



HAL
open science

A Decision-Making Tool to Provide Sustainable Solutions to a Consumer

Ricardo Santos, J. Matias, Antonio Abreu

► **To cite this version:**

Ricardo Santos, J. Matias, Antonio Abreu. A Decision-Making Tool to Provide Sustainable Solutions to a Consumer. 11th Doctoral Conference on Computing, Electrical and Industrial Systems (DoCEIS), Jul 2020, Costa de Caparica, Portugal. pp.63-78, 10.1007/978-3-030-45124-0_6 . hal-03741557

HAL Id: hal-03741557

<https://inria.hal.science/hal-03741557v1>

Submitted on 1 Aug 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

A Decision-Making Tool to Provide Sustainable Solutions to a Consumer

Ricardo Santos¹, J. C. O. Matias² and Antonio Abreu³

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

²Dept. 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 According to some existed studies, one of the economic sectors to achieve sustainability, is the household appliance sector. However, given the different issues (e.g. energy and water consumption, reliability, initial cost, design, noise, illuminance, etc.) to be considered, together with the existence of several brands and models from the market, brings some difficulties to a consumer, who wants to reach a good compromise between them, given its concerns, regarding each dimension of sustainability, namely; economic, social and environmental. By using multi-attribute value theory, combined with Evolutionary Algorithms (EA), it's possible to achieve sustainable solutions from the market. In this work, it's presented an approach to support a consumer, by achieving a set of sustainable household appliances from the market, based on its preferences and needs. A case study shall be used, to give an example of a global solution, where several benefits are achieved, including environment and economic ones.

Keywords: Decision Support Systems, Consumer Preferences, Sustainability, Multi-Objective Optimization, Multi-Attribute Value Theory (MAVT), Evolutionary Algorithms, Life Cycle Cost Analysis (LCCA).

1 Introduction

According to [1], sustainability measures are needed, with buildings representing about 39 % of the global energy consumption.

From that percentage, approximately 16% of the world's final electrical energy, is due to the residential sector ([2]), thus representing an important sector to be improved, through the use of sustainable actions or measures.

One way to do it, is through the electrical household appliances, where there has been made some improvements regarding energy efficiency and sustainability in

general ([3-6]). Such incentives, includes measures like the mandatory labeling ([4]), provides information to the consumer, regarding each electric household appliance (e.g. capacity (refrigerator), water and energy consumption (washing machine), initial investment (air-conditioner) ,etc.), with the goal of adjusting each available solution to the consumer's needs ([4-5]).

Although the benefits achieved with this kind of measures, it's somehow hard for a typical consumer, to obtain the best solution, adjusted to its needs and preferences.

This happens due to the existence of different options/solutions, available on market, whether in terms of brands and models, or even related to its features ([5-7]).

The introduction of multicriteria methods, such as multi-attribute value theory (MAVT), can support the consumer to preform sustainable choices, that attends, not only its preferences, but its concerns and needs as well, according to three sustainability's dimensions, namely, environment, economic and social.

Through previous work, evolutionary algorithms (EA), based on NSGA II algorithm, have been applied with success, when solving the type of problems presented in this work ([8-11]), by even solving with more efficiency than other methods ([10]), providing different and feasible solutions.

Therefore, and by following the research line, presented on previous works ([9-10] and [12-13]), this work presents an approach, supported by MAVT and NSGAI methods, to assist the consumer, by providing from the market, a set of sustainable appliances, adjusted to its different needs and priorities.

The approach presented here, will be demonstrated through a case study, from which, it is achieved a set of sustainable equipment's, that not only maximizes the consumer's economic, social and environment wellbeing, but also attends its preferences and needs.

Research Question

How to support a consumer, by choosing energy services (equipment for the residential sector) to achieve sustainable solutions to promote their economic, social and environmental well-being?

Hypothesis

H1: If by using Multi-Attribute Value Theory (MAVT), to include criteria on behalf of economic, social and environmental dimensions, combined with Multi-objective Evolutionary Algorithms (EA), it's possible to achieve sustainable solutions from the market of household appliances.

2 Relationship between the PhD Work and Technological Innovation for Life Improvement

This work is part of an approach, which was developed for a PhD work, applied on behalf of Technological Innovation for Life Improvement, with focus on human wellbeing.

By acting through different scientific areas, such as energy efficiency, decision support systems, ecological footprint, evolutionary algorithms, product life cycle assessment, among others, and promoting a digital world by using tools and concepts such as evolutionary algorithms from artificial intelligence and multicriteria decision making, it's possible to provide a better and sustainable future with high quality of life.

The impacts of such approach allow to enhance health and environment across the globe, by achieving at the same time, suitable and sustainable products to each individual, and improving its quality of life.

Therefore, this work can make some contributions specially at a sustainable level, maximizing therefore, the environmental, social and economic wellbeing, of everyone. The main goal is to support the decision-agent decisions, with an approach, implemented through an app, that allows the provision of sustainable solutions, regarding a set of criteria pre-established.

3 Literature Review

From several approaches, available on literature, the use of simulation methods, based on "what if" scenarios, is one of them (e.g. [13-14]), being normally used to explore a restricted number of an alternative solutions.

Other approaches, although, are mainly based on economic analysis, allowing to maximize energy savings, for a given initial investment (e.g.[15]), while other methods, explores retrofitting measures, based on benefit-cost analysis, CO₂ consumption, thermal comfort, investment savings, among others (e.g. [13][16]), with some of them, being combined with other systems too (e.g. [15-17]).

However, many of these approaches, presents some limitations, since it doesn't consider other relevant issues (e.g. energy labelling, environmental, legal, social issues, among others) to achieve solutions, adjusted to the needs of each person/occupant. Furthermore, they don't account the different attributes regarding each appliance available on market and suitable to the number of building occupants.

Recently, there are some works where it was developed multicriteria decision making (MCDM) based methods, to support consumers, or even professionals, in order to solve problems regarding building's retrofitting, by considering issues, like energy efficiency, the internal environment comfort and the depreciation of building elements (e.g. [14][17-19]). Others are based on the ranking of alternative options (e.g. [18-20]).

While MCDM methods, allows to choose the best set of feasible solutions, the adopted criteria are normally conflicted between each other, allowing thus, to obtain a solution that it is impossible to be optimal, considering all criteria.

Other MCDM models, found on literature, and based on Multiple-attribute value theory (MAVT), have been combined with optimization techniques to obtain feasible solutions (e.g. [11][17-21]).

However, these approaches don't account the different criteria regarding each electrical appliance available on market, regarding each dwelling and occupants.

Approaches, based on metaheuristics, have been also deployed into energy problems, as an efficient tool to achieve a set of feasible solutions, such as Particle Swarm Optimization (PSO) methods (e.g. [8]) and methods based on Genetic Algorithms (GA) (e.g. [13]), among others.

Although, none of these approaches have been integrated into a combined approach to choose sustainable appliances to a consumer, based on a set of attributes.

4 Research Contribution and Innovation

The method presented in this paper, intends to support a consumer, who wants to buy a set of energy services (household appliances), existed in the market (Figure1).

Each set of equipment's, are related to a given household appliance (energy service), considered to be bought by the consumer, and it corresponds to a set of candidate solutions, from which, it will be selected one solution at a time, to be proposed by the approach (Figure 1) as a sustainable individual solution, chosen based on the consumer's preferences, together with its concerns, regarding each sustainability's dimension.

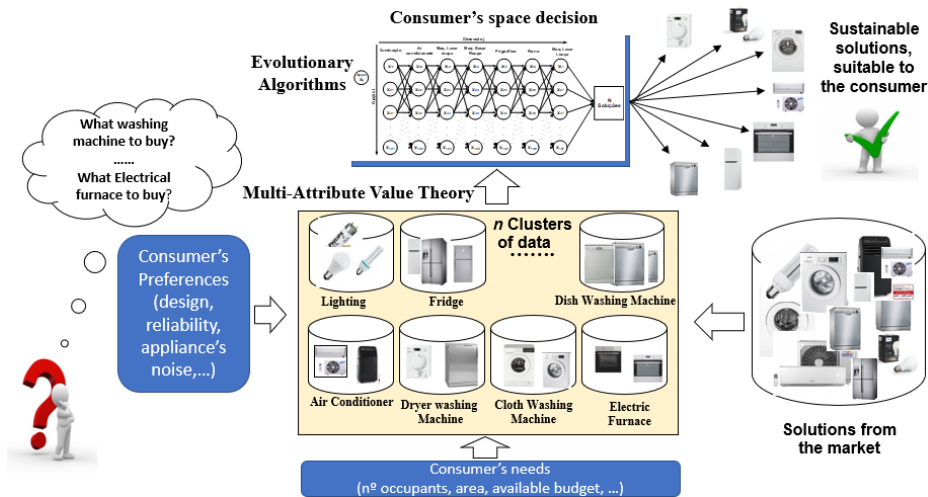


Fig. 1. Proposed approach (rough view).

The approach, presented on Fig. 1, can be better explained through a detailed view, presented on Fig. 2, where the 1st stage starts with the pre-selection of a set of candidate solutions (x_{ij}) from the market, and based on specific criteria.

Although the correspondent attributes/criteria, remains the same, the correspondent values, varies according to the number of occupants.

The adopted criteria used here, allows the pre-selection of the household appliances, available on market, so the decision space, can be reduced, considering

only the options, adjusted to the consumer needs, as well as to increase the efficiency of NSGAI, by obtaining optimal and feasible solutions with less time.

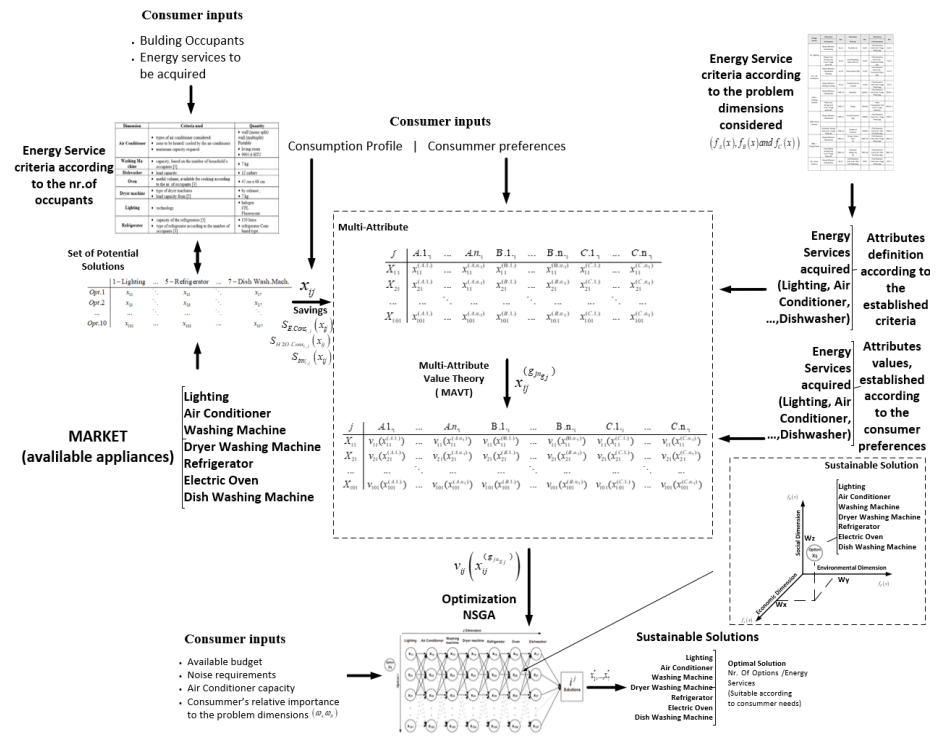


Fig. 2. Proposed approach (detailed view).

Therefore, and based on Fig.2, the pre-selection gives us a set of candidate solutions (x_{ij}) , where each one, can be formulated as an option i , associated to an energy service/household type j , to be bought by the consumer on market.

A consumer's consumption profile, was also considered, to preform Life Cycle Cost Assessment (LCCA) for each appliance, to achieve the corresponding savings, regarding energy consumption $(S_{E.Cons_{i,j}}(x_{ij}))$, initial investment $(S_{inv_{i,j}}(x_{ij}))$ and water consumption $(S_{H2O.Cons_{i,j}}(x_{ij}))$. Such savings were obtained through the comparison between the sustainable solution and the correspondent "less sustainable" (i.e. standard) one.

Considering the several issues, associated to each solution, as well as the consumer's social, economic and environment concerns, a set of criteria was established, for each energy service, and regarding the three dimensions considered, i.e.: A-Economics, B-Social and C-Environment. These criteria are shown on Table 3.

Table 3. Criteria defined according to the household appliance (energy service) type.

Household Appliance type	Dimension	Ref.	Dimension	Ref.	Dimension	Ref.
	A-Economics				C-Environment	
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 (Life Cycle— 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 labelling (Cooling)	AC.A6	Customer Service (warrant)	AC.B9	CO _{2e} (Avoided) Emissions during the usage phase	AC.C3
⋮	⋮	⋮	⋮	⋮	⋮	⋮
FE. – Oven (Electric)	Energy Efficiency Labelling	FE.A.1	Design	FE.B1	CO _{2e} (Avoided) Emissions during the usage phase	FE.C.1
	⋮	⋮	⋮	⋮	Accessibility (Product repaired by other people)	FE.C2
	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 Labelling	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 (Life Cycle— Usage phase) [€]	MLL.A.6	Perceived Satisfaction (by other clients)	MLL.B.6	Water Consumption (Life Cycle— Usage phase)	MLL.C.4

Therefore, MAVT was used to assist the consumer, by assessing a set of sustainable appliances, based on the attributes presented on Table 3.

Through these attributes, it was defined a decision variable $(x_{ij}^{(g_p)})$, related to each candidate solution/household appliance i , and belonging to a given appliance type/energy service j . This variable is defined based on criteria t , associated to an appliance type j and problem dimension g (i.e. A-Economical; B-Social and C-Environmental), namely:

$$g = \{A, B, C\} \wedge j = \{1, 2, \dots, 7\} \wedge t = \left\{ \{1, 2, \dots, n_{A_j}\} \cup \{1, 2, \dots, n_{B_j}\} \cup \{1, 2, \dots, n_{C_j}\} \right\} \wedge n_{A_j}, n_{B_j}, n_{C_j}, t, j \in \square \quad (1)$$

By following these notation and according to the criteria defined before, on Table 3, together with the assumptions made, the correspondent decision-variable, regarding each attribute considered $(x_{ij}^{(g_p)})$, can be aggregated and framed into a set of pay-off/behavior tables, regarding each energy service j . On Fig. 3 a), it's shown an example of this table, considering the energy service/household appliance type "Air Conditioner". The correspondent table, regarding the respective $(v_{ij}^{(g_p)}(x_{ij}^{(g_p)}))$ values, were achieved by using MAVT and the following relation:

$$x_{ij}^{(g_p)} \longrightarrow \left(\frac{\left| \frac{x_{ij}^{(g_p)} - x_{ij}^{(g_p, worst)}}{x_{ij}^{(g_p, best)} - x_{ij}^{(g_p, worst)}} \right|}{\left| \frac{x_{ij}^{(g_p)} - x_{ij}^{(g_p, worst)}}{x_{ij}^{(g_p, best)} - x_{ij}^{(g_p, worst)}} \right|} \right) \longrightarrow v_{ij}^{(g_p)}(x_{ij}^{(g_p)}) \quad (2)$$

Since that each decision value $(v_{ij}^{(g_p)}(x_{ij}^{(g_p)}))$, works with different scales and units, an equation was adopted to define the relation between the new and the previous value of $x_{ij}^{(g_p)}$, respectively $(v_{ij}^{(1)}(x_{ij}^{(g_p)}))$ and $(v_{ij}^{(2)}(x_{ij}^{(g_p)}))$, by also using the worst and better results, and by considering a given criteria g_{jt} , i.e.:

$$v_{ij}^{(1)}(x_{ij}^{(g_p)}) \longrightarrow \left(\frac{\left| \frac{v_{ij}^{(1)}(x_{ij}^{(g_p)}) - v_{worst_{jt}}(x_{ij}^{(g_p)})}{v_{better_{jt}}(x_{ij}^{(g_p)}) - v_{worst_{jt}}(x_{ij}^{(g_p)})} \right|}{\left| \frac{v_{ij}^{(1)}(x_{ij}^{(g_p)}) - v_{worst_{jt}}(x_{ij}^{(g_p)})}{v_{better_{jt}}(x_{ij}^{(g_p)}) - v_{worst_{jt}}(x_{ij}^{(g_p)})} \right|} \right) \longrightarrow v_{ij}^{(2)}(x_{ij}^{(g_p)}) \quad (3)$$

On Fig.3, it's given an example for an evaluation table ("Air Conditioning").

A.C.	A ₂₁	A ₂₂	...	A _{2n_{A2}}	B ₂₁	B ₂₂	...	B _{2n_{B2}}	C ₂₁	C ₂₂	...	C _{2n_{C2}}
X ₁₂	x ₁₂ ^(A₂₁)	x ₁₂ ^(A₂₂)	...	x ₁₂ ^(A_{2n_{A2}})	x ₁₂ ^(B₂₁)	x ₁₂ ^(B₂₂)	...	x ₁₂ ^(B_{2n_{B2}})	x ₁₂ ^(C₂₁)	x ₁₂ ^(C₂₂)	...	x ₁₂ ^(C_{2n_{C2}})
X ₂₂	x ₂₂ ^(A₂₁)	x ₂₂ ^(A₂₂)	...	x ₂₂ ^(A_{2n_{A2}})	x ₂₂ ^(B₂₁)	x ₂₂ ^(B₂₂)	...	x ₂₂ ^(B_{2n_{B2}})	x ₂₂ ^(C₂₁)	x ₂₂ ^(C₂₂)	...	x ₂₂ ^(C_{2n_{C2}})
...
X ₁₀₂	x ₁₀₂ ^(A₂₁)	x ₁₀₂ ^(A₂₂)	...	x ₁₀₂ ^(A_{2n_{A2}})	x ₁₀₂ ^(B₂₁)	x ₁₀₂ ^(B₂₂)	...	x ₁₀₂ ^(B_{2n_{B2}})	x ₁₀₂ ^(C₂₁)	x ₁₀₂ ^(C₂₂)	...	x ₁₀₂ ^(C_{2n_{C2}})

a)

A.C.	A ₂₁	A ₂₂	...	A _{2n_{A2}}	B ₂₁	B ₂₂	...	B _{2n_{B2}}	C ₂₁	C ₂₂	...	C _{2n_{C2}}
X ₁₂	v ₁₂ (x ₁₂ ^(A₂₁))	v ₁₂ (x ₁₂ ^(A₂₂))	...	v ₁₂ (x ₁₂ ^(A_{2n_{A2}}))	v ₁₂ (x ₁₂ ^(B₂₁))	v ₁₂ (x ₁₂ ^(B₂₂))	...	v ₁₂ (x ₁₂ ^(B_{2n_{B2}}))	v ₁₂ (x ₁₂ ^(C₂₁))	v ₁₂ (x ₁₂ ^(C₂₂))	...	v ₁₂ (x ₁₂ ^(C_{2n_{C2}}))
X ₂₂	v ₂₂ (x ₂₂ ^(A₂₁))	v ₂₂ (x ₂₂ ^(A₂₂))	...	v ₂₂ (x ₂₂ ^(A_{2n_{A2}}))	v ₂₂ (x ₂₂ ^(B₂₁))	v ₂₂ (x ₂₂ ^(B₂₂))	...	v ₂₂ (x ₂₂ ^(B_{2n_{B2}}))	v ₂₂ (x ₂₂ ^(C₂₁))	v ₂₂ (x ₂₂ ^(C₂₂))	...	v ₂₂ (x ₂₂ ^(C_{2n_{C2}}))
...
X ₁₀₂	v ₁₀₂ (x ₁₀₂ ^(A₂₁))	v ₁₀₂ (x ₁₀₂ ^(A₂₂))	...	v ₁₀₂ (x ₁₀₂ ^(A_{2n_{A2}}))	v ₁₀₂ (x ₁₀₂ ^(B₂₁))	v ₁₀₂ (x ₁₀₂ ^(B₂₂))	...	v ₁₀₂ (x ₁₀₂ ^(B_{2n_{B2}}))	v ₁₀₂ (x ₁₀₂ ^(C₂₁))	v ₁₀₂ (x ₁₀₂ ^(C₂₂))	...	v ₁₀₂ (x ₁₀₂ ^(C_{2n_{C2}}))

b)

Fig. 3. Example of evaluation table (Air Conditioner): a) $x_{ij}^{(g_p)}$; b) $v_{ij}^{(g_p)}$.

The final values were then calculated and stored in evaluation tables such as the one presented on Fig. 3 b), regarding each variable and energy service considered.

Then, an additive model, was used to aggregate such values, by considering each solution i regarding each household appliance j . Such aggregation is formulated by using three different objective functions, each one regarding to a sustainability's dimension considered. These functions are further optimized, by employing an optimization technique, based on NSGAI algorithm.

In this work, it was considered 10 appliances (candidate solutions), for each type of appliance. On total, there was considered here, 7 type of appliances (Figs. 1 and 2).

Besides the budget constraint, other constraints were considered in this work (e.g. appliances noise, air conditioner capacity, water consumption, among others).

Thus, and considering the MAVT model, this problem can be defined as:

$$\begin{aligned} \max \quad & V_m(x), & c/m = A, B, C \\ \text{subject to } & x \in X & c/V_m(x) = [V_A(x), V_B(x), V_C(x)]^T \end{aligned} \quad (4)$$

With x , being the decision variable, being defined as:

$$x \in X : x \in \{x_{ij}^{(A_j)}, x_{ij}^{(B_j)}, x_{ij}^{(C_j)}\} \wedge t, i, j \in \square \quad (5)$$

where,

$$j = \{1, \dots, 10\} \wedge i = \{1, 2, \dots, 7\} \wedge t = \left\{ \{1, \dots, n_{A_j}\} \cup \{1, \dots, n_{B_j}\} \cup \{1, \dots, n_{C_j}\} \right\} \wedge n_{A_j}, n_{B_j}, n_{C_j} \in \square \quad (6)$$

Being $V_A(x)$, $V_B(x)$ and $V_C(x)$, objective functions, referring each one, to a sustainability's dimension considered, namely; A-Economics, B-Social and C-Environment.

Therefore, each aggregate objective function, is achieved by:

$$V_g(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{g_j}} v_j(x_j^{(g_j)}) \quad w/g = \{A, B, C\} \wedge v_j(x_j^{(g_j)}) \wedge n_j, n_{g_j}, t, j \in \square \quad (7)$$

Thus, and through (7), the 3 objective functions, can be defined as:

$$\text{Economic Well-being} : \max V_A(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{A_j}} v_j(x_j^{(A_j)}) \quad (8)$$

$$\text{Social Well-being} : \max V_B(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{B_j}} v_j(x_j^{(B_j)}) \quad (9)$$

$$\text{Environment Well-being} : \max V_C(x) = \sum_{j=1}^{n_j} \sum_{t=1}^{n_{C_j}} (1 - v_j(x_j^{(C_j)})) \quad (10)$$

The second objective function (Social Well-being), is defined based on the attributes, established in this work together with the ones already defined on previous works, and regarding the remain objective functions (Santos et al, 2018) and Matias et al, 2019).

Furthermore, the functions of value $V_A(x)$, $V_B(x)$ and $V_C(x)$, were combined into a unique aggregated cost function, to be further optimized, as 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's dimension, thus resulting into:

$$V_{Total}(x) = V(V_A(x), V_B(x), V_C(x)) = \omega_A \cdot V_A(x) + \omega_B \cdot V_B(x) + \omega_C \cdot V_C(x) \quad (11)$$

Thus, and based on (2),(7) and (11), the model's cost function, can be described as:

$$V_{Total}(x) = \sum_{j=1}^{n_j} \left\{ \omega_A \cdot \sum_{i=1}^{n_{A_j}} \left(\frac{\left(x_{effect,j}^{(A_p)} - x_{pior,j}^{(A_p)} \right)}{\left(x_{melhor,j}^{(A_p)} - x_{pior,j}^{(A_p)} \right)} \right) + \omega_B \cdot \sum_{i=1}^{n_{B_j}} \left(\frac{\left(x_{effect,j}^{(B_p)} - x_{pior,j}^{(B_p)} \right)}{\left(x_{melhor,j}^{(B_p)} - x_{pior,j}^{(B_p)} \right)} \right) + \omega_C \cdot \sum_{i=1}^{n_{C_j}} \left(1 - \frac{\left(x_{effect,j}^{(C_p)} - x_{pior,j}^{(C_p)} \right)}{\left(x_{melhor,j}^{(C_p)} - x_{pior,j}^{(C_p)} \right)} \right) \right\} \quad (12)$$

This objective function, is subject to a set of constraints, regarding the sustainability's dimension, such as:

Economic – Budget:

$$r_1 : \sum_{j=1}^{n_{dim}} I_j(x_j) \leq available\ budget(\eta_{disp.}) \Leftrightarrow \sum_{\substack{j=1 \\ j \neq 2}}^{n_j} x_{ij}^{(A_{j4})} + x_{i2}^{(A_{25})} \leq \eta_{disp.} \quad (13)$$

Social (Comfort) - Lighting (minimum Illuminance)

$$r_2 : \frac{x_1^{(B_{15})}}{A} K_1 \geq E_{min} \quad with \quad K_1 = \frac{F_u \cdot n}{F_d} (light\ properties) \quad (14)$$

Social (Comfort) - Heating/Cooling needs

$$r_3 : x_2^{(B_{23})} \geq Q_{th.Aquec.(proj.)} \quad (15)$$

$$r_4 : x_2^{(B_{24})} \geq Q_{th.Arref.(proj.)} \quad (16)$$

Environment – Noise:

$$\begin{cases} r_{51} : x_{i1}^{(B_{11})} \leq Noise_{def,1} \\ r_{52} : x_{i2}^{(B_{21})} \leq Noise_{def,2} \\ \vdots \\ r_{56} : x_{i6}^{(B_{61})} \leq Noise_{def,6} \\ r_{57} : x_{i7}^{(B_{71})} \leq Noise_{def,7} \end{cases} \quad c/i = 5 \quad e \quad j = \{2,3,4,5,7\} \quad (17)$$

Environment – Water consumption

$$\begin{cases} r_{61} : x_{i3}^{(A,3,6)} \times 1 / \tau_{H_2O} \leq C_{MLR} \\ r_{62} : x_{i7}^{(A,7,5)} \times 1 / \tau_{H_2O} \leq C_{MLL} \end{cases} \quad (18)$$

Since this work reflects a PhD research, and given the relevant results achieved, it was considered (at first approach) a model, that accounted only 2 of the 3 dimensions referred here. Then, it was developed a model with the tree approaches.

Therefore, the NSGAI’s individual framework (Fig. 4) used here, regards the approach for the 2 and 3 dimensions of sustainability, since that for the approach with 2 dimensions, the structure is the same, although considering only 2 dimensions each.

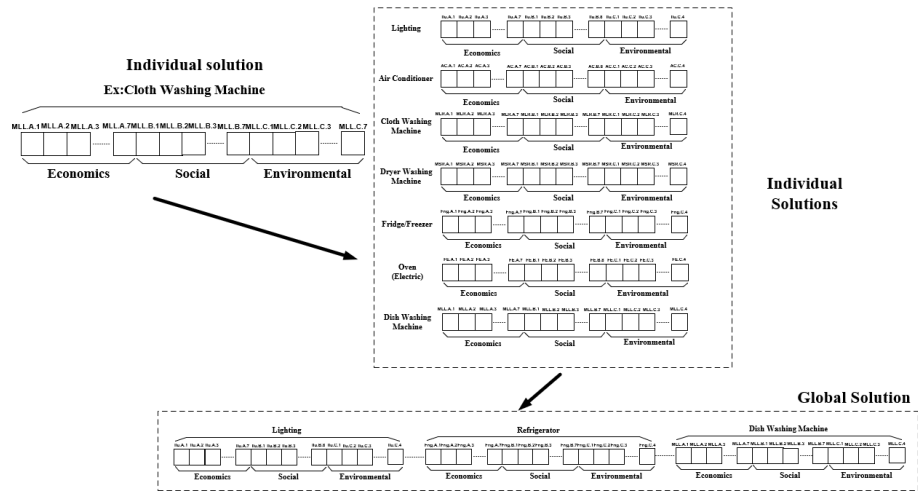


Fig. 4. NSGAI’s individual framework.

Thus, on both approaches, it was used real codification for the NSGAI’s individual framework (Fig. 5), given the nature of the decision variables, used in this work.

The case study, presented here, was used for both approaches, referred before and it was considered a consumer, who wants to buy a set of household appliances from

the market to its home, namely; dryer machine, lighting, air conditioner, dish washing machine, washing machine, electric oven and refrigerator.

The same consumer has a budget of 2300 € to buy the appliances, and it's intended to obtain a set of sustainable options, that maximizes its social, economic and environment wellbeing, according to a set of three relative importance weights, namely; ω_A (economic) and ω_B (social) and ω_C (environment).

The total number of the building's occupants is four. The area of the building, mainly the area of living room, was also considered, given the consumer's intention, by acquiring an air conditioner (heating and cooling needs), as well as to equip the building's living room with lighting.

The consumer's profile was also considered, through a set of assumptions based on the hours, weeks and years. However, the consumer can also define its usage profile, based on its needs, or by using the profile presented here, by default.

3 Results and Discussion

As it referred before, NSGAI (Non-Sorting Genetic Algorithm II) method was employed, by using Matlab, to optimize the aggregate function developed and presented on previous section.

Regarding the NSGAI's parameters, it was adopted the following techniques: roulette, as the selection method, double point, as the crossover method and normal random, as the mutation method.

The remaining parameters, regarding population size, crossover and mutation rate, were obtained and tested on previous works with only two dimensions ([9][13]). Such results were achieved after being performed several runs and experiments, regarding the change of such parameters.

The stop criteria were also tested, where it was achieved the maximum number of generations to be considered.

The behavior of NSGAI, in terms of combinations with crossover and mutation rates, was also tested on [9], by performing several combinations of crossover and mutation rates, to achieve a suitable combination of both.

Thus, the NSGAI's parameters used, were; a population size of 120 individuals, a max number of generations of 80, a crossover rate of 0,75 and a mutation rate of 0,15.

The NSGA II, was then applied to perform several scenarios, given the consumer's possible concerns, which was expressed by the correspondent values in terms of "weights", and regarding each one to a sustainability's dimension, i.e.; ω_A (economics) and ω_B (social) and ω_C (environment).

Therefore, and for each scenario, it was considered a different set of weights ($\omega_A, \omega_B, \omega_C$), in order to obtain different Pareto frontiers/surfaces, where each node represents a candidate solution, i.e., an aggregate sustainable solution, formed by the household appliances, regarding each energy service to be required.

The purpose, was to assess the model’s behavior through the achieved results, namely by assessing the impact of changing ω_A , ω_B and ω_C .

On Fig. 5, it’s presented different scenarios, regarding only two sustainability’s dimensions.

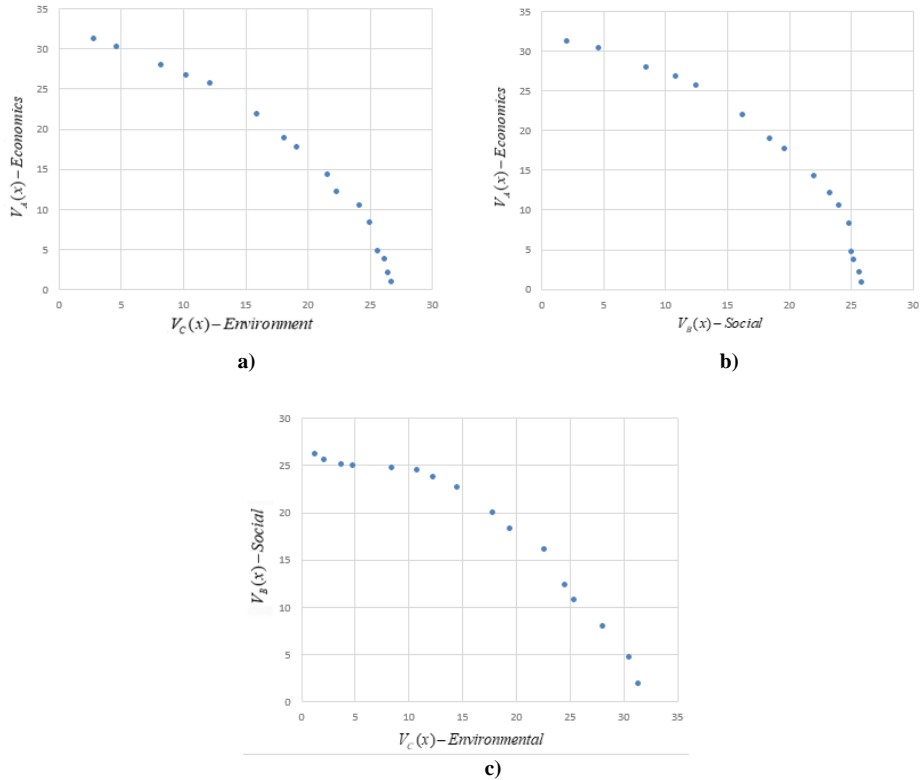


Fig. 5. A Pareto Frontier, considering different scenarios of ω_A , ω_B , ω_C ; a) Economical vs Environmental ($\omega_A = 0,72$, $\omega_B = 0,00$, $\omega_C = 0,28$), b) Economical vs Social ($\omega_A = 0,72$, $\omega_B = 0,28$, $\omega_C = 0,00$), c) Social vs Environmental ($\omega_A = 0,00$, $\omega_B = 0,72$, $\omega_C = 0,28$).

Sixteen candidate solutions were chosen considering the last generation by the algorithm, achieving therefore, a Pareto frontier.

Each point (or node) shows a global sustainable solution, formed by a set of sustainable (and individual) solutions (electrical appliances) by considering each appliance type, to be acquired by the consumer.

By looking at Fig.5, it’s possible to see the different trade-offs existed between the different scenarios and the impact of the correspondent weights (relative importance) used. For instance, on Fig. 5 a), we can see the trade-off, existed between the Economic and the Environmental well-being, with other trade-offs being noticed on Figures 5 b) and 5 c).

The impacts of the weights $(\omega_A, \omega_B, \omega_C)$, are also evident, where the predominance of each dimension is achieved with raising of the correspondent weight (e.g. Fig. 5 c)).

One of the nodes, it's presented on Table 4, regarding each scenario, by accounting a budget of 2300 € and 10 years of life cycle.

Table 4. A set of achieved solutions, regarding different scenarios $(\omega_A, \omega_B, \omega_C)$.

	Electrical Household Appliance	Standard Solution Total Invest. (€)	Efficient sol. Total Invest (€)	Investment Saving (€)	Energy Consumption Savings (€)	Water Consumption (avoided) (l)	CO2 emissions (avoided) (kg)	Manufacturer	Model type
Scenario 1 Economics vs Social $\omega_A = 0.72, \omega_B = 0.00, \omega_C = 0.28$	Light	15.89	09.53	5.34	59.40	-	28.90	GE	EFL23W
	Air Conditioning	368.00	299.00	69.00	1320.60	-	1315.70	Whirlpool	PACW9HP
	Refrigerator	234.00	399.00	-265.00	709.30	-	9.72	BECKEN	Be2016 Ix
	Washing Machine	310.00	349.00	-39.00	3.20	423.00	6.90	Bosch	SMS25A100E
	Dishwasher Machine	272.20	249.90	-33.00	5.60	322.10	95.10	INDESIT	EWE71252 W
	Oven	170.00	199.00	-29.00	1.70	-	2.20	Zanussi	ZZB21601XV
	Clothes dryer	349.00	419.00	-70.00	12.30	-	1.70	Electrolux	EDP2074PDW
	Total	1719.09	1924.43	-361.66	2111.15	745.10	1460.22	-	-
	Scenario 2 Economics vs Environmental $\omega_A = 0.72, \omega_B = 0.00, \omega_C = 0.628$	Light	15.89	09.53	5.34	59.40	-	28.90	GE
Air Conditioning		368.00	299.00	69.00	1320.60	-	1315.70	Whirlpool	PACW9HP
Refrigerator		250.00	529.00	-279.00	708.10	-	8.70	Candy	CFET 6182W
Washing Machine		310.00	349.00	-39.00	3.20	423.00	6.90	Bosch	SMS25A100E
Dishwasher Machine		262.00	294.00	-32.00	6.90	317.00	94.80	Siemens	WI12A222ES
Oven		170.00	199.00	-29.00	1.70	-	2.20	Zanussi	ZZB21601XV
Clothes dryer		349.00	419.00	-70.00	12.30	-	1.70	Electrolux	EDP2074PDW
Total		1727.89	2098.53	-374.66	2112.20	740.00	1458.90	-	-
Scenario 3 Social vs Environmental $\omega_A = 0.00, \omega_B = 0.25, \omega_C = 0.48$		Light	15.89	69.65	5.34	59.40	-	28.90	OSRAM
	Air Conditioning	352.00	279.00	69.00	1319.50	-	1322.60	SAMSUNG	AQV09PSBN
	Refrigerator	250.00	529.00	-279.00	708.10	-	8.70	Candy	CFET 6182W
	Washing Machine	320.10	351.99	-38.10	2.20	432.05	7.80	BALAY	3V5303IP
	Dishwasher Machine	262.00	294.00	-32.00	6.90	317.00	94.80	Siemens	WI12A222ES
	Oven	171.00	701.00	-28.30	2.82	-	2.33	Electrolux	EZC2430AOX
	Clothes dryer	368.00	449.00	-68.00	10.20	-	1.82	BOSCH	WTE84107EE
	Total	1738.99	2673,64	-371.06	2109.12	749.05	1466.95	-	-

According to Table 4, if the consumer, choses the solutions provided by this method, he can save for about 1727,89 €, avoid for about 1458,9 kg of CO₂ and saving approximately 740,06 liters, regarding water consumption, based on the life cycle defined (10 years).

Based on Table 4, Scenario 3, if the consumer choses the solutions, provided by this method, he can save for about 1738,99 €, avoid for about 1466,95 kg of CO₂ and saving approximately 749,05 regarding water consumption.

Based on both trade-offs, presented above, it was considered a scenario with three dimensions and their correspondent consumer's relative importance, i.e., $\omega_A = 0,65$, $\omega_B = 0,25$ and $\omega_C = 0,10$. The correspondent Pareto surface is obtained on Fig. 6 .

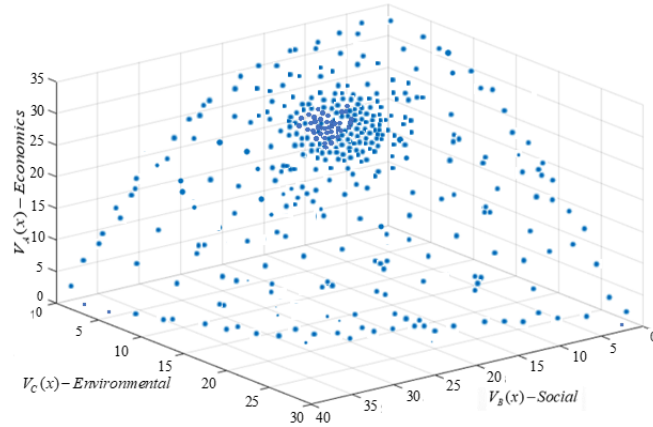


Fig. 6. Pareto Surface. Economical vs Social vs Environmental ($\omega_A = 0,65$, $\omega_B = 0,25$, $\omega_C = 0,10$).

Based on Figure 6, in the obtained Pareto surface, the crowding distance between the final solutions obtained, is higher in the region where the Economic dimension has more dominance, followed by Social, and at last, the Environmental one. This dominance order, between each dimension of sustainability, is somehow expected, given the relative importance's values (weight) considered ins this case for each dimension ($\omega_A = 0,65$, $\omega_B = 0,25$ and $\omega_C = 0,10$).

One of the nodes from that region, are shown on Table 5, regarding a sustainable solution, achieved for a budget of 2300 € and a life cycle defined, of 10 years.

Table 5. One of sustainable solutions, achieved from the pareto surface ($\omega_A = 0,65$, $\omega_B = 0,25$ e $\omega_C = 0,10$).

Electrical Household Appliance	Standard Solution Total Invest. (€)	Efficient sol. Total Invest (€)	Investment Saving (€)	Energy Consumption Savings (€)	Water Consumption (avoided) (l)	CO2 emissions (avoided) (kg)	Manufacturer	Model type
Light	16.88	49.04	5.35	62.20	-	27.60	Phillips	LEDspotMV
Air Conditioning	352.00	279.00	69.00	1319.50	-	1322.60	SAMSUNG	AQV09PSBN
Refrigerator	234.00	399.00	-265.00	709.30	-	9.72	BECKEN	Bc2016 Ix
Washing Machine	310.00	349.00	-39.00	3.20	423.00	6.90	Bosch	SMS25AI00E
Dishwasher Machine	272.20	249.90	-33.00	5.60	322.10	95.10	INDESIT	EWE71252 W
Oven	171.00	701.00	-28.30	2.82	-	2.33	Electrolux	EZC2430AOX
Clothes dryer	368.00	449.00	-68.00	10.20	-	1.82	BOSCH	WTE84107EE
Total	1724.80	2475.94	-262.65	2112.30	745.10	1466.07	-	-

According to Table 5, if the consumer, choses the solutions from this method, he can save for about 2112,30 €, avoiding for about 1466,07 kg of CO₂ and saving (approx.) 745,10 liters in terms of water consumption, according to the life cycle considered in this study.

4 Conclusions and Future Work

In this work, it was proposed a decision support method, to achieve sustainable electrical appliances, existed on market to a consumer, according to tree dimensions of sustainability, namely, Economic, Social and Environment.

The proposed approach has made use of a set of established criteria, in order to pre-select a set of candidate solutions, existed on market, and by following the consumer requirements.

By using such criteria (adjustable to each consumer's requirements), it's possible to define the decision space, formed by a set of candidate solutions, according to each type of appliance considered to be bought by the consumer.

Additionally, it was used additional criteria, integrated with MAVT, in order to model the preferences of the consumer, based on the tree dimensions of the problem, presented in this study.

The main goal of these procedure was to improve the consumer well-being, by acting on tree problem dimensions referred above, and according to the importance, given by the decision-agent (consumer).

After modelling the preferences of the consumer, where it was also accounted the ecological impact in terms of savings (e.g. water and CO₂), together with economic issues (energy consumption and initial investment savings) based on the lifecycle cost assessment (LCCA) of each household appliance, NSGAI was then applied, by maximizing the tree objective functions referred before.

The method presented in this work, allows to maximize all the tree dimensions of sustainability, considered here, by getting a group of sustainable (and alternative) appliances, existed on market, and suitable to each consumer preferences and concerns.

This also allows the consumer, to achieve a set of savings regarding energy consumption, CO₂ emissions, and water consumption.

As a future work, this approach could be extended into other energy services with a relevant impact in terms of sustainable development, like information technology's equipment's (e.g. computers, printers, among others).

According to what was mentioned before, all the defined attributes can be used into other world regions, although with some adjustments, given the differences on energy label classification frameworks.

Acknowledgments. This work was partially supported by the Fundação para a Ciência e Tecnologia, UIDB/00066/2020 (CTS – Center of Technology and Systems).

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. Manual da Etiqueta Energética, ADENE, Lisboa ISBN: 978-972-8646-36-3 (2017)
4. 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)
5. Fell, M.: Energy services: A conceptual review, *Energy Research & Social Science*, vol.27, pp.129--140, Springer (2017)
6. 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
7. 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.
8. 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.
9. Matias, J.C.O.; Santos, R.; Abreu, A. A Decision Support Approach to Provide Sustainable Solutions to the Consumer, by Using Electrical Appliances. *Sustainability* 2019, 11, 1143.
10. 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
11. 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)
12. 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>
13. Santos, R., Matias, J.C.O., Abreu, A., (2019) A New Approach to Provide Sustainable Solutions for Residential Sector IFIP Advances in Information and Communication Technology 2019, ISBN: 978-3-030-17771-3, DOI:10.1007/978-3-030-17771-3_29"
14. Chuah, J. W., Raghunathan, A., Jha, N. K. (2013), ROBESim: A retrofit oriented building energy simulator based on EnergyPlus, *Energy Build.*, vol. 66, pp. 88–103.
15. 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.
16. 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
17. Kaklauskas, A., Zavadskas, E. K., Raslanas, S., (2005) Multivariant design and multiple criteria analysis of building refurbishments, *Energy Build.*, 37(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, Pp. 118-129,ISSN 0360-1323,
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.