# The definition of a vulnerability index to prioritize public projects and policies in Portugal

## Mafalda Miranda Madeira de Gomes Sigorro

*Department of Engineering and Management, Instituto Superior Técnico*

**Abstract**

In a society where there is an increasing concern with efficiency and effectiveness, it is key that governments from each country follow this trend. Only by doing so, will they be able to promote a trustworthy relationship with its citizens. The deployment of public projects and policies shows of interest at the time of efficiency and effectiveness analysis. These affect, in a meaningful way, citizens daily lives and, correspondingly, the Government image. So, there is a clear need of a tool that is able to better prioritize investments, based on populations' real needs. Thus, for this dissertation, it becomes important to critically analyse the current state of public projects and policies in Portugal. It was possible to conclude that Portugal has a long-standing tradition of constant alteration of public policies. This, makes them unfit for the populations they affect. Several factors were analysed that influence or may influence the Portuguese population, focusing mainly on social, economic, environmental and governance dimensions. After surveying all the information that describes the problem, the review of literature was made. The aim was to define the concept of vulnerability and the way it is measured in order to use it as an ultimate criterion of an index. Thereafter a methodology of the use of multicriteria analysis was devised, applying the Choquet integral in modelling the decision-making preferences. This way, their preferences will be included in the prioritization of public policies in Portugal. The decision scope were municipalities instead of public projects and policies, as firstly defined for the dissertation[1].

**Key-Words:** Public Projects and Policies, Portugal, Vulnerability, Index, Multicriteria Analysis, Choquet Integral.

## 1. Introduction

The condition of public projects and policies (PPP) in any country is of great national interest. It concerns both top management – like decision makers and experts – and national citizens, even when they are not directly affected by those PPP.

Portugal is considered one of the countries that changes it's PPP the most. So, it is fragile, once distinctive positions, of conflicting natures, are occupied by the interpreters. These do not favour the knowledge of the Portuguese reality, nor does it lead to the creation of robust alternatives for PPP.

In Portugal, PPP are carried out based on the investment area or region of the country. However, the case where political factors have higher weight than what is reasonable is frequent. This leads to poor PPP allocation in regions that would not be selected if a more broad and strict analysis were conducted. The consequence of poor PPP is an expression of national discontentment, based on the feeling that individual basic needs are not being met.

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[1] It was not possible to change the dissertation title to be aligned with the scope alteration.

Over the last decades indices have been developed to classify the condition of a country, in the large variety of aspects that characterise it. None the less, there is not, still, an index that is capable of assembling all information present in all the existing indices. Thus, it is crucial for society to have an index that is capable of clustering all the information that characterises a country, in order to better classify it. This index may be a guide to prioritise PPP in order to improve its effectiveness.

The remainder of this paper is structured as follows. In the next section the case study is presented. In the third section is developed a review of the relevant literature. The fourth section, discusses the developed methodology, presenting the most relevant results. Finally, section five summarizes the conclusions of the study, indicating further research needs.

## 2. Problem Definition
### 2.1. Portugal's Public Projects and Policies

The need of PPP in any country is interdisciplinary. Public investments are considered an important tool of economic politics, in promoting long term goals of economic growth and employment creation (Pereira A. M., 2017). By analysing the condition of PPP in Portugal, it is easily recognised that there is poor resource management.

According to Eurostat, the Portuguese public investment of 1,5% of GDP[2] reached an historical minimum, not only in Portugal but in all European Union (EU), in all of the three decades of the statistical data of Eurostat. The Portuguese public investment was only higher than the Bulgarian public investment, which is considered the poorest country in the EU. Additionally, when compared with other European investment dependent countries, Portugal recorded the lowest public investment (Expresso, 2017). This is a public condemned measure, once it harms the potential growth of a country.

According to the political scientist Hugh Heclo, the construction of policies is a form of collective puzzle in the society's name, involving, at the same time, deciding and knowing (Heclo, 1974). Within PPP, it is always possible to choose. The efficiency of these choices is as large as it relies in a solid evaluation of social, economic and environmental aspects of the problem. In Portugal, the proposed PPP content by successive governments is wide-range. Besides that, proposals lack stability and continuity, which leads to the large dimension of the problem in hand. So, there is a need of introducing cooperating strategies between parties and social partners. This way, coherent and negotiated solutions, with medium-term horizons will be exacerbated.

### 2.2. Portugal's Vulnerability

Within the Portuguese context, there are several areas where a population may be considered vulnerable. It is possible to infer that, for Portugal, vulnerability cannot be viewed as unidimensional. It should be perceived as a set of different vulnerability drivers, namely economic, social, environmental and governmental aspects. Each of these fields is correspondently affected by a set of different factors. After a long research, it was possible to conclude that Portugal's vulnerability can be characterized by four key factors: Economic Factors, Social Factors, Environmental Factors and Governance Factors.

**Economic Factors –** Portugal is recovering from a period of great budgetary distress, which was the cause for the considerable size of the financial problems of the last years. So, the need for scrutiny in all public expenses becomes clear, once the Portuguese society lives in a climate of distrust and concernment (Pereira A. M., 2013). Within the economic factors it is important to analyse the Portuguese public debt. Public debt can be defined as the accumulated money that public administrations owe. To compensate for the poor performance on this indicator, the Government has been taking measures that negatively impact citizens. One of those measures is the reduction of public investment, which worsens the economic crises, affecting the citizens' life style.

**Social Factors –** Social vulnerability is one of the fields where there is the most research. Portugal has been considered the most unequal society between the analysed developed countries. Social inequalities are multi-dimensional and affect several fields. One of those is the citizen's level of education. When compared with other EU

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[2] Gross Domestic Product (GDP) - amount of goods and services produced by a country in a year. It includes the production done within the country borders, regardless if it is done by national or international companies (Infopedia, 2003-2018).

countries, Portugal presents a very low share of inhabitants that concluded, at least, high school (only 31,9% of the population, between the ages of 25 and 64) (Carmo *et al.,* 2012). Also, the unemployment level is of relevant social analysis. According to recent data (November 2017), Portugal was the 2nd EU country with the highest decrease in unemployment rate, comparing with the same period in 2016. However Portugal had one of highest rates in EU, being in the 3rd position of the ranking in the peak of the economic crisis. Portugal can also be characterised by an aging population. According to a demographic study on Europe, performed by Berlin Institute for Population and Development, all European countries are aging but not all are reducing their number of inhabitants. The last is a reality for countries that suffer with emigration and low birth rate, as it is in Portugal. Portugal is estimated to be the second most aged EU country until the end of the century (Instituto de Berlim para a População e o Desenvolvimento, 2017).

**Envirnmental Factors –** Studying environmental conditions is another theme with increase research. Nowadays climate change has been identified as one of the biggest environmental threats faced by the planet and humanity. Also, the increase of usage of fossil fuels and industrialization play a role to a more vulnerable environment. Air pollution has increase, globally, 8% since 2011. This lead to the exposure to dangerous levels of carbon dioxide of billions of people (Organização Mundial de Saúde, 2018). This increase establishes a state of public health emergency in several countries, which associated costs for countries are huge.

**Governance Factors –** Governance factors are of great interest when analysing vulnerability. Governance factors can be characterised by the inherent way that the Government influences the Portuguese society. There are three extensively studied fields, namely transparency, participatory budget and level of abstention. Over the last two decades, governments have been trying to improve local administration's communication. This way, they aim to guarantee citizens access to information, resorting to information technologies and communication (TIAC, 2013). This lead to the rise of Portugal Participatory Budget. This is a deliberate democratic process, direct and universal, through which people present investment proposals. After that, the proposals are chosen, through a vote process, deciding which projects are going to be implemented in different operation areas. Level of abstention can be defined as the absence of making use of the right to vote. It represents the number of electors that did not vote in a certain election of referendum. In Portugal, high abstention levels have been highly discussed, once the increase is visible each year.

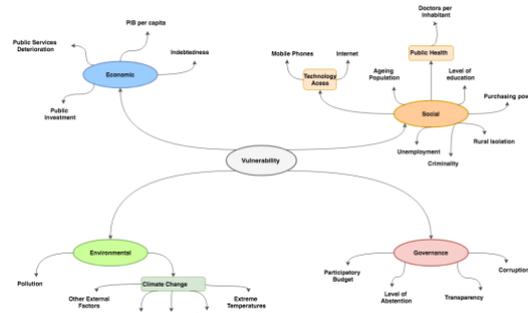With all the collected information, it was possible to develop the criteria map present on Figure 1.



**Figure 1** - Criteria map. The elipses represente factos, that can be divided into criteria. The rectangule represent criteria that are divided into subcriteria.

### 2.3. The use of Indexes and Indicators

There are numerous indicators and indexes that describe socioeconomic, social and environmental conditions. To better understand this subject, two indexes were analysed: the Gini Index and the Human Development Index.

The Gini Index usually calculates the inequality of income distribution between people but can also be used to compute inequalities in any distribution like land concentration, wealth, among others (Governo do Estado do Ceará, 2006). The index ranges between 0 and 1, however, to facilitate its reading values are multiplied by 100, making it to be presented in a percentage. The closest it is from 0%, the less unequal a country is (Pereira A. C., 2017). Portugal is still one of UE's most unequal countries, presenting itself in fourth in the ranking of the Morgan Stanley bank. It is only overtaken by United States of America, United Kingdom and Greece (Morgan Stanley, 2015).

The Human Development Index (HDI) is a composite index that aims to measure the level of human development of any country, enabling comparisons between countries. It measures the average of three basic dimensions of human development: long and healthy life, knowledge and decent

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standard of livelihood. Portugal is in the 41st position, among a 188 set of countries, with a total score of 0,843. Although it is one of the countries with the highest human development, Portugal is one of the EU countries, being only in a better position than Hungary, Lithonia, Croatia and Romania.

## 3. Literature Review
### 3.1. Concept of Vulnerability

The concept of vulnerability has been widely studied over the last decades. In the last 20 years, there has been an increase in fields of application (Beroya-Eitner, 2015). Authors mistake vulnerability for risk, the reason why it is so important to begin to differentiate them. Risk focuses on the seriousness of the consequences within a scenario. Vulnerability focuses on the scenario susceptibility, being defined as the measure of that susceptibility (Ezell, 2007). A broader concept of vulnerability is the potential of loss or risk, now or in the future (Cull & Vincent, 2010). According to most authors, vulnerability can be used in environmental, economic and social conditions, which makes this a fuzzy concept, once definitions may overlap (Hinkel, 2011).

Environmental vulnerability may be defined as the susceptibility to a hazard from environmental and social stresses and from the lack of capability to adapt to those events (Adger, 2006). Social vulnerability may be defined as the probability of a social group in a certain society to suffer an unequal extent of death, injuries, losses or disruptions of their livelihood during an extreme event, or that face difficulties higher than usual during the recovery of a disaster (Handmer & Wisner, 1998). Vulnerability can also be defined as the lack of economic resilience by populations (Briguglio, 1995).

In sum, vulnerability can be considered an intrinsic system characteristic, that is always present, even though it may be inactive between events. It is a dynamic characteristic that unveils during an event. Its extension depends on the magnitude of the event (Thywissen, 2006). Once vulnerability can be applied to multiple fields, the flexibility of the definition its essential. Flexibility is a prerequisite, that decreases the gap between conceptual vulnerability definitions and its operationalization (Rougé et al., 2015).

### 3.2. Measuring Vulnerability

Vulnerability is a theoretical concept, once it is not a visible phenomenon, which makes its measurement difficult (Hinkel, 2011). Vulnerability is a potential state of human societies, with a great variety of drivers that act and interact, on different scales, making the its evaluation challenging (Vincent, 2004). Therefore, there is a need for evaluation methods in a specific context (Cull & Vincent, 2010).

This measurement involves various practical challenges, like political will, context complexity of the analyzed problems, poor understanding of subjects related to the problem and the results' importance (Patt et al., 2009). In this regard, some techniques used to measure vulnerability were studied.

### 3.2.1. Techniques to measure vulnerability

There is a strong presence of the application of indicators and indexes in literature. Indicators are quantifiable structures, that provide information (Hammond et al., 1995). Indicators are ways to encapsulate a complex reality in one structure, by summing the whole number of intangible complex processes. Vulnerability indicators have been becoming more important in the last few years. Studies that are related with indicators' development are increasing (Beroya-Eitner, 2016).

Indicators can also be grouped to form indexes. The main advantage of this process is the wider range of variables that can be included, leading to more comprehensive reality models. To ensure the maximum validity and utility of these indexes, it is necessary that indexes are intuitively understood and unbiased. By providing only one vulnerability measure, based on meaningful indicators, indexes are of great practical application, especially to national levels (Vincent, 2004). So, indexes can also be used to build the connection between science and politics, which is of the upmost interest.

### 3.2.2. Multicriteria analysis in vulnerability measurement

Multicriteria analysis is a framework to classify or to score global scores of decision alternatives against multiple objectives, usually measured in different units (Hajkowicz & Collins, 2007). It is considered an explicit decision-making process, focused on problem structuring and solving. It involves several criteria and provides relative weighting systems (Bagdanaviciut et al., 2015). Thus, MCA represents a set of techniques potentially capable of improving

decisions' transparency, auditability and analytical accuracy (Dunning *et al.*, 2000). This tool may be defined as a decision model. It includes a set of options that need to be ranked or scored by a decision maker; a set of criteria, typically measured in different units; and a set of performance measures, that translate into scores to each decision option against each criteria (Hajkowicz & Collins, 2007).

Criteria must be selected according to a set of factors. Each criterion must be comprehensive and measurable. The criteria set must be complete (criteria must cover all aspects related to the decision problem), operational (to provide its use in a significant way within the analysis), decomposable (criteria must be decomposed in parts to simplify the process), non-redundant (to avoid that the same criteria as taken into account more than once) and must be minimum (the number of attributes must be kept as low as possible) (Malczewski, 1999).

Therefore, MCA is a systematic methodology that combines technical knowledge about benefits and trade-offs of specific choices with locally relevant criteria (Huang *et al.,* 2011). It is usually used to help decision-makers to compare and prioritize a set of individual or group actions (Penning-Rowsell *et al.,* 2005). By using MCA in political decisions, process transparency and analytical accuracy are improved, increasing public acceptance of the proposed alternatives (Linkov *et al.,* 2006).

### 3.3. Prioritizing Public Projects and Policies

A public project is a project that is executed, managed or supervised by a public administration, or implemented with the involvement of funds of the same administration. Thus, public projects are those that are primarily developed to public benefit (Gasik, 2016). Public projects usually have multiple stakeholders: public administration, contractors, and, above all, the administrative units' communities, in which project are implemented.

Large projects (like infrastructures, IT technologies, military, among others) are being increasingly used to deliver a great variety of goods and services. However, the projects' performance it is not satisfying: the wrong projects are selected, costs are underestimated, and benefits overestimated (Flyvbjerg, 2014).

Resource limitation translates into the inability of selecting all the presented projects. Choosing investments may have drastic impacts, in economic, social and environmental aspects, mainly due to the significant number of people that are direct and indirectly affected (Yin *et al.,* 2009).

Public projects prioritizations is a political diction with increased importance, due to the fact that they are publicly funded and also because of the amplified pressure to a higher efficiency.

## 4. Methodology
### 4.1. Analysis dimension

The study aims to evaluate investment alternatives in Portugal. The deployment proposal is that evaluation alternatives are Portuguese municipalities. Each Portuguese region is divided into several municipalities, summing, in total, 308 municipalities (278 in continental Portugal, 11 in Madeira autonomous region and 19 in Azores autonomous region). These are classified by the validated criteria. However, once the present work just intends to perform an experimental analysis, it is necessary to choose the municipalities to include in the analysis before validating the criteria. The main reason behind it is the fact that most criteria depend on the evaluated municipality.

Firstly, it was decided to exclude the autonomous regions of Madeira and Azores, once they possess specific characteristics. Then it was decided to consider the resident population of each municipality (PORDATA, 2018) as an inclusive and exclusive criterion of municipalities in the analysis. Thereby, the average resident population of each municipality was computed, obtaining 35 286 inhabitants per municipality. Then, a 10 000 inhabitants variation was assumed, obtaining resident populations within the ranges of 25 219 and 45 143 inhabitants, making up a total of 31 municipalities. So, the analysed sample represents 10% of the initial universe.

### 4.2. Criteria

To better structure the analysed problem, the initially proposed criteria were analysed, concerning its definition and measurement, as well as its relevance for the analysis. Also, the criteria were crossed with the municipalities, to understand if they would make sense within each municipality's context. Through the present work, there will be constructed and considered 9 criteria and

1 mutual weakening interaction, further ahead explained.

### 4.2.1.Economic Factors

By analysing economic factors, it was possible to conclude that criteria *Public Investment* ($g1$) and *Indebtedness* ($g2$) are easy to measure, reason why they are going to be included in the analysis. However, the same was not found in the criteria *Public services deterioration* and *GDP per capita*, reason why they are not going to be considered.

### 4.2.2.Environmental Factors

Regarding environmental factors, only *Increase of Pollution (g3)* was considered. Although the criterion *Climate Changes* was of interest, measurement was difficult, which is why it was excluded from the analysis.

### 4.2.3.Social Factors

Regarding the social factors the criteria selected for the analysis was the Ageing of population(g4), the level of Education(g5)and Unemployment (g6). The criteria are Public Health and correspondengly the subcriteria Doctors per inhabitant – Purchasing power, Rural Isolation and access to tecnology – and correspondengly the subcriteria Mobile phones and Internet – and Crime were excluded.

### 4.2.4.Social Factors

For social factors, the selected criteria were *Ageing Population (g4), Level of Education (g5)* and *Unemployment (g6).* The criteria *Public Health* – which had the sub criterion *Doctors per inhabitant – Purchasing Power, Rural Isolation, Technology Access* – which had the sub criteria *Sell phones* and *Internet* – and *Criminality* were excluded. The reasons behind it were vast, concerning mostly applicability in the analysed municipalities and difficulty of measurement.

### 4.3. Criteria Interaction

To structure the model, it was also necessary to consider the interaction between criteria, as well as the effects of that interaction. In fact, while developing criteria, it was perceived that some of them interacted. The interaction can be of mutual enhancement, known as synergy – when the global weight of both criteria is higher than the sum of the weights of both criteria individually – or of mutual weakening, known as redundancy – when the global weight of both criteria is lower than the sum of the weights of both criteria individually.

It was defined that criteria *Level of Education (g5)* and *Unemployment (g6)* interact, being the interaction of mutual weakening. In fact, it is easily understood that by increasing an individual education level, it is less likely that he will be susceptible to unemployment, once he has a higher degree of specialization. This is proven by several published data, reason why this interaction was chosen.

### 4.4. Description of the methodology

The work's starting point passed through realising the importance of criteria interaction. Criteria interaction studies have been increasing, being crucial to MCA models. Thus, the present work is based on the Choquet integral to aggregate multicriteria preferences.

The Choquet integral is a technique to cope with criteria interaction. It differs from weighted sum – in which a weight is given to each criterion – once it deals with the assignment of capacities to criterion, also known as fuzzy measures. The Choquet integral assigns a global weight (called, by sake of simplicity as capacities) $\mu(T)$ to each subset, $T$, of the considered criteria set, $G$. In fact, capacity or weight, $\mu(T)$, can be seen as the value assigned to a dummy projet. This corresponds to an action that presents a totally satisfactory performance in one criterion of the subset $T$ , and totally unsatisfactory performances in all remaining criteria of $G$ (excluding $T$).

If the global weight, $\mu(T)$, is different from the sum of the remaining criteria weights $\mu(\{g_i\})$ that belong to subset $T$, it must be interpreted as an interaction between criteria.

To apply the Choquet integral there are two fundamental steps:

a. To assign utility values to criteria performances in a standard interval scale;
b. To build capacity by assigning numerical values, $\mu(T)$ , to each subset of criteria $T$, in a ratio scale.

To determine utilities (in an interval scale) and capacities (in a ratio scale), and once the criteria set is quite broad, it was used the methodology suggested by Bottero *et al.* (2017). For that, it was used the methodology proposed by Figueira & Roy (2002) – the deck of cards. In this method, each scale level or dummy project is written in a card, with some additional information, if

necessary. Subsequently, the decision maker is asked to rank the cards, from the least to the most important. Then, to enable measuring the closeness between two successive levels or projects, the decision maker is asked to add blank cards. The insertion of blank cards aims to define a gap between concecutive levels. This way, preference intensity can be modeled, which is necessary to build both interval and ratio scales.

## 5. Methodology deployment
### 5.1. Criteria validation

First, it was necessary for the especialist to validate the identified criteria family. For that, a especilist was consulted, that validated the presented criteria family, as the excluded criteria. The especilist then acted as a decision maker.

### 5.2. Deck of cards' method
Then, the deck of cards' method was used to define utility levels and capacities of each criteria. In both cases, the interaction and dialogue between analyst and specialist – that acted as a decision-maker – was needed.

#### 5.2.1. Determining capacities

To build ratio scales for capacities, it was necessary to define specific objects, named *projects*. The followed method for this purpose was the one proposed by Marichal e Roubens (2000). These authors proposed a method to determine Choquet integral capacities, from a reference set of projects. This method may be perceived as an adaption of the swing weighting procedure[3]. Basing on this authors proposal, and assuming a minimum and maximum utility values of each criterion of 0 and 1, respectively, the projects to be build were the following:

❖ $n$ projects (as many as the criteria number), named as $p_j$, for all $j \in G$ that can be characterized by a vector of the form $(0, ..., 0, u_j(p_j) = 1, 0, ..., 0)$, where $p_j$ presents the higher utility on the criterion $j$ and the lowest in the remaining criteria.

❖ $|O|$ projects as many as the criteria pairs interacting) named by $p_k = p_{ij}, k = n + 1, ..., n + |O|$, that can be characterized by a vector in the form

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[3] Weight assigning method in a multiattribute utility function.

$(0, ..., 0, u_i(p_i) = 1, 0, ..., 0, u_j(p_j) = 1, 0, ..., 0)$, for all $\{i, j\} \in O$, where $p_k$ presents the higher utility on the criteria $i$ and $j$ e and the lowest in the remaining criteria.

For this work, there were 10 projects defined – 9 for each of the criterion, and 1 for the interacting criteria pair.

After presenting the projects to the specialist, he ranked the projects and inserted blank cards between consecutive levels, according to the methodology. The result of the interaction with the specialist is represented in Table 1.

**Table 1**- Ranking and blank cards given by the specialist

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| r1 | e1 | r2 | e2 | r3 | e3 | r4 | e4 | r5 | e5 | r6 | e7 | r8 | e8 | r9 | e9 | r10 | z |
| p8 | 3 | p3,p7,p9 | 2 | p5,p6 | 0 | p10,p4 | 1 | p1 | 0 | p2 | | | | | | | 4 |

After possessing ranking and number of blank cards data, it is possible to apply the proposed methodology by Bottero *et al.* (2017), to compute capacities. The results are present in Table 2.

**Table 2** - Capacities of the considered projects

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Capacities, $\mu_k$ | | | | | | | | | |
| p1 | p2 | p3 | p4 | p5 | p6 | p7 | p8 | p9 | p10 |
| 0,1745 | 0,1872 | 0,0979 | 0,1489 | 0,1362 | 0,1362 | 0,0979 | 0,0468 | 0,0979 | 0,1489 |

#### 5.2.2. Determining utilities

Choquet integral utility values are levels of a standard interval scale, usually between between [0,1]. To translate from the original scale levels of each criterion to a standard scale, it was necessary to use a procedure that considered the intensity of preferences between consecutive intervals of the scale. The methodology adopted was the one proposed by Bottero *et al.* (2017). The utilities of each scale level, for each criterion are presented in Table 3.

**Table 3** - Utility levels of each scale level, for each criterion

| Criterion | u(l1) | u(l2) | u(l3) | u(l4) | u(l5) |
|---|---|---|---|---|---|
| g1 | 0 | 0,4000 | 0,7000 | 0,9000 | 1,0000 |
| g2 | 0 | 0,4444 | 0,7778 | 0,8889 | 1,0000 |
| g3 | 0 | 0,4000 | 0,7000 | 0,9000 | 1,0000 |
| g4 | 0 | 0,4444 | 0,7778 | 0,8889 | 1,0000 |
| g5 | 0 | 0,4000 | 0,8000 | 0,9000 | 1,0000 |
| g6 | 0 | 0,4000 | 0,7000 | 0,9000 | 1,0000 |
| g7 | 0 | 0,3750 | 0,6250 | 0,8750 | 1,0000 |
| g9 | 0 | 0,4000 | 0,7000 | 0,9000 | 1,0000 |

### 5.3. Vulnerability Index

After defining the criteria, alternatives and interactions, it is possible to apply the Choquet integral, to compute the global score. This represents the Vulnerability Index of each municipality. The results are presented on Table 4.

The Vulnerability Index of the analysed municipalities is flanked by 0,4483 and 0,8232.

It is now important to recall the definition of the index itself. The problem in hand passes through the choice of investment alternatives, that are more vulnerable. This way, the considered alternatives must be the ones that present smaller Vulnerability Index values, thus being more vulnerable.

**Table 4** - Vulnerability Index of the analysed municipalities

| Alternative | Vulnerability Index |
|---|---|
| a13 | 0,4483 |
| a11 | 0,5626 |
| a28 | 0,5795 |
| a31 | 0,5882 |
| a29 | 0,5916 |
| a25 | 0,6219 |
| a23 | 0,6273 |
| a17 | 0,6378 |
| a21 | 0,6581 |
| a20 | 0,6597 |
| a16 | 0,6702 |
| a1 | 0,6706 |
| a9 | 0,6716 |
| a8 | 0,6823 |
| a5 | 0,6867 |
| a6 | 0,6973 |
| a4 | 0,6975 |
| a18 | 0,6982 |
| a22 | 0,7070 |
| a10 | 0,7094 |
| a3 | 0,7142 |
| a12 | 0,7164 |
| a27 | 0,7299 |
| a26 | 0,7367 |
| a14 | 0,7533 |
| a15 | 0,7543 |
| a24 | 0,7576 |
| a30 | 0,7612 |
| a7 | 0,8198 |
| a2 | 0,8219 |
| a19 | 0,8232 |

### 5.4. Sensitivity Analysis

After obtaining the results, it was necessary to perform a sensitivity analysis. A sensitivity analysis allows to evaluate the effect of altering a criterion's weight – named *capacity* from now forward – on an alternative global score. Thus, it is possible to test how the initial ranking keeps unaltered by altering the criteria's capacity, testing the results' robustness.

So, for each criterion, separately, the point at which the ranking suffered an alteration was analysed. The capacity of each criterion

varied between the range $[0,1]$, keeping the remaing capacities equal. There was also performed a sensitivity analysis on the interacting pair of criteria. Once this was a mutual weakening interaction, the capacity varied between the range $[-1,0]$.

To better understand the impact of the capacity variation of each criterion on the alternatives' ranking, a second analysis was performed. After analysing all the analysed spectrum, this analysis focuses on the effect of increasing or decreasing 10% the criterion's capacity. The reason behind this is the fact that it is considered that the error by the specialist, when allocating scores – that lead to computing the capacities – did not exceed 10%. This way, more significant results were expected.

Apart from these analysis, it was also considered important to analyse the influence of altering the capacities of the criteria of the same factors. There were only analysed economic, social and governance factors, once environmental factors only had one criterion. First, it was noted that the capacities of the criteria that belonged to the same type of factor had near capacities. So, the average capacity of each factor was computed. Then, the sensitivity analysis was performed, as it was for each criterion individually. However, for this analysis it was only considered relevant the analysis of the 10% variation of the average capacity.

By analysing the vulnerability index results presented on Table 4, it is easily seen that alternative a13 (first of the table, with 0,4483), is far from the alternative on the second position (a11, with 0,5626). However, if analysing the alternatives between the second and fifth places, they have close vulnerability indexes, presenting a higher distance from the sixth place – the gap goes from 0,003 to 0,03. Thus, to perform the sensitivity analysis, there will be only considered alternatives a13, a11, a28, a31 and a29. To better synthetize the most relevant conclusions drawn from the sensitivity analysis, Table 5 was built.

**Table 5** - Sensitivity Analysis' results

| Variation | g1 | g2 | g3 | g4 | g5 | g6 | g7 |
|---|---|---|---|---|---|---|---|
| -10% | Equal | a31-a29 | a31-a29 | a28-a31 | Equal | a31-a29 | Equal |
| +10% | Equal | Equal | a28-a31 | a31-a29 | a31-a29 | Equal | Equal |

| Variation | g8 | g9 | Interaction | Economic Factors | Social Factors | Governance Factors |
|---|---|---|---|---|---|---|
| -10% | Equal | Equal | Equal | a31-a29 | Equal | Equal |
| +10% | Equal | Equal | Equal | Equal | a31-a29 | Equal |

Concerning each criterion sensitivity analysis, it is possible to conclude that the capacity alteration made significant changes in the alternatives' ranking. This is valid for all the analysed criteria, as well as the for

criteria interaction. So, the changes produced by the capacity alteration in each criterion were not considered significant enough to be introduced.

Observing Table 5, there are some important conclusions that can be drawn. The first and second places of the ranking are always occupied by the same alternatives – a13 and a11, respectively. Then, most of the ranking alterations were on the third, fourth and fifth places. In fact, observing Table 5 it is seen that the fourth and fifth places switched their occupants 6 times, and the third and fourth places switched their occupants only twice. There was also any kind of ranking alteration when varying the capacity by 10%, which is positive for the robustness of the results.

So, ending sensitivity analysis, it is possible to recommend alternatives a13 and a11, with a 10% criterion capacity variation. It would also be possible to recommend alternatives a28, a31 and a29 with the proviso that the 10% criterion capacity variation is responsible for the switch of these alternatives in the ranking.

### 5.5. Analysis of the influence of the *z* ratio

In order to analyse the difference attractiveness between alternatives, it was analysed the influence of altering the z ratio. While interacting with the specialist, he only gave one value for the z ratio. So, this value took the vales of 3 and 5 – once the specialist gave the initial value of 4 – to observe its influence on the alternatives' ranking.

The ratio alteration made the ranking to alter. Besides that, also the vulnerability index changed. For a smaller ratio, the vulnerability index range decreased. For a larger ratio, the vulnerability index range increased. That responds to the expected. Modelling z is the difference of preference between most and least preferred alternative. So, it was expected that by augmenting the difference, the range would also increase; while by diminishing de difference, the range would decrease.

## 6. Conclusions
### 6.1. Main Conclusions

The present work aimed to respond to an emerging society need – the existence of a tool capable of prioritising municipal public investments, based on objective evaluations. This way, municipalities' sustainability would be guaranteed, through transparent and fair evaluations. These are essential to a higher satisfaction and confidence level of citizens on their governing authorities.

In this regard, a survey on the status of Portuguese public policies were made. The goal was to analyse which factors affected Portuguese society the most, in order to define a vulnerability index.

The first step was the definition of the main areas in which a population can be considered susceptible to a vulnerability situation. It was concluded that, within Portuguese society, there are four key vulnerability factors: economic, environmental, social and governance.

After identifying and framing the problem, it was important to move forward to the elaboration of a review of the relevant literature. This focused mainly on the definition of vulnerability, as well as the techniques of its measurement.

Having a strong theoretical foundation by literature review, the next step was the definition of the methodology. The followed methodology of this work was the one proposed by Bottero *et al.* (2017). In this methodology, specialist interation is made by using the deck of cards method.

Then, the methodology was implemented, accordingly to what it is described in Bottero *et al.* (2017).

At the end of the work, it is possible to conclude that the definition of the vulnerability index by MCA is possible and is at the Governements reach.

### 6.2. Main Limitations of the methodology

It is also possible to make some observations regarding the technique used in the present work. In this work, to build utilities and capacities, the Choquet integral method, supported by the deck of cards method was used. The goal of inserting blank cards between successive scale levels/dummy projects is to model the preferences' intensity. This is necessary to build ratio and interval scales.

The deck of cards method was suitable for its end. It is simple and user-friendly for the decision-maker, which simplified the communication.

The main disadvantage of this method is, without doubt, the total dependence on the decision-maker. Although the performances' table can be built without the decision-maker, only he is capable of giving essential data to build the model. This has great consequences, from which we can highlight the direct correspondence between the model and the introduced data. That is, the model is as good and the introduced data.

### 6.3. Future Developments

As a final remark, there are some final recommendations for future work.

A greater investment in analysing, treating and disclosing data that concern the Portuguese population is recommended Having publicly available data was one of the main difficulties encountered in the present work, even being the reason for the exclusion of some of the criteria. Thus this should be a priority for Government.

Then, to make the model a more robust one, the results could be compared with the results stemming from another model. A good candidate would be the MACBETH method MACBETH (Bana e Costa *et al.,* 2012). The application of this method would be of interest once it would enable the comparison between results. This could lead to the recommendation of more robust solutions. By using another method, it might have been possible to understand which would be the alternative to recommend with a higher level of security.

At last, the model could be used to prioritize projects and public policies and not only locations of investments. By adding complex variables, such as choosing between the investment between infrastructure or social policies, the model would become exponentially more complex. However, it would become a usefull tool to be used to help governments to choose investments.

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