A New Approach to Provide Sustainable Solutions for Residential Sector

Ricardo Santos, João Matias, António Abreu

A New Approach to Provide Sustainable Solutions for Residential Sector

Ricardo Santos[1 [0000-0001-5703-8139]], João C.O. Matias[2[0000-0003-4329-6246]], Antonio Abreu[3[0000-0001-8839-5606]]

[1] University of Aveiro, Portugal
GOVCOPP - University of Aveiro, Portugal
ricardosimoessantos84@ua.pt

[2]Dept. of Economics, Management, Industrial Engineering and Tourism (DEGEIT)
University of Aveiro, Portugal
C-MasT – University of Beira Interior
GOVCOPP - University of Aveiro
jmatias@ua.pt

[3] ISEL- Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa
CTS Uninova, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Portugal
ajfa@dem.isel.ipl.pt

Abstract: An energy-efficient appliance normally presents a lower energy consumption compared to a less efficient one, with a higher initial investment, although this not always happens. Additionally, each appliance, presents very different features, leading to some difficulties on its choice by the consumer (decision-agent).

On the other hand, each consumer, has specific and distinguished needs from other consumers, namely of social, economic or environmental nature. Even by adopting these criteria, this is not an isolated guarantee of an optimal solution for the consumer. It is then necessary to complement this approach with multicriteria, combined with optimization techniques. Evolutionary Algorithms (EA), could be used as an optimization technique, to provide sustainable solutions to the consumer, from the market. In this paper, it's presented an approach that integrates both concepts, where at the end, it shall be presented a case study, to demonstrate the application of the proposed method.

Keywords: Energy efficiency, Electrical appliances, Life Cycle Cost Analysis, Multi-Attribute Value Theory (MAVT), Multi-objective Optimization, Evolutionary Algorithms

1 Introduction

The residential sector, plays an important role, in achieving Sustainable Development (SD), with buildings accounting for about 40% of the energy consumed [1] [2].

In the last years, there was made some energy efficiency improvements, regarding electrical household appliances. One of such measures, was the mandatory labeling [3] [4], which allows to inform the consumer about important issues, specifically regarding each appliance (e.g. energy consumption, noise, capacity (fridge), etc.), promoting therefore a suitable use, adjusted to its needs [5].

However, and given the several options available on market (brands and models) as well as the appliances' features, it's difficult to analyze their benefit-cost ratio and therefore, what's the best solution to adopt, to satisfy the consumer needs [6][7].

In this sense, Multiple-Attribute Value Theory (MAVT), could be used as a method, based on a set of criteria, to define the space decision and both objective functions.

Furthermore, the use of optimization techniques, combined with MAVT, can support the decision-agent (consumer), by achieving sustainable solutions, through the household appliances to be acquired.

Given the previous work from [14], Evolutionary Algorithms (EA), have been successfully applied to solve this kind of optimization problem with less time than other algorithms, given their stochastic nature and global search ability [14][15].

Therefore, this work aims to contribute to the following PhD research question, by proposing an integrated approach, based on MAVT and Non-dominated Sorting Genetic Algorithm II (NSGAII), to provide sustainable solutions to the consumer and from the market, concerning Water, Energy and CO_2 savings, satisfying at the same time his different needs according to a set of criteria.

Research Question

Is it possible to develop a holistic model (Economic, Social and Environmental dimensions) to support decision making, based on evolutionary algorithms (EA), that allows the decision agent to obtain sustainable solutions?

Hypothesis

If by using Multi-objective Evolutionary Algorithms (EA), combined with Multicriteria analysis, it's possible to achieve several sustainable solutions to the consumer, by selecting household appliances from the market.

2 Relationship between the PhD work to Industrial and Service Systems

As it mentioned before, the industry and service sectors are going through profound transformation towards digitalization and integration of new levels of "smartness", originating therefore the 4th industrial revolution.

This transformation, is led by terms such as Industry 4.0, Smart Manufacturing and Economy 4.0, giving therefore an interdisciplinary character, expressed by an increasing digitalization and interconnection of systems, products, services and business models. The link between the physical and the cyber worlds, as well as the integration of the "exponential technologies", are key features of this innovation trend.

The paper presented here, is part of a methodology, which is being developed on behalf of a PhD work, to be applied in the context of the 4th Industrial Revolution.

Given its multidisciplinary character, by establishing the interconnection between several and different concepts (e.g. energy efficiency, investment decisions, environmental impact, evolutionary algorithms, product life cycle, among others) as well as being a link between physical systems and cyber worlds, this work can make some contributions specially at a sustainable level, maximizing therefore, the environmental, social and economic wellbeing for each decision agent (e.g. household consumers, companies, public institutions, etc.).

The example of application, presented in this work, can be extended to electrical appliances, regarding industry services, as well as other devices, applied in industry.

The approach presented here, can be suitable at the same time, to the world's different changes (e.g. prices, technology innovation, legislation, etc.), being therefore, a technological Innovation for Resilient Systems.

Therefore, the main goal is to support the decision-agent decisions, with a methodology, implemented by an app, that by making the interconnection between physical systems and cybernetic world, can provide sustainable solutions, regarding a set of criteria pre-established.

3 State of the Art/Related Literature

Methods like simulation (e.g. [18]) based on what if analysis, are usually employed to investigate a limited number of an alternative options.

There are some approaches, which are mainly economical, allowing therefore to obtain highest energy savings, for the same initial investment (e.g.[19-20]). Other approaches, explores several issues like benefit-cost analysis, initial investment, CO_2 savings, among others, related to retrofitting measures (e.g. [21]), where some of them, are even combined with measures and technologies too (e.g. [20]).

However, this type of approaches is considered somehow limited, since it does not account other important factors (e.g. environmental, energy labelling, legal, social factors, among others) to find solutions, suitable to the occupant needs, as well as, they don't consider the different criteria regarding each household appliance, available on the market, and according to the number of household occupants.

Nowadays, some works have developed multicriteria decision making (MCDM) models to support professionals to solve problems, associated with the retrofitting of buildings, by taking into consideration factors, such as the degradation of building elements, energy efficiency, and internal environment comfort. (e.g. [16]), although others, are based on the ranking of alternative solutions (e.g. [17]).

Although MCDM, allows to choose the best alternative on each set of viable options, the criteria adopted are usually conflicting on nature, giving therefore a solution that it is impossible to be optimal against all criteria.

In the same context, there are also other MCDM models, as well as Multiple‒attribute value theory (MAVT) models, found on literature, that combines optimization with multicriteria techniques in order to obtain feasible solutions, by exploring many alternative measures/solutions, pre-selected, according to a set of criteria, suitable to the consumer needs (e.g. [18-21]).

However, such approaches don't consider the different criteria regarding each household appliance, available on the market for each dwelling and its occupants.

Methods based on metaheuristics, have been also applied into energy problems, as an efficient tool to provide a set of feasible solutions, such as Particle Swarm Optimization (PSO) (e.g. [9]) and Genetic Algorithms (GA) (e.g. [13]), among others.

However, none of this methods have been integrated into a combined approach that allows to select efficient appliances to a decision-agent, according to a set of criteria.

4 Research Contribution and Innovation

The approach presented here, was developed to support a Decision-Agent (DA), who wants to acquire a set of electrical appliances (energy services) from the market.

On Fig.1, it is presented an approach to provide an optimal set of appliances, regarding each energy service, needed by the DA (e.g. Consumer).

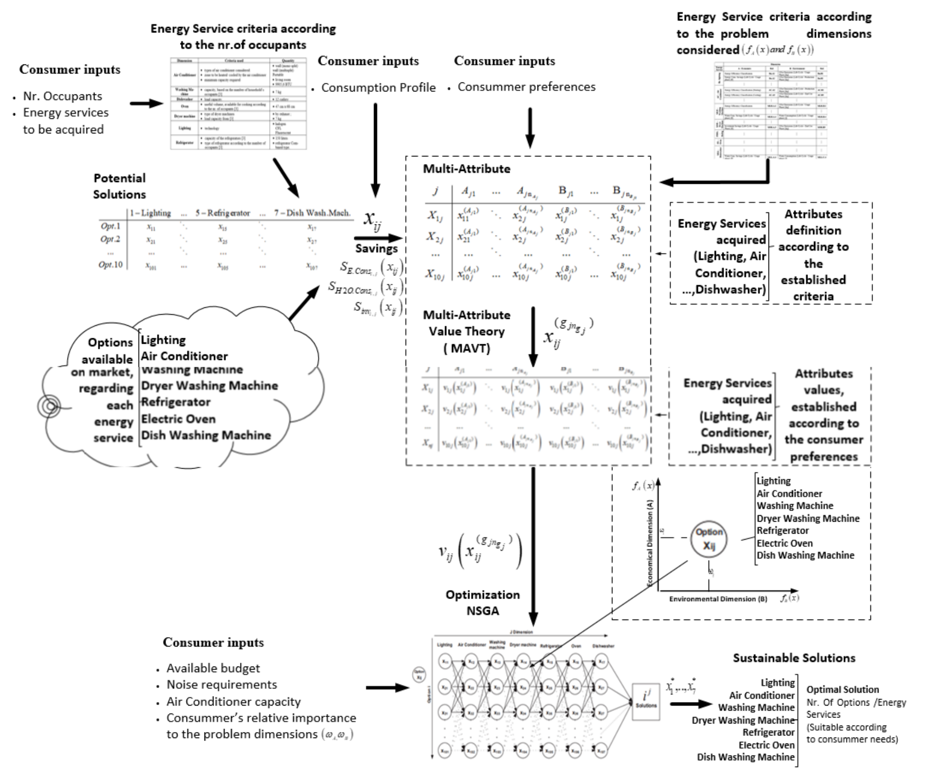

Fig. 1. Conceptual model

At first, a set of potential solutions (x_{ij}) are pre-selected from the market, according to specific criteria, pre-established, based on the number of occupants. The criteria are the same, although the value of the correspondent attributes, can change according to the building number of occupants. An example of such table, is given on ANNEX I (Table A1), regarding the case study presented here.

The pre-selection, allows to reduce the decision space, accounting only the solutions, suitable to the consumer needs, as well as to increase NSGAII efficiency, by achieving optimal solutions with less time.

Each one of this potential solution (x_{ij}), is then formulated as an option *i*, regarding energy service *j* , that can be acquired by the DA (consumer) from the market.

Given a DA (e.g. consumer) consumption profile (see example on ANNEX I (Table A2)), Life Cycle Cost Assessment (LCCA) is then preformed to achieve, for each appliance, the corresponding savings, regarding energy consumption ($S_{E.Cons_{i,j}}(x_{ij})$), water consumption ($S_{H2O.Cons_{i,j}}(x_{ij})$) as well as the initial investment ($S_{inv_{i,j}}(x_{ij})$). Both parameters, are savings, obtained from the comparison between the efficient and the correspondent "standard solution" (less efficient one).

Given the diversity of features, regarding each solution, as well as the DA's economic, social and environmental concerns, it was defined a set of attributes according to the consumer preferences and regarding each energy service, for the two problem dimensions; A-Economics, B-Environment. These attributes are presented on Table 1.

Table 1. Attributes used to define problem dimensions, regarding each energy service considered

	Dimension			
Energy Service	**A - Economics**	**Ref.**	**B - Environment**	**Ref.**
Ilu -lighting	Energy Efficiency Classification	**Ilu.A1**	CO_2e Emissions (Life Cycle - Usage Phase) [kg]	**Ilu.B1**
	Energy Cons. Savings (Life Cycle - Usage phase) [€]	**Ilu.A2**	CO_2e Emissions (Life Cycle - Production Phase) [kg]	**Ilu.B2**
	⋮	⋮	⋮	⋮
AC – Air Conditioner	Energy Efficiency Classification (Heating)	**AC.A2**	CO_2e Emissions (Life Cycle – Production Phase) [kg]	**AC.B2**
	Energy Efficiency Classification (Cooling)	**AC.A3**	CO_2e Emissions (Life Cycle – End Use Phase) [kg]	**AC.B3**
	⋮	⋮	⋮	⋮
MLR – Washing Machine	Energy Efficiency Classification	**MLR.A.1**	CO_2e Emissions (Life Cycle - Usage Phase) [kg]	**MLR.B.1**
	⋮	⋮	⋮	⋮
	Water Cons. Savings (Life Cycle - Usage phase) [€]	**MLR.A.4**	Water Consumption (Life Cycle - Usage phase) [l]	**MLR.B.4**
MSR – Dryer Machine	⋮	⋮	⋮	⋮
	Investment Savings (Life Cycle - Usage Phase) [€]	**MSR.A.3**	CO_2e Emissions (Life Cycle – End Use Phase) [kg]	**MSR.B3**
FRIG. - Refrig	⋮	⋮	⋮	⋮
FE – Oven	⋮	⋮	⋮	⋮
MLL - Dishwasher	⋮	⋮	⋮	⋮
	Water Cons. Savings (Life Cycle - Usage phase) [€]	**MLL.A.4**	Water Consumption (Life Cycle - Usage phase) [l]	**MLL.C.4**

The consumption profile was performed, by making a set of assumptions based on the hours, which was then extrapolated to a weekly and year base. However, the decision-agent (consumer) can also define its usage profile according to its needs, or by using the profile, considered in the case study presented here, as a default.

As it referred before, MAVT is used to support the DA, by evaluating a set of alternative solutions, according to a set of criteria/attributes established (Table 1).

Based on criteria from Table 1, it was defined $x_{ij}^{(g_{jt})}$, as the attribute regarding each alternative solution *i*, associated to a certain energy service *j*, stablished according to criteria t, associated to energy service *j* and problem dimension g considered (A – Economical; B - Environmental), i.e.:

$$g_{jt} \in \left\{ \left\{ A_{j1}, A_{j2}, .. A_{jn_{A_j}} \right\} \cup \left\{ B_{j1}, B_{j2}, .. B_{jn_{B_j}} \right\} \right\} \tag{1}$$

$$g = \{A, B\} \wedge j = \{1,2,..,7\} \wedge t = \left\{ \left\{ 1,2,..n_{A_j} \right\} \cup \left\{ 1,2,..n_{B_j} \right\} \right\} \wedge n_{A_j}, n_{B_j}, t, j \in \mathbb{N} \tag{2}$$

By following the notation described above and based on criteria stablished on Table 1, as well as the assumptions presented on Table A2 (ANNEX I) for the considered case study, it was defined the correspondent attribute behavior/pay-off $\left(x_{ij}^{(g_{jt})}\right)$, regarding each option *i*, belonging to energy service *j*. On Fig 1 a), it's presented an example of this table, regarding the energy service "Lighting".

Therefore, and according to MAVT, there is a value $v_{ij}^{(g_{jt})}\left(x_{ij}^{(g_{jt})}\right)$, associated to the attribute $x_{ij}^{(g_{jt})}$, such as:

$$\boldsymbol{x_{ij}^{(g_{jt})} \longrightarrow v_{ij}^{(g_{jt})}\left(x_{ij}^{(g_{jt})}\right)} \tag{3}$$

Given the 2 objectives considered, different attributes are used to measure the performance in relation to that set of objectives. This attributes, are usually measured on different measurement scales. Therefore, in order to transform the criteria to follow the same scale and units, it was used an expression to stablish the relationship between the new and the previous value of $x_{ij}^{(g_{jt})}$, respective $\left(v_{ij}^{(2)}\left(x_{ij}^{(g_{jt})}\right)\right)$ and $\left(v_{ij}^{(1)}\left(x_{ij}^{(g_{jt})}\right)\right)$, by using as well, the correspondent worst and better results, for a given criteria g_{jt}, i.e.:

$$v_{ij}(x_{ij}^{(2)}) = \frac{\left(v_{ij}^{(1)}(x_{ij}^{(g_{jt})}) - v_{worst.ij}(x_{ij}^{(g_{jt})})\right)}{\left(v_{better.ij}\;\;(x_{ij}^{(g_{jt})}) - v_{worst.ij}(x_{ij}^{(g_{jt})})\right)} \tag{4}$$

The new values of each $x_{ij}^{(g_{jt})}\left(v_{ij}\left(x_{ij}^{(g_{jt})}\right)\right)$, fills a new evaluation table, belonging to each energy service *j*. On Fig. 2, it's shown an example for the two tables regarding energy service "Lighting".

Lighting	$A.1_{.1}$	...	$A.n_{.1}$	$B.1_{.1}$	...	$B.n_{.1}$
X_{11}	$x_{11}^{(A.1.)}$	⋱	$x_{1n_1}^{(A.n_{A1}.)}$	$x_{11}^{(B.1)}$	⋱	$x_{11}^{(B.n_{B1})}$
X_{21}	$x_{21}^{(A.1.)}$	⋱	$x_{1n_1}^{(A.n_{A1}.)}$	$x_{21}^{(B.1)}$	⋱	$x_{21}^{(B.n_{B1})}$
...	...	⋱	...	...	⋱	...
X_{101}	$x_{101}^{(A.1.)}$	...	$x_{1n_1}^{(A.n_{A1}.)}$	$x_{101}^{(B.1)}$	...	$x_{101}^{(B._{B1})}$

a)

Lighting	$A.1_{.1}$	...	$A.n_{.1}$	$B.1_{.1}$	...	$B.n_{.1}$
X_{11}	$v_{11}\left(x_{11}^{(A.1.)}\right)$	⋱	$v_{11}\left(x_{1n_1}^{(A.n_{A1}.)}\right)$	$v_{11}\left(x_{11}^{(B.1)}\right)$	⋱	$v_{11}\left(x_{11}^{(B.n_{B1})}\right)$
X_{21}	$v_{21}\left(x_{21}^{(A.1.)}\right)$	⋱	$v_{21}\left(x_{2n_1}^{(A.n_{A1}.)}\right)$	$v_{21}\left(x_{21}^{(B.1)}\right)$	⋱	$v_{21}\left(x_{21}^{(B.n_{B1})}\right)$
...	...	⋱	...	...	⋱	...
X_{101}	$v_{101}\left(x_{101}^{(A.1.)}\right)$	...	$v_{101}\left(x_{101}^{(A.n_{A1}.)}\right)$	$v_{101}\left(x_{101}^{(B.1)}\right)$	...	$v_{101}\left(x_{101}^{(B.n_{B1})}\right)$

b)

Fig. 2. Example of evaluation table (Lighting energy service)): a) $x_j^{(g_{jt})}$ b) $v_{ij}\left(x_j^{(g_{jt})}\right)$

Based on the value attributes previously achieved, it was used the additive model to aggregate them, referred to each option *i*, regarding energy service *j*, which was further improved, by applying optimization techniques, by using NSGAII algorithm.

Given the trade-off, and the diversity of features, regarding each solution, the consumer will be confronted with a problem of combinatorial nature (Fig.1), where the number of combinations is dependent on the number of options to be considered, regarding each dimensions. This number, although, potentially bigger (23 million of combinations approximately for the case study considered), can be reduced, by assuming that the consumer cannot perform any choices (x_{ij}), given his limited budget (Fig.1).

Constraints like the air conditioner capacity and appliances noise minimal requirements, will also be accounted to suit consumer needs, to improve its social wellbeing.

After defining the value attributes of each potential solution, and by using the additive model, the problem presented here, can be formulated as follows:

$$max \quad V_m(x), \frac{c}{m} = A, B$$
$$subjecttox \in Xc/V_m(x) = [V_A(x), V_B(x)]^T \tag{5}$$

Where x is the decision variable vector, defined as:

$$x \in X : x \in \left\{x_{ij}^{(A_{jt})}, x_{ij}^{(B_{jt})}\right\} \wedge t, i, j \in \mathbb{N} \tag{6}$$

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

Where $V_A(x)$ and $V_B(x)$, are the aggregate objective functions, regarding each dimension considered (A-Economics; B-Environment):

$$V_g(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{g_j}} v_j(x_j^{(g_{jt})})\; w/g = \{A, B\} \wedge v_j(x_j^{(g_{jt})}) \wedge n_j, n_{g_j}, t, j \in \mathbb{N} \tag{8}$$

Therefore, and based on (8), the objective functions are:

$$EconomicWell - being: max\, V_A\,(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{A_{jt}}} v_j(x_j^{(A_{jt})}) \tag{9}$$

$$EnvironmentWell - being: max\, V_B\,(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{B_{jt}}} v_j(x_j^{(B_{jt})}) \tag{10}$$

The first objective function is based on the works of [14] and [22].

Using the additive model from MAVT, the aggregated function, results into a unique objective function, weighted by the DA relative importance (ω_g) as follows:

$$\begin{aligned} V(V_A(x), V_B(x)) &= \omega_A . V_A(x) + \omega_B . V_B(x) \\ &= \sum_{j=1}^{n_j} \left(\omega_A \sum_{t=1}^{n_{A_j}} v_j(x_j^{(A_{jt})}) + \omega_B \sum_{t=1}^{n_{B_j}} v_j(x_j^{(B_{jt})}) \right) \end{aligned} \tag{11}$$

The constraints, regarding economic and environment well-being/dimensions, are:

Economic – Budget:

$$r1: \sum_{j=1}^{n_{dim}} I_j(x_j) \leq available\ budget\left(\eta_{disp.}\right) \Leftrightarrow \sum_{j=1}^{n_{dim}} x_j^{(A_{jt})} \leq \eta_{disp.} \tag{12}$$

$$w/A_{j\,t} = \{A_{14}, A_{26}, A_{35}, A_{44}, A_{54}, A_{64}, A_{75}\} \wedge n\, t, j_{dim} \tag{13}$$

Environment – Noise:

$$r_j: Noise_j \leq Max.Noise_j \Leftrightarrow x_j^{(B_{jt})} \leq Max.Noise_j \tag{14}$$

$$w/B_{j\,t} = \{B_{24}, B_{35}, B_{44}, B_{54}, B_{64}, B_{75}\} \wedge n\, t, j_{dim} \tag{15}$$

The NSGAII individual framework, is presented as follows on **Fig. 2**:

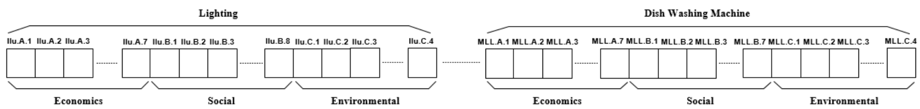

Fig. 3. NSGAII's individual framework

NSGAII's codification used, was real.

The model will be applied by using a case study, and considering a consumer (DA), who wishes to acquire 7 types of appliances. His building has four occupants (him included) and the relative importance's (ω_A and ω_B) are respectively 0,7 and 0,3. All the remaining assumptions, were made on Tables A1 and A2 (ANNEX I).

5 Results and Discussion

NSGAII was programmed in Matlab using the following parameters:

- Selection method: Tournament
- Crossover method: single point
- Mutation used: Normal Random Mutation

The remained NSGA-II parameters (initial population, crossover and mutation rate) were defined after several computational experiments.

The parameter of max generations was tested at first, where it was selected a maximum generation number of 90 to show that if 90 iterations were enough to find the Pareto frontier. Other parameters were also tested, such as the population size (100 individuals),the tournament size (10), the crossover rate (0.9), and the mutation rate (0.3). The obtained results, regarding 90^{th} and 100^{th} generations, are presented on Fig. 6 a), where it can be seen that both cases, have similar Pareto frontier. In this sense it was selected the max number iterations/generations of 90. Then, it was preformed several combinations of crossover and mutation rates of NSGA-II (Table. 2).

Table 2. Combinations of crossover and mutation rates used

Experiment	Crossover rate	Mutation rate
1	0.8	0.1
2	0.8	0.3
3	0.9	0.1
4	0.9	0.3

The combinations, presented on Table 2, were performed by setting a max iteration of 90. The correspondent results, are shown on Fig. 4 b), where it's noted that the small change on parameters, has little effect on the results. Thus, it was used the following parameters of NSGA-II to show the results of the present case: population size (100), max iteration (90), tournament size (10), crossover rate (0.9) and mutation rate (0,1).

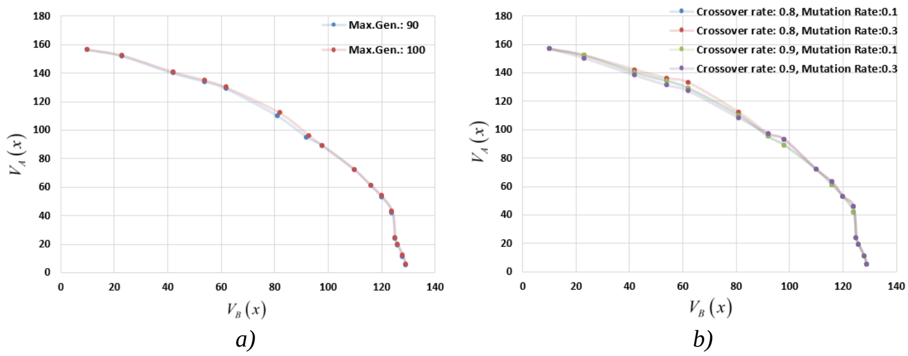

Fig. 4. Pareto frontier: a)for 90^{th} and 100^{th} generations b) different parameters (90^{th} Generation)

NSGA-II is applied on resolution of multi-objective problems. Therefore, the correspondent solution, is a Pareto frontier, which is gradually formed through an iteration process, where is an increase in the number of nodes of Pareto frontier in the early generations. Once the frontier was formed, better results of each node were founded in further iterations.

After NSGAII calculations, the Pareto frontier in Fig. 4 a), is therefore obtained, where each node represents a potential solution of the problem, i.e., a set of sustainable solutions (appliances), regarding each energy service required.

One of these nodes are presented on Table 3, as an example of a feasible solution obtained, considering a budget of 2100 €.

Table 3. Example of a sustainable solution obtained from this approach

Dimension	Stand. Solution Total Invest.	Effic. sol. Total Invest (€)	Invest. Saving (€)	Energy Consum. Savings (€)	Water Consum. Savings	CO2 Savings (kg)	Brand	Model
Lighting	15,89	09,53	5,34	59,4	-	28,9	GE	EFL23W
Air Conditioning	368,0	299,0	69,0	1320,6	-	1315,7	Whirlpool	PACW9HP
Refrigerator	250,0	529,0	-279,0	708,1	-	8,7	Candy	CFET 6182W
Dishwasher Machine	310,0	349,0	-39,0	3,2	423	6,9	Bosch	SMS25AI00E
Washing Machine	262,0	294,0	-32,0	6,9	317	94,8	Siemens	WI12A222ES
Oven	170,0	199,0	-29,0	1,7	-	2,2	Zanussi	ZZB21601XV
Clothes dryer	349,0	419,0	-70,00	12,3	-	1,7	Electrolux	EDP2074PDW
Total:	1724,9	2099,6	-374,7	2112,3	740	1458,9	-	-

It is also presented the CO_2 savings, regarding the choice of this solution, compared with the less efficient (standard) one (approx. values).

According to **Table 3**, if the consumer, opts for the solutions set, provided by this approach, he can save up to 2112,3 € per year, further contributing to a 1458,9 kg of

CO_2 and 740 litres of water, both savings/years, given the 10 years life cycle considered.

6 Conclusions and Further Work

In this work, it was presented an approach to provide sustainable household appliances from the market, to the decision-agent (consumer), by considering two objectives, regarding sustainability; environment and economic well-being.

Both solutions were pre-selected, according to a set of specific criteria and regarding each type of appliance, considered by the case study.

Criteria was used, to pre-select the appliances from the market, adjusting therefore, the method to the case study presented here. Other criteria, were combined with MAVT, to modelling the consumer preferences, according to the two problem dimensions.

The main objective, was to maximize the consumer well-being (environment and economics). The social wellbeing was also promoted, by suit the obtained solutions to the consumer needs.

The relative importance, given by the DA (consumer), was also considered, in order to weight the DA decision through both dimensions.

NSGAII, where then applied here, to get optimal solutions, by maximizing both dimensions, considering the environmental impact (CO_2 savings), as well as the economic rationality (initial investment and energy consumption savings) regarding the lifecycle of each appliance, during its usage phase.

The results show that this method performs well in this case, by providing optional and also, sustainable appliances, that attends the consumer needs.

We test different parameters (max number of iterations, crossover rate and mutation rate) and in the common range of values, these parameters are not sensitive to the results. Additionally, NSGA-II can also find the Pareto frontier of the solutions, providing therefore several alternative solutions to the consumer.

The achievements presented on this work, allows to proceed in a way of getting a more completed approach that maximizes both dimensions of sustainability (Economical, Environmental and Social) with the social dimension, being therefore integrated into the model developed here, in order to better express the consumer preferences, which will allow to answer the PhD research question presented here.

References

1. IEA: Energy Efficiency 2017 – Market Reports Series, OECD/IEA (2017)
2. Gul, M., Patidar. S. (2015). Understanding the energy consumption and occupancy of a multi-purpose academic building, In Energy and Buildings, Volume 87, Pages 155-165, ISSN 0378-7788
3. ADENE: Manual da Etiqueta Energética, ADENE, Lisboa ISBN: 978-972-8646-36-3 (2017)
4. DGEG.: Eficiência Energética em Edifícios – Programa E4, Direção Geral de Energia e Geologia, Lisboa (2002)

5. Wong, I., L., Krüger, E., Comparing energy efficiency labelling systems in the EU and Brazil: Implications, challenges, barriers and opportunities, In Energy Policy, vol.109, pp. 310-323, Springer, Heidelberg (2017)
6. Fell, M.: Energy services: A conceptual review, Energy Research & Social Science, vol.27, pp.129--140, Springer (2017)
7. Hoxha, E., Jusselme, T. (2017), On the necessity of improving the environmental impacts of furniture and appliances in net-zero energy buildings, In Science of The Total Environment, Volumes 596–597, Pages 405-416, ISSN 0048-9697
8. Ting, T.O.; Rao, M.V.; Loo, K.C. (2006) A novel approach for unit commitment problem via an effective hybrid particle swarm optimization. IEEE Trans. Power Syst., 21, 411–418.
9. Ko, M.J.; Kim, Y.S.; Chung, M.H.; Jeon, H.C.(2015), Multi-objective design for a hybrid energy system using genetic algorithm. Energies, 8, 2924–2949.
10. Randall, M., Rawlins, T., Lewis, A., Kipouros, T., Performance Comparison of Evolutionary Algorithms for Airfoil Design, In Procedia Computer Science, vol. 51, pp. 2267-2276, Springer Heidelberg (2015)
11. Goldberg, D.: Genetic Algorithms in Search Optimization and Machine Learning, Addison Wesley, Maryland (1989).
12. Chuah, J. W., Raghunathan, A., Jha, N. K. (2013), ROBESim: A retrofitoriented building energy simulator based on EnergyPlus, Energy Build., vol. 66, pp. 88–103.
13. Pombo, O., Allacker, K., Rivela, B., Neila, J., (2016) Sustainability assessment of energy saving measures: a multi-criteria approach for residential buildings retrofittingda case study of the Spanish housing stock, Energy Build. 116 pp.384e394.
14. 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, IFIP International Federation for Information Processing 2018, 2018-03-29, book-chapter Part of ISBN: 978-3-319-78574-5
15. Asadi, E., Silva, M. G., Antunes, C. H., Dias, L. (2012), Multi-objective optimization for building retrofit strategies: A model and an application, Energy Build., vol. 44, pp. 81–87
16. Caccavelli, D., Gugerli, H., Tobus (2002), A European diagnosis and decision-making tool for office building upgrading, Energy Build., vol. 34, no. 2, pp. 113–119.
17. Kaklauskas, A., Zavadskas, E. K., Raslanas, S., (2005) Multivariant design and multiple criteria analysis of building refurbishments, Energy Build., vol. 37, no. 4, pp. 361–372, 2005.
18. Pombo, O., Allacker, K., Rivela, B., Neila, J., (2016) Sustainability assessment of energy saving measures: a multi-criteria approach for residential buildings retrofittingda case study of the Spanish housing stock, Energy Build. 116 pp.384e394
19. Jafari, A., Valentin, V., (2017), An optimization framework for building energy retrofits decision-making, Building and Environment, Volume 115, Pages 118-129,ISSN 0360-1323, https://doi.org/10.1016/j.build-env.2017.01.020.(http://www.sciencedirect.com/science/article/pii/S0360132317300331)
20. Mauro, G.M., Hamdy, M., Vanoli, G.P., Bianco, N., Hensen, J.L.M. (2015) A new methodology for investigating the cost-optimality of energy retrofitting a building category, Energy Build. 107 pp. 456 e 478.
21. Heo, Y. , Augenbroe, G., Graziano, D., Muehleisen, R.T. , Guzowski, L., (2015) Scalable methodology for large scale building energy improvement: relevance of calibration in model-based retrofit analysis, Build. Environ. 87 pp. 342e350.
22. R.S. Santos, J.C.O. Matias, A. Abreu, F. Reis, Evolutionary algorithms on reducing energy consumption in buildings: An approach to provide smart and efficiency choices, considering the rebound effect, Computers & Industrial Engineering, Volume, 126,2018,Pages 729-755,ISSN 0360 8352, https://doi.org/10.1016/j.cie.2018.09.050

ANNEX I – Criteria and consumer profile given the case study considered

Table A.1. Criteria used to pre-select the appliances from the market (applied to case study)

Dimension	Criteria used	Quantity
Air Conditioner	• types of air conditioner considered: • zone to be heated/ cooled by the air conditioner • minimum capacity required	• wall (mono split) wall (multi split) Portable • living room • 9905,6 BTU
Washing Machine	• capacity, based on the number of household's occupants [3]	• 7 kg
Dishwasher	• load capacity.	• 12 cutlery
Oven	• useful volume, available for cooking according to the nr. of occupants [3]	• 47 cm x 68 cm
Dryer machine	• type of dryer machines • load capacity from [3]	• by exhaust ; • 7 kg
Lighting	• technology	• halogen CFL Fluorescent
Refrigerator	• capacity of the refrigerators [3] • type of refrigerator according to the number of occupants [3]	• 150 liters • refrigerator Combined type.

Table A.2. Assumptions taken, regarding the consumer usage profile

Emission factor [gCO2/kWh]	675	**Discount Factor [%]**		7
Life cycle (usage phase) [years]:	10	**Annual Factor**		7,02
Electrical Energy tariff [€/kWh]	0,162	**Water tariff [€/m3]**		1,19
Energy Service	**Usage Profile (h)**			
	Daily	**Weekly**	**Monthly**	**Annual**
Air Conditioner	2	12	48	576
Washing Machine	1	4	16	192
Dryer Machine	1	4	16	192
Refrigerator	11	77	330	4015
Electric Oven	1	2	8	96
Dish Washing Machine	1	4	16	192
Lighting	5	35	150	1825
Energy Service	**Usage Profile (Frequency)**			
	Daily	**Weekly**	**Monthly**	**Annual**
Air Conditioner	1	6	24	288
Washing Machine	1	4	16	192
Dryer Machine	1	4	16	192
Refrigerator	1	7	30	365
Electric Oven	1	2	8	96
Dish Washing Machine	1	4	16	192
Lighting	1	7	30	365