A multicriteria classification approach of energy efficiency governance in the European Union

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Abstract

Energy efficiency was brought into the world's policy agenda due to its significant effects toward attaining a sustainable energy future along. Since the European Union wants to lead the clean energy transition, it has been presenting ambitious targets for energy efficiency improvement. In 2014, the established target for 2020 on energy efficiency was 20%. However, it is likely that this goal will not be achieved. For this reason, it is necessary to rethink the current strategy to a more effective implementation plan. This dissertation intends to build and develop a Multi-Criteria Decision Aiding Method (MCDA) to assess the current governance capacities on energy efficiency of the 28 members states of the European Union. The literature review chapter explores what has been developed on energy efficiency governance and introduces the MCDA methodology, in particular the ELECTRE TRI-nC method. After gathering all data, the evaluation criteria are defined, and a set of parameters are chosen in order to execute the ELECTRE TRI-nC method. In the end, each country is classified according to its current governance efforts on energy efficiency into a set of pre-defined categories, which will be sustained by a sensitivity analysis.

Keywords: Energy Efficiency, Governance, European Union, Multi-Criteria Decision Aiding Methodology (MCDA), ELECTRE TRI-nC

Resumo

A eficiência energética surgiu na agenda política mundial devido aos seus efeitos significativos no alcance de um futuro energético sustentável. Visto que a União Europeia quer liderar a transição para uma energia limpa, esta tem vindo a apresentar objetivos ambiciosos para a melhoria da eficiência energética. Em 2014, estabeleceu o objetivo de melhoria para 2020 de 20%. Contudo, é provável que este objetivo não seja atingido. Por esta razão, é necessário repensar a estratégia atual para um plano de governança mais eficaz. Esta dissertação tem o objetivo de construir e desenvolver um método Multicritério de Apoio à Decisão (MCDA) para avaliar as capacidades atuais de governança de eficiência energética dos 28 estados membros da União Europeia. O capítulo da revisão de literatura explora o que tem vindo a ser desenvolvido no âmbito da governança em eficiência energética e introduz uma metodologia MCDA, em particular o método ELECTRE TRI-nC. Depois da obtenção dos dados, os critérios de avaliação são construídos e um conjunto de parâmetros é definido de forma a aplicar o método ELECTRE TRI-nC. No final, cada país é classificado de acordo com os seus esforços de governança em eficiência energética, em categorias pré-definidas que serão sustentadas por uma análise de sensibilidade.

Palavras-chave: Eficiência Energética, Governança, União Europeia, Metodologia de Apoio à Decisão Multicritério, ELECTRE TRI-nC

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List of Abbreviations and Acronyms

EC – European Commission

EE – Energy Efficiency

EED – Energy Efficiency Directive

EPV – Elementary Point of View

EU – European Union

FPV – Fundamental Point of View

GDP – Gross Domestic Product

GHG – Greenhouse Gas

IEA – International Energy Agency

MCDA – Multicriteria Decision Analysis

MS – Member States

NEEAP - National Energy Efficiency Action Plans

PPP - Purchasing Power Parity

SME – Small and Medium Enterprises

TFC – Total Final Consumption

TPES – Total Primary Energy Supply

WEC - World Energy Council

1. Introduction

1.1. Introduction to the Problem

There is not a commonly-accepted definition of energy efficiency (EE). The International Energy Agency (IEA) explains in its glossary that "something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input". The European Commission (EC) defines EE, in the Energy Efficiency Directive (EED), as the ratio of output of performance, service, goods or energy, to input of energy.

The main reason why EE was brought into the world's policy agenda was its significant effects towards attaining a sustainable energy future. Its benefits have been recognized over the last decades, especially since the late 1970s and the beginning of the 1980s, due to the oil crisis that led nations to plan new ways to sustain their needs and secure the necessary energy supply (Pereira, 2014). Indeed, technological change is the main reason for the decrease of energy consumption (considering constant demand), but it can also be improved through better organization, better management resources or even by better economic conditions in the sector (non-technical factors).

The improvement of EE might lead to the attainment of many goals, such as the reduction of energy costs, the increase of competitiveness, the support of innovation and the promotion of welfare. Therefore, it continues to gain attention as a key resource for economic and social development across all economies (IEA, 2014). EE is also a great cost-effective and readily available way to address many energy-related issues as it contributes to the sustainability of economic, environmental and social aspects (IEA, 2014). For these reasons EE was referred to as "first fuel with large untapped potential" in the *Capturing the Multiple Benefits of Energy Efficiency* report (IEA, 2014).

EE can also be regarded as a strategy to reduce greenhouse gas (GHG) emissions and its dangerous impacts. The reduction of GHG emissions can be mainly attained through the following situations: either due to the reduction of fossil fuel consumption or the increase of share of renewable energy sources in the energy mix of the countries. In addition, integrated solutions where EE and renewable energy work together deliver clean energy outcomes at the lowes cost (IEA, 2017a). According to the Market Report Series 2017 on EE by the IEA, the global energy intensity has declined at an average rate of 2.1% per year since 2010. This means that the world is able to produce more Gross Domestic Product (GDP) per each unit of energy consumed, which contributes strongly to the flattening of global energy-related GHG emissions (IEA, 2017a). In fact,since both EE and renewable energy sources lead to a decrease of the overall energy demand and of the dependence of fossil fuelsthese are regarded as the "twin pillars" of sustainable energy policy, along with renewable energy (Makridou, 2016).

Its benefits can be caused directly or indirectly (IEA, 2014). Directly, the main and the most obvious benefit is the energy savings. All these benefits could be also categorized according to the nature or character of their impact, their temporal scale and type of beneficiaries. There are four main levels of society that will be influenced: individual, sectoral, national and international.

Individual benefits are, for instance, the improvement of health and wellbeing, affordability, energy access and the increase of disposal income. Job creation, decrease of energy-related public expenditures and energy security are national level benefits, while industrial productivity, competitiveness, increased asset values and macroeconomic effects belong to sectoral level. The reduction of GHG emissions is probably one of the most important international benefit, but it also brings other effects as moderation of energy prices and better natural resource management (IEA, 2014).

To conclude, EE is an important element of the public policy agenda in industrialized countries and creates many beneficial impacts to society. However, the current plans of EE improvement show a great potential that it is not being totally explored.

1.2. Objectives of the Dissertation

The objective of this dissertation is to develop an MCDA model that will assess the EE governance capacities of the 28 countries of the European Union (EU).

The EC aimed to reach a 20% of improvement on EE until 2020, but recent projections predict that it will be improbable to achieve it (EC, 2017). With the foregoing in mind, it is important to understand how to develop a better strategy in order to ensure that targets are accomplished. So far, there are common goals for all 28 Member States (MS) and strategies that are developed individually. Indeed, different countries might contribute at different levels for the common objective due to their own and unique contexts, but the individual strategies must be aligned with each other. A starting point of this analysis is the evaluation of EE governance current efforts of all 28 countries. This evaluation will facilitate the identification of gaps, that will clarify which direction must be taken for the future strategies. In this way, it will be possible to develop more effective plans on EE improvement. This assessment will be operationalized through the ELECTRE TRI-nC method that will sort the 28 MS in predefined categories ordered by preference. This attribution will be supported by the performance of the countries in a set of defined criteria that will reflect their current efforts in the different areas of EE governance.

1.3. Phases of the Dissertation development

The approach followed is divided in five main steps.

The first step consists in the Problem Definition, which includes the energy sector context, a brief description of the current market trends that justifies the important role of EE, the main issues associated with EE and the current efforts made by the EU on this matter.

The second step is the Literature Review that focus on two topics that concern the presented problem: (1) EE governance, considering its theoretical frameworks and related issues; and, (2) Multiple Criteria Decision Aiding (MCDA) methods, since these are the type of methods used in the framework of this disseration, namely the method ELECTRE TRI-nC.

The third step consists in the development of the model by defining the dimensions to assess in each country regarding its EE governance capabilities. This phase will be developed based on two main inputs - the EE governance framework presented in the Literature Review and the available public data on the considered dimensions.

The fourth step will be the testing and validation of the developed model and the analysis of the results. A sensibility analysis will also be performed.

The last step will be the presentation of the final conclusions and some recommendations for future studies related to the presented topic and approach.

1.4. Structure of the Dissertation

This thesis is divided into six chapters:

- The first chapter introduces the study to be developed, its main objectives and its structure.
- The second chapter presents the context of the energy sector, its current trends, the specific problem to be analysed and the current efforts and challenges that the EU has been developing on the topic of EE improvement.
- The thirds chapter presents the Literature Review that focus on EE governance and introduces the MCDA methods, as well as their features that justify the utilization on the presented problem.
- The fourth chapter introduces the formal model and explains the rational on the criteria that will support the assessment. The Areas of Concern, the Fundamental Points of View and the Elementary Points of View are defined, the scales for evaluation of each criterion are constructed and the performances of the 28 countries are defined. Note that there are two considered performances of each MS, one related to the year of 2013 and another to 2016 in order to identify a possible evolution of the governance capacities during this period.
- The fifth chapter consists in the operacionalization of the model and the analysis of the results. This will be done throught the use of the software MCDA Ulaval which allows running the method ELECTRE TRI-nC.
- The sixth and last chapter exposes the final considerations, conclusions and recommendations for future studies on this topic.

2. Problem Definition

This chapter introduces the problem and its context. It starts with a brief explanation of the main concepts of the Energy Sector, followed by a description of issues associated with EE that shall be considered in the future analysis. It concludes with an explanation of the current efforts in the EU on EE improvement.

2.1. Introduction of the Energy Sector

The energy sources that are found in nature, by extraction or by capture are denominated primary energy and may be divided into three categories: fossil fuels, nuclear and renewables. Examples of fossil fuels are crude oil, hard coal and natural gas, all of them being non-renewable sources (OECD, 2015). On the contrary, renewable energy comes from sources that replenish (or renew) themselves naturally. Solar, wind, hydropower, geothermal resources and biomass are the main examples of this type of sources (Eurostat, 2017). All energy commodities that are produced from primary commodities are termed as secondary commodities or energy carriers. Electricity, when is generated by burning fuel (for instance), is an example of a secondary commodity (OECD, 2015).

In a specific country, the sum of its energy production and its energy imports, subtracting its exports and stock changes, is called the total primary energy supply (TPES) (IEA, 2017b). In other words, it is the total amount of available energy, even though it is not totally consumed as useful energy. The amount of energy that is useful is given by the total final consumption (TFC), that is calculated as the sum of consumption by the different end-use sectors in a country (IEA, 2017c). Another essential concept to understand the dynamic of the energy sector is the energy mix. The energy mix is the combination of the various primary energy sources used to meet the energy needs of a given geographic region (Planete Energies, 2015a). Naturally, the energy mix of a region depends on several factors, specifically: (1) the availability of usable resources domestically or the possibility of importing them; (2) the extent and type of energy needs to be met; and, (3) the policy choices determined by historical economic, social, demographic, environmental and geopolitical factors (Planete Energies, 2015a).

2.2. Energy Market Trends

The global energy landscape is changing, and the energy demand is growing at a high rate.

The world economy is expected to double over the next twenty years, with an average growth of 3.4% at Purchasing Power Parity (PPP) exchange rates (BP, 2017). The growth is largely driven by increases in productivity, but also by the growth of global population, that is projected to reach nearly 8.8 billion people by 2035 (BP, 2017). Much of the expected growth of the global economy is driven by emerging economies, where China and India account for around half of the increase (BP, 2017).

The growth of global economy will lead to more energy consumption, as depicted in Figure 1.

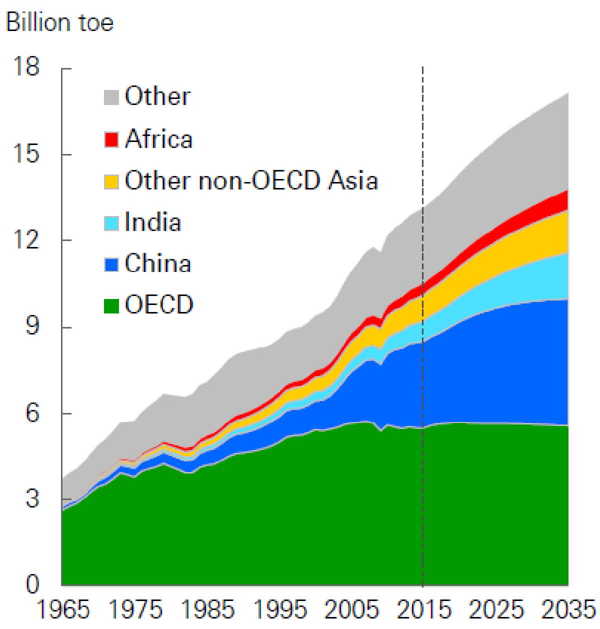


Figure 1: Energy consumption by region from 1965 until 2015 and predictions until 2035 (Source: *BP, 2017*)

At the same time the fossil fuels (coal, oil and gas), which are the most consumed energy sources, are limited. Concerns with the depletion of fossil fuels have persisted for decades, an example is the Hubbert's Peak Theory. During the 1979 oil crisis, Hubbert incorrectly predicted that the world would reach a 'peak oil' around the year 2000. This prediction was followed by many premature forecasts. The uncertainty of such predictions is mainly driven by the discovery of new reserves and technological developments (Our World in Data, 2017). According to these theories, an indicative estimate of how long fossil fuels could feasibly be consumed is the Reserves-to-Production (R/P) ratio for coal, oil and gas. The R/P ratio essentially divided the quantity of known fuel reserves by the current rate of production to estimate how long we could continue if this level of production remained constant. Based on BP's Statistical Review of World Energy 2016, as it is today, coal production would last about 115 years, while oil and natural gas would last around 50 years (Figure 2).

Today it is known that these resources will not run out as Hubbert predicted, however this uncertainty creates a great deal of instability regarding the future.

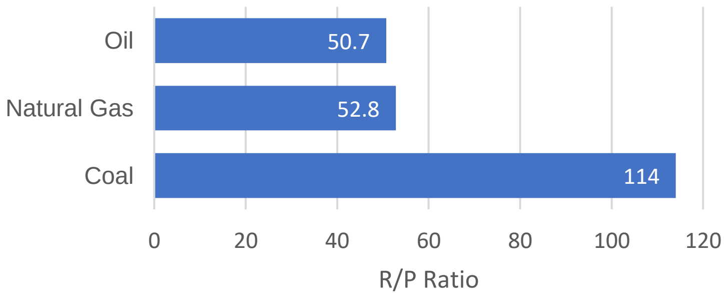


Figure 2: Years of fossil fuel reserves left (Adapted from *Our World in Data, 2017*)

Adding some more complexity to the problem, there are three seemingly conflicting objectives that are important for the sustainability of the energy sector (Planete Energies, 2015b):

- Energy security: Corresponds to the reliability of the energy supply ensuring to meet the current and future demand;
- Energy equity: Corresponds to the accessibility of energy around the world at an affordable cost;
- Environmental sustainability: Due to global warming effects, it is crucial to improve the efficiency of energy systems and to develop renewable and low GHG energy sources.

Indeed, the latter objective is currently the major concern and the most discussed topic. Either way, it is clear that the current *status quo* is not sustainable and that a shift on the current energy production and consumption systems is necessary.

The global energy mix has been transformed in the past with the introduction of coal in the 19^{th} century and oil in the 20^{th} century, but the past changes were always about additions of new energy forms, rather than replacements. It is also important to mention that there is no single ideal global energy mix (energy transition is specific for each region) and that energy systems take a long time to change since these transformations require technological breakthrough and radical changes by the final consumers to support them (Planete Energies, 2015b).

2.3. Energy Efficiency

This section focuses on issues that are associated with EE, and therefore, must be considered in the future analysis.

2.3.1. Barriers

The EE barriers are the mechanisms that inhibit a decision or behaviour that appears to be both energetically and economically efficient (Makridou, 2016). Barriers can either complicate the adoption of cost-effective EE technologies or slow down their diffusion. Some examples of these barriers are high investment cost, lack of funding and lack of awareness (Makridou, 2016).

There are several proposals for the categorization of EE barriers. The proposal of IEA (2010)is detailed in Table 1. Makridou (2016) divides EE barriers into two groups: structural (for instance, distortion in fuel prices, uncertainty about the future or government policies) and behavioural barriers (for instance, the perceived risk of EE investments, lack of information or lack of life-cycle thinking on the costs and savings). Pereira (2014) presentes a categorization model dividing EE barriers into three types: (1) technical system barriers, associated with technology and related costs; (2) technological regime barriers, based on human influence combined with the corresponding technology; and, (3) socio-technical regime barriers, strongly based on human factors.

Barrier	Examples
Market	- Market organisation and price distortions prevent customers from appraising the true value of EE - Split incentive problems created when investors cannot capture the benefits of improved efficiency
Financial	- Up-front costs and dispersed benefits discourage investors - Perception of EE investments as complicated and risky - Lack of awareness of financial benefits on the part of financial institutions
Information and awareness	- Lack of information and understanding to make rational consumption and investment decisions on the part of consumers
Regulatory and institutional	- Energy tariffs that discourage EE investment - Incentive structures encourages energy providers to sell energy rather than invest in cost-effective EE - Institutional bias towards supply-side investments
Technical	- Lack of affordable EE technologies suitable to local conditions - Insufficient capacity to identify, develop and implement and maintain EE investments

Table 1: Examples of barriers, adapted from IEA (2010)

2.3.2. Rebound Effect

Another important challenge in EE policy is the phenomenon known as 'rebound effect'. This effect occurs when EE is used to obtain more energy services rather than achieving energy demand reduction (IEA, 2014). Some benefits can come associated with an energy consumption price tag, just like when an improved energy affordability leads to an increase consumption of heating (IEA, 2014). Technological development creates more efficient equipment. Given that less energy is needed to obtain the same level of energy service (using the same equipment), the unitary costs of the service diminishes. This price decrease tends to lead consumers to spend more and increase the total energy consumption (Pereira, 2014). This effect can be explained by the behavioural and economic response to EE improvement.

However, this effect is still an under-researched and controversial topic. In countries with a big share of energy-intensive activities, the rebound effect may often be desirable since it enables the economy to capitalize further on its energy resources. It is important to be aware of any potential rebound effect and take it into account when calculating the actual energy demand reductions (for instance, GHG emissions reductions tied to lower electricity generation) (IEA, 2014).

2.3.3. EE Gap

Another misleading situation in the EE field is the difference between the cost-minimizing level of EE and the level of EE accomplished, known as the 'EE gap' or 'EE paradox' (Pereira, 2014). This consists in the difference between the technical feasible and economically viable improvements and the actual level of investment on those. This gap results in the potential efficiency improvement that is not accomplished due to barriers in the energy market (Pereira, 2014). This gap can be more complex than it sounds, and it might be related with the fact that people do not always make rational decisions (due to the lack of knowledge or the uncertainty about the effectiveness of the measures). For instance, if a renter decided about the energy use and pays the bills while the owner decides about the installed equipment (and chooses the cheapest alternative), the most cost-efficient combination will probably not be chosen. Although the literature trying to quantify this gap has been prolific over the last decade, its magnitude remains unclear (Makridou, 2016).

2.3.4. Measuring EE

Due to the lack of precise indicators of EE, energy intensity is usually used as a *proxy* of EE trends.

There are two main types of energy intensity: primary energy intensity, which is measured as TPES per unit of GDP); and, final energy intensity, which is measured by TFC per unit of GDP. TFC intensity may better reflect trends in end-use EE than TPES intensity because it excludes losses of fuel conversion in power generation. However, primary energy data are usually available earlier and are generally more reliable. Therefore, TPES intensity is more relevant to monitor overall energy demand and related GHG emissions (REN, 2017).

The main reason why energy intensity is not a precise EE indicator is because it is affected by other variables besides EE, such as structural changes in the economy and changes in the energy mix. In order to isolate EE from activity and structural effects it is required detailed data that are usually not available (REN, 2017).

2.4. EE in the EU

In October 2014 the European Council presented the 2030 Framework for climate and energy. This framework includes EU-wide targets and policy objectives until 2030. The established targets are (EC, 2018f): (1) a 40% cut in GHG emissions compared to 1990 levels; (2) at least a 27% share of renewable energy in the final consumption (target established in 2014); (3) at least 27% of EE improvement at EU level compared to projections; and, (4) support the completion of the internal energy market by achieving the existing electricity interconnection target of 10% by 2020 (EC, 2018f). These targets were based on an economic analysis with the focus on the achievement of decarbonization by 2050 in a cost-effective way. They were also meant to help the EU achieve a more competitive, secure and sustainable energy system (EC, 2018f).

Another objective of this strategy is to send a strong signal to the market promoting private investment in new pipelines, electricity networks and low-carbon technology. Besides, one of the proposed objectives on policy is to design a new governance system based on national plans for competitive, secure and sustainable energy, that follows a common EU approach and ensures stronger investor certainty, greater transparency, enhanced policy coherence and improved coordination across the EU (EC, 2018f).

In this context, EC released a package of measures called 'Clean Energy for all Europeans' on the 30th of November 2016 with the goal of creating a stable legislative framework to facilitate the clean energy transition. The EC wants the EU to lead the clean energy transition, and not only to adapt to it (EC, 2016a). The 'Clean Energy for All Europeans' package aims to enable EU delivering its Paris Agreement commitments and to help the EU energy sector become stable, competitive and sustainable. The three main goals of the package are (EC, 2018e):

1. Putting energy efficiency first;
2. Achieving global leadership in renewable energies;
3. Providing a fair deal for consumers.

The first goal includes different EE measures that focus on four main points (EC, 2016b):

1. Setting the framework for improving EE in general;
2. Improving EE in buildings;
3. Improving the EE performance of products (Eco-design) and informing consumers (energy labelling);
4. Financing of EE with smart finance for smart buildings proposal.

A clear signal of the EC commitment on this issue is the rising of the binding EU-wide target of 30% for EE by 2030 (EC, 2017) (which was previously set at 27% in 2014 (EC, 2018f)). With this aim, the review of the EE legislation unlocks the energy savings that boost growth in the EU's economy, investments and job creation, while the established target will reduce the EU's fossil fuel import bill (EC, 2016b).

There are many direct and tangible benefits that EE improvement brings for the different stakeholders in the European energy system. Firstly, the consumers will rapidly realise its impact on lowering their energy bill. They will have a clearer and more frequent information about the energy consumed. EE also addresses social imbalances in energy access, since the performance on buildings has a major impact on affordability of housing and energy poverty and has a positive impact on health, and the related costs (since efficient heating installations burn fewer fossil fuels and emit fewer air pollutants, thus improving air quality) (EC, 2016b). In Industry, EE is a vast and growing business opportunity with a huge untapped potential. The revised EED and the revised Energy Performance of Buildings Directive will significantly contribute to the competitiveness of European industry by increasing their market by 23.8 billion in the EU by 2030 and creating a building renovation market for Small and Medium Enterprises (SME) with a value between €80-120 billion (EC, 2016b). Regarding jobs, the whole 2030 energy and climate package could boost the EU's GDP by up to 1% by 2030, adding €190 billion into the EU's economy and creating up to 900,000 new jobs (EC, 2016b). Finally, EE is also one of the most cost-effective ways to ensure energy security (EC, 2016b).

2.4.1. Energy Efficiency Directive

Initially, in 2012 the EED established a set of binding measures to help the EU reach its 20% EE target by 2020. All EU countries are under this Directive and are required to use energy more efficiently at all stages of the energy chain, from production to final consumption. On the 30th of November 2016 the EC proposed an update to the EED to fit the new target of 30% improvement by 2030 (EC, 2017).

The Directive is structured in five chapters (EC, 2012):

- Chapter I: Subject matter, scope, definitions and energy efficiency targets (Articles 1 to 3);
- Chapter II: Efficiency in Energy Use (Articles 4 to 13);
- Chapter III: Efficiency in Energy Supply (Articles 14 and 15);
- Chapter IV: Horizontal Provisions (Articles 16 to 21);
- Chapter V: Final Provisions (Articles 22 to 30).

The first chapter establishes what are the objectives and who is under the requirements of this document. Additionally, it exposes the definitions of all relevant concepts on the topic and sets the base lines that enable MS establish and calculate their own targets (EC, 2012).

The second chapter appoints the several actions that MS shall plan and implement regarding the use of energy in their territories. Article 4 states that all MS shall develop a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings (public and private). Articles 5 and 6 set reference actions for public bodies' energy use, specifically on buildings and on all products and services purchased by public entities. Article 7 establishes that all MS shall set up an EE obligation scheme aiming to achieve energy savings through energy distributors and energy sales companies. Article 8 states the minimum requirements that all MS shall fulfil regarding energy audits and energy management, while Articles 9, 10 and 11 focus on metering and billing requirements. Article 12 indicates that MS shall promote consumer information and empowering programmes in order to facilitate an efficient use of energy by small energy consumers. In case of non-compliance, MS shall lay down the rules on penalties as stated in Article 13 (EC, 2012).

Chapter III presents two articles related to the efficiency on the supply side. Article 14 promotes the development and improvement of the potential of the application of high-efficiency cogeneration and efficient district heating and cooling. Article 15 ensures that national energy regulatory authorities develop a network of tariffs and regulations to provide incentives for grid operators for the implementation of actions on EE improvement (having as final objective the deployment of smart grids) (EC, 2012).

Chapter IV states several actions to support the entire EE improvement ecosystem. Article 16 focuses on qualification, accreditation and certification schemes, while Article 17 focuses on the promotion of clear and transparent information and training availability. Article 18 sets minimum requirements for the promotion of competitive energy services for small and medium enterprises (SME), and Article 19 elaborates on possible extra measures that MS shall deploy to complement their EE governance set. Article 20 approaches the establishment of national financing facilities for EE purposes. Finally, Article 21 refers to the conversion factors to be used in the calculation of energy savings (EC, 2012).

Chapter V concludes the document with final provisions on the implementation of the previous stated articles (EC, 2012).

2.5. Current Targets and Other Measures

The established target of 20% improvement on EE by 2020 will likely not be achieved, being the expected improvement until then only around the 18% or 19% (Euractive, 2014). Plus, on the 14th of June 2018, the EC reached a political agreement with the Parliament and the Council, which includes a binding EE target for the EU for 2030 of 32.5%, with a clause for an upwards revision by 2023 (EC, 2018d). Considering that the first targets probably will not be achieved when expected and that the 2030 target has risen, there is a great challenge to face in the European energy sector by all actors involved. More than ever, it is important to analyse the situation and understand all the possible solutions that present great potential of EE improvement.

The building sector presents a great deal of EE potential. Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU (EC, 2018c). Currently, about 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient, while only 0.4% to 1.2% (depending on the country) of the building stock is renovated every year (EC, 2018c). For this reason, the renovation of existing buildings presents a potential to lead to significant energy savings – potentially reducing the EU's total energy consumption by 5%-6% and lowering CO_2 emissions by about 5% (EC, 2018c). Besides the EED, the Energy Performance of Buildings Directive also promotes the improvement of the energy performance of buildings within the EU (EC, 2018c). Following the requirements in national building codes in line with this Directive, new buildings today consume only half as much as typical buildings from the 1980s (EC, 2018c).

There are also two instruments that focus on EE standards of everyday products: Energy Labelling framework Regulation and the Ecodesign Directive (EC, 2018b). EU energy labels help consumers choose energy efficient products. The labelling requirements are created under the EU's Energy Labelling framework Regulation, in a process coordinated by the EC (EC, 2018b). These regulations have been applied since the 1st of August 2017 and their implementation will be assessed by the EC by August 2025 (EC, 2018a). Also coordinated by the EC is the Ecodesigned Directive that aims to improve the EE of products and to eliminate the least performing products from the market. It also supports industrial competitiveness and innovation (EC, 2018b). The transpositions to national laws of all MS were concluded in June 2014 (EC, 2015). It is expected that these labels and standards will generate a yearly energy saving of around 175 Mtoe (million tonnes of oil equivalent) by 2020 (EC, 2018b).

2.6. Chapter Conclusions

Considering the difficult achievement of the current EE objectives, it is critical to plan and develop the tools to use. The combination of coordinated action by all relevant stakeholders at EU and national levels is critical. Therefore, a strong governance regarding EE is required to ensure coherency and complementarity in all policies and measures established. This chapter has provided a starting point for the study of EE governance frameworks, exposed on Chapter 3 on this document, which will support the EE governance capacity analysis of the 28 MS.

3. Literature review

This chapter explores the existing literature on two topics: the first part focuses on EE governance, while the second part introduces Multiple Criteria Decision Aiding (MCDA) methodology and presents the description of the chosen method that will be used in the following chapters – the ELECTRE TRI-nC.

3.1. Governance

This section is divided in three parts. The first part explores the definition of governance, while the second describes the existing literature on governance frameworks. The last part lists relevant studies and analysis made on the scope of EE governance.

3.1.1. Governance Definition

There is not a consensual concept of governance in literature (Jollands and Ellis, 2009). There is extensive literature on global and regional governance in several areas. However, there is a great lack of scholarly attention on the energy governance topic in spite of its extraordinary importance in current international affairs (Florini and Sovacool, 2009).

Florini and Sovacool (2009) define energy governance as "any of the myriad processes through which a group of people set and enforce the rules needed to enable that group to achieve desired outcomes". Jollands and Ellis (2009) defined EE governance as "the use of political authority, institutions and resources by decision makers and implementers to achieve improved EE". In 2011, Jollands *et al*. defined it as "the combination of legislative frameworks and funding mechanisms, institutional arrangements and co-ordination mechanisms, which work together to support implementation on EE strategies, policies and programmes".

Meyer-Ohlendorf *et al.* (2015) state that due to the lack of a formal definition of governance, the term remains vague and ambiguous, leaving ample room for interpretation. However, effectiveness, compliance, reporting and planning are considered central as governance issues.

3.1.2. Governance Frameworks

According to Turner (2015) an adequate governance framework for EE shall be in line with the principles of good governance, which are: (1) Effectiveness, by ensuring the achievement of agreed outcomes; (2) Transparency, concerning the energy market and the negotiation of intergovernmental energy agreements; (3) Accountability, through the existence of credible mechanisms for holding key actors; (4) Legitimacy, in order to ensure the meaningful participation by those affected by decision making; (5) Policy Coherence, through appropriate policy interventions; and, (6) Flexibility, to achieve the most appropriate balance in the negotiations.

According to Jollands and Ellis (2009), despite most of the current EE policies cover many sectors, most evaluations show that we are falling well short of its potential level. One reason that justifies this is that the estimation of potential tends to cover the whole economy (or large sectors), when policy measures only tends to be targeted towards smaller parts of the economy. Other reasons that also contributes to this problem are the EE gap (explained by the existing market barriers and market failures) and the 'rebound' effect. Jollands and Ellis state that the EE maximum potential in an economy will never be achieved if there is no understanding of the complete aligned governance framework, which is the central mechanism for marshalling drivers within the public and private sectors of an economy.

It is understandable why policy makers tend to focus on micro-level issues, since energy saving resources are widely spread amongst many individual actors in society and the existent barriers are very specific to particular sectors of the economy. Indeed, this micro-level EE policies have been quite successful on their sphere of influence, but there are still many gaps in policy coverage. This approach might be one strong reason why levels of EE typically do not improve rapidly as expected (Jolland and Ellis, 2009).

The level of a country's EE is the result of the interaction of wide range of variables addressing distinct concerns such associal, economic and environmental, so it is important that policy makers recognize that these complex and messy systems have unique features.

3.1.2.1. An EE Governance Framework

Jollands and Ellis (2009) proposed a broader and more holistic framework for EE governance assessment. Based on their combined experiences in EE policies, they identify a range of relevant issues covered by the governance concept:

- Foundations for governance, or in other words, the resources and structures required to establish a governance system:
    1. Institutional structure;
    2. Resources (people and finance);
    3. Human capacity and training;
    4. Political support/mandate.
- Governance activities, that refers to the actions that governance systems undertake:
    1. EE strategies to set direction and enable tools;
    2. Policy development processes that include the integration of EE with related climate change, social, economic and environmental policies;
    3. Mechanisms to fund EE;
    4. Monitoring EE programmes;
    5. Compliance and enforcement;
    6. Research and innovation.

Considering all these dimensions, Figure 5 shows a schematic outlining of the several dimensions of EE governance.

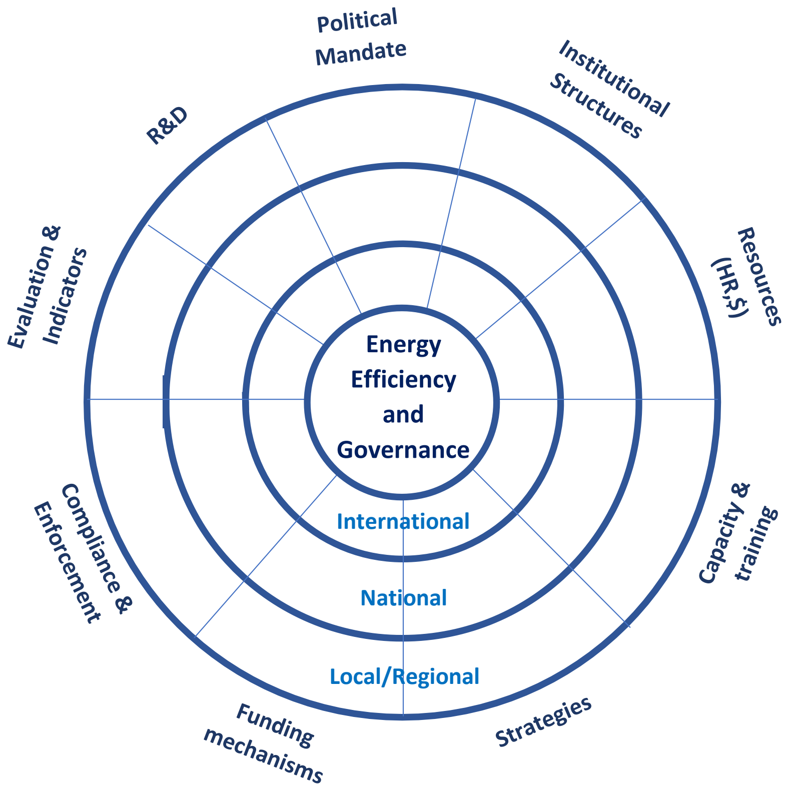


Figure 3: Schematic illustration of governance dimensions (adapted from Jollands and Ellis, 2009)

The concentric rings represent the various spatial levels and the segments represent the issues that are crucial to EE. Jollands and Ellis (2009) note that EE policy is not explicitly mentioned in this diagram, because this attempts to represent EE governance as the foundation on which EE policies are built and delivered. It is also important to notice that EE governance issues cannot be addressed without explicitly considering the policy mix.

Another purpose of this framework is to convey the interrelated aspects of the many dimensions of EE governance. For instance, a decision regarding an institutional structure at the national level can influence local actors and will also have implications on resource and human capacity requirements. For this reason, this scheme also demonstrates that these individual aspects cannot be tackled without explicitly contemplatingother dimensions (Jolland and Ellis, 2009).

3.1.3. Analysis on Energy Governance

Ringel (2018) analysed the impact of tele-coupling in the field of European climate and energy policy. The concept of tele-coupling describes physical connections and interdependencies between distant actors and regions. In this particular study, tele-coupling is defined as the outreach of not directly related actors across policy fields. A given example to explain this concept is the influence of soy bean demand in Europe on the producers in Brazil. Two types of interconnectivities were considered in this problem: (1) different policy fields; and, (2) different governance levels. Ringel (2018) identifies several barriers to the success of EE policies in Europe. One barrier consists in local actors being the ones who are delivering the objectives set by the EU which is translated into an absence of coordination mechanisms between all the actors of the different policy fields and governance levels. Local stakeholders (e.g., building insulations or up-take of efficient home appliances) make individual choices that are less determined in contributing to European targets due to the existence of the many EE barriers. That is why Ringel (2018) presents an analysis on finding a suitable multi-level governance structure to empower local actors and individual citizens to make better consumption choices. The validation process also showed that, apart from the "classical" coordination mechanisms which follow the legislative process in a multi-level governance setting, informal mechanisms (e.g., ad hoc meetings to discuss and exchange knowledge on policies and measures) play an increasingly important role. The final findings confirm the key role of formal vertical coordination structures e.g. coordination between the EU and MS), but also horizontal coordination (between entities at the same level) and, to a much larger extent, informal coordination mechanisms can help to align policies across several levels of governance and at spatial distance.

Delina (2012) defends that it must exist coherence between the current transformation of the energy systems and the governance of EE institutions. This paper, with a primarily descriptive nature (rather than analytical), presents a framework that builds on concepts encompassing three principal identifiers of coherence institutional governance: (1) Motivation: which looks on the context of the country (e.g., how the country puts primary importance on EE); (2) Capacity: which involves a dynamic and on-going process by which people and systems in the institution develop, operate and implement strategies to meet the objectives; and, (3) Interventions: which allows the reporting and evaluation of the programs and the set of activities conducted, promoted and implemented by the institution. However, it is important to note that institutions are socially constructed and thus can be hardly understood outside of their own contexts due to the relative importance of the various factors. There is not an ideal prescriptive approach to this matter for that reason.

Schlomann *et al.* (2014) explores the lack of clear definitions and common rules for the measuring of EE. The presented approach analyses the typical baseline formulations and the used accounting methods. In a political context, the change in EE of a system is often compared to the potential evolution of EE in the same system under different conditions, e.g. without EE policies in place. There are several baselines that can be meaningfully defined in a political context while the usual accounting methods contain a series of "adjustment settings" which may influence the degree of EE target achievement. The conclusion states that rigorous definitions should be used for formulating and monitoring EE targets in order to reach clear results.

Jollands *et al*. (2011) presented a study aiming to create the first comprehensive attempt to gather experience on EE governance throughout the globe. It also provides guidelines to governments and stakeholders interested in improving EE governance systems. The findings of this study are divided in three main areas: (1) Enabling frameworks, the basic building block of EE governance; (2) Institutional Arrangements, that provide the practical instruments by which EE policy is formulated and implemented; and, (3) Co-ordination Mechanisms to co-ordinate policy and programme implementation and to monitor the results. The conclusion of this study highlights that alternative governance mechanisms can achieve similar results and that each country presents its particular circumstances.

There are some case studies regarding EE governance with less conceptual approaches. Some examples are presented in the following paragraphs.

Santana and Bajay (2016) carried out a review of Brazilian industrial energy policies. After a detailed description of the most used instruments in energy policy worldwide and the current government actions to promote EE in the Brazilian industry, it was observed that the obtained results were quite limited. Still, several energy intensive industrial branches have large energy savings potential, both for electricity and heat. It was concluded that there were three main types of accessible measures to adopt in the short term that were not implemented yet, namely administrative measures, economic measures and improving the current informative policies.

Covary and Averesch (2013) presented an overview on energy policies in South Africa. In 2008, the country experienced rolling electricity blackouts, and since then the National Energy Efficiency Strategy has been revised to accelerate the development of EE policies and their implementation. This paper presented a methodology to assess the status of current policies in South Africa and identified several gaps, alignments and overlaps of the national energy system. A policy map was presented, reflecting the *status quo* of the EE landscape in the country.

Pereira and Silva (2017) developed a research to understand EE governance by analyzing a set of indicators covering aspects related to institutional, human, financial and political dimensions. This approach enables an analysis on the existing governance capacities, which represent the current level of support from areas that are crucial to the successful delivery of the planned EE improvements. These governance capacities serve as a *proxy* for the analysis of the existing support structures across the EU for the delivery of the EE targets. The methodology chosen was based on an adaptation of the framework presented by Jollands and Ellis (2009). In the end of the analysis, the 28 MS were divided in three clusters; (1) the Primary League cluster included the top-performing MS contributing to EE development; (2) the Secondary League corresponded to MS with a medium-low governance performance; and, (3) the Third League included the MS with low performance. Cyprus, Denmark and Italy were the countries in the Primary League, while Greece, Romania and Slovenia were classified as the Third League countries. All the others belonged to the Second League. These results allowed a more detailed perspective on the EU level and MS governance capacities. It was concluded that the disparities between individual MS governance capacities should be considered when devising and implementing future policies. Indeed, there is a need for a more robust governance monitoring and reporting system, including the development of transparent and comparable indicators and a more comprehensive assessment of the impact of good governance.

3.2. Multiple Criteria Decision Aiding

Multiple Criteria Decision Aiding (MCDA) copes with three main types of decision problems: ranking, sorting and choice. Ranking problems consist of rank ordering of all alternatives from the worst to the best looking at their evaluations on the considered criteria. The sorting problems consist in assigning each alternative to a predefined and preference ordered class. Finally, choice problems consist in selecting a subset of alternatives considered as the best (Corrente et al., 2013).

MCDA approaches may help to consider various levels of information, quantitative and qualitative and to take into account the subjective preferences of the decision maker (Figueiredo and Oliveira, 2009). The MCDA framework involves four typical stages: (1) Structuring, which concerns the formulation of the problem; (2) Evaluation, which consists on scoring and weighting of criteria. Scoring involves creating a model of intra-criteria preferences, that values the performance of different options for each criterion, while weighting involves the elicitation of the scaling constants that reflect the difference of attractiveness between criteria; (3) Testing, which consists in performing the sensitivity analysis and assessing robustness of the model; and, (4) Decision-making, where the choice of the alternatives takes place (Figueiredo and Oliveira, 2009).

Belton and Stewart (2002) emphasise the following points about MCDA:

- MCDA seeks to take explicit account of multiple, conflicting criteria in aiding decision making;
- MCDA process helps to structure the problem;
- The models used provide a focus and a language for discussion;
- The main objective is to help decision makers learn about the problem situation and their own and other values and judgements;
- The analysis serves to complement and to challenge intuition, acting as a sounding-board against which ideas can be tested. It does not seek to replace intuitive judgment or experience;
- The process leads to better considered, justifiable and explainable decisions;
- The most useful approaches are conceptually simple and transparent.

Considering the importance of the defined criteria in these methods, Bouyssou (1990) defines a criterion as "a real-valued function on the set A of alternatives, such that it appears meaningful to compare two alternatives a and b according to a particular point of view". The quality of the construction of a criterion is crucial for the quality of decision-aid. For Roy (1996) define three requirements regarding the relationships of criteria, which are: (1) Exhaustiveness, to avoid loss of information; (2) Cohesiveness, which deals with the compatibility that must exist between the role of each criterion when considering preferences; and, (3) Nonredundancy, or in other words, none of the criteria shall be considered redundant.

The meaning of "classification" in the scope of MCDA refers to the assignment of a set of alternatives described over a set of attributes (criteria) into predefined homogenous classes (Doumpos and Zopounidis, 2004). The developed model in this dissertation is an example of classification through an MCDA method, namely the ELECTRE Tri-nC from the ELECTRE methods family.

The word ELECTRE, in the ELECTRE methods, stands for *ELimination Et Choix Traduisant la REalité* (ELimination and Choice Expressing the REality). These aim to aid complex decision making and are particularly relevant in the following situations (Figueira et al., 2005):

- The decision maker wants to include in the model at least three criteria;

- Actions are evaluated on an ordinal scale or on a weak interval scale. These scales are not suitable for the comparison of differences;
- A strong heterogeneity related with the nature of the scales associated with the criteria exists, which makes it difficult to define a unique and common scale that could be used to substitute the original ones;
- Compensation of the loss on a given criterion by a gain on another one may not be acceptable for the decision maker. Therefore, these situations require the use of noncompensatory aggregation procedures;
- Existence of small differences of preferences may not be considered significant, therefore it is required the introduction of discriminating (indifference and preference) thresholds).

In this family of methods, where all of them derived from the ELECTRE I presented by Bernard Roy in the 60s, preferences are modeled by using binary outranking relations, which meaning states "*a is at least as good as b"*. These methods comprise two main procedures (Figueira et al., 2005):

- A multiple criteria aggregation procedure, allowing for the construction of one or several outranking relations aiming to compare in a comprehensive way each pair of actions;
- An exploitation procedure that leads to produce results according to the nature of the problem (choosing, ranking or sorting).

Particularly, the method ELECTRE TRI C is a method for sorting problems designed for dealing with decision aiding situations where each category from a completely ordered set is defined by a single characteristic reference action. This method was conceived to verify a set of natural structural requirements (conformity, homogeneity, monotonicity and stability) (Figueira et al., 2005). The ELECTRE TRI C was generalized to ELECTRE TRI-nC method where each category is defined by a set of several reference characteristic actions, rather than one. This feature is enriching the definition of each category and allows to obtain more narrow ranges of categories to which an action can be assigned to (Figueira et al., 2005). This last method is the one that will be used in the following chapters.

3.2.1. The Electre Tri-nC Method

Due to the multidimensional nature of reality, the chosen method must consider the multiplicity of factors, aspects and features during the decision aiding process. It must integrate different types of information, points of view, as well as the preferences of the decision makers. Finally, the chosen tool must also allow to describe, select, order or apply an ordinal classification to the objects of the decision (or actions) (Costa et al, 2016).

In MCDA, the family of ELECTRE methods is based on outranking relations (Costa et al, 2016), and presents two main components as previously stated - the construction phase of outranking relations, where actions are compared, and the exploration phase, that allows the elaboration of recommendations.

The method ELECTRE TRI-nC was the chosen to implement the presented problem. It is a sorting method composed by two joint rules (ascending and descending) that allow to select an interval of possible categories to characterize an action. This method might consider several reference actions to characterize each category (Costa et al, 2016).

3.2.1.1. Concepts, definitions and notations

Let $A = \{a_1, \ldots, a_i, \ldots\}$ denote the set of potential actions, which might be known *a priori* or progressively during the decision aiding process. The aim is to assign each of these actions to a set of completely ordered categories, $C = \{C_1, \ldots, C_h, \ldots, C_q\}$, with $q \geq 2$. Then, a coherent set of n criteria, $F = \{g_1, \ldots, g_j, \ldots, g_n\}$, with $q \geq 3$ is defined to evaluate any action considered to be assigned to a certain category. Note that if $n \geq 3$, the concept of concordance is not pertinent. The set of reference actions, $B = \{B_1, \ldots, B_h, \ldots, B_q\}$, allows to define the categories. The set $B_h = \{b_h^r,\ r = 1, \ldots, m_h\}$ is a subset of reference actions introduced to characterize category C_h, such that $m_h \geq 1$ and $h = 1, \ldots, q$. Let $B \cup \{B_0, B_{q+1}\}$ denote the set of $(q + 2)$ subsets of reference actions. The two extra subsets of reference actions, $B_0 = \{b_0^1\}$ and $B_{q+1} = \{b_{q+1}^1\}$, are defined as follows: $g_j(b_0^1)$ is the worst possible performance on criterion g_j, and $g_j(b_{q+1}^1)$ is the best possible performance on the same criterion g_j, for $g_j \in F$ (Almeida-Dias et al, 2010).

Each criterion g_j will be considered as a pseudo-criterion, which means that it has associated two thresholds: (1) the indifference threshold, q_j, between two performances, is the largest performance difference that is judged compatible with an indifference situation between two actions with different performances; and (2) the preference threshold, p_j, between two performances, is the smallest performance difference that when exceeded is judged significant of a strict preference in favor of the action with the best performance. Note that $p_j \geq q_j \geq 0$ (Costa et al, 2016). These thresholds are meant to consider the imperfect character of the data from the computation of the performances $g_j(a)$, for all $a \in A$, as well as the arbitrariness that affects the definition of the criteria. It is assumed that all criteria $g_j \in F$ are to be maximized, or in other words, the preferences increase when the criteria performances increase too (Almeida-Dias et al, 2010).

When using the outranking concept, the main meaning of "a outranks a'" according to g_j, denoted aS_ja', if "a is at least as good as a'" on criterion g_j. Considering the definitions of thresholds and pseudo-criterion, and two different actions, a and a', where $g_j(a) \geq g_j(a')$, it is possible to obtain three binary relations (Costa et al, 2016): (1) $|g_j(a) - g_j(a')| \leq q_j$, where a is indifferent to a' according to criterion, g_j, and denoted aI_ja'; (2) $g_j(a) - g_j(a') > p_j$, where a is strictly preferable to a' according to criterion, g_j, and denoted aP_ja'; and (3) $q_j < g_j(a) - g_j(a') \leq p_j$, where the judgement is ambiguous, and there are no sufficient reasons to conclude an indifference situation, nor a strict preference between the two actions. This hesitation can be referred as a is weakly preferable to a', and it is denoted by aQ_ja' (this term "weakly" is not associated with any preference intensity) (Costa et al, 2016).

3.2.1.2. Outranking relations

When constructing an outranking relation, there are three main concepts to consider: concordance, nondiscordance and credibility index. Concordance refers to the strength of the coalition of the criteria being in favour of the outranking relation aS_ja'. Nondiscordance happens when there are no criteria that are in opposition to the assertion aS_ja' (Costa et al, 2016). The credibility of the assertion "a outranks a'" (aSa') is defined by the credibility index, which requires the comprehensive concordance index and the partial discordance indices to be calculated.

The ELECTRE TRI-nC method requires to associate each criterion to a weight, w_j, such that $w_j > 0$, with $j = 1, \dots, n$ and $\sum_{j=1}^{n} w_j = 1$ (assuming the sum of all weights is 1). The comprehensive concordance index, $c(a, a')$, can be defined as follows (Costa et al, 2016):

$$c(a,a') = \sum_{j\in C(aPa')} w_j + \sum_{j\in C(aQa')} w_j + \sum_{j\in C(aIa')} w_j + \sum_{j\in C(a'Qa)} w_j\,\varphi_j \qquad (1)$$

where the parameter φ_j is:

$$\varphi_j = \frac{p_j-(g_j(a')-g_j(a))}{p_j-q_j} \in [0,1[\qquad (2)$$

Each criterion is considered in the fraction φ_j through its weight (or in other words, its relative importance). This fraction can be interpreted as the proportion of the voting power (the weight of criterion g_j) in favor of the assertion aSa'. Such a proportion is close to 1 when the hesitation is "closer" to indifference, and it is close to 0, when the hesitation is "closer" to strict preference. This method also allows to associate to each criterion veto threshold, denoted v_j, such that $v_j \geq p_j$. For each criterion, the veto effect is given by the partial discordance index, $d_j(a,a')$, $j = 1, \dots, n$, and is defined as follow:

$$d_j(a,a') = \begin{cases} 1, & if\ g_j(a)-g_j(a') < -v_j, \\ \frac{g_j(a)-g_j(a')+p_j}{p_j-v_j}, & if\ -v_j \leq g_j(a)-g_j(a') < -p_j, \\ 0, & if\ g_j(a)-g_j(a') \geq -p_j \end{cases} \qquad (3)$$

Finally, the credibility index, denoted by $\sigma(a,a')$, can be interpreted as a degree of credibility, which synthesizes the strength of the coalition of criteria being in favor of the assertion aSa' with the opposition of criteria being against this assertion. Thus, it combines $c(a,a')$ and $d_j(a,a')$ in the following way:

$$\sigma(a,a') = c(a,a') \prod_{j=1}^{n} T_j(a,a') \qquad (4)$$

where

$$T_j(a,a') = \begin{cases} \frac{1-d_j(a,a')}{1-c(a,a')}, & if\ d_j(a,a') > c(a,a'), \\ 1, & otherwise \end{cases} \qquad (5)$$

Let λ denote a credibility level as the minimum degree of credibility, which is considered or judged necessarily by the decision maker for validating or not an outranking statement considering all criteria from F. The minimum credibility level takes a value within the range [0.5,1] (Costa et al, 2016).

Consider $\sigma(\{a\}, B_h) = max_{r=1,\dots,m_h}\{\sigma(a, b_h^r)\}$ and $\sigma(B_h, \{a\}) = max_{s=1,\dots,m_h}\{\sigma(b_h^s, a)\}$. It is possible to define four λ-binary relations as follows (Costa et al, 2016):

a) λ-outranking: $\{a\}S^\lambda B_h \Leftrightarrow \sigma(\{a\}, B_h) \geq \lambda$;

b) λ-preference: $\{a\}P^\lambda B_h \Leftrightarrow \sigma(\{a\}, B_h) \geq \lambda$ and $\sigma(B_h, \{a\}) < \lambda$;

c) λ-indifference: $\{a\}I^\lambda B_h \Leftrightarrow \sigma(\{a\}, B_h) \geq \lambda$ and $\sigma(B_h, \{a\}) \geq \lambda$;

d) λ-incomparability: $\{a\}R^\lambda B_h \Leftrightarrow \sigma(\{a\}, B_h) < \lambda$ and $\sigma(B_h, \{a\}) < \lambda$.

3.2.1.3. Assignment procedure

The ELECTRE TRI-nC assignment procedure is composed of two joint rules, called the descending rule and the ascending rule. These rules allow to assign one or more possible categories to an action, a.

The function $\rho(\{a\}, B_h)$ allows to select one of two consecutive categories and assign it to a determined action. This function is defined as follows:

$$\rho(\{a\}, B_h) = \min\{\sigma(\{a\}, B_h), \sigma(B_h, \{a\})\} \qquad (6)$$

The descending rule states: choose a credibility level, $\lambda\left(\frac{1}{2} \leq \lambda \leq 1\right)$; decrease h from $(q+1)$ until the first value, t, such that $\sigma(\{a\}, B_t) \geq \lambda$ (C_t is called the descending pre-selected category) (Almeida-Dias et al, 2010):

a) For $t = q$, select C_q as a possible category to assign action a.

b) For $0 < t < q$, if $\rho(\{a\}, B_t) > \rho(\{a\}, B_{t+1})$, then select C_t as a possible category to assign a; otherwise, select C_{t+1}.

c) For $t = 0$, select C_1 as a possible category to assign a.

The ascending rule states: choose a credibility level, $\lambda\left(\frac{1}{2} \leq \lambda \leq 1\right)$; decrease h from zero until the first value, k, such that $\sigma(B_k, \{a\}) \geq \lambda$ (C_k is called the ascending pre-selected category) (Almeida-Dias et al, 2010):

a) For $k = 1$, select C_1 as a possible category to assign action a.

b) For 1< $k < (q+1)$, if $\rho(\{a\}, B_k) > \rho(\{a\}, B_{k-1})$, then select C_k as a possible category to assign a; otherwise, select C_{k-1}.

c) For $k = (q+1)$, select C_1 as a possible category to assign a.

Each rule selects one possible category to each action. When applying both rules at the same time, it is possible to determine the minimum and maximum categories to each action (if overlapped, it means that there is only one category to that action).

3.2.1.4. Strong features and weaknesses

This method presents several strong features, as well as some limitations. The qualitative scales of some criteria allow to consider original (verbal or numeric) performances, without the need of any recoding. In fact, all the criteria are processed as qualitative criteria, even when they have quantitative nature. The heterogeneity of scales is another important advantage, since the ELECTRE family methods preserve original performances of the actions on the criteria. Besides, these methods were conceived in such a way that they do not allow for compensation of performances among criteria, or in other words, the degradation of performances on certain criteria cannot be compensated by improvements of performances on other criteria. These methods also consider the imperfect knowledge of data and some arbitrariness when building criteria. Finally, the ELECTRE methods can model reasons for and against an outranking relation between two actions (Costa et al, 2016). Regarding the weaknesses of these methods, the first might be the fact of not being adequate to assign a score to each action, as many times decision makers wish. When all the criteria are quantitative, other methods might suit better. However, it needed a noncompensatory method, ELECTRE methods are still advised. One last limitation of this family is the intransitivity. This is only a weakness if it is imposed *a priori* that preferences should be transitive (Costa et al, 2016).

3.3. Development of the Model

In order to structure any multicriteria decision aiding problem, it is necessary to define the Areas of Concern (AC) and the Fundamental Points of View (FPV). These FPV will support the construction of the criteria considering their Elementary Points of View (EPV).

The AC present a wide scope regarding the concerns of different actors on the presented problem. Since these AC present a great scope, they can be disaggregated into FPV to focus on specific issues. Criteria will operationalize FPV and each criterion will present a preference direction (maximize or minimized) (Roy, 1996).

EPV, or elementary consequences, are effects or attributes that are recognized as consequences and present the characteristics. First, the effect or attribute must be described in such a way that different actors can understand its importance for at least one actor. Second, it must be sufficiently understood to allow a precise description of both of its specific repercussions, after the execution of a potential action (Roy, 1996). This description can be done by a primary scale associated with its consequences. A vague and ambiguous definition of a consequence can create confusion between two actors, which will not allow a clear perception of its impacts (Roy, 1996).

The construction of criteria must consider several elements. A first consideration is that the number of criteria shall not be less than 3 or more than 12 (Figueira *et al*., 2005). Then, it is important to consider the essential properties of criteria (Belton and Stewart, 2002):

- *Value relevance*, which allows decision makers to link the concept to their goals, thereby enabling them to specify preferences which relate directly to the concept of the criterion;
- *Understandability,* which states that decision makers have a shared understanding of concepts to be used in the analysis;
- *Measurability,* which guarantees that exists some degree of measurement of the performance of alternatives against the specified criteria;
- *Non-redundancy,* which ensures that there is not more than one criterion measuring the same factor.

When there is great detail on the analysed objectives, there are other properties to consider such as operationality, which is associated with the need to achieve a balance between completeness and conciseness, or in other words, the information required does not place excessive demands on the decision makers and the model is usable with reasonable effort (Belton and Stewart, 2002).

3.4. Chapter Conclusions

This chapter presented relevant concepts that are critical for the understanding of the presented problem. The first part focused on the definition of governance and in the existing literature on EE governance. Indeed, it is easy to notice that EE governance is still a topic quite underdeveloped in academic literature. There is not a formal definition of EE governance, which creates some uncertainty in its operationalization. Furthermore, defining a global concept of EE governance is a complex problem since each country presents its own reality and it is not a solution one size-fits-all. However, Jollands and Ellis (2009) were able to develop a solid and holistic framework of EE governance. This framework will be quite relevant on the development of the model in the following chapters. Even though it is possible to find some assessments regarding EE achievements of different countries, only the study developed in Pereira and Silva (2017), was aimed to analyse the EE governance capacities of different countries.

The second part introduced the MCDA methods, and in particular the ELECTRE TRI-nC, which is the method that will be used in the following chapters. The aim of this application will be to classify the 28 MS (which are the actions of this model) in a set of pre-defined categories, ordered by preference, according to their EE governance capabilities. In the end, it will be possible to understand which countries have been contributing more in the EE governance in Europe in the achievements of the common targets. The ELECTRE Tri-nC method is suitable for the presented problem due to its own nature. Some of the features that justify this is that the actions of the model will be evaluated in an ordinal scale (governance capabilities are defined by qualitative criteria) and the existence of a strong heterogeneity related to the scales of the criteria in this problem.

4. Formal Model

This section presents the formal model to be implemented. First, there is an introduction of the evaluation model, followed by an explanation of the rational that supports the construction of the criteria. Then, the criteria tree is presented, and each criterion is described with its proposed evaluation scale. The last part presents the performance table of the alternatives. Note that the decision maker in this dissertation is hypothetical.

4.1. Governance Framework and EED

The objective of this dissertation is to get a better understanding of the governance capacities of each MS in the scope of EE improvement. This understanding will be achieved through the implementation of an MCDA method that will allow the evaluation of these governance capacities, considering the current governance actions in each MS. In other words, the aim is to estimate the potential of each MS on EE improvements triggered by governance measures.

However, it is necessary to consider that some countries are able to achieve better results than others due to more favorable social, economic, political or environmental contexts. For this reason, it is important to realize which countries can take more responsibility on the matter in order to achieve the global target.

The process of comparing different countries is quite complex due to the number of variables (economic, social, political and environmental) that influence the governance efforts that each country chooses to take. Having this said, it is important to establish a “common ground”, where all countries have comparable responsibilities and duties.

The solution presented to establish the ‘common ground’ between MS, that will be used as the basis of the criteria construction is the EED. This choice is justified by three main reasons:

1. All MS must harmonize their national laws and governance measures with the Articles of the EED;
2. EED establishes targets that are based on national socio-economic indicators, which make the targets calibrated to each MS’s situation;
3. All measures triggered by EED compliance actions must be reported to the EC and are publicly available. In 2014 and 2017, all MS had to elaborate an extensive report, the National Energy Efficiency Action Plans (NEEAP), on all current measures and how they are complying with EED demands.

It was possible to identify overlaps between EED requirements and the EE governance framework that Jollands and Ellis (2009) had proposed, as it is shown in Figure 4.

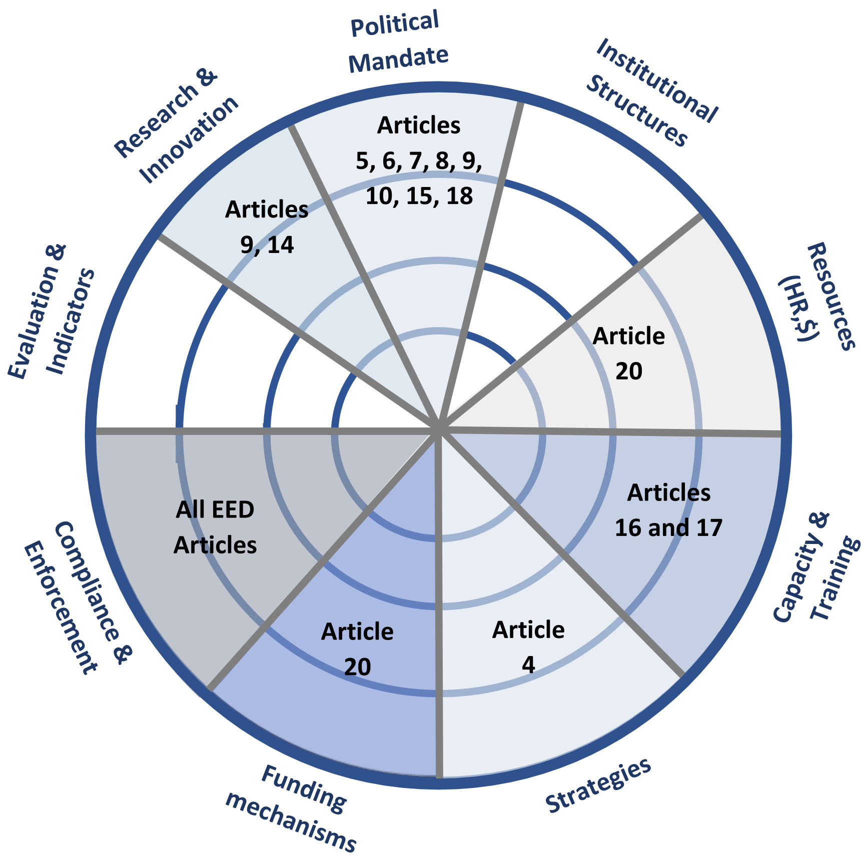


Figure 4: Overlap of the governance framework with EED articles

The set of the EED articles covers a great part of the presented governance framework.

Articles 9 and 14 may be classified as innovation, because: article 9 promotes the deployment of smart metering technology, which is still quite under-used; and, article 14 promotes the application of high-efficiency cogeneration and efficient district heating and cooling, which for many MS is also a quite under-deployed technology.

Articles 5 to 10, 15 and 18 refer to the measures that may be adopted based on the political mandate, since their implementation is mainly triggered by political measures: articles 5 and 6 cover actions on the public sector; article 7 states the need of obligation schemes on distributors and retail energy sales companies; article 8 promotes energy audits and energy management systems; articles 9 and 10 state the minimum requirements on metering and billing systems for all end-users; article 15 ensures that national energy regulatory authorities ensure the development of network tariffs and regulations to provide incentives for grid operators; and, article 18 promotes the availability of energy services for SMEs.

Article 20 promotes the development of an EE national fund and article 4 states that all MS shall develop a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings (both public and private). Articles 16 and 17 promote measures on the availability of qualification, accreditation and certification schemes and on information and training. Finally, all articles promote indirect compliance on their requirements since MS shall report to the EC all planned and implemented measures on the scope of the EED.

Note that not all EED articles were considered in this model. The articles to support the criteria for the model were chosen according to their type of requirements and their reporting nature. Some articles promote measures on certain issues but do not state concrete targets to be achieved, which makes the establishment of a comparison between the actions of different countries difficult and subjective.

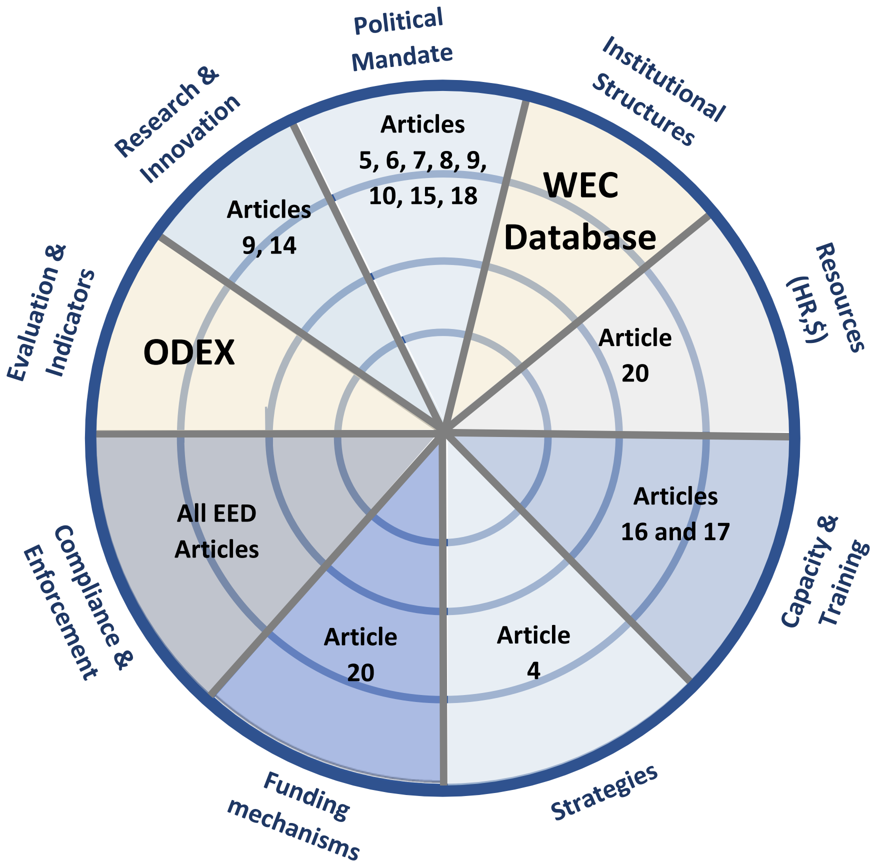


Figure 5: EE governance framework covered in all dimensions, and respective sources.

Considering that there is still two dimensions of the EE governance framework that are not covered by any EED article, two extra sources of information will be added to further develop criteria on these topics (Figure 5).

The source of information to approach the Evaluation and Indicators dimension is the Odyssee database. This database is part of the Odyssee-Mure project that is supported by H2020 programme of the EC and contains detailed EE and CO_2-indicators with data on energy consumption, their drivers (activity indicators) and their related CO_2-emissions (ODYSSEE-MURE, 2018a). This project developed the ODEX index to measure the EE progress in the whole economy of each country (ODYSSEE-MURE, 2018b), which will be used to assess the effective EE achievements of each MS. The smaller ODEX values represent better performances.

The Institutional Structure dimension will be represented by a criterion based on information by the World Energy Council (WEC) – Energy Efficiency Policy and Measures database (WEC, 2018). Note that there is not a formal decision maker supporting the development and evaluation of the criteria (hence, a hypothetical decision maker has been considered).

4.2. Construction of the Criteria Tree

This section presents the different elements of the criteria tree: Areas of Concern (AC), Fundamental Points of View (FPV), Elementary Points of View (EPV) and criteria.

4.2.1. Areas of Concern

In the analysis of the EE governance capabilities of the 28 MS, three AC will be considered:

AC_1 – **Energy Market Structure:** Reflects the impact of the several governance mechanisms that indirectly influence the improvement of EE in a country, in other words, the simple implementation of these actions does not guarantee energy savings. These mechanisms are triggered by different actors that present an influence on specific groups of stakeholders (from energy distributors and producers to the end-consumers). The objective is to understand the current efforts of this kind of measures on each country.

AC_2 – **Direct EE Improvement**: Reproduces the efforts made through mechanisms with direct impact on the EE improvement of each country. The implementation of such mechanisms creates quantifiable energy savings by itself, not depending on any other influences. The objective is to understand the current efforts of this kind on each country.

AC_3 – **Technical EE Improvement**: Displays the technical EE improvement of each country in a quantitative way, so that it is possible to understand the match between the existing governance mechanisms and the real EE improvement.

4.2.2. Fundamental Points of View

Considering the **AC_1**: **Energy Market Structure**, it is possible to disaggregate it into the following FPVs:

FPV_1 – **Political Mandate:** Considers the effort on EE improvement in the country triggered by political stakeholders;

FPV2 – Institutional Structures: Incorporates the effort on EE improvement in the country triggered by Institutional Structures dedicated to EE improvement and energy-related issues;

FPV_3 – **Capacity:** Reflects the availability and accessibility of programmes of Qualification, Accreditation and Certification that impact EE improvement in the country;

FPV_4 – Information Accessibility: Contemplates the amount and quality of information, provided by formal and non-formal mechanisms, regarding EE improvement accessible to the relevant stakeholders of the energy sector of the country;

FPV_5 – **Funding Mechanisms:** Regards the availability of funding mechanisms in the country destined to EE improvement initiatives.

Considering the **AC_2** – **Direct EE Improvement**: it is possible to disaggregate it into the following FPVs:

FPV_6 – **Strategies on End-Uses:** Accounts for the long-term strategies being developed on EE improvement regarding a specific type of stakeholders;

FPV_7 – Efficiency Improvement in Supply: Refers to the current mechanisms to improve EE during the production, distribution and transmission of energy in the country.

The last AC, **AC_3** – **Technical EE Improvement** only presents the following FPV:
FPV_8 – **EE Indicators:** Measures the real technical EE improvement on the whole economy of the country.

4.2.3. Criteria

The presented AC and FPV are operationalized by the criteria identified in the criteria tree of Table 2. Each criterion will be described in the following section.

Areas of Concern	Fundamental Points of View	Criteria	Elementary Points of View
AC_1: Energy Market Structure	**FPV_1**: Political Mandate	**g1:** EE performance of Public Sector	**c1:** Assessment of the exemplary role of public bodies' buildings on EE improvement
			c2: EE performance of public bodies' purchases
		g2: Availability of Energy Management Systems	**c3:** Availability of Energy Management Systems
		g3: Metering and Billing Reliability	**c4:** Metering Reliability
			c5: Billing Information Reliability
		g4: Accessibility of Energy Services by SME	**c6:** Accessibility of Energy Services by SME
	FPV_2: Institutional Structures	**g5:** EE Promotion by Institutional Structures	**c7:** Promotion by Institutional Structures
	FPV_3: Capacity	**g6:** Effectiveness of Qualification, Accreditation and Certification Schemes	**c8:** Effectiveness of Qualification, Accreditation and Certification Schemes
	FPV_4: Information Accessibility	**g7:** EE Information and Training Availability	**c9:** EE Information and Training Availability
	FPV_5: Funding Mechanisms	**g8:** Availability of EE Funding Mechanisms	**c10:** Availability of EE Funding Mechanisms
AC_2: Direct EE Improveme nt	**FPV_6**: Strategies on End-Uses	**g9:** Scope of National Building Renovation Strategy	**c11:** Scope of National Building Renovation Strategy
	FPV_7: Efficiency Improvement in Supply	**g10:** Efficiency in Supply	**c12:** Promotion of efficiency on heating and cooling
			c13: EE on Transformation, Transmission and Distribution
		g11: Effectiveness of the EE Obligation Schemes	**c14:** Effectiveness of the EE Obligation Schemes
AC_3: Technical EE	**FPV_8**: EE Indicators	**g12:** ODEX	**c15:** ODEX

Table 2: Criteria tree

The **AC_1** is defined by five FPV: (1) **FPV_1** is operationalized by the minimization of criteria **g1:** EE performance of Public Sector, **g2:** Availability of Energy Management Systems, **g3:** Metering and Billing Reliability and **g4:** Accessibility of Energy Services by SME; (2) **FPV_2** is operationalized by the minimization of criterion **g5:** EE Promotion by Institutional Structures; (3) **FPV_3** is operationalized by the minimization of criterion **g6:** Effectiveness of Qualification, Accreditation and Certification Schemes; (4) **FPV_4** is operationalized by the minimization of criterion **g7:** EE Information and Training Availability; and, (5) **FPV_5** is operationalized by the minimization of criterion **g8:** Availability of EE Funding Mechanisms. The **AC_2** is defined by two FPV: (1) **FPV_6** is operationalized by the minimization of criterion **g9:** Scope of National Building Renovation Strategy; and, (2) **FPV_7** is operationalized by the minimization of criteria **g10:** Efficiency in Supply and **g11:** Effectiveness of the EE Obligation Schemes. Finally, **AC_3** is defined by **FPV_8**: EE Indicators which is operationalized by the minimization of **g12:** ODEX.

4.3. Construction of Criteria Scales

This section presents a detailed explanation of the operationalization of each criterion and their respective elementary consequences (EPV) and the construction of the criteria.

4.3.1. g1: EE performance on the Public Sector [min]

The first criterion is based on the measures reported by the MS regarding articles 5 and 6 of the EED and in the NEEAPs of 2014 and 2017, each of them representing the consequences of one EPV: **c1**: (article 5) assessment of the exemplary role of public bodies' buildings on EE improvement; and **c2**: (article 6) assessment of the EE performance of public bodies' purchases. Both consequences are represented by a qualitative scale, since they are described using semantic expressions (Ensslin *et al*., 2001). Both qualitative scales present only four levels of evaluation, due to the different and inconsistent structures of the NEEAPs, which makes complicated to establish clear and straight-forward comparisons between the implemented measures of different EU countries.

- EPV 1: **Exemplary role of public bodies' buildings on EE improvement**.
  Article 5 of the EED states:

"1. *(…) each Member State shall ensure that, as from 1 January 2014, 3 % of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet at least the minimum energy performance requirements that it has set in application of Article 4 of Directive 2010/31/EU(…)"*

The objective of this EPV is to evaluate the compliance of the requirements of this article. For that end, the following 4-level qualitative scale was developed:

- Level 1 (L1) refers to the case when all planned measures are well founded and consistent with article 5 requirements. All established targets have been achieved;
- Level 2 (L2) refers to the case when all planned measures are well founded and consistent with article 5 requirements, but targets have not been achieved as expected;
- Level 3 (L3) refers to the case when there is a gap between the scope of the reported measures and the requirements of article 5;
- Level 4 (L4) refers to the case when there is no valuable information on reported measures regarding article 5.

- EPV 2: **EE performance of public bodies' purchases.** Article 6 of the EED states:

"*1. Member States shall ensure that central governments purchase only products, services and buildings with high energy-efficiency performance, insofar as that is consistent with cost-effectiveness, economic feasibility, wider sustainability, technical suitability, as well as sufficient competition, as referred to in Annex III (…)."*

The objective of this EPV is to evaluate the compliance of the requirements of article 6. For that end, the following 4-level qualitative scale was developed:

- Level 1 (L1) refers to the case when national law is completely harmonized with article 6 requirements regarding the purchasing of goods, services and buildings by public bodies;
- Level 2 (L2) refers to the case when national law is mostly harmonized with article 6 requirements, due to, at least, one type of purchases by public bodies (goods, services and buildings) is not completely aligned;
- Level 3 (L3) refers to the case when there is a general lack of detail on the three type of purchases by public bodies on the reported actions relative to article 6;
- Level 4 (L4) refers to the case when there is no valuable information reported regarding article 6.

The construction of this criterion is done by combining the two EPV by using multidimensional scales. There are five essential steps to perform this combination: (1) defining the levels of impact of each EPV; (2) defining the possible combination of these impacts; (3) eliminating all inviable hypothesis; (4) comparing the viable combinations and group them, if they are similar (these groups will define the impact levels); finally, (4) it is necessary to ensure that all levels are defined in a clear and concise way (Bana e Costa and Beinat, 2005).

The criterion will be evaluated through a qualitative scale with 7 impact levels that are described in Table 3.

Impact Level	Classification	Respective EPV combinations
L1	Very good compliance	Both L1.
L2	Good compliance	One EPV classified as L1 and the other as L2.
L3	Moderate compliance	Both EPV as L2, or one as L1 and the other as L3.
L4	Average compliance	An EPV as L2 and the other as L3, or, one as L1 and the other as L4.
L5	Weak compliance	Both EPV as L3, or one as L2 and the other as L4.
L6	Very weak compliance	One EPV classified as L3 and the other as L4.
L7	No compliance	Both L4.

Table 3: Levels of impact and respective EPV combinations of g1.

Table 4 shows the construction of criterion g1 through the combination of the all possible combinations between the two EPV, each with 4 levels, which creates 16 possible profiles.

EE Performance of Public Bodies									
	Exemplary role of public bodies' buildings				Purchasing by public bodies				Levels of multidimensional impact
	L1	L2	L3	L4	L1	L2	L3	L4	
Profile 1	X				X				**L1**
Profile 2	X					X			**L2**
Profile 3	X						X		**L3**
Profile 4	X							X	**L4**
Profile 5		X			X				**L2**
Profile 6		X				X			**L3**
Profile 7		X					X		**L4**
Profile 8		X						X	**L5**
Profile 9			X		X				**L3**
Profile 10			X			X			**L4**
Profile 11			X				X		**L5**
Profile 12			X					X	**L6**
Profile 13				X	X				**L4**
Profile 14				X		X			**L5**
Profile 15				X			X		**L6**
Profile 16				X				X	**L7**

Table 4: Construction of criterion g1 - EE performance of Public Bodies

All profiles defined in Table 4 are viable, even though they do not present the same probability of happening.

4.3.2. g2: Availability of Energy Management Systems [min]

The third criterion evaluates the availability of energy audits and energy management systems, since they help end-customers to understand their consumption and make more efficient choices. The data that supports this assessment are the reported measures regarding article 8 of the EED and in the NEEAPs of 2014 and 2017 of each MS. This criterion is built with a single EPV, which corresponds to consequence **c3**: availability of energy management systems. The evaluation will be supported by a qualitative scale since they are described using semantic expressions, again with only four levels of evaluation due to the inherent subjectivity of the reports on this article.

- EPV 3: **Availability of Energy Management Systems.** Article 8 of the EED states: *"1. Member States shall promote the availability to all final customers of high-quality energy audits which are cost-effective and:*

  (a) carried out in an independent manner by qualified and/or accredited experts according to qualification criteria; or

(b) implemented and supervised by independent authorities under national legislation.

The energy audits referred to in the first subparagraph may be carried out by in-house experts or energy auditors provided that the Member State concerned has put in place a scheme to assure and check their quality (…)"

The objective of this EPV is to evaluate the compliance of the requirements of article 8. For that end, the following 4-level qualitative scale was developed:

- Level 1 (L1) refers to the total harmonization between the national law with the requirements set in the article 8 of the EED for the three main types of end-consumers: non-SMEs, SMEs and households;
- Level 2 (L2) refers to the case when the national law is almost harmonized with the requirements of the article 8 of the EED, but at least one of the three main types of end-consumers (non-SMEs, SMEs and households) is not completely aligned;
- Level 3 (L3) refers to the case when the reported information presents general lack of detail regarding the requirements of article 8, and none of the three main types of end-consumers is fully aligned;
- Level 4 (L4) refers to the case when there is no valuable reported information regarding article 8.

4.3.3. g3: Metering and Billing Reliability [min]

The fourth criterion is based on the measures reported by MS regarding articles 9 and 10 of the EED and in the NEEAPs of 2014 and 2017, each of them representing the consequences of an EPV:

c4 – Metering reliability (article 9), and **c5 -** Billing Information reliability (article 10). Metering and Billing information are important in EE improvement since they provide information to end-customers that contribute to decisions for a better energy management. Both consequences are represented by a qualitative scale of four levels, since they are described using semantic expressions. The same issue about the subjectivity of the presented reports is present on these articles, and for that reason there are only four levels of evaluation on each EPV.

- EPV 4: **Metering Reliability**. Article 9 of the EED states:

"1. Member States shall ensure that, in so far as it is technically possible, financially reasonable and proportionate in relation to the potential energy savings, final customers for electricity, natural gas, district heating, district cooling and domestic hot water are provided with competitively priced individual meters that accurately reflect the final customer's actual energy consumption and that provide information on actual time of use.

Such a competitively priced individual meter shall always be provided when:

(a) an existing meter is replaced, unless this is technically impossible or not cost-effective in relation to the estimated potential savings in the long term;

(b) a new connection is made in a new building or a building undergoes major renovations, as set out in Directive 2010/31/EU.

2. Where, and to the extent that, Member States implement intelligent metering systems and roll out smart meters for natural gas and/or electricity in accordance with Directives 2009/72/EC and 2009/73/EC (…)"

The objective of EPV 5 is to evaluate the compliance of the requirements of article 9, through the following 4-level qualitative scale:

- Level 1 (L1) refers to total harmonization of standard metering with article 9 requirements and existent active plans to explore smart meters utilization;
- Level 2 (L2) refers to total harmonization of standard metering with article 9 requirements, but there are no plans to explore smart meters;
- Level 3 (L3) refers to the case when standard metering is not fully aligned with EED the requirements of article 9;
- Level 4 (L4) refers to the case when there is no valuable reported information regarding article 9.

- EPV 5: **Billing Information Reliability**. Article 10 of the EED states:

"1. Where final customers do not have smart meters as referred to in Directives 2009/72/EC and 2009/73/EC, Member States shall ensure, by 31 December 2014, that billing information is accurate and based on actual consumption, (…), including energy distributors, distribution system operators and retail energy sales companies, where this is technically possible and economically justified (…). Only when the final customer has not provided a meter reading for a given billing interval shall billing be based on estimated consumption or a flat rate.

2. Meters installed (…) shall enable accurate billing information based on actual consumption. Member States shall ensure that final customers have the possibility of easy access to complementary information on historical consumption allowing detailed self- checks (…)"

The objective of this EPV is to evaluate the compliance of the requirements of article 10. For that end, the following 4-level qualitative scale was developed:

- Level 1 (L1) refers to the case when billing information is accurate, based on actual consumption and it is transparent for all consumers. The access to such information is free for all end-costumers;
- Level 2 (L2) refers to the case when billing information is sometimes accurate and not always clear for final consumers. The access to such information is free for all end-costumers;
- Level 3 (L3) refers to the case when billing information is not always clear to the final consumers and, in some cases, end-consumers have to pay for it;
- Level 4 (L4) refers to the case when there is no valuable reported information regarding article 10.

The construction of this criterion is done by combining these two EPV using multidimensional scales, using the same steps ofcriterion g1. The assessment will be based on a qualitative scale with 7 levels that are described in Table 5.

Impact Level	Classification	Respective EPV combinations
L1	Very good compliance	Both L1.
L2	Good compliance	One EPV classified as L1 and the other as L2.
L3	Moderate compliance	Both EPV as L2, or one as L1 and the other as L3.
L4	Average compliance	An EPV as L2 and the other as L3, or one as L1 and the other as L4.
L5	Weak compliance	Both EPV as L3, or one as L2 and the other as L4.
L6	Very weak compliance	One EPV classified as L3 and the other as L4.
L7	No compliance	Both L4.

Table 5: Levels of impact and respective EPV combinations of g3.

Table 6 shows the construction of criterion g3 through the combination of the all possible combinations between the two EPV, each with 4 levels, which creates 16 possible profiles. All profiles are viable.

Metering and Billing Information									
	Metering Performance				Billing Information Performance				Levels of multidimensional impact
	L1	L2	L3	L4	L1	L2	L3	L4	
Profile 1	X				X				**L1**
Profile 2	X					X			**L2**
Profile 3	X						X		**L3**
Profile 4	X							X	**L4**
Profile 5		X			X				**L2**
Profile 6		X				X			**L3**
Profile 7		X					X		**L4**
Profile 8		X						X	**L5**
Profile 9			X		X				**L3**
Profile 10			X			X			**L4**
Profile 11			X				X		**L5**
Profile 12			X					X	**L6**
Profile 13				X	X				**L4**
Profile 14				X		X			**L5**
Profile 15				X			X		**L6**
Profile 16				X				X	**L7**

Table 6: Construction of criterion g3 – Metering and Billing Information

4.3.4. g4: Accessibility of Energy Services by SME [min]

The present criterion evaluates the availability of energy services for SMEs, since it is usually a group of end-consumers that does not present many accessible advantages and incentives for EE improvement. The data that support this assessment are the reported measures regarding article 18 of the EED and in NEEAPs of the 2014 and 2017 of each MS. This criterion is built with a single EPV, which corresponds to consequence **c6**: accessibility of energy services by SMEs. The evaluation will be performed through a qualitative scale with only three levels described by semantic expressions, due its subjectivity. The established reference was 5 reported measures per country, since it was considered enough to understand the current efforts on this area.

- EPV 6: **Accessibility of Energy Services by SME.** Article 18 of the EED states:

"1. Member States shall promote the energy services market and access for SMEs to this market by:

(a) disseminating clear and easily accessible information (…);

(b) encouraging the development of quality labels, inter alia, by trade associations;

(c) making publicly available and regularly updating a list of available energy service providers who are qualified and/or certified and their qualifications and/or certifications in accordance with Article 16, or providing an interface where energy service providers can provide information;

(d) supporting the public sector in taking up energy service offers, in particular for building refurbishment (…)"

The objective of this EPV is to evaluate the compliance of the requirements of the article 18 of the EED. For that end, the following 3-level qualitative scale was developed:

- Level 1 (L1) refers to the case when there are more than 5 measures reported regarding Article 18;
- Level 2 (L2) refers to the case when there are less than 5 measures reported regarding Article 18;
- Level 3 (L3) refers to the case when there is no information reported regarding the requirements of Article 18.

4.3.5. g5: EE Promotion by Institutional Structures [min]

The present criterion evaluates the dimension of Institutional Structures of the governance framework. Since there is no article in the EED that focus on Institutions to promote EE, this criterion is based on data from the World Energy Council: Energy Efficiency Policies and Measures[1]. This criterion is based in a single EPV that corresponds to consequence **c7:** EE

[1] https://wec-policies.enerdata.net/

promotion by Institutional Structures. The evaluation will be done through a qualitative scale of four levels, described by semantic expressions.

- EPV 7: **EE Promotion by Institutional Structures**.

This EPV aims to assess the intensity of the presence of Institutions that work on EE improvement. This assessment is done through the following 4-level qualitative scale:

  - Level 1 (L1) refers to MS that have a National Agency dedicated to EE promotion, with more than 50 staff members, and more than 10 local points spread all over the national territory to provide regional support;
  - Level 2 (L2) refers to MS that have a National Agency dedicated to EE promotion, with less than 50 staff members, and some local points spread all over the national territory to provide regional support;
  - Level 3 (L3) refers to MS that have a National Agency dedicated to EE promotion, with less than 50 staff members, and no local points for regional support;
  - Level 4 (L4) refers to cases where there is no valuable information regarding the presence of institutional structures for EE promotion.

4.3.6. g6: Effectiveness of Qualification, Accreditation and Certification Schemes [min]

It is important to ensure good levels of technical competence, objectivity and reliability of the relevant actors in the EE domain. For this reason, article 16 of the the EED states that MS shall set certification, accreditation and qualifications schemes. The reported measures on this article and in the NEEAPs of the 2014 and 2017 will support the present criterion (g6) that is based on the EPV 8, corresponding to the consequence **c8**: Effectiveness of qualification, accreditation and certification schemes. The assessment will be based on a qualitative scale of only three levels, because the scenarios are described by semantic expressions. Since the article does not establish a concrete target to be achieved, it is difficult to specify the effectiveness of the schemes, and for this reason there is only three evaluation levels.

- EPV 8: **Effectiveness of qualification, accreditation and certification schemes.** Article 16 of the EED states:

"1. Where a Member State considers that the national level of technical competence, objectivity and reliability is insufficient, it shall ensure that, by 31 December 2014, certification and/or accreditation schemes and/or equivalent qualification schemes, including, where necessary, suitable training programmes, become or are available for providers of energy services, energy audits, energy managers and installers of energy-related building elements as defined in Article 2(9) of Directive 2010/31/EU.

2. Member States shall ensure that the schemes referred to in paragraph 1 provide transparency to consumers, are reliable and contribute to national energy efficiency objectives (…)"

The objective of EPV 8 is to evaluate the compliance of the requirements of the article 16 of the EED. For that end, the following 3-level qualitative scale will be used to make this assessment:

- Level 1 (L1) refers to when there are more than 5 measures reported regarding the requirements of Article 16
- Level 2 (L2) refers to when there are less than 5 measures reported regarding the requirements of Article 16;
- Level 3 (L3) refers to when there is no information reported regarding the requirements of article 16.

4.3.7. g7: Information and Training Availability [min]

Another simple and important measure to support the entire governance framework is the availability of information and training, which is stated in the EED article 17. The reported measures on this article and in the NEEAPs of 2014 and 2017 will support the criterion g8, that is supported by EPV 9, corresponding to consequence **c9:** Information and Training Availability. The assessment is based on a qualitative scale of only three levels expressed by semantic expressions, due to the same reason of criterion g7.

- EPV 9: **Information and Training Availability.** Article 17 of the EED states:

"1. Member States shall ensure that information on available energy efficiency mechanisms and financial and legal frameworks is transparent and widely disseminated to all relevant market actors, such as consumers, builders, architects, engineers, environmental and energy auditors, and installers of building elements as defined in Directive 2010/31/EU. Member States shall encourage the provision of information to banks and other financial institutions on possibilities of participating, including through the creation of public/private partnerships, in the financing of energy efficiency improvement measures.

2. Member States shall establish appropriate conditions for market operators to provide adequate and targeted information and advice to energy consumers on energy efficiency (…)"

The objective of EPV 9 is to evaluate the compliance of the requirements of the article 17 of the EED, through the following 3-level qualitative scale:

- Level 1 (L1) refers to the case when there are more than 5 measures reported regarding the requirements of Article 17;
- Level 2 (L2) refers to the case when there are less than 5 measures reported regarding the requirements of Article 17;
- Level 3 (L3) refers to the case when there is no information reported regarding the requirements of article 17.

4.3.8. g8: Availability of EE Funding Mechanisms [min]

The eighth criterion focuses on the existence and availability of funding mechanisms to support EE improvement. This is referred in the Article 20 of the EED. There will be two different sources to support this criterion: the NEEAPs of 2014 and 2017 and the World Energy Council: Energy Efficiency Policies and Measures databases (also used in criterion g6). The EPV 10 is the foundation of the present criterion and corresponds to the consequence **c10**: Availability of EE Funding Mechanisms, that is assessed through a qualitative scale, since the scenarios are described by semantic expressions.

- EPV 10**: Availability of EE Funding Mechanisms.** Article 20 of the EED states:
  "1. Without prejudice to Articles 107 and 108 of the Treaty on the Functioning of the European Union, Member States shall facilitate the establishment of financing facilities, or use of existing ones, for energy efficiency improvement measures to maximise the benefits of multiple streams of financing (…)"

EPV 10 has the objective of evaluating the compliance of the requirements of the article 20 of the EED and the dimension of the available funds in each MS. Considering that different MS present different economical environments, a ratio of the National EE Fund (in €) per GDP per capita (in €) is used. The assessment is based on the following 4-level qualitative scale:

- Level 1 (L1) refers to the case when there is a National EE dedicated Fund. The ratio National EE Fund/GDP per capita is greater or equal than 20000;
- Level 2 (L2) refers to the case when there is a National EE dedicated Fund. The ratio National EE Fund/GDP per capita is smaller than 20000;
- Level 3 (L3) refers to the case when there is a National EE dedicated Fund but there are no concrete values reported;
- Level 4 (L4) refers to the case when there is no National EE fund reported.

Due to the lack of available information regarding the year 2016 on funding mechanisms of the 28 MS, the values considered in the model for this year on this criterion were the same used for the year 2013. It was considered that the countries maintained their status regarding these mechanisms in the period from 2013 to 2016. Even though it was not possible to account for the real evolution, this criterion was considered quite relevant for EE governance of any country, and for that reason it was included in both models.

4.3.9. g9: Scope of the National Building Renovation Strategy [min]

Considering that buildings hold a great potential for EE improvement, the EED article 4 states that every MS shall establish a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private. The strategies are reported in the NEEAPs of 2014 and 2017 and support the criterion g10, based on the EPV 11 that corresponds to the consequence **c11:** Scope of the National Building Renovation Strategy. The assessment is based on a qualitative scale of three levels, since the different scenarios are described by semantic expressions. The scale only present three levels due to the lack of detail expressed in these reports.

- EPV 11**: Scope of the National Building Renovation Strategy.** Article 4 of the EED states:

"Member States shall establish a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings, both public and private. This strategy shall encompass:

(a) an overview of the national building stock based, as appropriate, on statistical sampling;

(b) identification of cost-effective approaches to renovations relevant to the building type and climatic zone;

(c) policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations;

(d) a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;

(e) an evidence-based estimate of expected energy savings and wider benefits (…)"

The objective of EPV 11 is to evaluate the compliance of the requirements of the article 4 of the EED and the level of development of the strategy. The assessment is based on the following 3-level qualitative scale:

- Level 1 (L1) refers to when the reported strategy complies fully with the EED article 4 requirements;
- Level 2 (L2) refers to when the reported strategy does not comply with all the EED article 4 requirements;
- Level 3 (L3) refers when there is no information reported regarding the requirements of article 4.

4.3.10. g10: Efficiency in Energy Supply [min]

The eleventh criterion reflects the reported actions, in the NEEAPs of 2014 and 2017, regarding the two articles of the EED that focus on the efficiency of the energy supply - articles 14 and 15. Each article represents an EPV: **c12** – Promotion of efficiency on heating and cooling (article 14) and **c13** – EE on transformation, transmission and distribution (article 15). Both consequences are represented by a qualitative scale since the scenarios are described through semantic expressions. There are only three levels due to the lack of detail of the reported measures.

- EPV 12: **Promotion of efficiency on heating and cooling**. Article 14 of the EED states:

"1. By 31 December 2015, Member States shall carry out and notify to the Commission a comprehensive assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling, containing the information set out in Annex VIII. If they have already carried out an equivalent assessment, they shall notify it to the Commission.
The comprehensive assessment shall take full account of the analysis of the national potentials for high-efficiency cogeneration carried out under Directive 2004/8/EC.
At the request of the Commission, the assessment shall be updated and notified to the Commission every five years. The Commission shall make any such request at least one year before the due date.
2. Member States shall adopt policies which encourage the due taking into account at local and regional levels of the potential of using efficient heating and cooling systems, in particular those using high-efficiency cogeneration. Account shall be taken of the potential for developing local and regional heat markets (…)"

EPV 12 aims to assess the compliance of the requirements of Article 14, through a 3-level qualitative scale:

- Level 1 (L1) refers to when there is a consistent assessment reported to EC as required in article 4 and/or there are presented actions to expand the application of high-efficiency cogeneration and efficient district heating and cooling;
- Level 2 (L2) refers to when there is no assessment reported to EC and no presented plans to explore the application of high-efficiency cogeneration and efficient district heating and cooling;
- Level 3 (L3) refers to when there is no reported information regarding EED article 14;

- EPV 13: **EE on Transformation, Transmission and Distribution.** Article of the EED15 states:

"1. Member States shall ensure that national energy regulatory authorities pay due regard to energy efficiency in carrying out the regulatory tasks specified in Directives 2009/72/EC and 2009/73/EC regarding their decisions on the operation of the gas and electricity infrastructure.
Member States shall in particular ensure that national energy regulatory authorities, through the development of network tariffs and regulations, within the framework of Directive 2009/72/EC and taking into account the costs and benefits of each measure, provide incentives for grid operators to make available system services to network users permitting them to implement energy efficiency improvement measures in the context of the continuing deployment of smart grids.
Such systems services may be determined by the system operator and shall not adversely impact the security of the system.
For electricity, Member States shall ensure that network regulation and network tariffs fulfil the criteria in Annex XI, taking into account guidelines and codes developed pursuant to Regulation (EC) No 714/2009 (…)"

The objective of EPV 13 is to evaluate the compliance of the requirements of article 15 through the following qualitative scale:

- Level 1 (L1) refers to the case when there are reported measures ensuring that national regulatory authorities do pay due regard EE, as is required in EED article 15.
- Level 2 (L2) refers to the case when there are no reported measures ensuring that national regulatory authorities do pay due regard EE, as is required in EED article 15.
- Level 3 (L3) refers to the case when there is no reported information regarding EED article 15.

The construction of this criterion is done by combining these two EPV using multidimensional scales, using the same steps as criteria g1 and g3. The assessment will be based on a qualitative scale with 5 levels described in the following table.

Impact Level	Classification	Respective EPV combinations
L1	Very good compliance	Both L1.
L2	Good compliance	One EPV classified as L1 and the other as L2.
L3	Moderate compliance	Both EPV as L2 or one as L1 and the other as L3.
L4	Average compliance	One EPV classified as L2 and the other as L3.
L5	Weak compliance	Both L3.

Table 7: Levels of impact and respective EPV combinations of g10.

Table 8 shows the construction of criterion g10 through the combination of the all possible combinations between the two EPV, each with 3 levels, which creates 9 possible profiles (all viable).

Efficiency in Energy Supply							
	Promotion of efficiency in heating and cooling			Energy Transformation, Transmission and Distribution			Levels of multidimensional impact
	L1	L2	L3	L1	L2	L3	
Profile 1	X			X			L1
Profile 2	X				X		L2
Profile 3	X					X	L3
Profile 4		X		X			L2
Profile 5		X			X		L3
Profile 6		X				X	L4
Profile 7			X	X			L3
Profile 8			X		X		L4
Profile 9			X			X	L5

Table 8: Construction of criterion g10 – Efficiency in Energy Supply

4.3.11. g11: Effectiveness of the EE Obligation Schemes [min]

This criterion evaluates the effectiveness of implementation of the obligation schemes required by EED article 7. The data that supports this evaluation are the reported measures in the 2014 and 2017 NEEAP of each MS. This criterion is based on one EPV, which corresponds to consequence **c14**: effectiveness of the EE obligation schemes. The evaluation will be performedthrough a qualitative scale with only four levels of evaluation since they are expressed by semantic expressions. It is complicated to create more levels of evaluation due to the variety of structures of the reports that create subjectivity and make transparent comparisons hard to establish.

- EPV 14: **Effectiveness of the Energy Efficiency Obligation Schemes.** Article 7 of the EED states:

"1. Each Member State shall set up an energy efficiency obligation scheme. That scheme shall ensure that energy distributors and/or retail energy sales companies (…) operating in each Member State's territory achieve a cumulative end-use energy savings target by 31 December 2020, without prejudice to paragraph 2.

That target shall be at least equivalent to achieving new savings each year from 1 January 2014 to 31 December 2020 of 1,5 % of the annual energy sales to final customers of all energy distributors or all retail energy sales companies by volume, averaged over the most recent three-year period prior to 1 January 2013 (…)"

The objective of this EPV is to evaluate the compliance of the requirements of article 7. For that end, the following 4-level qualitative scale was developed:

- Level 1 (L1) refers to the case when all planned measures are well founded and consistent with article 7 requirements. All established targets have been achieved;
- Level 2 (L2) refers to the case when all planned measures are well founded and consistent with article 7 requirements, but targets have not been achieved as expected;
- Level 3 (L3) refers to the case when there is a gap between the scope of the reported measures and the requirements of article 7;
- Level 4 (L4) refers to the case when there is no valuable information on reported measures regarding article 7.

4.3.12. g12: ODEX [min]

The last criterion reflects the technical EE performance of each MS and it is supported by the EVP 15, that corresponds to the **c15:** ODEX, which is an index. The data source used for this criterion was the ODYSSEE-MURE database[2]. The ODYSSEE-MURE project developed the ODEX index aiming to measure the EE progress by main sector and for the whole economy (all

[2] http://www.odyssee-mure.eu/project.html

final consumers) of a country. The index is calculated as a weighted average of sectoral indices of EE progress (ODYSSEE-MURE, 2018b). The sectoral indices are calculated from variations of unit energy consumption indicators, measured in physical units and carefully selected to provide the best “proxy” of EE progress, from a policy evaluation viewpoint. The benefit of the utilization of these indices is that it enables to combine different units from different sectors. The weight used is the share of each sub-sector in the total energy consumption of sectors (ODYSSEE-MURE, 2018b). A value of ODEX equal to 90 means a 10% EE gain. This index is a better *proxy* for assessing EE trends at aggregate level than the traditional energy intensities, as they are cleaned from structural changes and from other factors not related to EE (ODYSSEE-MURE, 2018b). For this reason, this index was the chosen one to reflect the technical energy improvement of the countries. The weighting system has been defined in such a way that ODEX is equal to a rate of energy savings, or in other words, the ratio between the actual energy consumption (E) of the whole economy in year t and actual energy consumption (E) without energy savings (ES):

(1) $$ODEX = (\frac{E}{E+ES}) * 100$$

The energy savings are calculated as the sum of energy savings of each underlying sector. For instance, if the actual consumption of the sector is 50 Mtoe and if the energy savings are 10 Mtoe, ODEX is equal to $\frac{50}{60} * 100 = 83.3$. Such an index of 83.3 is equivalent to a rate of energy savings of 16.7% (ODYSSEE-MURE, 2018b). The variation of the weighted index of the unit consumption between t-1 and t is defined as follows:

(2) $$\frac{I_{t-1}}{I_t} = \sum_i EC_{i,t} * (\frac{UC_{i,t}}{IUC_{i,t-1}})$$

With UC_i: unit consumption index of sector I and EC_i: share of sector i in total consumption. ODEX is set at 100 for a reference year and successive values are then derived for each year t by the value of ODEX at year t-1 multiplied by $\frac{I_t}{I_{t-1}}$ (ODYSSEE-MURE, 2018b). Due to the construction of this index, the aim of this criterion is to minimize as much as possible the index (which implies more energy savings). Since there are still some data unavailable regarding the year 2016 for some countries, the ODEX values regarding 2015 were used as a proxy, since they were the best option to reflect the development of EE improvement of those countries in the period from 2013 to 2016.

4.4. Construction of the criteria performance table

Note that the alternatives in this problem are the 28 MS of the EU. These will be evaluated regarding their governance capabilities regarding EE improvement by the criteria previously presented. The data used to construct the performance tables of the models for the years 2013 and 2016 was gathered, as previously stated, from three data bases: World Energy Council: Energy Efficiency Policies and Measures databases (g5 and g8), ODYSSEE-MURE database (g12) and NEEAPs of 2014 and 2017 (all the other criteria) of the 28 countries (56 reports in total). Note that the information from the 2014 NEEAPs referred to the year of 2013 and the information of the 2017 NEEAPs referred to the year of 2016. The NEEAPs are publicly available in the EC website[3] and are usually organized in sections describing the implemented measures regarding each article of the EED. Some reports did not present the standard structure, which turned the process of data collection a long and complex process. Even in the reports of different countries with the same structures, the mode of reporting was different which created entropy in the process. During the construction of the evaluation levels of each criterion the amount and the quality of available information on each issue were considered. The analysis of all these documents had as output the performances of the 28 countries on all criteria for the both years, as seen in Tables 9 and 10. These are the data used as inputs for the model described in the next chapter.

		g1	*g2*	*g3*	*g4*	*g5*	*g6*	*g7*	*g8*	*g9*	*g10*	*g11*	*g12*
Austria	AT	2	1	1	1	1	1	1	1	2	2	1	82
Belgium	BE	2	3	4	1	4	3	1	3	3	5	4	75
Bulgaria	BG	3	2	1	1	4	1	1	4	1	1	3	66
Croatia	HR	4	2	3	1	2	1	1	3	2	1	2	84
Cyprus	CY	3	3	5	2	4	1	1	2	2	4	2	78
Czech Republic	CZ	3	2	1	1	3	1	2	1	2	2	2	79
Denmark	DK	3	1	1	1	2	1	1	1	2	1	2	84
Estonia	EE	5	2	3	1	2	1	1	3	3	4	2	75
Finland	FI	2	2	3	1	1	1	1	4	1	1	2	92
France	FR	3	2	5	3	1	2	1	4	2	3	3	85
Germany	DE	2	2	7	1	1	2	3	3	1	4	3	82
Greece	EL	2	2	3	1	4	2	1	3	1	1	2	70
Hungary	HU	2	2	3	1	4	1	1	4	1	2	2	78
Ireland	IE	2	2	3	1	3	1	1	3	2	2	2	73
Italy	IT	1	2	4	1	1	1	1	2	1	1	2	87
Latvia	LV	3	2	4	3	3	1	3	3	1	2	2	70
Lithuania	LT	5	2	3	2	2	2	3	3	3	2	4	73
Luxembourg	LU	2	2	3	1	4	1	1	4	1	2	1	83
Malta	MT	2	2	2	2	2	1	1	1	1	2	3	82
Netherlands	NL	2	2	4	2	1	2	1	4	1	1	2	76
Poland	PL	4	2	5	2	2	1	1	2	1	3	2	73
Portugal	PT	7	4	7	2	1	3	3	1	3	5	3	73
Romania	RO	2	2	5	2	3	1	1	1	1	2	3	66
Slovakia	SK	7	4	7	3	1	3	1	1	3	5	4	63
Slovenia	SI	4	2	3	1	3	1	1	1	2	1	2	78
Spain	ES	1	2	3	1	1	1	1	1	1	1	2	82
Sweden	SE	1	2	3	1	1	2	1	4	1	2	1	75
United Kingdom	UK	3	2	3	1	3	1	1	3	1	1	1	76

Table 9: Performance table for 2013

[3] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/national-energy-efficiency-action-plans (accessed in 18th September, 2018)

		g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12
Austria	AT	2	1	1	1	1	1	1	1	2	3	1	80
Belgium	BE	3	2	7	1	4	3	1	3	3	5	4	75
Bulgaria	BG	4	3	1	1	4	1	1	4	1	1	2	65
Croatia	HR	4	1	2	1	2	1	1	3	2	1	2	81
Cyprus	CY	4	2	5	2	4	1	1	2	2	2	1	77
Czech Republic	CZ	4	2	1	3	3	1	2	1	2	1	2	77
Denmark	DK	4	1	1	1	2	1	1	1	2	1	2	83
Estonia	EE	5	3	1	1	2	1	1	3	3	3	1	72
Finland	FI	2	2	1	1	1	1	1	4	1	1	2	91
France	FR	2	3	3	3	1	2	1	4	2	3	3	83
Germany	DE	2	2	4	1	1	2	3	3	1	2	3	80
Greece	EL	3	2	3	1	4	2	1	3	1	1	1	67
Hungary	HU	4	2	3	1	4	1	1	4	1	4	2	76
Ireland	IE	2	2	3	1	3	1	1	3	2	2	2	71
Italy	IT	1	2	3	1	1	1	1	2	1	1	2	86
Latvia	LV	2	2	4	2	3	1	3	3	1	2	2	68
Lithuania	LT	7	4	7	3	2	3	3	3	3	2	4	70
Luxembourg	LU	1	3	3	1	4	1	1	4	1	2	1	81
Malta	MT	3	1	2	2	2	1	1	1	1	2	1	80
Netherlands	NL	1	2	3	1	1	2	1	4	1	1	2	75
Poland	PL	4	2	6	1	2	1	1	2	1	3	2	71
Portugal	PT	7	3	4	1	1	1	1	1	3	1	1	72
Romania	RO	4	4	5	3	3	1	3	1	3	5	4	64
Slovakia	SK	3	3	7	1	1	2	1	1	2	1	2	60
Slovenia	SI	4	2	3	1	3	1	1	1	2	1	2	77
Spain	ES	1	2	3	1	1	1	1	1	1	1	2	80
Sweden	SE	1	3	3	1	1	2	1	4	1	2	1	74
United Kingdom	UK	4	2	4	1	3	1	3	3	1	2	2	74

Table 10 : Performance table for 2016

5. Model Implementation

This section considers the operationalization of the model previously presented. First, the criteria weighting procedure is described followed by the presentation of the ELECTRE TRI-nC model.

5.1. Criteria Weighting

The ponderation of the weights was done through the revised Simos' procedure (Figueira and Roy, 2002). This procedure is easy to understand even for those who do not have a great knowledge about MCDA. It presents two phases: the first one consists in gathering data with the decision maker (which in the present problem is a hypothetical decision maker); and the second part consists in the calculation to get the weights of each criterion.

In the first part it is defined a set of cards, being one card correspondent to one of the criteria previously defined. It is also defined a set of white cards. Then, according with the decision maker, the cards of the criteria are ordered by importance in a hierarchy. The card on the top presents the greatest weight (the most important) while the card on the bottom presents the smallest weight (the least important). In the case that decision maker considers that there are criteria with the same importance, the cards of these criteria are in the hierarchical level. After this, the white cards are added. The more white cards there is between two criteria, the bigger is the difference of importance between the two. If there are not white cards in the hierarchy, it is considered that the difference of two sequential levels of the hierarchy corresponds to one unit. If there is a white card between two levels then the difference of importance is considered two units, and so on.

The first step consisted in defining the proposed hierarchy shown in Figure 6.

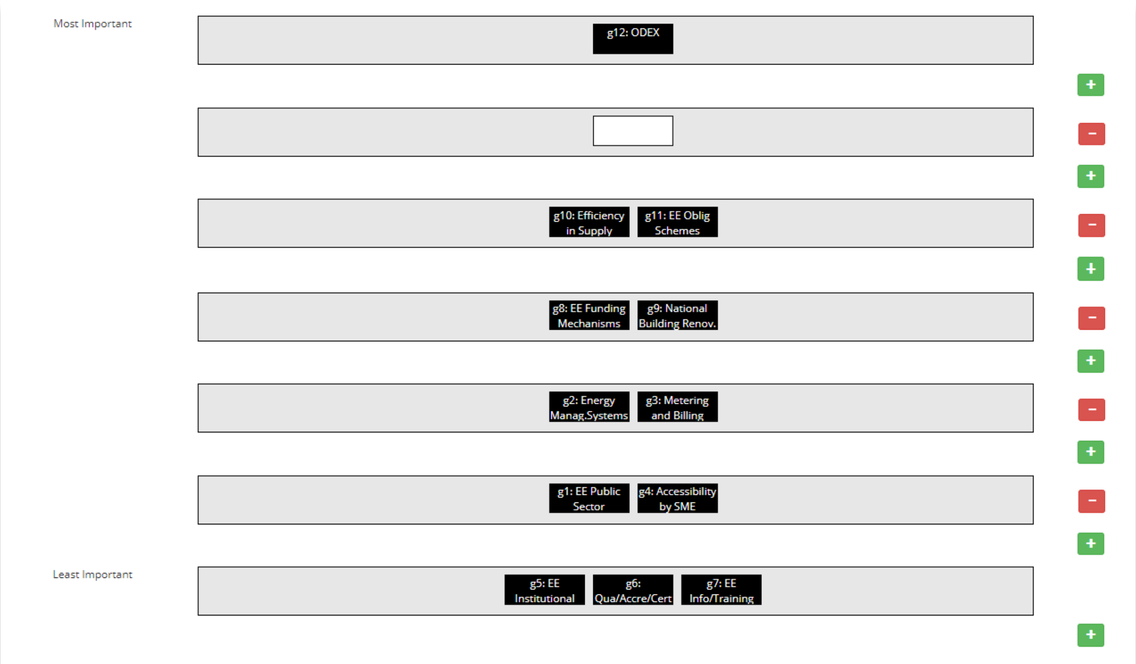


Figure 6: Hierarchy of Criteria – Hypothesis 1

The proposed hierarchy is defined by 7 levels, being the first the most important and the last the least important. In the first level, it was considered the criterion (**g12**) ODEX , since it reflects the technical EE achievements of each country, being these achievements the end goal of EE governance. The second level presents a white card stating the difference of importance of the criterion of the first level and the criteria of the third level. The third level considers (**g10**) Efficiency in Supply and (**g11**) Effectiveness of the EE Obligation Schemes. The fourth level considers (**g8**) Availability of EE Funding Mechanisms and (**g9**) Scope of National Building Renovation Strategy. The fifth level presents (**g2**) Availability of Energy Management Systems and (**g3**) Metering and Billing Reliability, while the sixth level presents (**g1**) EE performance of Public Sector and (**g4**) Accessibility of Energy Services by SME. The last level considers (**g5**) EE Promotion by Institutional Structures, (**g6**) Effectiveness of Qualification, Accreditation and Certification Schemes and (**g7**) EE Information and Training Availability.

The second part consisted in the implementationof this procedure in the Decspace[4] website. After introducing the hierarchy of criteria, it was necessary to define the number of times that the first criterion is more important than the last, which is represented by the variable Z. This variable was considered as 10 (Z=10). After this procedure, the weights were calculated (Figure 7).

Criterion	Non-Normalized Weight	Normalized Weight
g1: EE Public Sector	2.5	4.9
g2: Energy Manag.Systems	4	7.8
g3: Metering and Billing	4	7.8
g4: Accessibility by SME	2.5	4.9
g5: EE Institutional Structures	1	2
g6: Qua/Accre/Cert	1	2
g7: EE Info/Training	1	2
g8: EE Funding Mechanisms	5.5	10.8
g9: National Building Renov. Strat.	5.5	10.8
g10: Efficiency in Supply	7	13.7
g11: EE Oblig Schemes	7	13.7
g12: ODEX	10	19.6

Figure 7: Criteria Weights – Hypothesis 1

Due to the non-existence of a formal decision maker, it was also considered a second hypothesis of weights. This hypothesis defined all criteria as having the same importance, being considered as a neutral hypothesis. The results of both hypotheses will be compared after the final implementation of the model in order to complement the conclusions of this study. The same process was used in the operationalization of the second procedure(Figures 8 and 9).

4 http://decspace.sysresearch.org/

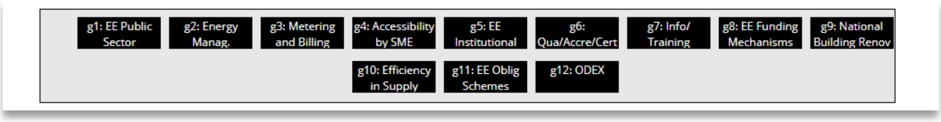


Figure 8: Hierarchy of Criteria – Hypothesis 2

Criterion	Non-Normalized Weight	Normalized Weight
g1: EE Public Sector	1	8.3
g2: Energy Manag.Systems	1	8.3
g3: Metering and Billing	1	8.3
g4: Accessibility by SME	1	8.3
g5: EE Institutional Structures	1	8.3
g6: Qua/Accre/Cert	1	8.3
g7: EE Info/Training	1	8.3
g8: EE Funding Mechanisms	1	8.3
g9: National Building Renov. Strat.	1	8.4
g10: Efficiency in Supply	1	8.4
g11: EE Oblig Schemes	1	8.4
g12: ODEX	1	8.4

Figure 9: Criteria Weights – Hypothesis 2

After the definition of the criteria's weights, it was carried out the model execution.

5.2. Definition of the Model's Elements

Categories	Performance	Reference actions	Criteria											
			g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12
C_4	Very Good	b_4^1	1	1	1	1	1	1	1	1	1	1	1	60
		b_4^2	1	1	2	1	1	1	1	1	1	1	1	80
C_3	Good	b_3^1	2	2	2	1	1	1	1	1	1	1	2	80
		b_3^2	3	2	3	1	2	1	1	2	2	2	3	85
C_2	Moderate	b_2^1	3	3	3	2	3	2	2	3	2	3	3	85
		b_2^2	5	3	4	3	3	3	3	3	3	4	3	90
C_1	Weak	b_1^1	7	4	7	3	4	3	3	4	3	5	4	90

Table 11: Performances of the reference actions of each category.

In this problem, the actions to be classified in the pre-defined categories are the current 28 MS of the EU. Four categories were defined, ordered by performance, to describe the performance of EE Governance of the MS:

- C_4 – Very Good performance;
- C_3 – Good performance;
- C_2 – Moderate performance;
- C_1 – Weak performance.

All categories were defined with two reference actions, except C_4, which corresponds to the lowest performance (Table 11). C_4 is defined by two reference actions represented by b_4^1 and b_4^2, C_3 is defined by b_3^1 and b_3^2, C_2 is defined by b_2^1 and b_2^2, and C_1 is only defined by b_1^1.

	Criteria											
Thresholds	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12
q	-	-	-	-	-	-	-	-	-	-	-	3
p	-	-	-	-	-	-	-	-	-	-	-	5

Table 12: Preference and Indifference thresholds of each criterion.

As explained in Section 3.2.1., the ELECTRE TRI-nC method uses thresholds of preference and indifference to model the imperfect character of the data, as well as the arbitrariness that affects the definition of the criteria. These thresholds were defined as shown in Table 12. Note that there were no thresholds defined for the criteria that is described by qualitative scales of levels, due to their nature these thresholds are not applicable. This happens because the attribution of a level in a criterion for a certain action is exclusive (it is not possible for an action to be defined by two different levels of a qualitative scale). Note that it would be possible to add veto thresholds as well. In this case, it was not considered any veto threshold. However, this attribution may vary with the preferences of different decision makers.

5.3. Insertion of parameters

The software that allows running the suggested model is named MCDA Ulaval[5]. It is a tool programmed in Java and it implements several MCDA methods. As it can be seen in Figure 10, this software is simple and so it is quick to understand its functionalities. When the programme is opened for the first time there are only two blank tables, the Alternative Set and the Criterion Set. The buttons (1) on the top of the window allow the introduction of the actions. The name and description are introduced directly in the table.

[5] Available for free in http://cersvr1.fsa.ulaval.ca/mcda/?q=en/node/4 (Accessed 20th January, 2018)

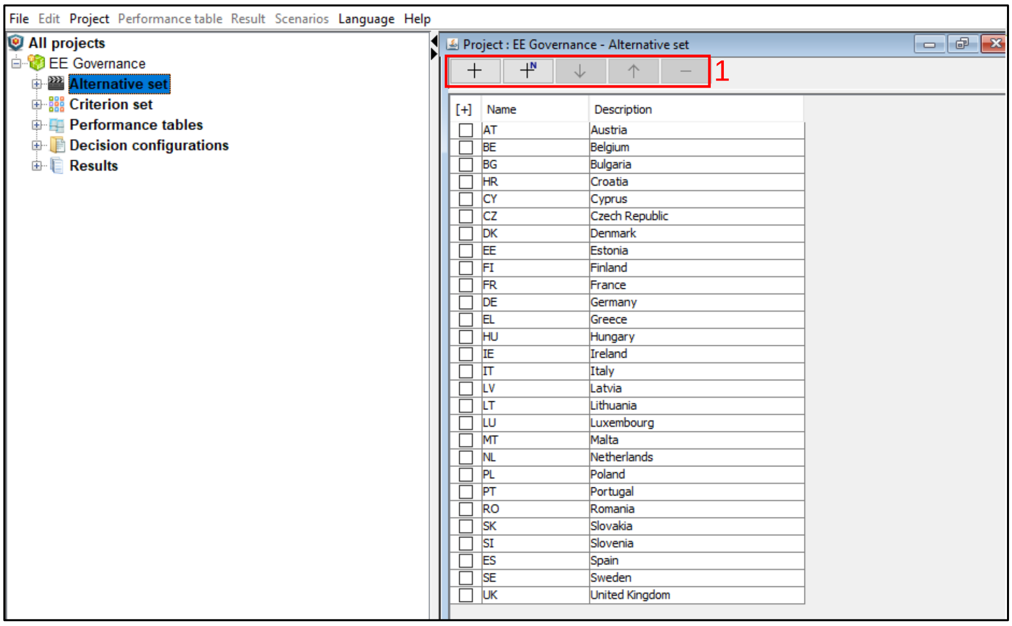


Figure 10: Introduction of the action in MCDA Ulaval.

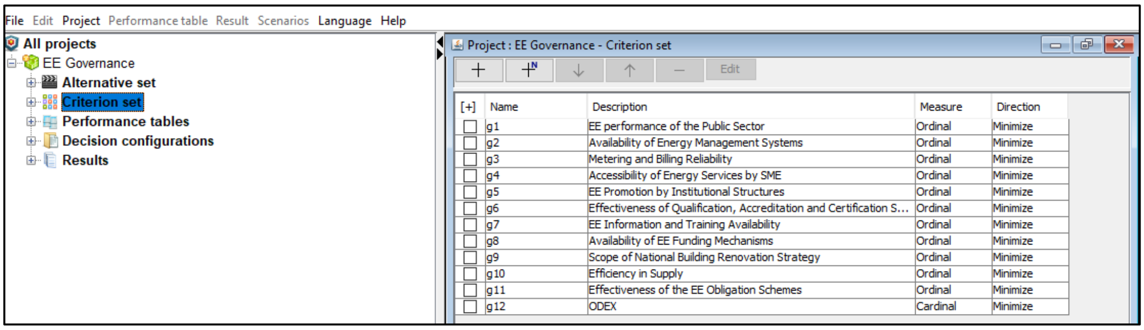


Figure 11: Introduction of criteria in MCDA Ulaval.

The next step is the insertion of the criteria, as shown in Figure 11. Just like in the alternative table, all values can be introduced directly in the table. At this point, it is necessary to define the type of measure (ordinal or cardinal) and the direction (minimize or maximize) for each criterion. In this case, all criteria will be minimized. Regarding the type of scales, the only important matter in ordinal scales are the values of the scale, while the distance of values does not have any meaning regarding its intensity. In these cases, it is not possible to compare differences of performances, and for that reason the indifference and preference thresholds are not applicable. On the contrary, in cardinal scales the distance of values in a scale is relevant since it translates the difference of intensity. This is only applicable in criterion g12.

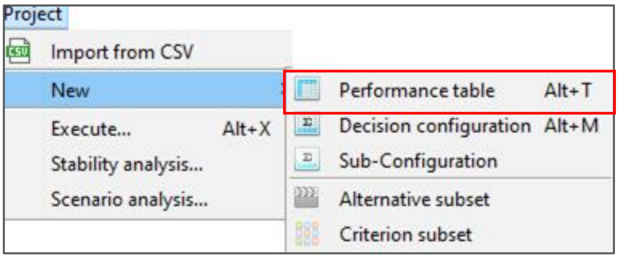


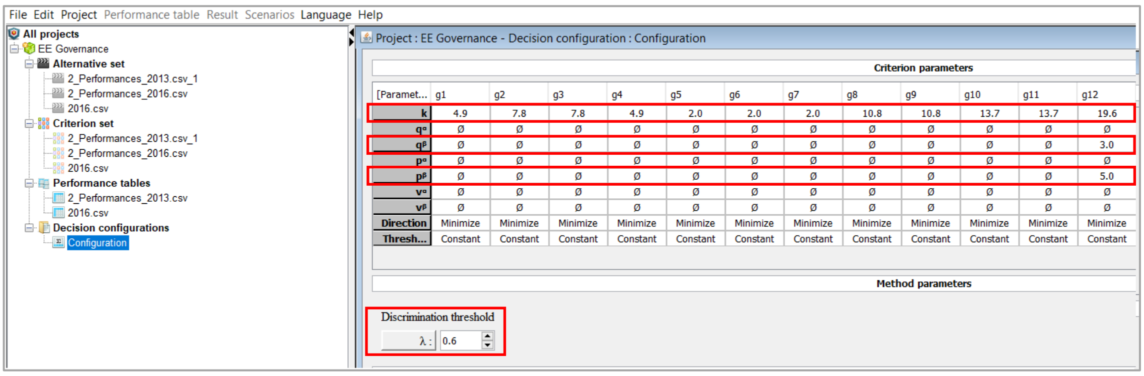
Figure 12: Menu for introduction of the performance table.

Project : EE Governance - Performance table : 2_Performances_2013.csv

[Alternative]	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12
Extent	6	3	6	2	3	2	2	3	2	4	3	29,00
AT	2	1	1	1	1	1	1	1	2	2	1	82,00
BE	2	3	4	1	4	3	1	3	3	5	4	75,00
BG	3	2	1	1	4	1	1	4	1	1	3	66,00
HR	4	2	3	1	2	1	1	3	2	1	2	84,00
CY	3	3	5	2	4	1	1	2	2	4	2	78,00
CZ	3	2	1	1	3	1	2	1	2	2	2	79,00
DK	3	1	1	1	2	1	1	1	2	1	2	84,00
EE	5	2	3	1	2	1	1	3	3	4	2	75,00
FI	2	2	3	1	1	1	1	4	1	1	2	92,00
FR	3	2	5	3	1	2	1	4	2	3	3	85,00
DE	2	2	7	1	1	2	3	3	1	4	3	82,00
EL	2	2	3	1	4	2	1	3	1	1	2	70,00
HU	2	2	3	1	4	1	1	4	1	2	2	78,00
IE	2	2	3	1	3	1	1	3	2	2	2	73,00
IT	1	2	4	1	1	1	1	2	1	1	2	87,00
LV	3	2	4	3	3	1	3	3	1	2	2	70,00
LT	5	2	3	2	2	2	3	3	3	2	4	73,00
LU	2	2	3	1	4	1	1	4	1	2	1	83,00
MT	2	2	2	2	2	1	1	1	1	2	3	82,00
NL	2	2	4	2	1	2	1	4	1	1	2	76,00
PL	4	2	5	2	2	1	1	2	1	3	2	73,00
PT	7	4	7	2	1	3	3	1	3	5	3	73,00
RO	2	2	5	2	3	1	1	1	1	2	3	66,00
SK	7	4	7	3	1	3	1	1	3	5	4	63,00
SI	4	2	3	1	3	1	1	1	2	1	2	78,00
ES	1	2	3	1	1	1	1	1	1	1	2	82,00
SE	1	2	3	1	1	2	1	4	1	2	1	75,00
UK	3	2	3	1	3	1	1	3	1	1	1	76,00

Figure 13: Performance table in MCDA Ulaval.

Then, through the menu shown in Figure 12 (Project – New – Performance Table), the performance tables are inserted in the software (Figure 13). These tables were previously prepared in an excel sheet in the csv format. This procedure happens for two tables of the two years in study – 2013 and 2016.



[Paramet...	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12
k	4.9	7.8	7.8	4.9	2.0	2.0	2.0	10.8	10.8	13.7	13.7	19.6
q^{α}	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
q^{β}	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	3.0
p^{α}	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
p^{β}	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	5.0
v^{α}	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
v^{β}	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
Direction	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize
Thresh...	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant	Constant

Figure 14: Criterion parameters and Discrimination threshold.

The next step consists in the insertion of the values of the weight (k) of each criterion, defined in the Section 5.1. (Figure 14). The thresholds of indifference (q) and preference (p) were also defined in the same table. The credibility level (λ), or the minimum degree of credibility, which is necessary for validating or not an outranking, was also defined in this section. For lower values of λ, there is less requirement with the existent uncertainties which creates more indifference occurrences. The opposite happens for higher levels of λ. It is typical to use values of λ between 0.6 and 0.7. In this case, λ was defined as 0.6.

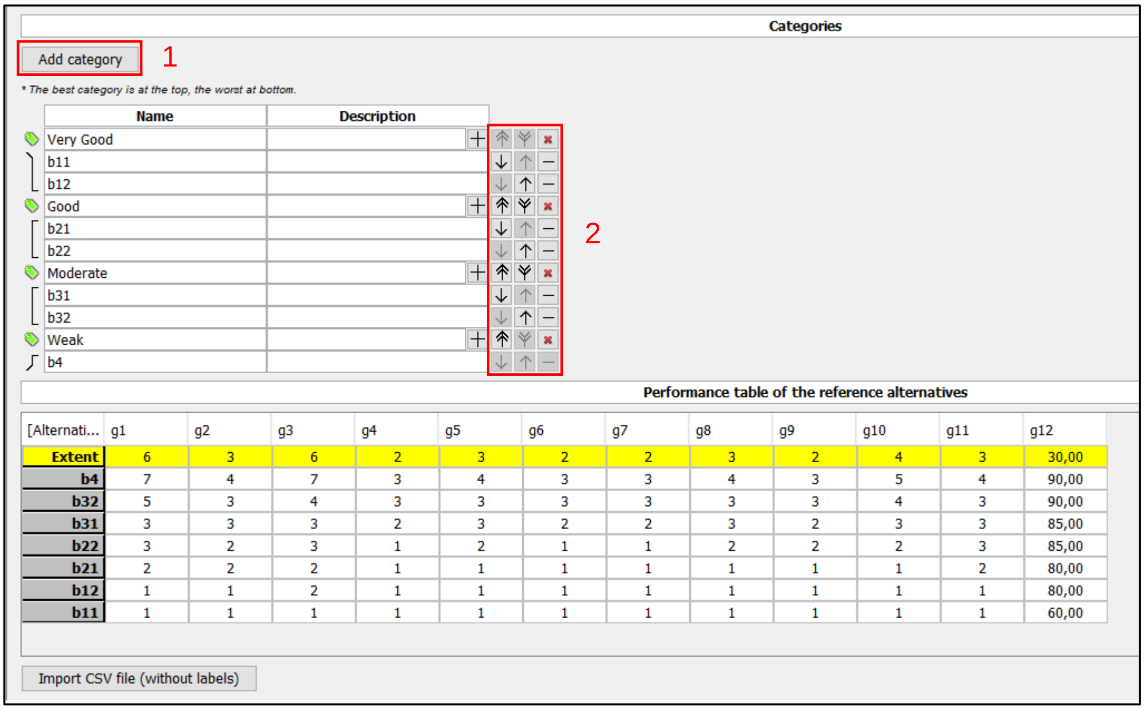


Figure 15: Reference actions and categories in MCDA Ulaval.

Figure 15, illustrates the insertion of the performances of the reference actions. A click in button 1 adds a category. The buttons in menu 2 allow to reorder the actions of reference and categories. It is possible to add the name and descriptions of each reference action directly in the table. The performance values are also added directly in the table with the reference actions.

The next section presents the main results obtained with the model.

5.4. Implementation of the Model

After all parameters are inserted, the model starts running in the menu *Project*, and then *Execute* (Figure 16). If there is any parameter that is not valid, a message appears on the screen. Since there are two performance tables, one for 2013 and another for 2016, this process was done twice for each hypothesis of weights. Note that in the model analysed in the present section, the parameters used are those defined in the previous three subchapters (Z=10 and $\lambda = 0.6$).

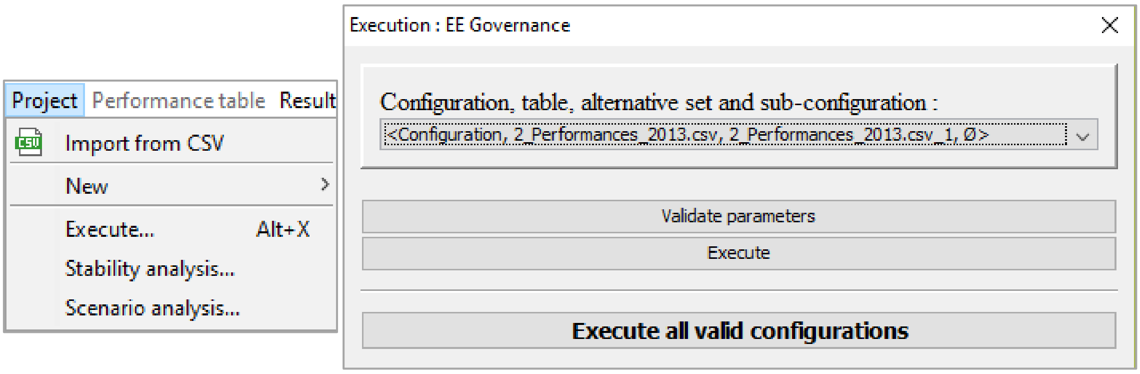


Figure 11: Execution menu in MCDA Ulaval.

The results of the first model can be seen in Figure 17 for both years. This first model corresponds to the definition of weights in Hypothesis 1. Note that, in some cases, there is a non-agreement between the maximum and minimum categories. This is justified due to the lack of enough data to attribute an action to only one category. These situations are usually solved with the input of a formal decision maker in order to attribute the action to the most adequate category.

Regarding the year of 2013, the majority of the countries are evaluated in the C_3 – Good category. There are four countries (14,3%) evaluated as minimum C_3 – Good and maximum C_4 – Very Good: Austria, Bulgaria, Spain and the United Kingdom. There are 18 countries (64,3%) attributed to C_3 – Good: Croatia, Czech Republic, Cyprus, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Romania, Slovenia and Sweden. Two countries are evaluated between categories C_2 – Moderate and C_3 – Good (7,1%): France and Germany. The three countries attributed to C_2 – Moderate (10.7%) are Belgium, Lithuania and Portugal and the only country classified in category C_1 – Weak (3.6%) is Slovakia.

In 2016 it is possible to check a soft overall improvement. This time there are 7 countries (25.0%) evaluated as minimum C_3 – Good and maximum C_4 – Very Good: Austria, Bulgaria, Denmark, Greece, Malta, Portugal and Spain. The only country between categories C_2 – Moderate and C_3 – Good (3.6%) is France and then, there are three countries attributed to C_2 – Moderate – Belgium, Lithuania, and Romania. Figure 18 provides a visual way to understand the evolution of each country between 2013 and 2016. The cases of uncertainty between two categories are defined as half categories (e.g., if it is between C_3 and C_4 is represented as 3.5).

Most countries maintained their category, 5 improved and 2 got worse. The two countries that presented worse results in 2016 are Romania and the United Kingdom. The situation of Romania is justified by the lack of data since its NEEAP of 2017 was not available in the EC website and the document used as source of information was the Annual Report of 2017 – which is quite limited in comparison to the NEEAP. In the end, there was significant lack of information to justify the measures. Regarding the United Kingdom, the drop is caused by the lack of quality in the information from NEEAP 2017, since many measures were not described with a good level of detail, and for that reason there was lack of evidence on the implementation of several measures. The United Kingdom's ODEX also dropped slightly in comparison to 2013. Portugal and Slovakia presented the best evolutions in the results, but both are justified with the lack of data available in 2014 NEEAPs. The Portuguese NEEAP of 2014 was a document of very poor quality regarding its purpose. Indeed, it described many actions for the EE improvement, but it did not respond to the matters exposed in EED. For this reason, the specific and needed information was not reported and so it was not possible to understand the real efforts for the year of 2013. In 2017, Portugal presented a proper NEEAP with the expected information and therefore was evaluated accordingly. A similar situation happened regarding Slovakia, since the NEEAP of 2014 was not available, and the source of information used for the 2013 model was its Annual Report of 2014, which is quite incomplete in comparison with the NEEAP. The other three countries that improved their categories in this period were Germany, Greece and Malta. Their improvements were supported by the better quality of evidence of their implemented measures reported in NEEAP of 2017.

The Balkan region presented good performances overall, especially Bulgaria and Greece. Both present very good evaluations in the most important criteria (g12), the ODEX, which sustains their good overall performance. At the same time, it is interesting that France and Germany did not present solid performances. Indeed, for both cases, the quality of the reported information in the NEEAPs was not generally detailed and based on evidence. Belgium was another example of a central European country with a performance that falls short. In both years, Belgium was only able to achieve the category C_2 – Moderate category.

Statistics :

<min,max>	#	%
<1,1>	1	3,5714%
<2,2>	3	10,7143%
<2,3>	2	7,1429%
<3,3>	18	64,2857%
<3,4>	4	14,2857%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_4 Very Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_3 Good
DE	C_2 Moderate	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_2 Moderate	C_2 Moderate
RO	C_3 Good	C_3 Good
SK	C_1 Weak	C_1 Weak
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_4 Very Good

Statistics :

<min,max>	#	%
<2,2>	3	10,7143%
<2,3>	1	3,5714%
<3,3>	17	60,7143%
<3,4>	7	25,0000%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_4 Very Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_4 Very Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_3 Good
DE	C_3 Good	C_3 Good
EL	C_3 Good	C_4 Very Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_4 Very Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_3 Good	C_4 Very Good
RO	C_2 Moderate	C_2 Moderate
SK	C_3 Good	C_3 Good
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

Figure 17: Results for 2013 (left) and 2016 (right) for the set of weights defined in Hypothesis 1.

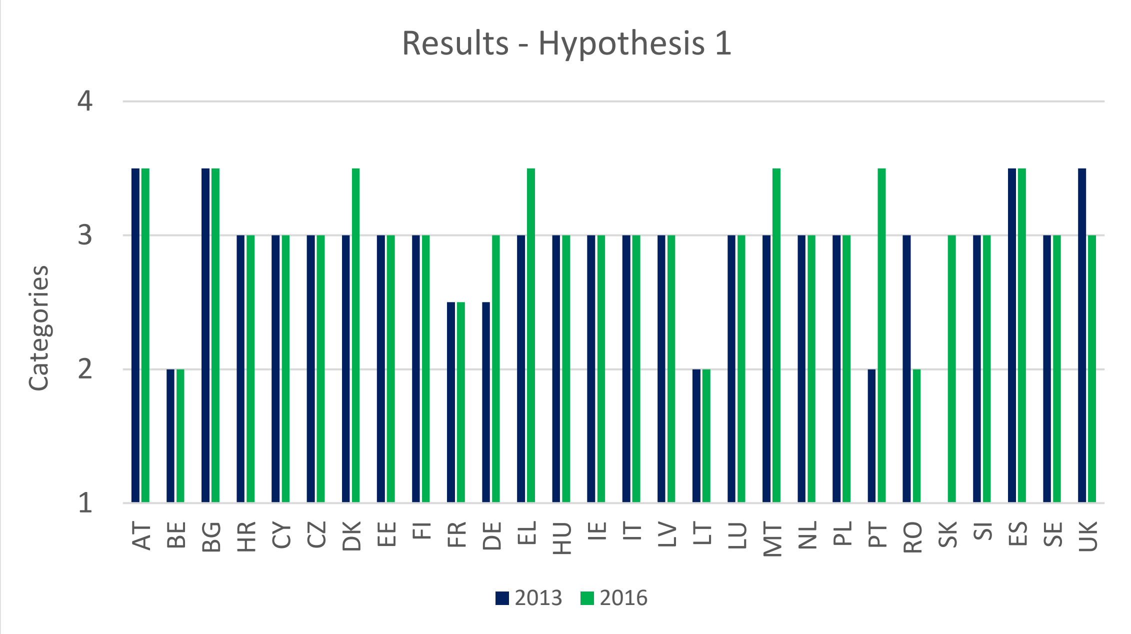


Figure 18: Evolution of performances on EE governance capacities of the 28 MS in EU – Hypothesis 1.

The Hypothesis 2, which considers all criteria equally important, presented results generally aligned with Hypothesis 1, as it can be seen in Figure 19.

For the year of 2013, there are five differences in comparison to Hypothesis 1:

- Cyprus dropped from a clear C_3 – Good to a minimum of C_2 – Moderate and a maximum of C_3 – Good;
- Denmark raised from C_3 – Good to a minimum C_3 – Good and maximum C_4 – Very Good;
- France dropped from a minimum of C_2 – Moderate and a maximum of C_3 – Good to C_2 – Moderate category;
- And, Bulgaria and United Kingdom dropped from a minimum of C_3 – Good and maximum C_4 – Very Good to a clear C_3 – Good.

For the year of 2016, there are also four differences in comparison to Hypothesis 1:

- Bulgaria dropped from a minimum C_3 – Good and maximum C_4 – Very Good to a clear C_3 – Good;
- France also dropped from a minimum of C_2 – Moderate and a maximum of C_3 – Good to C_2 – Moderate category;
- Greece dropped from a minimum of C_3 – Good and maximum C_4 – Very Good to a clear C_3 – Good;
- And, Lithuania dropped from a C_2 – Moderate category to the lowest performance of 2016, a minimum of C_1 – Weak and maximum C_2 – Moderate.

Statistics :		
<min,max>	#	%
<1,1>	1	3,5714%
<2,2>	4	14,2857%
<2,3>	2	7,1429%
<3,3>	18	64,2857%
<3,4>	3	10,7143%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_3 Good
HR	C_3 Good	C_3 Good
CY	C_2 Moderate	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_4 Very Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_2 Moderate
DE	C_2 Moderate	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_2 Moderate	C_2 Moderate
RO	C_3 Good	C_3 Good
SK	C_1 Weak	C_1 Weak
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

Statistics :		
<min,max>	#	%
<1,2>	1	3,5714%
<2,2>	3	10,7143%
<3,3>	19	67,8571%
<3,4>	5	17,8571%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_3 Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_4 Very Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_2 Moderate
DE	C_3 Good	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_1 Weak	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_4 Very Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_3 Good	C_4 Very Good
RO	C_2 Moderate	C_2 Moderate
SK	C_3 Good	C_3 Good
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

Figure 19: Results for 2013 (left) and 2016 (right) for Hypothesis 2 (equal weights for all criteria).

The evolution of the performances of all 28 MS between 2013 and 2016 for Hypothesis 2 can be seen in Figure 20 below.

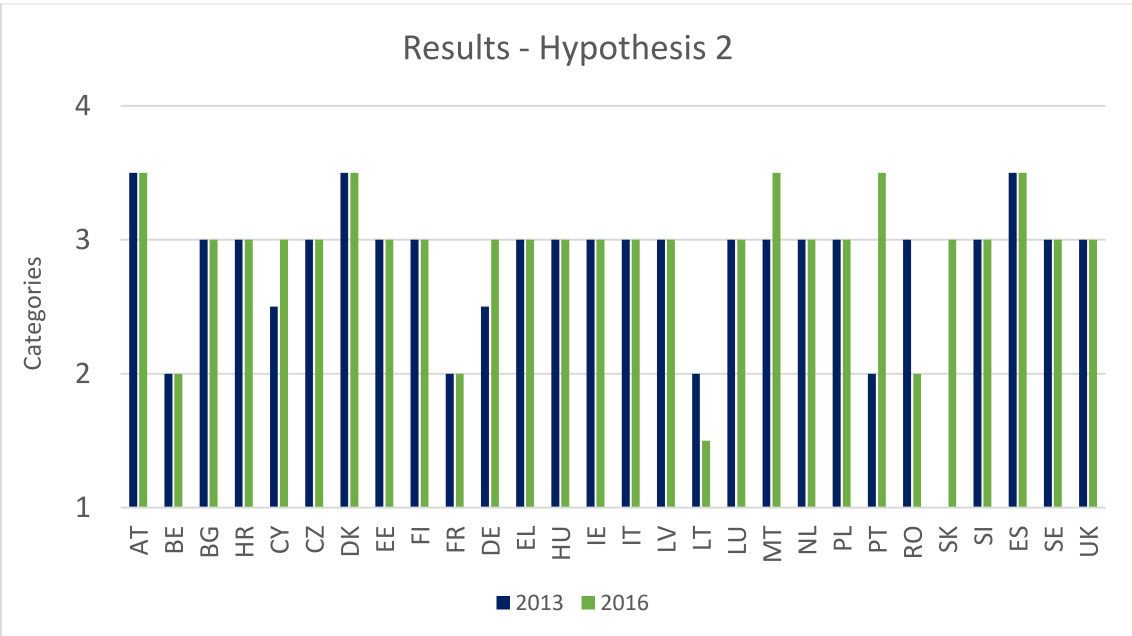


Figure 20: Evolution of performances on EE governance capacities of the 28 MS in EU – Hypothesis 2.

The next section presents an analysis of the model's behaviour and how it is influenced by the different parameters.

5.5. Sensitivity Analysis

This section evaluates the influence of the change of the parameters in the final results of the model. The objective is to understand the robustness of the presented analysis, first by increasing the value of the credibility index and then by changing the value of Z.

5.5.1. Changing the credibility index λ

As it was previously stated, λ typically varies between 0.6 and 0.7, so this time the model is implemented with the credibility index as 0.7. The results are shown in Figure 21.

In Figure 21.a), which corresponds to the model of weights defined in Hypothesis 1 and the year of 2013, the differences of the results comparing with the model with the same hypothesis and year, but λ = 0.6, are the following:

- Bulgaria drops to C_3 – Good;
- France and Germany drop to C_2 – Moderate;
- Slovakia improves to a minimum of C_1 – Weak and a maximum of C_2 – Moderate;
- And, the United Kingdom drops to C_3 – Good.

In Figure 22.b), it is possible to identify the following changes comparing to the same model for the year of 2016:

- Bulgaria, Denmark and Greece drop to C_3 – Good;
- And, France drops to C_2 – Moderate.

The same analysis can be done for the Hypothesis 2, represented in Figure 22 c) and d). Regarding the year of 2013 and the comparison with the same model and different λ, the results for λ = 0.7 differ in the following countries:

- Denmark drops to C_3 – Good;
- And, Slovakia also improves to a minimum of C_1 – Weak and a maximum of C_2 – Moderate.

For the year of 2016, the same comparison differs in the following evaluations

- Denmark, Malta and Portugal drop to C_3 – Good.

Statistics :

<min,max>	#	%
<1,2>	1	3,5714%
<2,2>	5	17,8571%
<3,3>	20	71,4286%
<3,4>	2	7,1429%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_3 Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_2 Moderate
DE	C_2 Moderate	C_2 Moderate
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_2 Moderate	C_2 Moderate
RO	C_3 Good	C_3 Good
SK	C_1 Weak	C_2 Moderate
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

Statistics :

<min,max>	#	%
<2,2>	4	14,2857%
<3,3>	20	71,4286%
<3,4>	4	14,2857%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_3 Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_2 Moderate
DE	C_3 Good	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_4 Very Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_3 Good	C_4 Very Good
RO	C_2 Moderate	C_2 Moderate
SK	C_3 Good	C_3 Good
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

a) 2013 – Hypothesis 1 b) 2016 – Hypothesis 1

Statistics :

<min,max>	#	%
<1,2>	1	3,5714%
<2,2>	4	14,2857%
<2,3>	2	7,1429%
<3,3>	19	67,8571%
<3,4>	2	7,1429%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_3 Good
HR	C_3 Good	C_3 Good
CY	C_2 Moderate	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_2 Moderate
DE	C_2 Moderate	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_2 Moderate	C_2 Moderate
RO	C_3 Good	C_3 Good
SK	C_1 Weak	C_2 Moderate
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

c) 2013 – Hypothesis 2

Statistics :

<min,max>	#	%
<1,2>	1	3,5714%
<2,2>	3	10,7143%
<3,3>	22	78,5714%
<3,4>	2	7,1429%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_3 Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_2 Moderate
DE	C_3 Good	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_1 Weak	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_3 Good	C_3 Good
RO	C_2 Moderate	C_2 Moderate
SK	C_3 Good	C_3 Good
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

d) 2016 – Hypothesis 2

Figure 21: Results for λ=0.7.

5.5.2. Changing parameter Z

This section explores the behaviour of the model by changing the value of Z in the process of definition of the weights. Note that Z corresponds to the the number of times that the most important criterion is more important than the least important.

Statistics :

<min,max>	#	%
<1,1>	1	3,5714%
<2,2>	3	10,7143%
<2,3>	2	7,1429%
<3,3>	18	64,2857%
<3,4>	4	14,2857%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_4 Very Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_3 Good
DE	C_2 Moderate	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_2 Moderate	C_2 Moderate
RO	C_3 Good	C_3 Good
SK	C_1 Weak	C_1 Weak
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_4 Very Good

a) Year 2013, Z=9.

Statistics :

<min,max>	#	%
<2,2>	3	10,7143%
<2,3>	1	3,5714%
<3,3>	17	60,7143%
<3,4>	7	25,0000%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_4 Very Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_4 Very Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_3 Good
DE	C_3 Good	C_3 Good
EL	C_3 Good	C_4 Very Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_4 Very Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_3 Good	C_4 Very Good
RO	C_2 Moderate	C_2 Moderate
SK	C_3 Good	C_3 Good
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

b) Year 2016, Z=9.

<min,max>	#	%
<1,1>	1	3,5714%
<2,2>	3	10,7143%
<2,3>	2	7,1429%
<3,3>	18	64,2857%
<3,4>	4	14,2857%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_4 Very Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_3 Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_3 Good
DE	C_2 Moderate	C_3 Good
EL	C_3 Good	C_3 Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_3 Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_2 Moderate	C_2 Moderate
RO	C_3 Good	C_3 Good
SK	C_1 Weak	C_1 Weak
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_4 Very Good

c) Year 2013, Z=11.

<min,max>	#	%
<2,2>	3	10,7143%
<2,3>	1	3,5714%
<3,3>	17	60,7143%
<3,4>	7	25,0000%

ACTION	Minimum	Maximum
AT	C_3 Good	C_4 Very Good
BE	C_2 Moderate	C_2 Moderate
BG	C_3 Good	C_4 Very Good
HR	C_3 Good	C_3 Good
CY	C_3 Good	C_3 Good
CZ	C_3 Good	C_3 Good
DK	C_3 Good	C_4 Very Good
EE	C_3 Good	C_3 Good
FI	C_3 Good	C_3 Good
FR	C_2 Moderate	C_3 Good
DE	C_3 Good	C_3 Good
EL	C_3 Good	C_4 Very Good
HU	C_3 Good	C_3 Good
IE	C_3 Good	C_3 Good
IT	C_3 Good	C_3 Good
LV	C_3 Good	C_3 Good
LT	C_2 Moderate	C_2 Moderate
LU	C_3 Good	C_3 Good
MT	C_3 Good	C_4 Very Good
NL	C_3 Good	C_3 Good
PL	C_3 Good	C_3 Good
PT	C_3 Good	C_4 Very Good
RO	C_2 Moderate	C_2 Moderate
SK	C_3 Good	C_3 Good
SI	C_3 Good	C_3 Good
ES	C_3 Good	C_4 Very Good
SE	C_3 Good	C_3 Good
UK	C_3 Good	C_3 Good

d) Year 2016, Z=11.

Figure 22: Results with Z=9 and Z=11, both for λ=0.6.

It is possible to see in Figure 22 the results of the models for Z = 9 and Z = 11. For Z = 9 (λ=0.6), the results were the same as Z = 10 (λ=0.6). The results for Z = 11 (λ=0.6) were also the same as for Z = 10 (λ=0.6).The results of the model for Z = 9 and Z = 11 with λ=0.7 are exactly the same of the model for Z = 10 and λ=0.7.

The model was also implemented for Z = 6 and Z = 14 for both credibility indexes. The results for Z = 6 and λ=0.6 were the same as for Z = 10 and λ= 0.6. For Z = 6 and λ=0.7, the only difference comparing to Z = 10 and λ=0.7 is the classification of Portugal in 2016, which increased for a minimum of C_3 – Good and maximum C_4 – Very Good. For Z = 14 and λ = 0.6, the results also maintained the same as for Z = 10 and λ = 0.6. The only difference in results in Z = 14 and λ = 0.7 in comparison with Z = 10 and λ = 0.7 was the clear classification of Greece as C_4 – Very Good in 2016. In a general way, the results were very consistent even with different parameters used in the model.

5.6 Observations

Due to the limitation of two decimals places in the software MCDA Ulaval, it is possible that some precision has been lost in the implementation of the model.

As previously referred, there were some cases where it was not possible to attribute only one category to a country and instead it was defined a minimum and a maximum category. These situations happened due to the lack of enough data to define only one category. All results seemed consistent and any evaluation was considered unacceptable.

The analysis of the behaviour of the model with different credibility indexes and weight ponderations showed that the results were generally solid and did not present many variations in comparison with the first version of the model.

6. Conclusions and Future Research

EE, or as defined in the EED "the ratio of output of performance, service, goods or energy, to input of energy" is a hot topic in world's policy nowadays, due to its beneficial impact towards a sustainable energy future. Besides technological improvements, EE can also be achieved by changing behaviours on how resources are managed. For this reason, it can be achieved with relative low investment and effort. The benefits brought by EE improvement are many and spread in different areas. Regarding its environmental impact, it contributes to the reduction of GHG emissions. Economically, EE contributes to competitiveness and to reducing energy costs. Indirectly, it contributes to the increase of disposable income and improvement of energy access, as well as to job creation. Still, probably the main reason EE is such a great deal is the urgent need to establish a new *status quo* in the global energy market. Reaching environmental sustainability should be the biggest priority nowadays, but managing the required transition is also very important to keep economic and social factors balanced.

The second chapter starts by providing a small context on the mechanisms of the energy sector and the current energy market trends. Then, the three main issues associated with EE are defined: (1) the barriers, which are mechanisms that inhibit a decision or behaviour that appears both energy and economically efficient (Makridou, 2016); (2) the rebound effect, which occurs when EE is used to obtain more energy services rather than achieving energy demand reduction (IEA, 2014); and, (3) the EE gap, which consists in the difference between the technical feasible and the economically viable improvements and the actual level of investment on those (Pereira, 2014). The next sections of this chapter focus on the relationship between EE and the EU. Here, it is possible to understand that the EED is one of the most important tools of the EU to deal with EE in all MS. This Directive dedicated exclusively to EE established binding targets and mandatory measures that all countries in the EU must comply. The report of these measures is ensured by the NEEAPs that are delivered by the 28 countries to the EU in intervals of 4 years. These long reports describe the current efforts planned and implemented regarding the requirements of each article of the EED. Considering that there is a great probability of the targets do get achieved in 2020, the EU realised that is necessary to increase the governance efforts in Europe in order to compensate what was underachieved so far. In order to increase governance efforts, it is important to understand the current capacities on EE governance of all countries. This understanding will help to define an alignment between all individual strategies to reach easily the final common goal.

In the third chapter, two topics were explored: EE Governance and MCDA methods. These were the focus since the following chapters aim to resolve a problem in EE Governance through an MCDA method named ELECTRE TRI-nC. Regarding EE Governance, it can be concluded that there is a significant lack of literature coverage on the topic. Still, it was possible to understand some discussed problems and to analyse a holistic proposal of the framework proposed by Jollands and Ellis (2009). MCDA methods might be applied in different type of problems with different objectives, and in this case, the aim will be the consideration of a sorting problem. This will consist in the assigning of alternatives (the 28 MS) to a predefined set of categories. Specifically, the chosen method was the ELECTRE TRI-nC due to the features of this problem, such as: more than three criteria, the evaluation is based on an ordinal scale and there is a strong heterogeneity associated with these scales.

The fourth chapter consists in the beginning of the construction of the model. In a first phase, the existing available data was compared with the EE governance framework of the Jollands and Ellis (2009) in order to understand what type of data was accessible and what type was not. The next step was to understand what dimensions of the framework were not covered by the data, and how this could be overcome. In the end, it was possible to gather information that covered all dimensions, mostly from the NEEAPs of the years 2014 and 2017 and other two databases to complement the topics that were not so well developed in these reports (ODYSSEEY-MURE and WEC – EE Policy and Measures databases). Note that the reported information of each NEEAP was considered in the model of the previous years, 2013 and 2016. With all the data gathered, it was possible to define the areas of concern, the fundamental points of view and the criteria that would support the operationalization of the model. Then, the evaluation scales of each criterion were defined. The final part of the chapter consisted in the definition of the performance tables for the years of 2013 and 2016 for the 28 countries.

The fifth chapter presented the model execution and its results. After the definition of the weights and the model parameters, the model was implemented on the software MCDA Ulaval. The inherent procedures were briefly described. Since there is not a formal decision maker, two scenarios were defined for the weights distribution – Hypothesis 1, which presented a hierarchy of the criteria and Hypothesis 2, which worked as a control version since it considered all weights with the same importance. The results appeared quite consistent, even after the sensitivity analysis. In each model considered, the 28 countries were attributed to 4 categories ordered by preference: C_1 – Very Good, C_2 – Good, C_3 – Moderate and C_4 – Weak. None of the countries was clearly attributed to C_1 – Very Good. Due to lack of data, there were some cases where a country would be attributed to a minimum and a maximum category, since it was not possible to be assigned clearly to one of them. The countries that showed better overall performances were Austria and Spain. The country that presented the worst performance in both years was Latvia, even though Slovakia presented worst results in 2013 (justified by the lack of reporting quality of the 2013 NEEAP). Belgium, France and Germany had performances below the average in almost all model versions. In the end, most of the countries were attributed to C_2 – Good category, which indicates that mandatory measures by the EU present a good global level of compliance.

Indeed, there are some considerations that must not be forgotten. First, note that this dissertation is a first approach on the evaluation of EE governance capacities and there is a general lack of data to support all defined criteria. In this case, since most of the criteria was based on information reported in the NEEAPs, the information of these reports played the major role on the final performances of each country. Indeed, the information reported on these documents does not ensure total reliability and transparency. Some countries might have described their measures as if they were more successful than in reality, and others might have delivered incomplete reports that do not show the real quality of their initiatives. In the end, these are problems that happen in any self-assessment. A possible solution is to create a qualified team or entity, aware of a factual and transparent framework of evaluation, that performs the evaluation for all 28 MS. However, this would need more investment of capital, human resources and time. Generally, it was also identified a lack of evidence to support the results that are communicated in the reports. Most of times, there were not presented quantitative indicators of the performances of each measure, being only referred qualitative judgments. This creates some fuzziness and subjectivity on the final evaluation. A small point of improvement that might contribute to soften this situation is the creation of a fixed template for the NEEAPs. In this way, each country would know exactly what type of information must be reported, what type of information is missing to complete the assessment and it would also facilitate the comparisons between different countries. Another structural limitation was the strong presence of only one Directive on the whole framework. Even though, the EED covers most of the dimensions of the EE governance framework, it did not cover everything in each dimension. This dissertation focused on the evaluation of the areas that already are covered by European legislation, but others might be added. For instance, the dimension of Strategy in the EE governance framework was focused on the National Building Renovation Strategy, but of course many other strategies on other issues should be included. In this case, this one was the only included because it was the only currently required by European legislation. Another additional point to consider in future studies is the identification and quantification relations between criteria. In the limit, it would be interesting to develop a study on EE governance capacities by sector, in order to understand what type of measures have a greater impact in the energy savings of a country. In this way, it would be possible to create a more effective strategy to reach the common targets in the future.

In a general way, it is possible to understand that the European mandatory measures present a moderate level of compliance, and that the general commitment of reporting to EC by MS has improved since 2014 until 2017. Having this said, it would be beneficial to have a more rigid and demanding European legal framework on EE in the medium and long term. There is still room for improvement, even in countries with high competitiveness in their market as Germany and France.

This study presented a new approach for the assessment of EE governance capacities based on an MCDA method. In the end, it is clear that, as much as EE and energy sustainability are important for our society, there is a lack of studies and efforts that aim to contribute to the solution of this problem.

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