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Sustainability analysis of the Portuguese public hospitals

A multicriteria approach

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Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Preface

The work presented in this dissertation has been performed at Centre of Management Studies of Instituto Superior Técnico (CEG-IST) and Civil Engineering Research and Innovation for Sustainability (CERIS), under the supervision of Professor José Rui de Matos Figueira and Professor Ana Sara Silva Rodrigues da Costa, and within the frame of the hSNS FCT - Research Project (PTDC/EGEOGE/30546/2017): "Portuguese public hospital performance assessment using a multicriteria decision analysis framework".

Acknowledgements

As I am writing this section today, the end of my academic journey is closer to coming to an end. I cannot help but to look back not only on the last 5 years, on IST, but also on the rest of my life and education path that led to this moment. Mostly, I feel like I should use this page to appreciate the people that have been with me along the way.

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Thank you all for this journey.

Abstract

The growing concern over sustainable development is leading organizations to account for their actions and to change their values, mission, or even strategic goals. The healthcare sector has transitioned into a more corporatized activity where hospitals behave as enterprises, having more freedom of management, which requires more responsibility. Also, the high impact of the healthcare sector in a country's socio-economic environment requires a great deal of investment, not just monetary, to assure the long-term viability of this activity, which is proportional to the level of sustainability. To answer these problems, it is important to define ways to analyse the impact of the healthcare public sector, particularly of the hospitals, since these are the core of the healthcare sector's activity. This work describes the current research developed in Sustainability in Healthcare and proposes a framework to evaluate the sustainability of the Portuguese public hospitals, using a Multicriteria Decision Aiding method, the ELECTRE TRI-nC. The literature review alongside the input of a Decision-Maker allows to withdrawal a set of criteria to measure sustainability of the public hospitals. Having in mind the methodology detailed, a model is built and implemented in a software that allows sorting the hospitals into categories. After the sensitivity and robustness analyses of the results, it is possible to identify the best two hospitals considering the criteria defined. From these analyses, a second model is proposed to allow sorting the set of hospitals into more categories, having a more differentiated set of results to propose to the DM.

Keywords: Portuguese healthcare system; Sustainability; Measuring Sustainability in Hospitals; Multicriteria Decision Aiding; ELECTRE TRI-nC.

Resumo

A crescente preocupação com o desenvolvimento sustentável tem levado as organizações a responsabilizar-se pelas suas ações e a mudar os seus valores, missão, ou objetivos estratégicos. O setor da saúde transitou para uma atividade mais corporativa, tendo mais liberdade de gestão, o que exige mais responsabilidade. Além disso, o elevado impacto do sector da saúde no ambiente socioeconómico de um país exige um grande investimento, não apenas monetário, para assegurar a viabilidade a longo prazo desta atividade, que é proporcional ao nível de sustentabilidade. Para responder a estes problemas, é importante definir formas de analisar o impacto do sector público dos cuidados de saúde, particularmente dos hospitais, já que estes são o núcleo da atividade do sector da saúde. Este trabalho descreve a investigação atual desenvolvida em Sustentabilidade nos Cuidados de Saúde e propõe um modelo para avaliar a sustentabilidade dos hospitais públicos portugueses, utilizando um método Multicritério de Apoio à Decisão, o ELECTRE TRI-nC. A revisão de literatura, juntamente com a contribuição de um decisor, permite retirar um conjunto de critérios para medir a sustentabilidade dos hospitais públicos. Tendo em mente a metodologia, é construído e implementado um modelo num software que permite classificar os hospitais em categorias. Após as análises de sensibilidade e robustez dos resultados, é possível identificar os dois melhores hospitais tendo em conta os critérios definidos. A partir destas análises, um segundo modelo é proposto para permitir classificar os restantes de hospitais em mais categorias, tendo um conjunto mais diferenciado de resultados a propor ao decisor.

Palavras-chave: Sistema Nacional de Saúde Português; Sustentabilidade; Avaliar a Sustentabilidade dos Hospitais; Apoio à decisão multicritério; ELECTRE TRI-nC.

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Nomenclature

Greek symbols

σ: Credibility index

λ: Credibility level

Subscripts

a: Actions

g: Criteria

B: Reference actions

F: Family of criteria

C: Categories

p: Preference threshold

q: Preference threshold

B_h: Sub-set of reference Actions

w: Weights

c: Concordance index

d: Partial discordance index

Glossary

TBL: Triple Bottom Line

MCDA: Multicriteria Decision Aiding

DGS: Directorate-General for Health (*Direção Geral da Saúde)*

NPM: New Public Management

SNS: Nacional Healthcare Service *(Serviço Nacional de Saúde)*

LBS: Health Basis Law (*Lei de Bases de Saúde*)

RHA: Regional Health Administrations

SLS: Local Health System (*Sistema Local de Saúde*)

SA: State-Owned Hospital Enterprises *(Sociedades Anónimas)*

EPE: Public State Enterprises (*Empresas Públicas dos Estado*)

ULS: Local Health Units (*Unidades Locais de Saúde*)

CSR: Corporate Social Responsibilities

OECD: Organization of Economic Cooperation and Development

DA: Decision Aiding

DM: Decision-Maker

Chapter 1

Introduction

This first chapter consists of the introduction of the work developed. Starting in Section 1.1 there is the motivation that led to the execution of this dissertation. Section 1.2 presents the objectives intended to fulfil. Section 1.3 presents the research methodology used during the execution of this work. And finally, Section 1.4 presents the structure followed.

1.1 Motivation

"*As human beings, we are vulnerable to confusing the unprecedented with the improbable. In our everyday experience, if something has never happened before, we are generally safe in assuming it is not going to happen in the future, but the exceptions can kill you and climate change is one of those exceptions"* – Al Gore, 2009, about the importance of sustainable development (Bethge et al., 2009).

The Brundtland Report, in 1987, defined *sustainable development* as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (World Comission on Environment and Development, 1987). Over the last 30 years, we have witnessed a significant change of mindset regarding the impact of man's activity on the world.

Concerns about the intensive use of limited resources such as oil, the cutting down of the world's largest forest to produce paper, or the opening of land for industrial purposes, point to serious threats to the well-being of future generations. Drinking water, fuels availability, even the air we breathe, all things essential to today's society have a limit, and it is up to us to find sustainable solutions to safeguard the basic elements of life for future generations (Magdoff, 2013).

In 2007, Al Gore was awarded the Nobel prize for peace for promoting a reflection about the world's climate situation. It is of great importance to account for the emissions of pollutant gases to the atmosphere as well as the disposal of waste in natural habitats such as the ocean, in order to implement measures to slow down the rhythm of the visible climate changes caused by the impact that man's pollution has on the environment (The Norwegian Nobel Institute, 2007).

Another significant milestone of the 21st century is the COVID-19 pandemic. The complete change of pace that this pandemic brought to the world showed not only the fragility of the healthcare systems of both developed and developing countries, but also the social inequalities of the world and the importance that the healthcare sector has on a country's economy. If it was not clear before, it is now evident the impact that community health issues have on society, and that the healthcare systems and organizations are vital players to the world and countries' economy, because if healthcare systems collapse, the economy also suffers from it (Jones et al., 2021).

Among all the lessons that the COVID-19 pandemic brought, the most important is the high necessity to assure that the social protection systems are solid and well-funded. Thus, when it comes to the healthcare system, it is important to invest in prevention and health promotion, as well as in a larger healthcare workforce and equipment. It is also important to boost health literacy, in an attempt to avoid health inequalities. Investing in this service means investing in people, in resilience, solidarity and ultimately in the wellbeing of our society and economy (EuroHealthNet, 2021).

Tackling the combination of issues previously present is of great importance. Assuring that the healthcare systems, which are a vital part of a country's economy, are contributing to the sustainable development is a crucial task for the sustainability movement that is utterly necessary to assure the wellbeing of future generations.

Hospitals are at the heart of health care systems. Not only are they a crucial part of the health system, providing other services that small clinics and family health units cannot, but they are also responsible for most of the interactions between healthcare stakeholders and represent the bulk of the costs incurred by the sector. As such important actors, hospitals require a high level of attention, and so, when tackling the healthcare system, it is important to dedicate more effort to hospitals. When it comes to sustainability, it is important to ensure that hospitals fulfil their ultimate purposes by providing health services to every beneficiary, managing their costs efficiently, and contributing to the well-being of future generations.

Given these necessities, it is important to understand the role of the hospitals on these last issues. Thus, the motivation of this dissertation is to understand the sustainability efforts of the Portuguese public hospitals. Therefore, this dissertation proposes a multicriteria analysis framework to evaluate the level of sustainability of the Portuguese public hospitals.

1.2 Objectives

This dissertation aims to analyse sustainability in the Portuguese public hospitals. To do so, it is important to understand the environment and the basic concepts related to this dissertation such as the concept of sustainability and the Triple Bottom Line (TBL) approach to sustainability, the wrapping and the running of the Portuguese Healthcare system that englobes the public hospitals.

After understanding the topic of the problem at hand, it is necessary to define how it is going to be handled. Before measuring sustainability in healthcare, it is first important to understand how this topic is currently explored. Thus, it is necessary to conduct a state-of-the-art review of sustainability in healthcare in order to define the grounds on what is done and what needs to be explored in this dissertation

To analyse the sustainability of the Portuguese public hospitals it is proposed a Multicriteria Decision Aiding approach (MCDA). As the name indicates, MCDA approaches are used to aid in multicriteria decision-making problems, meaning that it deals with decision-type situations where it is necessary to consider more than one factor that influences the outcome of the decision (El Amine et al., 2014), which rightfully applies to this dissertation since sustainability involves several factors (Correia, 2019; Kenton & Berry-Jonhson, 2020). Thus, to evaluate the sustainability of the Portuguese Public hospitals it will be applied a MCDA sorting method, the ELECTRE TRI-nC, which allows sorting the hospitals into categories. These categories are predefined and ordered according to a global sustainability level that respects the set of criteria previously defined.

Thus, aiming at analysing the sustainability of the Portuguese public hospitals, the main objectives of this dissertation are:

- To build and implement a model capable of measuring the topics identified in the state-of-the-art review and that also include the input of the specialist whom the decision aiding must be given to, the Decision Maker (DM).
- To obtain results from this implementation that can lead to a reflection of the of the sustainability of the Portuguese public hospitals.

1.3 Research methodology

The methodology used is very sequential-oriented. The goal is to present the topics starting from a more general point-of-view, narrowing it down to a particular or specific topic, culminating in the implementation of the research

The research methodology is divided in 5 stages:

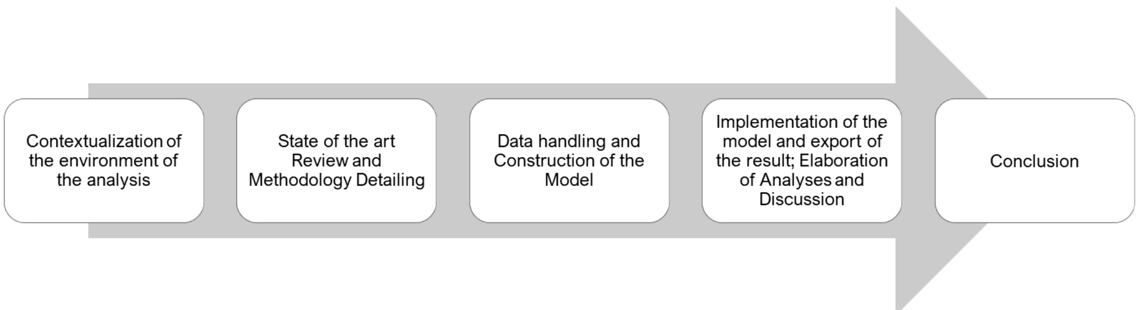

Figure 4.1: Methodology of this Dissertation

The first stage consists of the contextualization of the problem, where it is introduced the Portuguese healthcare sector and the general concept of sustainability. The second stage consists of the research of the work developed on the topic of the dissertation, where it is going to be explored the development of sustainability in healthcare, and a theoretical presentation of the methodology of analysis. The third stage consists of the analysis of the data available, and a further construction of the model. The Fourth Step is the implementation of the model and the elaboration of needed analysis to conduct a discussion of the results. The final step consists of the conclusion, which englobes a detailing of the main milestones achieved, an overview of the limitations found, and the proposal of future research topics.

1.4 Structure

The work is divided into seven chapters:

- This first chapter is the Introduction, where it is introduced the topic of the this study, the objective, the research methodology and the structure of the dissertation.
- The second chapter is the Problem definition, where it will be explored the Portuguese National Healthcare system and the concept of sustainability and the triple bottom line approach.
- The third chapter consists of the Literature review, where is conducted a presentation of the state-of-the-art of sustainability in healthcare, and the presentation of the main topics to evaluate the in the analysis of the sustainability of the Portuguese public hospitals.
- The fourth chapter is the Methodology, where it is detailed how the problem will be handled. It consists of two main sections: the first explaining the main concepts of Multicriteria Decision aiding, which is utterly necessary to understand the second section, which consists in the presentation of the MCDA method chosen to apply to this problem, the ELECTRE TRI-nC method.
- The fifth chapter consists of presentation of the Case Study, where it is displayed the process of formulating the Model, the definition of actions, criteria, and model parameters.
- Chapter 6 presents the implementation and execution of the model built in the previous chapter. It is also conducted the results exploitation, as well as several analyses of the results and a further discussion.
- The last chapter consists of the Conclusion, where it is presented the main goals achieved through this work, the main limitations found, and a proposal of future researches.

Chapter 2

Problem definition

The present chapter attempts to clarify the context of this research work. Section 2.1 presents an overview of the Portuguese Public Healthcare System (SNS): how it was founded, its evolution, its most important milestones and current constitution in the present day. Section 2.2 introduces the concept of Sustainability according to the triple bottom line approach.

2.1 National healthcare system: The Portuguese public hospitals' framework

The Portuguese National Healthcare is an institution from which the Portuguese State assures the right to health – prevention, promotion, and surveillance – to every citizen. This institution dates back to 1979, however, the path to its establishment started long before that. In this section, it is elucidated how the SNS was founded, explaining how healthcare was provided before the SNS. Thereafter, an overview of the evolution of the SNS is conducted, from its foundation until the present day, culminating in an analysis of the evolution of health indicators of the Portuguese population, and a listing of the major hospitals and health units' constituents of the SNS analysed in this dissertation.

2.1.1 Before the SNS

During the 19th century, the world was affected by six pandemics of *cholera*, due to increased circulation and commerce flows brought by the industrial revolution (CBC News, 2008). In the 20th century, three *influenza* pandemics have spread throughout the globe, mostly during the periods of the world wars, causing millions of deaths (Kilbourne, 2006). These events led to significant developments in the theory of disease, such as the germ theory, advancements in vaccines and antibiotic developments, which culminated in the implementation of several large-scale programs of eradication and control of diseases throughout the world. The necessity of cooperation between countries to promote such programmes led to the foundation of the first international healthcare associations, committees, and conferences, leading to great advances in medicine and healthcare services all around the globe.

Portugal took his first steps when Ricardo Jorge, who is considered the founding father of our modern healthcare system, founded the Directorate-General for Health (*Direção Geral da Saúde - DGS*) in 1899 – 1901 (Graça, 2015). However, from this time until the 70's, the healthcare services were very scarce. The institutions in charge of providing basic healthcare were mostly independent institutions and those who were funded by the State were in very poor conditions. The institutions present in that time were (Baptista, 2019):

- Misericórdias: An institution founded in 1498, whose actions were based on the ideas of Christian solidarity, of helping those in need regardless their social position or possessions. They would install and manage hospitals that would be available for all population. They were funded mainly by the church (Infopedia, 2021).
- Charities: Just like misericordias, other small charity institutions provided healthcare services to people in need. These institutions were funded mainly by charity donations.
- Specialized Healthcare services focused on disease prevention, for example: vaccination.
- Specialized and Non-Specialized State Hospitals, only present in the largest district centres.
- Private Clinics directed to High Social Classes.

This period was characterized not only by low levels of health in the population but also low levels of professionalization in the healthcare institutions.

After meeting the political and social conditions arising from the Portuguese political restructuring of the 1970s, the State felt obligated to take actions in the healthcare sector leading to profound changes in the sector aimed at reducing barriers on the access to basic healthcare, not only economically but also geographically.

In 1971, the right to health of all citizens was promulgated, according to the law decree n°413/71, September 27th, assuring the State gets a more active role on healthcare (DGS, 2021). This period was marked by the beginning of the progressive appearance of the first regional Hospitals and health centres.

In 1974, the SNS was created, granting universal and free healthcare to all citizens. However, it was not until 1979 that the State officialised the Healthcare Politics provided under the article 64° of the Portuguese Constitution of 1976 – The implementation of a national and universal, general and free Healthcare System – that culminated in the establishment of the Nacional Healthcare Service or "*Serviço Nacional de Saúde*" (SNS) that we know today (Decreto Da Aprovação Da Constituição, Artigo 64º de 10 de Outubro Da Assembleia Da República, 1976).

2.1.2 The evolution of the SNS

Throughout the following decades until the present day, the SNS went through several significant milestones to build the institution that it is today. In this Sub-section it will be conducted an overview of the major events that happened during the 80's, the 90's and the 21st century regardless the evolution of the SNS.

From 1980 to 1989:

In the beginning of this decade, in 1982, the SNS gained financial autonomy, and Regional Health Administrations (RHA) were created, according to the law decree n°254/82 (Decreto-Lei n.º254/82 de 29 de Junho Do Ministério Dos Assuntos Sociais, 1982). The Financial Management Department of Healthcare is made responsible for the management of funds given to the Health Administration.

In the next year, due to the growing importance of the sector associated not only with the service volume, respective infrastructures, but also with the social weight it represents, the Health Ministry is officiated, according to the law decree nº344-A/83 (Decreto-Lei n.º 344-A/83 de 25 de Julho Da Presidência Do Conselho Ministro, 1983).

At last, in 1988, the public expense growth associated with the health sector led the government to take actions in order to optimize this sector's management - the law decree n°19/88 approves the Hospital's management law (Decreto-Lei n.º 19/88 de 21 de Janeiro Do Ministério Da Saúde, 1988). Similar to other European countries, management organs are reinforced, dropping the current collegial regime, and implementing a new guardianship management regime. Business Management methods are applied to this sector and to its respective infrastructures and services.

This decade was marked by the adoption of the first measures to implement the *New Public Management* (NPM) Paradigm. This Paradigm originated in the United Kingdom and already used in several European countries, affirms that the State role should be less interventional, taking part only to assure equity, sustainability, control and accountability through regulation, leaving the management itself to non-government officials (Nunes, 2016).

From 1990 to 1999:

This decade is considered the turning point to the Portuguese healthcare system. In 1990, the Law nº 48/90 aproves the LBS (*Lei de Bases de Saúde)* (Lei n.º 48/90 de 24 de Agosto Da Assembleia Da Républica, 1990). For the first time, health is acknowledged not only as a right to every citizen but also as a joint responsibility of society and State. This law recognized the coexistence of public and private healthcare services, making the State, non-beneficiary users of SNS and private beneficiaries responsible for healthcare. However, the LBS brought a sharp growth to private healthcare services which led to disagreements in respect of equality to its access, mainly in the quality of services, since the private sector has larger funds, and this leads to a higher quality healthcare.

As an effort to fix the inequalities brought by the LBS, in 1992 the government implements moderator fees and exemptions to emergency healthcare services and appointments and complementary means of diagnostic in outpatient scheme take place, according to the law decree nº 54/92 (Decreto-Lei n.º 54/92 de 11 de Abril Do Ministério Da Saúde, 1992). Revenues were allocated to medical acts' costs which contributed to SNS' revenues, reflecting a quantity and quality growth in healthcare services, mainly in services provided to the less fortunate. The diploma assures the social justice principals, where the most fortunate pay their part for the healthcare they benefit from so that the poorest do not have to pay what they cannot afford.

Another milestone of this decade happened in 1995, when Health User Card is created (SNS, 2021e).

Finally, in 1999 it is established the Local Health System (SLS) regime by the law decree nº 156/99 (Decreto-Lei n.º 156/99 de 10 de Maio Do Ministério Da Saúde, 1999). The SLS's are represented by the Hospitals, Health Centres, and other public or private institutions of healthcare services of a given region. According to this regime, all these institutions must articulate their resources, based on a complementarity principle, in order to promote health and manage resources more efficiently, by geographic region.

All these milestones of the 90's represented major important steps to the informatization of the healthcare sector observed in the next two decades.

From 2000 to the present day:

The early 2000's were marked by the active presence of the British NPM Paradigm. As was the case in 1980's, the Portuguese Healthcare sector took extra steps in separating itself from the government by becoming more independent in terms of finances and management. Even though in the 80's the SNS was granted financial independence, public hospitals still had limited administrative and financial autonomy, being totally controlled by the Ministry of Health. Also, there was an installed necessity to reduce hospitals depts, resources waste and deficits. The public health sector was in crisis, therefore, in 2002 a new hospital management regime was approved to introduce major changes to the LBS. According to the law nº 27/2002, a new corporate management model was applied to all the hospitals belonging to the SNS, turning them into State-Owned Hospital enterprises (SA) (Lei n.º 27/2002 de 8 de Novembro Da Assembleia Da Républica, 2002). At this point, hospitals worked just like business companies, following the usual commercial laws applied to all types of enterprises. In 2005 the SA's become EPE (Public State Enterprises), which gave the public hospitals more instruments to promote effectiveness and efficiency from the SNS' resources (Decreto-Lei n.º 93/2005 de 7 de Junho Do Ministério Da Saúde, 2005).

At the year of 2003 the law decree nº309/2003 creates the Health Regulatory Agency – this event marks the complete separation of the government function, before as operator and funder, to regulator and supervisor (Decreto-Lei n.º 309/2003 de 10 de Dezembro Do Ministério Da Saúde, 2003).

The following years were marked by the establishment of the services that still exist to this day.

- 2004: The State established a regime of reimbursement of the price of meds.
- 2006: The National Network for Integrated Continued Care was founded.
- 2007: Appearance of the first's Family Health Units (FHUs).
- 2008: Creation of the SNS health centre groupings – this was a very important milestone because it allowed not only a tight and balanced management of the healthcare services of each group but also a significant improvement in the access to healthcare services.

– 2015: Establishment of the National Network of Palliative Care.

The beginning of this current century was also marked by the informatization of things in a worldwide scale. The Portuguese Healthcare sector was no exception. Internally, the healthcare sector was undergoing through the modernization of the administrative services which allowed sharing information between healthcare institutions, public or private, about patients and resources. Publicly, the main measures that aimed at the public informatization of this sector started in 2011 with the generalization of the electronic prescription and in 2012 with the take-off of the User-Portal, which allowed the user to schedule appointments or confirm surgeries (SNS, 2021e).

2.1.3 The evolution of health throughout the years

Naturally, the evolution of the healthcare systems had impact on public health. For instance, before 1960, most people who lived outside of the large cities did not have access to hospitals to give birth or to receive treatments for common diseases. To compare the evolution of healthcare system with the evolution of health in the population the following table was conceived (PORDATA, 2020d, 2020c, 2020b, 2020a, 2020e, 2021).

Table 2.1: Health evolution' indicators from 1960 until 2010

Indicator/Year	*1960*	*1970*	*1980*	*1990*	*2000*	*2010*
Women's life expectancy at birth [yrs.]	66.4	70.3	74.8	77.5	79.9	82.4
Men's Life expectancy at birth [yrs.]	60.7	64	67.8	70.6	72.9	76.5
Perinatal mortality rate	42.2 ‰	38.9 ‰	23.8 ‰	12.4 ‰	6.2 ‰	3.5 ‰
Infant mortality rate	77.5‰	55.5 ‰	24.3 ‰	10.9 ‰	5.5 ‰	2.5 ‰
SNS' total expense per capita [€]	--	--	34.2	181.4	609.6	1021.1
Birth Rate	24.1 ‰	20.8 ‰	16.2 ‰	11.7 ‰	11.7 ‰	9.6 ‰
Consultations [thousands]	8039.9	17602.1	280306	30023.0	35847.2	43734.3
Hospitalisations [thousands]	463.5	619.8	878.4	1086.4	1171.7	1202.4

As expected, before the SNS, given the low value of SNS' total expense per habitant on health, the access to basic healthcare was more restricted, with less consultations and hospitalizations. Thus, it is logic that some indicators such as the life expectancy is naturally lower, and the perinatal and infant mortality rate higher. Also, given the lack of healthcare services such as treatments and consultations, the life expectancy at birth was predictably lower, both in women and men.

As the SNS evolved, so has the access to healthcare and information available: The birth rate decreased due to higher level of information and circulation of birth control methods.

Finally, as expected, with the progressive evolution of the healthcare services and its access, it is possible to observe a positive evolution on the Health Indicators such as life expectancy, perinatal and infant mortality and number of consultations and hospitalizations.

2.1.4 Institutions of the SNS: The Portuguese public hospitals

The Portuguese State reassures the right to health protection through the Healthcare System, which covers all institutions and official healthcare services related to the Ministry of Health, including the SNS. The present structure of the Healthcare System is represented in Figure 2.1 (Simões & Hernández-Quevedo, 2017).

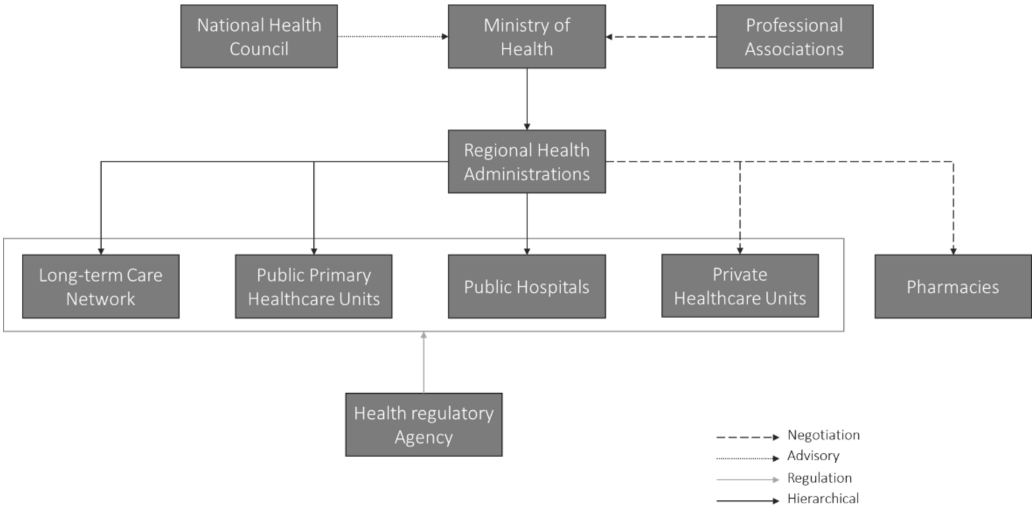

Figure 2.1: Portuguese Healthcare System

The Ministry of Health advised by the National Health Council, is at the top of the hierarchy of the SNS. The ministry divides its efforts by Regional Health Administrations (RHA). Each RHA coordinates 5 establishments:

- Long-term Care Network, that provides the local populations with a variety of need programmes and services, such as School's Health programs, addiction intervention programs, Mental Health programs, Integrated Management of Diseases, and others (SNS, 2021c).
- Public Primary Healthcare Units, which englobe the Family Health Units.
- Public Hospitals and the institutions related to their activity
- Private Healthcare Units, however, the Ministry of Health and the RHAs do not have control over these entities, they merely negotiate terms and conditions to provide the most fare healthcare services in both private and public institutions, and to have a coordinated system.
- Pharmacies, which are also not controlled by the RHA, but play an important role on society and in the institutions of the SNS, so they negotiate with the RHA to coordinate their activity with the needs of the local society and healthcare institutions.

Lastly, there is the Health Regulatory Agency, a government institution in charge of assuring the good function of the healthcare providers, such as the Long-term Care Network, the Primary Healthcare Units, the Public Hospitals, and the Private Healthcare Units.

For the purpose of this dissertation, the focus will be on the public hospitals. These have the mission to provide differentiated healthcare services, by articulating with the other healthcare institutions within the SNS. In 1968, the General Hospital Regulation defined hospitals as public interest services, instituted, organized, and administered with the objective of providing the population with health care rehabilitative and curative medical assistance, and also to collaborate in disease prevention, teaching, and scientific research (SNS, 2016). In Portugal there are 3 types of public hospital's facilities (SNS, 2021d):

- The majority of the public hospitals are EPEs. As mentioned in the previous sections, EPEs is a type of public enterprise taking the form of a legal person governed by public law, whose creation is the initiative of the State for the pursuit of purposes for which it is responsible (Nunes, 2020)
- There are also the Public Institutions (IPs), which are a type of institution that is part of the indirect administration of the State or autonomous regions. These are constituted by legal persons under public law, who have their own assets, which by rule must meet the requirements for financial and administrative autonomy. The most known public healthcare facilities that are IPs are the "*Instituto Nacional da Farmácia e do Medicamento - INFARMED"* and the *"Instituto Português do Sangue e da Transplantação".* Even though IPs are not actual public hospitals, these institutions are crucial to the functioning of the public hospitals, providing and managing essential supplies such as drugs, blood, and donated organs (Santos, 2020).
- Lastly, there is the Public-Private Partnerships (PPP). PPPs are constituted through a relationship between the public sector and a private institution, in a form situated between traditional contracting and privatisation. They differ from traditional contracting, where the private party is only responsible for the construction of the infrastructure, which is not the case in PPPs. They are also different from privatisation given that the State continues to have responsibilities, whereas in privatisation there is a definitive transfer of the asset to the private party, and the risk is transferred entirely to the latter. Currently, there are 2 public hospitals in a PPP regime in Portugal: *Hospital Beatriz Ângelo (Loures)* and *Hospital de Cascais Dr. José de Almeida* (Nunes, 2020).

For purposes of transparency to the public, the SNS displays a variety of healthcare indicators of most hospitals in Portugal. These indicators are represented in the Benchmarking Section of the SNS website, where the hospitals are organized in 5 groups B, C, D, E and F, displayed in table 2.2 (SNS, 2021b). The groups are based on a statute issued by the Health ministry to categorize the hospitals and healthcare institutes into logical groups, which are (Portaria n.º 82/2014 de 10 de Abril Do Ministério Da Saúde, 2014):

- **Group I**: Hospital facilities with a direct area of influence of between 75 000 and 500 000 inhabitants, providing the medical and surgical areas of internal medicine, neurology, paediatrics, psychiatry, general surgery, orthopaedics, anaesthesiology, radiology, clinical pathology, hemotherapy and physical medicine for rehabilitation. They may also have some additional services such as ophthalmology and cardiology, but not medical genetics, immuno-allergology, paediatric cardiology, vascular surgery, neurosurgery, plastic surgery, cardiothoracic surgery, maxillo-facial surgery, paediatric surgery and neuroradiology (Benchmarking' groups B and C).

– **Group II**: are the hospital establishments that provide the medical and surgical services of Group I to their own direct area of influence. They also have an indirect area of influence, to which they provide the valences of ophthalmology, pneumology, cardiology, rheumatology, gastroenterology, nephrology, clinical haematology, infectious diseases, medical oncology, neonatology, immuno-allergology, gynaecology/obstetrics, dermatology-venereology, otorhinolaryngology, urology, vascular surgery, neurosurgery, pathological anatomy, nuclear medicine, and neuroradiology. They may have additional valences, except for clinical pharmacology, medical genetics, paediatric cardiology, cardiothoracic surgery, and paediatric surgery (Benchmarking group D).
– **Group III**: are hospital establishments covering all medical and surgical specialties, where those of greater differentiation and sub-specialisation are subject to authorisation by the Minister of Health. They have a direct and indirect area of influence for all their valences (Benchmarking Group E).
– **Group IV**: Specialised hospital establishments in the areas of oncology (group IV-a), physical medicine and rehabilitation (group IV-b) and psychiatry and mental health (Benchmarking Group F).

Table 2.2: Hospitals, Hospitals Centres and ULS's in SNS's Benchmarking groups

Group B	Group C	Group D	Group E	Group F
CH P. Varzim	CH Barreiro M.	H. E. S. Évora	CHU Porto	IPO Porto
CH Médio Ave	ULS Alto Minho	H. F. Fonseca	CHU L. Central	IPO Coimbra
ULS C. Branco	H. Cascais	CH Algarve	CH L. Ocidental	IPO Lisboa
H. Stª Mª Maior	H. Loures	CH T. Viseu	CHU Lisboa Norte	
H. V. F. Xira	CH E. D. Vouga	H. Garcia Orta	CHU S. João	
ULS Nordeste	ULS Norte Alentejano	H. Braga	CH Uni. Coimbra	
ULS L. Alentejo	CHU Cova Beira	CH VN Gaia/Espinho		
ULS Guarda	ULS Baixo Alentejo	CH TM A. Douro		
CH Oeste	CH Baixo Vouga			
	CH Tâmega Sousa			
	H. D. Santarém			
	CH Setúbal			
	CH Leiria			
	CH Médio Tejo			
	H. Sª O. Guimarães			
	ULS Matosinhos			

2.2 Sustainability definition: The triple bottom line approach

Sustainability has become increasingly an important concern to society and therefore to the companies, thus it is important that organizations incorporate sustainability into their strategies.

For the past few years, society has been witnessing environmental decisions which proved to jeopardize not only long-term life on the planet but also short-term, which is the case of natural catastrophes caused by the global warming. Additionally, the continuously growth of the world population is leading to resource depletion such as water and commodities, and waste disposal.

To act on this problem, business leaders throughout the globe need to understand the concept of sustainability in order to develop measures to prevent disasters.

The sustainability awareness has been around since the 70's however it was not until the 80's that critics started to reach consensus regarding its definition. The World Commission on Environmental and Development defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their needs" (World Comission on Environment and Development, 1987). Nowadays, sustainability can be summarized very well using the TBL approach.

The Triple Bottom Line: People, Planet and Profit:

For the purpose of this study, it is important to understand the basis of the TBL approach to sustainability. This model sits on the three most important dimensions of sustainable development - Environmental Quality, Social Equity and Economic Benefits – and affirms that these are the key to long-term strategies for companies to make the transition to sustainability.

Some people find some dimensions more important than others, so sustainability is illustrated sometimes with the three dimensions overlapping. For instance, some consider that in the scope of sustainability, the environmental dimension is portrayed as a larger system, with two subsystems, Social and Economic, being these last ones limited. However, in this work it will be considered the TBL approach where all dimensions have the same importance and are considered individually, not excluding the chance of having common factors between each other's. The TBL dimensions are represented in the 3 pillars, Economic, Social and Environmental (Correia, 2019; Kenton & Berry-Jonhson, 2020):

- The Economic Pillar (Profit): The main focus of this dimension sits on the value created by the organization but not just in internal financial terms. It considers the long-term impacts that certain decisions have on matters such as financial stability of the market, employment, and economic growth of the company itself and its market - Does the business help local suppliers stay in business and innovate? Or do these activities put the local economy at risk? Do they pay employees enough to stimulate economic growth and spending? Do they choose materials that are economically a good investment?

- The Social Pillar (People): This dimension is concerned about the wellbeing of people, weather they are employees, stakeholders, shareholders or just members of the society. Recently, a new trend for large companies has arisen where organizations promote Corporate Social Responsibilities (CSR) initiatives. Companies tend to be more socially sustainable as more CSR initiatives they have, which gives them a better image for the public as companies who are concerned about society. Another concern of this dimension focuses on the employee's welfare and weather the company is acting correctly towards them. Overall, the main questions that this dimension poses are: Is this business a job-growth driver in the city? Is this company and its employees giving back to the community? Does this business support local initiatives and grow the overall sustainability of your community/region? Does this company implement fair hiring standards? Are the employees safe and happy? Is this company considered an ethical company?
- The Environmental Pillar (Planet): Finally, this dimension fucuses on the organization's efforts to reduce environmental impacts and minimize their ecological footprint. It concerns the use of resources such as water, electricity, fuels, and other materials like paper and plastic, and weather their use is essential to their activity or if it is considered waste. It also evaluates the responsible use of Earth's resources given their limitations and the impact that it has on the environment and future generations. Nowadays, in order to promote an environmentally sustainable image, companies started to adopt some green initiatives such as recycling in the workplace, replace their current production supplies for recycled materials, create Circular Economies in their production and other initiatives that promote the responsible use of Earth's resources and minimizes the negative impact of their production on the environment.

The continuous growth of sustainability concerns in society has made companies more aware of the necessity to include sustainable measures in their activities. The TBL approach states a methodological path to sustainability, highlighting three essential action points, from which enterprises can draw an action plan to implement a sustainable conduct in their day-to-day operations. However, it is still necessary to quantify the sustainability actions performance, which is still considered as an ambiguous task (Correia, 2019; Kenton & Berry-Jonhson, 2020).

2.3 Summary

In this chapter introduces the context of this dissertation. In Section 2.1, by chronological order, it was presented the evolution of the Portuguese National Healthcare services. Throughout this section, it is possible to visualize an exponential evolution of the health sector over the last century, which reflected in a clear positive evolution of public health indicators such life expectancy, and infant mortality rate.

In Section 2.2, it was conducted a brief and general introduction to the sustainability's TBL approach, starting by defining sustainability itself, and explaining the general aspects of each dimension of the TBL model. The conceptual definition of corporate sustainability is a very general and vague concept. It varies in terms of not only factors to consider in each dimension, but also the efforts necessary to implement sustainability endeavours, and how to measure them, according to the type of activity that is being considered.

As previously mentioned, nowadays hospitals are acting as enterprises following normal business methods. Thus, in the context sustainability, questions can be raised as how the Portuguese public hospitals implement sustainable measures in their activity and how to quantify and measure them.

For the next chapter it will be explored the topic of Sustainability in hospitals, and how to measure it according to the TBL approach.

Chapter 3

Literature Review

The present chapter presents the current research of the topic of sustainability in healthcare, particularly in hospitals. The first section introduces the evolution of sustainability in healthcare, comparing different perspectives and definitions, converging into a detailed explanation of each one of the sustainability pillars in the healthcare sector. The second section introduces the theme of Measuring Sustainability in Hospital, where it is provided a review of the efforts made on the topic so far, and it is suggested a set of Fundamental Points of View (FPVs) to measure sustainability in hospitals. This section ends with a clarification of Composite Indicators in the scope of measuring sustainability.

3.1 Sustainability in Healthcare

Present-day society expects organizations to focus upon the concept of sustainability in their activity, which has led organizations to drastically change the way they do business. Some organizations define sustainability as a central element of the business itself, where sustainability is used in the business as the core activity (Yang et al., 2017); other organizations see sustainability as an integral part of their strategy, vision or/and culture to affirm themselves as sustainable organizations, maintaining their usual activity (Jin & Bai, 2011); some see sustainability as a factor to consider the strategic level of the organization in which part of an organization's decisions or actions are made considering sustainability variables (Engert et al., 2016). However, there is a lack of clarity as to how firms can implement sustainability in their business making it challenging to plan for sustainability.

Healthcare systems, in particular hospitals, are characterized as very complex systems that consist of many stakeholders, such as shareholders, doctors, patients, community, etc. Actions and decisions taken by the hospitals must consider its large range of stakeholders. Naturally, when it comes to sustainability in healthcare, it is not only about the environment around the hospitals but also about the social and economic wellbeing of these stakeholders (Pereno & Eriksson, 2020). However, there is not a general definition of sustainability in healthcare. The healthcare sector struggles not only with this latter reason but also with the lack of research on sustainability in this sector. In fact, a decade ago, public hospitals did not include sustainability efforts in their planning, nor in their initiatives given that the concept was still very ambiguous to society and firms. Even though Hospitals would conduct some sustainability initiatives, like recycling plastics, these were not a business conscious effort of sustainability nor a strategic decision. Similar to other areas of business, in the healthcare sector, sustainability awareness has had an exponential growth over the last decade and nowadays hospitals have started to include sustainability in their activity more fervently (Rodriguez et al., 2020).

Since the start of sustainability awareness, some studies have been made in order to answer the question of what sustainability in healthcare is. Most scholars around the globe have centred the topic of healthcare sustainable practices on environmental sustainability for reducing the impact of healthcare operations, particularly hospitals, concerning medical waste and resource usage. Some even affirm that medical waste has become a main cause of disease spreading due mainly to air and soil pollution around the hospitals, which increases the concern in waste management. On the other hand, the evolutions of healthcare services have brought a search not only for better service levels with fewer costs, but also for consumer, employee, and society wellbeing, which has increased the awareness of social and economic sustainability factors (Marimuthu & Paulose, 2016).

Recently, the concept of sustainability has evolved, and there are many perspectives on how to approach sustainability. Over the years different theories have been emerging where the three sustainability pillars can be independent or depend on each other, and some dimensions can even overlap other dimensions (Hopwood et al., 2005). But one thing is certain, regardless of any perspective to sustainability, all approaches must consider the long-term focus and the need to balance economic, social, and ecological interests when discussing whether a healthcare system is sustainable or not (Fischer, 2015). Overall, a sustainable healthcare system aims at increasing the economic sustainability of health care systems, reducing their impacts on the environment, and promoting a new social perspective to care (Pereno & Eriksson, 2020).

For the purposes of this dissertation, it is used the triple bottom line approach to sustainability, considering each pillar as an individual rather than a part of another one, not excluding the chance of the pillars having dependent factors on each other. When it comes to sustainability in healthcare, particularly using this approach, it is necessary to understand what each pillar needs to consider.

3.1.1 Environmental Sustainability in healthcare

Perhaps the most mainstream topic of sustainability is the environment. In 2015, 196 countries signed the Paris Agreement, a legally binding international treaty on climate change that aimed at limiting global warming where the involved parties agreed to lower their gas emissions to achieve a climate-neutral world by mid-century (Paris Agreement, 2015).

The control and eradication of hospital infections is a major factor of environmental impact. These activities require intensive use of water and energy, disposable products, and toxic detergents and disinfectant to sanitize the hospital facilities and equipment, preventing the spreading of infections. Disposable products, represent the largest part of hospital waste. Water and energy use, essential to the daily activity of the hospitals, have also a negative impact on the environment. Finally, the use of toxic substances for disinfection and cleaning, are highly pollutant activities, not only because of the production itself (plastic packaging, pollutant 'air emissions) but also for the procurement of these products and the disposable of these toxic substances in a sewer (Daschner & Dettenkofer, 1997).

Other concerns were raised regarding the limitations of resources. The intensive use of limited resources has been proved as an endangering factor for future generations (Galli et al., 2015). The concept of environmental sustainability relies mainly on these last issues.

Just like in every other sector, the healthcare sector needs to implement sustainable measures and initiatives. A hospital can be considered environmentally sustainable if it is able to deliver health services while implementing the most possible efforts in the following seven categories (Duque-Uribe et al., 2019; McGain & Naylor, 2014):

- Hospital Design: Hospital Building and its design are responsible for around 10% of the full lifetime costs. It has been proven that a better design of the hospitals, with more efficient routes and space usage, energy sources, waste management systems can decrease not only economic costs, but also increase ecological efficiency.
- Energy: Energy consumption in hospitals represents around 20% of the public hospitals, most of it is from lighting purposes, and equipment. The goal of this category is to find efficient and preferably reusable energy sources to reduce the environmental impact.
- Water: About 1% of a normal developed country city's water consumption is from hospitals. It is estimated that it is possible to save up to 25% by applying simple measures such as sub-metering and datalogging metres, dual flush toilets, flow restrictors on showers and hand basis, etc.
- Travel: This category is related to CO_2 emissions associated with ambulances private and public transportation. These can be cut by renewing the ambulance fleet to electric vehicles or by creating incentives for patients to use public transportation, by raising parking fees for example.
- Procurement: Procurement is linked to the acquisition of goods. In hospital activities, the use of disposable goods such as gloves, masks, or uniforms has one of the highest levels of the public sectors. It also requires a vast level of supplies to assure health and hygiene in a hospital. Since this category represents the highest healthcare carbon footprint, the goal is to reduce the use of these products or substituting them for reusable or more eco-friendly products if possible.
- Waste: The healthcare sector is known for very high levels of daily waste due to the type of products it uses. Waste management and recycling measures can reduce the environmental impact of this category.
- Staff Behaviour: Individual behaviour of the staff can improve the attitudes taken inside the hospitals. For instance, if the staff is not concerned about sustainable practices, chances are the staff would not recycle in the workplace. Therefore, it is necessary to implement

staff-directed green initiatives to build awareness over environmentally sustainable practices among the hospital staff.

3.1.2 Social Sustainability in healthcare

The topic of socially sustainability in healthcare converges all on stakeholder's wellbeing. When considering a public hospital environment, social sustainability focuses not only on internal agents – patients, doctors, nurses, janitors, and other employees – but also on external agents such as owners, shareholders, suppliers, the community, and the State. All these agents represent important roles by driving the change towards social sustainability and providing insights into the integration of sustainable practices in healthcare.

Generally, a social sustainable health service can be stated as an organizational system that is reinforced with sufficient resources and activities to meet individual and public health needs, always considering all those involved (Marshal et al., 2015).

However, there are still barriers to implement social sustainability in healthcare. The most considerable barrier is lack of knowledge and awareness of the topic, but there are other obstacles such as poor corporate structures that impose conflict of interest between the responsible entities, high levels of bureaucracy within the institutions, costs, and resources limitations. But since the trend is to evolve into a more sustainable system, hospitals can take advantage of innovation and technological advancement, open communication and information sharing, organizational culture and strategy, resources efficiency, and sustainable supply chain practices, which would help organizations lead the shift to socially sustainable practices in the hospital's environment. For instance, clear communication is needed among all stakeholders to set goals early and to implement, evaluate and communicate the outcomes, thereby facilitating healthcare sustainability trends (Hussain et al., 2018).

3.1.3 Economic Sustainability in healthcare

Economical sustainability is a key factor, which can not only lead to budgetary cuts to the quality healthcare services but can also encourage qualitative views to approach savings from the point of view of selective reduction and optimisation of resources, processes, and supplies (Pereno & Eriksson, 2020).

An economically sustainable healthcare system is one that can spend the minimum amount of financial costs in order to provide the necessary resources to the healthcare activity. Thus, from the economic point of view, increasing healthcare expenditures demands greater efficiency in the delivery of services (Duque-Uribe et al., 2019). This means that to account the economic sustainability of a service, it is necessary to know the level of resource efficiency. Therefore, economic sustainability is dependent on the social and environmental sustainability factors, specifically the resources efficiency, whether it is materials (medical supplies, machines, energy, water, etc.) or human resources (doctors, nurses, and other employees).

When it comes to hospital activity, the economic pillar can have into account not only costs of services, patients or staff but also other indicators such as revenue, economic growth, profitability level of savings and investments (Duque-Uribe et al., 2019).

3.2 Measuring Sustainability in Hospitals

Over the past decade, the focus on measuring the performance of healthcare services has increased in a very significant way, especially in the private sector. The corporatisation of the health sector has increased the competition between hospitals, which has raised the need to measure the level of services delivered by hospitals in order to find competitive advantages. Thus, public entities such as the Agency of Healthcare Research and Quality have put up efforts towards the measure of performance of the healthcare institutions to account the hospitals for quality of medical care in order to improve services and public attendance (Handle et al., 2001).

The growth of sustainability awareness and concerns raises the need of organizations to understand how to measure the efforts on this subject, not only because it helps to track and access progress, but also to attract stakeholders, evaluate sustainability-related trade-offs, meeting or anticipating requirements, finding barriers, and rewarding good practices. Another great concern of measuring sustainability is accountability. The Paris Agreement requires a collective effort to lower gas emissions, therefore, all institutions need to be held accountable for their actions, not only regarding the political obligations brought by the Paris Agreement but also for the public and the institutions themselves can understand the social, economic and environmental impact its activity has (Nisen, 2012; U. S. Department of Transportation, 2021; Paris Agreement, 2015). The role of the healthcare industry represents a vital sector not only in countries' economies, but also in the impact that this sector has on society. Besides the high social-economic value this sector has, it represents a significant impact on the environment (Duque-Uribe et al., 2019).

After defining the concept of sustainability in healthcare and the factors considered in each one of the triple bottom line pillars, it is necessary to design a measurable framework to evaluate the sustainability efforts of the healthcare industry. However, assessing sustainability is a complex task with many factors to consider of different importance, and so it cannot be done in a direct way. In the scope of MCDA it is necessary to develop a framework that includes all these factors in logical, ponderable, and measurable way. Thus, to measure the sustainability in the hospitals it is necessary to create a set of criteria that aggregates information into logic groups to consider all the factors that sustainability needs to evaluate (Amine et al., 2014).

However, in the further chapters it will be explained that the construction of the criteria set in MCDA problems depends on three important factors:

- The research on the topic of the problem.
- The available data that can characterize the criteria set (indicators, reports, etc.).

– The input of a Decision Maker (DM).

Considering these factors, in this chapter it is proposed a set of Fundamental Points of View that characterize the main theoretical topics to approach on this research, and to cover on the criteria set, defined in Chapter 5. It is important to state that the FPVs were also selected, discussed, and approved by the DM, based on the research presented before and the experienced and specific knowledge of the DM.

Figure 3.1 illustrates a diagram with the FPVs identified to evaluate sustainability in healthcare, which is divided by the three sustainability pillars: The Environmental pillar considers as FPV the Procurement Consumption and Waste of Resources; The Social pillar FPVs includes the Quality of Healthcare Services and Community Wellbeing; and the Economic pillar FPVs considers the Cost of Services and the Efficiency.

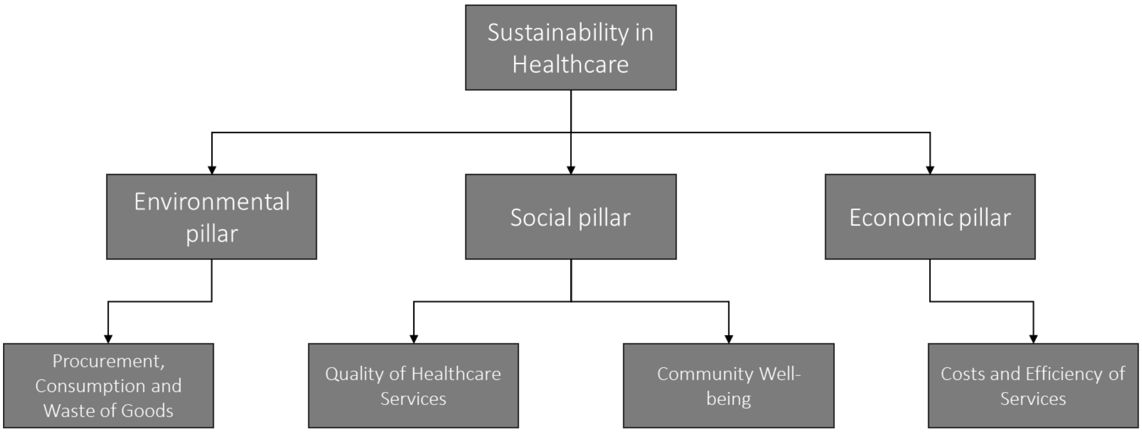

Figure 3.1: Sustainability in Healthcare FPVs

The next sub-sections (3.2.1 to 3.2.5) detail each FPV, and the theoretical subjects the criteria belonging to each FPV should measure.

3.2.1 Procurement, Consumption and Waste of Goods

As mentioned in Section 3.1, Procurement is the act of obtaining goods or services, and when it comes to business purposes it is usually referred to as acquisitions on large scales. It is generally associated with the final act of purchasing but it can also include the procurement process overall, which is an influential factor for companies when it comes to the final decision of purchasing (Young & James, 2020). That said, this criterion evaluates the environmental side of the procurement process and whether the goods being acquired are excess and can be reduced, reducing the harmful impact that excessive consumption of goods, especially hospital products, has on the environment (Duque-Uribe et al., 2019). The purpose of this criterion is to evaluate the hospitals' reports on costs with goods acquired by a common denominator, in order to be possible to compare values between hospitals.

Besides the Procurement and consumption of goods, hospital waste is a highly contributing factor to the negative impact of the healthcare sector on the environment. After knowing the procurement of resources, to perform a better analysis, it is important to understand which or what percentage of these resources are going to waste (Duque-Uribe et al., 2019).

3.2.2 Quality of Healthcare Services

Quality in healthcare is a wide-ranged concept that can be simplified by the framework proposed by the Institute of Medicine (IOM), which divides the definition of quality in healthcare into six dimensions (Institute of Medicine (IOM), 2001):

- Safety of the patient: It is vital to assure that the patients are not harmed from the care that is delivered with the intention of treating them.
- Effectiveness of the service: The service provided must be based on scientific knowledge and the benefits of the interventions must exceed the risks.
- Person-centeredness: The care provided must be respectful and specific to the patient's needs preferences and values.
- Timeliness: The timeliness of intervention is crucial; it is important to assure minimal wait times and delays of services.
- Efficiency: It is important to avoid waste of equipment, supplies, ideas, and energy.
- Equity of care: Assure that the care provided to the patients is the same regardless their gender, ethnicity, geographic location, and socioeconomic status.

To have a social sustainable hospital is important to account its quality (Duque-Uribe et al., 2019). Thus, the criteria that represent this FPV must account for the six dimensions described.

3.2.3 Community Well-being

Community Well-being is the combination of social, economic, environmental, cultural, and political conditions identified by individuals and their communities as essential for them to flourish and fulfil their potential. The effects of healthcare services, in the scope of community well-being, reflect on the community profile indicators. As seen in the previous chapter, the evolution of healthcare has brought significant changes in community profile indicators such as age expectancy at birth, the mortality rate at birth, and general mortality rate. Thus, the "community well-being" criterion must have into consideration the healthcare factors that are proved to affect directly or indirectly those community profile indicators, so it is possible to withdraw conclusions and compare the effects that each hospital individually have on the community that surrounds them (Wiseman & Brasher, 2008).

3.2.4 Costs and Efficiency of Services

The first economic FPV will be the cost of services. The purpose of this criterion is to account the hospitals' spending on healthcare service delivery, more specifically on staff costs. These costs should be based on a common denominator, for instant cost by patient, so that it is possible to evaluate and compare different institutions. However, a higher value on costs of services does not necessarily mean that the hospital is less economically sustainable. As mentioned in the previous section, when evaluating the costs, it is important to consider if the service is efficient, given that greater expenditures demand greater efficiency in the delivery of services (Duque-Uribe et al., 2019).

In the scope of economic sustainability, efficiency refers to acquiring a greater health benefit, using the resources available, or achieving a certain benefit in a way that minimizes the costs or resource usage. In healthcare, there are two types of economic efficiency: Technical efficiency and Allocative efficiency. Technical efficiency refers to the best way to achieve a certain outcome, for instance, if there are two interventions for a patient to improve his condition which one uses the fewer resources or is less time-consuming? As for Allocative efficiency, it refers to the allocation of the budget for example and concerns the opportunity cost of choosing a certain procedure, or investment over another.

Overall, this FPV is concerned with the management of the costs, and the hospital's capability to be efficient (York Health Economics Consortium, 2016).

All the criteria that characterize the FPV's must gather a set of information that characterizes it, which in theory, should be represented in indicators. These indicators can be grouped together in the criteria following conceptual and logical ways, forming composite indicators, which can be used to measure and assess sustainability according to the FPVs presented (Gibari et al., 2019).

3.2.5 Composite Indicators and Performance

Composite indicators are increasingly recognised as a useful tool in policy analysis and public communication. They provide simple comparisons of units that can be used to illustrate the complexity of our dynamic environment in wide-ranging fields (Gibari et al., 2019).

According to the Organization of Economic Cooperation and Development (OECD), a composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured. It measures multi-dimensional concepts which cannot be captured by a single indicator. Ideally, a composite indicator should be based on a theoretical framework, which allows individual indicators to be selected, combined, and weighted in a manner that reflects the dimensions or structure of the subject being measured (OECD, 2013).

To build a composite indicator, the OECD proposes a methodology of ten steps to rightfully define it (Nardo et al., 2008):

1. <u>Theoretical Framework</u>: This step guarantees a clear understanding and definition of the multidimensional.
2. <u>Data Selection</u>: This step needs to assure the quality of the indicators and the data selected, its weaknesses and strengths, and give a summary of its main characteristics.

3. Imputation of missing data: Important to provide a complete dataset, through estimations of the missing values. It is also important to provide the reliability of the imputed values.
4. Multivariate analysis: This should be used to study the overall structure of the dataset, assess its suitability, and guide subsequent methodological choices.
5. Normalisation: this step guarantees the ability to compare indicators, by adjustments and or transformation of scales, respecting the theoretical framework and the data properties.
6. Weighting and aggregation: This step should be done along the lines of the underlying theoretical framework. It guarantees the selection of the appropriated weighting and aggregation of the indicators, following the theoretical framework and the data properties.
7. Uncertainty and sensitivity analysis: should be carried out to evaluate the robustness of the composite indicator in terms of selection of the indicators, normalization scheme, imputation of data, and weights.
8. Back to the data: This is needed to reveal the main drivers for an overall good or bad performance, assuring transparency of the results of the previous steps.
9. Links to other indicators: This step serves to correlate the composite indicator or its dimensions to other existing single or composite indicators if the theoretical framework requires so.
10. Visualisation of results: The last step is of great importance since a good representation of the results reflects on good interpretability, so it is necessary to assure that the selected visualization technique is one that shows the most information in a clearer way.

This last methodology serves as a basis for the construction of composite indicators that are present in several MCDA approaches and methods. Many authors claim that MCDA methods are highly suitable in multidimensional frameworks when aggregating single indicators into a composite one, since this process involves making choices when combining criteria of different natures, and it requires a number of steps in which decisions must be made. For the purposes of this research work, the MCDA method to be applied is the ELECTRE TRI-NC method (Elimination and Choice Expressing Reality), an outranking relation approach method that uses criteria to sort actions into categories (Gibari et al., 2019).

3.3 Summary

This chapter presents a Literature review of the theme of this study. In Section 3.1 it was conducted a presentation of the research made on the topic of sustainability in healthcare. Even though sustainability is still an ambiguous term in the healthcare sector, without a standard definition, and very different opinions on how to approach it, by converging many opinions and studies, it is possible to understand the concept of sustainability in healthcare as a wide-ranged subject, and what main aspects are concerned in each pillar.

In Section 3.2 it was explored the subject of measuring sustainability in hospitals. Using the information gathered before and given that there is not a guide of defined criteria to assess sustainability in healthcare, it was developed a set of theoretical FPV's, based on the definitions presented in Section 3.1 that will guide the following work of defining a criteria set to implement in a model. It was also introduced the topic of composite indicators to measure sustainability through MCDA methods.

Therefore, in the next chapter it will be conducted a review of the subject of Decision Aiding (DA) and the ELECTRE TRI-nC method to be used further on, which will consist of the detailing of the methodology of this work, that will allow to evaluate the sustainability level of the Portuguese public hospitals.

Chapter 4

Methodology

Having presented the context of the study and the research already developed on the subject of measuring sustainability in hospitals, it is now relevant to define the methodology of analysis to apply to the problem. This chapter starts by introducing in Section 4.1 the holistic subject of this work: Multicriteria Decision Aiding, which will allow a better understanding of the second section. Section 4.2 that introduces the method chosen to use: The ELECTRE TRI-nC method.

4.1 Multicriteria Decision Aiding: Concept, definition, and applications

Many decisions involve multiple factors. For instance, choosing a new job involves pondering over the salary, the location, the field of work, health insurance, and other commodities, etc. However, for the person choosing the job – the Decision-Maker (DM) – some factors can be of greater importance, such as the location and the salary rather than the field of work, meaning that the field of work has less weight on the decision than the salary or the location. This complicates the decision, especially when considering several alternatives with several different factors. In the work of Goodwin & Wright (2014), the authors explain that the human mind has a limited capacity for complex calculations and that technological devices, such as calculators, complement our consciously admitted cognitive limitations. People have to use "approximate methods" to deal with most decision problems and, as a result, they seek to identify satisfactory, rather than optimal, courses of action. These approximate methods, or rules of thumb, are often referred to as "heuristics" (Goodwin & Wright, 2014).

However, some decisions have higher complexity and require more precision. Decision Aiding (DA) was first proposed by Nobel Prize winner Herbert Simon in the nineteen sixties (El Amine et al., 2014). Nowadays, DA can be defined as the activity of the person who, through the use of explicit, but not necessarily completely formalized models, help to obtain elements of responses to the questions posed by a stakeholder in a decision process. Even when DA is provided for a single DM, it is rare for him/her to have in mind a single clear criterion. Usually, complex decisions imply several aspects that cannot be considered alone, because it could lead to a different solution. Thus, a Multicriteria Decision Aiding (MCDA) approach can be applied to avoid neglecting certain aspects of realism, by delimiting a broad spectrum of points of view likely to structure the decision process concerning the actors involved, constructing a family of criteria which preserves, for each of them, without any fictitious conversion, the original concrete meaning of the corresponding evaluations, and facilitating debate on the respective role that each criterion might be called upon to play during the decision aiding process (Roy, 2016).

The work of Bernard Roy (2005) states that there are three essential elements in MCDA that usually play a fundamental role in analysing and structuring the decision aiding process, in close connection with the decision process itself. These are: Actions, Criteria, and the Problematic.

Actions

Constitute the object of the decision, or that which decision aiding is directed towards. The notation usually used in MCDA for different actions is a_i, with $i = 0, \dots, \mathrm{m}$, where m is the total amount of different actions.

Criteria

A criterion g is a tool constructed for evaluating and comparing potential actions according to a point of view that must be well-defined. The notation usually used in MCDA for different criteria is g_j, with $j = 0, \dots, n$, where n is the total amount of different criteria considered.

This evaluation must consider, for each action a_i, all the pertinent effects or attributes linked to the considered point of view, which is denoted by $g(a)$ and called the performance of that action according to this criterion.

The performance of an action according to a certain criterion is denoted on a scale. However, scales can be very different when considering a variety of factors, for instance, measuring satisfaction by "unsatisfied", "neutral" or "satisfied" has a completely different notation than measuring the temperature of a room in degree Celsius (for instance, an interval like]-20º C, 50º C[). Thus, it is important to distinguish various types of scales that can be used (Lee, 2016):

- *Nominal scales:* These scales could simply be called "labels", since they are used for labelling variables, without any quantitative value. For instance, "What is your hair colour? A-Brown, B-Black, C-Blonde or D-Ginger" is a nominal scale.
- *Purely ordinal scales*: Often called *qualitative scales*, they are characterized by the fact that the gap between two degrees does not have a clear meaning in terms of preference difference. These scales can be verbal scales when the pair of consecutive degrees does not necessarily reflect an equal preference difference along the scale (it is the case of measuring satisfaction mentioned in the previous paragraph); or numerical scale, when a difference *Y* between two degrees does not necessarily reflect an invariant preference difference when moving the considered pair of degrees along the scale.
- *Interval scales:* These are numeric scales in which we know both the order and the exact differences between the values. In these scales, a 0 does not mean an absence of value but another value used on the scale. The usual example given for explaining interval scales is Celsius temperature, where the difference between 20ºC and 30ºC is the same as the

difference 80ºC and 70ºc, which is 10 degrees Celsius. These scales allow the use of statistic tools such as mode median, mean, and standard deviation.

- *Cardinal or ratio scales*: Also called *quantitative scales*, these are numeric scales where the degrees are defined by referring to a clear quantity in a way that gives meaning to the absence of quantity and to the existence of a unit, allowing to interpret each degree as the addition of a given number, which can be integer or fractional, of such units. The ratio between two degrees can have a meaning, which does not depend on the degrees considered. These scales are the most complete type of scales in terms of data analysis, since it allows the largest range of descriptive and inferential statistics to be applied. Good examples of these types of scales include height weight and duration.

When building the criteria and their respective relations, it is necessary to assure some important logical requirements of criteria, which should be (Roy, 2016):

- Consensual, to assure that all actors, the analysts, and the DMs agree with the criteria.
- Independent, to assure that each criterion is individual and not affected by the rest of the criteria.
- Operational, to assure that the efficiency of the criteria set.
- Measurable, to fulfil the ultimate purpose that they are being created for, which is to measure something.
- Exhaustive, to treat all parts or aspects without omission.
- Cohesive and Concise, to assure the criteria is structure and organized in a unified way.
- Non-Redundant, to avoid superfluous repetition or overlapping of aspects in the criteria.

Problematic

In the scope of MCDA, the Problematic refers to how DA is visualized. The first problematic dimension is the description problematic, which answers to what type of problem is being held, what kind of results are supposed to be obtained from the work, and how to deal with the problem in the most appropriate way. There is also the choice problematic that is oriented to the selection of a small number of higher-ranked actions, in a way to select the single best alternative. The third dimension of the problematic is sorting. It is directed to assign each action to a certain category. Finally, there is the ranking problematic which is concerned with the complete or partial preorder of the actions set, according to a certain logic classification procedure, allowing to put actions in classes when their indifferent, to facilitate comparisons between the action throughout the work.

These three elements – Actions, Criteria, and the Problematic – are constant to every MCDA problem. Nevertheless, there are many different modelling approaches for MDCA problems. The main are (Gibari et al., 2019):

- *Elementary methods*. These methods form the basis of initial MCDA assessments. They can reduce complex problems to a singular basis for the selection of a preferred option by simple conditions. The most common elementary methods are the Simple Additive Weighting and the Weighted Product.

- *Value and utility-based methods*. The idea consists of designing a means of associating a real number with each alternative and producing a preference order for the alternatives, based on the DMs value judgements. Within this group, the *Multi-Attribute Utility Theory* involves the determination of partial utility functions to calculate a global utility function *U*, while the *Multi-Attribute Value Theory* involves the determination of partial value functions and to establish weights for each criterion to calculate a global value function *V*. The main methods are the SMART method – "*Simple Multi-Attribute Rating Technique*" (Olson, 1996), and the MACBETH method – "*Measuring Attractiveness by a Categorical Based Evaluation Technique*" (Bana E Costa & Vansnick, 1999).
- *Outranking methods*. These methods are based on the comparison between pairs of options to determine whether "alternative *a* is at least as good as alternative *b*". From this family of methods, the two most common ones are PROMETHEE - "*Preference Ranking Organization Method for Enrichment Evaluation"* (Brans & Mareschal, 2005), and ELECTRE – "*Elimination and Choice Expressing Reality"* (Figueira et al., 2005). From the family of the ELECTRE methods comes the chosen to apply in this work, the ELECTRE Tri-nC, which will be explored in the next section.
- *Data Envelopment Analysis-based methods*. The approach to the problems is done by linear programming as an instrumental element, for the purpose of evaluating the efficiency of a set of comparable units.
- *Distance Functions-based methods*. The basic idea of these methods consists of substituting the maximization of a function comprehending the preferences of the DM, as a utility function, by the minimization of the distance existing between an alternative and a point or points enjoying good preferential properties.

As mentioned, the method chosen to use is from the family of ELECTRE methods, which dates to the decade of 1960. Its acronym stands for the French expression "*ELimination Et Choix Traduisant la REalité"* (ELimination and Choice Expressing the REality). The ELECTRE methods comprehend two main procedures: the construction of one (or more) outranking relation(s) aimed at comparing each pair of actions, and the exploitation procedure that elaborate recommendations from the results obtained in the construction of the outranking relations. From the variety of ELECTRE methods, the ELECTRE TRI method is designed to assign actions, objects, or items to ordered categories defined *a priori* (Figueira et al., 2005).

The next section will present the method chosen to explore in this dissertation, which consists of a variation of the ELECTRE TRI method: The ELECTRE TRI-nC method.

4.2 The ELECTRE TRI-nC method

In the scope of MCDA, there have been many developments in methods that allow to describe select, order, or sort the object of the decision. This method arises from the necessity of sorting the object of a decision (action, alternative, etc.) into a set of categories. As mentioned, for the sorting problematic in question, it is necessary to define these categories *a priori.*

The goal of this work is to propose a framework to evaluate the sustainability of the Portuguese public hospitals. In the previous chapters, it is possible to observe that sustainability in healthcare has many different factors. Using a MCDA approach to a certain problem, allows to analyse and evaluate the topic in question using multiple criteria, which is extremely important when evaluating sustainability because it allows to consider all constituents of the TBL approach (Correia, 2019) to sustainability in different criteria, and to weight the impact of the different aspects of sustainability in the decision process.

According to the TBL, it is possible to have a hospital that is economically sustainable, if the costs of services is low and/or well managed, but it is not socially sustainable if the quality of services delivered is low. Thus, it also makes sense to define categories that include these possible differences in order to evaluate sustainability considering all the different factors, and not just order or select a hospital with overall better performance, without detailing its characteristics according to the criteria. When measuring the sustainability of a hospital, given its wide-ranged definition, it is important to provide to the DM(s) all the information of the category of that certain hospital. Thus, the ELECTRE TRI-nC method is a good solution to evaluate the sustainability since it allows to define categories that include as much information as possible, and each category can have more than one hospital in it.

The ELECTRE TRI-nC is a sorting method that considers several reference actions for characterizing each category. Unlike the ELECTRE TRI-C, in the ELECTRE TRI-nC method, there are no constraints for introducing only one reference action as typical of each category, since, usually, in real-life problems, it is useful to characterize categories through more than one reference action. This method uses two allocation rules – *Ascending rule* and *Descending rule* – so that, when used together, it is possible to select an interval of categories to allocate to an action. (Almeida-Dias et al., 2010, 2012).

The next sub-sections will present the fundamental concepts of the ELECTRE TRI-nC method.

4.2.1 Concept and Notations

There are four sets $A, F, C,$ and B that represent the basic data to consider when applying the ELECTRE TRI-nC method. Let $A = \{a_1, \dots, a_i, \dots, a_z\}$ be the set of potential actions, which can be known *a priori* or it can be constructed progressively throughout the DA process. It can also be constructed a criterion g to characterize potential actions according to a certain point of view. The performance of an action a according to a criterion is given by $g(a)$. A family of criteria can be represented by the set $F = \{g_1, \dots, g_j, \dots, g_n\}$, with $n \geq 3$ to assure the pertinence of the concept of concordance, explained in the next section. $C = \{C_1, \ldots, C_h, \ldots, C_q\}$, with $q \geq 2$, is the set of categories where $B = \{B_1, \ldots, B_h, \ldots, B_q\}$ is the set of reference actions that allow defining those categories, which is the result of an interactive construction process between the DM and the analyst. The set $B_h = \{b_h^r, r = 1, \ldots, m_h\}$ is the sub-set of reference actions that characterize the category C_h, such that $m_h \geq 1$ and $h = 1, \ldots q$.

When modelling, it is important to know the preference and indifference thresholds that allow dealing with the imperfections and arbitrariness associated with the data that defines the criteria. Thus, three important definitions must be considered while modelling the data:

- *Preference threshold*. The preference threshold p between the performances of two actions corresponds to the minimal difference of performance, which when exceeded, the action whose performance is better is considered preferable.
- *Indifference threshold*. The indifference threshold q between the performances of two actions corresponds to the maximum difference of performance, which is considered compatible with situations of indifference between two actions of different performance levels.
- *Pseudo-criterion with constant thresholds*. A criterion g_j is considered a *pseudo-criterion* or a *criterion with thresholds* when it is associated with two thresholds: the preference threshold p_j and the indifference threshold q_j, such that $p_j \geq q_j \geq 0$.

From these considerations, it is possible to withdraw the following considerations, for each criterion, when considering two distinct actions, a and a', where $g_j(a) \geq g(a')$, for a given criterion g_j to maximize:

- $|g_j(a) - g_j(a')| \leq q_j$: this relation indicates that a is *indifferent* to a' according to the criterion g_j, and is represented by aI_ja'.
- $g_j(a) - g_j(a') > p_j$: this relation indicates that a is *strictly preferable* to a' according to criterion g_j, and is represented by aP_ja'.
- $q_j < g_j(a) - g_j(a') \leq p_j$: this relation represents an ambiguity zone, where the advantage of a over a' is not enough to assume indifference or strictly preference between the two actions. This represents that a is *weakly preferable* to a' according to criterion g_j and is represented by aQ_ja'.

4.2.2 Outranking Relations

An outranking relation can be stated as a binary relation defined on the set of actions A such that a is preferred over a' if there are enough arguments to affirm that a is at least as good as a', and there are not enough arguments to refute this statement. This outranking relation is represented by aS_ja' (Figueira et al., 2005).

To build an outranking relation, it is necessary to consider three concepts: Concordance, Non-Discordance, and Credibility.

Concordance

To accept aS_ja', it is necessary that most criteria are in favour of this relation. To evaluate the global concordance, it is used the *concordance index* given by $c(a.a')$.

However, in order to calculate this index, it is necessary to introduce a very important concept of the ELECTRE TRI-C method and of MCDA – the weight of a criterion: weight w_j is associated to each criterion g_j, with $j = 1,\dots,n$ and $\sum_{j=1}^{n} w_{j=1}$ and represents the relative importance that an individual criterion as over the whole criteria set.

Knowing all the necessary concepts it is now possible to define the concordance index:

$$c(a.a') = \sum_{j\in C(aPa')} w_j + \sum_{j\in C(aQa')} w_j + \sum_{j\in C(aIa')} w_j + \sum_{j\in C(a'Qa)} w_j\varphi_j$$

where

$$\varphi_j = \frac{p_j - ((g_j(a') - g_j(a))}{p_j - q_j} \in [0,1[$$

Non-Discordance

To accept aS_ja', it is necessary that none of the criteria that is inserted in the minority opposed to aS_ja' uses its veto power over this relation. The non-discordance index allows to have into consideration the veto effect of a criterion, using the *veto threshold*, given by v_j, such that $v_j \geq p_j$. For each criterion, the veto effect is modelled through the *partial discordance index* $d_j(a.a'), j = 1,\dots n$, defined by:

$$d_j(a,a') = \begin{cases} 1 & \text{, if } g_j(a) - g_j(a') < -v_j \\ \dfrac{(g_j(a) - g_j(a') + p_j}{p_j - v_j} & \text{, if } -v_j \leq g_j(a) - g_j(a') < -p_j \\ 0 & \text{, if } g_j(a) - g_j(a') \geq -p_j \end{cases}$$

Credibility

The credibility index reflects how the affirmation "a is *at least as good* as a'" is justified when every criterion of F is considered. This index is defined as $\sigma(a,a')$, and is calculated by:

$$\sigma(a,a') = c(a,a') \sum_{j=1}^{n} T_j(a,a'),$$

where

$$T_j(a,a') = \begin{cases} \dfrac{1-d_j(a,a')}{1-c(a,a')} & \text{, if } d_j(a,a') > c(a,a') \\ 1 & \text{, otherwise.} \end{cases}$$

According to the ELECTRE TRI-nC method, the credibility level, λ, corresponds to the minimum level of credibility, $\sigma(a,a')$, which is necessary to validate an outranking relation taking into account the criteria from F.

λ usually takes a value in $[0{,}5; 1{,}0]$. Considering $\sigma(a,B_h) = max_{r=1,\dots,m_h}\{\sigma(a,b_h^r)\}$ e $\sigma(B_h,a) = max_{s=1,\dots,m_h}\{\sigma(b_h^s,a)\}$, where B_h is a reference action of set B, it is possible to identify four binary relations for λ:

- λ-prevalence: $\{a\}S^{\lambda}B_h <=> \sigma(\{a\},B_h) \geq \lambda$;
- λ-preference: $\{a\}P^{\lambda}B_h <=> \sigma(\{a\},B_h) \geq \lambda \wedge \sigma(B_h,\{a\}) < \lambda$;
- λ-indiference: $\{a\}I^{\lambda}B_h <=> \sigma(\{a\},B_h) \geq \lambda \wedge \sigma(B_h,\{a\}) < \lambda$;
- λ-incomparability: $\{a\}R^{\lambda}B_h <=> \sigma(\{a\},B_h) < \lambda \wedge \sigma(B_h,\{a\}) < \lambda$.

4.2.3 Assignment Procedure

When assigning action a to categories, the ELECTRE TRI-nC method uses two allocation rules: The *Descending rule* and the *Ascending rule*, which are applied simultaneously.

Each rule selects one category for a given action, which usually allows defining a minimal and maximal category for an action, providing a potential interval of categories for that action. If the two rules have the same solution for a given action, then there is only one possible category to assign to that action.

To use these rules, it is necessary to use a selection function given by:

$$\rho(\{a\},B_h) = min\{\, \sigma(\{a\},B_h)\,,\sigma(B_h,\{a\})\,\}$$

Descending Rule

Firstly, it is necessary to choose a credibility level $\lambda(\frac{1}{2} \leq \lambda < 1)$. Then decrease the value of h, from $(q+1)$ until the first value of t, such that $\sigma(\{a\},B_h) \geq \lambda$:

- For each $t = q$, select C_q as a possible category to allocate to action a;
- For $0 < t < q$, if $\rho(\{a\},B_t) > \rho(\{a\},B_{t+1})$, then select C_t as potential category to allocate for action a. Otherwise, select C_{t+1}.
- For $t = 0$, select C_1 as potential category to allocate to action a.

Ascending Rule

Firstly, it is necessary to choose a credibility level $\lambda(\frac{1}{2} \leq \lambda \leq 1)$. Then increase the value of h, from 0 until the first value of k, such that $\sigma(B_k,\{a\}) \geq \lambda$:

- For each $k = 0$, select C_1 as a possible category to allocate to action a;

- For $1 < k < (q+1)$, if $\rho(\{a\}, B_k) > \rho(\{a\}, B_{k-1})$, then select C_k as potential category to allocate for action a. Otherwise select C_{k-1}.
- For $k = (q+1)$, select C_q as potential category to allocate to action a.

4.2.4 Application of the method

Having in mind all these last concepts and algorithms presented, it is important to understand how to implement them in a complete and real model, which can be a quite long and complex task to develop without the help of a computer software. For the purpose of this dissertation, it was chosen the MCDA-ULaval software, to develop the model to measure sustainability in the Portuguese public hospitals, using the ELECTRE TRI-nC method, and then to extract the results after running the method, to analyse and withdraw conclusions.

The MCDA-ULaval is a free tool programmed in Java, developed in *Université Laval* (Pearl-kb, 2016), that supports the MCDA methods from the ELECTRE family algorithms, including the ELECTRE TRI-nC method. It allows creating a project, including in the model all the elements necessary for the ELECTRE TRI-nC method such as actions, criteria, decision configurations, and thresholds. After executing the model, the MCDA-ULaval software allows not only to export the results and generate graphics, but also to perform scenario analysis of the results, and stability analysis, providing the analyst with a more complete information of the results to withdraw conclusions (Abi-Zeid et al., 2021; Verdasca, 2016).

4.2.5 Advantages and limitations of the ELECTRE-TRI-nC method

After presenting the method, it is possible to withdraw observations regarding its application in the context of MCDA, namely its advantages and disadvantages, which contribute to more informed and conscious use of the method.

The main advantages of the ELECTRE-TRI-nC method are (Costa & Figueira, 2016):

- Possibility to use not only quantitative scales, but also qualitative scales for building the criteria.
- Possibility to use heterogeneous scales, keeping the original performances of the criteria without normalization.
- Possibility to define weights of the criteria.
- Possibility to assign more than one category to an action, which approximates the model to reality.
- When building criteria, the use of indifference and preference thresholds allows considering the imperfect character of the data and its arbitrariness.
- Non-compensatory behaviour of the method – if for example there is a bad performance on a criterion, this cannot be compensated with a good performance in another criterion systematically.

- Through this method, when modelling it is also possible to consider concordance, discordance, and the use of the veto threshold, which reinforces the non-compensatory character of the method.

As for the limitations associated with ELECTRE TRI-nC method, most are common limitations of the ELECTRE methods. These are (Costa & Figueira, 2016):

- If the DM wants to attribute scores to the action, these methods are not appropriate.
- If the scales are quantitative, there are more efficient methods to apply than the ELECTRE methods.
- The fact that the preferences are imposed *a priori* requires that these be transitive, which represents a weakness.

4.3 Summary

This chapter presented an introduction to the topic of DA, narrowing it down to the method of choice – the ELECTRE TRI-nC method. This method is designed to assign a set of ordered and pre-defined categories to a set of actions, considering the performance of each action according to a set of criteria.

The fact that ELECTRE TRI-nC uses both qualitative and quantitative scales and allows to assign more than one category to an action, uses preference and indifference thresholds to consider the imperfection and arbitrariness of the data, allows the model to be closer to reality.

For the upcoming problem, which is to evaluate and measure the sustainability of the Portuguese public hospitals, the method ELECTRE TRI-nC will allow to sort the hospitals into categories considering the performance each hospital according to a set of sustainability criteria that was previously defined, using a very realistic and complete model.

Chapter 5

Case Study

The current chapter presents the case study of this work. In the scope of MCDA and the decision process, this chapter presents the process of the model formulation, the definition of actions, criteria, and model parameters.

5.1 Overview

The present structure of the Portuguese health care system allows hospitals to behave as enterprises, which not only gives the hospitals more freedom to manage themselves autonomously, but also adds up more responsibility for their management choices.

When it comes to the urgent issue of sustainability, hospitals must account for their efforts towards sustainable development in order to reward good efforts or sanction bad practices. It is utterly necessary to develop a framework that allows measuring the sustainability levels of the hospitals, considering the most complete definition of sustainability that englobes the three pillars: Environmental Quality, Social Equity and Economic Benefits.

The literature review conducted allowed to define the concept of sustainability in healthcare, specifying each pillar:

- The Environmental Sustainability in healthcare is concerned with hospital waste, and the impact it has on the environment, and also the excessive procurement and consumption of resources.
- The Social Sustainability is concerned with the wellbeing of the hospital's stakeholders: staff, patients, and the community.
- The Economic Sustainability is concerned with the efficiency associated with the use of hospital expenditure.

Considering the definition of sustainability in healthcare it was possible to build the settle a set of general criteria, which, for the scope of the model formulation will now be called Fundamental Points of View (FPVs), that would allow measuring the sustainability of the Portuguese public hospitals. For the environmental pillar, the FPV is "Procurement, Consumption and Waste of resources". The social pillar has two FPVs, the "Quality of Healthcare Services", and the "Community wellbeing". The economic pillar has one FPV, the "Costs and Efficiency of Services".

To analyse and measure something that considers multiple criteria it is useful to use MCDA approaches, thus, it is proposed the method ELECTRE TRI-nC. The benefit of this method relies on the fact that it allows sorting the hospitals into sustainability categories considering the criteria defined, which provides the DM with more complete feedback of the decision process.

The next step consists in the application of the methodology described to the case of the Portuguese public hospitals in order to evaluate their sustainability levels and withdraw conclusions. Thus, to apply the method it is first important to specify which hospitals are going to be evaluated and build the model, setting all the relevant parameters. The model is then applied using the software MCDA-ULaval that choosing the ELECTRE TRI-nC method. The program will provide a set of results, which after the elaboration of suitable and adequate analyses that will allow to withdrawal conclusions regarding the chosen set of actions (hospitals) and their sustainability categories.

5.2 Model

The process of problem structuring was made through a pseudo bottom-up approach. The difference between a bottom-up approach and a top-down approach, is that a top-down approach tends to be objective-led, starting with a more general statement of the overall objectives of the problem detailing these objectives along the way, when a bottom-up approach is alternative-led, beginning with the elicitation of detail stimulated by thinking of the strengths and weaknesses of these details in the model, and building a model from the specific to the general (Belton & Stewart, 2002). Since the model relies on the information presented in the ACSS benchmarking platform, this had to serve as a reference to the entire construction of the model. The model also relies on the concepts of the literature review, specifically the concept of sustainability in healthcare, and FPV's identified.

Additionally, the entire process of building the model, the definition of the actions, the criteria set and the parameters, such as thresholds and weights, were defined alongside with the DM. Throughout this dissertation it has been mentioned the existence of a DM in the decision process as someone with a vital role to the problem. As mentioned in the previous chapter, the DM is the actor that requests and has the interest in the decision. Usually, and in this case, the DM is an expert in the field where the problem takes place, in this case, in the field of the Portuguese public healthcare sector (Roy, 2016). Any interaction and questioning between the analyst and the DM, or any actors involved into the decision-making process, may have some unpredictable or imperceptible effect, meaning that the analyst may suggest an approach and the DM may change or give some inputs according to his area of expertise and preferences. Thus, the process to define the criteria and to build the model is highly dependent of the DM's point of view and personal preferences.

For the construction of the model, and throughout the entire work, there is a strong influence of the DM's point of view and preferences not only in the construction of the model but also on the very approach to the topic of sustainability in healthcare. In the literature review, it was seen that there are several different ways to measure sustainability in healthcare, and that there is not a consensus in every topic that goes on each pillar. Therefore, it is important to understand, under the point of view of the DM, the approach that he/she has on the topic of sustainability in healthcare, and what should be measured in the model, according to the DM's point of view.

The process of the model construction started out with an exchange of thoughts between the analyst and the DM regarding the definition of sustainability in healthcare and the FPV considered in each pillar. After reaching a consensus, the criteria set was built by associating and aggregating the indicators available at the ACSS into logical criteria capable to characterize the FPVs defined in the Literature Review.

The action set was defined a priori to the criteria set since it was necessary to assure the existence of all the information available in each action of the set. Lastly, it was discussed with the DM the parameters associated with the implementation of the model such as Reference Actions, Thresholds and Weights.

5.2.1 Actions

Alongside the DM and according to the information available in the ACSS benchmarking platform, it was possible to gather a set of 26 public hospitals to evaluate according to the criteria defined.

The selection of action had to consider if all the selected action had the information available on the indicators selected to characterize the criteria set. Thus, the hospitals whose information was incomplete were excluded from the actions set. Also excluded from the set are the specialized hospitals such as Psychiatric hospitals and the Oncology institutes.

As for PPP'S and former PPP's, these were excluded for not having all the information available in the indicators.

The final set of actions is:

a_1: Centro Hospitalar Barreiro/Montijo, EPE
a_2: Centro Hospitalar de Leiria, EPE
a_3: Centro Hospitalar de Lisboa Ocidental, EPE
a_4: Centro Hospitalar de Setúbal, EPE
a_5: Centro Hospitalar do Baixo Vouga, EPE
a_6: Centro Hospitalar do Oeste, EPE
a_7: Centro Hospitalar e Universitário de Coimbra, EPE
a_8: Centro Hospitalar Entre Douro e Vouga, EPE
a_9: Centro Hospitalar Médio Tejo, EPE
a_{10}: Centro Hospitalar Póvoa de Varzim/Vila do Conde, EPE
a_{11}: Centro Hospitalar Tâmega e Sousa, EPE
a_{12}: Centro Hospitalar Tondela-Viseu, EPE
a_{13}: Centro Hospitalar Trás-os-Montes e Alto Douro, EPE
a_{14}: Centro Hospitalar Universitário Cova da Beira, EPE
a_{15}: Centro Hospitalar Universitário de Lisboa Central, EPE

a_{16}: Centro Hospitalar Universitário de São João, EPE

a_{17}: Centro Hospitalar Universitário do Algarve, EPE

a_{18}: Centro Hospitalar Universitário do Porto, EPE

a_{19}: Centro Hospitalar Universitário Lisboa Norte, EPE

a_{20}: Centro Hospitalar Vila Nova de Gaia/Espinho, EPE

a_{21}: Hospital da Senhora da Oliveira, Guimarães, EPE

a_{22}: Hospital Distrital da Figueira da Foz, EPE

a_{23}: Hospital Distrital de Santarém, EPE

a_{24}: Hospital Espírito Santo de Évora, EPE

a_{25}: Hospital Garcia de Orta, EPE

a_{26}: Hospital Santa Maria Maior, EPE

5.2.2 Criteria

To build the criteria tree, it is important to have data to complement the set of criteria chosen. In the scope of the Portuguese public hospitals' network, and specifically to this work, the data available is limited to the ACSS benchmarking platform and the published indicators on said platform. However, the definition of the set of criteria was not a process strictly based on the information available on the ACSS benchmarking platform. The process had in consideration the work developed in the literature review, more specifically in the sustainability pillars, and their definition, and the FPVs defined. Thus, the process to build the criteria tree was mix between a bottom-up a top-down approach, were the pillars and the fundamental point of view served as a guiding point to build the criteria and sub-criteria, which were defined according to the indicators available in the ACSS. Thus, after having defined each pillar and the FPVs that characterize them, the next step was to select the set of indicators in the ACSS benchmarking platform that would allow building the criteria family. The gathered set of indicators is:

- <u>% 1st Consultations Carried out in adequate time</u>: Percentage of consultations that were carried out without delay, and in the appropriate time for the patient condition.
- <u>% of SAL enrolees (surgical admission list) within the MGRT (maximum guaranteed response time)</u>: Percentage of patients enrolled in the surgical waiting list within the maximum guaranteed response time compared to the total number of patients enrolled in the surgical waiting list.
- <u>% Readmission within 30 days (Different Calendar Years)</u>: Percentage of patients that have been readmitted in the 30 days after the discharge
- <u>% of hospitalisations with more than 30 days</u>: Percentage of patients whose hospitalization lasted longer than 30 days, considering the total amount of hospitalizations.

– % of hip fractures with surgery performed in the first 48 hours: Percentage of hip fractures with surgery performed within the first 48h of admission, considering the total amount of hip fractures with surgery performed.
– Central Venous Catheter-Related Bloodstream Infections Rate: Percentage Bloodstream infections related to the Central Venous Catheter, considering the total amount of utilization of the Central Venous Catheter.
– Post-Operative Sepsis p/100,000: Number of post-operative sepsis in 100,000 operations.
– Average Time Before Surgery: Average of the wait times for surgery of all surgeries scheduled.
– Pharmaceutical Expenditure per Standard Patient: Expenses related to the acquisition of pharmaceutical products per standard patient.
– Expenditure in Drugs per Standard Patient: Expenses related to the acquisition of drugs and medications per standard patient.
– Expenditure of Clinical Consumables per Standard Patient: Expenses related to the acquisition of clinical consumables products per standard patient.
– Staff Expenditure per Standard Patient: Expenses related to the staff body (Doctors, nurses, assistants, management, etc.) per standard patient.
– Outsourcing Expenditure per Standard Patient: Expenses related to contracts of external services, such as staff, energy, maintenance, etc.
– Annual Occupancy Rate in Admissions: This rate is given by R = (Nº of days of acute patients admissions) / ((Nº of acute patients beds) x 30,4375 x (Nº of months)). According to the ACSS the reference value for this indicator is around 85%.
– Average Time in Admissions: This indicator was built using two other indicators from another platform of the ACSS website, the ACSS Monthly Monitoring of Hospitals platform (SNS, 2021a). The indicators used were Monthly Practised Capacity, from which it was possible to calculate the total number of beds per year, and the Occupancy rate, which allowed to account for the total of days in general patient admissions per year. The formula used to calculate the indicator is: R = (Nº of days of acute patient's admissions) / ((Nº of acute patients beds) x 30,4375 x (Nº of months))

After having defined the indicators that would allow backing the FPVs, it was possible to define the set of logical criteria that would make use of these indicators to characterize the FPV's. The criteria and sub-criteria defined are represented in Table 5.1. In this table it is possible to find a summary of the pillar, the respective FPV's that each pillar considers, and the criteria and sub-criteria that characterize each FPV.

Table 5.1: Criteria Set

Pillar	Fundamental point of view	Criteria	Sub-criteria
Environmental	Procurement, consumption and waste of resources	g_1 Consumables acquired per patient	$g_{1,1}$ Expenses with Pharmaceutical Products
			$g_{1,2}$ Expenses with Drugs
			$g_{1,3}$ Expenses with Medical Supplies
Social	Quality of healthcare services	g_2 Safety in post-operations	
		g_3 Safety in hospitalizations	
		g_4 Care Appropriateness	$g_{4,1}$ re-admissions
			$g_{4,2}$ Long hospitalizations
			$g_{4,3}$ Time before surgery
		g_5 Timeliness in urgent procedures	
	Community well-being	g_6 Timeliness of medical intervention	
		g_7 Access to scheduled services	
Economic	Costs and Efficiency of Services	g_8 Occupancy	
		g_9 Outsourcing Expenditure	
		g_{10} Staff Expenditure	
		g_{11} Time in Admissions	

It is yet necessary to characterize it, specifying which indicators used in each criterion, the scale used in each criterion, and the preference direction of the scale. The criteria set is as follows.

$-\boldsymbol{g_1}$ **- Consumables acquired per patient**: This criterion belongs to the FPV "Procurement, Consumption and Waste of goods", which evaluates the hospital's expense level in procured goods per standard patient and the potential waste it represents. As mentioned in the literature review, a higher level of procurement is associated with worse environmental impact, and so the preference direction of this criterion is to minimize it (Duque-Uribe et al., 2019).

This is constituted by three sub-criteria:

- $g_{1,1}$: Expenses with pharmaceutical products, drugs and medical supplies, characterized by the indicators "*Pharmaceutical Expenditure per Standard Patient".*
- $g_{1,2}$: Expenses with pharmaceutical products, drugs and medical supplies, characterized by the indicator "*Expenditure in Drugs per Standard Patient".*
- $g_{1,3}$: Expenses with medical supplies, characterized by the indicator "*Expenditure of Clinical Consumables per Standard Patient".*

This criterion evaluates the expenses per standard patient, giving an overview of the hospital's expenses, per standard unit, which allows to compare and visualize the level of acquisitions of goods of each hospital. The aggregation of the sub-criteria is made through the sum of the values of the three sub-criteria since these are represented by the same unit (€/per standard patient). The level of expense per standard patient is proportional to the procurement level, since a higher procurement is associated with a worse environmental impact, the preference direction of this criterion's values is to minimize. For the purposes of this dissertation, and given that hospitals do not explicitly report their waste (SNS, 2021b), this criterion needs to verify the level of use of the resources acquired, evaluating if these are having the supposed effect or are potentially going to waste.

$-g_2$ **Safety in post-operations:** This is the first criterion of the FPV "Quality of healthcare services". The criterion will have a qualitative scale, and it will be characterized by the indicator "*Post-Operative Sepsis p/100,000".*

In the literature review it is explained that a higher rate of hospital's caused infections represents a lower safety of the services delivered by the hospital and a worse impact on the quality of the services provided by the hospital, since it inspires less trust in the patients. Thus, Since the indicator that characterizes this criterion is inversely proportional to the safety in post-hospitalization, the preference direction is to minimize them.

$-g_3$ **Safety in hospitalizations:** This criterion also represents the FPV "Quality of healthcare services". The criterion will have a qualitative scale, and it will be characterized by the indicator "*Central Venous Catheter-Related Bloodstream Infections Rate".* Since the indicator that characterizes this criterion is inversely proportional to the safety in hospitalizations, the preference direction is to be minimize.

Similar to the previous criterion, the indicator that represents this criterion also consists of a type of hospital's caused infection, which has a bad impact on the quality of the healthcare services, specifically in the safety parameter, and reflects negatively on the social sustainability of the hospital.

$-g_4$ **Care Appropriateness:** The third criterion of the FPV "Quality of healthcare services" is Care Appropriateness. As mentioned in the literature review, it evaluates the hospital's ability to deliver its services to the patient, focusing on the benefit to the patient. It is expected that the services are supported by evidence-based or scientific guidelines since it generally reflects on health benefits, like increased life expectancy, pain relief, and increased quality of life. It is important to state that to have appropriate care, the benefits of the treatments or interventions must be higher than the risks, such as hard recovery processes, mortality rates and associated side effects.

A hospital with a high level of Care Appropriateness inspires more trust and confidence in the patients. Also, it contributes to the overall quality of the hospital, thus preference direction of the criterion Care Appropriateness is to maximize it.

The criterion has a qualitative scale, organized in levels of performance, based on the following sub-criteria:

- $g_{4,1}$ - Re-admissions, characterized by the indicator "*% Readmission within 30 days (Different Calendar Years)*": Reflects the need to re-admit which may indicate that the care appropriateness was low in the first place. Therefore, the preference direction of this sub-criterion is to minimize.
- $g_{4,2}$ - Long hospitalizations, characterized by the indicator "*% of hospitalisations with more than 30 days*": Reflects that the care is taking too long, which can indicate not only a constrain to the patient but also possible complications with the care. Thus, the preference direction of this indicator is to minimize it.
- $g_{4,3}$ - Time Before Surgery, characterized by the indicator "*Average Time Before Surgery": E*valuates the waiting time for surgery since a patient has been admitted to the hospital. Longer wait time can result in complications and constrains to the patient health and life, therefore the preference direction of the sub-criterion Time Before Surgery is to minimize it.

The method to aggregate the sub-criteria is explored in Section 5.2.2.1 of this chapter.

$-\boldsymbol{g_5}$ **Timeliness in urgent procedures:** This criterion is also from the FPV "Quality of healthcare services" and evaluates the hospital's ability in responding to urgent procedures, evaluating essentially the urgent services.

The indicator that is available to characterize this criterion is the "*% of hip fractures with surgery performed in the first 48 hours"* since it concerns a medical procedure that must be fulfilled as soon as possible.

The preference direction of the criterion is to maximize, since longer wait times in urgent procedures can result in serious complications, and the scale used in this criterion is quantitative, given that the criterion is characterized solely by one indicator.

$-\boldsymbol{g_6}$ **First consultations carried out in time:** The criterion First consultations carried out in time is one of the two criteria of the FPV "Community Well-being". It evaluates if the hospital is assuring the community with healthcare delivered on time. As mentioned in the literature review, timeliness is a very important aspect to assure a positive evolution of health indicators of a community, such as increased life expectancy and lower mortality rates, since a timely medical intervention can prevent future complications.

This criterion is characterized by the indicator "*% 1st Consultations Carried out in adequate time*". This indicator evaluates the percentage of timely consultations, thus the preference direction of this criterion is to maximize. The scale used will be quantitative.

$-\boldsymbol{g_7}$ **Access to scheduled services**: The second criterion of the FPV "Community Well-being" is Access to scheduled services. It evaluates the capability of the hospitals to assure a timely intervention. As previously mentioned, the timing of medical intervention is a highly contributing factor to the positive evolution of health indicators.

The criterion is characterized by the indicator "*% of SAL enrolees (surgical admission list) within the MGRT (maximum guaranteed response time)*". This indicator evaluates the percentage of patients whose surgeries were performed on time, thus the preference direction of this criterion is to maximize it. Furthermore, the scale used is quantitative.

$-g_8$ **Occupancy:** Lastly, the economic pillar is characterized in the literature review by the FPV "Costs and Efficiency of Services". The first criterion of this FPV is Occupancy. It represents an economic efficiency-oriented criterion that evaluates the activity level of the hospital. Economic efficiency is when all goods and factors of production in an economy are distributed or allocated to their most valuable uses and waste is eliminated or minimized (Barnier, 2020). According to the ACSS benchmarking and to the input of the DM, the ideal value of Occupancy to assure maximum economic efficiency is 85% (SNS, 2021b).

The criterion has a quantitative scale and it is characterized by the indicator "*Annual occupancy rate in admissions*". The performances associated with this criterion are obtained by the difference of the Annual occupancy rate in admission and the ideal value, 85%. The preference direction is to minimize it since a larger value represents a greater distance to the ideal level of Occupancy.

$-g_9$ **Staff expenditure:** The second criterion of the FPV "Costs and Efficiency of Services" is the Staff expenditure, which quantifies the cost associated with the hospital staff per standard patient and is characterized by the indicator "*Staff Expenditure per Standard Patient*". The fact that the costs are quantified per a comparable unit among hospitals, which in this case is per patient, it is possible to compare the values of staff per patient and wonder whether a higher value could be the reflection of mal-practices or poor management.

Thus, since a higher staff expenditure per patient contributes negatively to the level of economic sustainability, the preference direction of this criterion is to minimize it. The scale used is also quantitative.

$-g_{10}$ **Outsourcing expenditure:** The third criterion of the FPV "Costs and Efficiency of Services" is the Service expenditure, which quantifies the cost associated with the hospital staff per standard patient and is characterized by the indicator "*Outsourcing Expenditure per Standard Patient*", with a qualitative scale.

Since a higher outsourcing expenditure contributes negatively to the level of economic sustainability, the preference direction of this criterion is to minimize it.

$-g_{11}$ **Time in admissions:** The last criterion of the FPV "Costs and Efficiency of Services" is the Time in admissions, which quantifies the time patients spent in average in admissions. Longer admission represents a worse economic impact, since it is more expensive for the hospital, the rotation of beds is consequentially lower, and the efficiency of the service decreases. The indicator that characterizes this criterion is the "*Average time in admissions*", and the scale used is qualitative.

Since a higher Time in admissions contributes negatively to the level of economic sustainability, the preference direction of this criterion is to minimize it.

5.2.2.1 Aggregation of the sub-criteria of g_4

As it can be seen in the previous section, criterion g_4 is characterized by sub-criteria. These sub-criteria are not possible to aggregate using simple mathematic calculations, which requires another way to aggregate these sub-criteria. The method chosen was based on an innovative approach proposed by Rocha et al. (2021), who suggested the construction of a qualitative scale for the criterion based on the results of the implementation of the ELECTRE TRI-C method using the sub-criteria of such a criterion (Rocha et al., 2021). Therefore, criterion g_4 is presented in the model with a qualitative scale, described in five performance levels based on the performance of the three sub-criteria.

The ELECTRE TRI-C method will be used to measure the set of sub-criteria, as well as the MCDA-ULaval programme. This will allow the actions to be assigned to one of the five levels of performance, which will subsequently be used as the input for the criterion g_4's performance in the final model. As a result, it is necessary to create a model that includes the sub-criteria, their related Reference actions, Weights, and Thresholds, and run it through the MCDA-ULaval software using the ELECTRE TRI-C method. Because the DM was only able to define one reference action per category for the sub-criteria set, the ELECTRE TRI-C method was used in the sub-criteria set to simplify this part of the process and avoid adding more complexity by suggesting more than one reference action per sub-criteria at the risk of suggesting an unfeasible approach. (Bana E Costa & Beinat, 2010).

5.2.3 Construction of the performance tables

Having defined the set of actions to evaluate and the criteria set used to assess the actions, it is important to assemble the date according to the values of the indicators of the criteria for each action.

Since the model is built in two phases, where the first phase is a model for the aggregation of the criterion g_4, and the second in the final model. Thus, there should be two performance tables for both models, in 2019 and 2020. Table 5.2 displays the performances of the sub-criteria of g_4 in 2019 and 2020. Table 5.3 and 5.4 represent the performance tables of the final model, respectively in the years of 2010 and 2020. Let us notice that the performances associated with the criteria g_4 are obtained through the method explained in the last section and considering the model parameters to be explained and detailed in the following sections.

Table 5.2: Performance of the sub-criteria of g_4 in 2019 and 2020

Actions	**2019**			**2020**		
	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$
Direction	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize
Scale	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal
a_1	7,87%	4,73%	1,05	6,64%	5,14%	1,23
a_2	8,62%	2,69%	0,71	7,59%	3,02%	0,76
a_3	6,79%	5,47%	1,45	5,99%	6,20%	1,22
a_4	8,48%	3,31%	0,95	8,05%	3,64%	1,08
a_5	6,72%	2,81%	0,44	5,97%	3,29%	0,56
a_6	7,88%	2,78%	0,92	7,09%	2,89%	0,82
a_7	9,06%	4,39%	1,37	7,33%	4,87%	1,54
a_8	7,32%	2,83%	0,60	7,18%	3,17%	0,62
a_9	9,66%	3,67%	0,72	9,17%	4,24%	0,87
a_{10}	6,05%	1,01%	0,60	5,64%	1,82%	0,62
a_{11}	6,50%	3,37%	0,63	5,30%	3,75%	0,68
a_{12}	8,33%	4,87%	1,79	5,04%	4,58%	1,72
a_{13}	11,76%	2,65%	1,04	10,65%	2,88%	1,20
a_{14}	7,60%	4,45%	0,73	9,10%	5,46%	0,82
a_{15}	8,35%	5,65%	1,43	5,16%	5,01%	1,64
a_{16}	8,23%	4,36%	1,01	7,41%	4,48%	1,00
a_{17}	7,48%	5,90%	1,38	6,75%	6,17%	1,39
a_{18}	6,74%	4,06%	0,75	6,30%	4,89%	0,79
a_{19}	10,02%	4,97%	1,04	6,80%	5,36%	0,96
a_{20}	7,43%	3,72%	0,87	6,93%	3,56%	0,79
a_{21}	7,79%	4,08%	0,58	7,31%	5,82%	0,54
a_{22}	8,50%	2,91%	0,82	8,54%	3,28%	0,98
a_{23}	10,47%	3,38%	1,10	10,71%	3,55%	1,18
a_{24}	5,50%	3,60%	0,34	4,75%	3,68%	0,43
a_{25}	7,31%	4,90%	1,19	6,11%	5,34%	1,13
a_{26}	7,77%	1,70%	0,49	8,58%	2,40%	0,59

Table 5.3: Performance table of final model of 2019

Actions	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
Direction	Minimize	Minimize	Minimize	Maximize	Maximize	Maximize	Maximize	Minimize	Minimize	Minimize	Minimize
Scale	Cardinal	Cardinal	Cardinal	Ordinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal
a_1	1 738,00€	4713,20	0,15%	1	29,52%	87,00%	76,74%	2,12%	512,00€	2 115,00€	3,03
a_2	1 208,00€	2128,37	0,00%	2	37,50%	57,29%	71,82%	1,23%	572,00€	1 936,00€	3,15
a_3	2 606,00€	7506,31	0,86%	2	31,45%	69,87%	58,50%	6,28%	500,00€	1 807,00€	2,88
a_4	2 525,00€	7252,96	0,26%	2	55,06%	66,27%	60,92%	0,73%	541,00€	2 056,00€	3,08
a_5	1 670,00€	4981,47	0,32%	2	74,91%	72,09%	90,00%	1,80%	545,00€	2 262,00€	3,17
a_6	1 178,00€	854,70	0,13%	2	30,86%	55,80%	71,37%	0,49%	612,00€	2 542,00€	3,12
a_7	2 685,00€	7062,89	0,19%	2	45,41%	60,75%	60,80%	4,12%	456,00€	1 683,00€	2,95
a_8	1 424,00€	5218,93	0,00%	2	15,35%	73,68%	83,26%	6,92%	521,00€	2 032,00€	3,36
a_9	1 622,00€	4843,43	0,00%	2	20,73%	78,14%	76,75%	5,95%	926,00€	2 389,00€	3,32
a_{10}	628,00€	0,00	0,00%	3	84,35%	91,09%	99,64%	5,08%	605,00€	2 522,00€	2,92
a_{11}	1 230,00€	4249,62	0,00%	2	58,45%	59,57%	86,71%	8,24%	629,00€	1 798,00€	3,73
a_{12}	1 717,00€	5837,89	0,09%	1	28,15%	77,01%	45,37%	4,52%	519,00€	1 928,00€	3,27
a_{13}	1 669,00€	2297,69	0,00%	2	63,04%	57,00%	74,94%	5,23%	590,00€	1 888,00€	3,30
a_{14}	1 901,00€	5264,07	0,00%	2	47,37%	72,51%	73,94%	4,92%	709,00€	2 650,00€	2,92
a_{15}	2 810,00€	6899,93	0,20%	1	27,41%	70,98%	56,37%	60,70%	475,00€	2 025,00€	3,53
a_{16}	2 201,00€	5838,76	0,78%	2	57,78%	51,66%	72,67%	55,84%	359,00€	1 467,00€	3,52
a_{17}	2 205,00€	7774,13	0,19%	2	14,88%	71,50%	73,12%	5,39%	657,00€	2 213,00€	3,30
a_{18}	2 809,00€	7233,31	0,45%	2	30,89%	73,84%	77,15%	13,09%	314,00€	1 451,00€	3,58
a_{19}	3 447,00€	14025,00	0,36%	1	36,84%	62,24%	57,33%	3,72%	439,00€	1 559,00€	3,24
a_{20}	1 830,00€	5599,61	0,09%	2	52,89%	53,18%	79,31%	1,92%	340,00€	1 681,00€	3,17
a_{21}	2 886,00€	4397,84	0,00%	2	45,62%	49,67%	77,40%	1,55%	506,00€	1 566,00€	3,03
a_{22}	841,00€	4503,54	0,00%	2	59,65%	74,99%	93,46%	9,90%	412,00€	1 995,00€	2,74
a_{23}	1 903,00€	11548,34	0,00%	2	23,46%	62,75%	61,44%	7,15%	679,00€	2 128,00€	2,84
a_{24}	2 011,00€	8003,75	0,33%	2	16,51%	69,79%	73,28%	0,60%	546,00€	1 734,00€	3,12
a_{25}	1 821,00€	6030,52	0,18%	2	15,31%	78,49%	48,05%	3,40%	445,00€	1 591,00€	3,23
a_{26}	1 008,00€	0,00	0,00%	3	39,18%	87,23%	99,57%	4,82%	435,00€	1 137,00€	3,28

Table 5.4: Performance table of final model of 2020

Actions	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
Direction	Minimize	Minimize	Minimize	Maximize	Maximize	Maximize	Maximize	Minimize	Minimize	Minimize	Minimize
Scale	Cardinal	Cardinal	Cardinal	Ordinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal	Cardinal
a_1	1 263,00€	2620,01	0,34%	2	24,24%	76,43%	54,17%	9,22%	656,00€	2 801,00€	2,77
a_2	922,00€	628,93	0,10%	2	35,19%	49,97%	75,77%	10,78%	659,00€	2 325,00€	2,71
a_3	1 962,00€	13625,05	1,63%	2	26,00%	56,30%	45,63%	14,34%	651,00€	2 332,00€	2,58
a_4	1 921,00€	3637,13	0,41%	2	45,61%	51,36%	47,07%	8,22%	697,00€	2 716,00€	2,80
a_5	1 310,00€	2197,98	0,12%	2	75,74%	61,23%	85,94%	11,45%	1 021,00€	2 639,00€	2,69
a_6	967,00€	0,00	0,29%	2	39,76%	40,72%	67,67%	7,49%	613,00€	3 414,00€	2,83
a_7	1 867,00€	8127,28	0,33%	2	34,88%	41,46%	45,12%	15,66%	624,00€	2 291,00€	2,54
a_8	1 137,00€	5782,09	0,00%	2	44,74%	66,24%	80,68%	1,43%	1 249,00€	2 463,00€	3,16
a_9	1 180,00€	4247,24	0,45%	2	40,13%	48,76%	71,39%	5,88%	937,00€	3 265,00€	2,89
a_{10}	481,00€	1587,30	0,00%	3	87,39%	81,76%	97,45%	13,22%	814,00€	3 477,00€	2,62
a_{11}	887,00€	3057,31	0,00%	2	58,29%	54,83%	83,85%	5,69%	625,00€	2 282,00€	3,31
a_{12}	1 292,00€	0,00	0,00%	2	11,24%	61,84%	34,33%	8,21%	783,00€	2 414,00€	2,80
a_{13}	1 246,00€	8390,24	0,09%	2	71,72%	45,97%	67,41%	4,39%	828,00€	2 420,00€	2,94
a_{14}	1 424,00€	6926,41	0,00%	1	36,67%	64,31%	64,47%	13,83%	588,00€	3 389,00€	2,60
a_{15}	2 209,00€	10799,60	0,68%	2	31,30%	63,15%	44,63%	4,01%	390,00€	2 526,00€	2,96
a_{16}	1 853,00€	11560,48	0,77%	2	83,06%	51,51%	74,57%	7,06%	823,00€	1 788,00€	2,84
a_{17}	1 735,00€	8235,47	0,22%	2	14,08%	64,22%	47,79%	5,76%	377,00€	2 715,00€	2,89
a_{18}	2 246,00€	14195,78	0,25%	2	56,08%	76,53%	69,68%	0,59%	600,00€	1 769,00€	3,08
a_{19}	2 808,00€	17937,15	0,30%	2	51,95%	53,98%	49,59%	5,76%	428,00€	1 979,00€	2,90
a_{20}	1 531,00€	5046,41	0,08%	2	57,86%	46,23%	77,40%	7,64%	765,00€	2 025,00€	2,83
a_{21}	2 187,00€	6810,69	0,00%	2	44,49%	41,88%	69,29%	14,88%	511,00€	2 070,00€	2,50
a_{22}	702,00€	1587,30	0,00%	2	46,81%	67,14%	90,94%	17,19%	856,00€	2 653,00€	2,48
a_{23}	1 578,00€	5136,87	0,00%	2	15,18%	53,71%	51,25%	8,39%	707,00€	2 542,00€	2,80
a_{24}	1 369,00€	8239,99	0,36%	3	38,22%	64,35%	63,86%	14,83%	562,00€	2 416,00€	2,56
a_{25}	1 347,00€	11382,56	0,88%	2	15,51%	57,74%	39,47%	0,28%	659,00€	2 062,00€	3,12
a_{26}	785,00€	2777,78	0,00%	2	31,37%	72,20%	95,73%	1,22%	760,40€	2 255,00€	3,06

5.3 Model Parameters

This section is dedicated to the definition of the remaining parameters left to define of the model. Having the actions, the criteria and the performances defined, there is some parameters yet to define. These are Weights, Categories, Reference actions, Thresholds, and Credibility level.

5.3.1 Criteria Weighting

In a decision-support context, knowing the preferences of the DM and determining the weights of criteria are very difficult issues. There are several methods to determine the weights of criteria. J. Simos has proposed a very simple method using cards to indirectly determine numerical values for weights (Figueira & Roy, 2002). This procedure is very suitable for contexts where we need to prioritise not one but several sets of weights for various reasons (multiple DMs, robustness analysis, etc.). The procedure also aims to provide the analyst with the information needed to assign a numerical value to the weights of each criterion, which is of extreme importance in ELECTRE type methods (Figueira & Roy, 2002).

The technique used to collect information consists of three steps (Figueira & Roy, 2002):

1. It is provided to the DM a set of cards, each one representative of a criterion, in no specific order as not to impose any judgment upon the DM. For the case of the final model, there were 11 cards, one for each criterion. It is also provided a set of blank cards, the same size as the criteria cards, but with no information on them. There are no restrictions on the number of white cards to use.

2. Secondly, it is requested to the DM to order the criteria cards from the most important to the least important. The DM may attribute the same importance to two or more criteria and in that case, the respective cards stay in the same position of the sequence.

3. Lastly, is asked the DM to reflect on the difference between consecutive criteria in the sequence that he/she defined. If the DM thinks that a difference between to criterion is more significant than the difference between two other sets of criteria in the sequence, he/she places one or more blank cards in between the criteria that have the more significant difference of importance. No blank card means that the criteria do not have the same weight and that the difference between the weights can be chosen as the unit for measuring the distances between the weights. Let u denote this unit. One white card means a difference of two times u. Two white cards mean a difference of three times u, etc.

However, for this analysis, it was chosen the revised Simos procedure of Figueira and Roy (SRF), so to complement more the criteria weighting process, and to allow to have more input of the DM preferences. This process consists of the 3 initial steps and an additional definition of a parameter – the ratio z – which must reflect the relative difference between the most preferred criterion and the least preferred (Figueira & Roy, 2002).

To implement this procedure, it was used a web-based platform, DECSPACE[1], where the DCM-SRF method was selected. The scheme of the SRF procedures for both models is represented in Figure 5.1.

[1] http://app.decspacedev.sysresearch.org/#/workspace (Accessed on 27th September 2021)

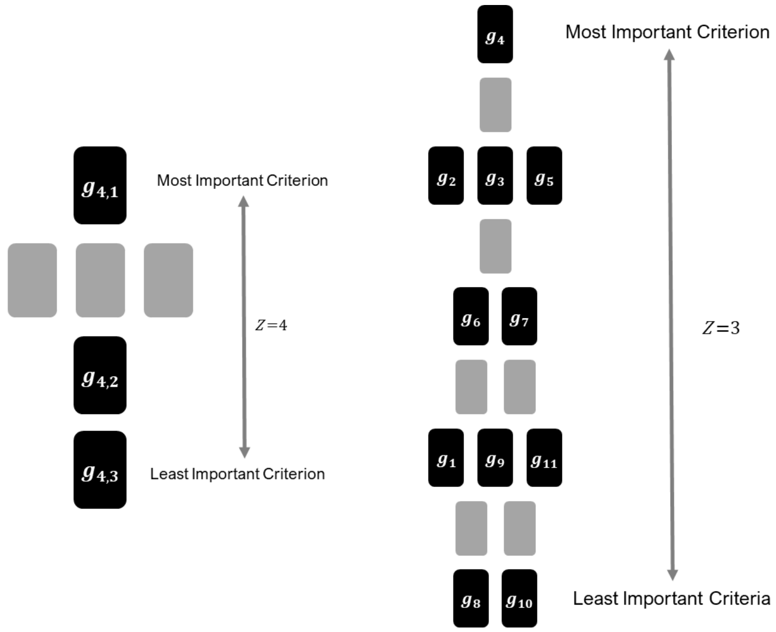

Figure 5.1: SRF procedure scheme to obtain the weights for the sub-criteria of g_4 on the left-hand side, and of the final model on the right-hand side

The resulting weighs of the final criteria and the sub-criteria of g_4 are represented in Tables 5.5 and 5.6, respectively.

Table 5.5: Weights of the sub-criteria of g_4

Weights	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$
Non-Normalized	4	1.6	1
Normalized	60.61	24.24	15.15

Table 5.6: Weights of the final model criteria

Weights	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
Non-Normalized	1.6	2.6	2.6	3	2.6	2.2	2.2	1	1.6	1	1.6
Normalized	7.27	11.82	11.82	13.63	11.82	10	10	4.55	7.27	4.55	7.27

5.3.2 Categories, Reference Actions and Thresholds

Having in mind the main goal of this analysis, which is to sort the selected group of public hospitals, in this case, actions, to Categories of Sustainability previously defined, it is important to define the Categories and characterize them.

As mentioned in the Methodology chapter, the categories are defined and characterized according to the preferences of the DM. For this analysis, it was defined 5 categories, ordered by the overall sustainability performance level that it represents, as:

– C_5: Excellent
– C_4: Very Good
– C_3: Good
– C_2: Sufficient
– C_1: Bad

The categories are characterized by reference actions that are representative of the respective category (they can be real hospitals or dummy ones). It is necessary to define the reference level of each criterion in each category. In ELECTRE TRI-nC, each category can be characterized by more than one reference action.

Note that to build this model it was necessary to build a second model for the sub-criteria of g_4. The previously defined set of categories was also the same as the final model, with the same designations. Since this model was built to assemble a qualitative scale for the criterion g_4, the performance of the actions would be qualified in 5 levels, according to the category that they were sorted into. For instance, if an action was sorted into category C_5, the performance of that action for the final model in the criterion g_4 is 5.

For the model of g_4, it was used the ELECTRE TRI-C model, where, for each category, there is only one reference action to characterize it. As for the final model, the method used is the ELECTRE TRI-nC, where a category can have more than one reference action to characterize it. Tables 5.7 and 5.8 represent the characterization of the categories, according to the reference actions defined alongside the DM.

Table 5.7: Reference Actions of the final model

Category	Performance	Reference Action	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
C_5	*Excellent*	b_5^1	3000	0	0	5	100	100	100	2.5	500	1500	2
C_4	*Very Good*	b_4^1	5000	150	0.05	4	90	95	95	5	750	2000	2.5
		b_4^2	5000	500	0.1	3	90	95	95	5	750	2000	2.5
C_3	*Good*	b_3^1	7500	500	0.1	2	80	90	90	10	1000	2500	3
C_2	*Sufficient*	b_2^1	15000	1000	0.15	2	70	85	85	20	1250	3000	3.5
		b_2^2	15000	1000	0.15	1	70	85	85	20	1250	3000	3.5
C_1	*Bad*	b_1^1	30000	5000	0.2	1	60	80	80	30	1500	3500	4

Table 5.8: Reference Actions of the model sub-criteria of g_4

Category	Performance	Reference Action	$g_{4.1}$	$g_{4.2}$	$g_{4.3}$
C_5	*Excellent*	b_5^1	0	0	0.05
C_4	*Very Good*	b_4^1	1	1	0.25
C_3	*Good*	b_3^1	2.5	2.5	0.5
C_2	*Sufficient*	b_2^1	5	5	1
C_1	*Bad*	b_1^1	7.5	7.5	1.5

Through the course of defining the criteria, the categories, and the reference actions, it was quite perceptive the arbitrariness, subjectivity and uncertainty associated with the process and the data.

As mentioned in the Methodology chapter, ELECTRE methods deal with the imperfect nature of the data using thresholds. For most of the criteria, it was defined a preference threshold and an indifference threshold. The veto threshold was also defined at this stage. These are represented for both models on Tables 5.9 and 5.10.

Table 5.9: Thresholds of the model sub-criteria of g_4

Thresholds	$g_{4,1}$	$g_{4,2}$	$g_{4,3}$
p	0.1	0.05	0.03
q	0.05	0.01	0.01
v	1	0.5	0.25

Table 5.10: Thresholds of the final model

Parameters	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
q	5	5	0.01	-	0.5	0.5	0.5	0.5	5	5	0.01
p	25	10	0.02	-	3	1	1	1	20	30	0.05
v	2500	1000	0.05	∅	10	5	5	5	250	500	0.5

Lastly, the last parameter left to define for both models is the credibility level, which reflects on how strong the majority of the criteria that agree that *a* is at least as good as *b* should be, in order to establish this conclusion, taking into account the criteria weights. The higher the majority level required, the less will the number of outranking relations be but the stronger is their justification (Dias & Mousseau, 2018). For instance, to the DM was presented 3 reference values to serve as a guide (Dias & Mousseau, 2018):

- 0.5 ; 0.51 (simple majority).
- 0.67 (majority of 2/3).
- up to 1 (unanimity).

The DM defined for both models a credibility level of 0.75.

5.4 Summary

This chapter presented the elaboration of the case study to implement and analyse. Throughout this process, it became clear the necessity of having two models, one to aggregate and build a qualitative scale for the criterion g_4 and the main final model that englobes all the criteria, including the g_4.

Also in this chapter, it was defined, for both models, the necessary parameters to implement them in the *MCDA-ULaval* software: the action set, the criteria set, performance tables, and the decision configurations (categories, reference actions, weights, thresholds, and credibility level). The process to obtain the data is the result of an extensive and exhaustive interaction between the analyst and the DM.

Further on, the data obtained in this chapter is to be put through the *MCDA-ULaval* software, to execute the ELECTRE TRI-C method on the model of g_4 and the ELECTRE TRI-nC on the final model. This step will allow the analyst to process the results, conduct analysis and withdraw conclusion regarding the sustainability of the Portuguese public hospitals in the years 2019 and 2020. The next chapter presents the remaining steps of this analysis - the implementation and execution of the models; the exploitation of the results provided by the software and the elaboration of adequate analysis that provides a foundation to withdraw conclusions to provide to the DM.

Chapter 6

Implementation, Results and Discussion

The current chapter presents the implementation and execution of the model built in the previous chapter. It is also conducted exploitation of results, as well as Sensitivity and Robustness analyses of the results and a further discussion.

6.1 Model Execution

In the previous chapter, it was defined all the aspects of the model to be evaluated: Actions, Criteria, Categories, Reference Actions, Weights, Thresholds and Credibility Level. As mentioned, these values served as an input to the software. This first section presents a sequence of steps to implement the data obtained in the previous chapter in the MCDA ULaval software and the execution of the model. Only the final model is illustrated since the implementation is quite similar in both models (the illustration of the model of g_4 using the ELECTRE TRI-C method can be found for consultation in Appendix A).

The first step was to insert the Action set and the Criteria set as seen in Figure 6.1 and 6.2 respectively.

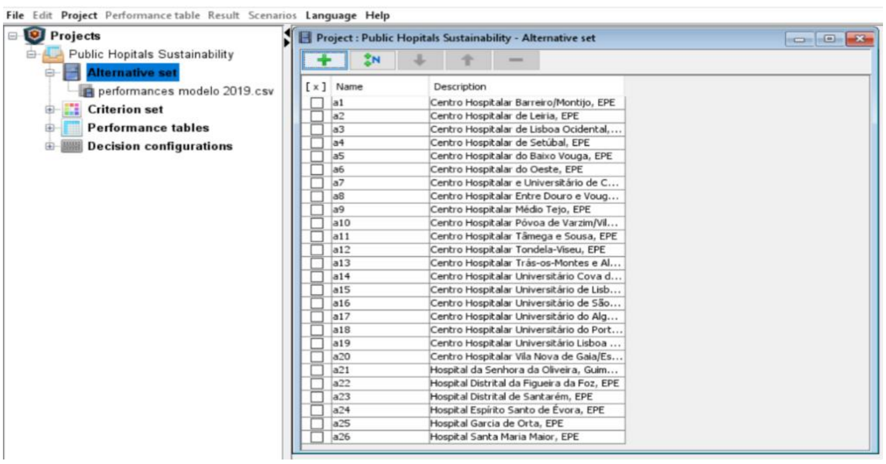

Figure 6.1: Action's Set for MCDA ULaval

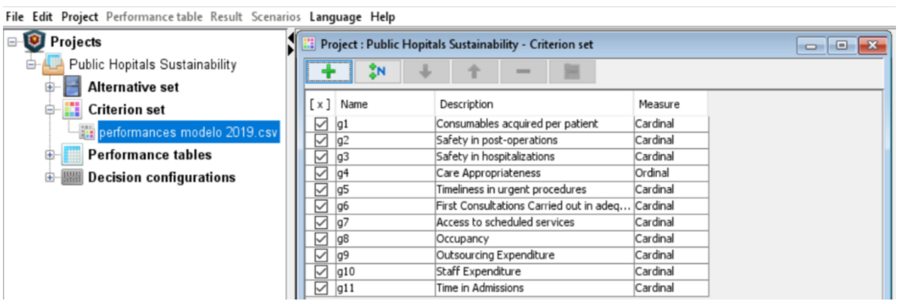

Figure 6.2: Criteria Set in MCDA ULaval

When inserting the criteria set, it is important to assure that the scale of the criterion g_4 is qualitative and not quantitative. Thus, in the column "Measure" for the criterion g_4 is selected the option "Ordinal" instead of "Cardinal".

The next step is to insert the performance table. Figure 6.3 illustrates the performance table of the final model in the year 2019.

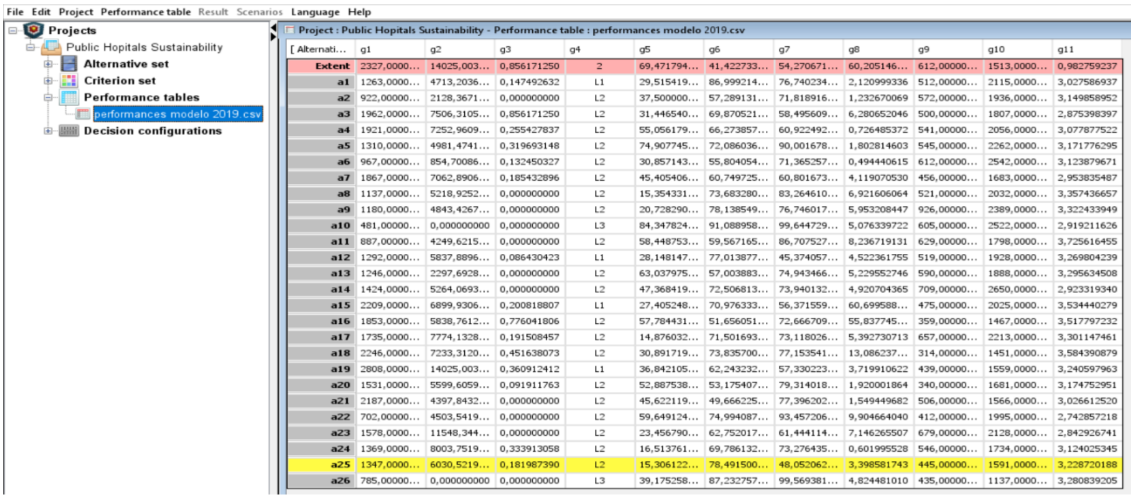

Figure 6.3: Performance Table of final model 2019 for MCDA-ULaval

Thereafter, it is necessary to choose the method in order to insert the decision configurations. For the final model it was chosen the ELECTRE TRI-nC. After selecting the method, the Decision Configuration box appears to be filled with the respective data, as seen in Fig 6.4.

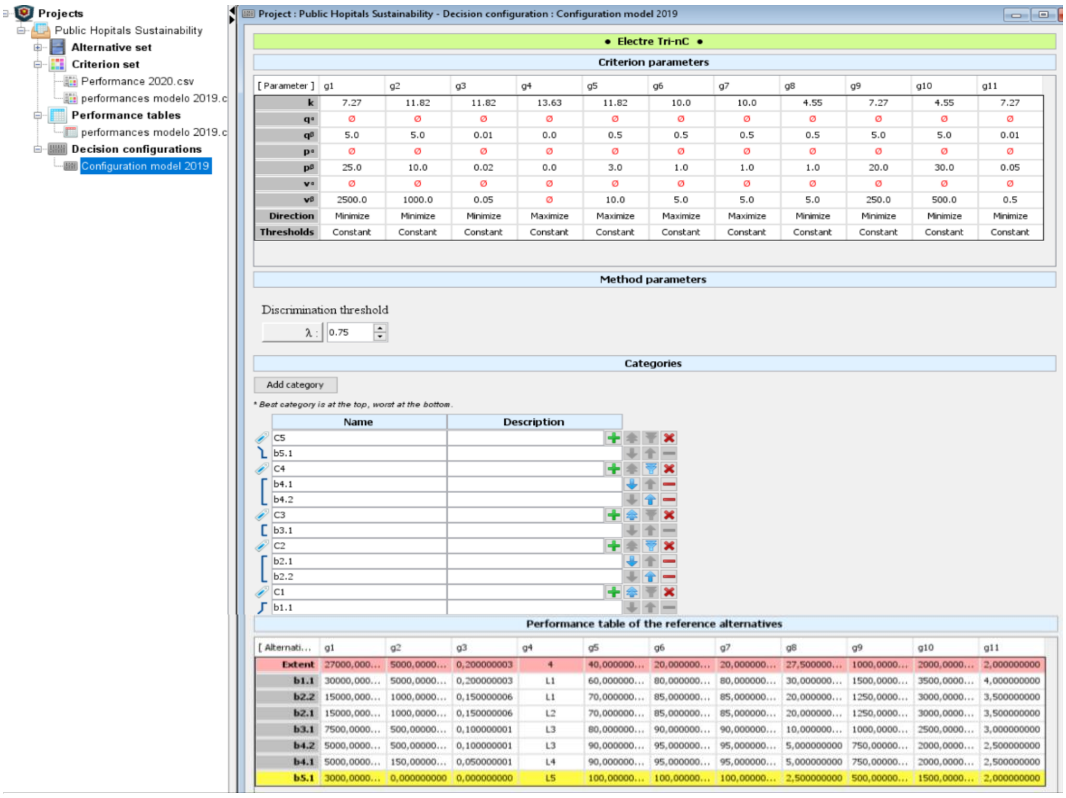

Figure 6.4: Decision Configurations in MCDA ULaval

As it can be observed, the decision configuration box contains three sections:

- Criterion parameters: This section concerns the Weights (k), the Indifference Threshold (q), the Preference Threshold (p) and the veto parameter (v) of each criterion. These values were filled with the data of Tables 5.6 and 5.10.
- Categories: This section concerns the creation of the categories and the reference actions that characterize them. To fill this section, it was used the data of Table 5.7.
- Performance table of reference actions: Concerns the value of the reference actions of each criterion. These values were filled with the date of Table 5.7.

The process was repeated for the year 2020, where the only different input was the performance tables. After having all the necessary inputs inserted in the software it is possible to execute the program, by pressing the execute button on the software.

6.2 Results

After inserting all the necessary data and validating its coherency, it is possible to execute the model. When the model is executed, a table of assignments appears, with each action assigned to a minimum and a maximum category. For the years 2019 and 2020, the results obtained are as shown in Table 6.1.

Table 6.1: Assignment of Actions into maximum and minimum categories in the years 2019 and 2020

Action	2019		2020	
	Minimum	Maximum	Minimum	Maximum
a_1	C_1	C_4	C_1	C_4
a_2	C_1	C_4	C_1	C_4
a_3	C_1	C_4	C_1	C_4
a_4	C_1	C_4	C_1	C_4
a_5	C_1	C_4	C_1	C_4
a_6	C_1	C_4	C_1	C_4
a_7	C_1	C_4	C_1	C_4
a_8	C_1	C_4	C_1	C_4
a_9	C_1	C_4	C_1	C_4
a_{10}	C_4	C_5	C_2	C_5
a_{11}	C_1	C_4	C_1	C_4
a_{12}	C_1	C_4	C_1	C_4
a_{13}	C_1	C_4	C_1	C_4
a_{14}	C_1	C_4	C_1	C_4
a_{15}	C_1	C_4	C_1	C_4
a_{16}	C_1	C_4	C_1	C_4
a_{17}	C_1	C_4	C_1	C_4
a_{18}	C_1	C_4	C_1	C_4
a_{19}	C_1	C_4	C_1	C_4
a_{20}	C_1	C_4	C_1	C_4
a_{21}	C_1	C_4	C_1	C_4
a_{22}	C_1	C_5	C_1	C_4
a_{23}	C_1	C_4	C_1	C_4
a_{24}	C_1	C_4	C_1	C_4
a_{25}	C_1	C_4	C_1	C_4
a_{26}	C_1	C_5	C_1	C_4

The results obtained for each year are presented in two columns: Minimum Category, which corresponds to a Pessimist point of view, and a Maximum Category, which represents the Optimist point of view. For each action, a Maximum and Minimum Category was assigned.

As it is possible to observe in the graphs of Figure 6.5, the categories assign in the Pessimist and Optimist perspective are quite homogeneous which reflects that the model contains various demanding restrictions that difficult the differentiation of the assignment of the actions. Also, the intervals of categories assigned between the pessimist and optimist perspectives are very large.

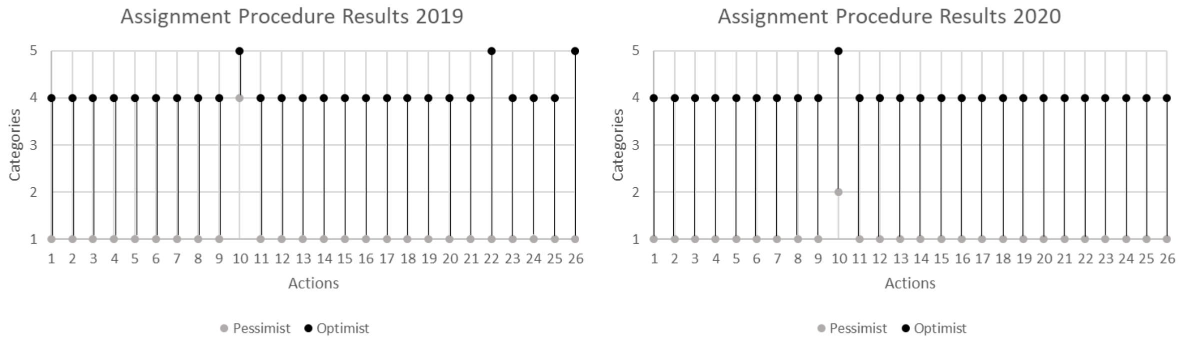

Figure 6.5: Assignment Procedure Results Graphs of 2019 and 2020

In 2019, 23 out of 26 actions, which correspond to 79.31% of the total actions were assigned to categories C_1 and C_4, to the Pessimist and Optimist perspectives, respectively. Actions a_{22} and a_{26} were assigned to the categories C_1 and C_5. As for action a_{10}, the "best action", was assigned to Category C_4 in the pessimist perspective and to C_5 in the optimist perspective. Action a_{10} is considered the best action since the maximum and minimum categories are higher than the remaining categories assign to the other actions.

In 2020, 25 out 26 actions (96.15% of the total set of actions) were assigned to categories C_1 and C_4. Action a_{10} presents itself once again as the best action, assign to categories C_2 and C_5.

The results are very inconclusive. With the information gathered so far, it is only possible to make assumptions about the best actions. It is of extreme importance to perform a set of analysis that will not only allow to understand what's causing a lock on the assignment procedure but also obtain a more conclusive date to provide to the DM.

6.2.1 Sensitivity Analysis

The purpose of this first analysis is to identify the sensitive parameters in the model, and how they impact the final result.

As mentioned, it is important to understand why the results obtained were so undifferentiated, and this analysis will allow testing several parameters of the model and the impact they have on the result.

A sensitive analysis usually consists of measuring the impact that uncertainties of one or more input variables have on the output variables.

Since the goal is to evaluate the impact of uncertainties in the input variables, the choice of the variables to be analysed is dependent on the uncertainty level associated with them. A parameter that has a high level of arbitrariness and uncertainty associated with it is the credibility level, so that will be the first parameter to be tested.

Changing the Credibility level

As mentioned in chapter 4 and 5, the credibility level is a value between]0.5;1] that reflects on how strong the majority of the criteria that agree that a is at least as good as b should be, in order to establish this conclusion, taking into the account the criteria weights. In other words, a strong credibility level requires a larger majority of criteria agreeing that an action *a* outranks the general value of a reference action *a'*.

A sensitivity analysis on the credibility level will allow understanding how the variation of this parameter affects the final results, and the assignment of actions into categories.

The credibility level used in the model is considered a pretty strong credibility level, that requires a majority of 75% concordance among the criteria in an outranking relation. In this analysis the goal is to understand what would happen if the credibility level were less strong. To do so, the model of 2020 was executed two more times with the credibility levels of 0.65 and 0.55. It was expected to have more actions assigned to different levels than the ones obtained before.

The results of changing the credibility level are represented in Table B.1. The Credibility level suffered a variation of 0.20 points and yet nothing change on the assignment procedure (Appendix B).

Thus, this means that the results are not sensitive to the credibility level defined by the DM. It is necessary to elaborate more sensitivity analysis on other parameters to understand the most influential factor to the results.

Changing the criteria Weight

Although the weights of the criterion were obtained by collaborating with our DM, these may suffer some variation which reflects the uncertainty of the DM while making evaluations throughout this process. To better understand how these variations can affect our results we need to perform a sensitivity analysis on the weights of our criteria.

To do so, the SFR was conducted once again. To execute this analysis three models were used:

- Model A, the original model of 2020.
- Model B, except this time it was retrieved all the blank cards in the SRF procedure to have less differentiated intervals of weighs. maintaining all the other parameters the same as model A
- Model C, exactly the same as Model A but adding 1 blank card to each interval of blank cards in the SRF procedure.

The weights used are summarized in Table 6.2.

Table 6.2: Weights Variation for Sensitivity Analysis

Weights	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
Model A	7,27	11,82	11,82	13,63	11,82	10	10	4,55	7,27	4,55	7,27
Model B	7,14	11,91	11,91	14,29	11,91	9,52	9,52	4,76	7,14	4,76	7,14
Model C	7,24	11,84	11,84	13,82	11,84	9,86	9,86	4,61	7,24	4,61	7,24

After executing the method, the results of the assignment procedure did not vary, as can be observed in Table B.2 (Appendix B) which demonstrates that the results are not sensitive to the criteria weight's variation.

Thus, it is necessary to continue to look for the parameter of the model that is strongly influencing the results.

Changing the Veto Thresholds

The veto thresholds can have a significant value to the final results of the model. The value of the veto threshold represents the difference in performance between a certain action a and a reference action a' that leads to refuting the affirmation of a outranking a', meaning that a lower value of a veto threshold can highly influence the result of the assignment procedure since one the performance of one criterion can refute an outranking relation.

For the analysis, 3 models were considered (Table 6.3):

- Model A: The original model of 2020, without any change in any parameter
- Model D: The model of 2020, with the veto threshold multiplied by 2, maintaining the remaining parameters the same.
- Model E: The model of 2020, with the veto threshold multiplied by 4, maintaining the remaining parameters the same.

Table 6.3: Veto Thresholds Variation for Sensitivity Analysis

v	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
Model A	2500	1000	0,05	∅	10	5	5	5	250	500	0,5
Model D	5000	2000	0,1	∅	20	10	10	10	500	1000	1
Model E	10000	4000	0,2	∅	40	20	20	20	1000	2000	2

The results of this analysis are represented in Table 6.4. As it is possible to observe, the results of the assignment procedure suffered a significant change when increasing the values of the veto threshold defined by the DM. This means that not only that the veto threshold has a high influence on the results of the assignment procedure, but also that the values defined by the DM for the Veto threshold were too small to provide a more differentiated and complete analysis of the problem in hands.

Sensitivity analysis allows the analyst to understand the bottlenecks of the model and further propose a better suggestion to the DM. The fact that it was possible to identify the influential parameter that was constraining the result allows the analyst to provide the DM with more complete feedback, and more insight into the model defined initially by both.

For the discussion of the results, it is interesting to have in consideration the results obtained in this analysis to open a more comprehensive debate regarding the sustainability of the Portuguese public hospitals.

Table 6.4: Results of the Assignment procedure for Sensitivity Analysis on the Veto Thresholds

Action	Model A		Model D		Model E	
	Pessimist	Optimist	Pessimist	Optimist	Pessimist	Optimist
a_1	C_1	C_4	C_1	C_3	C_1	C_2
a_2	C_1	C_4	C_1	C_3	C_1	C_3
a_3	C_1	C_4	C_1	C_3	C_1	C_3
a_4	C_1	C_4	C_1	C_3	C_1	C_3
a_5	C_1	C_4	C_1	C_3	C_1	C_2
a_6	C_1	C_4	C_1	C_4	C_1	C_4
a_7	C_1	C_4	C_1	C_3	C_1	C_3
a_8	C_1	C_4	C_1	C_4	C_1	C_3
a_9	C_1	C_4	C_1	C_3	C_1	C_3
a_{10}	C_2	C_5	C_2	C_4	C_2	C_4
a_{11}	C_1	C_4	C_1	C_4	C_1	C_4
a_{12}	C_1	C_4	C_1	C_4	C_1	C_4
a_{13}	C_1	C_4	C_1	C_3	C_1	C_3
a_{14}	C_1	C_4	C_1	C_4	C_1	C_4
a_{15}	C_1	C_4	C_1	C_3	C_1	C_2
a_{16}	C_1	C_4	C_1	C_3	C_1	C_3
a_{17}	C_1	C_4	C_1	C_3	C_1	C_3
a_{18}	C_1	C_4	C_1	C_3	C_1	C_2
a_{19}	C_1	C_4	C_1	C_3	C_1	C_3
a_{20}	C_1	C_4	C_1	C_3	C_1	C_3
a_{21}	C_1	C_4	C_1	C_4	C_1	C_4
a_{22}	C_1	C_4	C_1	C_4	C_2	C_3
a_{23}	C_1	C_4	C_1	C_4	C_1	C_4
a_{24}	C_1	C_4	C_1	C_3	C_1	C_3
a_{25}	C_1	C_4	C_1	C_3	C_1	C_2
a_{26}	C_1	C_4	C_1	C_4	C_2	C_4

6.2.2 Robustness Analysis

Having the results of the sensitivity analysis, it is interesting to elaborate a robustness analysis of the model designed. The difference between the two a sensitivity analysis and a robustness analysis lies in the approach and objective of the research: while robust analysis deals with the design of the model considering the necessary assumptions, sensitivity analysis aims at testing the results with the view of considering the parameters or inputs that can influence the outputs and stability of the results (Belton & Stewart, 2002).

A robustness analysis allows the analyst to test several scenarios, under different assumptions, to understand the robustness of the model itself. The more robust the model is, the fewer impact changes in assumptions will have on the final results, and the more similar outcomes will emerge in the generated scenarios.

In a robustness analysis, the method is to build different scenarios following a tree scheme. Therefore, the scenarios built considered more than one change to the initial model, which is not the case in a sensitivity analysis.

In the Robustness analysis, the scenarios were built by changing three parameters:

- The veto thresholds, using three scenarios, the original values defined with the DM; the original values multiplied of all the veto thresholds multiplied by 2; and the original values of all the veto thresholds multiplied by 4 (See Appendix C, Table C.1)
- The credibility level, using the same values considered in the sensitivity analysis – 0.75; 0.65 and 0,55.
- The ratio coefficient z used in the SRF procedure to determine the weights of the criteria, using the original value of z, which was 3 and new values for $z = 2$ and $z = 4$ (see Appendix C, Table C.2)

The tree scheme used in the robustness analysis can be observed in Figure 6.6.

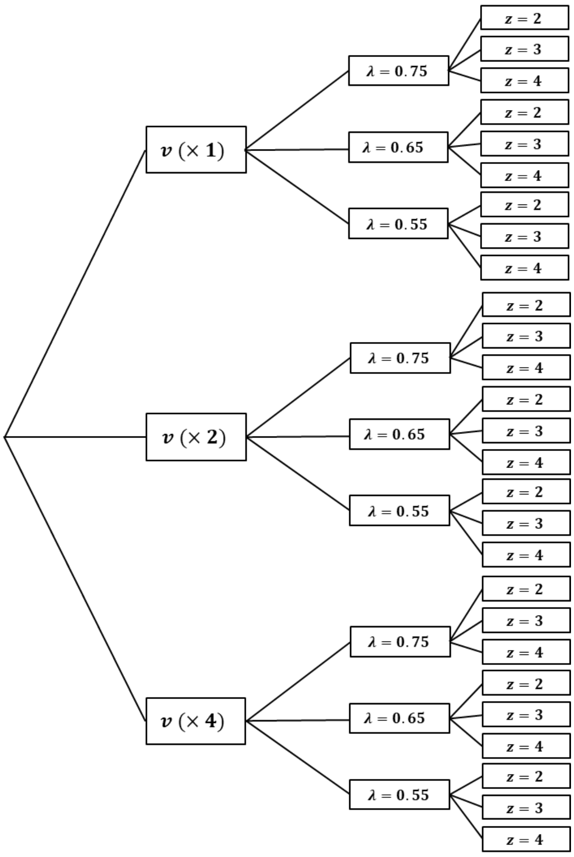

Figure 6.6: Robustness Analysis Scheme

For each tree branch, a model was executed, resulting in a total of 18 models, with 36 scenarios, considering the Pessimist and Optimist perspectives, with a total of 936 assignments.

The results of the assignment procedure for the Robustness Analysis in the Optimist and Pessimist Perspective are presented in Table C.3 and C.4 in Appendix C, respectively.

Changing the credibility level and the weights proved to have no impact when done separately in the sensitivity analysis, probably due to the restrictions imposed by the veto thresholds. In the robustness analysis, that was not the case anymore. When considering the increased values for the veto thresholds, the variations in the credibility level and in the weights of the criteria reflected on changes on some assignments in the assignment procedure.

Overall, the increased values in the veto thresholds, like in the sensitivity analysis, resulted in the actions being assigned to lower categories, in the Optimist perspective. In the original model, with $z = 3$, $\lambda = 0.75$ and $veto\ (\times 1)$, 96.15% of the total set of actions were assigned to category C_4, and the remaining 3.85% to category C_4. When changing the veto to $veto\ (\times 2)$, the results changed significantly, with 61.53% of the total set of actions assigned to category C_4 and the remaining 38.47% assigned to category C_3.

As for the values in the credibility levels, the effect of lowering their value reflects on some actions being assigned to lower categories as well, and to have a more overall differentiated assignment procedure than with higher values of credibility levels. For instance, considering the scenario of $z = 3$, $\lambda = 0,.5$ and $veto\ (\times 2)$, 61.53% of the total set of actions were assigned to category C_4 and the remaining 38.47% were assigned to category C_3. For the scenario with $z = 3$, $\lambda = 0,65$ and $veto\ (\times 2)$, the percentage of actions assigned to category C_4 decreased to 23.08% and the remaining 76.92% were assigned to category C_3.

Lastly, the variation in the ratio coefficient z reflects on a higher difference between the weights of the most important criterion and the less important criteria. The final weights, for $z = 2$ and $z = 4$ are presented in Table C.1 in Appendix C The variation of the ratio z had a smaller impact on the results of the robustness analysis, with just a few actions assigned differently for each value of z. Also, the impact of varying z is only perceived for higher values of the veto threshold, and lower values of the credibility level.

Overall, considering the different scenarios analysed, it is possible to conclude that the model is not very robust, since there are significant changes in the results for the different scenarios. However, the different scenarios can be used to compare the results with the original model, since the assignment procedure in this model is quite undifferentiated.

6.3 Discussion

The execution of the initial model, let us call it Model A, only proved to be useful to determine the best action(s), since the generality of the actions were assigned to category C1 (minimum) and C4 (maximum) and only a few were assigned to C5 (maximum) and to C2(minimum) or C4 (minimum).

From the implementation and execution of Model A, the best hospitals in terms of the sustainability are:

- a_{10}: *Centro Hospitalar Póvoa de Varzim/Vila do Conde*, EPE, for both years 2019 and 2020 assigned to Category 5: Excellent in the Optimistic Perspective.
- a_{22}: *Hospital Distrital da Figueira da Foz, EPE*, assigned to Category 5: Excellent in 2019.
- a_{26}: *Hospital Santa Maria Maior, EPE*, also assigned to Category 5: Excellent in 2019.

These three hospitals stand out from the remaining actions that in both years were assigned to Category 4: Very Good.

However, as mentioned, the conclusions obtained from this model were very incomplete, given that it is not possible to compare or make any assumptions about the remaining 23 Hospitals. For that reason, the robustness and sensitivity analysis were an adding point to develop more models and to understand some outranking relations that were not being considered in Model A.

Looking into the sensitivity and robustness Tables 6.4, C.3 and C.4, the best model to have in consideration, having in mind the parameters defined with the DM, is the model with $z = 3, \lambda = 0.75$ and $veto\ (\times 2)$ – Model D, since it is the scenario with the closest assumptions to the ones initially defined with the DM, and where the results display new and relevant conclusions, represented in Tables 6.5 and 6.6.

Table 6.5: Assignment Results Statistics - Model D

Minimum and Maximum Categories	**Actions (2020)**	**Actions (2019)**
C_1, C_3	16 (61.53%)	14 (53.86%)
C_1, C_4	9 (34.6%)	10 (38.46%)
C_2, C_4	1 (3.84%)	1 (3.84%)
C_4, C_4	-	1 (3.84%)

Table 6.6: Assignment Results - Model D

Action	2019		2020	
	Minimum	Maximum	Minimum	Maximum
a_1	C_1	C_3	C_1	C_3
a_2	C_1	C_3	C_1	C_4
a_3	C_1	C_3	C_1	C_3
a_4	C_1	C_3	C_1	C_3
a_5	C_1	C_3	C_1	C_3
a_6	C_1	C_4	C_1	C_3
a_7	C_1	C_3	C_1	C_3
a_8	C_1	C_4	C_1	C_4
a_9	C_1	C_3	C_1	C_3
a_{10}	C_2	C_4	C_4	C_4
a_{11}	C_1	C_4	C_1	C_4
a_{12}	C_1	C_4	C_1	C_3
a_{13}	C_1	C_3	C_1	C_4
a_{14}	C_1	C_4	C_1	C_4
a_{15}	C_1	C_3	C_1	C_3
a_{16}	C_1	C_3	C_1	C_3
a_{17}	C_1	C_3	C_1	C_3
a_{18}	C_1	C_3	C_1	C_4
a_{19}	C_1	C_3	C_1	C_3
a_{20}	C_1	C_3	C_1	C_4
a_{21}	C_1	C_4	C_1	C_4
a_{22}	C_1	C_4	C_2	C_4
a_{23}	C_1	C_4	C_1	C_4
a_{24}	C_1	C_3	C_1	C_3
a_{25}	C_1	C_3	C_1	C_3
a_{26}	C_1	C_4	C_1	C_4

Analysing the results statistics presented in Tables 6.5 and 6.6, it is possible to withdraw some conclusions:

- The overall performance of all actions is better in 2019 than in 2020, thus, the hospitals were generally more sustainable in 2019, and there is a decline in the performance from 2019 to 2020.
- The most sustainable hospital, according to this Model, is a_{10}: *Centro Hospitalar Póvoa de Varzim/Vila do Conde*, EPE, followed by a_{22}: *Hospital Distrital da Figueira da Foz, EPE,* for both 2019 and 2020.
- The hospitals assign to lower categories are in between the levels C_1: Bad and C_3: Good, and represent more than half of the entire set of hospitals, in both years.
- The intermediate hospitals are assigned to Categories C_1:Bad and C_4: Very Good.
- The best hospitals differ from the intermediate due to their minimum assigned category, that is C_2: Sufficient for the second-best, and C_4:Very Good for the best performing hospital.

It is important to go back and analyse the performance tables and the weights to better understand the results obtained. The criteria with more weight are g_4, g_2, g_3 and g_5. These criteria are all from the Social Pillar, and the performance of the actions in these criteria are the most weighted in the overall performance of each action. Thus, even though there might be criteria with different performances, the performance of these four criteria will count more for the results, and that is probably why the assignment procedure seems very correlated with the performances of the actions in those criteria.

The results the analyst should provide to the DM are not only the results of the implementation and execution of Model A, but also from Model D. It is also beneficial to complement the information with the result of the Sensitivity and Robustness Analysis that display some bottlenecks in Model A, and that led to the construction of the different scenarios of the Robustness Analysis and the use of Model D to allow the DM to expand the understanding of the model, and the outranking relations found.

For future implementations or reviews of the work done, particularly when it comes to the model formulation and implementation, it will be interesting to review the model parameters chosen by the DM, especially the Veto threshold, and to build a model that has the Environmental, Social and Economic criteria more balanced, so to have a more differentiated result in the assignment procedure.

Chapter 7

Conclusion

This chapter marks the end of this dissertation. In the first section, it is provided an overview and an insight of the work done. Additionally, it is analysed the main constraints found during the elaboration of this analysis. To close this study, it is conducted a proposition for future research on the topic of this work.

7.1 Final Remarks

The increased knowledge of sustainability that has occurred over the previous century has resulted in substantial societal transformations. One of the primary issues that is driving the new sustainability movements that are growing across many sectors is the evolution in a sense of responsible living to allow future generations to have a good quality of life. While the world is reducing the use of disposable products, plastics, and the emissions of toxic gases and pollutants associated with the activity of many sectors of the economy, the healthcare sector continues to be a major contributor to the use of these products because there is no alternative and the sector's activity is highly dependent on them.

If the Covid-19 Pandemic taught us anything, it is that healthcare is an extremely important aspect of society, the economy, and even the environment. When everyone was obliged to stay indoors, the world witnessed the extraordinarily difficult logistics involved with healthcare services, which were trying to stay afloat in many cases. A country's entire economy could collapse if it does not have a strong healthcare system.

Sustainability is not only concerned with the environmental impacts but also the economic and social impacts that a certain activity has. This dissertation addressed the topic of Sustainability in healthcare. In this particular study, the focus was set on the Sustainability of Portuguese public hospitals. The main goal of this work was to account for the efforts of the hospitals for sustainable developments, in order to further reward good efforts, or sanction bad practices.

The FPVs identified in the literature review served as a theoretical foundation for developing a framework for assessing the sustainability of hospitals, which was the study's focus. The adoption of MCDA techniques is evident given that sustainability is a complex and wide-ranged subject that requires the use of such techniques.

Chapter 4 provided a theoretical grasp of how the ELECTRE TRI-nC approach works, which was necessary for developing the model with the DM – A person or a representative of an entity in whose name or for whom the decision aiding must be given is normally one or more DM in the scope of MCDA procedures. The DM in this instance is a specialist in the Portuguese public healthcare system.

It was possible to assemble an ELECTRE TRI-nC model with the DM by remembering all of the concepts and notations, as well as the method's strengths and limitations.

The main inputs to build the model were:

- The research (FPV’s) of Chapters 2 and 3.
- The input of specified knowledge and personal preferences of the DM.
- The information that was available on the ACSS Benchmarking.

A set of eleven criteria was created based on the inputs. Additionally, alongside the DM, the remaining parameters of the ELECTRE TRI-nC, such as Categories, Reference actions to characterize the categories, Thresholds, and Weighs, which were obtained by the use of the SRF procedure. The entire process of building and setting the model’s parameters is quite extensive. Throughout this process, many versions of criteria were discussed until reaching a final consensus on the set of criteria. Afterward, the remaining aspects of the model were defined.

As for the set of actions, these were selected according to the areas of expertise - large hospitals and hospital centres without any specific specialization. Additionally, the hospitals whose data were missing from the indicators of the ACSS Benchmarking were excluded from the set. This selection resulted in an action set constituted by 26 hospitals. Even though some hospitals were excluded from the analysis, such as PPPs, which would be interesting to include in this study, the set of actions selected allowed a quite comprehensive analysis of the Portuguese public hospitals, focused on the hospitals with the same type of activity.

Afterward the model was inserted in the MCDA-ULaval, a decision support software, that allowed to obtain results. Chapter 6 describes the process of implementation of the model defined in Chapter 5 into the software and the results obtained from this implementation. Given that the results were inconclusive for the majority of the hospitals, two analyses were carried out. Firstly, a sensitivity analysis was performed to understand what was influencing the results. From this analysis it was possible to understand that the Veto threshold values were too low to begin with and constituted a bottleneck to the creation of more diversified outranking relations. Then a second analysis was conducted: a Robustness analysis. This analysis was important not only to elaborate scenarios that could be used as a reference for the discussions but also to test the robustness of the model designed, which proved to be somewhat weak.

By creating more scenarios, the discussion of the results was based on two models: Model A the initially defined with the DM, and Model D, that allowed the analyst to perfect the understanding of the outranking relation, and to withdraw more conclusion regarding the assignment of hospitals into the Sustainability Categories.

To sum up, it was possible to identify two hospitals that outstand the remaining set of hospitals in terms of performance of the sustainability criteria, which occupied the higher-ranked categories in both years: a_{10}: *Centro Hospitalar Póvoa de Varzim/Vila do Conde*, EPE and a_{22}: *Hospital Distrital da Figueira da Foz, EPE.* The remaining set of actions was divided into two other levels with 10 and 9 hospitals (respectively in 2019 and 2020) in a medium level of performance, and the remaining 14 and 16 hospitals assigned to a lower level of performance in sustainability.

From this analysis, it is important to understand that more than half of the hospitals do not have a good performance according to the sustainability criteria defined with the DM and this particular model' perspective, and there is a lot of space for improvement. Furthermore, it is also important to recognise that these models value the Social Pillar more than the other two pillars of sustainability, therefore, the results reflect highly on the social sustainability of the hospitals rather than the Environmental and Economic Sustainability that do not have a highly significant weight on the results.

To sum-up, in this research work, the main objectives such as understanding the context of this study, developing a framework capable of analysing the sustainability of the public hospitals that included not only the theoretical foundation defined in the state of the art, but also the preferences of DM, and obtaining results and relevant conclusions from this analysis, were all achieved.

7.2 Limitations and Recommendations

Sustainability in healthcare is a recent topic of analysis. There is not a typical or consensual framework on how to address and measure sustainability in healthcare. Furthermore, the indicators available to measure sustainability lack information specially when it comes to environmental issues. For instance, it is difficult to measure the waste of products, and emissions of pollutants associated with the hospital's activity since there are no direct indicators that concern these values.

To evaluate the environmental pillar of sustainability in hospitals it is only possible to use indirect information. For instance, in this study, the waste of goods was addressed as the possibility of being higher as the procurement and consumption of goods per patient increase. It is evident that a higher Procurement has a negative impact on the environment since this category represents the highest healthcare carbon footprint, given that it implies the use of disposable goods such as gloves, masks, or uniforms and a vast level of supplies to assure health and hygiene in a hospital. However, even though the use of products per patient increases from one hospital to another, that might not necessarily mean there is waste. Some hospitals, particularly the large hospitals, receive more difficult cases, and the value of goods acquired to treat these patients is higher. This introduces the second limitation of this research – The lack of Case-mix indicators, which, unfortunately, was not possible to obtain the authorization to consult. In the presence of these types of indicators, the data, particularly the indicators of costs used in the Environmental and Economic criteria, would be more realistic to the hospital's activity and would provide a stronger and more robust analysis.

Adding to the limitations of the lack of information to the criteria set building, there is the uncertainty associated with the development of MCDA models that represent real situations which usually is subject to errors and quite a few limitations.

The construction of categories and Reference actions were objects of some uncertainty and arbitrariness. Even though the DM was a specialist in the field of study, the process of attribution of values for the reference actions is object of some arbitrariness, which might affect the robustness of the data.

Furthermore, the same arbitrariness was found when defining the thresholds, particularly the Veto thresholds, which negatively affected the results of the model.

Lastly, the attribution of weights to the criteria has preferred the social pillar of the TBL approach, and the other two pillars had less contribution for the results, which affects the conclusions regarding the Sustainability in those two pillars.

7.3 Future Research

In 2015, 193 nations committed to the United Nations Sustainable Development Goals (SDGs), defined in Transforming our world: the 2030 agenda for sustainable development. The SDGs are based on the principle of promoting equity and leaving no one behind in the process of economic, social and environmental development. Regarding this work' context, it will be interesting to evaluate the progress to the Portuguese healthcare sector in the SDGs, by developing a common framework of analysis for every country and to further conduct a comparison of the efforts made towards sustainable development.

To improve the results, and go further on this study there are three suggestions of improvements for further research:

- The use/creation of other indicators to reinforce the environmental pillar analysis.
- The use of case-mix indicators to allow a comparison based on the difficulty of cases that each hospital receives.
- The development of a model with more distributed weights among the three pillars and fewer constraints associated with the veto thresholds, in order to obtain more comprehensive results of the overall sustainability

Furthermore, on a more innovative perspective, it will be interesting to explore new sustainable products, to replace the disposable products that are causing the footprint associated to the Procurement of hospital supplies.

Lastly, having a general framework to analyse the hospitals in terms of sustainability, it is important to regulate sanctions and benefits based on efforts of sustainable development.

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Appendix A

This section displays the illustration of the implementation of the model of the sub-criteria of g_4 using the ELECTRE TRI-C.

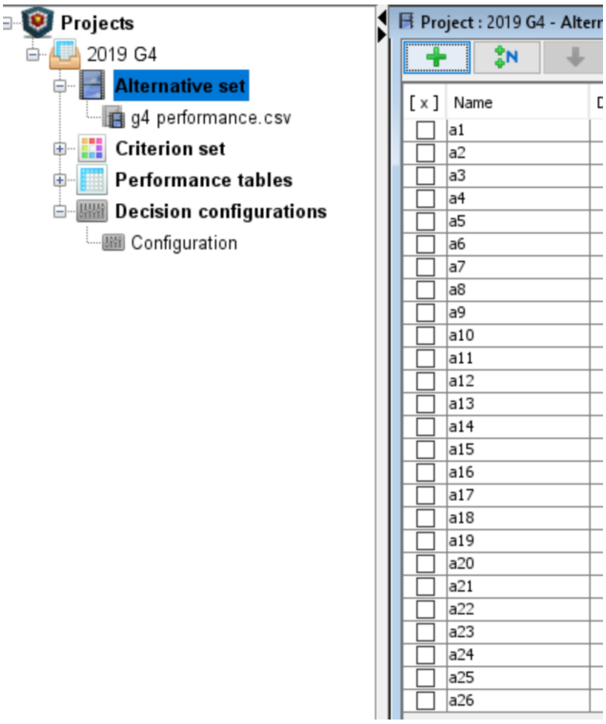


Figure A.1: Action Set for model of g_4

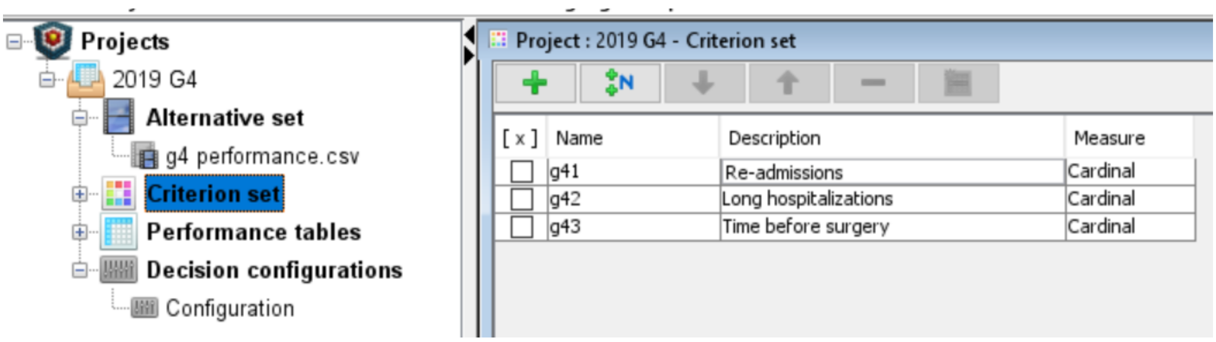
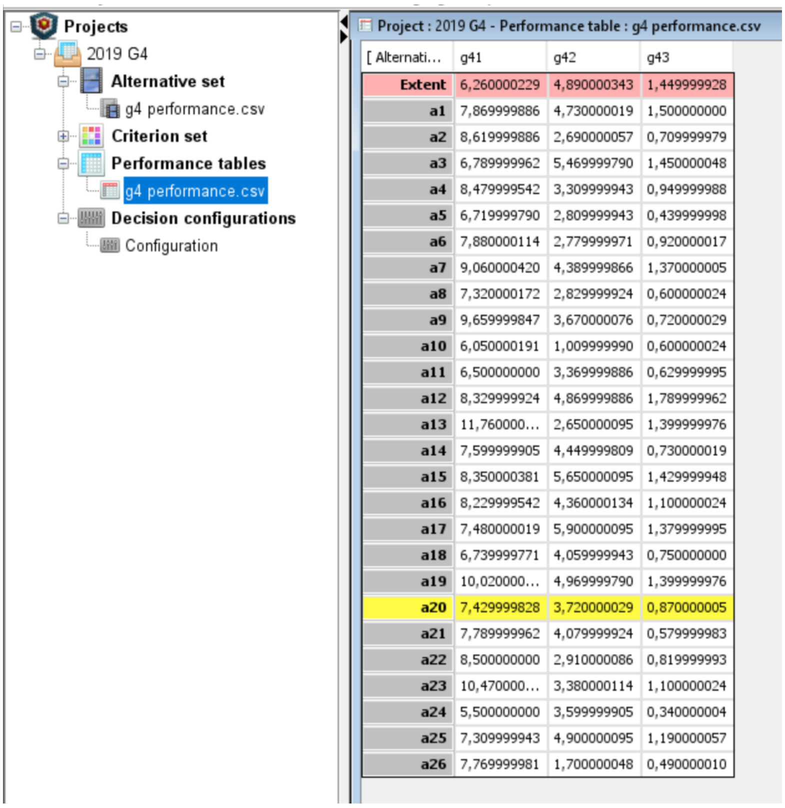
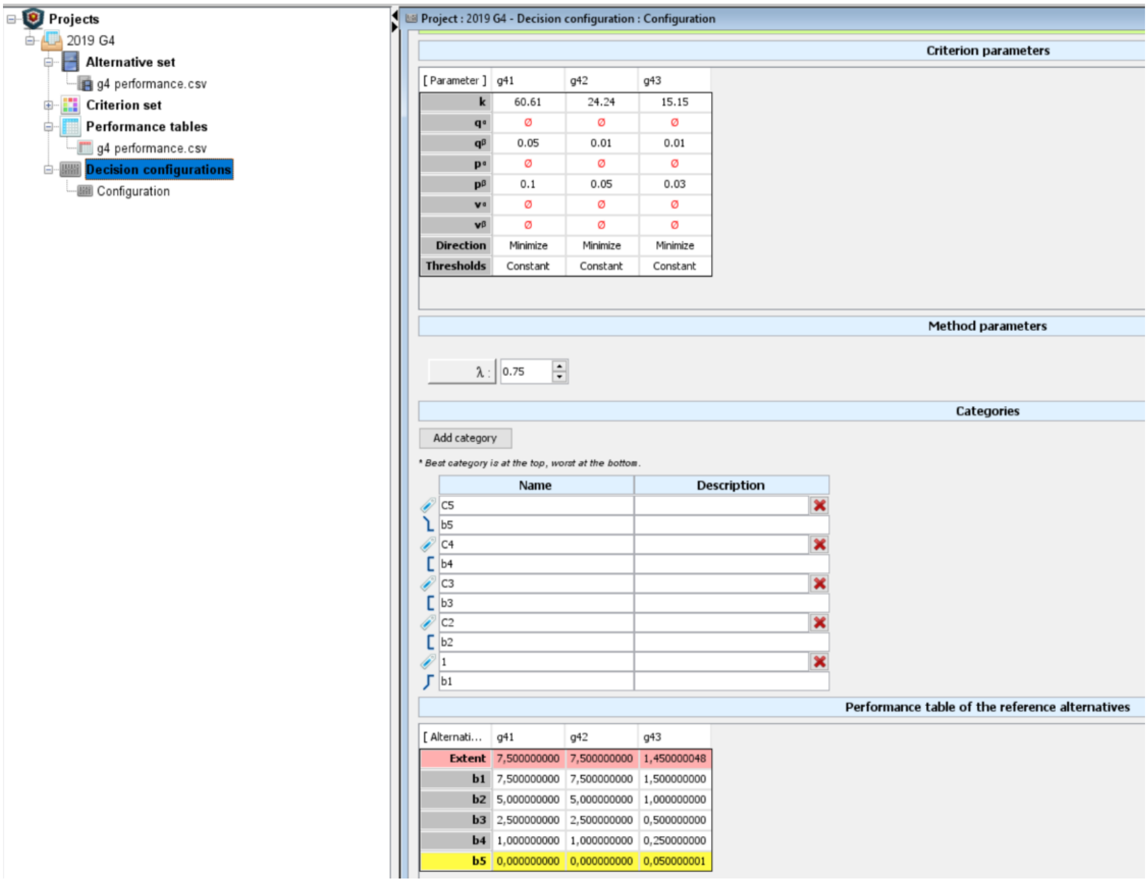


Figure A.2: Criteria Set for model of g_4



[Alternati…	g41	g42	g43
Extent	6,260000229	4,890000343	1,449999928
a1	7,869999886	4,730000019	1,500000000
a2	8,619999886	2,690000057	0,709999979
a3	6,789999962	5,469999790	1,450000048
a4	8,479999542	3,309999943	0,949999988
a5	6,719999790	2,809999943	0,439999998
a6	7,880000114	2,779999971	0,920000017
a7	9,060000420	4,389999866	1,370000005
a8	7,320000172	2,829999924	0,600000024
a9	9,659999847	3,670000076	0,720000029
a10	6,050000191	1,009999990	0,600000024
a11	6,500000000	3,369999886	0,629999995
a12	8,329999924	4,869999886	1,789999962
a13	11,760000…	2,650000095	1,399999976
a14	7,599999905	4,449999809	0,730000019
a15	8,350000381	5,650000095	1,429999948
a16	8,229999542	4,360000134	1,100000024
a17	7,480000019	5,900000095	1,379999995
a18	6,739999771	4,059999943	0,750000000
a19	10,020000…	4,969999790	1,399999976
a20	7,429999828	3,720000029	0,870000005
a21	7,789999962	4,079999924	0,579999983
a22	8,500000000	2,910000086	0,819999993
a23	10,470000…	3,380000114	1,100000024
a24	5,500000000	3,599999905	0,340000004
a25	7,309999943	4,900000095	1,190000057
a26	7,769999981	1,700000048	0,490000010

Figure A.3: Performance Table for model of g_4 of 2019



[Parameter]	g41	g42	g43
k	60.61	24.24	15.15
qᵅ	Ø	Ø	Ø
qᵝ	0.05	0.01	0.01
pᵅ	Ø	Ø	Ø
pᵝ	0.1	0.05	0.03
vᵅ	Ø	Ø	Ø
vᵝ	Ø	Ø	Ø
Direction	Minimize	Minimize	Minimize
Thresholds	Constant	Constant	Constant

Name	Description
C5	
b5	
C4	
b4	
C3	
b3	
C2	
b2	
1	
b1	

[Alternati…	g41	g42	g43
Extent	7,500000000	7,500000000	1,450000048
b1	7,500000000	7,500000000	1,500000000
b2	5,000000000	5,000000000	1,000000000
b3	2,500000000	2,500000000	0,500000000
b4	1,000000000	1,000000000	0,250000000
b5	0,000000000	0,000000000	0,050000001

Figure A.4: Decision configurations for the model of g_4

Appendix B

This section presents the results of Sensitivity Analysis on the Credibility Level and the Criteria Weight.

Changing the Credibility Level

Table B.1: Sensitivity Analysis results on Credibility Level

Action	λ=0,75		λ=0,65		λ=0,55	
	Pessimist	Optimist	Pessimist	Optimist	Pessimist	Optimist
a_1	C_1	C_4	C_1	C_4	C_1	C_4
a_2	C_1	C_4	C_1	C_4	C_1	C_4
a_3	C_1	C_4	C_1	C_4	C_1	C_4
a_4	C_1	C_4	C_1	C_4	C_1	C_4
a_5	C_1	C_4	C_1	C_4	C_1	C_4
a_6	C_1	C_4	C_1	C_4	C_1	C_4
a_7	C_1	C_4	C_1	C_4	C_1	C_4
a_8	C_1	C_4	C_1	C_4	C_1	C_4
a_9	C_1	C_4	C_1	C_4	C_1	C_4
a_{10}	C_2	C_5	C_2	C_5	C_2	C_5
a_{11}	C_1	C_4	C_1	C_4	C_1	C_4
a_{12}	C_1	C_4	C_1	C_4	C_1	C_4
a_{13}	C_1	C_4	C_1	C_4	C_1	C_4
a_{14}	C_1	C_4	C_1	C_4	C_1	C_4
a_{15}	C_1	C_4	C_1	C_4	C_1	C_4
a_{16}	C_1	C_4	C_1	C_4	C_1	C_4
a_{17}	C_1	C_4	C_1	C_4	C_1	C_4
a_{18}	C_1	C_4	C_1	C_4	C_1	C_4
a_{19}	C_1	C_4	C_1	C_4	C_1	C_4
a_{20}	C_1	C_4	C_1	C_4	C_1	C_4
a_{21}	C_1	C_4	C_1	C_4	C_1	C_4
a_{22}	C_1	C_4	C_1	C_4	C_1	C_4
a_{23}	C_1	C_4	C_1	C_4	C_1	C_4
a_{24}	C_1	C_4	C_1	C_4	C_1	C_4
a_{25}	C_1	C_4	C_1	C_4	C_1	C_4
a_{26}	C_1	C_4	C_1	C_4	C_1	C_4

Changing the Weights of the Criteria

Table B.2: Sensitivity Analysis Results on Weights

Action	Model A		Model B		Model C	
	Pessimist	Optimist	Pessimist	Optimist	Pessimist	Optimist
a_1	C_1	C_4	C_1	C_4	C_1	C_4
a_2	C_1	C_4	C_1	C_4	C_1	C_4
a_3	C_1	C_4	C_1	C_4	C_1	C_4
a_4	C_1	C_4	C_1	C_4	C_1	C_4
a_5	C_1	C_4	C_1	C_4	C_1	C_4
a_6	C_1	C_4	C_1	C_4	C_1	C_4
a_7	C_1	C_4	C_1	C_4	C_1	C_4
a_8	C_1	C_4	C_1	C_4	C_1	C_4
a_9	C_1	C_4	C_1	C_4	C_1	C_4
a_{10}	C_2	C_5	C_2	C_5	C_2	C_5
a_{11}	C_1	C_4	C_1	C_4	C_1	C_4
a_{12}	C_1	C_4	C_1	C_4	C_1	C_4
a_{13}	C_1	C_4	C_1	C_4	C_1	C_4
a_{14}	C_1	C_4	C_1	C_4	C_1	C_4
a_{15}	C_1	C_4	C_1	C_4	C_1	C_4
a_{16}	C_1	C_4	C_1	C_4	C_1	C_4
a_{17}	C_1	C_4	C_1	C_4	C_1	C_4
a_{18}	C_1	C_4	C_1	C_4	C_1	C_4
a_{19}	C_1	C_4	C_1	C_4	C_1	C_4
a_{20}	C_1	C_4	C_1	C_4	C_1	C_4
a_{21}	C_1	C_4	C_1	C_4	C_1	C_4
a_{22}	C_1	C_4	C_1	C_4	C_1	C_4
a_{23}	C_1	C_4	C_1	C_4	C_1	C_4
a_{24}	C_1	C_4	C_1	C_4	C_1	C_4
a_{25}	C_1	C_4	C_1	C_4	C_1	C_4
a_{26}	C_1	C_4	C_1	C_4	C_1	C_4

Appendix C

This appendix presents the auxiliary tables of the robustness analysis.

Table C.1: Variation of the values of the Veto Thresholds for the Robustness Analysis

$veto$	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11
$\boldsymbol{v}\ (\times\ \mathbf{1})$	2500	1000	0,05	Ø	10	5	5	5	250	500	0,5
$\boldsymbol{v}\ (\times\ \mathbf{2})$	5000	2000	0,1	Ø	20	10	10	10	500	1000	1
$\boldsymbol{v}\ (\times\ \mathbf{4})$	10000	4000	0,2	Ø	40	20	20	20	1000	2000	2

Table C.2: Variation of the values of the Weights for the Robustness Analysis

Weights	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
Z=2	7,88	10,91	10,91	12,13	10,91	9,69	9,69	6,06	7,88	6,06	7,88
Z=3	7,27	11,82	11,82	13,63	11,82	10	10	4,55	7,27	4,55	7,27
Z=4	6,91	12,36	12,36	14,55	12,36	10,18	10,18	3,64	6,91	3,64	6,91

Table C.3: Optimist Perspective in Assignment Procedure of Robustness Analysis

Action	$v\ (\times 1)$									$v\ (\times 2)$									$v\ (\times 4)$								
	$\lambda = 0,75$			$\lambda = 0,65$			$\lambda = 0,55$			$\lambda = 0,75$			$\lambda = 0,65$			$\lambda = 0,55$			$\lambda = 0,75$			$\lambda = 0,65$			$\lambda = 0,55$		
	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$
a_1	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_2	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_3	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_5	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_6	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_2	C_2
a_7	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_8	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2
a_9	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{10}	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_5	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3
a_{11}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_2	C_3	C_2	C_2
a_{12}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_4	C_4	C_4	C_3	C_3	C_2	C_3	C_2	C_2
a_{13}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2
a_{14}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_4	C_4	C_4	C_2	C_2	C_2	C_2	C_2	C_2
a_{15}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{16}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2
a_{17}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{18}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_4	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{19}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2
a_{20}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{21}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_4	C_4	C_4	C_3	C_3	C_3	C_2	C_2	C_2
a_{22}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3
a_{23}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_4	C_4	C_4	C_3	C_3	C_3	C_2	C_2	C_2
a_{24}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{25}	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{26}	C_5	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_4	C_3	C_3	C_3	C_3	C_3	C_3

Table C.4: Pessimist Perspective in Assignment Procedure of Robustness Analysis

Action	$v\ (\times 1)$									$v\ (\times 2)$									$v\ (\times 4)$								
	$\lambda = 0,75$			$\lambda = 0,65$			$\lambda = 0,55$			$\lambda = 0,75$			$\lambda = 0,65$			$\lambda = 0,55$			$\lambda = 0,75$			$\lambda = 0,65$			$\lambda = 0,55$		
	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$	$z = 2$	$z = 3$	$z = 4$
a_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_2	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_3	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_4	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_5	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_2
a_6	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_7	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_8	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_1	C_1	C_2	C_2	C_2
a_9	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{10}	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_3	C_3	C_3	C_3	C_3	C_3	C_2	C_2	C_2	C_3	C_3	C_3	C_3	C_3	C_3
a_{11}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{12}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{13}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{14}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{15}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{16}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{17}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{18}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{19}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{20}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{21}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{22}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2
a_{23}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{24}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{25}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1
a_{26}	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_1	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2	C_2