0,60	0,07	1,00	0,00	0,00	0,93	2,60	0,86	1,00	0,75	0,00	1,00	0,44					4,05	0,93	1,00	1,00		2,93	9,58
		BALAY	3SB975B	exaustão	0,90	0,29	0,17	0,83	0,83	0,71	3,73	0,29	0,50	0,75	0,00	0,55	0,00					2,09	0,71	0,50	0,50		1,71	7,53
		WHIRLPOOL	DDLX 70112	p/condensação	0,60	0,64	0,62	0,38	0,38	0,36	2,98	1,00	1,00	0,75	0,00	0,55	0,33					3,64	0,36	1,00	1,00		2,36	8,98
		ZANUSSI	ZDP7202PZ	p/condensação	0,70	0,32	0,67	0,33	0,33	0,68	3,03	0,29	1,00	0,75	0,39	0,54	0,17					3,13	0,68	1,00	1,00		2,68	8,85
		ELECTROLUX	EDP2074PDW	p/condensação	0,60	0,00	0,57	0,43	0,43	1,00	3,03	0,14	1,00	0,75	0,39	0,51	0,94					3,72	1,00	1,00	1,00		3,00	9,76
		BOSCH	WTE84107EE	p/condensação	0,70	0,00	0,58	0,42	0,42	1,00	3,12	0,14	0,00	1,00	1,00	0,51	1,00					3,65	1,00	0,00	0,00		1,00	7,76
		SMEG	DHT83LIN	Bomba de Calor	1,00	0,07	0,00	1,00	1,00	0,93	4,00	0,29	1,00	0,00	0,41	0,50	1,00					3,19	0,93	1,00	1,00		2,93	10,12
		ELECTROLUX	EDH3685TDW	Bomba de Calor	0,90	0,71	0,08	0,92	0,92	0,29	3,82	0,43	0,50	0,56	0,23	0,63	0,95					3,29	0,29	0,50	0,50		1,29	8,39
		ZANUSSI	ZDH8333W	Bomba de Calor	0,80	0,07	0,28	0,72	0,72	0,93	3,52	0,00	1,00	0,56	0,23	1,00	0,96					3,74	0,93	1,00	1,00		2,93	10,19
Frigorifico - Subcritérios					FRIG.A.1	FRIG.A.2	FRIG.A.3	FRIG.A.4	FRIG.A.5	FRIG.A.6	ViA(x)	FRIG.B.1	FRIG.B.2	FRIG.B.3	FRIG.B.4	FRIG.B.5	FRIG.B.6	FRIG.B.7	FRIG.B.8			ViB(x)	FRIG.C.1	FRIG.C.2	FRIG.C.3		ViC(x)	V(x)
Frig. - Frigorífico	Sol.Re	WHIRLPOOL	ART867-G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	-	-		-	-
	Sol.Eficientes	CANDY	CFET 6184 XPU	-	1,00	1,00	0,29	0,71	0,71	0,00	3,71	0,67	0,77	0,67	0,75	0,18	0,78	0,00	0,87			3,81	0,71	0,39	0,39		1,49	9,02
		CANDY	CFET 6182 W	-	0,70	0,83	0,86	0,14	0,14	0,17	2,84	0,50	1,00	0,42	0,00	0,18	0,92	0,00	0,83			3,02	0,14	0,00	0,00		0,14	6,00
		BECKEN	Bc2016 Ix	-	0,90	0,70	1,00	0,00	0,00	0,30	2,90	0,67	0,87	0,88	0,00	1,00	1,00	0,06	1,00			4,48	0,00	1,00	1,00		2,00	9,38
		ELECTROLUX	EN3390MOW	-	1,00	0,63	0,13	0,87	0,87	0,37	3,87	0,67	0,10	0,71	0,67	0,43	0,94	0,31	0,00			3,83	0,87	0,07	0,07		1,00	8,69
		BALAY	3KSB5410	-	1,00	0,59	0,83	0,17	0,17	0,41	3,17	0,00	0,15	0,83	0,56	1,00	1,00	0,19	0,42			3,73	0,17	0,37	0,37		0,92	7,82
		BOSCH	KGV33VL31S	-	1,00	0,59	0,57	0,43	0,43	0,41	3,43	0,00	0,10	0,83	1,00	1,00	0,72	0,94	0,94			4,60	0,43	0,38	0,38		1,18	9,20
		INDESIT	LI70 FF1 X	-	0,90	0,69	0,80	0,20	0,20	0,31	3,10	1,00	0,00	0,50	0,33	0,48	0,31	0,50	0,78			3,12	0,20	0,38	0,38		0,96	7,18
		HOOVER	HDCF 184 WD/1	-	1,00	1,00	0,46	0,54	0,54	0,00	3,54	0,67	0,77	0,00	0,44	0,09	0,00	0,82	0,71			2,79	0,54	0,38	0,38		1,31	7,64
		SAMSUNG	RB29FSRNDSA	-	0,90	0,00	0,63	0,37	0,37	1,00	3,27	0,00	0,10	1,00	0,33	0,88	0,42	1,00	0,82			3,74	0,37	0,39	0,39		1,14	8,15
		CANDY	CF 18 S WIFI/1	-	0,90	0,83	0,00	1,00	1,00	0,17	3,90	0,67	0,77	0,00	0,00	0,31	0,00	1,00	0,95			2,75	1,00	0,39	0,39		1,78	8,42
Forno Electrico- Subcritérios					FE.A.1	FE.A.2	FE.A.3	FE.A.4	FE.A.5		ViA(x)	FE.B.1	FE.B.2	FE.B.3	FE.B.4	FE.B.5						ViB(x)	FE.C.1	FE.C.2	FE.C.3		ViC(x)	V(x)
FE - Forno Electrico	Sol.Re	Miele	H399B	-	-	-	-	-	-		-	-	-	-	-	-						-	-	-	-		-	-
	Sol.Eficientes	ELECTROLUX	EZB3430AOX	-	0,80	0,98	0,85	0,15	0,02		2,80	0,75	0,18	0,18	0,91	0,91						2,93	0,02	0,39	0,39		0,79	6,53
		ELECTROLUX	EZC2430AOX	-	0,90	0,97	0,00	1,00	0,03		2,90	0,73	0,18	0,73	0,75	0,73						3,11	0,03	0,00	0,00		0,03	6,04
		BOSCH HBA43S36	HBA43S360E	-	1,00	0,18	0,56	0,44	0,82		3,00	1,00	1,00	1,00	0,75	0,73						4,48	0,82	1,00	1,00		2,82	10,29
		CATA	Cme 7007 X	-	0,80	0,89	0,85	0,15	0,11		2,80	0,75	0,31	0,31	1,00	1,00						3,37	0,11	0,07	0,07		0,24	6,41
		ZANUSSI	ZZB21601XV	-	0,70	0,78	1,00	0,00	0,22		2,70	0,75	0,73	0,73	0,88	0,88						3,95	0,22	0,37	0,37		0,97	7,62
		BOSCH	HBA21B250E	-	0,80	1,00	0,78	0,22	0,00		2,80	1,00	0,73	0,73	0,00	0,72						3,17	0,00	0,38	0,38		0,75	6,72
		BOSCH	HBA42R350E	-	0,90	0,00	0,62	0,38	1,00		2,90	1,00	0,25	0,27	0,00	0,70						2,22	1,00	0,38	0,38		1,76	6,88
		BALAY	3HB557XM	-	0,80	0,35	0,54	0,46	0,65		2,80	0,75	0,73	0,73	0,75	0,75						3,70	0,65	0,38	0,38		1,42	7,92
		SIEMENS	HB22AR521E	-	0,80	0,71	0,76	0,24	0,29		2,80	1,00	0,71	0,83	0,72	0,72						3,98	0,29	0,39	0,39		1,06	7,85
		SIEMENS	iSensoric HB42AR555E	-	0,80	0,00	0,55	0,45	1,00		2,80	1,00	0,09	0,20	0,00	0,00						1,29	1,00	0,39	0,39		1,78	5,87
Maquina Lavar Louça- Subcritérios					MLL.A.1	MLL.A.2	MLL.A.3	MLL.A.4	MLL.A.5	MLL.A.6	ViA(x)	MLL.B.1	MLL.B.2	MLL.B.3	MLL.B.4	MLL.B.5	MLL.B.6					ViB(x)	MLL.C.1	MLL.C.2	MLL.C.3	MLL.C.4	ViC(x)	V(x)
MLL - Maquina Lavar Louça	Sol.Re	ZANUSSI	DW683	-	-	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-	-
	Sol.Eficientes	BOSCH	SMS46GW01E	-	1,00	0,11	0,77	0,23	0,23	0,89	3,23	0,00	1,00	0,50	0,63	0,63	0,00					2,75	0,89	0,39	0,39	0,45	2,12	8,10
		DAEWOO	DDW-MQ1214S	-	0,80	0,11	0,79	0,21	0,21	0,89	3,01	0,75	0,92	1,00	0,75	1,00	0,44					4,86	0,89	0,00	0,00	0,00	0,89	8,76
		SIEMENS	iSensoric SN215I01AE	-	1,00	1,00	0,43	0,57	0,57	0,00	3,57	0,50	1,00	0,50	0,75	0,55	0,00					3,30	0,00	1,00	1,00	0,45	2,45	9,32
		BOSCH	SMS25AI00E	-	1,00	1,00	0,68	0,32	0,32	0,00	3,32	0,50	1,00	1,00	0,75	0,55	0,33					4,14	0,00	0,07	0,07	0,95	1,08	8,54
		BOSCH	SMS24AW02E	-	0,90	0,00	0,82	0,18	0,18	1,00	3,08	1,00	0,83	1,00	0,75	0,54	0,17					4,29	1,00	0,37	0,37	0,95	2,70	10,07
		BALAY	3VS303IP	-	0,90	0,00	0,95	0,05	0,05	1,00	2,95	1,00	1,00	1,00	0,75	0,51	0,94					5,19	1,00	0,38	0,38	1,00	2,75	10,89
		SIEMENS	iSensoric SR25M834EU	-	0,90	0,11	0,46	0,54	0,54	0,89	3,44	0,00	0,83	0,00	1,00	0,51	1,00					3,34	0,89	0,38	0,38	0,45	2,10	8,88
		BALAY	3VS303BP	-	0,70	0,11	1,00	0,00	0,00	0,89	2,70	1,00	0,92	1,00	0,00	0,50	1,00					4,42	0,89	0,38	0,38	0,44	2,09	9,21
		ELECTROLUX	ESL7344RO	-	1,00	0,11	0,00	1,00	1,00	0,89	4,00	0,00	1,00	0,50	0,56	0,63	0,95					3,63	0,89	0,39	0,39	0,67	2,33	9,96
		ELECTROLUX	ESF5206LOX	-	0,90	0,11	0,74	0,26	0,26	0,89	3,16	0,75	1,00	1,00	0,56	1,00	0,96					5,26	0,89	0,39	0,39	0,78	2,45	10,87

Figure 1. Definition of the table of values associated with the options available in the market that was considered in this work.

References

1. IEA (2019). *Energy Efficiency 2019—Market Reports Series*; OECD/IEA: Paris, France, 2019.
2. IPCC (2015). *Climate Change 2014: Mitigation of Climate Change Summary for Policymakers and Technical Summar*; Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, 2015; ISBN 978-92-9169-142-5.
3. EC (2019) 2020 Climate & Energy Package. Available online: https://ec.europa.eu/clima/policies/strategies/2020_en (accessed on28 March 2019).
4. Anastasiades, K.; Blom, J.; Buyle, M.; Audenaert, A. Translating the circular economy to bridge construction: Lessons learnt from a critical literature review. *Renew. Sustain. Energy Rev.* **2020**, *117*, 109522, doi:10.1016/j.rser.2019.109522.
5. EU (2019) Climate and Energy Framework. Available online: https://www.consilium.europa.eu/en/policies/climate-change/2030-climate-and-energy-framework/ (accessed on18 March 2019).
6. ADENE (2017). *Energy Labelling*; ADENE: Lisbon, Portugal, 2017; ISBN 978-972-8646-36-3.
7. DGEG (2012). *Eficiência Energética em Edifícios—Programa E4*; Direção Geral de Energia e Geologia: Lisboa, Portugal, 2012. (in Portuguese).
8. Wong, L.; Krüger, E. Comparing energy efficiency labelling systems in the EU and Brazil: Implications, challenges, barriers and opportunities. *Energy Policy* **2017**, *109*, 310–323.
9. Mc Alister, C.; Green, S.; Fayole, C. *Discussion Paper: Eco-Design as Part of Circular Economy—Implications for Market Surveillance*; ECOS: Brussels, Belgium, 2018.
10. Corbett, J.; Wardle, K.; Chen, C. Toward a sustainable modern electricity grid: The effects of smart metering and program investments on demand-side management performance in the US electricity sector 2009-2012. *IEEE Trans. Eng. Manag.* **2018**, *65*, 252–263, doi:10.1109/TEM.2017.2785315
11. Zapelloni, G.; Rellán, A.G.; Pastora, M.; Bugallo, B. Sustainable production of marine equipment in a circular economy: deepening in material and energy flows, best available techniques and toxicological impacts. *Sci. Total Environ.* **2019**, *687*, 991–1010, doi:10.1016/j.scitotenv.2019.06.058.
12. Schroeder, P.; Anggraeni, K.; Weber, U. The relevance of circular economy practices to the sustainable development goals. *J. Ind. Ecol.* **2019**, *23*, 77–95
13. Hao, S.; Kuah, A.T.; Rudd, C.D.; Wong, K.H.; Lai, N.Y.G.; Mao, J.; Liu, X. A circular economy approach togreen energy: Wind turbine, waste, and material recovery. *Sci. Total Environ.* **2020**, *702*, 135054.
14. Tang, J.; Tong, M.; Sun, Y.; Du, J.; Liu, N. A spatio-temporal perspective of China's industrial circular economy development. *Sci. Total Environ.* **2019**, *706*, 135754.
15. Fell, M. Energy services a conceptual review. *Energy Res. Soc. Sci.* **2017**, *27*, 129–140.
16. Hoxha, E.; Jusselme, T. On the necessity of improving the environmental impacts of furniture and appliances in net-zero energy buildings. *Sci. Total Environ.* **2017**, *596–597*, 405–416, ISSN 0048-9697.
17. Ko, M.J.; Kim, Y.S.; Chung, M.H.; Jeon, H.C. Multi-objective design for a hybrid energy system using genetic algorithm. *Energies* **2015**, *8*, 2924–2949.
18. Pombo, O.; Allacker, K.; Rivela, B.; Neila, J. Sustainability assessment of energy saving measures: A multi-criteria approach for residential buildings retrofitting a case study of the Spanish housing stock. *Energy Build.* **2016**, *116*, 384–394.
19. Randall, M.; Rawlins, T.; Lewis, A.; Kipouros, T. Performance Comparison of Evolutionary Algorithms for Airfoil Design. *Procedia Comput. Sci*. **2015**, *51*, 2267–2276.
20. Santos, R.; Abreu, A.; Matias, J.C.O. Energy Efficiency in buildings by using evolutionary algorithms: An approach to provide efficiency choices to the consumer, considering the rebound effect. In Proceedings of the Technological Innovation for Resilient Systems: 9th IFIP WG 5.5/SOCOLNET Advanced Doctoral Conference on Computing, Electrical and Industrial Systems, DoCEIS 2018, Costa de Caparica, Portugal, 2–4 May 2018; Springer: Basel, Switzerland, 2018; ISBN 978-3-319-78574-5.
21. Rubaiee, S.; Cinar, S.; Yildirim, M.B. An Energy-Aware Multiobjective Optimization Framework to Minimize Total Tardiness and Energy Cost on a Single-Machine Non preemptive Scheduling. *IEEE Trans. Eng. Manag.* **2018**, *66*, 699–714. doi:10.1109/TEM.2018.2846627
22. Jafari, A.; Valentin, V. An optimization framework for building energy retrofits decision-making. *Build. Environ.* **2017**, *115*, 118–129, doi:10.1016/j.buildenv.2017.01.020.

23. Chuah, J.W.; Raghunathan, A.; Jha, N.K. ROBESim: A retrofit oriented building energy simulator based on EnergyPlus. *Energy Build.* **2013**, *66*, 88–103.
24. Jain, A.S.; Saikia, P.; Rakshit, D. Thermal energy performance of an academic building with sustainable probing and optimization with evolutionary algorithm. *Therm. Sci. Eng. Prog.* **2020**, *17*, 100374, doi:10.1016/j.tsep.2019.100374.
25. Mauro, G.M.; Hamdy, M.; Vanoli, G.P.; Bianco, N.; Hensen, J.L.M. A new methodology for investigating the cost-optimality of energy retrofitting a building category. *Energy Build.* **2015**, *107*, 456–478.
26. Heo, Y.; Augenbroe, G.; Graziano, D.; Muehleisen, R.T.; Guzowski, L. Scalable methodology for large scale building energy improvement: Relevance of calibration in model-based retrofit analysis. *Build. Environ.* **2015**, *87*, 342–350.
27. Le, K.N.; Tam, V.W.; Tran, C.N.; Wang, J.; Goggins, B. Life-Cycle Greenhouse Gas Emission Analyses for Green Star's Concrete Credits in Australia. *IEEE Trans. Eng. Manag.* **2019**, *66*, 286–298, doi:10.1109/TEM.2018.2832094
28. Santos, R.S.; Matias, J.C.O.; Abreu, A.; Reis, F. Evolutionary algorithms on reducing energy consumption in buildings: An approach to provide smart and efficiency choices, considering the rebound effect. *Comput. Ind. Eng.* **2018**, *126*, 729–755, doi:10.1016/j.cie.2018.09.050.
29. Santos, R.; Matias, J.C.O.; Abreu, A. A New Approach to Provide Sustainable Solutions for Residential Sector. *IFIP Adv. Inf. Commun. Technol.* **2019**, *553*, 329–342, doi:10.1007/978-3-030-17771-3_29