

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO



Design of new energy policies and actions for the empowerment of consumers through energy communities

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February 10, 2023

Resumo

Atualmente, os governos têm estabelecido políticas energéticas para investigar, administrar, gerir e utilizar os recursos energéticos com o menor impacto ambiental negativo possível. Reduzir o consumo e o desperdício de energia, no sector residencial, está a tornar-se cada vez mais crucial para a União Europeia. De forma a ser possível realizar esta transformação, os 27 países europeus devem apoiar o cumprimento das normas de desempenho energético através de ajuda financeira e assistência técnica. Em Portugal, as políticas energéticas estão centradas na transição e na eficiência energética de forma a reduzir a procura de energia e promover a utilização de fontes limpas e renováveis. Com o objetivo de colocar em prática estas políticas energéticas, Portugal estabeleceu alguns planos nacionais, tais como: (i) o Plano Nacional Integrado de Energia e Clima, (ii) o Roteiro Nacional de Carbono, (iii) o Plano Nacional de Ação para a Eficiência Energética, e (iv) o Plano Nacional de Ação para Energias Renováveis.

O trabalho desenvolvido no âmbito desta dissertação abrange essencialmente o PNEC e o RNC. O PNEC 2030 representa o principal instrumento de política energética e climática em vigor, e as suas ações estão projectadas para o período de 2021 a 2030. Por sua vez, o RNC 2050, definido pelo governo de Portugal, surge como uma forma de criar medidas que contribuam para a descarbonização da economia nacional.

Uma das principais contribuições deste trabalho, é a análise das políticas energéticas existentes em Portugal e na União Europeia, nos últimos 50 anos, no setor dos edifícios. Deste modo, esta dissertação tem como principal objetivo a criação de políticas alternativas ao cenário energético em vigor, que promovam a contribuição dos cidadãos, de forma a atingir a descarbonização do consumo de energia em 2050. O principal foco deste trabalho é promover a evolução da eficiência energética no setor dos edifícios residenciais e de serviços.

O desenvolvimento destas políticas, é realizado através de uma ferramenta existente de planeamento energético, a LEPA, que foi utilizada para modelar, testar e validar a implementação das atuais políticas energéticas e do plano nacional de eficiência energética na região Norte de Portugal. Mais concretamente, a LEPA fornece estimativas sobre os custos e benefícios da aplicação das diferentes ações energéticas, permitindo prever as necessidades da região Norte, de forma a atingir e exceder as metas ambiciosas estabelecidas. Esta ferramenta permite a simulação do cenário energético atual, juntamente com a criação de novas alternativas a este cenário. Assim, este trabalho culminou no desenvolvimento de 4 alternativas, sendo que duas se basearam em planos existentes, o PNEC e o RNC. Por outro lado, a terceira alternativa consistiu na implementação de medidas relacionadas com a substituição de eletrodomésticos menos eficientes, por equipamentos mais eficientes. A principal contribuição deste trabalho reside no desenvolvimento da Alternativa 4 que consistiu na conjugação das medidas implementadas nas Alternativas 2 e 3, de forma a atingir um valor de emissões de gases com efeito de estufa em 2050 próximo de zero, sem ser necessário aumentar drasticamente os custos de investimento.

Um importante resultado e conclusão deste trabalho é que, embora as políticas energéticas em vigor em Portugal tenham como objetivo a descarbonização do sector dos edifícios, existem

ainda várias formas possíveis e rentáveis de conseguir atingir os objetivos desejados com menores custos de investimento.

Desta forma, as políticas energéticas devem apoiar as mudanças significativas e urgentes no sector da energia. Além disso, devem permitir aos consumidores participar na gestão do sistema energético, aumentando a utilização das fontes de energia renováveis.

Palavras-Chave— Edifícios, Políticas e Ações, Descarbonização, Eficiência Energética, PNEC, RNC.

Abstract

Currently, governments have established energy policies to investigate, administer, manage, and use energy resources with the least negative environmental impacts possible. Reducing energy consumption and energy waste in the residential sector is becoming increasingly crucial for the European Union (EU). It is clear that for this transformation to be possible, the 27 EU countries must support compliance with minimum energy performance standards with financial aid and technical assistance. Energy policies in Portugal are heavily focused on transition and Energy Efficiency (EE), to reduce energy demand and promote the use of clean and Renewable Energy Sources (RES). In order to put these energy policies into practice, Portugal has established some national plans, such as: (i) the National Energy and Climate Plan (PNEC), (ii) the National Carbon RoadMap (RNC), (iii) the National Action Plan for Energy Efficiency (PNAEE), and (iv) the National Action Plan for Renewable Energy (PNAER).

In this work, special attention was given to the PNEC and RNC. The PNEC 2030 is the primary energy and climate policy instrument, and its actions are projected for 2021 to 2030. Furthermore, the RNC 2050 is defined by the government of Portugal as a means of creating measures that contribute to the decarbonisation of the national economy.

One of the main contributions of this dissertation is to carry out a review and analysis of the energy policies existing in Portugal in the last 50 years in the buildings sector. Additionally, the same analysis was carried out for the EU case. In this way, this dissertation has as its main objective the creation of alternative policies to the energy scenario in force, which promote the contribution of citizens to achieve the complete decarbonisation of energy consumption in 2050. The main focus of this work is to promote the evolution of EE measures in the residential and services buildings sector.

The development of the work was carried out through an existing energy planning tool, Local Energy Planning Assistant (LEPA), that was used to model, test and validate the implementation of current energy policies and national EE plan in the Northern region of Portugal. More precisely, LEPA provides estimates on the costs and benefits of applying different energy actions, allowing to foresee the needs for the Northern region to achieve and exceed ambitious targets. This tool allows the simulation of the current energy scenario, along with the creation of new alternatives to this scenario. This work allowed the development of 4 alternatives, being that two were based on existing plans, the PNEC and the RNC, respectively. On the other hand, the third alternative consists of implementing measures related to the replacement of less efficient appliances for more efficient equipment. A major contribution of this work is the design and simulation of Alternative 4, which consists of combining the measures implemented in Alternatives 2 and 3 to achieve a value of Greenhouse Gas (GHG) emissions in 2050 close to zero without drastically increasing the value of the investment cost.

An important conclusion is that even though the energy policies in force in Portugal aim at the complete decarbonisation of the buildings sector, there are still several possible and profitable ways to achieve the desired targets with lower investment costs.

In this way, public policies must support significant and urgent changes in the energy sector. Additionally, they should allow and promote consumer engagement in the management of power systems, expanding the penetration of RES in buildings.

Keywords— Buildings, Policies and Actions, Decarbonisation, Energy Efficiency, PNEC, RNC.

Acknowledgements

First of all, I want to offer my sincere gratitude to everyone who contributed to this project in any manner along the way.

I would like to express my gratitude to my supervisor, Prof. Dr. Manuel Matos, and in particular to my co-supervisor, Dr. Tiago Soares, for their assistance in helping me get over the challenges that this work presented and for their support and advice.

Then, I would like to thank my parents. Words are not enough to express how thankful I am for everything. Thank you for all the opportunities, advice, support and love. Without you, it would not have been possible to complete this chapter.

To my sister Joana, my biggest example, thank you for encouraging me to be better every day and for supporting me at all times. I would also like to thank my brother-in-law Tiago for all his support and, finally, my nephew Tomás, who even without knowing, always gave me the strength to finish this work surrounded by laughter.

To Francisco, for all his wise advice and support, and especially for his tireless help in achieving my ambitions. A thank you is not enough for helping me to complete this huge goal.

To my friends, Ed, Tavares, Banderas, Tropa, Enes, Toto, Saleiro and Freitas and to all the other friends that I made at university, thanks for the good moments that we spent together throughout these years. They will remain forever in my memory.

Last but not least, to my friends of always, Drecas, Ritinha and Mari, who, despite hearing many no's from my part because of this piece of work, always supported me. My warmest thanks, and may we continue to celebrate each other's achievements.

Sara Capelo

*"It is our choices (...), that show what we truly are,
far more than our abilities."*

-J.K. Rowling,
"Harry Potter and the Chamber of Secrets."

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Abbreviations

ADENE	Portuguese Energy Agency
BAU	Business As Usual
CEC	Citizens Energy Communities
CHP	Combined Heat and Power
CSC	Collective Self-Consumption
DGEG	General Directorate of Energy and Geology
DHW	Domestic Hot Water
DL	Decree-Law
EC	European Commission
ECO.AP	Energy Efficiency Programs in Public Administration
EE	Energy Efficiency
EED	Energy Efficiency Directive
EEF	Energy Efficiency Found
EF	Environmental Found
ELPRE	Long-Term Strategy for the Renovation of Buildings
EnC	Energy Community
EnCs	Energy Communities
EnU	Energy Union
EPA	Energy Policies and Actions
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Contract
ECS	Energy Certification System
ESD	Energy Services Directive
ESE	Public Contract Regime with the Energy Service Companies
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GVA	Gross Value Added
HDR	High Dynamic Range
IMC	Inter-Municipal Communities

IMI	Municipal tax on Properties
IMT	Municipal Tax on Transmission of Properties
INDC	Intended Nationally Determined Contributions
INE	National Statistics Institute
LEPA	Local Energy Planning Assistant
MS	Member States
NEEAPs	National Energy Efficiency Plans
NZEB	Nearly Zero Energy Building
PAES	Program to Support more Sustainable Buildings
PNAEE	National Action Plan for Energy Efficiency
PNAER	National Action Plan for Renewable Energy
PNEC	National Energy and Climate Plan
PPEC	Plan for Promoting Efficiency in Electricity Consumption
PRR	Recovery and Resilience Plan
PV	Photovoltaic
RCCTE	Regulation of Thermal Behaviour Characteristics of Buildings
REC	Renewable Energy Communities
RECS	Regulation of Energy Performance of trade and Services Buildings
REH	Regulation of Energy Performance of Residential Buildings
RES	Renewable Energy Sources
RNC	National Carbon RoadMap
RSECE	Air-Conditioning Energy Systems Codes
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1

Introduction

This chapter will present a brief and generic overview of the motivation to develop this dissertation.

First, a description of the importance of studying Energy Policies and Actions (EPA) for the improvement of EE and comfort in buildings, and hence the empowerment of consumers, will be introduced. Finally, a detailed description of this dissertation's main goals, related projects and publications and structure is presented.

1.1 Context and Motivation

In the last couple of decades, EPA have been increasingly important in improving the EE of buildings, allowing citizens to reduce energy costs whilst improving energy comfort.

In Europe, different policies were applied to encourage retrofitting of buildings with increased adoption of RES, as well as the use of more sustainable and energy-friendly materials. However, the transition to climate-neutral buildings depends on a strong financial component on EE, which calls for more focused financial mechanisms, new financial models, and more active involvement from financial institutions [1].

Portugal was one of the first nations in the world to set goals for achieving carbon neutrality by 2050 [1]. The main methods used by Portugal's energy and climate policies to achieve carbon neutrality are enhanced EE, the quick RES expansion, and significant electrification of energy demand. Additionally, the primary concerns are reducing reliance on energy imports and keeping access to inexpensive energy [2]. At the present time, there are several EPA for the empowerment of consumers through Energy Communities (EnCs) to improve EE levels, reduce energy consumption and increase the levels of self-consumption and self-sufficiency in cities. In its Recovery and Resilience Plan (PRR), Portugal is seeking better to integrate its energy system into the European grid and enable clean energy exports to the EU. Plans also include the development of solar, hydrogen and biomass energy sources and the creation of a new development institution (a green banking institution) [3].

Citizens Energy Communities (CEC) should play a key role in the electrification and decarbonisation of society by providing tools that will enable citizens to actively participate in the

energy transition [4]. Consumers can use the excess energy generated by the major producers. In other words, there will be no more wasted energy, which will reduce electricity costs at the end of the month and cut GHG emissions. The participation of citizens and communities as partners in energy projects is transforming the energy system [5]. However, most consumers are not aware of the opportunities supported by these policies. Many EPA become difficult to enforce due to a set of regulatory barriers coupled with unbearable investment requirements from the consumer side.

Nevertheless, introducing the Energy Community (EnC) systems in developed and developing countries represents a modern solution to engage local communities and increase their participation in energy problems. Consequently, local communities will be able to identify local energy needs, take part in initiatives and bring people together to achieve common goals such as the reduction of energy cost, CO₂ emissions, and dependence on the national grid.

Once the energy sector is currently at a turning point in re-organising its legal framework, it is crucial to discuss these issues. This work aims to solidify knowledge and understand that Portugal has a wide range of measures to support the decarbonisation of buildings, including certifications and financial support mechanisms for renovations.

This work aims to map the evolution of EPA towards the improvement of buildings' energy performance in Portugal. Based on this review, it is also intended to assess the impact of existing buildings-related energy policy actions in the Northern region of Portugal in terms of required investment and GHG emissions and to propose alternative scenarios.

1.2 Objectives

The decarbonisation of the energy sector depends heavily on the application and success of EPA, as a stimulus for people to change their habits in using energy in buildings. The continuous introduction of RES and other EE measures supported by energy policies and subsidies is essential. However, EPA should be properly designed according to local/regional needs.

To achieve carbon neutrality by 2050, the electricity production system and urban mobility must be completely decarbonised. Additionally, significant changes must be made in how citizens use energy and resources, with a focus on an economy that is supported by RES, uses resources efficiently, and is based on circular economy models. It is vital to reconsider the idea of construction and invest in urban regeneration, viewing cities as intelligent living entities [6].

In this context, this dissertation proposes to overcome the identified limitations by studying in detail the current and future EPA being implemented in Portugal, namely in the Northern region. More precisely, it studies the changes that may be necessary for the residential and services buildings sectors, in the Northern region of Portugal, to reach the ambitious carbon-neutral targets in 2050.

A set of EPA scenarios (also called alternative scenarios) is built upon a reference scenario, which is based on the PNEC [7] and the RNC [8]. The PNEC establishes specific lines of action to reduce carbon intensity and promote the energy renewal of the building stock for 2030, while the RNC defines the roadmap to reach carbon neutrality by 2050.

In the context of simulating the economic, environmental and social impacts of current and future EPA in the Northern region of Portugal, the specific objectives defined for this dissertation are threefold:

- To provide a detailed review of the current energy policies applied in Portugal and in the EU;
- To perform an analysis of the impact of current EPA in the Northern region of Portugal, considering the national plans for the decarbonisation of buildings;
- To design, develop and simulate a new energy policy framework for carbon neutrality by 2050 with lower investment costs;

1.3 Related projects and publications

The work developed in the scope of this dissertation partially concerns the objectives and results of two research projects, namely:

- DECARBONIZE – Development of strategies and policies based on energy and non-energy applications towards CARBON neutral cities via digitalization for citizens and society (NORTE -01-0145-FEDER-000065);
- DECMERGE – Decentralized decision-making for multi-energy distribution grid management (2021.01353.CEECIND).

The developed work has resulted in the writing of a scientific paper, available in Appendix C, to be submitted to the Energies journal. The following should be referred to:

- Sara Capelo, Tiago Soares, Isabel Azevedo, Wellington Fonseca, Manuel Matos, “Analysis of energy policies for the decarbonisation of energy consumption in buildings: The case of the Northern region of Portugal”, Energies, to be submitted.

1.4 Structure of the Dissertation

This dissertation is organized into six chapters. In addition to the present introductory chapter, the structure of this dissertation includes five other chapters.

Chapter 2 provides a state-of-the-art overview of existing EPA in the EU and with a special focus on Portugal. It also includes a timeline review of the main energy policies applied in Portugal in the last 50 years. In addition, some tools for the development, testing and simulation of EPA are also addressed.

Chapter 3 describes the operation of the LEPA tool that can be used for the design, simulation and analysis of the potential impact of EPA applied to local and/or regional context of a country.

Chapter 4 presents a case study focused on the simulation of current energy policies in Portugal in the specific context of the Northern region of Portugal.

Chapter 5 represents a set of simulations concerning different goals and alternatives based on the national roadmaps for the continuous decarbonisation of buildings to 2030 and 2050. Additionally, alternatives for the carbon neutrality of buildings with lower investment costs in 2050 are also designed and simulated.

Finally, in chapter 6, an overall conclusion of the work done is drawn. Suggestions and motivation for future work derived from the results of this dissertation are presented.

Chapter 2

Overview of Energy Policies and Actions

The present chapter reviews the most crucial EPA for buildings in the European and national context. In this way, the chapter begins with a brief description of EPA in the context of the EU, where a review of the evolution of European energy policies relative to EE in buildings in the last 50 years is provided.

Furthermore, a complete characterisation of the EPA on EE in buildings (including renewables) in the case of Portugal is performed. Some of the existing support plans are clarified, such as the Environmental Fund (EF) and the Program to Support more Sustainable Buildings (PAES). Following this, a brief introduction to the impact that EnCs may have on EE in buildings is carried out.

Finally, contextualization of the existing tools for energy planning, commonly used for studying and developing energy policies, is provided.

2.1 The energy policy in the European Union context

Currently, 80% of all GHG emissions in the EU are caused by energy production and use [9]. To make matters worse, a significant part of the energy used in buildings today is wasted due to old and outdated construction methods, inefficient systems or appliances, and a lack of efficient technological control systems. So, buildings have the considerable unmet potential for energy savings, contributing to around 40% of the EU's final energy and 36% of its CO₂ emissions [1].

Hence, their involvement in the atmospheric emissions of CO₂ brought on by the burning of fossil fuels, energy production and consumption has a considerable impact on climate change.

Since the United Nations Framework Convention on Climate Change (UNFCCC) was established at the Rio Conference in 1992, [10] and the Kyoto Protocol that followed in 1997 [11], climate change has been widely acknowledged as one of the most critical global challenges. It is still a top priority for governments all over the world [9].

The political project, presented in 2015, aims to create an Energy Union (EnU), which will be based on an integrated energy system [12]. In this system, energy can flow freely across borders based on competition, the best possible resource use, and effective market regulation. It also aims to help promote economic growth in the EU, improve energy security and reduce the impact of climate change. This strategy is based on three policy objectives: security of supply, sustainability and competitiveness. It also has defined priorities around five interlinked and mutually reinforcing policy strands: (i) energy security, (ii) a fully integrated internal energy market, (iii) EE, (iv) decarbonisation of the economy, and (v) promotion of energy research, innovation and competitiveness [12].

As one of the ten priorities of the European Commission (EC), the EnU is claimed to be the vector that can significantly contribute to making Europe a sustainable, low-carbon and environmentally friendly economy, taking the lead in the production of renewable energy and the fight against global warming.

Investments in the energy area also create new jobs, growth and investment opportunities in the development of RES, new technologies, EE measures and infrastructure renewal, which will contribute to reducing costs for residential and businesses and promote growth and exports.

In recent years, the Paris Agreement, adopted in December 2015 [13], represents a bridge between today's policies and climate neutrality before the end of the century. Its central objective aims to strengthen the global response to climate threats and reinforce countries' capacity to deal with climate change's impacts. This agreement has set an ambitious direction for investment in low-carbon innovation and fulfilling the ambitious commitments made by the EU in Paris on climate change. It should be noted that the Paris agreement has become one of the leading energy policy priorities as two-thirds of GHG emissions result from energy production and use [14]. Finally, the Paris Agreement sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2°C above pre-industrial levels and pursuing efforts to limit it to 1.5°C [15]. EE in buildings supported by new energy policies will significantly contribute to these ambitious targets.

2.1.1 Overview of 50 year policy evolution

It is possible to review 50 years of the EE policies adopted by the EU and some of the policies adopted by its Member States (MS) since the 1970s, in an effort to improve energy security and equity, reduce the impact on the environment, and increase the competitiveness of the European economy [1].

Since 2000, the EC has released several EE action plans to outline its strategic vision and recommend initiatives like new laws or enhanced regulations.

The SAVE Directive (93/76/EEC) [16] of 1993, which represents the first central EU policy on EE, consists of implementing programs introducing sufficient thermal insulation provisions in new buildings. However, the implementation of this directive was not as fast, strong and successful as expected. This was partially caused by MS laxly adopting national standards or failing to include efficiency requirements or standards in their national building codes.

In 2002, the SAVE Directive [16] was partly replaced by the Energy Performance of Buildings Directive (EPBD) [17], and the remaining articles were replaced by the directive on energy end-use efficiency and energy services in 2006 [18].

The EC published the second EE action plan in 2006. The goal was to save 20% of annual primary energy consumption by 2020 compared to baseline energy consumption predictions for 2020, by controlling and reducing energy demand and focusing on consumption and supply. Up to 2020, this goal required annual savings of almost 1.5% [19].

Furthermore, the 2005 green paper on EE served as the foundation for the policies and initiatives of the 2006 action plan. The green paper on the European energy strategy emphasised the need to boost the EU efficiency strategy. The plan estimated that by 2020, residential buildings might save up to 27% of their current energy use, and commercial buildings might save up to 30% [1].

Following the adoption of the 2006 action plan in March 2007, EU leaders pledged to transform Europe into a highly energy-efficient, low-carbon economy and set the "20-20-20" targets, which were articulated as [20]:

- 20% less GHG emissions than they were in 1990;
- An increase in the percentage of energy coming from RES to 20%;
- EE improvements lead to a 20% reduction in primary energy consumption in the EU.

The Energy Services Directive (ESD) (2006/32/economy) [18] is the SAVE Directive's successor and the Energy Efficiency Directive (EED)'s predecessor. The ESD, adopted in 2006, created the groundwork for establishing indicative national targets that would result in at least a 9% reduction in energy use by 2016 and imposed reporting requirements through the creation of National Energy Efficiency Plans (NEEAPs). Although the ESD did not specifically address buildings, it did include some rules on finance, Energy Performance Contract (EPC)s, metering and billing. These clauses were made more substantial in the succeeding EED, which is covered below.

It is crucial to note that the EED (2012/27/EU) [21], which was adopted in December 2012 as a component of the European energy and climate package, established the legal basis for the 2020 targets and other provisions outlined in the 2011 EE action plan. In terms of absolute primary and final energy consumption levels by 2020, this directive quantified the 20% EE target. It required MS to establish their own EE goals at the national level to contribute to the overarching EU target.

To strengthen some of the EPBD original rules and capture more significant energy savings as specified in the 2006 action plan, the EC published the recast of the EPBD in 2009 (2010/31/EC) [22].

The EPBD recast's primary goal was to guarantee that the level of ambition of the national minimum energy performance requirements imposed by the MS in terms of energy savings and GHG emission reduction remained the same. This results from some national standards being too modest and inefficient compared to their costs.

For this purpose, Article 9 of the EPBD introduced the concept of Nearly Zero Energy Building (NZEB), according to which all new private buildings must adhere to nationally defined NZEB requirements by January 2021.

According to the NZEB concept, all new buildings must be NZEB by the end of 2020, and new buildings occupied by public entities must be NZEB by the end of 2018. An NZEB is characterised as a structure with extremely high EE. The energy needed should be provided to a large part by renewable energy generated on-site or nearby. Figure 2.1 can be used to summarise the idea of NZEB.

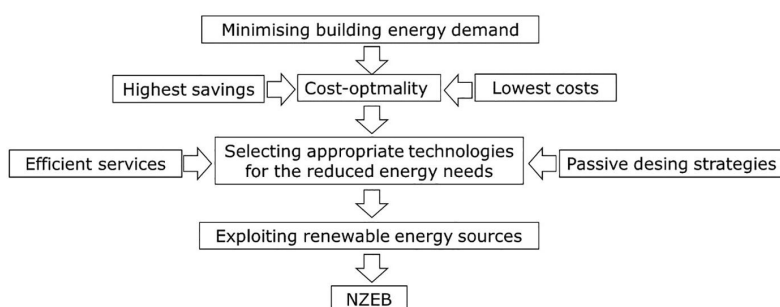


Figure 2.1: Flowchart of the NZEB concept [23].

2.1.2 The 2011 Energy Efficiency Action Plan

A reduction in GHG emissions of 40% in 2030, 60% in 2040, and 80-95% [24] in 2050 compared to 1990 levels was one of the far-reaching goals outlined in the roadmap for moving to a competitive low carbon economy in 2050, which was presented in 2011 by the new Commission.

A new EE action plan was also established at the same time by the commission. The plan emphasised the need for more energy renovations in the private and public sectors. It included EE criteria for public buildings due to the significant energy savings potential of building renovations. The plan, in particular, suggested that at least 3% of central government buildings be renovated annually.

As part of the Intended Nationally Determined Contributions (INDC) to the UNFCCC process leading to the Paris Agreement, the EU adopted energy and climate targets for 2030 in 2014. These were specified as the following [25]: (i) a minimum 27% share of renewable energy consumption, (ii) a 40% decrease in GHG emissions relative to 1990 levels, and (iii) a minimum of 27% energy savings. In 2018, the targets for renewable energy and EE were changed to 32% and 32.5%, respectively, due to negotiations about establishing the legal foundation for the targets [1].

On June 2018, the Directive (2018/844/EU), EPBD [26] was published, and the revised provisions entered into force on July 2018. With the aim of a decarbonised building stock by 2050 and the mobilisation of investments to achieve this goal, this revision contains specific adjustments to the current EPBD that are meant to speed up the cost-effective repair of existing buildings.

The modification also promotes the diffusion of electric vehicles by requiring the installation of electro-mobility infrastructure in building parking lots. Additionally, it adds new rules to improve technical building systems and intelligent technologies, such as building automation.

The **EE** policy spans over five decades. It has accomplished significant achievements in scope, size, and ambition since it first focused on energy security in the 1970s. Therefore, the overview of these policies is available in Appendix A, (Figure A.1).

When examining the outcomes brought by European policies, it is fascinating to see how the national minimum energy performance standards, applicable to new construction and significant renovations, have changed over the period covered by the **EPBDs**.

Over the past ten years, the building concept has consistently changed along with the energy requirements. Several definitions have been introduced, starting with high-performing buildings, such as (i) net zero source/site buildings, (ii) autonomous, (iii) zero-emission buildings, and (iv) zero carbon buildings. As previously mentioned, an essential **EU** program for advancing buildings' **EE** has been the **EPBD**. Despite earlier attempts, the fundamental advances in increasing **EE** have come from the **EPBD** (2002), the Ecodesign (2005), and the **ESD** (2006), as well as the additional improvements and reinforcement from the **EPBD** recast (2010), and the **EED** (2012).

It is essential to give more specialised consumer information (such as through improved energy performance certificates) and financial assistance through specialised instruments, enabling end users to invest in **EE**. Future regulations must consider that buildings must increasingly perform to higher standards, striking a favourable balance between energy produced and consumed.

Last but not least, a solid financial component on **EE** is crucial for the transition to climate-neutral buildings, requiring the development of new economic models, targeted financial mechanisms, and increased involvement from financial institutions.

2.2 The energy policy in the Portuguese context

2.2.1 Portuguese policies and actions on Renewable Energy

Renewable energy policies are intended to incorporate environmental benefits, particularly the reduction of **GHG** emissions compared to fossil fuel-based energy systems.

Presently, in some periods, when meteorological conditions are favourable, Portugal is able to produce its domestic primary energy from **RES**. The Portuguese **RES** generation accounted for 49.3% of total generation in 2022. Meanwhile, renewable generation accounts for 28% of the electric sector globally [27]. Natural resources (such as water, wind, biomass, sun, and earth's heat) that are naturally and routinely renewed sustainably, even after being used to produce electricity or heat, are the source of renewable energy. They allow hydroelectric, wind, solar, biomass, oceanic and geothermal energy production. Consequently, producing energy from **RES** reduces the need to import fossil fuels, particularly coal and natural gas. For this reason, Portugal will be less dependent on foreign energy and will reduce **GHG** emissions.

According to the Directive (2009/28/EC) [28], and the respective recast - **EU** Directive (2018/2001) [26], the **EU** established the goal of increasing the share of **RES**, while Portugal committed to the target of 31% share of energy from **RES** in the gross final energy consumption and 10% share in the transport sector by 2020 [29].

The EU Regulation (2018/1999) [30] approved targets that aim to reach, in 2030, a 32% share of energy from renewable sources in final gross consumption, a 32.5% reduction in energy consumption, a 40% reduction in GHG emissions from 1990 levels, and a 15% reduction from 2005 levels [29]. The EC also presented the legislative package "Clean energy for all Europeans" in 2016, intending to promote the energy transition in the 2021–2030 decade.

The significant national energy and climate policy instrument for 2021–2030 was Portugal's PNEC for the 2030 horizon. The PNEC 2030 sets the following national goals for 2030 (Figure 2.2): (i) to reach 15% of electricity interconnections to encourage EU countries to interconnect their installed electricity production capacity; (ii) to incorporate 47% of energy from RES in the final gross energy consumption; (iii) to achieve a reduction of 35% in primary energy consumption to improve EE; and (iv) to reduce GHG emissions by 45 to 55%, compared to emissions recorded in 2005 [29].

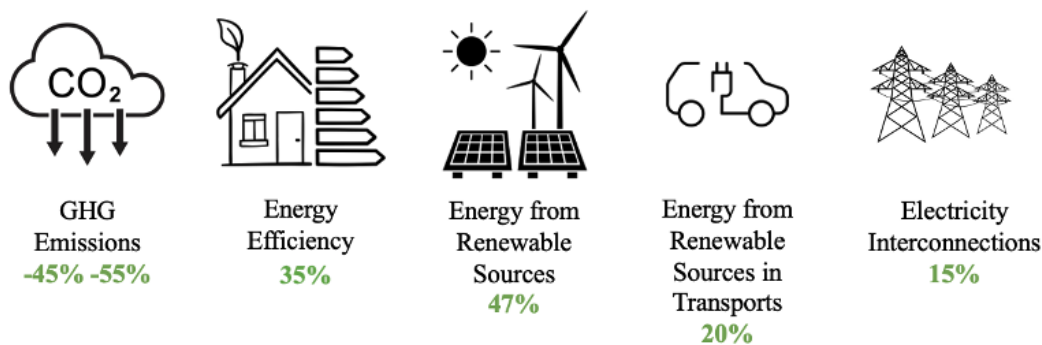


Figure 2.2: PNEC national targets for 2030, adapted from [7].

This plan seeks to set targets and objectives on GHG emissions, renewable energy, EE, energy security, internal market, research, innovation, and competitiveness, along with a clear strategy for achieving them. The PNEC is serving as the primary energy and climate policy tool for the years 2021–2030. While Portugal is getting ready to meet its 2020 challenge, which calls for a 31.0% objective for incorporating renewable energy into energy consumption, it is critical creating new goals for the 2021–2030 decade [7].

The PNEC must align with the aspirations and narratives outlined in the RNC 2050 since it is a crucial national policy instrument for establishing the strategic pathways for the extended past toward carbon neutrality.

One of the goals of the RNC 2050 is to visualise society in 2050 and the trajectory that will enable portuguese society to attain the political goal of carbon neutrality in that year. Carbon neutrality is a balance of zero between GHG emissions, not carbon dioxide, and the removal or sequestration of the same gases. Once this objective is attained, it is anticipated to be maintained. It is necessary to know that significant social and economic transformation will be needed [31].

The percentage of RES included in gross final energy consumption in 2020 in Portugal, was 34%, exceeding the objective aim by three percentage points. The percentage of RES in the electricity sector was 58%, in the heating and cooling sector 41.5%, and in the transport sector

was 9.7% [32]. The evolution of Portugal's use of renewable energy can be seen in the following graph (Figure 2.3).

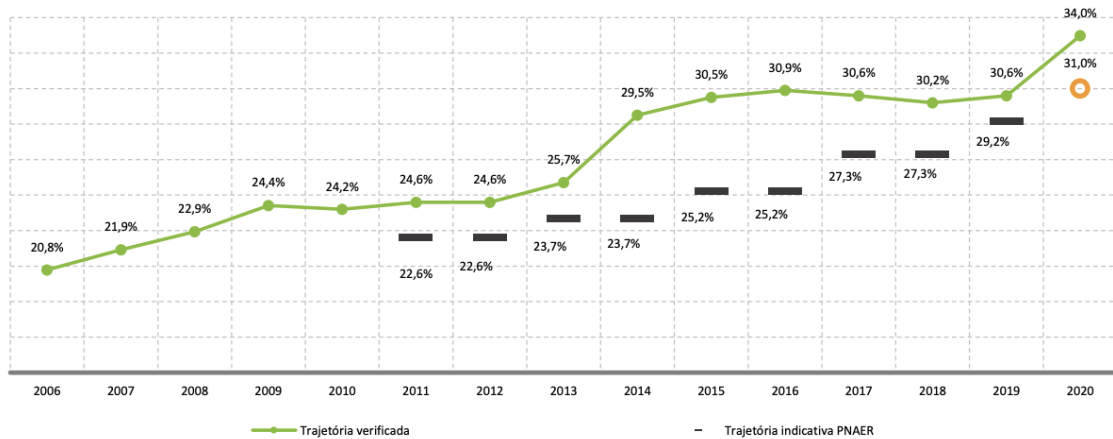


Figure 2.3: Evolution of the incorporation of renewables into final gross consumption of energy according to Directive (2009/28/EC) - [in Portuguese] [32].

2.2.2 Portuguese policies and actions on Energy Efficiency in buildings

EE can be defined as the optimization of energy consumption [33]. The threat of depletion of reserves of fossil fuels, the pressure of economic results, and environmental concerns are crucial points that define EE as one of the solutions to tackle climate change. Furthermore, learning how to use energy responsibly is necessary to establish a better future.

The buildings sector is responsible for the consumption of approximately 40% of final energy in Europe and around 30% in the case of Portugal. However, it is known that more than 50% of this consumption can be reduced by EE measures, which represents an annual reduction of 400 million tons of CO_2 , almost the totality of the amount established in the Kyoto Protocol [34].

The Kyoto Protocol, adopted on 11 December 1997, covers the UNFCCC, by committing developed countries and economies to reduce GHG emissions in conformity with agreed individual targets.

According to this, Portugal has assumed a path towards carbon neutrality. In this transition, priority was given to EE and the reduction of energy consumption, which will have energy sufficiency as a fundamental basis. Portugal had established the concern with energy consumption in buildings since the early 90s when the Regulation of Thermal Behaviour Characteristics of Buildings (RCCTE) and Air-Conditioning Energy Systems Codes (RSECE), were published [35], due to a first regulatory base to guarantee thermal comfort and buildings quality.

The adjustment of national legislation imposed by the EPBD published in the Directive (2002/91/EC) [17] settled that the MS of the EU had to implement an Energy Certification System (ECS) - *Sistema de Certificação Energética* - to inform the citizens about the thermal quality of buildings when constructing, selling or renting them. This document also states that this certification should cover all residential and service buildings, public or private.

Buildings [ECS](#) was implemented through the publication of the Decree-Law ([DL](#)) (78/2006) [36] and, due to the obligation of adjusting national legislation imposed by the [EPBD](#), were approved the [DL](#) (79/2006) [37] and the [DL](#) (80/2006) [38]. These decree-laws were related to the energy buildings certification and were reformulated by the Directive (2010/31/EU) [22]. Compared to the directive approved in 2002, the new one has some significant changes, such as the elimination of the 1000 m^2 limit in cases of significant renovations, the introduction of requirements in terms of air conditioning systems, or the intensification of inspection processes and quality of energy certificates.

In Portugal, the [EPBD](#)'s recast has been replaced into national law through [DL](#) (118/2013) [39], which includes the amendments to [RCCTE](#) and [RSECE](#), which are renamed Regulation of Energy Performance of Residential Buildings ([REH](#)) and Regulation of Energy Performance of trade and Services Buildings ([RECS](#)), respectively. The [DL](#) has as main intentions the following statements: (i) to ensure regulatory enforcement to energy-efficient conditions and the use of renewable energy systems following the requirements contained in the [REH](#) and [RECS](#), (ii) to certify energy performance in buildings, and finally (iii) to identify corrective measures and measures to improve energy performance in buildings. Thus, buildings become subject to minimum standards of [EE](#), air conditioning systems, Domestic Hot Water ([DHW](#)), lighting, use of renewable energy, and energy management. In other words, the [REH](#), establishes the requirements for residential buildings, new or susceptible to interventions, and the parameters for identifying the energy performance of all residential buildings and their technical systems. Considering that, the [RECS](#) establishes the conditions to be observed in the design, construction, operation, and maintenance of commercial and service buildings and their technical systems. It also settles the requirements for the characterisation of their energy performance to promote [EE](#) and air quality.

The major concern introduced by the transposition of the new directive was the dissolution of the obligation to carry out periodic audits of indoor air quality during the energy certification process. Actually, from 2009 to 2013, several audits were executed on public and private buildings where the problems detected were severe and required significant investments from the public purse. As a result of the transposition of the [EPBD](#) 2010, these audits were withdrawn from the scope of the [ECS](#) [35].

The base legislation of the new [ECS](#), established by [DL](#) (118/2013) [39], has been revised several times since 2013. The various ordinances, dispatches and associated laws also underwent some changes. The [DL](#) (68-A/2015) [40] corresponds to the first reformulation of the [DL](#) (118/2013) [39] and it establishes provisions on [EE](#) and co-generation production. The [DL](#) (194/2015) [41] and the [DL](#) (251/2015) [42] corresponds to the second and third reformulation of [DL](#) (118/2013) [39], respectively. Consequently, the [EF](#) was published through the [DL](#) (42-A/2016) [43] and it will be described in the (Section 2.2.5). In 2018, Directive (2010/31/EU) [22] was replaced by Directive (2018/844/EU) [44] which consists of the [EPBD](#) recast. Hence, in 2020, was published the [DL](#) (101-D/2020) [45], which partially transposes the [EPBD](#) recast and establishes the requirements applicable to buildings to improve their energy performance and regulates the [ECS](#) for buildings. After that, in 2021, the [DL](#) (102/2021) [46] establishes the requirements

for accessing and exercising the activity of technicians in the building ECS. In fact, in January of 2021, a new regulation was implemented in Portugal, which states that new buildings must be NZEB [47]. It is up to each MS of the EU to define NZEB and establish the concept in their own legislation.

In this way, Portugal established different rules for residential buildings (Table A.1) and for commercial and service buildings (Table A.2), available in Appendix A. These rules are related to useful energy for space heating, primary energy, renewable energy and EE indicators.

Finally, to better interpret the timeline of these policies, (Figure 2.4) depicts a diagram explaining the evolution of EE policies for buildings in Portugal.

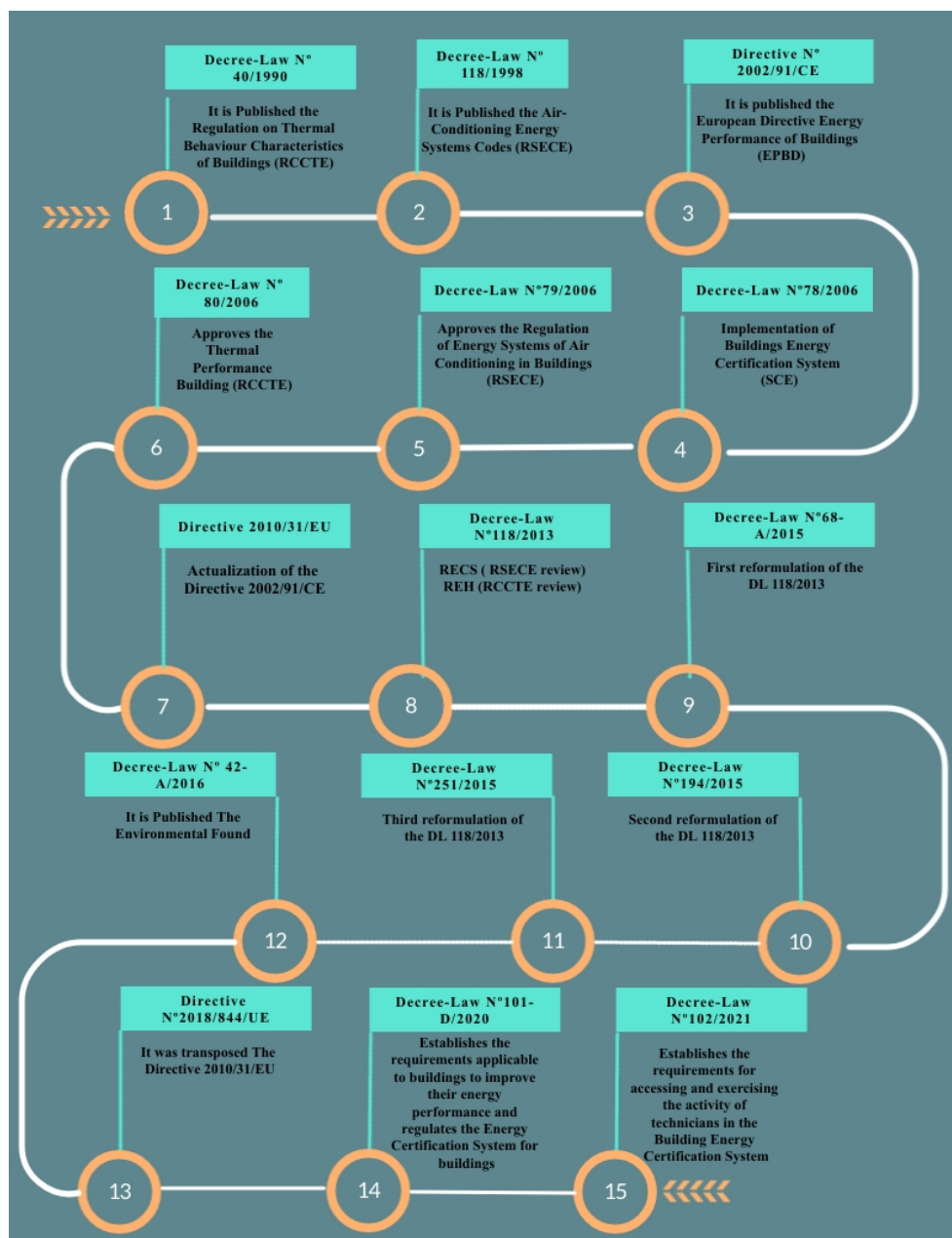


Figure 2.4: Timeline of Portugal's energy efficiency policies in buildings.

2.2.3 Energy Certification System

The Buildings' [ECS](#) is a system that performs energy assessments of buildings to ensure and promote the improvement of their energy performance. In the assessment, it is possible to identify the building's energy vectors and consumption, in which recommendations are given for future improvements. The certificates are then issued with relevant information about the building's energy performance.

"Certificar é Valorizar" is the brand of Buildings' [ECS](#) in Portugal, which evaluates and classifies the energy performance of buildings managed by the Portuguese Energy Agency ([ADENE](#)) [48], within the scope of European and national energy policies for the building sector. The [ECS](#) classifies buildings from a range of scores from A+ to F, with the former being very efficient and the latter not efficient. However, since March 1st 2021, energy labels were reframed, as detailed in (Section 2.2.4). The energy certificate, executed by independent and qualified professionals, establishes the necessary measures according to the property, which will enable a reduction in energy consumption. It is particularly important what determines energy certification, such as:

- The constructive solutions of the property, for instance: walls, roofs, floors and windows;
- Any equipment associated with air conditioning systems and equipment for producing [DHW](#);
- The existence of equipment that uses [RES](#).

It is important to refer that this certificate also identifies tax benefits and access to specific financing when available. For example, it is possible to enjoy a refund of the Municipal Tax on Transmission of Properties ([IMT](#)), when rehabilitating the buildings or benefitting from the reduction of Municipal tax on Properties ([IMI](#)). There is an obligation to exhibit the energy certificate in new buildings, existing buildings with rehabilitation works that need big interventions, in all non-residential buildings with areas greater than 1000 m^2 or 500 m^2 in the case of shopping centres, hypermarkets, supermarkets and others. It is also an obligation to buildings that are owned by a public entity with areas greater than 250 m^2 and are occupied by a public entity and frequently visited by the public [49]. Lastly, any residential or service building that initiates a process or intention to sell or lease must have a valid energy certificate and indicate the energy class in the advertisement. The validity period of these certificates varies according to the type of certificate, and building [49]:

- Ten years for residential buildings and small commercial and service buildings;
- Eight years for large commercial and service buildings. It must be renewed at the end of this period.

2.2.4 The Energy Labeling

[EU](#) legislation has removed the A+, A++, and A+++ classes from the labels of several household appliances. The labels are now displaying a simpler scale that is easier to interpret, ranging from

A (most efficient) to G (least efficient). It is essential to mention that this classification will not be static. There will be a regular evaluation, taking into account technological advances. When several types of equipment reach class A, there will be a new scaling to encourage the research and development of more efficient equipment. Therefore, it is pretty likely that, during these early days, a person will not find class A equipment on the market (according to the new scale)[50].

To have a better interpretation of this classification, (Figure 2.5) presents the scale established by the ECS.



Figure 2.5: Transition of energy label classification [50].

The energy label established by the EU is the easiest way for a consumer to find out which appliances are the most energy-efficient. It is mandatory for several categories of products, which must be provided by the appliance manufacturers, and must be correctly displayed in physical shops and online. To make reading the labels more accessible, the energy label has a universal character. It is unique and the same in all countries of the European economic area.

In addition to the new energy scale, the new label has gained a digital component by including a QR code that allows the consumer to access the European product database and consult detailed information about the product. Another significant change made to energy labels has to do with the use of pictograms. These were already common in the old labels and remained in the new version, but some have been slightly changed, and others are entirely new. This is the case for EE in High Dynamic Range (HDR) mode on televisions and monitors or the washing time for washing machines. Furthermore, the labels provide additional information, such as annual energy consumption, noise emission, equipment capacity, water consumption, or washing time. This information, specific to each product category, varies from label to label. How energy consumption is displayed has also changed and is now more prominently displayed in the center of the label. It is displayed in kWh/year for refrigerators, in kWh/1000 hours for screens and lamps, or in kWh/1000 cycles for dishwashers and washing machines.

Figure (A.2), available in Appendix A, shows an example of previous (A)) and actual (B)) energy labels to highlight the changes made in the energy labels.

2.2.5 Environmental Fund

The EF has been created to guarantee the fulfilment of environmental policies. This fund makes it possible to concentrate the resources of existing funds, in order to obtain an instrument with a more significant financial capacity and greater adaptability to the challenges posed.

For this reason, it was created through the DL (42-A/2016) [43] the EF, which consists of supporting environmental policies through the national and internationally established goals. These goals are related to climate change, water resources, waste, and the conservation of nature and biodiversity. The DL (42-A/2016) [43] has already been revised and updated several times since 2016 and establishes communications with other different national funds, public or private, European or international.

Currently, the EF supports a variety of supports. A complete and precise description of each of these programs is explained in the following chapters.

2.2.5.1 Portuguese Recovery and Resilience Plan – PRR

The Portuguese PRR is a national application program with an execution period of 2026. It aims to implement reforms and investments that will allow Portugal to return to sustained economic growth, ensuring the exit from the pandemic crisis and guaranteeing a resilient future for the country [51]. This plan is structured in three dimensions, resilience, climate transition, and digital transitions.

For this project, it is essential to highlight the energy field. Energy is framed within the "Climate Transition" dimension, which includes an ambitious sustainability schedule, significantly changing the panorama of mobility, decarbonisation, and the bio-economy of EE. It must accelerate the transition to clean and renewable energy, develop the circular economy, and change the mobility paradigm, taking into account the need to preserve the future of new generations [52].

This dimension intends, through the development of research, innovation, and the application of more efficient energy production and consumption technologies, to promote the best use of the country's resources and develop the economic sectors around renewable energy production. It concentrates 18% of the global amount of the PRR. It is achieved through six components focused on reducing carbon emissions of the most relevant sectors and greater incorporation of energy from RES, for example, the sea, the decarbonisation of industry, and EE in buildings [51].

The EE in buildings component aims to rehabilitate and make buildings more energy-efficient, providing countless social, environmental, and economic benefits for people and companies. It establishes as reforms the Long-Term Strategy for the Renovation of Buildings (ELPRE), the 2030 Energy Efficiency Programs in Public Administration (ECO.AP), and the long-term national strategy to combat energy poverty [52].

The PRR foresees investments of 300 M€ for EE in residential buildings, 240 M€ for EE in central public administration buildings, and 70 M€ for EE in service buildings [51]. It is essential to mention that the PRR supports several building EE programs. In the following sub-chapters, the programs that are currently in force are described.

2.2.5.2 Program to Support More Sustainable Buildings – PAE+S

The **PAES** was developed in 2020 and has already had two successful editions. This program's main concerns are financing measures to improve energy and environmental efficiency, the renovation of the current residential sector, and the contribution to carbon neutrality for Portugal [53].

The first phase of **PAES** allowed supporting around 5021 eligible applications, which means a total of 1,750.000 €, during 2020 [54][55].

Due to the verified success of **PAES**, the second phase of this program had essential changes such as [53]:

- The change in the maximum limit of eligible expenses for typology 2;
- The alteration of the wording of typology 2, allowing the use of other materials in addition to those of a natural base, with a lower contribution;
- The inclusion of a stage of request for clarification and/or additional elements to the candidate for a single time;

Among these crucial changes of the second phase, the budget allocation increased to 30 M€. There is also an increase in the support for more improvement measures. Finally, now the candidate can count on technical monitoring and energy certification provided by a qualified expert of the **ECS**.

It is important to refer that with the implementation of this program, a goal was established. It consists of reducing at least 30% [53] of primary energy in renovated buildings whose project typologies have been financed. The program implementation exceeded the expected funding level, far exceeding the intended limit to be made available in this program's first and second phases. This program has already had five phases of budget extension, currently standing at 135 M€, which demonstrates the enormous success of its application [53].

Table (A.3), available in Appendix A, illustrates the types of interventions and the maximum incentive attributed to each. In other words, the limit value of support for expenditure considering the 85% contribution.

The program to support more sustainable buildings covers six types of intervention, for instance, [53]:

- Typology 1 - Efficient windows with class "A+";
- Typology 2 - Application or replacement of thermal isolation and replacement of entrance doors;
- Typology 3 - Efficient systems and equipment that use renewable energy;
- Typology 4 - Photovoltaic (**PV**) panels and other equipment for producing renewable energy for self-consumption;
- Typology 5 - Water efficiency by replacing equipment with more efficient equipment;
- Typology 6 - Green facades and roofs and bio-climatic architecture solutions.

2.2.5.3 Program "Vale Eficiência"

The "Vale Eficiência" program represents a measure to combat energy poverty that promotes improving homes' energy performance and thermal comfort, contributing to reducing the energy bill. This program is also part of Portugal's [PRR](#). The development of these measures presents numerous advantages, namely, increasing energy performance and the environment of buildings, better conditions of habitability, and consequently, the reduction of the billed energy and ecological footprint. It was established as an objective, the issuance of 100,000 "Vales Eficiência" to support families until 2025, at the value of 1300 € each. This incentive aims for these families to invest in improving the thermal comfort of their homes, either by intervening in their surroundings or by replacing or acquiring energy-efficient equipment and solutions. The present phase of the program aims to deliver 20,000 vouchers [56].

The "Vale Eficiência" program also aims to stimulate and boost economic and social development, with local and national companies that will provide services to families under this program, boosting economic recovery, wealth generation, and job creation. The program is aligned with the goals related to energy and climate, to achieve carbon neutrality by 2050. The realization of this program is coordinated by the [EF](#), with support from [ADENE](#) and the General Directorate of Energy and Geology ([DGEG](#)) [57].

The present program aims at supporting interventions of the following typologies [58]:

1. Replacement of non-efficient windows by efficient windows of minimum energy class equal to "A";
2. Application or replacement of thermal insulation in the residential building envelope, as well as the replacement of entrance doors:
 - (a) Thermal insulation in exterior or interior roofs or floors;
 - (b) Thermal insulation in external or internal walls;
 - (c) Exterior entrance and sliding doors (doors of an autonomous fraction to be intervened).
3. Installation of space heating and/or cooling and sanitary hot water ([DHW](#)) systems, energy class "A" or higher;
 - (a) Heat Pumps;
 - (b) Solar thermal systems;
 - (c) High-efficiency biomass boilers and stoves.
4. Install [PV](#) panels and other renewable energy production equipment for self-consumption.

It should be noted that, unlike the [PAES](#), this program aimed at the most vulnerable families only received 16,800 applications. This program failed due to the way the aid was attributed since families depended on companies. The program established that the voucher could be submitted

only after the finalisation of the works to obtain the remuneration. The attribution of great responsibility to the companies in dealing with the bureaucracy is due to the high level of illiteracy of the families, which makes many of these micro enterprises refuse the projects.

On the other hand, the universe of people eligible to have access to this incentive is very small. It is worth noting that the program is restricted to families that benefit from social tariffs and simultaneously own the house where the intervention occurs. Most people with a social tariff are poor and do not own a home but rent it. In this way, two conditions lead to low adherence to this incentive.

To combat this problem, the government plans to extend the application deadline or increase the value of the vouchers [59].

2.2.5.4 Program to support the renovation and increase of the energy performance of service buildings.

This program's goal is to fund initiatives that advance [EE](#) and the use of other resources, as well as to strengthen the production of energy from [RES](#) in a self-consumption scheme, all of which contribute to an improvement in the power and environmental performance of service buildings.

The actions to be supported aim, on average, to result in a 30% decrease in energy consumption in the affected buildings (which is the minimum level to be ensured for large commercial and services structures), as well as a 20% reduction in water supply used in these buildings [60]. The actions to be developed in existing buildings that support the objectives outlined in the [ELPRE](#), in the [PNEC](#), as well as other environmental goals, are therefore eligible for funding through this program.

It is intended to support applications that can integrate the following types of improvement and respective sub typologies, to be developed in a building or multiple buildings contemplated in the same energy certificate, as shown in (Table [A.4](#)), available in Appendix [A](#).

2.2.5.5 Program to support the implementation of renewable energy communities and collective self-consumption.

Nowadays, the energy transition assumes an energy revolution coupled with the digital transition, equipped with innovative approaches, game-changing ideas, business models, obstacles, and opportunities [61].

First and primary, the Collective Self-Consumption ([CSC](#)) - *Autoconsumo Coletivo* - and Renewable Energy Communities ([REC](#)) - *Comunidades de Energia Renováveis* - enable people, businesses, and other public and private entities to create, consume, share, store, and sell the energy produced from [RES](#). By doing this, they are actively engaging in the energy transition and the conversion of traditional electrical networks into intelligent electrical networks that may add value to their services.

The **REC** and **CSC** promote a fair, cohesive, and democratic transition in our society by strengthening social and territorial cohesion, creating equal conditions for all, and removing barriers through access to participation in shared energy services, job creation, and increased competitiveness [61].

This program aims to fund initiatives supporting the **CSC** and **REC** regime's requirements for producing electricity from **RES**. It is specifically intended that the supported measures can, on average, result in a minimum 30% reduction in primary energy consumption in the benefited buildings and help increase by at least 93 MW the capacity for self-consumption and/or **REC** in the residential, central public administration, and services sectors [61]. The targets approved for the implementation of this program are described in (Table 2.1).

Table 2.1: Targets of the program to support the implementation of renewable energy communities and collective self-consumption [61].

Designation	Description	Objective
Energy efficiency in residential buildings	Additional capacity to produce renewable energy for self-consumption and use in renewable energy communities in the private residential sector.	35 MW
Energy efficiency in central public administration buildings	Additional capacity to produce renewable energy for self-consumption and use in renewable energy communities in central government buildings.	28 MW
Energy efficiency in service buildings	Additional capacity to produce renewable energy for self-consumption and use in renewable energy communities in the private service sector.	30 MW

This program aims at supporting interventions of the following typologies [61]:

- Typology a) - Residential buildings: The projects under the **CSC** or **REC** apply to existing single-family homes, as well as multi-family homes or their autonomous fractions;
- Typology b) - Central public administration buildings:
 1. Existing structures employed by the state, central administration services and funds, central administration non-profit institutions, public business sector, regulatory entities, and public entities endowed with legal identity and autonomy are covered by the **CSC** and/or **REC** initiatives;
 2. Financial and administrative organisations that carry out administrative tasks to further the objectives of the state and are in charge of making changes to existing structures for use by the public administration;
 3. Those businesses classified as being in the public business sector are those that the government wholly owns and, if they engage in any form of commercial activity, do so by providing services generally of economic interest.

- Typology c) - Commerce and services buildings: according to article 3(w) of DL (101-D/2020) [62], dated December 7, the CSC and/or REC projects apply to current commercial and service buildings in the private sector.

2.2.6 Long-term strategy for the renovation of buildings in Portugal

The ELPRE in Portugal developed by ADENE and DGEG has as its primary goals to encourage the energy renovation of existing buildings in the national park in 2018, to enhance their EE and gradually reduce their carbon footprint while also assisting in the reduction of energy poverty [63]. By 2050, this policy will significantly advance the national and EU's goal of becoming carbon neutral.

By 2030, increasing comfort, reducing energy poverty, and improving the EE of 65% of the existing residential structures built before 1990 will take priority. The legislation will be expanded in 2040 to include any remaining dwellings before 2016, which in 2018, make up all of the existing structures in the national park. In terms of non-residential structures, the policy calls for intervention in 27% by 2030 and 52% by 2040, with public buildings receiving priority [64].

The measures provided are grouped into seven vectors of action: building renovation, intelligent buildings, energetic certification, training and qualification, combating energy poverty, and information and awareness monitoring [65].

One of the primary goals of the strategy is to promote the enhancement of the energy performance of the nation's building stock, enhancing, until 2050, a cumulative saving of primary energy of 34% and a reduction of CO₂ emissions of 77%, compared to 2018. This will help Portugal achieve its energy and climate goals [63].

Finally, the targets of this program are interventions in the building envelope, the replacement of inefficient systems with more efficient methods, the promotion of energy from RES, and the adoption of technical solutions when appropriate for the practical achievement of the energy renovation objective of the covered buildings. Among other measures, these interventions include developing and creating financing programs for renovation and mobilising public and private investment.

Concerning the investment required to achieve the goals outlined, about 143 B€ are needed, with the most significant share corresponding to the residential sector. In turn, the financial return on investment, after 30 years, is estimated at 112,289 M€ for residential buildings and 108,547 M€ for non-residential buildings [64].

2.2.7 Energy performance contracts in Portugal

EPC is regarded as a crucial tool in the energy transition because it is one of the primary methods for implementing energy savings initiatives with outside financing.

An EPC is a contract between a beneficiary and a provider of an EE improvement measure that is validated and tracked during the contract's duration. The investments (labour, supply, or service) associated with that metric are paid for in connection to an agreed-upon level of increased

EE or another agreed-upon energy performance indicator, such as monetary savings [66]. The beneficiary of the EE improvement measures and the supplier of those EE measures are the two principal actors in the execution of EPC contracts.

Due to several obstacles, such as a lack of confidence in service providers and a lack of funds to pay for contracts and services, EPC has only recently increased in Portugal. Although there are two models for EPC types currently available: (i) The guaranteed savings model and (ii) The shared savings model, the bulk of contracts that already exist (67%) correspond to the shared saving model [67]. This demonstrates that the EPC market in Portugal is still under development and that this strategy may be regarded as good while the market is still emerging for such contracts.

Moreover, Portugal's critical EPC market participants are ESCOs, facilitators, clients, financial players, and regulatory stakeholders. An ESCO is a natural or legal person who provides energy services in the form of EPC in a final customer's facility or premises. An EPC facilitator is a person or company that will typically offer the client the expertise and direction needed to conduct an EPC project successfully, which will generally continue for the whole project's duration. The clients, for the EPC market in Portugal span from a variety of public to private sectors, including municipalities, the health and education fields, offices, industry, and residential. The financial actors are all who have a role in supporting the finances of the EPC such as a bank. Finally, the regulatory stakeholders are the entities in the public sector that has a higher level in the EPC market and that can take regulatory actions on EPC, including the portuguese government, ADENE or DGEG which oversees EE in Portugal [66].

Lastly, in Portugal, the main EPC related regulations, directives and policies are [66]:

- The NEEAPs (DL 50/2010 [68]) - that creates the Energy Efficiency Found (EEF), and establishes a management structure, to support and advance the execution of its programs and initiatives, including the technical management of the fund;
- The EEF (DL 50/2010 [68]) - aims to fund programs and activities that support the measures included in the NEEAPs. This law aims to unify the funding and support process for initiatives implementing policies and practices that reduce final energy demand and contribute to the achievement of national EE targets;
- The ECO.AP - aims to achieve a 30% EE level in the EE trends and policies in Portugal. The goal of this program is to make it possible for the state to reduce energy use in services and organizations, GHG emissions, and contribute to an improved economic impact;
- The Public Contract Regime with the Energy Service Companies (ESE) (DL 29/2011 [69]) - intends to define the public sector's role in the development and promotion of the energy services market, as well as the implementation of policies to increase end-use EE;
- The Plan for Promoting Efficiency in Electricity Consumption (PPEC) whose primary goal is to fund activities that enhance efficiency and reduced electricity use across various customer categories;

- The EPBD (DL 118/2013)[39] - that promotes the continuation of the energy certification of buildings.

2.3 Energy Communities

Community action on energy has increased significantly over the past decade, spurred by concerns about climate change and rising energy costs [70]. Nowadays, EnC is a promising framework to enable a decarbonised economy. However, it is yet to be well understood by the overall population. EnC initiatives are more likely adopted by citizens who prefer to be actively involved in environmental issues. EnC measures often require upfront investments, and their relationship to long-term individual benefits is non-trivial to the general public. For this reason, it is of utmost importance to mobilize communities, as well as provide accessible information, to support and actively participate in initiatives that promote energy reduction or the production of energy from RES. Although, the most widely identified barrier is the suite of financial constraints holding back community action [70]. This means that the government must continue to improve and guarantee investment funds that support citizens and increase consumer mobilization to participate in EnCs.

Consumers are currently seen as passive participants in the administration of the energy system. However, a new paradigm known as the REC may cause that idea to shift in the near future. EnC projects were very prevalent in Portugal in the early 20th century and were connected to modest hydropower facilities and local electricity distribution systems. Community-based approaches, however, became less relevant as the power-generating system became more centralised during the course of the 20th century. The biggest gap in portuguese aim is the absence of specific initiatives for REC development. Equally, its development is not encouraged by the lack of clear implementation goals [5].

The revised renewable energy directive [71] and the electricity market directive [72] both recognize the vital role that communities will play in the energy transition. There are enforceable rights for citizens to engage in EnCs. It is the responsibility of the national government of each country to ensure that unfair barriers do not block their path [73].

2.4 Energy Planning

2.4.1 Definition of local sustainable energy planning

Local energy and climate change projects first emerged in the 1990s. However, pioneering cities have only begun creating their local energy and climate action plans in the last ten years in response to addressing climate change and other local objectives in an integrated approach [74].

Planning involves a decision-making process that includes setting targets and identifying and selecting strategies to achieve those objectives. The notion of local sustainable energy planning used in this dissertation is based on the new energy paradigm, which claims that energy services can be increased not only by increasing supply but also by using energy more efficiently. The

degree of services that energy offers to citizens is the goal of energy systems planning. Once sustainable development is the overall purpose of the energy planning process, economic, environmental and social factors must be considered during this analyse.

Therefore, the primary objective of local sustainable energy planning is to determine how future energy service requirements could be fulfilled in the context of various sustainability goals. Greater sustainability can be attained through an energy system of the future that, from a longer-term view, lowers adverse environmental effects while increasing the potential for social and economic development.

Since the planning involves the entire community, the activities will impact the community's social welfare, economic development, and environmental protection. The willingness of businesses and citizens to change their behaviour will determine how effectively initiatives are implemented. Therefore, it is essential to include local actors' values and preferences and consider their perspectives while developing the energy sector to ensure the process's legitimacy and openness [74].

2.4.2 Energy planning tools

There are a vast number of methods and tools that can be used for local energy planning. In this way, this sub-section will present the main energy planning tools used in the literature, focused on the portuguese context. The tools under consideration are: (i) Times-PT, (ii) Times-Évora, and (ii) Times-Iberia.

In this dissertation, the [LEPA](#) tool was chosen since it is simpler and easier to handle when compared to the Times-PT (Section 2.4.2.1). Its functioning is described in (Chapter 3).

2.4.2.1 Times-PT

Since its conception in 2004, Times-PT [75] has benefited from the peer review by various national partners from the industrial, electricity, oil, and end-use energy sectors.

It is a sophisticated technology that employs linear programming to create a least-cost energy system to meet the demand for energy services. This system is optimised across medium to long time horizons while considering several user constraints, such as CO_2 emissions. From 2005 to 2050 (in 5-year steps), this tool characterises the entire chain of the portuguese energy system, including energy imports and production (such as oil and biorefineries), transformation (such as the production of power and heat), distribution, exports, and end-use consumption, in the industrial, residential, services, agricultural, and transport sectors, as well as each of their sub-sectors [76].

The portuguese research project E2POL [77] and the [EU](#) research project NEEDS [78] serve as the initial development environments for the Times-PT model. The model has emerged during the past ten years as a critical instrument supporting national policies to mitigate climate change and, to a lesser extent, air pollution.

2.4.2.2 Times-Évora

The Times-Évora [75] is similar to Times-PT. However, it represents a city-specific energy system model that accurately depicts the energy use in Évora municipality's buildings, including residential and non-residential structures, transportation systems, and other energy uses, such as public lighting and small-scale industry.

In terms of energy usage, it will also stand in for the water and sewage systems and the city's waste management system. The model's primary goal is to pinpoint the ideal combination of strategies and tools that may be used to advance the achievement of the sustainable goals of the cities [76].

2.4.2.3 Times-Iberia

The Times-Iberia [75] technical-economic equilibrium is a model that incorporates the whole energy/emissions system of two nations, Spain and Portugal. This model also involves potential long-term developments until 2050 (with five-year periods), connected through trading primary energy resources.

Times-Iberia has as base year 2005, and it is elaborated to perform energy statistics from 2005 to 2010. These statistics correspond to plant capacity, electricity production and final energy consumption.

Chapter 3

Local Energy Planning Assistant

This chapter provides an overview of the energy planning tool used in this dissertation (namely, [LEPA](#) tool) as the basis for the simulation of current and new [EPA](#) in the context of the Northern region of Portugal.

The [LEPA](#) software is a tool for the decision-making process of local/regional energy planning. This tool can incorporate the values and preferences of the local actors into the energy planning process to maintain transparency and create well-balanced decisions. The tool consists of an MS Excel spreadsheet including several sheets developed in [\[74\]](#).

This tool is divided into two primary sections: *(i)* The modelling of the energy system for the base year and respective evolution over time, the reference scenario, and *(ii)* The creation and evaluation of alternatives, which will be explained in the following sub-chapters. The reference scenario is the starting point for developing and evaluating alternative pathways, i.e, the alternatives are compared against the reference scenario.

Figure [3.1](#), presents the framework applied in this work through [LEPA](#), organised into four sections: start, inputs, methodology and results. Finally, some of the changes/improvements (performed during the realization of this dissertation) that are necessary for the proper functioning of the tool will be presented.

3.1 Start

The "Start" sheet is used to specify the location (municipality/region and country), the base year and the time horizon for which the target was set, and links to all the other sheets.

Note that the territorial scope of this tool is at the local level, so this work is mainly defined for the Northern region of Portugal. Additionally, it was determined that 2020 was the base year and 2050 was the time horizon for energy policies' assessment.

3.2 Inputs

The "Inputs" section is one of the main sections, being crucial for the tool implementation. It consists of only one step (Figure 3.1), which is the modelling of the energy system for the base year and building the reference scenario. It involves filling input sheets concerning the energy demand and supply for the base year. The demand sectors are used to insert energy use data and key socio-economic variables for each sector: residential, services, transport, industry, agriculture and fisheries and street lighting. The supply sector (energy supply) is used to provide detailed characterisation regarding the use of primary energy resources and electricity and heat/cold production from the National Electricity Mix, local Combined Heat and Power (CHP) plants, small-scale local electricity production and green electricity purchases. Finally, it is necessary to enter the data related to energy costs, investment-cost and socio-economic indicators for the reference year as well as the expected evolution over time.

The projection of the evolution of the energy system within the time horizon is performed based on the expected evolution of the socio-economic indicators (population, transportation habits, economic growth, etc.), as well as technological evolution (average efficiency, etc.).

It should be noted that the primary concern of this work is the development and simulation of EE policies applied to the buildings sector, so only the sheets corresponding to the residential and services sectors were addressed.

3.3 Methodology

This sub-chapter is divided into two main steps (steps 2 and 3) and concerns the methodology used in the tool for energy planning.

The second step illustrated in (Figure 3.1) is dedicated to the characterisation of the Business As Usual (BAU) scenario, in terms of primary energy supply, final energy demand and GHG emissions. The BAU refers to the natural evolution of the energy system, being a possible comparison to the alternatives. The primary energy supply refers to the energy derived from natural resources such as coal, crude oil and natural gas. These calculations are based on the final energy demand for the selected area/region, in the case of this work, the Northern region of Portugal. It also considers the national energy balance for the characterisation of the energy transformation processes. They represent essential data for the remaining sheets of the tool, namely the Electricity Mix, in which the evolution of GHG emissions is calculated. Finally, GHG emissions were determined based on the objectives defined in the RNC [8], where their development until 2050 is presented.

The third step illustrated in (Figure 3.1) refers to the development of different alternatives to the reference scenario. Using the alternative generation table included in the LEPA tool, it is possible to generate options by combining activities with the appropriate degree of implementation.

3.4 Results

Afterwards, analysing the results obtained through the **LEPA** tool is possible, being divided into two main steps. The fourth step (Figure 3.1) concerns the analysis of the results by energy vector, namely final energy, useful energy, primary energy and **GHG** emissions. Note that final energy is the provided energy made accessible to the user without considering transition losses. The portion used to deliver energy services is referred to as useful energy. The term primary energy describes the energy derived from natural resources.

Consequently, the fifth step (Figure 3.1) concerns the analysis of reducing **GHG** emissions vs. the investment cost for its implementation and the respective impacts of each alternative compared to the reference scenario. In this way, it is possible to determine the impact in terms of **GHG** emissions and the required investment. The decision-makers can better understand the balance between the expected investment and the benefits of each choice.

Thus, it is possible to select the best alternative after completing the five steps mentioned above.

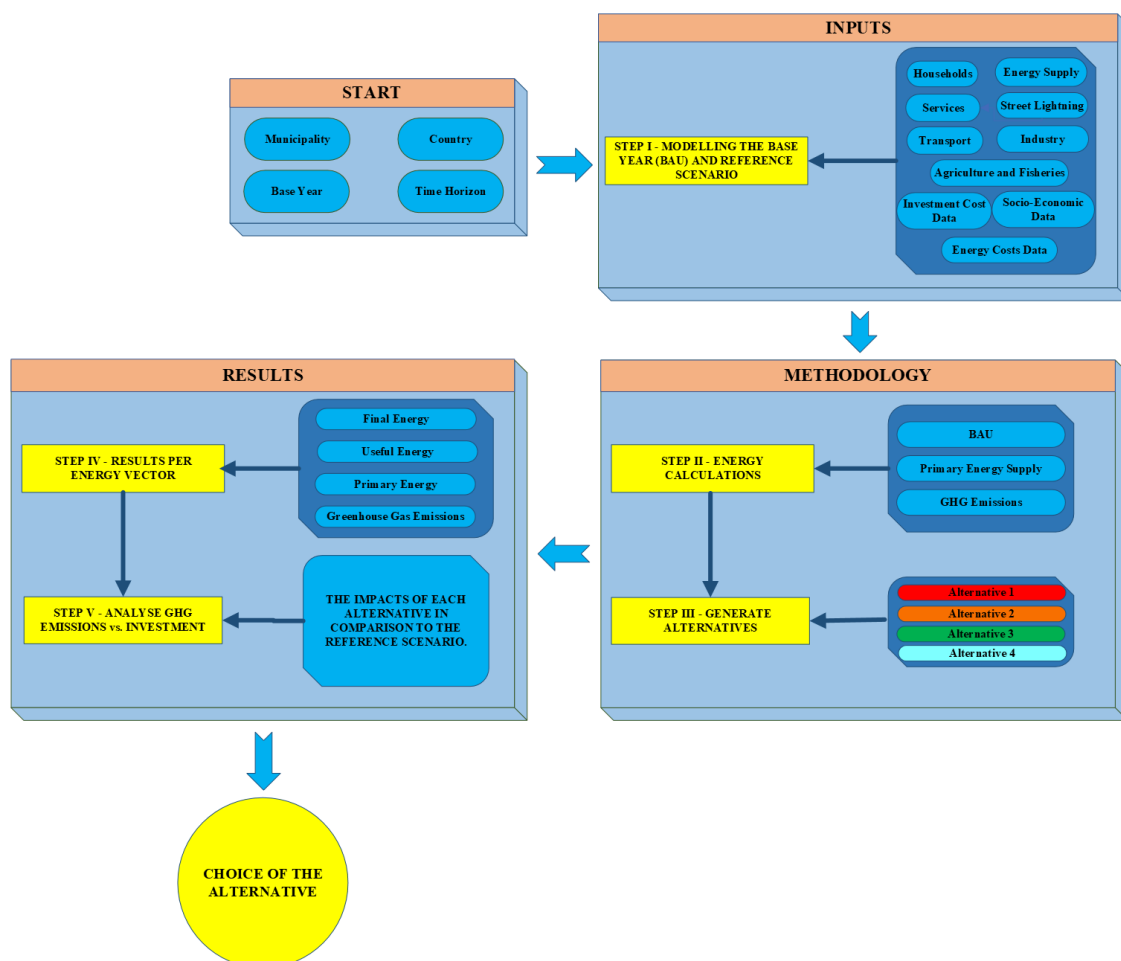


Figure 3.1: Flowchart of the functioning of the Local Energy Planning Assistant tool.

3.5 LEPA Tool Modifications

The energy planning tool was developed in 2009 with a time horizon of 2030. Therefore, it was necessary to make some significant changes since some crucial aspects needed to be considered for this work's development. Initially, it was necessary to modify the whole tool regarding the base year and time horizon, adapting all the data to the year 2050. Then, it was necessary to analyse all the existing energy measures/policies in the tool since some needed to fit with the most current features in the field. Consequently, it was essential to introduce new measures adapted to existing policies and current government roadmaps, such as:

- Replacement of halogen lamps with LED;
- Replacement of compact fluorescent lights with LED;
- Replacement of fireplaces with heat recovery with heat pumps;
- For existing heat pumps, couple solar thermal systems;
- Replacement of conventional fireplaces with electrical heater for solar auxiliary radiant floors;
- Replacement of electrical heaters for heat pumps with solar support;
- Replacement of fireplaces with heat recovery with heat pumps with solar support;
- Replace outdated and non-interoperable heat pumps for heat pumps with solar thermal support;
- Replace outdated and non-interoperable heat pumps for heat pumps with solar **PV** support.

Subsequently, it was necessary to check the calculations of each of the alternatives, and it was found that it would be required to make some changes. When applying the aforementioned energy measures, it was found that the initial tool did not attach importance to energy generation equipment through solar energy. In this way, the calculation formula for this technology was changed so that the inclusion of solar thermal and **PV** equipment was considered and impacted the final energy. Nowadays, this technology significantly influences the energy production of buildings and will be crucial in the future. Thus, the tool is now updated with such considerations.

In the following chapter (Chapter 4), it is possible to verify a detailed characterisation of the case study.

Chapter 4

Case Study Characterisation

This chapter provides a practical example of the application of the decision support tool for local energy planning. The location chosen for this methodology is the Northern region of Portugal since it is the intended location for applying the different energy policies in force under the scope of the DECARBONIZE project.

It is important to refer that this chapter is divided into two main sections. The first one is about the description of the location under study (Section 4.1). On the other hand, the second part (Section 4.2) is about the complete characterisation of the case study, which includes an explanation of all the data necessary to insert and all the assumptions that had to be made due to the lack of data at a local level.

4.1 Description of the location under study

The Northern region of Portugal has around 3,6 million inhabitants, which corresponds to 35% of the total population of Portugal. This region consists of 86 municipalities, and 1426 parishes [79].

In addition, the municipalities are organised into eight Inter-Municipal Communities (IMC), which constitute level III of the Nomenclature of Territorial Units for Statistics (NUTS III), approved by the EC. The eight sub-regions which constitute the North region are the following: "Alto Tâmega", "Alto Minho", "Área Metropolitana do Porto", "Ave", "Cávado", "Douro", "Tâmega e Sousa", and "Terras de Trás-os-Montes".

Figure (4.1) depicts the map of the Northern region of Portugal, illustrating the eight IMC.

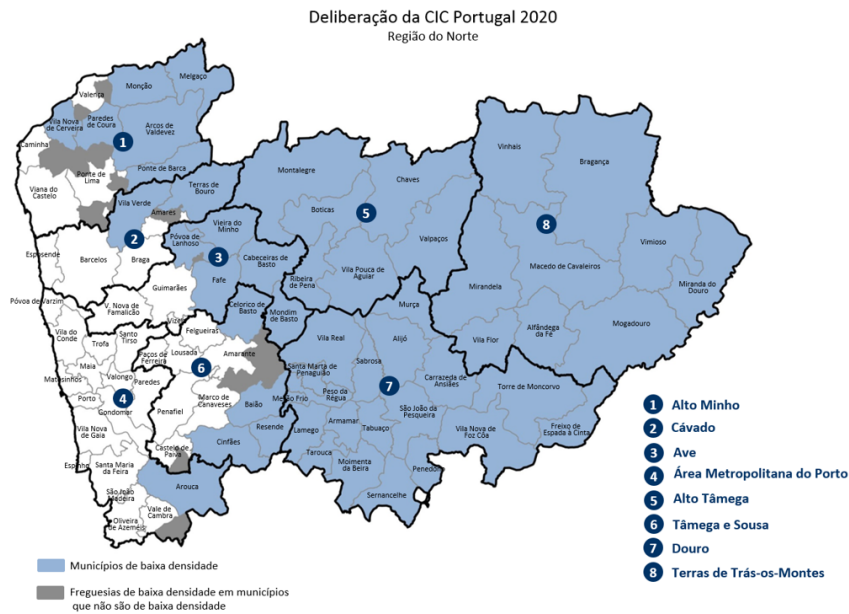


Figure 4.1: Map of the Northern region of Portugal, accounting for the main inter-municipal community areas [79] - [in Portuguese].

4.2 Modelling the energy system of the Northern region of Portugal

It is worth mentioning that this dissertation focuses on the conception and simulation of energy policies in the residential and service sectors. Therefore, only sections of the [LEPA](#) tool and data regarding residential and service buildings were considered. An overview of the input data required to fill in the [LEPA](#) tool has been made.

It is important to note that in the other sectors addressed by the tool, namely: transport, industry, agriculture, fishing and public lighting, it was necessary to update the final energy demand value referring to electricity since these values affected the calculation of [GHG](#) emissions for the residential sector [80]. These values were updated based on the document on electricity consumption by activity sector. Obtaining the input data is the first stage when using the end-use energy model. Because not all the necessary information is readily available at the municipal level, this is undoubtedly one of the more difficult tasks when applying the technique for energy planning. Numerous assumptions and scaling-down from other administrative levels, such as regional or national, have been made due to data availability restrictions and a lack of bottom-up municipal data.

4.2.1 Residential Sector

The values referring to the final energy demand per energy carrier and the key-socio economic variable (the number of occupied dwellings) for the residential buildings sector are shown in (Table

4.1). It is also possible to observe where this data was taken from and the estimating techniques in the absence of local data.

The table shows that the number of occupied residential buildings was taken from National Statistics Institute (INE) until 2020, and the remaining values until 2050 were determined based on a trend function.

Table 4.1: Input data for the base year and identification of potential sources or estimates for the residential sector.

Data	Municipal level data Source	Other sources and estimates
Electricity	Electricity consumption by the activity sector	-
Natural Gas	Natural gas consumption in the internal market	-
Oil Products	Sales by the municipality and activity sector	-
Wood	Not Available	Estimates based on national wood consumption by sector, and the total population of Portugal and the Northern region (INE, 2020)
Solar Radiation	Not Available	Estimates based on national photovoltaic domestic production by sector, and the total population of Portugal and the Northern region (INE, 2020)
Waste Heat	Not Available	Assumed equal to zero
Renewable Heat	Not Available	Estimates based on national solar thermal energy consumption by sector, and the total population of Portugal and the Northern region (INE, 2020)
Number of occupied dwellings	National Statistics Institute (INE, 2001-2020)	-

4.2.1.1 Base Year

After the energy demand data for the residential sector has been defined, it is required to determine, for the base year, the breakdown by the end use of each energy carrier. For this purpose, (Figure 4.2) was consulted, referring to the distribution of energy consumption by energy source and type of use [81].

It is essential to consider that the use of energy sources in the kitchen "Cozinha" includes the consumption of the following equipment: stove with oven, induction hob, free-standing oven, grill (non-electric) and fireplace. In addition, home appliances "Equipamentos Eléctricos" includes the consumption of the following equipment: fridge, freezer, dishwasher, washer and dryer, TV, computer and vacuum cleaner. Since the necessary data to determine the breakdown by end use was unavailable for each of the equipment, estimates were made using the percentage of average monthly consumption corresponding to each piece of equipment.

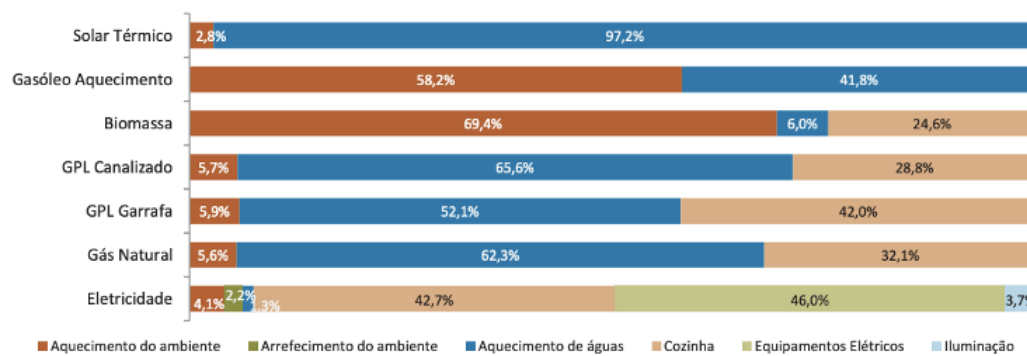


Figure 4.2: Distribution of energy consumption in residential buildings by energy source and type of use - Portugal, 2020 [81] - [in Portuguese].

4.2.1.2 Reference Scenario

Regarding the reference scenario, the national low-carbon roadmap [82] was used to calculate the evolution factor of the demand for energy services per dwelling. This roadmap provides data regarding the evolution of the need for energy services in the residential sector for two pre-defined scenarios (low and high), where 2010 equals 100.

The two socioeconomic scenarios make two different assumptions about economic and social progress. The Gross Domestic Product (GDP) is projected to grow at a higher rate of 3% per year from 2016 to 2050 under the high scenario, along with an increase in population. On the other hand, the low scenario is defined by a lower rate of economic growth, taking into account a GDP growth rate of 1%/year for the same period, as well as a decline in the population and a lower rate of economic growth [82]. Table (4.3) illustrates the data used.

Ano	Aquecimento		Arrefecimento		Aquecimento água		Refrigeração		Cozinha		Iluminação		Máquina de lavar roupa		Máquina de loiça		Máquina secar roupa		Outros equipamentos eléctricos	
	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto
2010	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2015	106	115	110	108	100	101	99	100	100	101	109	110	100	101	100	102	116	117	102	103
2020	113	130	119	141	100	103	99	102	100	103	117	120	99	102	112	117	131	135	105	113
2025	118	144	128	161	99	105	98	103	99	105	124	131	98	103	123	132	145	153	106	124
2030	124	157	136	181	98	106	97	105	98	106	131	142	96	104	133	147	159	172	108	135
2035	128	175	144	202	97	108	96	106	97	108	137	153	94	105	143	163	171	191	109	148
2040	132	176	150	222	95	109	94	108	95	109	143	164	93	106	152	179	183	210	110	162
2045	135	186	156	242	93	110	92	109	93	110	147	175	90	107	159	194	193	229	110	176
2050	136	195	160	258	90	111	89	110	90	111	150	186	87	108	169	204	201	248	109	191

Figure 4.3: Evolution of the need for energy services in the residential sector for two pre-defined scenarios (low and high) [82] - [in Portuguese].

Considering that the base year is 2020 and the reference scenario is 2040 when analysing this data, it is necessary to make an average between the high and low scenarios and then a proportion between the reference year and the base year, thus obtaining the evolution factor of the demand for services.

Table (B.1), available in Appendix B shows the calculations performed. The value indicated in green corresponds to the demand evolution factor determined for the space heating and cooling for the reference scenario.

4.2.2 Services Sector

Similar to what has been performed for the residential buildings sector (Section 4.2.1), (Table 4.2) shows the locations from which the input data was taken for the service buildings sector.

Table 4.2: Input data for the base year and identification of potential sources or estimates for the services sector.

Data	Municipal level data Source	Other sources and estimates
Number of Employed Population	PORDATA-Statistics about Portugal and Europe (PORDATA, 2020)	-
Electricity	Not Available	Estimates based on the energy balance- Electricity consumption by the activity sector and the total employed population of Portugal and the Northern region (PORDATA,2020)
Natural Gas	Not Available	Estimates based on the energy balance- Natural gas consumption by the activity sector and the total employed population of Portugal and the Northern region (PORDATA,2020)
Oil Products	Not Available	Estimates based on the energy balance- Oil total by the activity sector and the total employed population of Portugal and the Northern region (PORDATA,2020)
Wood	Not Available	Estimates based on the energy balance- wood and waste by the activity sector and the total employed population of Portugal and the Northern region (PORDATA,2020)
Solar Radiation	Not Available	Assumed equal to zero
Waste Heat	Not Available	Assumed equal to zero
Renewable Heat	Not Available	Estimates based on the energy balance- Solar thermal energy consumption by the activity sector and the total employed population of Portugal and the Northern region (PORDATA,2020)

4.2.2.1 Sectoral Gross Value Added (GVA)

For this sector, it is also necessary to indicate the Gross Value Added (GVA) for the base year and its annual rate of change to estimate this value for the desired time horizon. As the necessary data is unavailable at the local level, it was necessary to look for the number of people employed by significant economic activity sectors in Portugal to estimate the GVA for the Northern region. The

sector used corresponds to the tertiary sector, where the economic activities presented in (Table 4.3) were selected.

Table 4.3: Economic activities selected for the calculation of the sectoral gross value added [83].

Economic Activities	Portugal - GVA(€)
Wholesale and retail trade, repair of motor vehicles and motorbikes	18299229233
Accommodation, food and beverage service activities	3005491128
Information and communication activities	7353168132
Real estate activities	2825394338
Consultancy, scientific and technical activities	6890425558
Administrative and support service activities	6213842501
Education	930489461
Human health and social work activities	3398970696
Arts, entertainment, sports and recreation	931710217
Other service activities	619001404

After having the GVA value for Portugal, the proportion with the number of employed population was determined to know what the GVA for the Northern region is, as suggested in [74]. The remaining values up to 2050 were determined using the respective gross value-added rate.

4.2.2.2 Base Year

Since the data needed to calculate the end-use breakdown of each energy carrier for the base year for the service buildings sector were not available, it was necessary to estimate these values based on data obtained in 2009 [84] and the values for residential buildings in 2009 and 2020.

4.2.2.3 Reference Scenario

The procedure for calculating the energy demand evolution factor for the services buildings sector is similar to the residential sector (Section 4.2.1). Again, using the national low carbon roadmap through (Table 4.4) corresponding to the evolution of demand for the scenarios (low and high), it is possible to determine the desired values.

Ano	Aquecimento		Arrefecimento		Aquecimento água		Refrigeração		Cozinha		Iluminação		Iluminação pública		Equipamentos eléctricos	
	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto	Baixo	Alto
2010	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2015	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2020	100	103	101	105	101	104	101	104	101	103	105	115	100	102	108	122
2025	101	107	103	111	102	108	102	108	102	107	111	132	101	104	117	149
2030	102	110	105	117	103	113	103	113	103	111	115	143	101	106	124	170
2035	103	112	107	123	105	117	105	117	105	115	117	150	102	109	129	186
2040	104	115	110	130	106	121	106	121	106	119	119	155	103	111	133	201
2045	105	118	112	136	108	126	108	126	108	124	120	161	104	114	137	217
2050	106	120	114	143	109	130	109	130	110	128	122	167	105	117	141	234

Figure 4.4: Evolution of the need for energy services in the services sector for two pre-defined scenarios (low and high)-[*in Portuguese*][82].

Consequently, were obtained the results, shown in (Table B.2) available in Appendix B, for space heating and cooling in the services building sector.

4.2.3 Energy Supply Inputs

Following the flowchart of the tool (Figure 3.1), it is necessary to enter the energy supply data for the year 2020. For this purpose, the national energy balance [85] was used, which contains the primary energy values referring to thermoelectric production, renewables and cogeneration plants, as well as the value of imports and exports of electricity produced. Furthermore, data regarding the use of oil products in terms of primary energy and the equivalent value available for final use were also introduced.

In this sheet of the LEPA tool, it is also necessary to indicate the value of electricity produced for local micro-generation in terms of renewables. Since these values are not available for the Northern region of Portugal but at a national level, it was necessary to consult the map of renewable electricity producing centres in Portugal [86]. Through this map, it is possible to count how many small hydro, biogas, wind and PV power plants up to 10 MW are installed in the Northern region. Then, it is necessary to multiply the calculated proportions by the annual decentralised mini/micro-production of biogas, the hydro, wind, geothermal and solar in tonnes of oil equivalent (toe). It should be noted that there is no geothermal production in the Northern region of Portugal.

4.2.4 Socio-Economic Data

Firstly, in this tool sheet, data are entered regarding the number of inhabitants for the base year and the time horizon, i.e., up to 2050. To make this projection, it was essential to determine the annual variation rate of the population at a local level. Using the data made available by the INE for the projection of the resident population in Portugal, it is possible to determine this rate of change for the Northern region. Since the data on the number of inhabitants is available every five years, this rate also varies every five years.

Next, it is necessary to introduce the data relative to the GDP of the region for the year 2020 as well as its projection in the time horizon. The values used are represented in (Table 4.4).

Table 4.4: Potencial GDP growth rates [87].

Potential GDP growth rates					
Year	2000-07	2007-18	2018-30	2030-40	2030-60
Portugal	1.6	0.5	1.1	1.5	1.0

Finally, the values for the average occupancy of dwellings for the base year and time horizon are entered. The average number of residents in the dwellings can be consulted in the "Censos" [88] for the years 1981, 2001 and 2011. The values for the time horizon are the result of estimates.

4.2.5 Energy Costs Data

At this stage of the work, it is required to enter the costs per energy carrier for the buildings sector. This data is entered up to 2020, and the remaining information is determined based on a trend function. All the data is provided by the DGE on documents related to fuel prices in Portugal, and converting the units to equivalent tons of oil is only necessary [89].

4.2.6 Investment Cost Data

Finally, it is also necessary to enter the investment cost values for each technology in terms of €/kWh for the residential and service building sectors.

These values were determined based on each appliance's current prices and annual energy consumption. To simplify, the explanation of these calculations is represented in (Table B.3) in Appendix B, the example of Led lamps. Knowing each lamp's value and consumption in 1000h, it is possible to obtain the investment needed for implementing this type of equipment. In the case of the led lamps, it was necessary to verify that the average number of hours of operation per year was, at most, the average life of the source. The same rationale was used for the remaining equipment.

4.2.7 Electricity National Mix

This is the last part of the tool that requires input data and concerns the evolution of the electrogeneration system in the time horizon. Since it is necessary to determine the percentage of electricity at the final energy level, the RNC [8] was used as a basis. Through a complete analysis of this document, it is known that in 2050 there should be a total decarbonisation of the electrogeneration sector, namely 100% renewables in electricity production. It is also known that the consumption of coal will end in 2030. Concerning RES, it is possible to understand through the roadmap that PV technology will assert itself with more significant evidence, as well as wind energy which increases its participation significantly. These two technologies will jointly ensure 50% of the electricity generated in 2030 and 70% in 2050, respectively. It is also intended to reach 94% in 2030, 97% in 2040 and 100% of renewables in electricity generation [8].

This information in the RNC [8] made it possible to determine what percentages to put in the Electricity Mix sheet for the portion of electricity.

Figure (4.5) presents the evolution of the installed capacity of the power generation sector and its carbon intensity for the time horizon.

INSTALLED CAPACITY	2015	2020	2030	2040	2050
	19.9	22.5	29.3 30.3	42 42.4	53.2 54.5
Coal	1.8	1.8	0.0	0.0	0.0
Natural Gas	4.8	4.9	3.5 4	2.3 2.4	0.2
Fuel Oil	0.8	0.7	0.2	0.1	0.0
Hydroelectric	4.6	4.6	5.1	5.1	5.1
Hydroelectric with pumping	1.6	2.5	3.4	3.4	3.4
Onshore Wind Power	5.0	5.2	8 7	10	12 13
Offshore Wind Power	0.0	0.0	0.3 0.4	0.3 1.2	0.2 1.3
Centralised Solar PV	0.3	1.4	4.6 5	9.9 9.3	14.4 13
Decentralised Solar PV	0.2	0.5	2.3	7.1 7.6	12 13
Geothermal	0.0	0.1	0.1	0.1	0.0
Biomass/Biogas/Waste	0.8	0.9	1.4 1.6	1.4	1.8 1.4
Batteries	0.0	0.0	0.6 1.2	2.3 1.3	4.1 4
Hydrogen	0.00	0.00	1.25 1.29	4.61 13.71	12.99 21.49

Unit: GW

Figure 4.5: Evolution of the installed capacity of power generation sector, including its carbon intensity [8].

Chapter 5

Results

This chapter concerns the results obtained for the case study under analysis. It should be noted that the use of the term Alternatives refers to [EPA](#) with different characteristics.

Chapter [5](#) is organised into six main sections, where the first one (Section [5.1](#)) is related to the results obtained for the [BAU](#). The others refer to the results of the development of the four alternatives (Sections [5.2](#), [5.3](#), [5.4](#), and [5.5](#)). Finally, the section corresponding to the comparison of all alternatives is presented (Section [5.6](#)).

5.1 BAU

After entering all the data in the energy planning tool, it is possible to analyse the results obtained for the [BAU](#), which will then be compared with the results obtained by implementing the different alternatives.

In the first place, it is necessary to clarify the following concepts for the analysis of the [BAU](#) results. Primary energy is an energy source which has not yet undergone any transformation. It is obtained from natural resources such as minerals, plants, animals, water, sun, wind, tides and others. Primary energy is often used as a raw material to produce other types of energy. Final energy refers to that which is received by consumers, i.e., it is how energy is commercialized. In other words, this is the energy distributed to clients of the most diverse types: residential, industrial, agricultural, commercial and even public roads. Final energy has various purposes: to illuminate, to drive household appliances, to move vehicles and to heat, for example, water. It is worth mentioning that in the very use of final energy, considerable energy losses occur. As previously mentioned, there are losses during the use of energy. In other words, the electricity made available for consumption is not fully used. This gives rise to the concept of useful energy, that which is used to satisfy needs, whether for heat, air conditioning, lighting, mobility or production.

This sub-chapter is divided into two parts. The first part (Section [5.1.1](#)) refers to the characterisation of [BAU](#) for the residential sector, and the second part (Section [5.1.2](#)) refers to the description of [BAU](#) for the services sector. It is essential to mention that, for the [BAU](#), all measures currently in force contribute. The time horizon established for analysing the results is from 2020

to 2050. An analysis every 10 years was determined to simplify the perception of the evolution of the outcomes.

5.1.1 Residential Sector

This section corresponds to the results obtained for residential buildings.

Figure (5.1) depicts the primary, useful and final energy demand for each time horizon, namely, 2020, 2030, 2040 and 2050.

In this graph, it is possible to observe that the evolution of final energy demand decreases throughout the years. This result is due to the expected decrease in the use of natural gas, oil products and wood. From 2030 onwards, it is also intended to suppress the use of fossil heat. Regarding the useful energy demand, there will be significant growth until 2050. Through the calculations made in the [LEPA](#) tool, these values are justified by the sharp increase of electricity in the end use of water heating, space heating and cooling. It should also be noted that the use of electricity in cooking also contributes to this growing evolution. Finally, the evolution of the primary energy demand is decreasing. These results are due to the constant evolution of the efficiency of the existing equipment in the buildings. This sharp decrease is also because the target is to achieve decarbonisation by 2050.

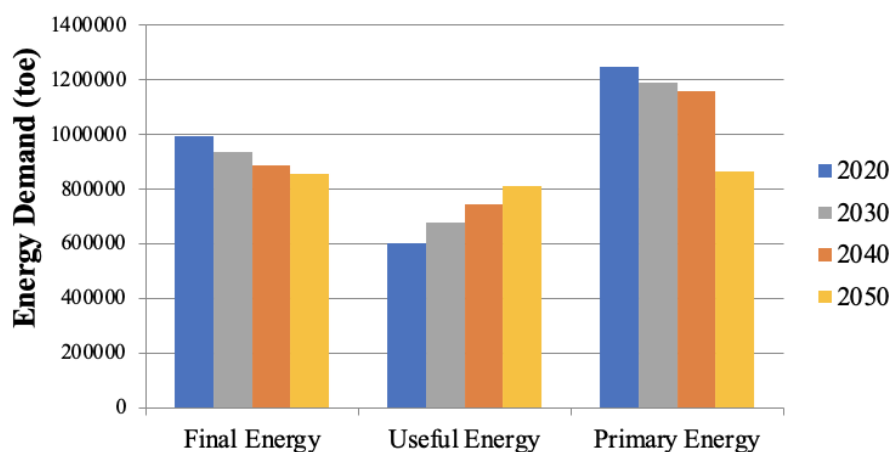


Figure 5.1: Evolution of primary, useful and final energy demand, for each time horizon, for the residential sector.

Then, it is possible to determine the evolution of emissions over time. Figure (5.2) shows that emissions reduction is very pronounced, especially in 2050, since it is intended that this year, the percentage of [RES](#) in electricity production will be about 100%. It represents around 4% of existing [GHG](#) emissions in 2020.

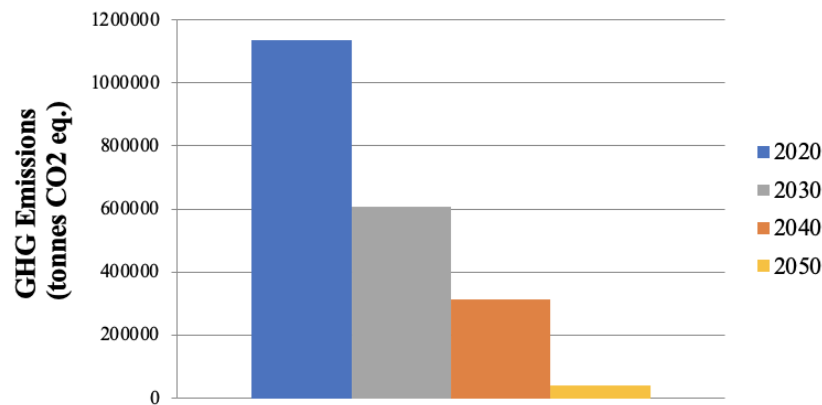


Figure 5.2: Greenhouse gas emissions for the residential sector.

Finally, it is possible to analyse the estimated breakdown of residential' final energy demand by end-use over time through (Figure (5.3)).

It is essential to highlight the years 2020 and 2040, corresponding to the base year and reference scenario, respectively. In 2020, space heating and cooking represented a large share of the final energy use, accounting for 25% and 32%, respectively. Hot water represents 22% and household appliances 19% of total final energy use. In 2040, the reference scenario, the bulk of final energy demand is still for cooking. Still, there is a slight increase in energy used for household appliances and a decrease in energy used for space heating and hot water. These small changes can be explained by the continuous replacement of appliances with more efficient appliances, i.e., by the natural evolution of technology.

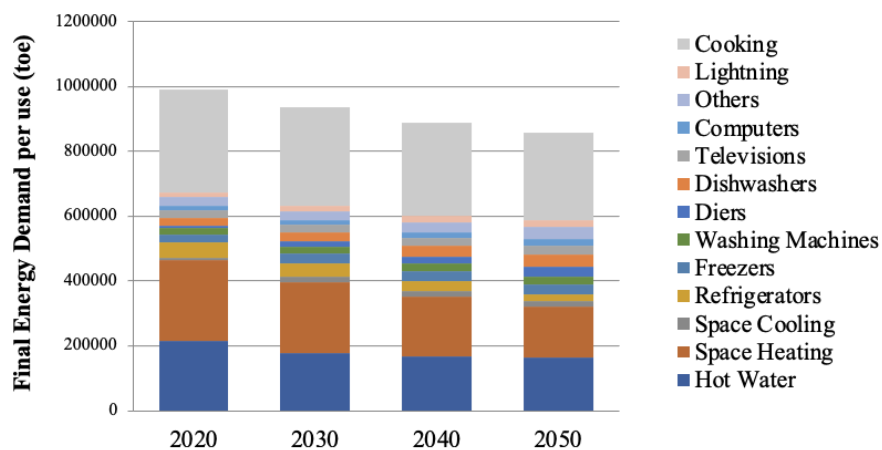


Figure 5.3: Final energy demand per use for the residential sector.

5.1.2 Services Sector

A similar analysis of the residential buildings has been made for the services buildings. As it was possible to observe before, through the energy planning tool, it is possible to see in Figure 5.4 the corresponding primary, useful and final energy demand for the services sector.

When compared with the graph for the residential sector (Figure 5.1), Figure 5.4 presents some differences. This is because, as explained in section (4.2.2.2), the information needed to calculate the end-use breakdown of each energy carrier for the base year was not available. In this way, it was necessary to estimate these values based on data obtained in 2009 and the values for residential buildings in 2009 and 2020, which caused the results for primary, useful and final energy to be affected. Being aware of this, primary, useful and final energy show an increasing evolution mainly due to the increased use of electricity.

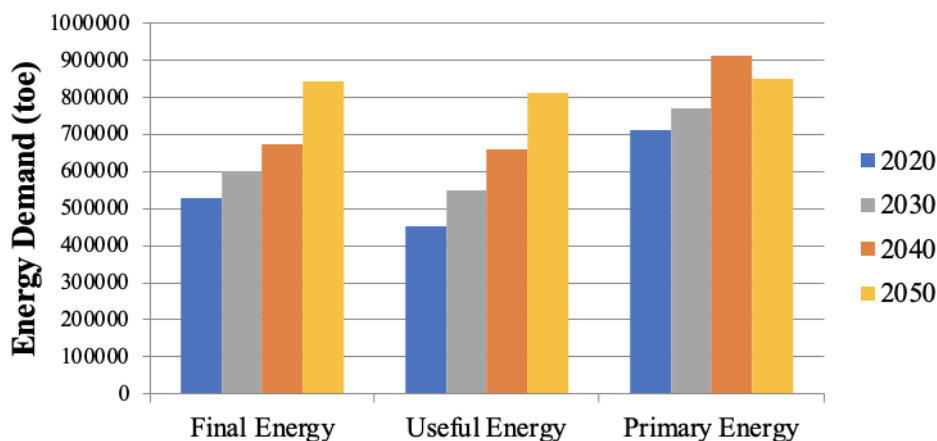


Figure 5.4: Evolution of primary, useful and final energy demand for each time horizon, for the services sector.

The evolution of GHG emissions for the services sector is depicted in Figure 5.5. Emissions will fall sharply by 2050, again due to the requirement to produce electricity from RES. In this figure, it is possible to verify that the emissions present a reduction of 94% in 2050 when compared with the year 2020.

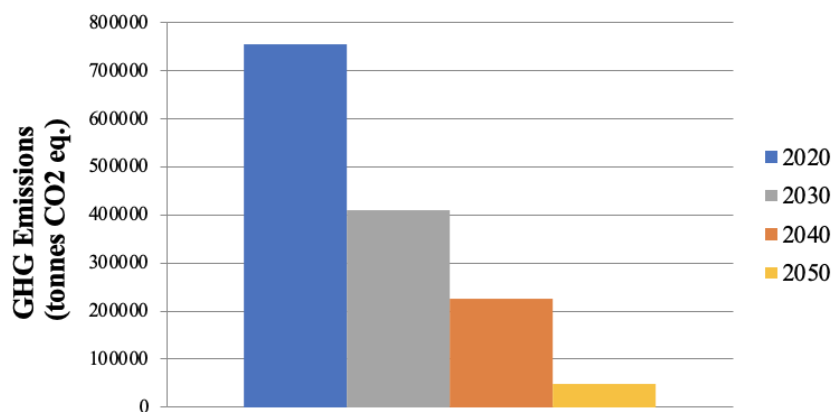


Figure 5.5: Greenhouse gas emissions for the services sector.

Lastly, the breakdown of final energy demand by end-use over time is presented in Figure 5.6. The demand for household appliances represents a large share of the final energy use, accounting

for 30% for the base year and the reference scenario. Lightning also accounts for a significant share of final energy demand, around 25% in 2020 and rising to 27% in 2050.

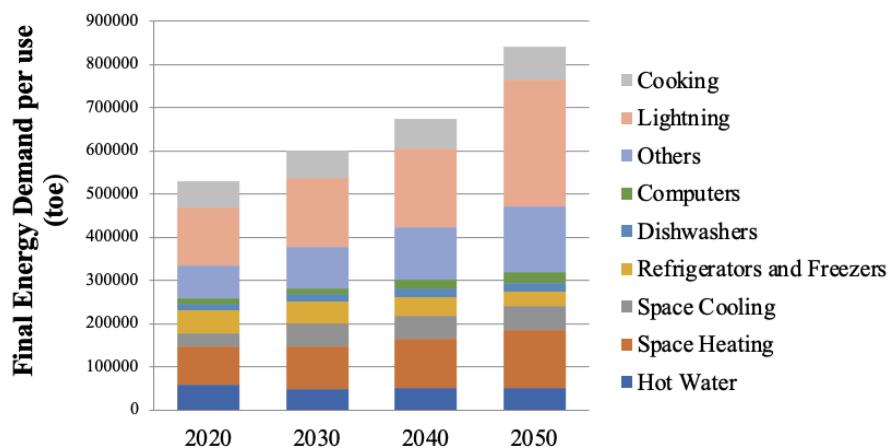


Figure 5.6: Final energy demand per use for the services sector.

5.2 Alternative 1

The Alternative one is based on the [PNEC](#). By applying this alternative, whose objectives are directed to 2030, it is possible to have a closer view of the results to be achieved since they are projections for eight years from now.

The [PNEC](#)'s strategic goals include encouraging the energy transition through a solid commitment to renewable energies and [EE](#) and integrating mitigation goals in sectorial policies. These goals will allow the country to achieve carbon neutrality by 2050.

It is described in Figure 2.2 specifically, the objectives that are intended to achieve with the implementation of Alternative 1. Since this work focuses on residential and service buildings, targets for renewables in transport and electricity interconnections will not be considered.

5.2.1 Residential Sector

5.2.1.1 Renewable Energy

According to the [PNEC](#), concerning [RES](#), it was established that the weight of their representation should be around 47% in 2030 [7]. The estimated trajectories for the sectoral share of renewable energy in final energy consumption are shown in Table 5.1.

Table 5.1: Estimated trajectories for the sectoral share of renewable energy in final energy consumption [7].

	2020	2025	2030
Electricity	60%	69%	80%
Space Heating and Space Cooling	34%	36%	38%
Transports	10%	13%	20%

Since, for this case study, the transport sector is not considered, only the objectives to be achieved for electricity and space heating and cooling were taken into account.

Firstly, the case of the target to be achieved for space heating and cooling was analysed. To reach 38% in 2030, the following measures had to be implemented: (i) Replacement of conventional fireplaces with electrical heaters for solar auxiliary radiant floors, around 63%; (ii) Replacement of electrical heaters for heat pumps with solar support, around 50% and (iii) Replacement of fireplaces with heat recovery with heat pumps with solar support, around 50%.

In (Table 5.2), it is possible to verify that the intended goal was achieved in 2030.

Table 5.2: Results of Alternative 1, for renewables in space heating and cooling in the residential buildings sector.

	2030	2040	2050
Electrical heater for solar auxiliary radiant floors	4%	7%	9%
Heat pump for solar auxiliary radiant floors	18%	20%	20%
Central boiler for solar auxiliary radiant floors	4%	2%	0%
Hydronic Radiant Floors with Solar water heater	11%	16%	20%
Total Useful Energy	38%	44%	50%

Regarding the objective defined for the trajectory of electricity in final energy consumption, the measure: Increase the percentage of total electricity of the sector that is produced locally through RES was applied to about 80%. Finally, to strengthen the weight of renewable energies to 47% in 2030, all equipment dependent on RES in hot water, space heating and cooling were analysed, and the following results (shown in Table 5.3) were obtained:

Table 5.3: Results of Alternative 1, for the % of renewable energy in the residential sector.

	2030	2040	2050
Total Renewable Electricity (toe)	303082	292921	285570
Solar Water Heater (toe)	89311	106518	117829
Hydronic Radiant Floors with Solar water heater (toe)	16582	28044	40789
Total Final Energy (toe)	831626	797980	809552
% of Renewable Energy	49%	54%	55%

As it is possible to verify, the proposed objective was surpassed, having been obtained for 2030, about 49% of the share of renewables in the residential sector.

5.2.1.2 GHG Emissions

Another of the objectives set by the PNEC concerns GHG emissions. This objective is based on GHG emissions in 2005 and establishes that in 2030 the reduction of GHG should be around 35% for the residential sector, compared to 2005.

As can be seen in Table 5.4, the goal was clearly achieved since, in 2030, the percentage of GHG emissions reduction corresponds to 83%.

Table 5.4: Results of Alternative 1, for GHG emissions in the residential buildings sector.

GHG Emissions for the Residential Sector		
BY(2020)	RC(2030)	A1(2030)
1141058	612150	463280
% of Emissions Reduction		83%

Regarding the percentage of total emissions, the PNEC establishes that in 2030 this value should be around 45% to 55%. In Table 5.5, it is possible to see that this goal was exceeded.

Table 5.5: Results of Alternative 1, for total GHG emissions.

Total GHG Emissions		
BY(2020)	RC(2030)	A1(2030)
5261696	3956938	3593086
% of Emissions Reduction		95%

5.2.1.3 Energy Efficiency

Finally, the EE target needs to be met. According to the PNEC, it is expected to reduce primary energy consumption by 35% in 2030 [7], compared to 2005. This policy intends: (i) To reduce primary energy consumption in the various sectors in the context of sustainability and cost-effectiveness, (ii) To focus on EE and the efficient use of resources, (iii) To privilege the rehabilitation and renovation of the built environment, and (iv) To promote zero-emission buildings. It is also known that to ensure compliance with the 35% EE target in 2030, Portugal should have a primary energy consumption of up to 20,7 Mtoe [7].

Since only the residential and services building sectors are considered in this case study, it was necessary to determine what is the maximum allowable primary energy consumption limit in the residential building sector. This value was determined using the energy balance in the year 2005.

After comparing this value with the primary energy consumption for the year 2030, it was found that the desired goal was achieved. It was possible to achieve a reduction of EE in the

residential sector, around 33% compared with 2005. Thus, for the EE target, it was not necessary to implement any measures.

5.2.1.4 Impacts of the Alternative

After analysing the targets to be met for Alternative 1, it is possible to determine the investment cost of the measures applied. In Figure 5.7, it can be seen that a large investment is required for space heating and cooling, especially for 2050. These results are due to the fact that the PNEC establishes that it is essential to reinforce thermal comfort in the heating and cooling of buildings. It is also possible to notice that the investment in hot water is only for the years 2030 and 2040.

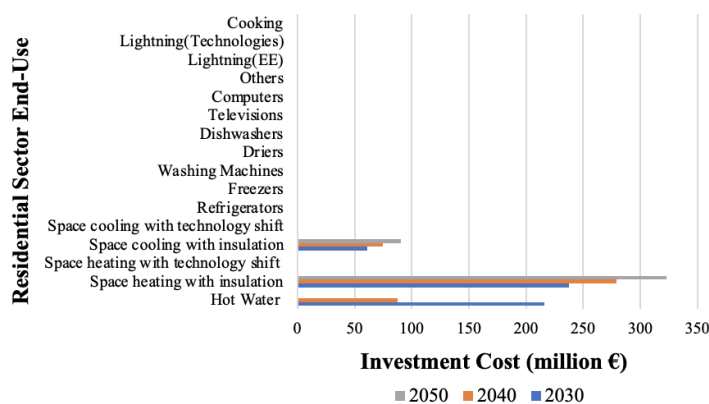


Figure 5.7: Alternative 1, the investment cost for the residential sector (million €).

Afterwards, it is possible to analyse the final energy evolution for each energy vector in the residential sector (Figure 5.8). One can observe that the final energy concerning electricity and solar radiation is increasing throughout the time horizon. This is because it is intended to promote electrification and decarbonisation in buildings. It is also possible to notice that the values obtained for natural gas, oil products and wood decrease over the years, even reaching zero in 2050.

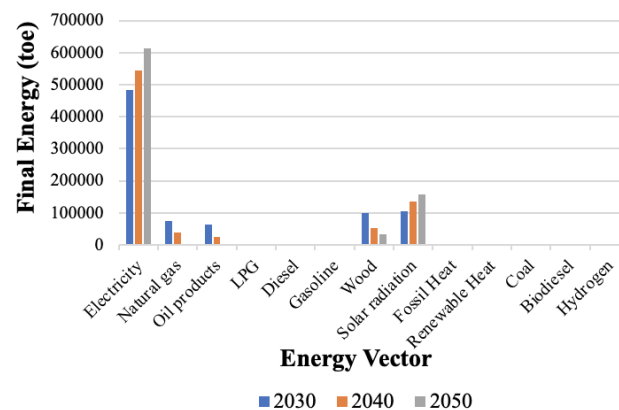


Figure 5.8: Alternative 1, the final energy of each energy vector for the residential sector.

Finally, it is possible to compare the results obtained for GHG emissions and the investment cost of the measures applied for the residential sector through Figure 5.9. It is possible to verify that this alternative allows a sharp decrease in emissions over the time horizon, reaching values close to zero. One can also see that the investment cost has decreased significantly over the years.

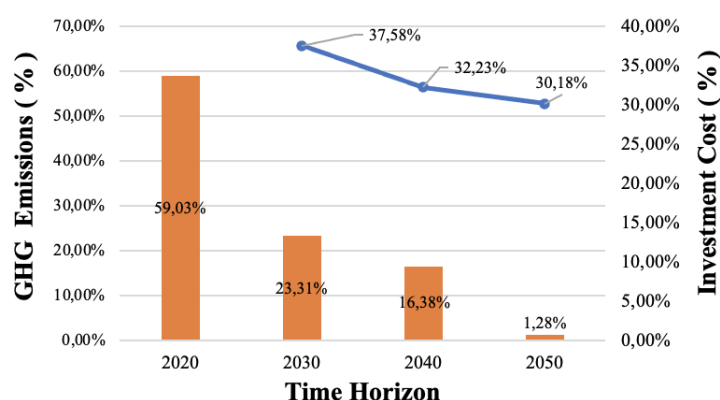


Figure 5.9: Alternative 1, comparison between emissions and the investment cost for the residential sector.

5.2.2 Services Sector

For the services sector, the principle for identifying the measures implemented for Alternative 1 is similar to the one used for residential buildings (Section 5.2.1).

5.2.2.1 Renewable Energy

For the service buildings sector, the targets for increasing the share of renewable energy are the same as for residential buildings. It was also considered the trajectories for the sectoral share of renewable energy in final consumption defined in Table 5.1.

The target to be achieved for space heating and cooling was analysed. To reach 38% in 2030, the following measure had to be implemented: Replace outdated and non-interoperable heat pumps for heat pumps with PV support, around 55%.

In (Table 5.6), it is possible to verify that the intended goal was achieved in 2030.

Table 5.6: Results of Alternative 1, for renewables in space heating and cooling in the services buildings sector.

	2030	2040	2050
Electrical heater for solar auxiliary radiant floors	0%	0%	0%
Heat pump for solar auxiliary radiant floors	37%	38%	38%
Central boiler for solar auxiliary radiant floors	0%	0%	0%
Hydronic Radiant Floors with Solar water heater	1%	2%	3%
Total Useful Energy	38%	39%	41%

Regarding the objective defined for the trajectory of electricity in final energy consumption, the measure: Increase the percentage of total electricity of the sector that is produced locally through RES was applied to about 80%.

Finally, to strengthen the weight of renewable energies to 47% in 2030, all equipment dependent on RES in hot water, space heating and cooling were analysed. Table 5.7 depicts the results of the implementation of this measure. As it is possible to verify, the proposed objective was surpassed, having been obtained for 2030, about 66% of the share of renewables in the services sector.

Table 5.7: Results of Alternative 1, for the % of renewable energy in the services sector.

	2030	2040	2050
Total Renewable Electricity (toe)	365468	405989	509600
Solar Water Heater (toe)	14539	26601	38142
Hydronic Radiant Floors with Solar water heater (toe)	2673	6164	11774
Total Final Energy (toe)	577470	648174	813543
% of Renewable Energy	66%	68%	69%

5.2.2.2 GHG Emissions

Once again, the logic used for the service sector is the same as that used for residential buildings (Section 5.2.1.2). This objective is based on GHG emissions in 2005 and establishes that in 2030 the reduction of GHG should be around 70% for the services sector, compared to 2005.

As can be seen in Table 5.8, the goal was clearly achieved since, in 2030, the percentage of GHG emissions reduction corresponds to 87%.

Table 5.8: Results of Alternative 1, for GHG emissions in the services buildings sector.

GHG Emissions for the Services Sector		
BY(2020)	RC(2030)	A1(2030)
754953	410648	409205
% of Emissions Reduction	87%	

5.2.2.3 Energy Efficiency

For the target set for EE in the service buildings sector, the procedure for verifying the achievement of this target was similar to the one carried out for the residential buildings sector (Section 5.2.1.3).

In this case, it was only necessary to select the value for primary energy consumption in the sector in consideration. It was again verified that when comparing the limit value established in 2005, the proposed goal was achieved without adding new measures.

5.2.2.4 Impacts of the Alternative

As previously carried out, it is possible to determine what is the impact of Alternative 1 in the service buildings sector.

Firstly, it is possible to analyse the investment needed to implement the selected measures (Figure 5.10). It is verified that only investment is applied to space heating and cooling, and this is because it is necessary to introduce a new measure to reach the established target for the reinforcement of renewable energies. This investment is increasing over the years.

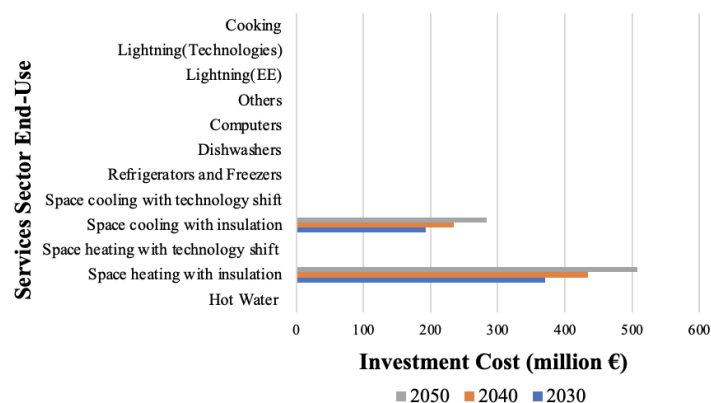


Figure 5.10: Alternative 1, the investment cost for the services sector (million €).

Then, it is possible to analyse the distribution of the final energy by energy vector (Figure 5.11). It can be verified that over the time horizon, electricity and solar radiation increase, and the remaining ones decrease. This shows that the objective of increasing the introduction of RES is being fulfilled.

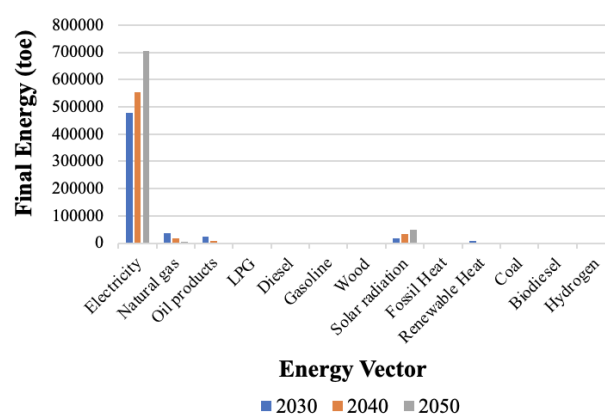


Figure 5.11: Alternative 1, the final energy of each energy vector for the services sector.

Finally, it is possible to compare the evolution of GHG emissions with the investment cost of this alternative in Figure 5.12. Once again, there is a sharp decrease in the GHG emission values. However, contrary to the residential sector, the investment value has increased over the years. This

increase is explained by the growing evolution of the investment cost of space heating and cooling technologies.

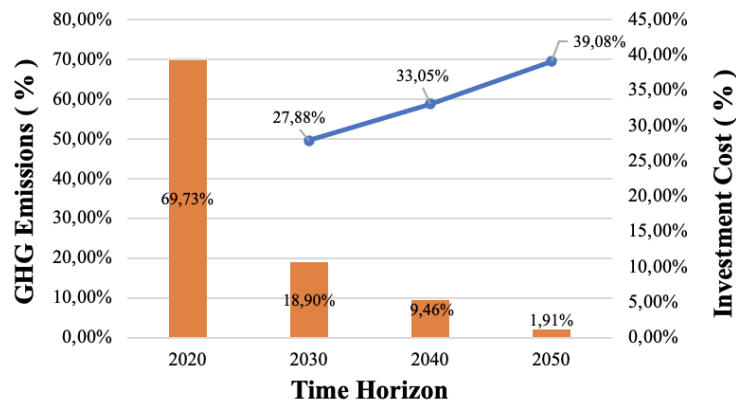


Figure 5.12: Alternative 1, comparison between emissions and the investment cost for the services sector.

5.3 Alternative 2

Alternative two considers the application of the **RNC**, which sets the achievement of carbon neutrality by 2050 as a commitment.

Involving all sectors of the economy and society, **RNC 2050** enables the vision of the primary future trend lines and the essential economic and social adjustments. The employment of solar thermal and heat pumps in buildings, both residential and commercial, will considerably contribute to the decarbonisation of the environment due to the nearly total electrification of energy consumption and significant **EE** benefits through enhanced building insulation.

In buildings, energy is used to provide energy services such as space heating and cooling, lighting, refrigeration and food preparation, and sanitary water heating, among others. It is known that the building sector is responsible for 5% of the country's **GHG** emissions [8].

The goal is to reduce **GHG** emissions by 97% (heating) and 96% (cooling) in the residential sector and 100% in the services sector, (compared to 2005 levels), with the incorporation of renewable energy in heating and cooling to be 66% and 68% [8].

A strengthening of thermal comfort in homes in terms of heating and cooling is anticipated in the residential and services sector. This comfort improvement results from the industry's ongoing trend toward electrification, which is accomplished using more efficient machinery like heat pumps.

This increase in comfort does not directly translate into a rise in final energy consumption, as insulation measures are predicted to lower heating energy consumption by 26% in 2040 and roughly 50% in 2050 in the residential sector [8].

Figure 5.13 and Figure 5.14 show over the time horizon which objectives the roadmap sets out to achieve in the residential and services sectors, respectively. Alternative two is based on these targets.

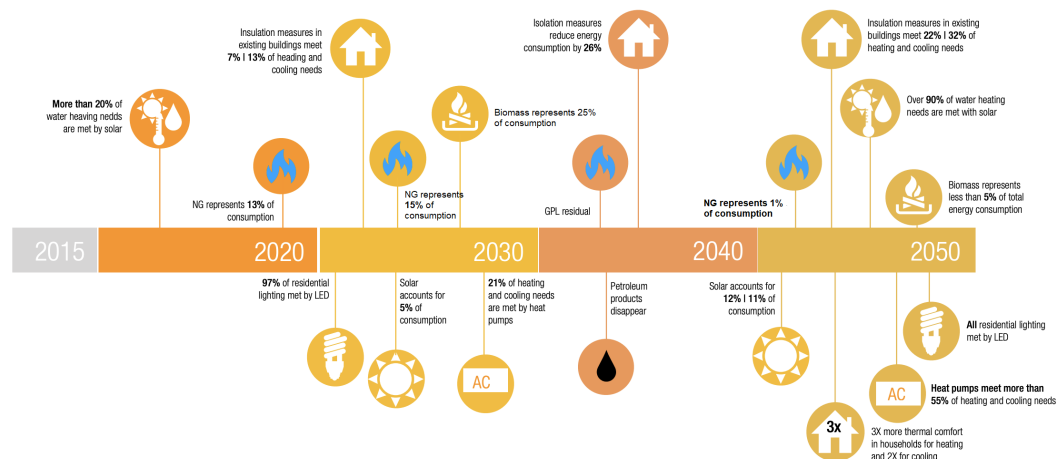


Figure 5.13: Timeline of residential sector's carbon neutrality pathway up to 2050, as defined by the RNC2050, adapted from [8].

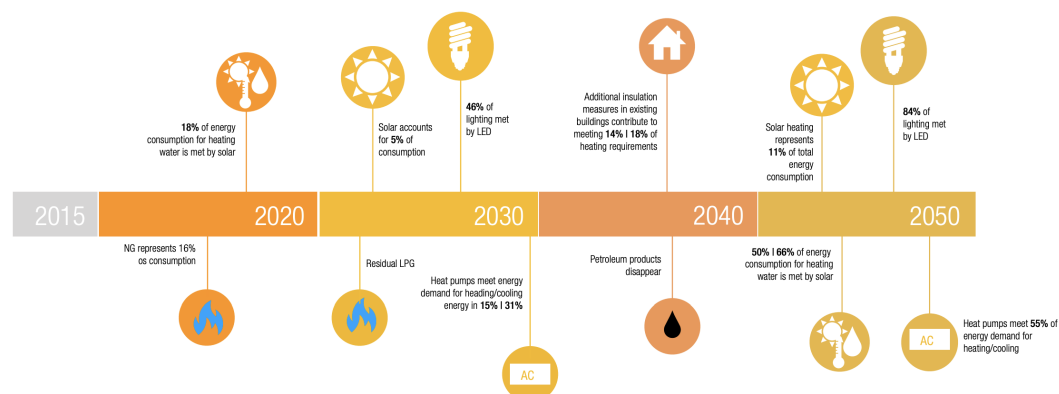


Figure 5.14: Timeline of services sector's carbon neutrality pathway up to 2050, as defined by the RNC2050, adapted from [8].

5.3.1 Residential Sector

5.3.1.1 Hot Water

After defining the objectives to be achieved in Alternative 2, it is possible to analyse the results. It is intended that more than 90% of the water heating needs to be met with solar support.

To achieve this objective, the following measures were implemented: (i) The replacement of fossil fuel water heaters with solar thermal systems supported by efficient electric heaters, (ii) The replacement of natural gas heaters with solar thermal systems supported by efficient electric heaters, and (iii) The replacement of conventional electric heaters with solar thermal systems.

Since the target still needed to be met after adding these measures, it was necessary to add a new measure: For the existing heat pumps couple solar thermal systems. This measure has made it possible for about 100% of water heating to be met by solar energy in 2050.

Table 5.9 illustrates the evolution of the implementation of this measure.

Table 5.9: Results of Alternative 2, for water heating in the residential building sector.

Technology	2030	2040	2050
Conventional storage water heater for solar auxiliary heating	8%	12%	15%
Heat pump water heater for solar auxiliary heating	11%	18%	24%
Gas tankless water heater for solar auxiliary heating	4%	1%	0%
Conventional storage water heater for solar auxiliary heating	9%	5%	1%
Solar water heater	65%	62%	61%
Total	98%	98%	100%

5.3.1.2 Space Heating

It is known that heat pumps are required to meet heating and cooling needs by 55% for space heating. Since this target was already completed in 2030, no measures had to be applied under Alternative 2.

5.3.1.3 Lightning

Concerning lighting, the RNC aims for all lighting to be provided by LEDs. Since there were no measures in the tool for equipment replacement, it was necessary to add two new measures: (i) The replacement of halogen lamps with LED, and (ii) The replacement of compact fluorescent lights with LED. By adding these two measures, it was found that it is possible to achieve 100% by 2050.

Table 5.10 shows the percentage use of each type of lamp over time.

Table 5.10: Results of Alternative 2, for lightning in the residential buildings sector.

Technology	2030	2040	2050
Compact Fluorescent Lamps	21%	6%	0%
Tungsten Halogen Lamps	1%	0%	0%
LED	60%	85%	100%
Total	82%	91%	100%

5.3.1.4 Natural Gas Consumption

Another goal to be achieved is that natural gas consumption should represent about 1% of total consumption. To achieve this, the following measures were applied: (i) The replacement of fossil fuel stoves with electric induction stoves, around 2%, (ii) The replacement of natural gas stoves

with electric induction stoves, around 2%, and finally, (iii) The replacement of electric stoves with electric induction stoves, around 8.5%.

The combination of these measures means that in 2050, natural gas consumption will represent around 0.2% of total consumption, achieving the defined objective.

5.3.1.5 Thermal Insulation

The measures are expected to satisfy 22% and 32% of the heating and cooling demand for thermal insulation, respectively.

Therefore, approximately 11% has been applied to the measure for reducing heating needs in buildings and 11% to decreasing cooling needs. Applying these measures shows that the total useful energy decreases as the percentage of application of the measure increases.

5.3.1.6 Renewable Energy

According to the [RNC](#), it is intended that by 2050, renewable in heating and cooling will account for about 66% and 68%, respectively.

Firstly, it was necessary to identify which renewable technologies are in heating and cooling and their influence on achieving this goal. Then, the following measure was applied: To increase the percentage of total electricity of the sector that is produced locally through [RES](#). This measure was used in about 40%, reaching nearly 67% of renewables in heating and cooling, as seen below in Table 5.11.

Table 5.11: Results of Alternative 2, for renewables in space heating and cooling in the residential buildings sector.

Space Heating		Space Cooling	
Technology	Final Energy 2050 (toe)	Technology	Final Energy 2050 (toe)
Electrical heater	0	-	-
Electrical heater for solar auxiliary radiant floors	19524	-	-
Heat Pump	13484	Heat Pump	15355
Heat pump for solar auxiliary radiant floors	5796	-	-
Total (toe)	38804	-	-
Total Final Energy (toe)	116296	Total Final Energy (toe)	15355
% of Renewable Energy in Space Heating	33%	% of Renewable Energy in Space Cooling	100%
% of Renewable Energy			67%

5.3.1.7 Wood

Wood should represent less than 5% of total energy consumption. To achieve this goal, it was necessary to apply a new measure: The replacement of fireplaces with heat recovery with heat pumps.

By applying this measure to around 12% of the equipment, it is possible to verify that wood will represent around 4.29% of total energy consumption in 2050, thus complying with the established objective.

5.3.1.8 GHG Emissions

Finally, it is necessary to ensure that the emission reduction target is achieved.

This objective is based on GHG emissions in 2005 and establishes that in 2050 the reduction of GHG should be around 97% compared to 2005. As seen in (Table 5.12), with this case study, it is possible to overcome the goal of reaching 2050, a 99% GHG reduction.

Table 5.12: Results of Alternative 2, for GHG emissions in the residential buildings sector.

GHG Emissions for the Residential Sector		
BY(2020)	RC(2050)	A2(2050)
1141058	40406	27604
% of Emissions Reduction		99%

5.3.1.9 Impacts of the Alternative

This step analyses the relationship between Alternative 2's advantages and the total investment needed. By creating an investment-cost graph, each alternative's overall benefit value score, as computed in (Section 4.2.6), can be shown alongside its investment requirements.

It should be noted that the investment costs associated with each year correspond to the price necessary to achieve certain values of emissions and final energy in that specific year. In Figure 5.15, it can be seen that there was a need to invest in cooking, space heating and cooling, hot water, and lightning. These investments are due to the need to meet the targets set for these technologies. It is important to emphasize that the high investment in cooking equipment in 2030 refers to the need to replace existing equipment with more efficient equipment.

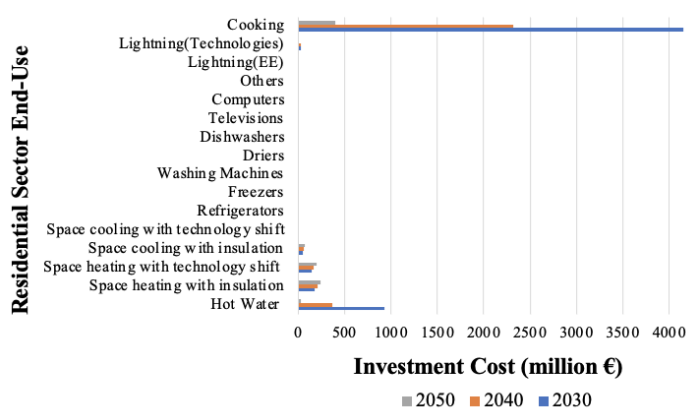


Figure 5.15: Alternative 2, the investment cost for the residential sector (million €).

Next, it is possible to analyse through Figure 5.16 the evolution of the final energy by energy carrier. Since it is necessary to prioritise the electrification and decarbonisation of buildings, it can be seen that the final energy for electricity and solar radiation has increased over the years.

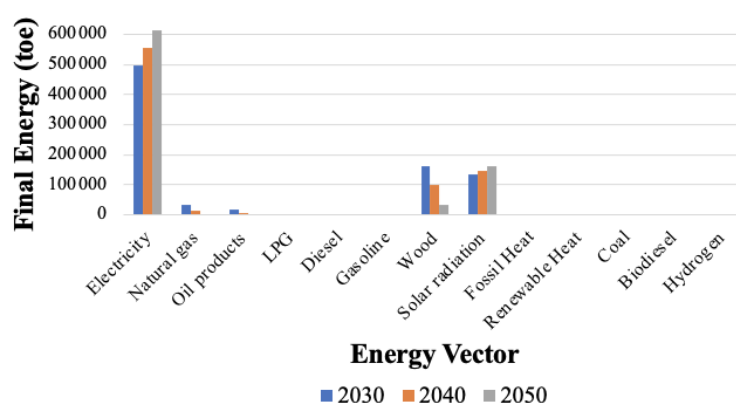


Figure 5.16: Alternative 2, the final energy of each energy vector for the residential sector.

Finally, Figure 5.17 presents the comparison between the evolution of GHG emissions and the investment cost after the implementation of proposed measures for Alternative 2. It can be seen that these values are proportional and that the decrease is quite sharp in both cases. As intended, the GHG emission values for 2050 are close to zero, representing a 98% reduction compared to the values obtained in 2020.

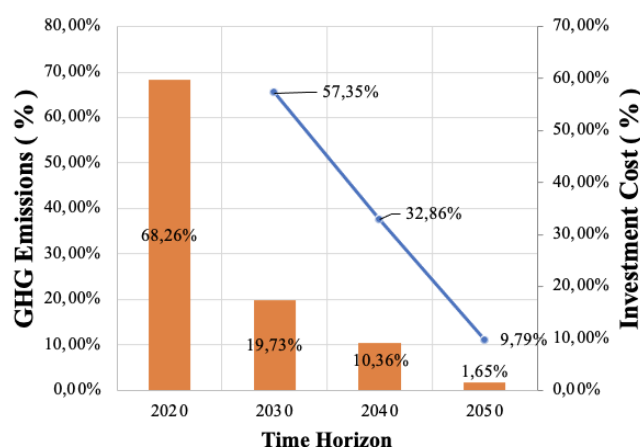


Figure 5.17: Alternative 2, comparison between emissions and the investment cost for the residential sector.

5.3.2 Services Sector

For the services sector, the principle for identifying the measures to be implemented for Alternative 2 is similar to the one used for residential buildings (Section 5.3.1).

The objectives are described in Figure 5.14, and the results can be analysed below.

5.3.2.1 Hot Water and Space Heating

According to the RNC, solar is intended to account for about 50% to 60% of water heating and heat pumps for 55% of heating needs.

Before applying any measures for these end-uses in Alternative 2, it was verified that the reference scenario initially defined already met these objectives. Therefore, it was not necessary to implement any measures for water heating and space heating.

5.3.2.2 Lightning

Following the example of residential buildings, for lighting in service buildings, it was also necessary to add two new measures to ensure that by 2050, 84% of the lighting was LED-supplied.

The measures implemented were the same as those defined previously: (i) The replacement of halogen lamps with LED, and (ii) The replacement of compact fluorescent lights with LED. The evolution in using the different types of lamps over time can be seen in (Table 5.13). It can be seen that by 2030, the 2050 target has already been achieved.

Table 5.13: Results of Alternative 2, for lightning in the services buildings sector.

Technology	2030	2040	2050
Compact Fluorescent Lamps	24%	9%	0%
Tungsten Halogen Lamps	1%	0%	0%
LED	61%	89%	100%
Total	86%	98%	100%

5.3.2.3 Thermal Insulation

For thermal insulation, the measures are intended to meet 14% to 18% of heating needs. Thus, the action was implemented: Reduce the heating needs of buildings by around 14%.

Applying this measure makes it possible to verify that the total energy used for space heating decreases, fulfilling the intended objective.

5.3.2.4 Renewable Energy

Concerning renewable energies, the RNC aims to account for between 66% and 68% of space heating and cooling, respectively.

To attain this goal, it was necessary to apply the following measure at 12%: Increase the percentage of total electricity of the sector that is produced locally through RES.

As it is possible to see in Table 5.14, in 2050, the percentage of renewables in heating and cooling corresponds to 71%, thus exceeding the target.

Table 5.14: Results of Alternative 2, for renewable energy in space heating and cooling in the services buildings sector.

Space Heating		Space Cooling	
Technology	Final Energy 2050 (toe)	Technology	Final Energy 2050 (toe)
Electrical heater	0	-	-
Electrical heater for solar auxiliary radiant floors	0	-	-
Heat Pump	21443	Heat Pump	54258
Heat pump for solar auxiliary radiant floors	27995	-	-
Total (toe)	49438	-	-
Total Final Energy (toe)	115851	Total Final Energy (toe)	54258
% of Renewable Energy in Space Heating	43%	% of Renewable Energy in Space Cooling	100%
% of Renewable Energy			71%

5.3.2.5 Solar Heating

For the service buildings sector, it is intended that solar heating accounts for 11% of total energy consumption.

To achieve this goal were identified which technologies depend on this type of use for water heating and space heating. Afterwards, as it turned out that the objective still needed to be reached, it was necessary to add a new measure for space heating: For existing heat pumps, couple them with solar thermal systems.

The implementation of this measure by 40% allows for reaching the target of 11% of solar thermal in the total consumption in 2050. Table 5.15 illustrates the calculations performed.

Table 5.15: Results of Alternative 2, for solar heating in the services buildings sector.

Hot Water		Space Heating	
Technology	Final Energy 2050 (toe)	Technology	Final Energy 2050 (toe)
Conventional storage water heater for solar auxiliary heating	982	Electrical heater for solar auxiliary radiant floors	0
Heat pump water heater for solar auxiliary heating	3460	Heat pump for solar auxiliary radiant floors	27995
Gas tankless water heater for solar auxiliary heating	2266	Central boiler for solar auxiliary radiant floors	0
Conventional storage water heater for solar auxiliary heating	2266	Hydronic Radiant Floors with Solar water heater	11913
Solar water heater	38142	-	-
Total Final Energy Solar Heating (toe)			87025
Total Final Energy (toe)			801343
% Solar Heating			11%

5.3.2.6 GHG Emissions

Finally, it is necessary to analyse GHG emissions for the services sector. The RNC sets an objective to achieve a reduction of 100% compared to 2005.

In Table 5.16, it is possible to verify that this objective is achieved for Alternative 2 since 99.8% GHG emission reduction was obtained.

Table 5.16: Results of Alternative 2, for GHG emissions in the services buildings sector.

GHG Emissions for the Services Sector		
BY(2020)	RC(2050)	A2(2050)
754953	48832	37447
% of Emissions Reduction		99,8%

5.3.2.7 Impacts of the Alternative

In order to analyse the impact of the implementation of Alternative 2, Figure 5.18 shows the evolution of the investment cost for the service buildings sector. It is possible to verify that there is a strong investment in lighting technologies and space heating. This is due to the measures established by the RNC for this sector.

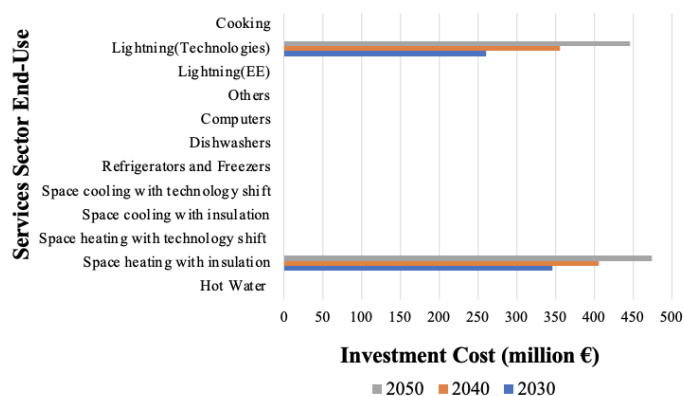


Figure 5.18: Alternative 2, the investment cost for the services sector (million €).

Afterwards, it is possible to analyse the evolution of final energy by energy carrier Figure 5.19, where the evolution of electricity is the most accentuated throughout the time horizon. It can also be seen that the evolution of solar radiation is also increasing, a fact justified by the strong implementation of RES in the system.

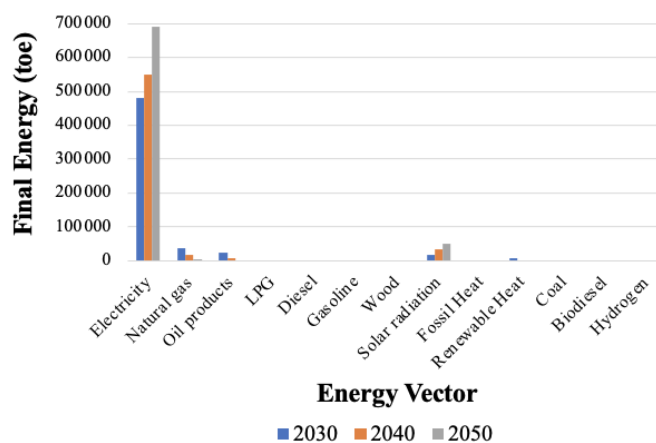


Figure 5.19: Alternative 2, the final energy of each energy vector for the services sector.

Finally, a comparison was made between the evolution of GHG emissions and the evolution of investment cost over the years, depicted in Figure 5.20. It can be seen that, contrary to the residential sector, the value of the investment cost increases while GHG emissions decrease. In 2050 it is possible to obtain a reduction of emissions of about 97% compared to the year 2020.

The increased investment refers to the growing investment cost of implementing space heating and lighting technologies.

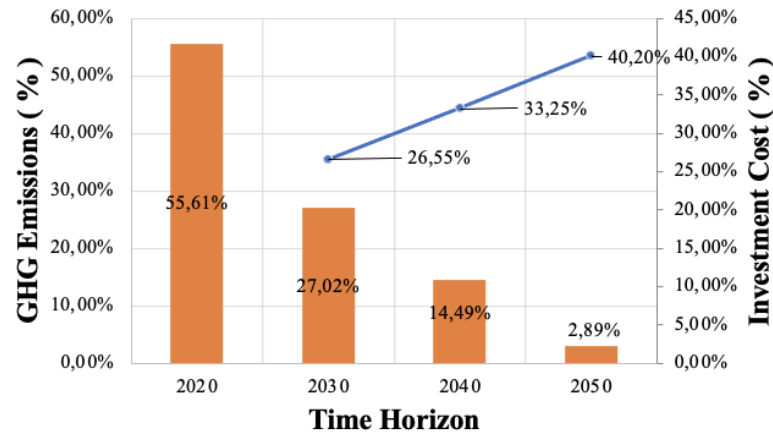


Figure 5.20: Alternative 2, comparison between emissions and the investment cost for the services sector.

5.4 Alternative 3

Alternative three was developed with the suggestion to implement measures to improve **EE** in household appliances. This alternative emerges as a need to complement the plans in force. It is verified that, both in the **PNEC** and the **RNC**, there are no specific measures for the replacement of less efficient appliances by more efficient ones. In practice, this alternative is more accessible to implement than some existing ones since it is easier to replace a refrigerator than a conventional fireplace that is part of the building construction.

It should be noted that a target of 45% for the most efficient equipment has been set for 2050. The impacts of implementing Alternative 3 in the residential (Section 5.4.1) and services (Section 5.4.2) sectors will be explained in the following sub-chapters.

5.4.1 Residential Sector

Five **EE** improvement measures for residential buildings were applied to household appliances. The measures are described below: (i) Replacement of less efficient refrigerators with class A, B or C equipment, around 100%, (ii) Replacement of less efficient freezers with class D appliances, around 8%, (iii) Replacement of less efficient washing machines with class A, B or C equipment, around 50%, (iv) Replacement of less efficient driers with A+, A++ and A+++ class equipment, around 89%, and (v) Replacement of less efficient dishwashers with class A, B or C equipment, around 75%.

After introducing these measures, it is possible to analyse the investment cost of these measures over the time horizon, depicted in Figure 5.21. There is a substantial investment in electrical

appliances whose efficiency has been improved. Refrigerators and dishwashers are the most costly as they are the appliances with the highest €/kWh consumed.

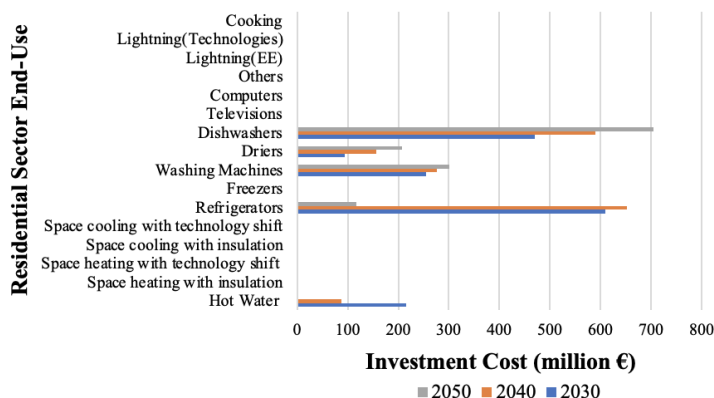


Figure 5.21: Alternative 3, the investment cost for the residential sector (million €).

It is then possible to analyse which is the distribution of the final energy by energy vector, presented in Figure 5.22. It can be seen that both electricity and solar radiation increase and the remaining decrease. This is because the aim is to achieve decarbonisation by 2050.

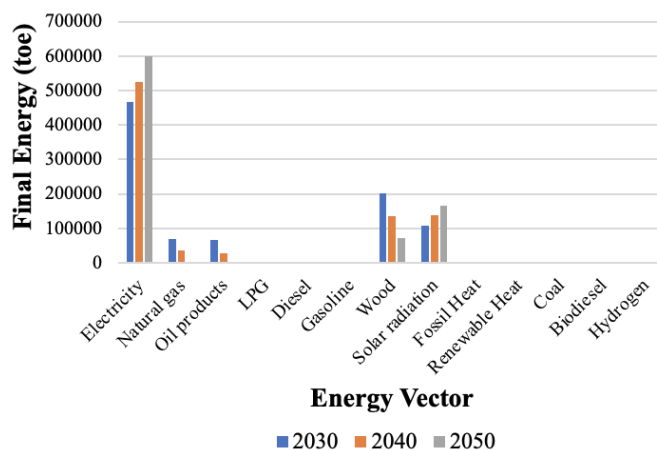


Figure 5.22: Alternative 3, the final energy of each energy vector for the residential sector.

Finally, Figure 5.23 shows the comparison between GHG emissions evolution and the investment cost after the implementation of proposed measures for Alternative 3. It is possible to verify a sharp drop in emissions over time, with a reduction of about 98% compared to 2020. The investment cost tends to follow this decrease.

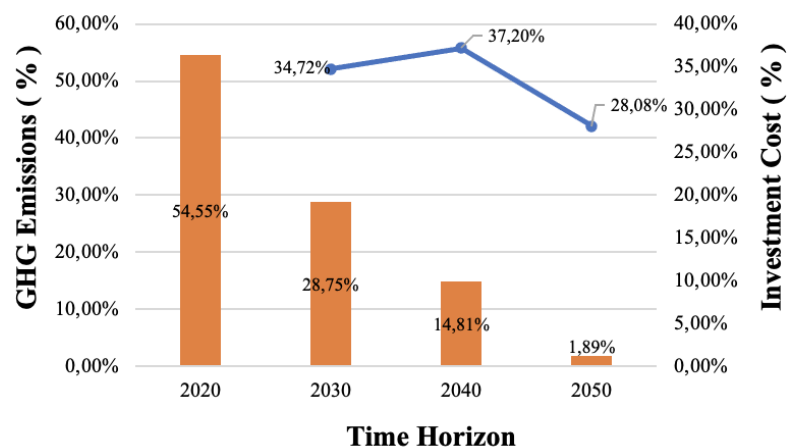


Figure 5.23: Alternative 3, comparison between emissions and the investment cost for the residential sector.

5.4.2 Services Sector

The analysis of the impact of Alternative 3 in the service buildings sector is similar to that carried out previously for the residential sector (Section 5.4.1). For the services sector, only one measure concerning the improvement of the EE of domestic appliances was applied. This measure replaces less efficient refrigerators and freezers with class A, B and C equipment. Firstly, the investment cost of implementing this measure, shown in Figure 5.24, was analysed. The investment cost is seen to decrease, with a slight increase in 2040, caused by the increased investment cost of refrigerators and freezers.

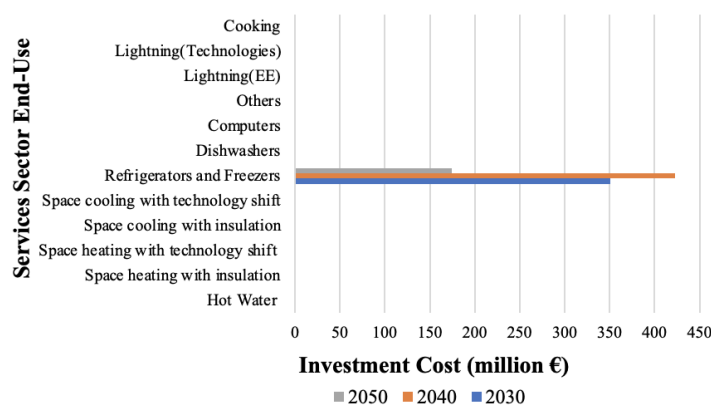


Figure 5.24: Alternative 3, the investment cost for the services sector (million €).

Then, the evolution of final energy by each energy carrier along the time horizon was analysed, as presented by Figure 5.25. An increasing evolution of electricity and solar radiation for the services sector is verified, as it is strongly intended to implement the use of RES.

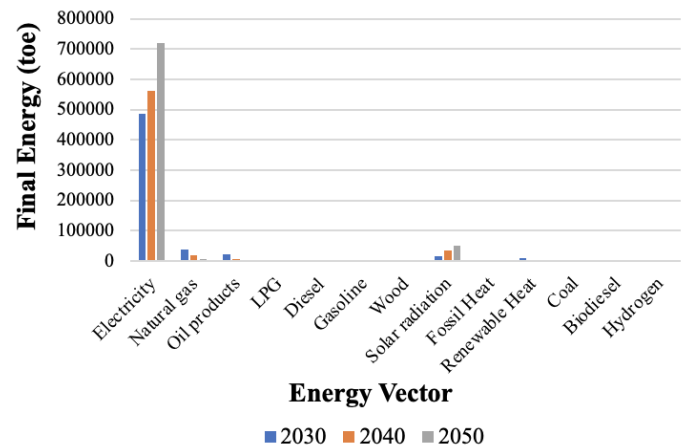


Figure 5.25: Alternative 3, the final energy of each energy vector for the services sector.

Finally, a comparison was made between the evolution of emissions and the investment cost and is illustrated in Figure 5.26. There is a marked decrease in GHG emissions since decarbonisation is intended to be achieved by 2050. The investment cost follows this trend, although, in 2040, there is a small increase.

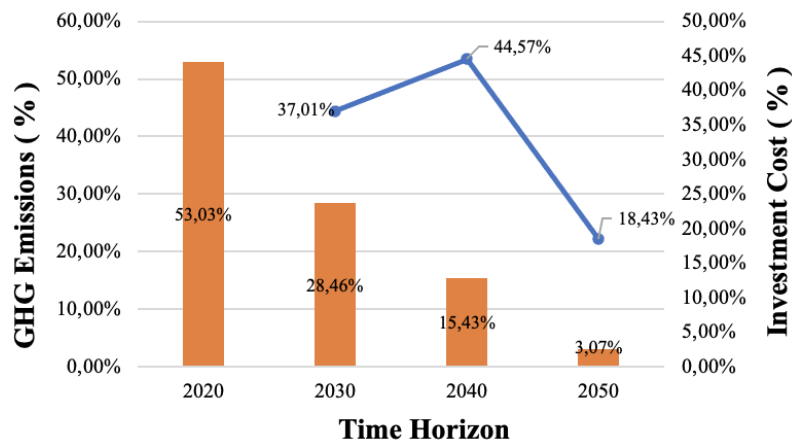


Figure 5.26: Alternative 3, comparison between emissions and the investment cost for the services sector.

After analysing the results obtained for Alternative 3, it was found that by simply acting on the appliances, the results of the investment cost obtained are close to those of changing equipment in space heating and hot water (Alternatives 1 and 2). However, it is noted that GHG emissions did not reduce significantly.

In this way, it was necessary to create a fourth alternative that combined the measures of Alternative 3 and some strategic measures in water and space heating. More precisely, the goal is to strategically combine the best of alternatives two and three (find synergies) to obtain a new alternative that has as good or better results in reducing GHG emissions with a lower investment cost.

5.5 Alternative 4

This alternative is based on the combination of the measures implemented in Alternatives 2 and 3. Therefore, this alternative is a solution to improve the results obtained for GHG emissions, with lower investment cost. Adjusting the values initially defined for each measure was necessary to obtain better results. In Section 5.5.1 and Section 5.5.2, the measures applied are described, as well as the results obtained.

5.5.1 Residential Sector

For the residential sector, the following measures were used: (i) Reduce the heating needs of buildings, by around 11%, (ii) Reduce the cooling needs of buildings, by around 11%, (iii) Replacement of natural gas heaters with solar thermal systems supported by efficient electric heaters (iv) Replacement of fossil fuel water heaters with solar thermal systems supported by efficient electric heaters, and (v) Increase the percentage of total electricity in the sector that is produced locally through RES. These last 3 measures were fully implemented. It should be noted that these were the only measures implemented concerning Alternative 2 since they were the only ones that influenced the reduction of GHG emissions.

Regarding the measures of Alternative 3, it was only necessary to adjust one measure related to the replacement of less efficient dishwashers by class A, B or C equipment from 30% to 5%, to obtain better results.

The results obtained for the combination of these two alternatives are shown below. Firstly, the investment cost of this alternative was analysed (Figure 5.27). As expected, there is a large investment in household appliances, space heating, and hot water equipment.

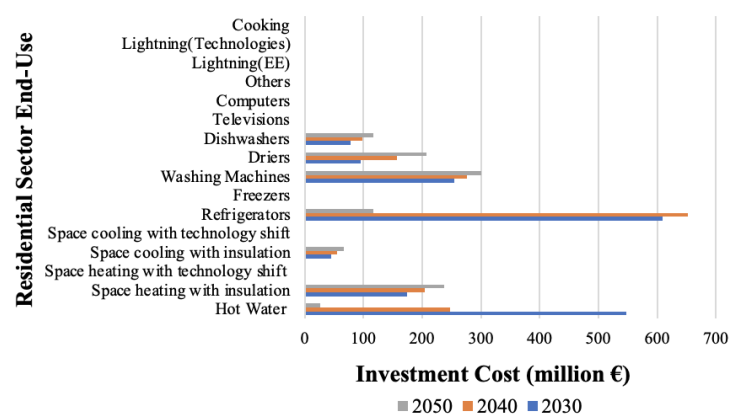


Figure 5.27: Alternative 4, the investment cost for the residential sector (million €).

Afterwards, the distribution of final energy over the time horizon was analysed and presented in Figure 5.28. One can see that electricity and solar radiation have an increasing evolution.

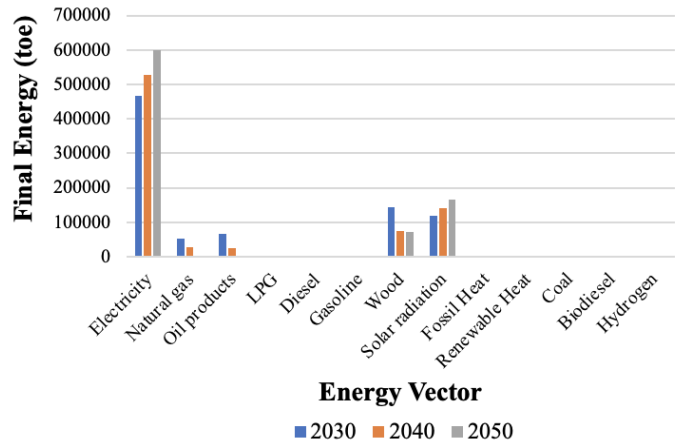


Figure 5.28: Alternative 4, the final energy of each energy vector for the residential sector.

Finally, the comparison between the evolution of GHG emissions and the investment cost was determined and illustrated in Figure 5.29. It is possible to verify that, with this alternative, the emissions present a reduction of nearly 99%, compared with the 2020 values. The investment cost of these measures follows this decrease, verifying that this alternative would be a good solution to implement.

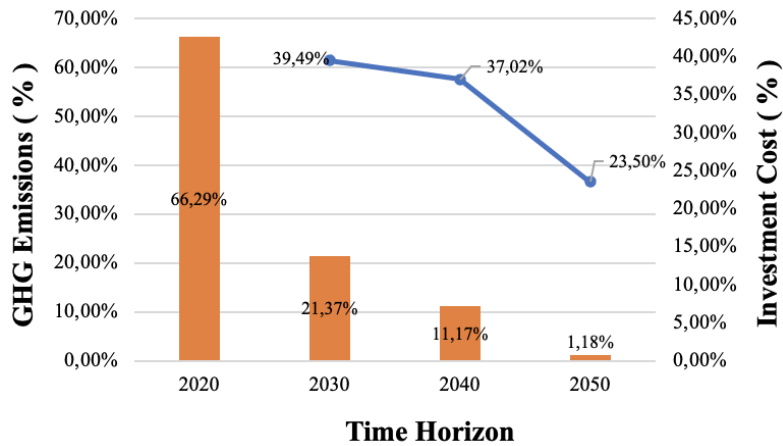


Figure 5.29: Alternative 4, comparison between emissions and the investment cost for the residential sector.

5.5.2 Services Sector

The analysis of the results obtained for the services sector is similar to that for the residential sector provided in the previous section, i.e., (Section 5.5.1). In this case, the measure implemented in Alternative 3 for this sector remains unchanged, and then the measures of Alternative 2 that influence the decrease of GHG emissions are included. The following measures were applied: (i) Reduce the need for heating buildings by around 14%, and (ii) Increase the percentage of the sector’s total electricity that is produced locally through RES, that was fully implemented.

Implementing these measures for the services sector in Alternative 4 led to the following results. Figure 5.30 illustrates the investment cost necessary for implementing this alternative. It is therefore only needed to invest in improving the EE of refrigerators, freezers and space heating technologies.

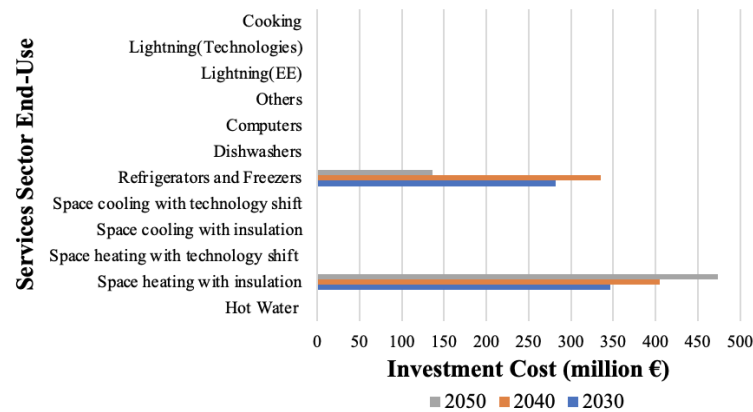


Figure 5.30: Alternative 4, the investment cost for the services sector (million €).

Once again, each energy carrier's final energy evolution was also studied, as shown in Figure 5.31. These results are in agreement with those previously obtained for the residential sector. More precisely, there was again an increase in electricity and solar radiation and a reduction in the use of fossil fuels.

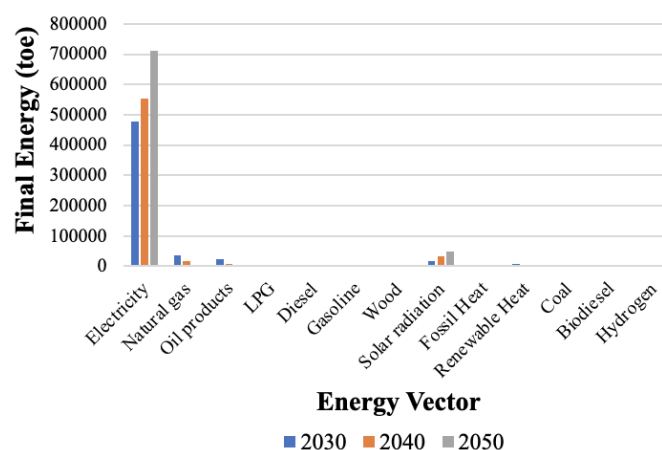


Figure 5.31: Alternative 4, the final energy of each energy vector for the services sector.

Finally, Figure 5.32 compares the evolution of emissions with the investment cost. Once again, it can be seen that the emission values will be close to zero in 2050 and that the investment cost of these measures follows this trend.

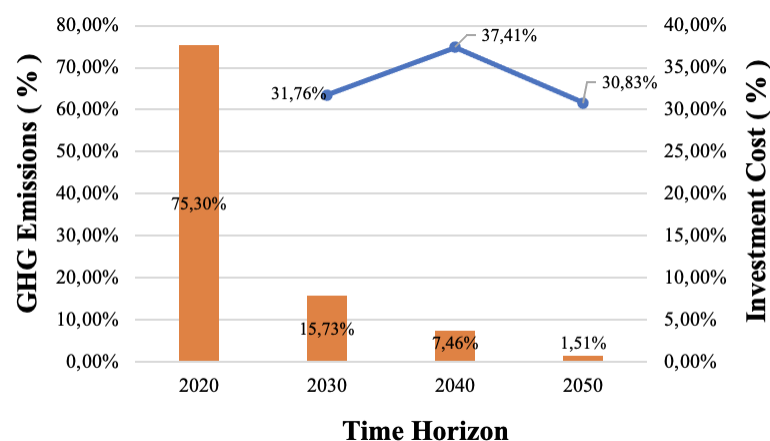


Figure 5.32: Alternative 4, comparison between emissions and the investment cost for the services sector.

5.6 Comparison between Alternatives

This section is designed to simplify the comparison and the discussion of all alternatives. Graphics regarding the evolution of emissions and the investment cost of each alternative were developed, two of the main elements of the evaluation of this dissertation. This analysis is detailed below and is divided into the residential (Section 5.6.1) and services (Section 5.6.2) sectors.

5.6.1 Residential Sector

For a proper comparison between the applied and developed alternatives, a set of figures were computed and can illustrate the expected behaviour of each alternative throughout the time horizon established in this study.

By analysing Figure (5.33), although Alternative 2 is worthwhile in the short term, it is possible to verify that Alternative 4 (which combines measures implemented in two alternatives) presents better results in terms of emissions in 2050, with a reduction of about 98% of GHG emissions when compared to 2020. As expected, it is possible to conclude that the values obtained for the BAU are higher than the alternatives.

Regarding the required investment cost (illustrated in Figure 5.34), one can derive different conclusions depending on the perspective of the analysis. It should be mentioned that the total investment throughout the horizon gives different directions when compared with single-time analysis. That is, some alternatives may induce a higher investment cost in more recent years than close to the time horizon and vice versa. It can be seen that Alternative 1 requires the least investment, around 1,370 M€. This is because few measures were implemented for this alternative, as many of the targets had already been achieved. It is also possible to verify that Alternatives 3 and 4 require low investment, with a total investment of approximately 4,738 and 4,567 M€, respectively. Overall, Alternative 4 is better than Alternative 2, whose investment cost is 9,529 M€, as it has lower investment costs and achieves less value of GHG emissions. Furthermore,

Alternative 4, becomes a better solution than Alternative 3 because it is more complete in terms of the application of measures in other energy vectors and due to its GHG emissions value. With the creation of Alternative 4, an attempt was made without radically increasing the value of the investment cost of Alternative 2 to reach GHG emissions levels close to zero in 2050. When analysing these results, it is verified that this objective was accomplished, considering Alternative 4 a good option to implement.

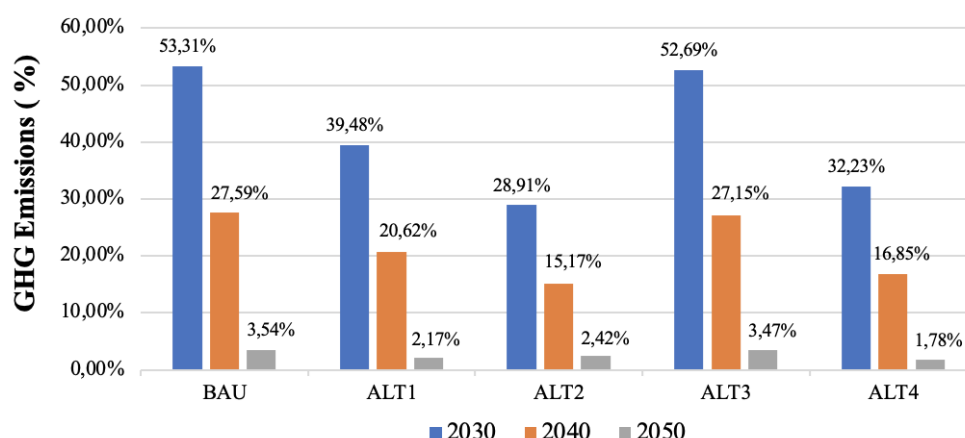


Figure 5.33: Comparison of the evolution of GHG emissions between the reference scenario (BAU) and the alternatives for the residential sector (%).

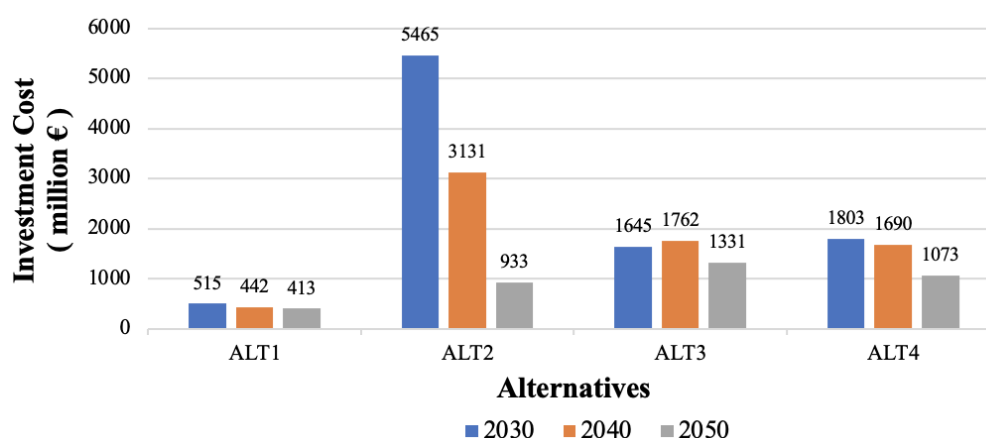


Figure 5.34: Comparison of the evolution of Investment Cost between alternatives for the residential sector (million €).

5.6.2 Services Sector

For the services sector, a similar analysis was carried out. In Figure 5.35, concerning GHG emissions, it is verified that Alternative 4 is, in fact, a good alternative in comparison to the reference scenario. Once again, one can observe a significant reduction in the value of GHG emissions in 2050, when compared to 2020, of about 98%.

Regarding the investment cost (Figure 5.36), it is verified that Alternative 3 is the one that implies a lower investment, around 948 M€. However, this alternative concerns only measures related to the replacement of appliances by more energy-efficient appliances. Alternative 4, compared to Alternative 2, presents a better result since it implies a lower total investment cost, around 1,980 M€ and presents a GHG emissions value close to zero in 2050.

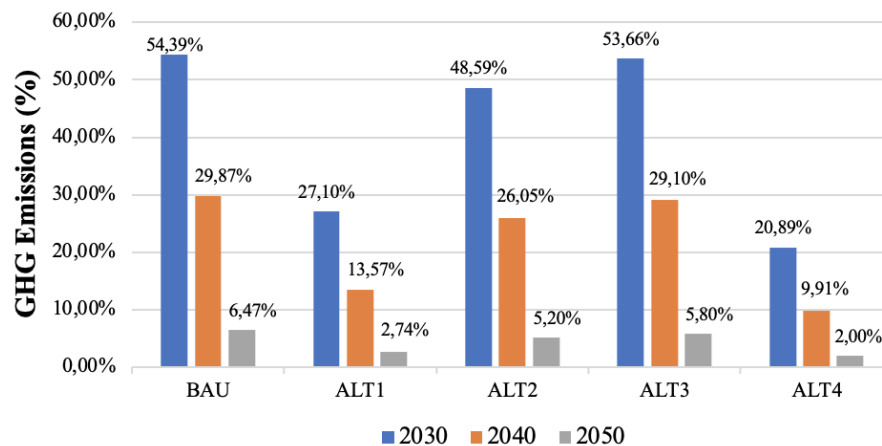


Figure 5.35: Comparison of the evolution of GHG emissions between the reference scenario (BAU) and the alternatives for the services sector (%).

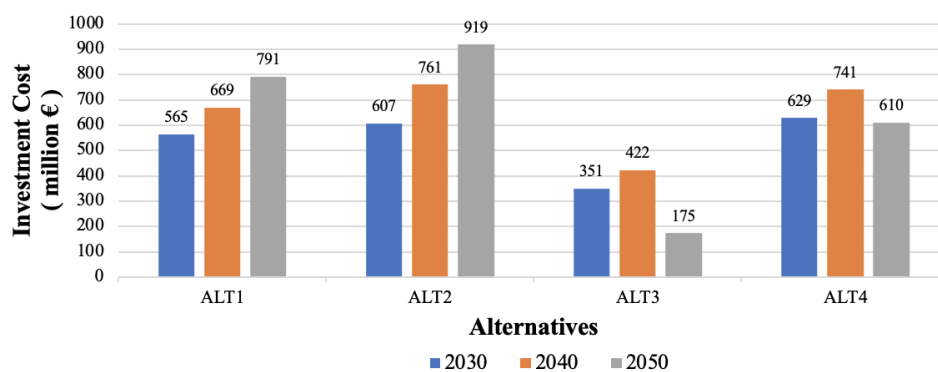


Figure 5.36: Comparison of the evolution of Investment Cost between alternatives for the services sector (million €).

Finally, Table 5.17 was drawn up to summarise the level of implementation of the different types of use in each alternative (+, ++ or +++). Each category represents a level of implementation for a given type of use, allowing for a comparison between alternatives. It is important to point out that Table 5.17 does not quantify the share of measures adopted in each type of use but rather correlates to their impact in each alternative. For instance, measures toward water heating have a higher relative importance in Alternative 2 than in Alternative 4. Therefore, it is possible to verify that Alternatives 2 and 4 are the most complete choices and, consequently, the ones that obtain the most satisfactory results. It should be considered that n/a means not applicable.

To summarise, Alternative 1 (Section 5.2) focuses on implementing measures related to the thermal insulation of buildings and also invests in space heating and cooling. Alternative 2 (Section 5.3) focuses more on water heating and lighting, including measures related to space heating and cooling. On the other hand, Alternative 3 (Section 5.4) focuses only on improving the EE of household appliances. Finally, Alternative 4 (Section 5.5), which represents the combination of Alternatives 2 (Section 5.3) and 3 (Section 5.4), implements measures related to water heating, space heating and cooling, combined with measures to improve the EE of equipment. It is essential to highlight that all alternatives created contribute to the reduction of GHG emissions and, in general, to the ultimate target of full decarbonisation of the energy system.

Table 5.17: Analysis and comparison of the measures applied in the different types of use for each alternative.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Water Heating	n/a	+++	n/a	++
Thermal Insulation	+++	++	n/a	++
Space Heating and Cooling	++	+++	n/a	++
Energy Efficiency	++	n/a	++	+
Household Appliances	n/a	n/a	+++	++
Lightning	n/a	+++	n/a	n/a
Renewable Energies	++	++	n/a	n/a
Cooking	n/a	+	n/a	n/a
GHG Emissions	++	++	+	+++

Chapter 6

Conclusions

This chapter presents the most significant conclusions of the work developed. It includes a critical analysis of the addressed energy policies and the obtained results to highlight the objectives achieved and the contribution to state-of-the-art. Furthermore, perspectives for future work are also presented.

6.1 Main Outcomes and Contributions

The challenges towards carbon neutrality are huge and should be promoters of structural changes aimed at economic growth and improving the quality of life of citizens. Only in this way will it be possible to meet the objectives and targets set by national and European action plans in the area of energy and climate. The dynamism of actions aimed at promoting [EE](#) (e.g., replacement of conventional equipment with [RES](#)) in the most diverse socioeconomic sectors is a requirement, and it is perhaps in the residential and services area that it is most important to invest.

The national energy policy places the highest importance on [EE](#). This concern is coupled with a high level of external energy dependence, which has decreased significantly over the last 20 years, mainly to the nation's investment in [RES](#). Massive changes will be made to Portugal's energy policy to increase energy independence and decarbonise energy production and consumption.

One of the country's main goals identified in this dissertation is to achieve decarbonisation by 2050 and improve [EE](#) in the building sector. This suggests a paradigm shift in the energy system where electricity gradually replaces fossil fuels, provided that its production is supported by primary energy sources of renewable origins, such as hydro, wind and solar. In this context, one of this dissertation's main contributions is modelling, testing and validating the implementation of current [EPA](#) and of the national [EE](#) plan in the Northern region of Portugal. This work was developed using an energy planning tool for local assessment, namely the [LEPA](#). This tool provides estimates on the costs and benefits of applying different energy actions, allowing to forecast of the required energy measures to achieve and exceed the ambitious targets for the Northern region of Portugal. It also allows the simulation of the current energy scenario, along with the creation of new alternatives to this scenario.

More precisely, this work focused on the development of 4 alternatives, two of which were based on existing plans, the **PNEC** and the **RNC**, respectively. The **PNEC** presents a short-term vision with the year 2030 as the target year for reaching a goal of 80% renewable electricity consumption. The **RNC** outlines the trajectory to be pursued to achieve carbon neutrality in 2050 and identifies the most affordable ways to do so under different scenarios of socioeconomic growth.

On the other hand, the third alternative is a new one consisting of implementing measures related to the replacement of less efficient appliances for more efficient ones. That is, it aims to improve **EE** in buildings through the refurbishment of all appliances in buildings. Finally, Alternative 4 consists of combining the measures implemented in Alternatives 2 and 3, to reach a value of **GHG** in 2050 close to zero, without drastically increasing the value of the investment cost. In this way, this dissertation allows the creation of alternative policies to the energy policies in force, which promote the contribution of citizens to achieve the decarbonisation of energy consumption in 2050. Therefore, fundamental changes are needed in how energy and resources are used, investing in an economy based on **RES** and using resources efficiently.

One important result and contribution is that the creation of Alternative 4 allows for investment cost savings of approximately 52% for the residential sector, and 13% for the services sector when compared to Alternative 2. Regarding **GHG** emissions, it is possible to obtain an emissions reduction gain in 2050 for Alternative 4, of around 0,64% for the residential sector and 3,2% for the services sector, when compared with Alternative 2.

Finally, it is possible to conclude that to achieve carbon neutrality, and consequently improve the **EE**, the strategy should include a fundamental rehabilitation of the buildings. It is through an integrated intervention in the various elements of the building, such as the insulation of walls and roofs, the replacement by more efficient air conditioning and hot water production equipment, and the use of **RES**, such as solar thermal or **PV** systems, that it is possible to increase the **EE** of the building, improve comfort conditions, reduce the energy bill and, consequently, achieve the decarbonisation goals.

6.2 Perspectives for Future Work

Throughout the development of this work, several ideas have arisen to proceed with the present work's evolution potentially. As a result, the following ideas can be recognised for the ongoing development of the **LEPA** tool:

- More accurate modelling of energy resources. Adapting the **LEPA** tool to currently used energy resources, including the contribution of solar radiation in the different types of end-use;
- Include an analysis of batteries in short/medium term, as they make it possible to support the need to balance supply and demand and transfer electricity from one period to another, with different time scales;

- Continue updating the timeline of [EE](#) policies in buildings in Portugal and carry out this study for renewable energies and the introduction of electric vehicles, to simplify information for citizens;
- Extend this case study to Portugal's Central and Southern regions, as well as Archipelagos, as they may have different energy policy needs, depending on their current situation and advancements in [EE](#) in buildings;
- Improve [LEPA](#) tool with optimization procedures for the energy balance and forecasting of energy and supply demand.

Appendix A

Data from the Overview of Energy Policies and Actions

Figure A.1 shows the overview of 50-year policy evolution in the EU, described in Section 2.1.2.

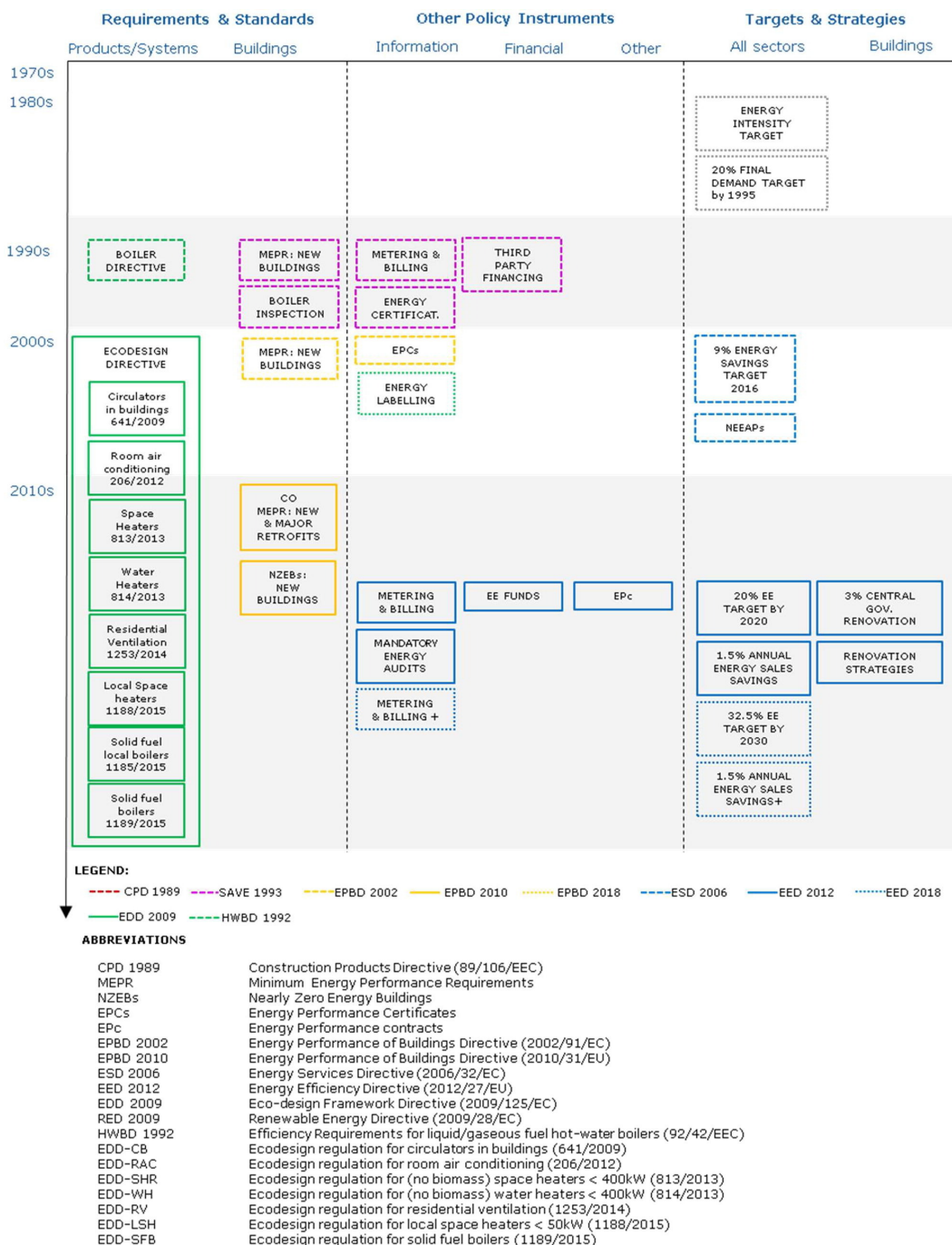


Figure A.1: Overview of 50-year policy evolution in the area of energy efficiency in buildings in the EU [1].

Table A.1 represents the different requirements for NZEB residential buildings, and Table A.2 for NZEB commercial and service buildings.

Table A.1: Requirements for NZEB residential buildings [90].

Requirements for NZEB residential buildings	
Useful energy for space heating:	
NCI and NI are the useful energy indicator for heating, calculated and rated, respectively.	$NCI/NI \leq 75\%$
Primary energy:	
NTC and NT are the calculated and nominal primary energy indicators, respectively.	$NTC/NT \leq 50\%$
Renewable energy sources must supply air conditioning and domestic hot water uses	$\geq 50\%$

Table A.2: Requirements for NZEB commercial and services buildings [90].

Requirements for NZEB commercial and services buildings	
Maximum value of the energy efficiency Indicator (IEES) and the energy class ratio (RIEE):	$IEEs \leq 75\%IEEs_{ref}$ $RIEE \leq 0,50$

Figure A.2 shows an example of the previous a) and actual b) energy labels.

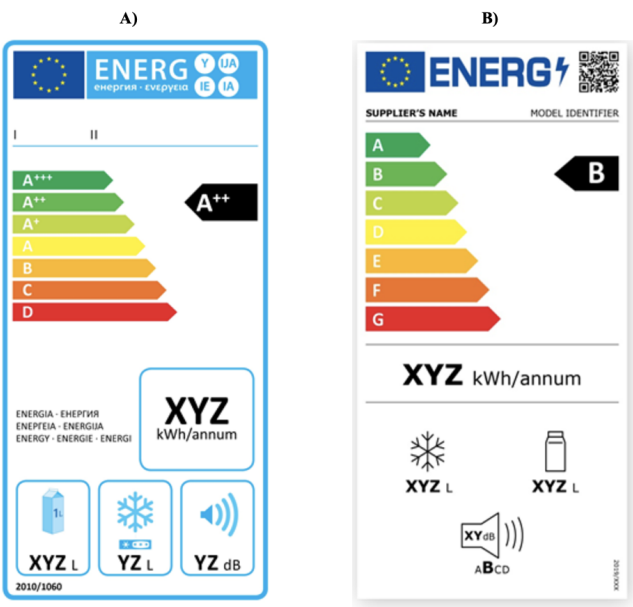


Figure A.2: Example of an old a) and actual b) Energy Label [52].

Table A.3 illustrates the types of interventions and the maximum incentive attributed by PAES, described in Section 2.2.5.2.

Table A.3: Targets of the program to support more sustainable buildings [53].

Typology Number	Project	Contribution	Maximum Incentive
1.	Replacement of inefficient windows with efficient windows, with an energy class equal to A+	85%	1500,00€
2.	Application or replacement of thermal isolation on roofs, walls or floors, as well as replacing entrance doors		
2.1	Roofs and/or floors		
2.1.1	Using natural-based materials (eco-materials) or incorporating recycled materials	85%	3000,00€
2.1.2	Using other materials	65%	3000,00€
2.2	Walls		
2.2.1	Using natural-based materials (eco-materials) or incorporating recycled materials	85%	4500,00€
2.2.2	Using other materials	65%	4500,00€
2.3	Entrance Doors	85%	750,00€
3.	Space heating and/or cooling and/or domestic hot water systems, which use renewable energy, of energy class A+ or higher, namely:		
3.1	Heat Pumps	85%	2500,00€
3.2	Thermal Solar Systems	85%	2500,00€
3.3	High efficiency biomass boilers and stoves	85%	2500,00€
4.	Installation of photovoltaic panels and other renewable energy production equipment for self-consumption	85%	2500,00€
5.	Interventions aimed at water efficiency through:		
5.1	Replacement of water use devices at home with more efficient ones	85%	750,00€
5.2	Installation of solutions that allow the intelligent monitoring and control of water consumption	85%	200,00€
5.3	Installation of rainwater harvesting systems	85%	1500,00€
6.	Interventions for the incorporation of bioclimatic architecture solutions, which involve the installation or adaptation of fixed elements of buildings such as shading, green houses and green roofs or facades, favoring natural-based solutions	85%	3000,00€

Table A.4 shows the targets of the program to support the renovation and increase of the energy performance of service buildings, described in Section 2.2.5.4.

Table A.4: Targets of the program to support the renovation and increase of the energy performance of service buildings [91].

Intervention Typology	
1.	Opaque and glazed envelope
1.1	Replacement of glazed areas (windows and doors) for more efficient ones.
1.2	Interventions to incorporate bioclimatic architecture solutions which involve installing/adapting fixed building elements favoring natural-based solutions.
1.3	Application/replacement of thermal isolation in roofs, walls, floors, entrance doors
1.4	Install systems that promote natural ventilation of interior air and/or natural lighting.
2.	Intervention in technical systems.
2.1	Actions aimed at optimizing the use of fluorinated gases in existing air conditioning/DHW (domestic hot water) systems or their replacement with natural or alternative refrigerants
2.2	Installation or replacement of heat exchangers to take advantage of the return water temperature at hot water usage points or equivalent systems.
2.3	Install/replace HVAC (heating, ventilation, and air conditioning) and/or DHW systems.
2.4	Installation/improvement of thermal insulation systems for producing, storing, and distributing fluids for heating water and/or air conditioning with fluorinated gases
2.5	Actions in lighting systems, considering only the complete replacement of luminaries
2.6	Implementing systems or other solutions that reduce primary energy consumption in buildings, for example, HVAC, pumping, compressed air, or swimming pools
2.7	Install energy management solutions, including centralized management systems, through monitoring and controlling equipment or systems to reduce energy consumption and associated costs. Incorporation of sensors and light flow regulators
3.	Energy production is based on renewable energy sources for self-consumption
3.1	Installation of electrical energy production systems for self-consumption through renewable sources with and without energy storage.
3.2	Installation and/or replacement of space heating, cooling, hot water systems, which use renewable energy.
3.2.1	Heat pumps.
3.2.2	Solar thermal systems for the production of DHW.
3.2.3	High-efficiency biomass boilers/heat recovery systems with/without hot water storage
4.	Water Efficiency.
4.1	Replacement of water use devices with more efficient ones, including interventions for reducing water losses.
4.2	Install systems to use rainwater and/or grey water and/or water for reuse.
4.3	Implement solutions for intelligent monitoring and control of water consumption
5.	Immaterial Actions.
5.1	Energy audits and the issuing of ex-ante and ex-post Energy Certificates within the scope of the SCE.
5.2	Consultancy/audit actions in energy and/or water efficiency are essential to implementing the measures.

Appendix B

Data from the Case Study

Table B.1, shows the calculations performed for the demand evolution factor determined for the space heating and cooling in the reference scenario for the residential sector (Section 4.2.1.2).

Table B.1: Calculations performed for the demand evolution factor determined for the space heating and cooling in the reference scenario for the residential sector.

Space Heating						Space Cooling					
Year	Low	High	Average	Proportion	%	Year	Low	High	Average	Proportion	%
2010	100	100	100			2010	100	100	100		
2015	106	115	110,5	-0,090535	0,9	2015	110	108	109	-0,161538	0,8
2020	113	130	121,5	0	1,0	2020	119	141	130	0	1,0
2025	118	144	131	0,0781893	1,1	2025	128	161	144,5	0,1115385	1,1
2030	124	157	140,5	0,1563786	1,2	2030	136	181	158,5	0,2192308	1,2
2035	128	175	151,5	0,2469136	1,2	2035	144	202	173	0,3307692	1,3
2040	132	176	154	0,2674897	1,27	2040	150	222	186	0,4307692	1,43
2045	135	186	160,5	0,3209877	1,3	2045	156	242	199	0,5307692	1,5
2050	136	195	165,5	0,3621399	1,4	2050	160	258	209	0,6076923	1,6

Table B.2, shows the calculations performed for the demand evolution factor determined for the space heating and cooling in the reference scenario for the services sector (Section 4.2.2.3).

Table B.2: Calculations performed for the demand evolution factor determined for the space heating and cooling in the reference scenario.

Space Heating						Space Cooling					
Year	Low	High	Average	Proportion	%	Year	Low	High	Average	Proportion	%
2010	100	100	100			2010	100	100	100		
2015	100	100	100	-0,0147783	1,0	2015	100	100	100	-0,0291262	1,0
2020	100	103	101,5	0	1,0	2020	101	105	103	0	1,0
2025	101	107	104	0,0246305	1,0	2025	103	111	107	0,038835	1,0
2030	102	110	106	0,044335	1,0	2030	105	117	111	0,0776699	1,1
2035	103	112	107,5	0,0591133	1,1	2035	107	123	115	0,1165049	1,1
2040	104	115	109,5	0,0788177	1,08	2040	110	130	120	0,1650485	1,17
2045	105	118	111,5	0,0985222	1,1	2045	112	136	124	0,2038835	1,2
2050	106	120	113	0,1133005	1,1	2050	114	143	128,5	0,2475728	1,2

Table B.3 shows an example of calculating the investment cost of led lamps, explained in Section 4.2.6.

Table B.3: Example of calculating the investment cost of led lamps.

LED		
Price	4,5	€
Consumption (1000h)	7	kWh/1000h
Consumption (1825h)	12,775	kWh/1825h
Investment	0,643	€/kWh
Average number of hours of Operation	5	h
Average number of hours of Operation/Year	1825	h/year
Average Lifetime of the Source	15000	h

Appendix C

Scientific Paper - “Analysis of energy policies for the decarbonisation of energy consumption in buildings: The case of the Northern region of Portugal”

Article

Analysis of energy policies for the decarbonisation of energy consumption in buildings: The case of the Northern region of Portugal

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Abstract: Portugal's energy policymaking mainly focuses on achieving economy-wide decarbonisation, primarily through the expansion of Renewable Energy Sources (RES) participation within the energy sector in combination with Energy Efficiency (EE), as part of the pathway to cost-effective carbon neutrality by 2050. This work has two main goals. The first is to provide a detailed review of existing Energy Policies and Actions (EPA) in Portugal to improve EE and reduce CO₂ emissions in the building sector. The second focuses on using the Local Energy Planning Assistant (LEPA) tool for modelling, testing, validating and comparing the implementation of current and alternative EPA, as well as the national EE plan, in the Northern region of Portugal. Initial results show that the electrification of heating and cooling, EE measures, and the proliferation of RES are crucial for achieving climate neutrality goals. One important conclusion is that the modelling of alternative EPA has shown that EPA in force can be improved, leading to a reduction in the required investment cost and an increase in Greenhouse Gas (GHG) emissions reduction.

Keywords: Buildings, Decarbonisation, Energy Efficiency, Energy policies and actions.

1. Introduction

1.1. Background and Motivation

In the last couple of decades, EPA have been increasingly important in improving the EE of buildings in Europe, allowing citizens to reduce energy costs whilst improving comfort. Portugal was one of the first nations in the world to set goals for achieving carbon neutrality by 2050 [1]. The main methods used by Portugal's energy and climate policies to achieve carbon neutrality are enhanced EE, the rapid expansion of renewable electricity generation, and significant electrification of energy demand. The primary concerns are reducing reliance on energy imports and keeping access to inexpensive energy [2]. Currently, there are several EPA for the empowerment of consumers through energy communities to improve EE levels, reduce energy consumption and increase the levels of self-consumption and self-sufficiency in cities.

Community action on energy has increased significantly over the past decade, spurred by concerns about climate change and rising energy costs [3]. Energy Community (EnC) is a promising framework to enable a decarbonised economy. However, it is yet to be well understood by the overall population. EnC initiatives are more likely adopted by citizens who prefer to be actively involved in environmental issues. EnC measures often require upfront investments, and their relationship to long-term individual benefits is non-trivial to the general public. Thus, it is of utmost importance to mobilize communities, as well as provide accessible information, to support and actively participate in initiatives that promote energy reduction or the production of energy from RES. Although, the most

Citation: Capelo, S.; Soares, T.; Azevedo, I.; Fonseca, W.; Matos, M. Analysis of energy policies for the decarbonisation of energy consumption in buildings: The case of the Northern region of Portugal. *Journal Not Specified* **2023**, *1*, 0. <https://doi.org/>

Received:

Revised:

Accepted:

Published:

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widely identified barrier is the suite of financial constraints holding back community action [3]. This means that the government must continue to improve and guarantee investment funds that support citizens and increase consumer mobilization to participate in energy communities.

This work aims to map the evolution of EPA towards the improvement of buildings' energy performance in Portugal. Based on this review, it also aims at assessing the impact of existing buildings-related energy policy actions in the Northern region of Portugal in terms of required investment and GHG emissions and propose alternative scenarios.

1.2. Literature Review

Energy use is a subject of the utmost relevance due to the urgency of sustainability and its intrinsic relationship with society and quality of life. Over the last decades, it has been thoroughly discussed about anthropic driven climate change. In 2016, Paris Agreement set worldwide goals towards decarbonisation by 2050 and keeping temperature increase below the 1.5°C threshold [4]. The carbon-intensive society, as observed after the industrial revolution, is non-compliant with the maintenance of global temperature levels. Therefore, achieving net-zero carbon emissions is imperative. According to [5], efficiency improvement plans, and increasing usage of RES are among the crucial steps to be taken toward GHG emissions mitigation.

More than a third of the world's final energy consumption and over 40% of all pollutant emissions are attributed to the buildings sector, making it a crucial target for EE and resource conservation policies. In Portugal, the building sector represents 30% of final consumption [6]. The Energy Performance of Buildings Directive (EPBD), a crucial piece of European policy implemented in 27 nations with particular modifications, aims to increase the energy performance of buildings, including the energy performance of the building envelope as well as of the respective systems (water heating and space heating and cooling).

The literature is rich in reviewing the different aspects of the EPA, as well as in simulating and analyzing its impact in different countries, especially at the European Union (EU) level [1]. However, it often overlooks its impact and suitability at the local governance level.

In this particular, the authors in [7] examine the lessons discovered when developing national EE programs and trace the development from 2007 to 2020. The adoption of standardised reporting ways, the installation of stronger monitoring systems, the development of evidence-based target-setting methodologies, and a wider consideration of policy packages resulted in significant improvements in the most recent national energy and climate plans. The need to set up systems that encourage the adoption of targets in keeping with a country's cost-effective EE potential is one of several areas with substantial potential for additional improvements, along with the need for a more cohesive reporting structure for policies and initiatives.

Nevertheless, a few works have sought the suitability and applicability of the national EPA in Portugal. Using the guidelines of the Portuguese Government's objectives for the following decades and a significant portion of renewable energy supply, the work in [8] presents technical alternatives on a Portuguese scale for the power system to achieve the target of reducing CO₂ emissions. The study shows the significance of pumping hydro-power plants for the integration of variable RES and establishes the least load capacity value of thermal power plants necessary to sustain the security standards of the Portuguese electrical system. The results demonstrated that RES could completely meet Portugal's long-term electricity needs in terms of energy balance.

Ferreira *et al.* analyzes the Portuguese Energy Certification System (ECS), and the regulation applied to the residential sector, considering complementary solutions for improving EE in residential buildings. The proposed solutions include interior and exterior thermal insulation, a lower air renovation ratio, light-coloured exterior walls, a better glazing system, shading elements, and a Trombe Wall. The latter provides both convective and radiative heat within a household. Complementary, the LNEG [9] developed software

to calculate the results of applying the ECS 2006 methodology. Then, the PTnZEB [10] calculation tool, currently employed by qualified experts, was developed for implementing the methodology of roadmap 2013 and 2016. The approaches were tested and analyzed on a single-family home that was constructed and approved in 2009, as detailed in [11]. Indicators assessed include energy needs, final and primary energy consumption, CO₂ emissions, and share of RES.

Although having the same end goal of promoting domestic EE, each member state of the EU employed different measures according to their specific needs. For instance, to decrease energy use, some nations have implemented building performance requirements, information campaigns, and building energy codes, among other measures. Others recommended using financial tools like tax rebates and subsidies [12]. In this way, [12] assessed the effects of financial and tax incentive policies on the EE of residential properties in 19 districts in Portugal from 2014 to 2021. The results suggested that buildings with higher EE (certificates A+, A, and B) are negatively impacted by per capita income. As a result, Portugal's income is insufficient and prevents investment in highly energy-efficient homes.

From the literature, it is clear that EU member states must employ energy policy instruments suited to their economic and energy structures in the buildings sector because adopting well-designed policies can result in significant energy savings [12].

Nevertheless, current studies have been scarce in analyzing the impact of the current and future EPA in Portugal, more precisely at the local/regional level, for achieving ambitious carbon-neutral targets by 2050. Therefore, the present study highlights the impact of the current EPA in Portugal at the local level, namely in the Northern region of Portugal.

1.3. Main Contributions

This work proposes to overcome the identified limitations by studying in detail the current and future EPA being implemented in Portugal, namely in the Northern region of Portugal. More precisely, it studies the changes that may be necessary for the residential and services buildings sectors, in the Northern region of Portugal, to reach the ambitious carbon-neutral targets in 2050. A set of EPA scenarios (also called alternative scenarios) is built upon a reference scenario, which is based on the National Energy and Climate Plan (PNEC) and the National Carbon Roadmap (RNC). The PNEC establishes specific lines of action to reduce carbon intensity and promote the energy renewal of the building stock for 2030, while the RNC defines the roadmap to reach carbon neutrality by 2050.

Thus, with the objective of simulating the economic, environmental and social impacts of current and future EPA in the Northern region of Portugal, the main contributions of this paper are threefold:

- To provide a detailed review of the current energy policies applied in Portugal;
- To perform a detailed analysis of the impact of the current EPA in the Northern region of Portugal, considering the national plans for the decarbonisation of buildings;
- To design, develop and simulate a new energy policy framework for carbon neutrality by 2050 with lower investment costs.

1.4. Paper Structure

The remainder of the paper is structured as follows. Section 2 presents an overview of Portuguese EPA focused on renewable energy and EE in buildings. Section 3 describes the LEPA tool, used for the design, simulation and analysis of the potential impact of EPA applied to a local and /or regional context. Section 4 describes the case study focused on the simulation of the current EPA in Portugal in the specific context of the Northern region of Portugal. Finally, section 5 gathers the most important conclusions.

2. Portuguese Energy Policies

2.1. Portuguese Policies and Actions on Renewable Energy

Renewable energy policies are intended to incorporate environmental benefits, particularly the reduction of GHG emissions compared to fossil fuel-based energy systems.

In 2021, fossil fuel accounted for 65.4% of primary energy consumed in Portugal, followed by the energy used to produce electricity (14%), biomass (4.9%) and others (5.9%) [13]. There are still challenges ahead to fully decarbonise the energy system. The electricity sector, however, presents a share of RES considerably higher compared to the rest of the world. The Portuguese RES generation accounted for 49.3% of total generation in 2022. Meanwhile, renewable generation accounts for 28% of the electric sector globally [14].

According to the EU Renewable Energy Directive (2009/28/EC) [15], and the respective recast - EU Directive (2018/2001) [16], the EU established the goal of increasing the share of RES, while Portugal committed to the target of 31% share of energy from RES in the gross final energy consumption and 10% share in the transport sector by 2020 [17].

The most relevant national energy and climate policy instrument for 2021–2030 is Portugal's PNEC for the 2030 horizon. The PNEC 2030 sets the following national goals (Figure 1): (i) to reach 15% of electricity interconnections to encourage EU countries to interconnect their installed electricity production capacity; (ii) to incorporate 47% of energy from RES in the final gross energy consumption, and 10% in the transport sector; (iii) to achieve a reduction of 35% in primary energy consumption to improve EE; and (iv) to reduce GHG emissions by 45 to 55%, compared to emissions recorded in 2005 [17].

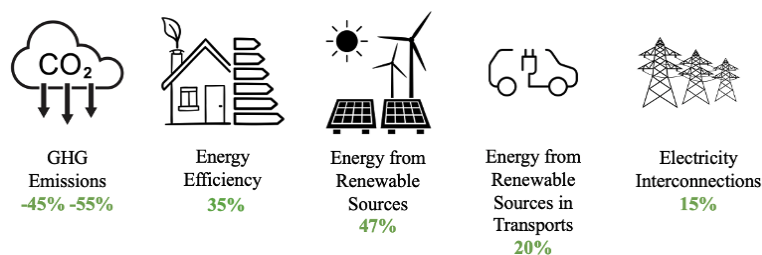


Figure 1. PNEC national targets for 2030, adapted from [18].

This plan seeks to set targets and objectives on GHG emissions, renewable energy, EE, energy security, internal market, research, innovation, and competitiveness, along with a clear strategy for achieving them.

Portugal met its challenge of incorporating 34.0% of RES in energy consumption by 2020. Therefore, it was essential to create new targets for the 2021-2030 decade [18].

2.2. Portuguese Policies and Actions on Energy Efficiency in Buildings

EE can be defined as the optimization of energy consumption [19]. The threat of depletion of reserves of fossil fuels, the pressure of economic results, and environmental concerns are crucial points that define EE as one of the solutions to tackle climate change.

In parallel, the buildings sector is responsible for the consumption of approximately 40% of final energy in Europe and around 30% in the case of Portugal. However, it is known that more than 50% of this consumption can be reduced by EE measures, which represents an annual reduction of 400 million tons of CO₂, almost the totality of the amount established in the Kyoto Protocol [20].

According to this, Portugal has assumed a path towards carbon neutrality. In this transition, priority was given to EE and the reduction of energy consumption, which will have energy sufficiency as a fundamental basis. Portugal had established the concern with energy consumption in buildings since the early 90s when the regulation of thermal behaviour characteristics of buildings and air-conditioning energy systems codes, were published [11], due to the first regulatory base to guarantee thermal comfort and building quality.

The adjustment of national legislation imposed by the EPBD published in the Directive (2002 /91 /EC) [21] settled that the member states of the EU had to implement an ECS to inform the citizens about the thermal quality of buildings when constructing, selling or renting them. This document also states that this certification should cover all residential and service buildings, public or private.

Consequently, the base legislation of the new ECS, established by Decree-Law (DL) (118/2013) [22], has been revised several times since 2013. The various ordinances, dis-patches and associated laws also underwent some changes.

The Environmental Fund was published through the DL (42-A/2016) [23]. In 2018, Directive (2010/31/EU) [24] was replaced by Directive (2018/844/EU) [25], which consists of the EPBD recast. Hence, in 2020, was published the DL (101-D/2020) [26], which partially transposes the EPBD recast and establishes the requirements applicable to buildings to improve their energy performance and regulates the ECS for buildings. After that, in 2021, the DL (102/2021) [27] establishes the requirements for accessing and exercising the activity of technicians in the building ECS. In fact, in January of 2021, a new regulation was implemented in Portugal, which states that new buildings must be Nearly-Zero Energy Buildings (NZEB) [28]. It is up to each EU member state to define NZEB and establish the concept in their own legislation.

Finally, to better interpret the timeline of these policies, (Figure 2) depicts a diagram explaining the evolution of EE policies for buildings in Portugal.

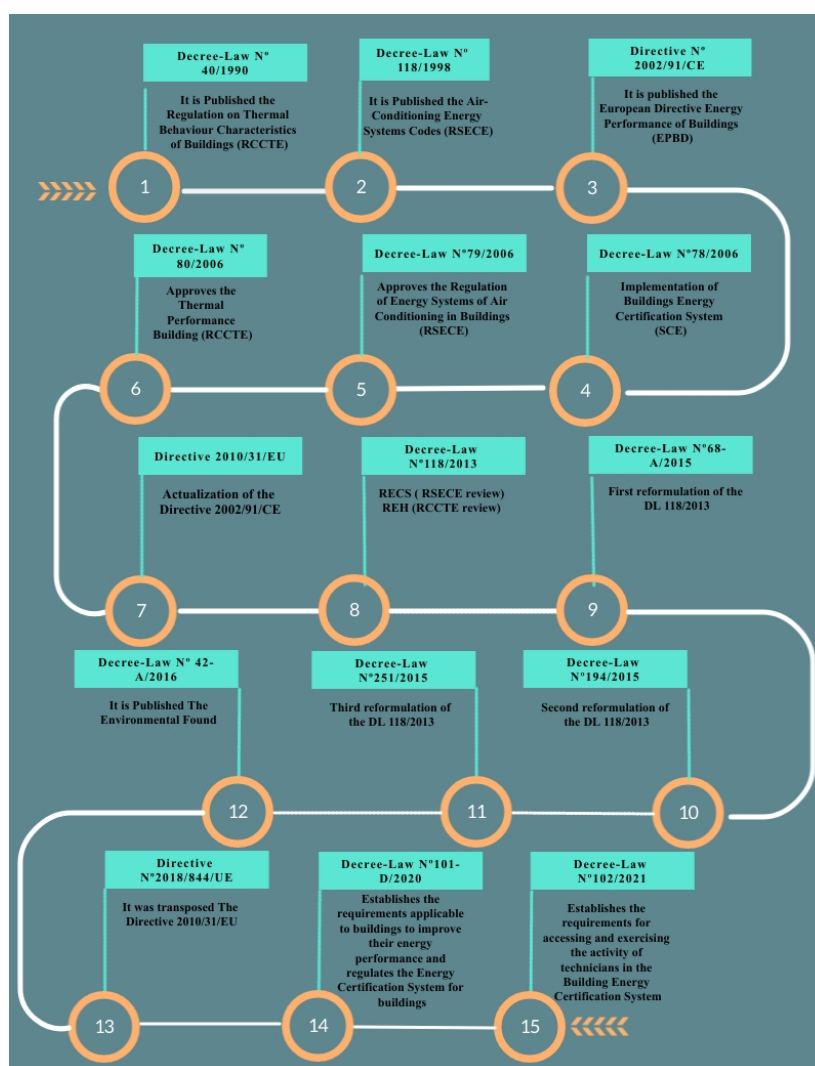


Figure 2. Timeline of Portugal's energy efficiency policies in buildings.

3. Local Energy Planning Assistant - LEPA

The LEPA software [29] is a tool for the decision-making process of local energy planning. This tool can incorporate the values and preferences of the local actors into the energy planning process to maintain transparency and create well-balanced decisions. The tool consists of an MS Excel spreadsheet including several sheets developed in [29].

This tool is divided into two primary sections: (i) The modelling of the energy system for the base year and respective evolution over time, the reference scenario; and (ii) The creation and evaluation of alternatives, which will be explained in the following sub-chapters. The reference scenario is the starting point for developing and evaluating alternative pathways, i.e. the alternatives are compared against the reference scenario.

Figure (3) presents the framework applied in this work through LEPA, organised into four sections: start, inputs, methodology and results.

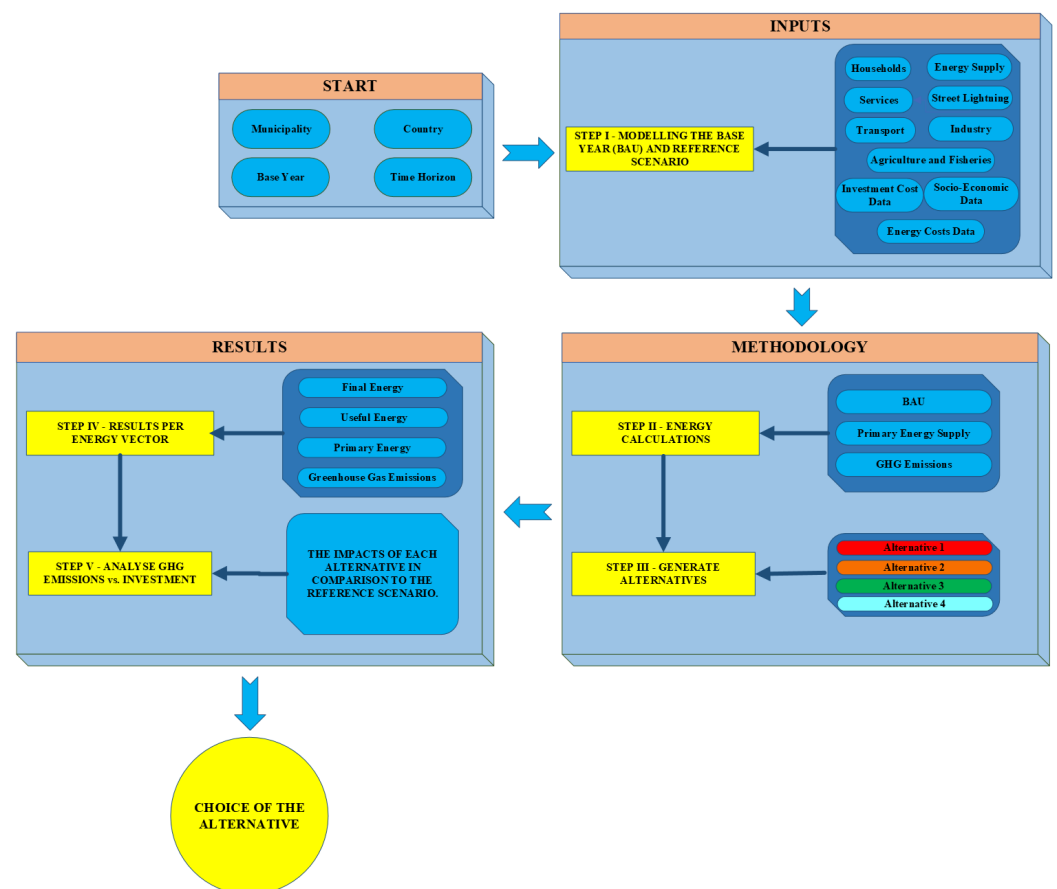


Figure 3. Flowchart of the functioning of the Local Energy Planning Assistant tool.

3.1. Start

The "Start" 3.1 sheet is used to specify the location (municipality/region and country), the base year and the time horizon for which the target was set, and links to all the other sheets. Note that in the present work, the territorial scope of this tool is the Northern region of Portugal. Additionally, it was determined that 2020 was the base year and 2050 was the time horizon for energy policies' assessment.

3.2. Inputs

Section 3.2 is one of the main sections, being crucial for the tool implementation. It consists of only one step (Figure 3), which is the modelling of the energy system for the base year and building the reference scenario. It involves filling input sheets concerning the energy demand and supply for the base year. Finally, it is necessary to enter the data

related to energy costs, investment-cost and socio-economic indicators for the reference year as well as the expected evolution over time. The projection of the evolution of the energy system within the time horizon is performed based on the expected evolution of the socio-economic indicators (population, transportation habits, economic growth, etc.), as well as technological evolution (average efficiency, etc.).

3.3. Methodology

This sub-chapter is divided into two main steps (steps 2 and 3) and concerns the methodology used in the tool for energy planning.

The second step illustrated in Figure 3 is dedicated to the characterisation of the Business As Usual (BAU) scenario in terms of primary energy supply, final energy demand and GHG emissions. The BAU refers to the natural evolution of the energy system, being a possible comparison to the alternatives. The primary energy supply refers to the energy derived from natural resources such as coal, crude oil and natural gas. These calculations are based on the final energy demand for the selected area/region, in the case of this work, the Northern region of Portugal. It also considers the national energy balance for the characterisation of the energy transformation processes. They represent essential data for the remaining sheets of the tool, namely the Electricity Mix, in which the evolution of GHG emissions is calculated. Finally, GHG emissions were determined based on the objectives defined in the RNC [30], where their development until 2050 is presented. Through a complete analysis of this document, it is known that in 2050 there should be a total decarbonisation of the electrogeneration sector, namely 100% renewables in electricity production. It is also known that the consumption of coal will end in 2030. Concerning RES, it is possible to understand through the roadmap that photovoltaic technology will assert itself with more significant evidence, as well as wind energy which increases its participation significantly. These two technologies will jointly ensure 50% of the electricity generated in 2030 and 70% in 2050, respectively. It is also intended to reach 94% in 2030, 97% in 2040 and 100% of renewables in electricity generation in 2050 [30].

This information in the RNC [30] made it possible to determine what percentages to put in the Electricity Mix sheet for the portion of electricity.

The third step illustrated in Figure 3 refers to the development of different alternatives to the reference scenario. Using the alternatives generation table included in the LEPA tool, it is possible to generate options by combining activities with the appropriate degree of implementation. For example, it is possible to apply measures related to thermal insulation, space heating and cooling, appliance efficiency, and lighting efficiency, among others.

3.4. Results

The analysis of the results obtained through the LEPA tool is divided into two main steps. The fourth step (shown in Figure 3) concerns the analysis of the results by energy vector, namely final energy, useful energy, primary energy and GHG emissions.

Consequently, the fifth step (depicted in Figure 3) concerns the analysis of reducing GHG emissions vs. the investment cost for its implementation and the respective impacts of each alternative compared to the reference scenario.

In this way, it is possible to determine the impact in terms of GHG emissions and the required investment. The decision-makers can better understand the balance between the expected investment and the benefits of each choice.

Thus, it is possible to select the best alternative after completing the five steps mentioned above.

4. Assessment of energy policies in the Northern region of Portugal

This section presents the application of the LEPA tool to assess current energy policies in the context of the Northern region of Portugal. In addition, it presents the results of potential measures (alternatives) that can be adopted to achieve carbon neutrality by 2050,

considering a significant reduction in the expected investment costs. A comparison of the different alternatives is also provided.

4.1. Case Characterisation

The Northern region of Portugal has around 3,6 million inhabitants, which corresponds to 35% of the total population of Portugal. This region consists of 86 municipalities, and 1426 parishes [31].

In addition, the municipalities are organised into eight inter-municipal communities, which constitute level III of the Nomenclature of Territorial Units for Statistics (NUTS III), approved by the European Commission. The eight sub-regions which constitute the Northern region are the following: "Alto Tâmega", "Alto Minho", "Área Metropolitana do Porto", "Ave", "Cávado", "Douro", "Tâmega e Sousa", and "Terras de Trás-os-Montes".

Figure (4) depicts the map of the Northern region of Portugal, illustrating the inter-municipal communities.

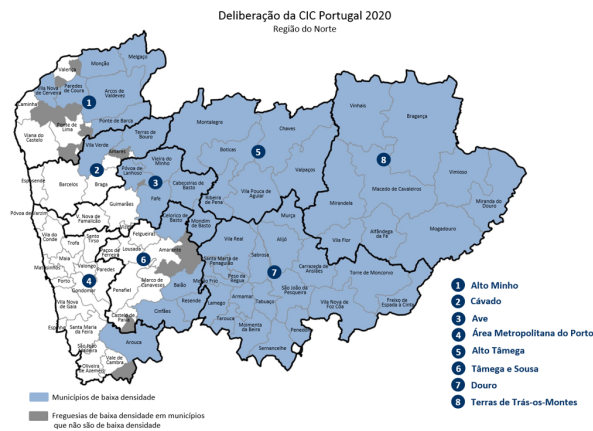


Figure 4. Map of the Northern region of Portugal, accounting for the main inter-municipal community areas (source: [31]) - [in Portuguese].

4.2. Methodology of the Alternatives

This section concerns the methodology behind the Alternatives and the rationale behind them (Table 1). It should be noted that the use of the term Alternatives refers to EPA with different characteristics.

Alternative 1 is based on the PNEC. By applying this alternative, whose objectives are directed to 2030, it is possible to have a closer view of the results to be achieved since they are projections for eight years from now. It was determined that Alternative 2 would be based on the RNC, which sets the achievement of carbon neutrality by 2050 as a commitment. On the other hand, Alternative 3 is a new one consisting of implementing measures related to the replacement of less efficient appliances for more efficient ones. That is, it aims to improve EE in buildings through the refurbishment of all appliances in buildings. Finally, Alternative 4 consists of combining the measures implemented in Alternatives 2 and 3 to reach a GHG value in 2050 close to zero without drastically increasing the value of the investment cost.

Table 1 summarises the level of implementation of the different types of use in each alternative (+, ++ or +++). Each category represents a level of implementation for a given type of use, allowing for a comparison between alternatives. It is important to point out that Table 1 does not quantify the share of measures adopted in each type of use but rather correlates to their impact in each alternative. For instance, measures toward water heating have a higher relative importance in Alternative 2 than in Alternative 4. Therefore, it is possible to verify that Alternatives 2 and 4 are the most complete choices and, consequently,

the ones that obtain the most satisfactory results. It should be considered that n/a means not applicable.

Table 1. Analysis and comparison of the measures applied in the different types of use for each alternative.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Water Heating	n/a	+++	n/a	++
Thermal Insulation	+++	++	n/a	++
Space Heating and Cooling	++	+++	n/a	++
Energy Efficiency	++	n/a	++	+
Household Appliances	n/a	n/a	+++	++
Lightning	n/a	+++	n/a	n/a
Renewable Energies	++	++	n/a	n/a
Cooking	n/a	+	n/a	n/a
GHG Emissions	++	++	+	+++

4.3. Results

This section exposes the main results of the reference scenario (BAU) and the simulations for the selected alternatives, taking into account their impact on GHG emissions and the investment cost for their deployment. For the sake of simplicity, it is noteworthy that special emphasis is given to Alternatives 2 and 4 due to their characteristics to achieve carbon neutrality by 2050. A comparison of the alternatives is also highlighted.

4.3.1. Business-as-usual scenario

The business-as-usual (BAU) scenario consists of simulating all policies, actions and measures currently in force. The time horizon established for analysing the results is from 2020 to 2050. An analysis every 10 years was determined to simplify the perception of the evolution of the outcomes. In Figure 5 and Figure 6, it is possible to observe the evolution of the GHG emissions for the Northern region, according to BAU for the residential and services sector, respectively. The values obtained through the reference scenario will be compared with the results obtained in each alternative. As expected, it is possible to conclude that the values obtained for the BAU are higher than the alternatives, both for the residential and the services sector.

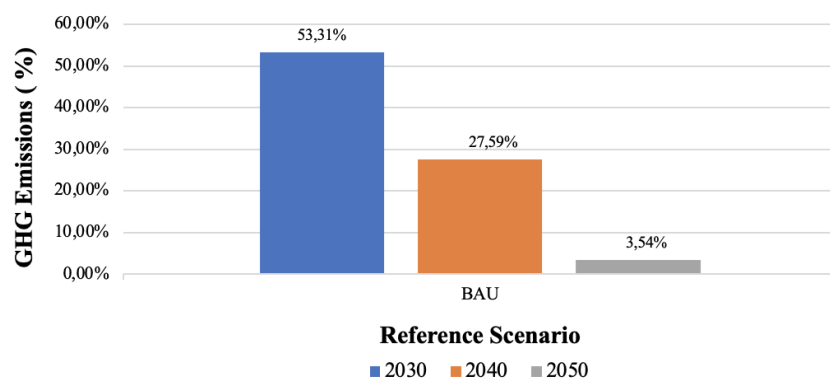


Figure 5. BAU - Evolution of GHG emissions for the residential sector (%).

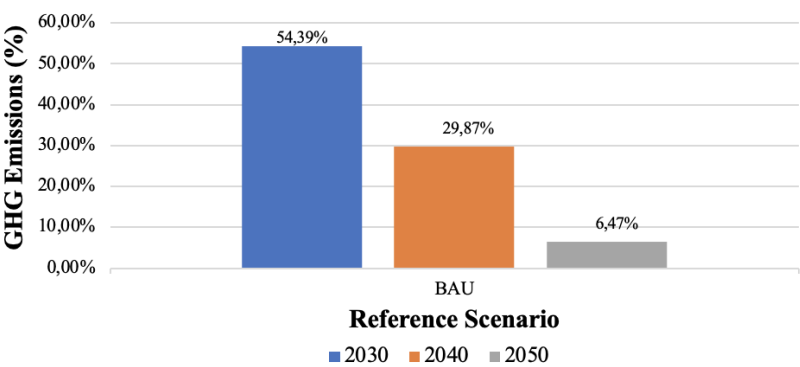


Figure 6. BAU - Evolution of GHG emissions for the services sector (%).

4.3.2. Alternative 2

In buildings, energy is used to provide energy services such as space heating and cooling, lighting, refrigeration and food preparation, and sanitary water heating, among others. It is known that the building sector is responsible for 5% of the country’s GHG emissions [30]. The goal is to reduce emissions by 97% (heating) and 96% (cooling) in the residential sector and 100% in the services sector (compared to 2005 levels), with the incorporation of renewable energy in heating and cooling to be 66% and 68% [30].

Figure 7 and Figure 8 illustrate the objectives that the roadmap (RNC [30]) sets out over the time horizon for the residential and services building sectors, respectively. Alternative two is based on these targets.

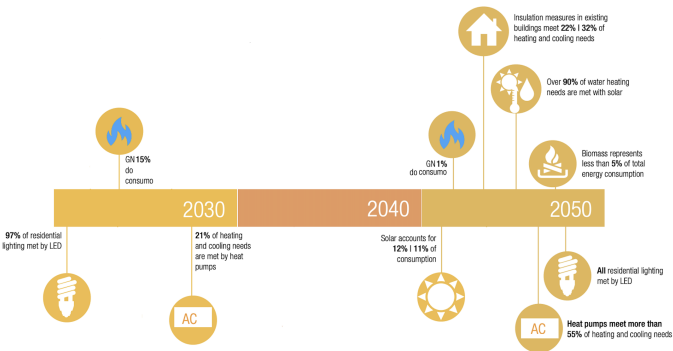


Figure 7. Timeline of residential sector’s carbon neutrality pathway up to 2050, as defined by the RNC2050, adapted from [30].

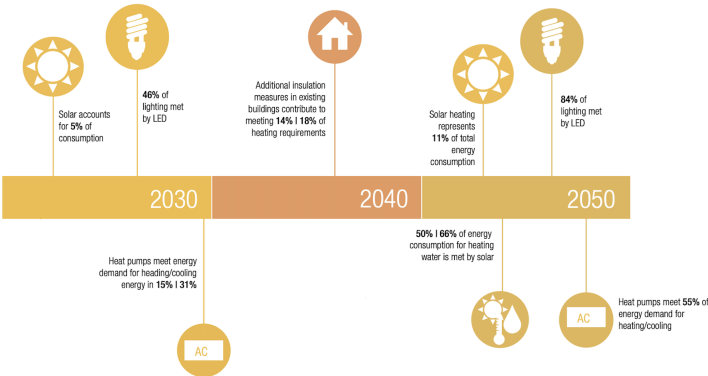


Figure 8. Timeline of services sector’s carbon neutrality pathway up to 2050, as defined by the RNC2050, adapted from [30].

Figure (9) presents the comparison between the evolution of GHG emissions and the investment cost after the implementation of proposed measures for Alternative 2. Emissions are forecasted to decrease from 68.26% in 2020 to 1.65% in 2050. In terms of investment cost, a consistent reduction is also observed. In 2030, costs are predicted to be at 57.35%, considerably reducing to 9.79% by 2050.

As it is possible to observe, Alternative 2 allows an emission reduction of about 98.35% when compared to 2020 for the residential sector.

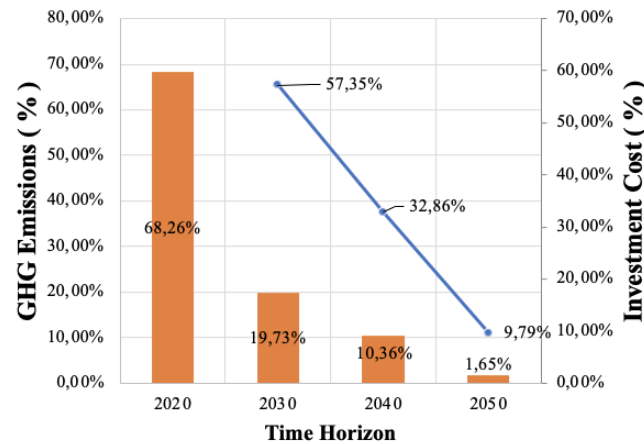


Figure 9. Alternative 2 - Comparison between emissions and the investment cost for the residential Sector.

For the services sector, the principle for identifying the measures to be implemented for Alternative 2 is similar to the one used for residential buildings. Hence, Figure 10 presents the comparison of the evolution of GHG emissions and the evolution of investment cost over the years for the services sector.

For this sector, it is possible to verify that GHG emissions are reduced by about 97.1%, compared with the 2020 values. The increased investment refers to the growing investment cost of implementing space heating and lighting technologies.

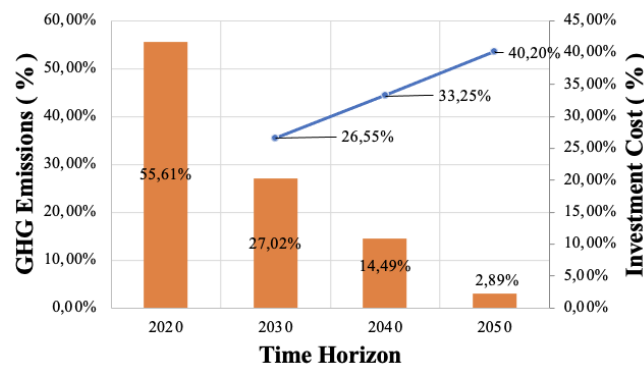


Figure 10. Alternative 2 - Comparison between emissions and the investment cost for the Services Sector.

4.3.3. Alternative 4

This alternative is based on the measures implemented in Alternatives 2 and 3. It is verified that, both in the PNEC and the RNC, there are no specific measures for the replacement of less efficient appliances by more efficient ones.

Therefore, Alternative 4 is a solution to improve the results obtained for GHG emissions with lower investment costs. Adjusting the values initially defined for each measure

was necessary to obtain better results. The results obtained from the combination of these two alternatives are shown in this section.

For the residential sector, the comparison between the evolution of GHG emissions and the investment cost was determined, as depicted in Figure 11. It is possible to verify that, with this alternative, the emissions present a reduction of nearly 99%, compared with the 2020 values. The investment cost of these measures follows this decrease, verifying that this alternative would be a good solution to implement.

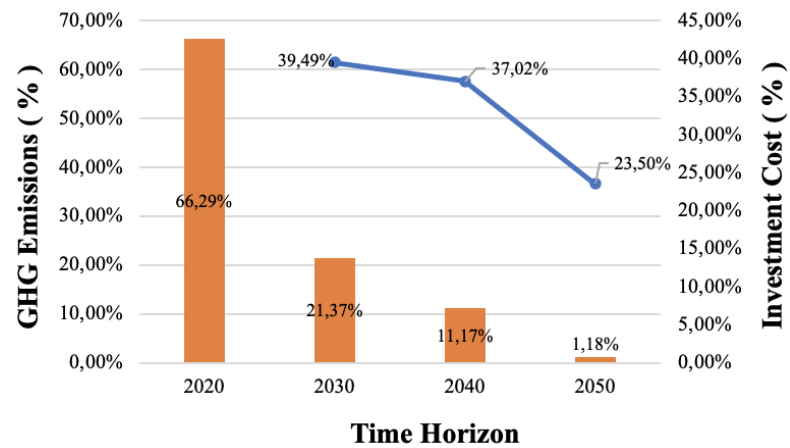


Figure 11. Alternative 4 - Comparison between emissions and the investment cost for the residential sector.

The analysis of the results obtained for the services sector is similar to that for the residential sector. In this case, the measure implemented in Alternative 3 for this sector remains unchanged, and then the measures of Alternative 2 that influence the decrease of GHG emissions are added. Finally, Figure 12 presents a comparison of the evolution of emissions with the investment cost. Once again, it can be seen that the emission values will be close to zero in 2050 and that the investment cost of these measures follows this trend.

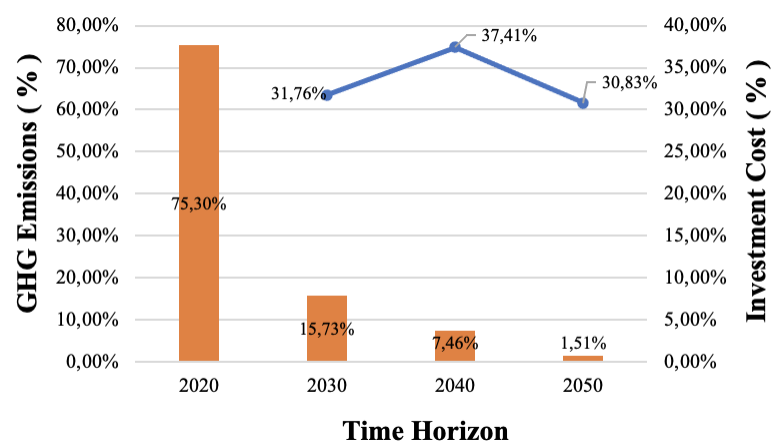


Figure 12. Alternative 4 - Comparison between emissions and the investment cost for the Services Sector.

4.3.4. Comparison between Alternatives

This section is designed to simplify the comparison and the discussion of all alternatives. Figure 13 and Figure 14 present the evolution of emissions and the investment cost of each alternative for the residential buildings sector, respectively. A similar analysis is illustrated in Figure 15 and Figure 16 for the services building sector.

By analysing Figure 13 concerning the residential sector, although Alternative 2 is worthwhile in the short term, it is possible to verify that Alternative 4, which combines measures implemented in Alternative 2 and Alternative 3, presents better results in terms of emissions. A reduction of about 98% of GHG emissions between 2020 and 2050 is achieved.

Regarding the required investment cost (illustrated in 14), one can derive different conclusions depending on the perspective of the analysis. It should be mentioned that the total investment throughout the whole time frame gives different directions when compared with single-time analysis. That is, some alternatives may induce a higher investment cost in the beginning than close to the time horizon or vice-versa.

It is possible to verify that Alternatives 3 and 4 are the ones that require the least investment, with a total investment of approximately 4,738 and 4,567 M€, respectively. Alternative 4, becomes a better solution than Alternative 3 because it is more complete in terms of the application of measures in other energy vectors and due to its GHG emissions value.

With the creation of Alternative 4, an attempt was made without radically increasing the value of the investment cost of Alternative 2 to reach GHG emissions levels close to zero in 2050. One can conclude that this objective was accomplished, considering Alternative 4 a good option to implement.

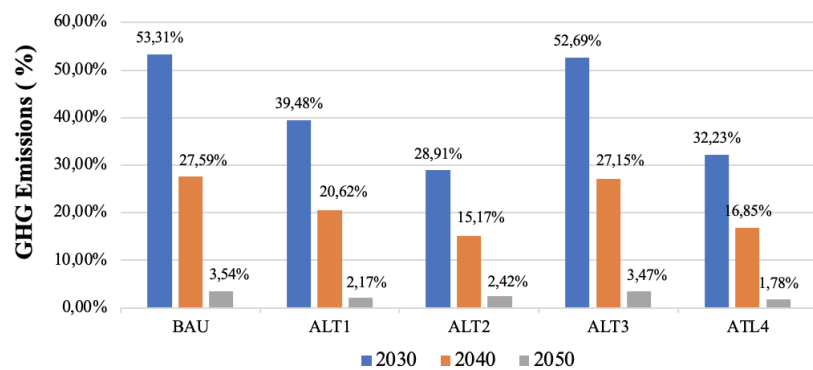


Figure 13. Comparison of the evolution of GHG emissions between alternatives for the residential sector (%).

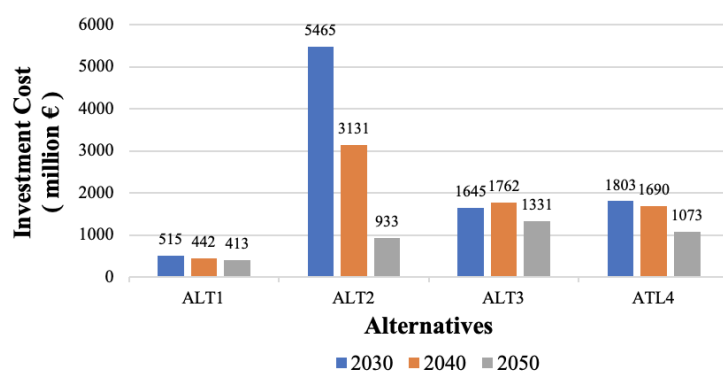


Figure 14. Comparison of the evolution of Investment Cost between alternatives for the residential sector (million €).

For the services sector, a similar analysis was carried out. In Figure 15, concerning GHG emissions, it is verified that Alternative 4 is, in fact, a good alternative in comparison to the reference scenario. Once again, one can observe a significant reduction in the value of GHG emissions in 2050, when compared to 2020, of about 98%.

Regarding the investment cost (illustrated in Figure 16), one can verify that Alternative 3 is the one that implies a lower investment, around 948 M€. However, this alternative

concerns only measures related to the replacement of appliances by more energy-efficient appliances. Alternative 4, compared to Alternative 2, presents a better result since it implies a lower total investment cost, around 1,980 M€ and presents a GHG emissions value close to zero in 2050.

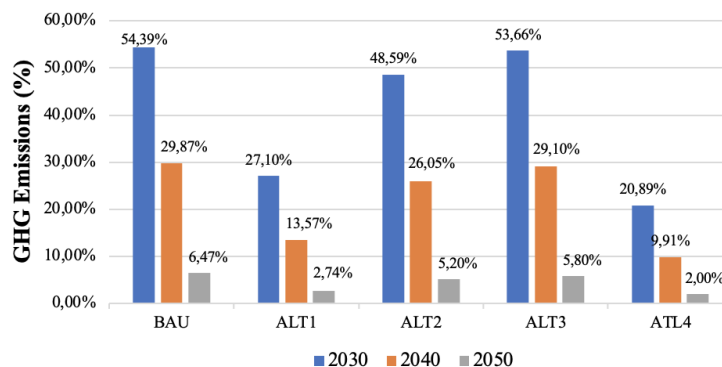


Figure 15. Comparison of the evolution of GHG emissions between alternatives for the services sector (%).

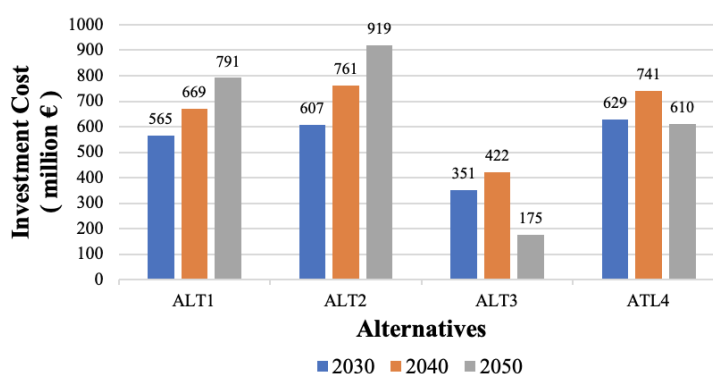


Figure 16. Comparison of the evolution of Investment Cost between alternatives for the services sector (million €).

5. Conclusions

The challenges towards carbon neutrality are huge and should be promoters of structural changes aimed at economic growth and improving the quality of life of citizens. Only in this way will it be possible to meet the objectives and targets set by national and European action plans in the area of energy and climate. The dynamism of actions aimed at promoting EE (e.g., replacement of conventional equipment with RES) in the most diverse socioeconomic sectors is a requirement, and it is perhaps in the residential and services area that it is most important to invest.

This work aimed to develop an alternative that achieves near-zero GHG emissions by 2050 focused on the Northern region of Portugal whilst not leading to larger investment requirements.

To summarise, Alternative 1 focuses on implementing measures related to the thermal insulation of buildings and also invests in space heating and cooling. Alternative 2 focuses more on water heating and lighting, including measures related to space heating and cooling. On the other hand, Alternative 3 focuses only on improving the EE of household appliances. Finally, Alternative 4 relies on the combination of Alternative 2 and Alternative 3. It is important to highlight that all alternatives created contribute to the reduction of GHG emissions and, in general, to the ultimate target of full decarbonisation of the energy system.

By analysing the results obtained, it was possible to verify that Alternative 4 allows for investment cost savings of approximately 52% for the residential sector and 13% for the services sector when compared to Alternative 2. Regarding GHG emissions, it is possible to obtain an emission reduction gain in 2050 for Alternative 4 of about 0,64% for the residential sector and 3,2% for the services sector when compared to Alternative 2.

An important conclusion is that, even though the energy policies in force in Portugal aim at the complete decarbonisation of the buildings sector, there are still several possible and cost-effective ways to achieve the desired targets with lower investment costs. Finally, it is possible to conclude that to achieve carbon neutrality and consequently improve the EE, the strategy should include building energy retrofiting. It is through an integrated intervention in the various elements of the building, such as the insulation of walls and roofs, the replacement by more efficient air conditioning and hot water production equipment, the use of RES, such as solar thermal or photovoltaic systems, that it is possible to increase the EE of the building, improve comfort conditions, reduce the energy bill and, consequently, achieve the decarbonisation goals.

Author Contributions

Conceptualization, S.C., T.S., I.A., W.F. and M.M.; Data curation, S.C., T.S. and I.A.; Formal analysis, S.C., T.S., I.A., and W.F.; Investigation, S.C. and T.S.; Methodology, S.C., T.S. and I.A.; Supervision, T.S., W.F. and M.M.; Validation, S.C. and T.S.; Writing—original draft, S.C. and T.S.; Writing—review & editing, S.C., T.S., I.A., W.F. and M.M.; All authors have read and agreed to the published version of the manuscript.

Funding

This research received partial support from the Norte Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF), within the DECARBONIZE project under agreement NORTE-01-0145-FEDER-000065 and by the Scientific Employment Stimulus Programme from the Fundação para a Ciência e a Tecnologia (FCT) under the agreement 2021.01353.CEECIND.

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Data Availability Statement: Not applicable

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BAU	Business As Usual
DL	Decree-Law
ECS	Energy Certification System
EE	Energy Efficiency
EnC	Energy Community
EPA	Energy Policies and Actions
EPBD	Energy Performance of Buildings Directive
EU	European Union
GHG	Greenhouse Gas
LEPA	Local Energy Planning Assistant
NZEB	Near Zero Energy Building
PNEC	National Energy and Climate Plan
RES	Renewable Energy Sources
RNC	National Carbon RoadMap

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