Marco de Sousa Domingues

ASSESSMENT OF BARRIERS TO THE ENERGY TRANSITION

Dissertation in the context of the Master Energy for Sustainability, advised by Professor Pedro Moura and Eng. Fernando Martins presented to the Department of Mechanical Engineering of the Faculty of Sciences and Technology of the University of Coimbra

July 2023

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE DE COIMBRA

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Resumo

A transição para um sistema energético sustentável é um desafio global devido às elevadas emissões de gases de efeito estufa do setor energético. Nesse contexto é necessário identificar os obstáculos e desafios para uma transição energética limpa e rápida, utilizando as estratégias mais eficientes e sustentáveis com os recursos disponíveis.

Este trabalho pretende responder às seguintes questões: Quais são os obstáculos e desafios a ultrapassar para se conseguir uma transição energética limpa e rápida? Quais as estratégias que podem ser implementadas para promover eficazmente a integração e adoção de veículos elétricos no setor automóvel, contribuindo para uma transição energética sustentável e eficiente? Quais são as principais estratégias e ações políticas que podem promover a adoção generalizada de fogões elétricos de indução como uma alternativa sustentável aos fogões a gás, garantindo um sector de cozinha mais eficiente em termos energéticos e amigo do ambiente? Como assegurar eficazmente a transição das caldeiras a gás para as bombas de calor, tendo em conta fatores como a relação beneficio-custo, a eficiência energética e o impacto ambiental, de modo a obter um sistema de aquecimento sustentável e resiliente?

Esta tese explora transições sustentáveis em três áreas-chave: a mudança de veículos de combustão interna para veículos elétricos (VEs), a substituição de aquecedores de água a gás por bombas de calor e a transição de fogões a gás para fogões elétricos de indução. O objetivo é identificar e explicar as diferenças económicas entre estes sistemas e determinar qual a opção mais rentável. Ao analisar fatores como os custos de aquisição, as despesas de instalação, o consumo de energia, a manutenção e os fundos públicos, é efetuada uma avaliação abrangente. Os resultados revelam que, embora as opções elétricas possam ter custos iniciais mais elevados, oferecem vantagens económicas a longo prazo devido a um menor consumo de energia e a requisitos de manutenção reduzidos. Além disso, as alternativas elétricas demonstram um desempenho ambiental superior, minimizando as emissões de carbono e apoiando a utilização de fontes de energia renováveis.

A tese conclui que a adoção de veículos elétricos, bombas de calor e placas de indução está alinhada com o objetivo de alcançar uma sociedade sustentável e resiliente. O apoio do governo, os avanços tecnológicos e uma maior sensibilização do público são cruciais para promover a adoção destas tecnologias mais limpas. Ao optarem ativamente por práticas sustentáveis, os indivíduos e as comunidades podem contribuir para atenuar as alterações climáticas e criar um futuro mais sustentável. Em conclusão, a implementação de políticas estratégicas, tecnologias inovadoras e a promoção de uma cultura de mobilidade sustentável são passos cruciais para alcançar um futuro mais sustentável.

Palavras-chave: Transição Energética, Eficiência Energética, Neutralidade Carbónica, Plano Nacional de Energia e Clima, Energia Sustentável.

Abstract

The transition to a sustainable energy system is a global challenge due to the high greenhouse gas emissions of the energy sector. It is therefore important to identify the barriers and challenges to a clean and rapid energy transition using the most efficient and sustainable strategies with the available resources.

This work intends to answer the following questions: What are the obstacles and challenges to overcome in order to achieve a clean and rapid energy transition? What strategies can be implemented to effectively promote the integration and adoption of EVs in the transport sector, contributing to a sustainable and efficient energy transition? What are the key strategies and policy actions that can promote the widespread adoption of electric induction cooktops as a sustainable alternative to gas stoves, ensuring a more energy-efficient and environmentally friendly cooking sector? How can the transition from gas boilers to heat pumps be effectively facilitated, taking into consideration factors such as cost-effectiveness, energy efficiency, and environmental impact, to achieve a sustainable and resilient heating system?

This thesis explores sustainable transitions in three key areas: the shift from internal combustion vehicles to electric vehicles (EVs), the replacement of gas water heaters with heat pumps, and the transition from gas stoves to electric induction cooktops. The objective is to identify and explain the economic differences between these systems and determine which option is more cost-effective. By analyzing factors such as acquisition costs, installation expenses, energy consumption, maintenance, and government funds, a comprehensive evaluation was developed.

The findings reveal that while electric options may have higher upfront costs, they offer long-term economic advantages due to lower energy consumption and reduced maintenance requirements. Additionally, electric alternatives demonstrate superior environmental performance by minimizing greenhouse gas emissions and supporting the use of renewable energy sources. The thesis concludes that embracing electric vehicles, heat pumps, and induction cooktops aligns with the goal of achieving a sustainable and resilient society. Government support, technological advancements, and increased public awareness are crucial in promoting the adoption of these cleaner technologies. By actively choosing sustainable practices, individuals and communities can contribute to mitigating climate change and creating a more sustainable future. In conclusion, the implementation of strategic policies, innovative technologies, and the promotion of a sustainable mobility culture are crucial steps to achieve a more sustainable future.

Keywords: Energy Transition, Energy Efficiency, Carbon Neutrality, National Climate Energy Plan, Sustainable Energy.

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ACRONYMS

EU – European Union

EV – Electric Vehicle

FCEV – Fuel Cell Electric Vehicle

HEV – Hybrid Electric Vehicle

ICV– Internal Combustion Vehicle

PHEV – Plug in Hybrid Electric Vehicle

PHEV – Plug in Hybrid Electric Vehicle

1. INTRODUCTION

1.1. Motivation

The energy transition is an issue that is present in the political and social environment, becoming one of the main challenges for society in general. End consumers are the heart of the energy transition, and it will only be possible with a strong focus on end use. Although there is a demonstrated motivation by the consumer and the political agent to switch toward more efficient processes, there are still many consumers who face considerable barriers. The crucial goal is to ensure the use of sustainable energy sources from renewable sources, with low or zero CO_2 emissions. Since it is possible to generate electrical energy through almost zero-emission means, the next step is to make the switch from polluting processes such as fossil fuels to renewable sources.

Achieving zero emissions in 2050 requires a fast and efficient transition. Since electricity is the area where a more efficient energy transition can be possible, new ways will have to be developed to replace inefficient processes with better ones and to change fossil fuels with electricity generated from renewable sources. Therefore, a transition is inevitable, whether through the implementation of renewable means or even by increasing energy efficiency in various areas [1]. An energy transition implies several things, such as a shift in electricity generation to renewable or non-polluting means, investing in the efficiency of various equipment, opting whenever possible for public collective means, and establishing decisive policies in massifying certain transition promotions [2].

In recent years energy consumption has been growing exponentially worldwide, with the increase in population and the increase in electric goods, such as vehicles or residential appliances. Since consumption is steadily increasing, it makes even more sense to act now to combat the pollution caused by dioxide carbon emissions. Climate change is a major obstacle for humanity, being a European and global problem. Therefore, developed countries have an important leadership and innovation role in implementing new forms of energy transition in order to reduce emissions and decrease the known impacts of climate change [3].

The focus of the energy sector consists mostly of policies defined by the European Union to achieve successful levels of energy efficiency and mainly to achieve full electrification in the energy sector by 2050. These measures were defined in the Paris Agreement, as well as the implementation of the National Energy and Climate Plan (NECPs) as the main energy policy implementations.

This study aims to understand all political and economic barriers to an efficient energy transition and correlate the established goals mainly in Portugal. Regarding the energy transition, a detailed analysis of the difficulties and effectiveness of technical implementations is expected.

1.2. Objectives

It has been understood that the European Green Deal Plan considers a sustainable and efficient energy transition. However, some decisive barriers can change the course and some of them are unpredictable. The main changes are people's consumer mentality and lack of knowledge, as well as achieving ever more efficient products and obtaining electricity mostly or entirely from renewable energy.

The study under discussion aims to answer the following questions:

- *What are the barriers and weaknesses present in the European Green Deal regarding decarbonization and energy efficiency? The objective is to understand the different barriers to the policies introduced in the European Union and their impact on the results by 2050.*
- *What will provide the best strategy to ensure an efficient sustainable energy transition with the resources currently available? The objective is to assess which political or economic frameworks are responsible for accelerating the energy transition efficiently.*
- *How can the introduction and replacement of electric vehicles in the automotive sector be facilitated to achieve a more sustainable and efficient energy transition? The objective is to identify the factors that have the largest impact on the successful integration of electric vehicles in the automotive industry, as well as to understand the barriers and challenges that may hinder their adoption.*
- *Analyze the challenges and opportunities of introducing and replacing gas-powered kitchen appliances with electric alternatives, taking into account factors such as energy efficiency, environmental impact, cost-effectiveness, and user experience.*
- *What are the key strategies and policy actions that can promote the widespread adoption of electric induction cooktops as a sustainable alternative to gas stoves, ensuring a more energy-efficient and environmentally friendly cooking sector?*
- *How can the transition from gas boilers to heat pumps be effectively facilitated, taking into consideration factors such as cost-effectiveness, energy efficiency, and environmental impact, to achieve a sustainable and resilient heating system?*

Based on the objectives stated above, this study seeks to provide a comprehensive analysis of the different factors influencing the transition toward a more sustainable and efficient energy system in Portugal. By identifying the barriers and challenges faced by policy makers, businesses and individuals in achieving a low carbon economy, the study aims to provide insight into the most effective strategies and policies that can be implemented to accelerate the transition process.

In conclusion, this study aims to contribute to the ongoing discussion on the challenges and opportunities of achieving a sustainable and efficient energy transition in the European Union. By addressing the key questions and objectives outlined above, the study seeks to provide valuable insights into the most effective strategies and policies for promoting a sustainable and efficient energy system in the future.

1.3. Structure

This work is structured into seven different chapters. This first chapter presents the motivations on the topic of the moment, the energy transition, and the impacts of policy decisions.

The second chapter focuses on the literature review on energy transition methodologies, their barriers, and decisive methods.

The third chapter presents an analysis of the barriers and transition associated with the implementation of a comprehensive infrastructure to combat the energy transition, namely the implementation and replacement of electric vehicles by internal combustion vehicles. Chapter four presents a detailed economic analysis of the electric vehicle sector, including costs associated with battery production, charging infrastructure, and government incentives.

Chapter five addresses the adoption and replacement of gas systems with electric systems in residential houses, including an economic analysis of the costs associated with the transition. Six chapter presents a detailed economic analysis of electric heating systems, including energy production, distribution, and storage costs.

The last chapter summarizes the results of the thesis and proposes recommendations for policy makers and industry stakeholders to support successful electrification of different sectors.

2. STATE OF ART

2.1. Barriers and Challenges

The main objective of the study is to analyze the different forms of implementation and barriers faced in the transition to a more sustainable energy system. Energy transition has never made more sense to combat Green House Gas (GHG) emissions and decarbonization. Change is inevitable and the main goal is to overcome all barriers, effectively and efficiently. The European Union and all member states including Portugal are aligned to fight climate change with very promising goals. [4].

From the global perspective, the adoption of corporate mechanisms, especially toward optimizing the use of renewable energy for economic growth stimulation and sustainability is encouraged. In doing so, the global drive toward attaining the SDGs by 2030 will become realizable rather than remain a mere aspiration [5].

The barriers are differentiated into three very important factors, economic, social and political. The adoption of new technologies, especially renewable ones, involves high investment and the vital role of the government is to guide people and businesses to become interested in these types of commitments. All barriers are felt and there is great difficulty in dealing with some of them. However, as the European Union has well-defined directives and goals, national policies must be aligned in order to achieve the proposed goals. In Fig. 1 is possible to observe that the intended goals were not reached, making 2030 seem further away [6], [7].

The major goals of the first directives defined were to attack problems where they can have the greatest impact. Buildings, in particular residential ones, have the greatest energy consumption in the EU, followed by the transport and industry sectors. Since buildings are the sector that consumes the largest shares, it is where major changes can be made. Fig. 2 presents the percentage of energy consumption by sector.

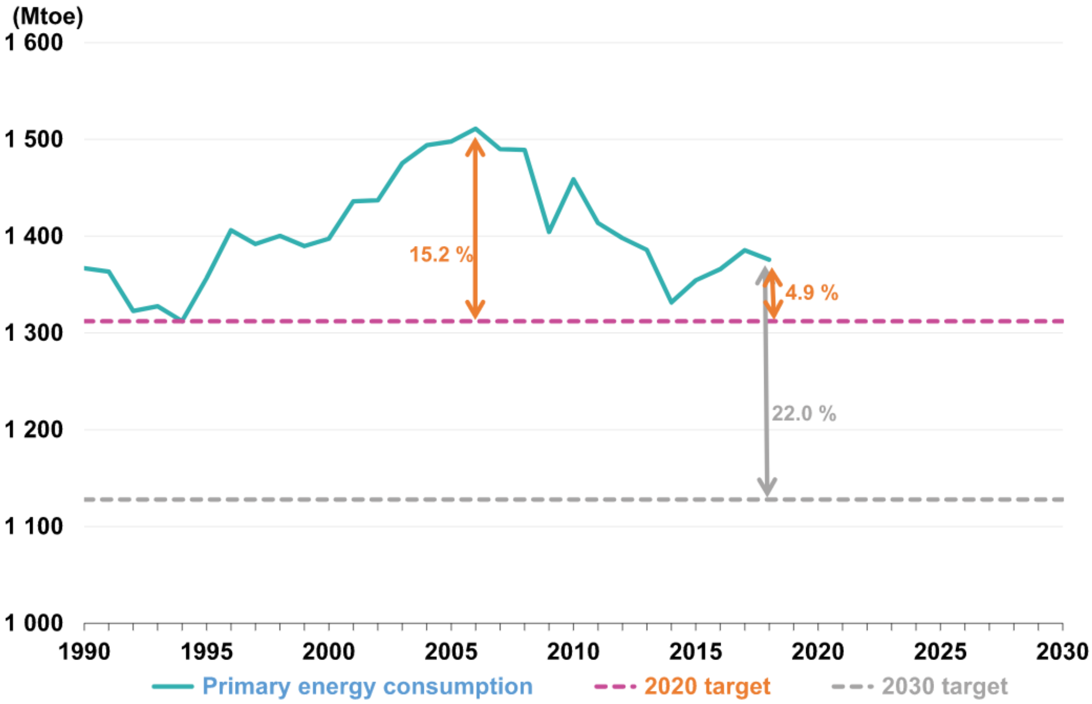

Fig. 1 – Distance to 2020 and 2030 targets for primary consumption, EU-27 [8].

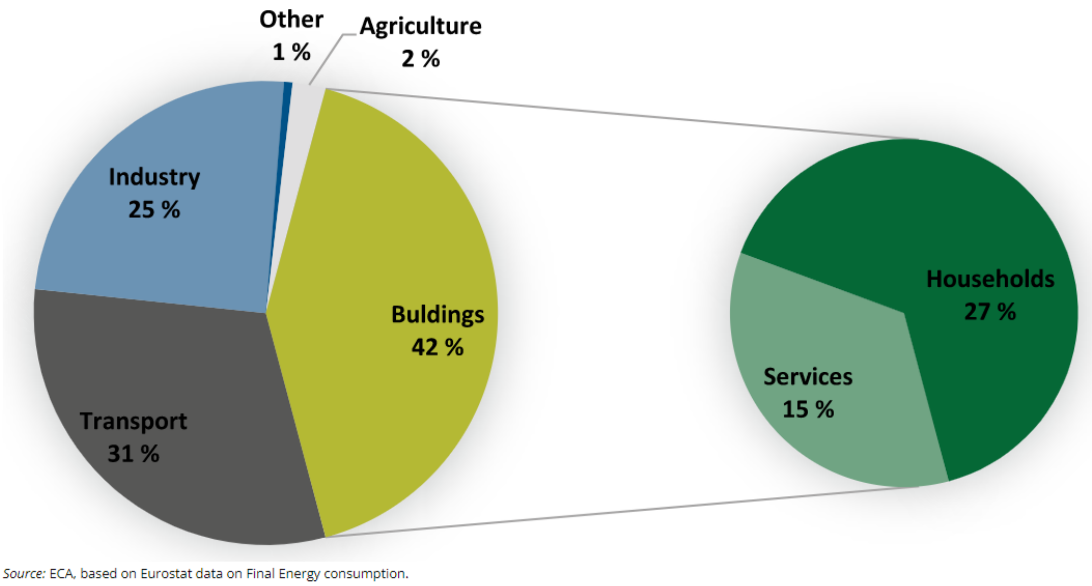

Fig. 2 - 2017 Energy consumption by sector in EU (% of total) [9].

This sector is responsible for the consumption of approximately 40% of the final energy in Europe and about 30% in the case of Portugal. This sector, for having a high energy consumption, will be a sector where the energy transition will have greater potential. It is also possible to make renovations in order to achieve more efficient coatings, insulation, heating, and lighting [6], [10], [11].

2.2. Decarbonization

Electricity has proven essential to decarbonize the planet. Electricity generation from renewable sources allows for the development and creation of a sustainable and efficient world. Since electricity is used on a global scale and with high intensity, for that reason it is up to everyone and especially governments, to encourage change regarding generation, as well as its efficient use. Decarbonization is possible by reducing emissions from fossil fuels. The sectors with the highest emissions should be the principal sectors to be reformed.

Climate change is a global concern, and the Paris agreement of 2015 was crucial to fight it. In this agreement, the major commitments were all the member states of the European Union among 195 countries [12].

It is fundamental to stop emitting carbon and drive it to zero by 2050. However, the world is dumping 55 billion tons of carbon pollution into the atmosphere every year and to get halfway to zero by 2030, it is essential to reduce annual emissions by about 10 percent a year, but the annual emissions were never reduced in any year in the history of the planet. The carbon emissions come from four sectors of their economy. The first is the electric grid, the second is transportation, the third is industrial and the fourth is buildings [13]. One big problem is that carbon dioxide is embedded in every aspect of the industrial economy. Every car, truck, airplane, house, electrical socket and industrial process now emits carbon dioxide. If the electrical grid is decarbonized, and all energy consumption processes are electrified, it is possible to achieve a zero-carbon economy.

One way to fight this is the integration of renewable generation, namely solar and wind power. The prices of solar and wind have plummeted in recent years and solar photovoltaics is now the cheapest form of electricity generation and wind power is the second in renewable generation options by 2020 [14]. However, there are several ways to attack these problems, and energy efficiency is also a crucial point to improve. The transport sector is responsible for one of the largest shares of emissions, accounting for almost a quarter of all CO_2 emissions in the European Union, by 2017 [15]. A possible approach to tackling and solving this problem effectively would be to introduce electric vehicles in the automotive sector.

An important factor is the relationship between energy consumption and economic growth, as well as economic growth with GHG emissions. These relationships show similar parity and growth in the past. It can be seen in Fig. 3 that in recent decades it was possible to achieve a separation from its usual parity at the same time as there has been an increase in the electrification of the economy.

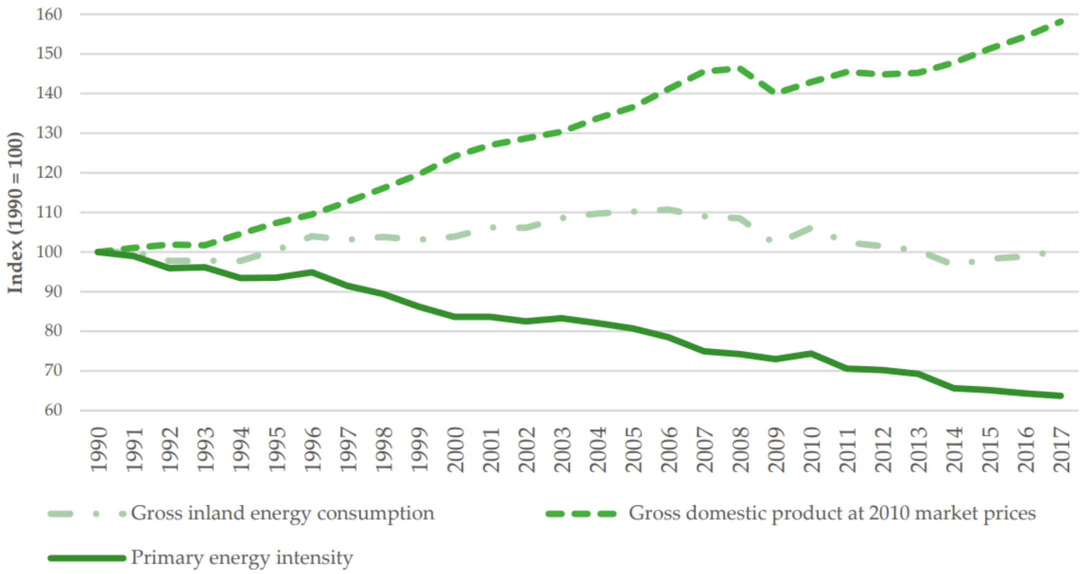

Fig. 3 - Trends in energy intensity, gross domestic product, and gross inland energy consumption in EU[16]**.**

Although energy consumption has remained in a constant area, the primary use of energy intensity has been decreasing while at the same time gross domestic product is increasing. This evidence of decreasing primary energy intensity has not slowed economic growth or the energy transition, quite the opposite. It is possible to corroborate that the decrease in CO_2 emissions has not slowed down economic growth despite the policies implemented so far.

Reducing carbon emissions is an important element in the European Union's implementation of policies to achieve carbon neutrality by 2050 [12] This ambitious goal can be achieved if it is followed according to a plan and periodic monitoring.

This monitoring and confirmation of the achievement of the targets are done through various carbon indicators. Adequate monitoring will be decisive and will not be easy for the following reason: First, the monitoring system is not yet fully developed, despite being widely monitored. Although the monitoring plan is in operation it is still being improved in an effort to facilitate the comparison of data and results between member states [17]. With this, it can be said that there is not yet a 100 % defined plan but through the various data obtained by numerous papers it is possible to have an approach to measure the success of decarbonization.

As the EU aims to achieve carbon neutrality by 2050, an economy with net zero emissions of greenhouse gases, it faces the challenge of technology and achieving decisive and challenging targets. This major goal has at its center a green agreement, the Paris agreement, this agreement allows to dictate a testimony and commitment from all member states to comply with the agreement. This is an opportunity to transition to a neutral society to build a better future for all. From the energy sector to industry, mobility, buildings, agriculture and the forest sector will all play a crucial role. It is certain that the EU is leading the transition with new technologies and ingenious solutions in diverse areas such as industry, finance and research to ensure equal justice in the energy transition [18]– [20].

2.3. Renewable and Energy Efficiency Process

Energy efficiency is the use of a technology that performs the same level of service with less energy use and seeks to improve the use of energy sources. Renewable generation has become more popular and much because of the need for zero emissions because the price of generation has decreased significantly. Renewable production allied with more efficient processes are an important role in reaching the agreements defined.

To meet the new EU 2030 climate target, efficiency needs to be prioritized. The energy efficiency target of 35% relates to the reduction of primary energy consumption. When looking at the electricity industry value chain which is composed of generators, transmission, distribution and utilities, the reduction of primary energy can take place at the generators, utilities and consumers [21]. Energy efficiency in the lens of a primary energy reduction strategy suggests three courses of action: the conversion of fossil fuel power plants, the reduction of GHG emissions and the increased share of renewables.

In order to achieve the defined goals, the final consumer will also play a fundamental role. Both the ordinary citizen and the companies themselves will have their mission. There are a few factors that can be essential to energy saving measures that contribute to greater energy efficiency:

- Thermal insulation of hot surfaces
- Optimization of equipment operating conditions
- Elimination of hot fluid leaks
- Utilization of residual fuels or heat sources
- Correct dimensioning of energy installations
- Elimination of compressed air leaks
- Recovery of thermal energy in air compressors
- Replacing conventional motors with high efficiency motors
- Installation of VSDs (Electronic Speed Drives)
- Change of tariff option
- Load shedding
- Power factor compensation
- Optimization and control of lighting
- Better use of natural lighting conditions
- Implementation of energy management systems
- Installation of cogeneration systems

Energy efficiency is important to European goals and for a sustainable energy transition and this sustainability is supported by three pillars of the industry, transformation, decarbonization, and the decentralization and digitalization of networks.

Not only Portugal, but all European Union member states have committed to follow a deep decarbonization path. Through these goals, it has been possible to set very competitive objectives and sustainable trajectories.

In 2015 the European Union defined the main objectives of energy policy:

- Diversify Europe's energy sources, ensuring energy security through solidarity and cooperation between EU countries;
- To ensure the functioning of a fully integrated internal energy market, allowing the free flow of energy across the EU through adequate infrastructure and without technical or regulatory obstacles;
- Improve energy efficiency and reduce dependence on energy imports, reduce emissions and boost jobs and growth;
- "Decarbonize" the economy and move towards a low-carbon economy, in line with the Paris Agreement;
- Promoting research into clean and low-carbon energy technologies and prioritizing research and innovation to drive the energy transition and improve competitiveness.

To understand a more detailed individual and collective profile and compare the use of primary energy from low-carbon sources,

Fig. 4 presents data for the last 55 years.

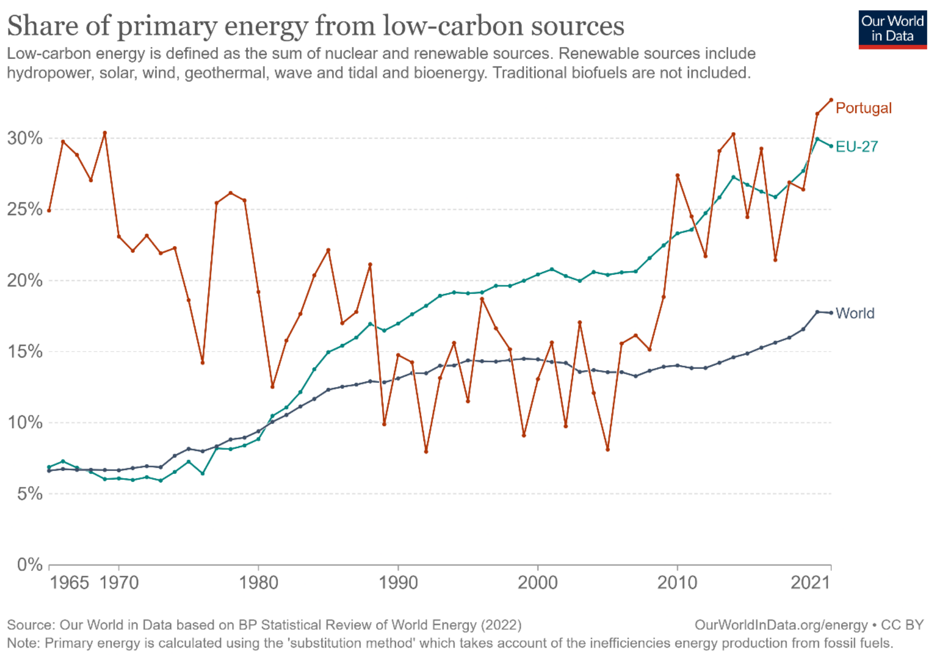

Fig. 4 – Share of primary energy from low-carbon sources [22].

This graph allows concluding a lot from just three locations, the world, the European Union including all member states, and Portugal. The Portuguese case had an interesting beginning, after 1990 it was overtaken by the statistics of an average of the world and the European Union, but that quickly caught up with the other elements in a few years because Portugal suffered a major development requiring more energy for it. It is also concluded that the European Union is on average better than the rest of the world, leading to say that the EU has a mentality of decarbonization with the adoption of renewable energies more defined than the rest of the world.

In order to achieve the objectives, European Union imposed several directives. First, they set a timeline until 2020. In December 2012 several directives on energy efficiency entered into effect. These directives obliged the Member States to focus on energy efficiency targets to guarantee the central goal of reducing energy consumption by 20% by 2020[23]. These were the first steps on a path of energy efficiency, which were slow in the first years, but have evolved and met some deadlines over time. All Member States had the possibility to apply minimum but demanding requirements as part of their energy-saving efforts. And in order to see progress, each country was required to publish its quarterly national energy efficiency action plans. At the moment the new horizon is until 2030. There has always been a strong focus by the European Union on energy efficiency, the principles being to ensure a secure, sustainable, and competitive energy supply. There were ambitious new targets of 30% energy consumption reduction agreed upon in a proposal up to 2030[23]

There has always been some disagreement among member states, but the focus has remained the same, to reach 2050 with zero emissions, despite some ups and downs. The adoption of a very ambitious green pact has forced the European Commission to reformulate some growth strategy targets. Energy efficiency is important and is aligned with the progress set to achieve carbon neutrality by 2050.

Some of the targets chosen to achieve ambitious results were:

- Construction of power plants and renewable generation parks;
- Emission reductions in transportation;
- Tax incentives for individuals and businesses for a more efficient and faster energy transition;

The challenges for energy efficiency are vast, and companies have shown that they are ready and willing to support this cause. The most significant contribution comes from state tax support, but also from private investment in energy efficiency. Not only in European policies, but companies themselves have acted and are acting on their own to achieve better levels of energy efficiency. Many companies have replaced high-energy-consuming equipment with more efficient, low-energy-consuming equipment for the same result. It is also remarkable to feel the change in the mentality of people and companies despite the expected financial returns.

Also, the policies imposed were subject to control by competent technicians who audited the companies with the objective of analyzing the energy behavior of buildings and companies. This control allows the identification of companies that do not comply with the directives imposed by the European Union.

The Portuguese government proposes ambitious goals for GHG emission reduction between 2021-2030 and 2031 to 2050. It intends to decarbonize all sectors by about 55% by 2030. According to several Portuguese experts, Portugal is positioned as one of the EU countries that have made the most progress in energy efficiency policies between the years 2017 and 2020 [24]. Although Portugal was struggling from 2012 to 2015, it had great development and reached optimal levels within all member states afterward. Table 1 shows the targets to achieve by 2030 compared to 2005.

Table 1 – Portuguese targets for the 2030 horizon [24],[25].

Target	Emissions	Energy Efficiency	Renewable	Renewable Transports	Electrical Interconnections
2030 (Portugal)	-45% to -50%	35%	47%	20%	15%
2050 (European Union)	-90%	75%	65% to 100%	65% to 90%	95%

The places where the most progress has been made in energy efficiency are in the industry, transport and building renovations. Transport in Portugal was the sector with the highest progress in all member states [26], [27].

To accelerate the energy transition and achieve more efficient processes, governments should:

- Support the union and formation of a coalition for the Energy Transition that will bring together leading countries to develop long-term energy transition strategies, promoting low-carbon investments, and increasing investor confidence in low-carbon economic growth;
- Expand public sector investment in research, development and demonstration;
- Cooperate and strengthen international programs, bringing countries together globally Technology Collaboration and Innovation Mission Programs to define a joint agenda for renewable technology innovation that will identify critical innovation needs to be developed, emerging and developing markets and prepare collaborative strategies to meet the goals;
- Understand and improve the collective global unity between public and private sector parties on the subject of innovation.
- Raise more full-scale projects applicable to everyday life with public or private funding, as well as test pilot programs on innovative technologies.
- Develop more technical and quality standards in order to facilitate control in cross-border trade and the exchange of innovative technologies.

- Align efforts and economic volume to help sectors in need of decarbonization. The most relevant sectors are energy-intensive industries (iron, steel and cement production) and transport (freight, aviation, and shipping)[28].

2.4. European Framework and Political Objectives

This section aims to understand and analyze existing work on the energy transition in Europe. There are multiple studies focused on a global, continental and national perspective with different approaches to decisions about a sustainable energy transition. The main objective is to obtain perfect decarbonization where the influence of the socio-political and techno-economic context is understood, concluding which energy path will define a better course [29] The European Commission through the Directorate General for Energy of the European Commission (DG ENER) evaluates through internal studies the impact and development that policies have achieved. This collection of information is generally based on quantitative arguments that allow outlining the next policy decisions regarding European directives. These types of studies have had frequent updating allowing them to improve decisions and assess the main challenges associated with decarbonization with a focus on political and technological understanding, where three studies have been carried out in recent years.

The scenario of developing and focusing and improving old decisions focuses on the sustainability, competitiveness and security of the EU energy system. It is through several factors that it is possible to drive decarbonization, namely: energy efficiency, renewable energy, nuclear energy and carbon capture and storage, which allow forming of an energy roadmap toward an energy transition by 2050. This work requires the interaction of a wide audience including technology, consumers, and a board of investors [30].

There is the goal of clean energy is to assess all member states throughout the process with the next assessment and target being by 2030. Carbonization is expected to result in a 2°C increase by 2030. However, it is expected that there will be large increases in energy efficiency of around 30%. It is clear that the European Union has a long-term vision of leading the way in decarbonization. Because Europe wants climate neutrality it is investing heavily in realistic technological solutions, educating its citizens, and aligning policy with industry. All the while maintaining social justice along this transition path [31].

Numerous EU-funded research projects are underway that aim to expand the knowledge and techniques used in the energy transition today. This transition is accented by some important factors being: political, economic, social, environmental, technological and global. The European Union has been fighting for some years now, and through protocols and agreements between countries, commitments and goals have been accomplished, starting with the Kyoto protocol, which dictated the beginning of a path of decarbonization [32].

Fig. 5 reflects an improvement in policy approaches over time. Although growth has been evident in energy efficiency, the renewable component of electricity generation has been slowly growing and taking the place of fossil fuels. Climate threats have put increasing pressure on policy direction and decisions, and so the positive evolution of decarbonization and energy transition is clear [29].

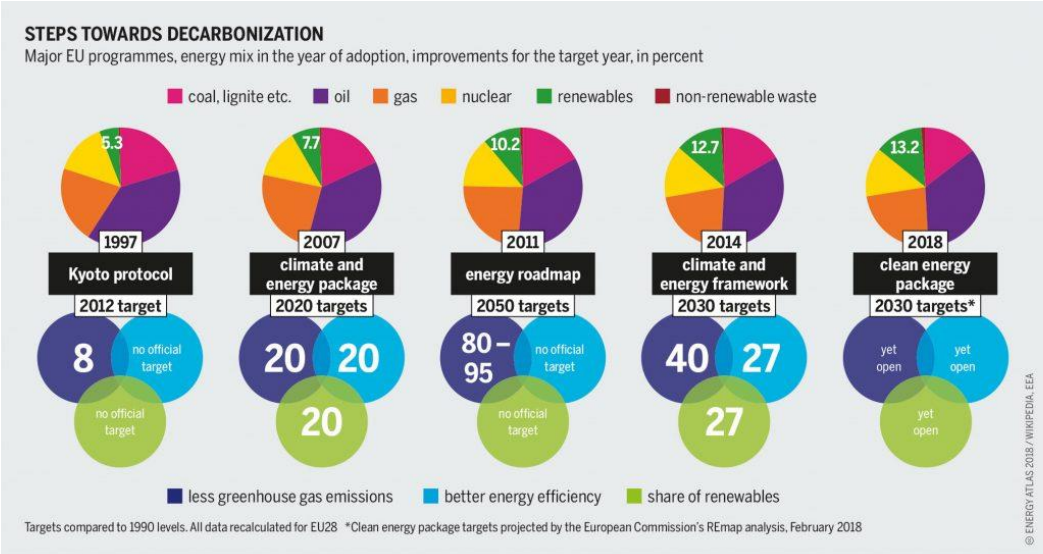

Fig. 5 - Steps towards decarbonization [33]

2.5. Electrification of Process

The world faces considerable challenges related to population growth and its direct influence on the environment, energy, and other natural resources. There are numerous environmental concerns and the intensive exploitation of resources has led mainly in the European Union to a wave of political decisions aimed at mitigating climate change. These excessive emissions for several years are now stopped with the goals and agreements of decarbonization by 2050. Several sectors contribute negatively to greenhouse gas emissions, and the energy sector is key to achieving sustainable development.

There are several sectors with high emissions where it is possible to intervene in order to achieve more interesting results in the short term. It is possible to address and achieve emission savings through the electrification of various sectors, when using electrification produced by renewable means.

It is vital to note that although electrification is a prime candidate for solving the emissions problem, it is currently positioned in the production graph a big cut from fossil-fuel. Despite having already reached more than 50% renewable production it is important to establish a strong basis in the Portuguese load diagram, distributing and orienting the seasonal and periodic loads in an orderly and balanced manner. It is noted that Portugal still has a varied availability of renewable generation such as hydro, wind, photovoltaic, biomass, biogas and geothermal in order of production capacity in 2021 as is shown in the following graph.

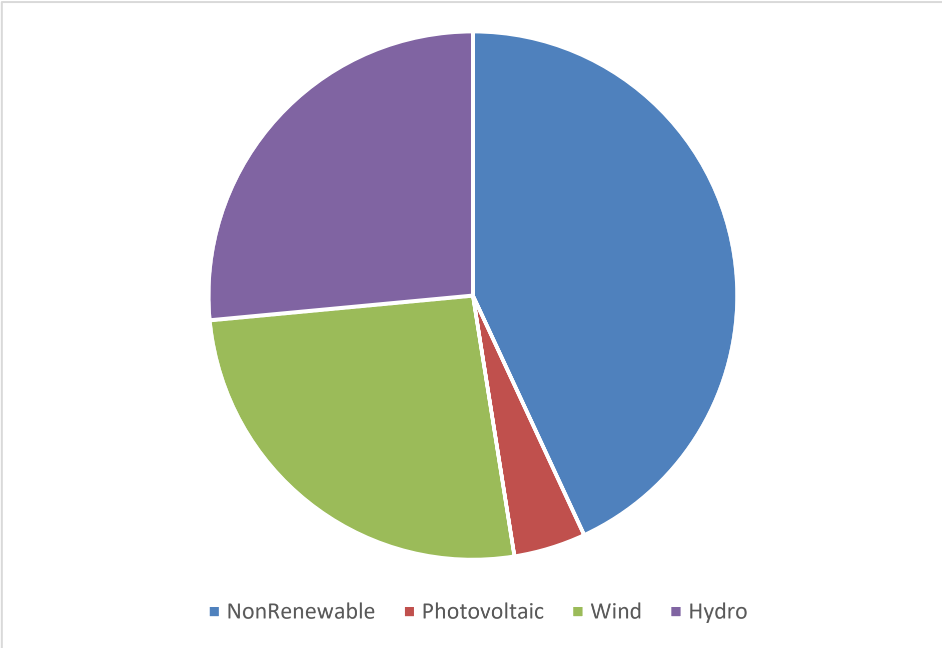

Fig. 6 – Availability of electric energy for consumption 2021 in Portugal [34]

These main means of resolution can be the effective introduction of 100% electric vehicles and the replacement of fossil fuel burning equipment in the residential sector by fully electric equipment. In this thesis, we will study mainly the economic, technical and political barriers to implementing these ways to address decarbonization.

3. TRANSITION TO ELECTRIC: EXPLORING THE ADOPTION OF ELECTRIC VEHICLES

The adoption of electric vehicles (EVs) and the replacement of gas systems with electric systems in buildings are two important steps toward reducing greenhouse gas emissions and improving air quality. These actions are essential to achieve the goal of a carbon-neutral society and to mitigate the effects of climate change.

In recent years, the adoption of electric vehicles in Portugal has increased, thanks in part to government incentives such as tax reductions and subsidies. This trend is expected to continue as electric vehicle technology continues to improve, battery costs continue to decrease, and charging infrastructure becomes more widely available. However, there are still challenges to overcome, including the initial cost of electric vehicles and the need for adequate charging infrastructure. Similarly, the electrification of vehicles faces several barriers, including high initial costs, range anxiety, and a lack of charging infrastructure. Furthermore, concerns over the environmental impact of battery production and disposal pose significant challenges.

To determine the impact of the barriers to EV adoption, a comparative analysis will be conducted. The analysis will consider the cost of ownership, including the purchase price, maintenance costs, and fuel costs, of EVs and conventional vehicles. It will also evaluate the availability and quality of charging infrastructure in different areas and assess the environmental impact of battery production and disposal.

In conclusion, the adoption of electric vehicles is essential step toward achieving a carbon-neutral society. While there are challenges to overcome, such as the initial cost of electric vehicles and the need for adequate charging infrastructure, the benefits of these actions, including reduced greenhouse gas emissions and improved air quality, make them necessary for a sustainable future.

3.1. Adoption of Electric Vehicles

The automotive sector is one of the most responsible for the increase in greenhouse gas emissions, due to the high dependence on oil and its derivatives. Portugal, being aligned with the goals set by the EU, has created legislation that aims to regulate the various sectors of the economy in the rationalization of intensive consumption of fossil fuels. Despite technological advances and some significant increases in Electric Vehicle sales, it is still noted that this sector is considered to have the greatest dependence on fossil resources, which account for 36% of the country's energy consumption. Furthermore, in the transport sector, road transport is considered to be the most polluting in greenhouse gas emissions with contributions of 23% [35]. In the transportation sector, it is possible to relate and identify that the main consumers of energy are light-duty and heavy vehicles, so this will be the main agent to direct the efforts in the fight to reduce emissions.

Based on the Fig. 7 analysis, there is a downward trend in GHG emissions since 2017. However, to achieve the expected annual reductions the transport sector is a strong candidate for such an improvement.

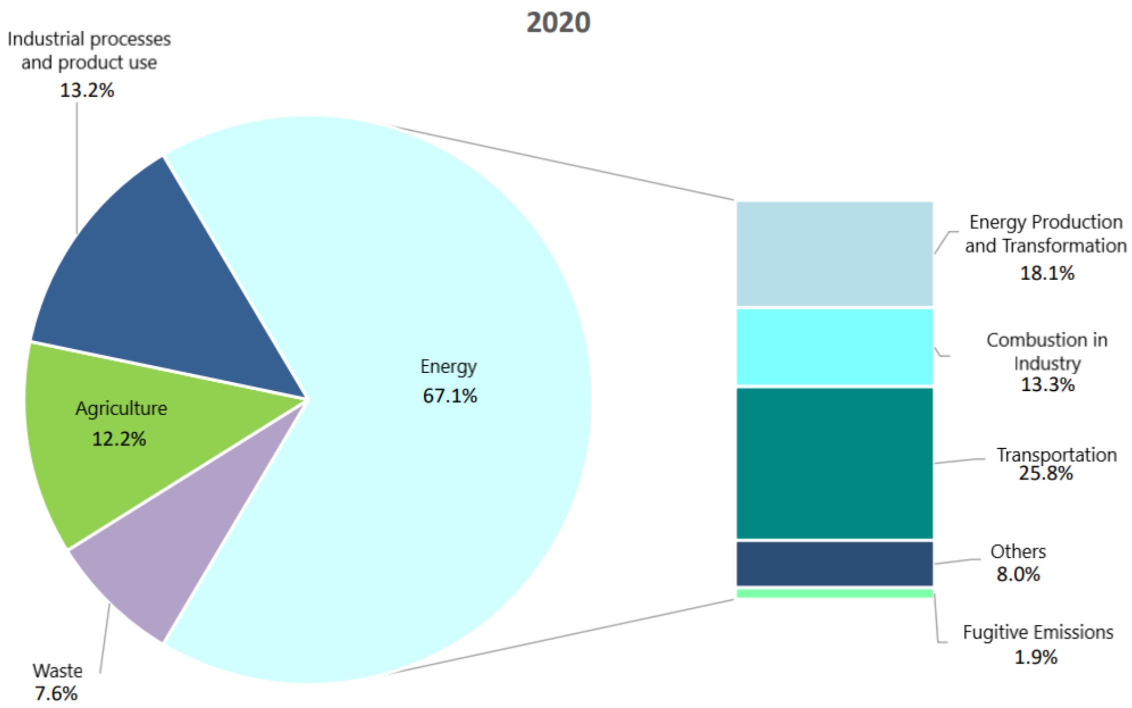

Fig. 7 – CO2 emissions by sector [36]**in 2020** [36]

The electrification of transportation, when considering the implementation of an economically and politically viable charging network is widely regarded as a viable strategy to reduce oil dependency as well as the environmental impacts of road transport. This sector can embrace the help of the energy sector when provided by renewable sources.

3.2. EV Market

The electric vehicle market has been rapidly growing over the past few years, with technological advancements leading to lower purchase prices and higher ranges. This innovation has attracted a larger customer base, with consumers not only interested in technological advancements but also in protecting the environment. The increasing sales of EVs have been a recognition of the economic and environmental advantages that these vehicles offer. In 2020, nearly 8000 EVs were sold in Portugal, and this number increased to 14000 in 2021, representing a significant growth in sales. However, the sales of EVs in 2022 have shown an even more impressive performance, with almost 40000 vehicles sold [37].

This exponential increase in sales can be attributed to several factors. Firstly, there has been an increasing awareness of the impact of climate change, with more people looking for ways to reduce their carbon footprint. Additionally, governments and regulatory bodies have been implementing policies to incentivize the purchase of electric vehicles, such as tax breaks and subsidies. Furthermore, the range and performance of EVs have improved significantly in recent years, which has alleviated concerns over range anxiety and made EVs a more viable option for consumers. All these factors combined have contributed to the significant growth of the EV market, and this trend is expected to continue as technology continues to improve and environmental awareness increases. Fig. 8 illustrates the impressive growth of the EV market in Portugal from 2020 to 2022.

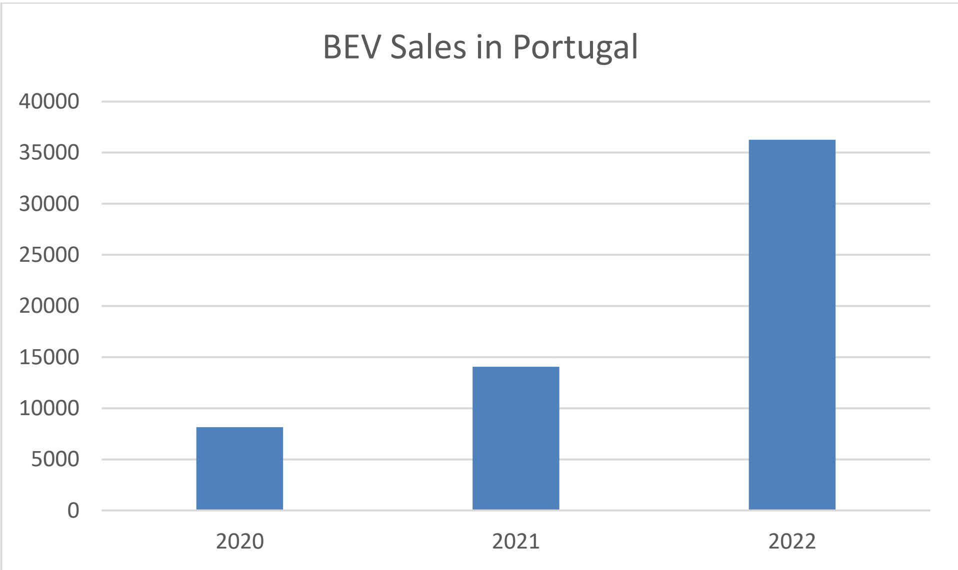

Fig. 8 – BEV Sales in Portugal from 2020 to 2022 [38]

The Portuguese market has witnessed significant growth in the electric vehicle sector with the availability of 101 electric vehicle models from 29 different brands. This remarkable growth can be attributed to policies implemented by the government that encourages companies to produce more electric vehicles and fewer internal combustion vehicles. This has resulted in the development of new models and improvements in existing ones. Furthermore, the increasing awareness and acceptance of electric vehicles in Europe have also contributed to the surge in the Portuguese market.

The development of the electric vehicle market in Portugal highlights the importance of government policies in promoting sustainable transportation. By incentivizing the production of electric vehicles, Portugal has been successful in attracting more models and brands, providing consumers with a wide range of options to choose from. As a result, electric vehicles are becoming more accessible to a larger portion of the population, and this trend is expected to continue in the coming years. The growth of the electric vehicle market in Portugal also reflects the broader shift towards cleaner and more sustainable transportation across Europe and the world [39].

Global sales of electric vehicles have been increasing, driven by the launch of new EV models and rising fuel prices. Government incentives for buyers have further stimulated demand, but EV supply remains limited, resulting in long lead times for delivery. Despite this, the growth of the EV market is significant as it marks a shift towards a more sustainable and environmentally friendly transport system.

Demand for EVs is driven by growing concern about the environmental impact of traditional gasoline vehicles, as well as the economic benefits of owning an EV, such as reduced fuel and maintenance costs. In addition, the launch of new EV models with longer ranges and lower purchase prices has made them more attractive to consumers. However, economic uncertainty around the world may impact new EV orders in the future.

The sales of electric vehicles have experienced substantial growth globally from 2020 to 2022. In 2020, there were 2.5 million electric vehicles sold worldwide, and this number increased to 6.5 million in 2021. However, the growth in sales is particularly remarkable in 2022, with a total of 10.5 million electric vehicles sold [40]. This surge in demand can be attributed to several factors, including the launch of several new electric vehicle models, rising fuel prices, and government incentives to encourage the adoption of more sustainable transportation alternatives.

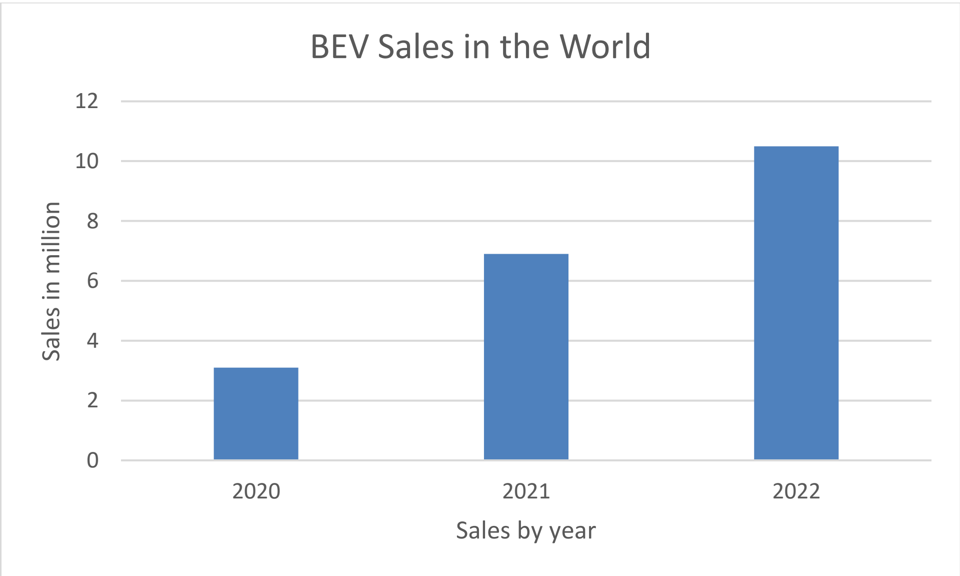

Fig. 9 - BEV Sales in the World from 2020 to 2022 [41]

Overall, the growth of the EV market highlights the importance of the transition to cleaner and more efficient transport systems, and the need for continued investment in EV infrastructure and technology.

Although electric vehicles provide several advantages, they also have limitations. The main factors to consider when buying an EV are the cost of purchasing them, the cost of electricity, the life cycle of the batteries, the range of the vehicle and the possible need to review the home electrical installation and contracted power.

There are many varieties of electric vehicles more specifically:

- EV "Electric Vehicles" or BEV "Battery Electric Vehicles" – Cars powered entirely by electric motors.
- HEV "Hybrid Electric Vehicle" – Hybrid car that has both engine and an electric motor.
- PHEV "Plug-in Hybrid Electric Vehicle" – Hybrid car with an engine and electric motor and it can also be powered by a rechargeable battery pack.
- FCEV "Fuel Cell Electric Vehicle" – Hydrogen chemical reaction generates electricity to power the electric motors.

Although a variety of electric vehicles exist, only EVs or BEVs will be focused on in this study.

3.3. Environmental impacts of EVs

The transport sector is still responsible for a huge share of greenhouse gas emissions in Portugal. This transportation sector is predominant and essential to people's day-to-day activities. However, mentalities are being changed because people are starting to realize all the danger that is made by excessive emissions. This awareness made people recognize all efforts that electric vehicles can achieve and that is why they have been gaining more notoriety[42].

Even more remarkable is the high level of emissions in about 60% of the entire sector is represented by light-duty vehicles. Although the following **Fig. 10** represents the European Union in 2019, it is very similar to the Portuguese perspective today.

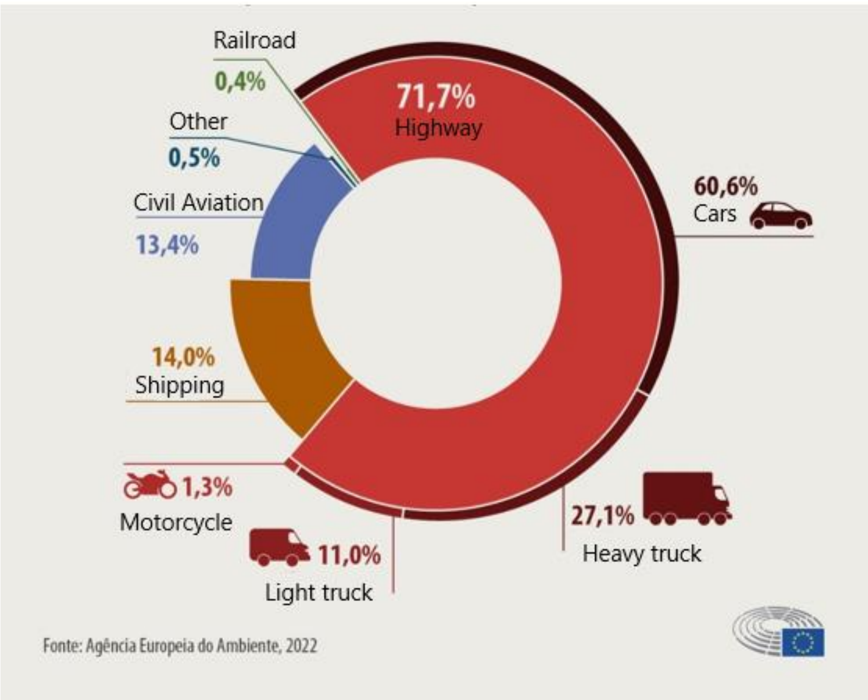

Fig. 10 - Distribution of CO_2 emissions in the EU by type of transport in 2019[43]

Electric vehicles are rapidly gaining popularity as a key solution for reducing emissions and improving energy efficiency. Although these vehicles do not produce greenhouse gases during operation, their production has a significant environmental impact, particularly in the manufacture of batteries. However, there are methods to mitigate these impacts, such as sustainable sourcing of materials and the use of renewable energy in the manufacturing process.

It is fundamental to highlight that the environmental benefits of electric vehicles are only fully realized when their lifetime emissions are considered in comparison to those of internal combustion vehicles. It is also essential to recognize that emission levels depend on the generation mix of the country where the vehicle is receiving its charge. It is therefore essential to compare the lifecycle emissions of different types of EVs and consider the impact of the energy sources used to recharge them [44].

According to [42], electric vehicles have the potential to significantly reduce CO_2 emissions when compared to petrol cars. In the best-case scenario, an electric car with a battery produced in Sweden and driven in Sweden can emit up to 83% less CO_2 than petrol cars. However, the emissions during the production of batteries are still high, and there are methods to reduce emissions during production, such as using renewable energy sources. It is important to note that the lifecycle emissions of electric vehicles are dependent on the generation mix of the country where it is being charged.

Hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) have much higher lifecycle emissions than battery electric vehicles (BEVs). HEVs only achieve a 21% reduction in lifecycle emissions compared to an equivalent petrol car, while PHEV improvements are limited to 26%. Additionally, if a hybrid electric vehicle is powered by a blend of e-fuels and petrol, it would only reduce its lifecycle emissions by 5% compared to powering the same vehicle with petrol[45].

The study also predicts that electric cars bought in 2030 will reduce CO_2 emissions four-fold thanks to an EU grid relying more and more on renewables. Even with hypothetical scenarios of hybrid electric vehicles powered by pure renewable e-fuel, the cleanest battery electric vehicle would still be 27% cleaner than the pure e-fuel hybrid, mainly due to the low efficiency of the e-fuel production process[46]. Overall, it is clear that electric vehicles have the potential to significantly reduce emissions, but there is still room for improvement in terms of reducing emissions during production and increasing the use of renewable energy sources.

In addition to the above conclusions, a visual comparison can also help to understand the environmental impact of different types of vehicles. Fig. 11 shows a comparison of the CO_2 emissions of an average battery electric vehicle (BEV) and a diesel car, assuming driving in Portugal. As can be seen, the BEV emits significantly less CO_2, about 70% less, compared to the diesel car. This highlights the potential of electric vehicles to reduce greenhouse gas emissions and contribute to the fight against climate change[47].

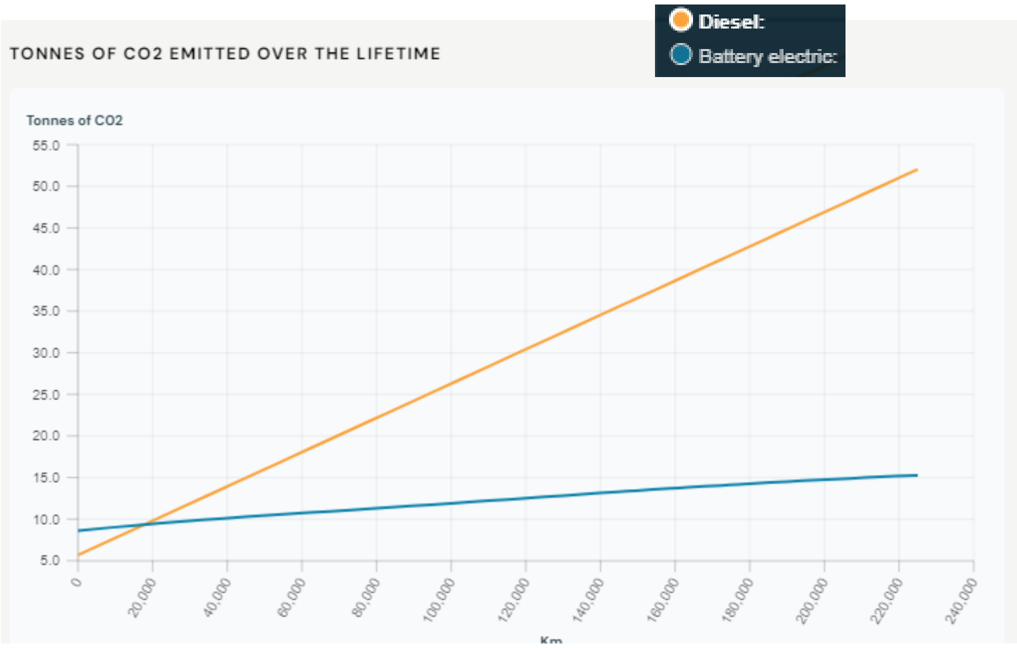

Fig. 11 – Tonnes of CO2 emitted over the life time[48]

3.4. Electrification of the sector

Necessity never really droves the interest in the electrification of the automotive sector. Electric vehicles have existed since the late nineteenth century. However, there was never a great interest nor was the present technology really developed for reliable and lasting use. Additionally, the low cost of oil has proven to be a determining factor in the lack of adoption of the electric market in the automotive sector. Currently, there are factors that value and allow the growth of electrics in the automotive sector such as the increase in the price of oil and the strong mission of energy transition mainly by the European Union.

The electric vehicle has a key role in this transition with a more sustainable purpose. Currently, the Portuguese market is increasingly receptive to electric vehicles because it has progressively improved their performance, autonomy and efficiency[49].

To sustain a change in mentality and vehicles it is necessary to install a network in the country capable of accommodating such needs. There are alternatives to achieve complete penetration such as the massive deployment of electric vehicles in the transportation sector. It will only be possible with the help of legislators taking necessary decisions and actions. Governments should encourage this through tax rebates primarily. It will also be important to support projects that demonstrate advantages in electrification such as modernizing the grid, adapting legislation to the physical need, or creating more charging stations.

Portugal's commitment to the adoption of electric vehicles may result in a slightly lower increase in electric generation capacity compared to the European average of 75%. However, estimates suggest that the Portuguese electricity system still needs a high increase in capacity by 2050 to support the electrification of the automotive, buildings and industrial sectors. This is in line with the European average, but the fact that Portugal is already committed to this transition may explain why the required increase is slightly lower [50].

It is noted the enormous growth in charging stations not only in Europe but also in Portugal, counting 4528 charging stations domestically. As can be seen in Fig. 12, the supply network is increasingly efficient, making travel progressively easier. This national network is more concentrated in the big cities, making the interior of the country more vulnerable in terms of charging[51].

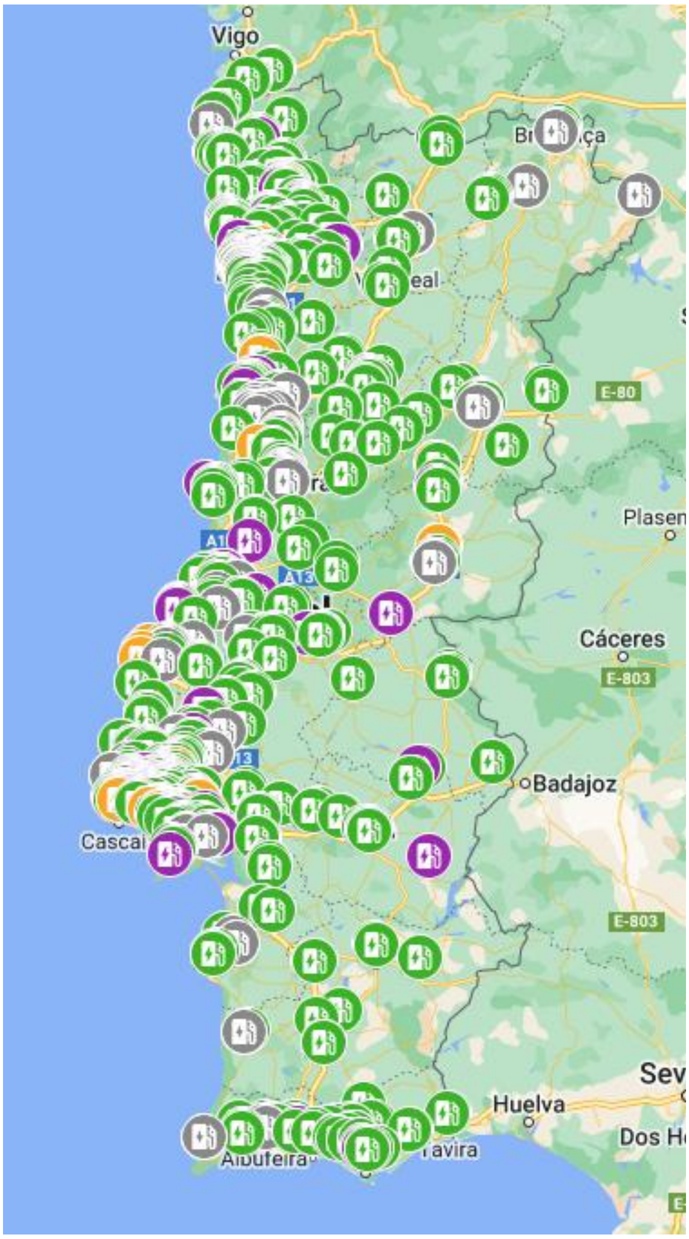

Fig. 12 -Electric charging station in Portugal [52]

The widespread implementation of electric vehicle charging stations in Portugal is a complex process involving several barriers. One of the main barriers is the impact on low and medium voltage infrastructure due to the large-scale implementation of chargers in public places and the mandatory installation of charging stations in residences. This will require laws requiring the implementation of charging stations and preparing the entire electrical installation to accommodate all the power needed, especially in residential buildings that are going to be built.

In addition to infrastructural challenges, the availability of adequate parking spaces is another critical barrier to the implementation of electric vehicle charging stations. Many buildings, especially in urban areas, do not have adequate parking spaces for charging stations. This presents a challenge for multi-dwelling units, where installing charging stations for each individual dwelling may be difficult or expensive. In addition, public parking areas such as shopping centers and airports may not be equipped with charging stations, limiting the ability of electric vehicle owners to charge their vehicles when away from home.

Another significant obstacle is the cost of installing charging stations. The installation of charging stations can be costly, especially in older buildings that require upgrades to existing electrical systems. The cost of high-power charging stations can also be a deterrent to widespread adoption of electric vehicles, especially for individuals or businesses with limited financial resources.

Finally, upgrading existing infrastructure to accommodate the growing demand for electricity is a significant obstacle. Electricity demand from electric vehicles may require upgrades to existing electrical systems and distribution networks. This can be particularly challenging in areas with aging infrastructure, where upgrades can be costly or difficult to implement. The installation of high-power charging stations may also require significant upgrades to the electrical infrastructure to ensure that sufficient power is available to meet charging demand.

To overcome these barriers, stakeholders in the automotive and energy sectors need to collaborate and develop strategies that address the challenges of installing electric vehicle charging stations. Addressing these barriers will be critical to the success of the transition to electric vehicles in Portugal and will pave the way for a sustainable future.

4. ECONOMIC EVALUATION OF TRANSPORT ELECTRIFICATION

The adoption of electric vehicles poses a challenge for potential buyers due to the costs associated with switching the entire facility to charge the vehicle, both the grid as well as private installations. This cost, along with other factors such as the limited range of some electric vehicles, can discourage many people from switching to electric cars. However, governments and car manufacturers are taking steps to reduce barriers to adoption, such as offering incentives to install charging stations and improving battery technology to increase range. As the cost of electric vehicles and associated infrastructure continue to decrease, it is likely that more people will be encouraged to make the switch to sustainable transportation.

The following presupposes and quantification of costs will discuss recent new vehicles in order to make a simple and explicit comparison. Will the costs all add up to make the purchase of an electric vehicle worthwhile? The costs can extend to purchase costs, maintenance, fuel, lifetime, re-design of electrical installations, and other important costs in a decision. There are also related issues such as legislation that needs to be reformulated to encourage the acceptance of the electric vehicle market.

4.1. Purchase price and tax incentives

The acquisition cost can often be a decisive factor in the adoption of an electric vehicle. Electric vehicles currently cost on average 5,000 to 10,000 € more than an internal combustion vehicle[53]. One of the main reasons for this is the price of the batteries. Nevertheless, the price of a battery, which is a significant value in the value of the vehicle, has been decreasing its cost. The European Federation for Transport and Environment through recent studies has found that electric cars will be cheaper to buy than internal combustion vehicles [47].

The price difference has been decreasing over time. In 2010, the cost of the battery was significant at around €600 per kWh. By 2015 it had already been halved and in 2021 the price was around €100 per kWh [53].

Although the Portuguese incentive is not the same as the German one, this value can reach 4000€, which is already a considerable amount of savings to encourage the purchase of these electric vehicles[54]. It is also important to mention that there are and will continue to be incentives for the purchase of this type of vehicle, mainly 100% electric. There are also tax incentives, such as, for example, the exemption from payment of ISV and IUC for 100% electric vehicles [55].

It can be concluded that the acquisition prices of electric vehicles are getting lower and lower, which can translate into an advantage or match in relation to internal combustion vehicle prices.

4.2. Charging Infrastructure for EVs

The electricity infrastructure in Portugal requires improvements in terms of generation, transmission and distribution for several reasons. First, the growing demand for electricity due to the increased use of electric vehicles, buildings and industry requires an expansion of generation capacity. Second, aging infrastructure, particularly in distribution and transmission systems, requires modernization to improve efficiency and reliability. Finally, the integration of renewable energy sources, such as wind and solar, into the grid requires infrastructure upgrades to ensure a stable and secure supply of electricity. In addition, the shift to renewables in the Portuguese generation market, including the phasing out of coal-fired generation and generation from fossil fuels, increases the urgency of upgrading infrastructure to support the transition to a more sustainable energy system.

Additionally, generation will be a crucial factor in this transition, and renewable sources such as solar, wind and hydro must increasingly contribute to the system. Transmission and distribution must also be strengthened to support the increased power needed for charging stations and the daily charging of electric vehicles. This involves upgrading the weakest points of the grid and replacing outdated or inadequate equipment. On the other hand, the relevant legislation must be evaluated and updated to ensure that the infrastructure meets the necessary standards.[53][54].

To own an electric vehicle in Portugal, the driver should install a home charging station to achieve faster charging times compared to the standard Portuguese socket. This installation typically involves a charging power ranging from 3.7 kW to 7.4 kW, with an average charging time between 2.5 to 4.5 hours, significantly less than the 8 hours required by a conventional socket [56]. These charging stations, also known as wall-boxes, come with a price tag of approximately 900€ to 1400€, not including the costs associated with installation and any necessary changes to the electrical system. Moreover, in addition to the costs of the wall-box, there is also a need for increased network capacity, which comes with its own associated costs, as well as a higher contracted power for the consumer [57].

Electric vehicles (EVs) are rapidly emerging as a viable technological solution to decarbonize the passenger and heavy-duty transport sectors. Despite historical challenges and barriers, EVs are gaining momentum globally, albeit with a relatively small market share. The resurgence of EVs can be attributed to factors such as the rising costs of fossil fuels, growing concerns about climate change, and advancements in electric battery and motor technologies. These vehicles operate based on the fundamental principle of current flow, which generates magnetism to propel a rotor. EVs comprise essential components, including battery storage, inverters for converting DC to AC, AC electric induction motors, and energy recovery systems.

Charging EVs requires access to external power sources, and there are four distinct charging modes available. Mode 1 involves using a regular household socket and is suitable for smaller, low-power vehicles. Mode 2 utilizes a dedicated charging cable with a control system for efficient and protected charging. Mode 3 utilizes charging stations (Wall-boxes) and provides semi-rapid charging, striking a balance between speed and cost. Mode 4, with its high charging power, enables fast charging but requires specialized equipment and is not recommended for daily use due to potential battery integrity concerns. The understanding of EV technology and charging modes is crucial for optimizing their adoption and addressing the associated challenges. This information can be found in more detail in annex A.

4.3. Fuel and energy consumption

It has already been proven that electric vehicles are one step ahead in terms of fuel costs. But to prove such evidence will be shown values that corroborate this statement in Tabel 2.

An EV Volkswagen e-Golf model consumes on average about 17.5 kWh per 100 km which translates to an average electricity price of 0.035€ per km [58]. In average terms, an average family vehicle travels a distance of 20000 km per year, which results in a consumption cost of 700 € and 1815 € for an electric vehicle and a diesel vehicle, respectively[58]. In other words, a diesel vehicle today can cost 1115 € more in fuel than an electric vehicle in a year. Charging an electric vehicle at outside charging stations can significantly increase the cost of charging, which would result in a smaller difference in fueling price compared to fueling a diesel vehicle. However, the charging price is still relatively high due to applied taxes and fees, which can affect the overall cost of ownership of an electric vehicle. For larger and heavier vehicles, the savings can be higher.

Tabel 2 – Prices of fuel according to DGEG fuel prices (January of 2023)[59]

Fuel	Average price (per liter/ per kWh)	Consumption /100km	Average price per 100km	Average price per year
Gasoline	1,65 €	5,5L/100km	9,07 €	1815€
Electric	0,20€ /kWh normal tariff 0,14€/kWh bi-hourly tariff	17,5 kWh/100km	3,5€ normal tariff 2,45€ bi-hourly tariff	700€ normal tariff 490€ bi-hourly tariff

In more practical terms an electric vehicle can differ greatly in the cost of charging depending on various methods and locations of charging. In this study, three different ways of charging will be compared, of which the least convenient is charging outside the residence because it is vulnerable to discovering the location vandalized or inoperable.

The three methods are:

- The 100% home charging. This type of user is common in a person who only uses the vehicle from home to work, work to home, and just that.

- The 80% charging at home and 20% charging outside the house. This type of charging is very common for a user who only uses the outdoor chargers as a last resort, making short trips and some long ones, but never going too far away from their residence area.

- And 50% charging at home and 50% charging outside the home. It is very common for a user with long trips away from home.

The charging behavior of electric vehicle users can be classified into three categories based on the amount of charging done at home and outside. Those who only use their vehicle for short trips and charge exclusively at home fall into the 100% at-home charging category. The second category, 80% charging at home and 20% charging outside the home, is for users who rely primarily on charging at home but may use public charging stations for occasional longer trips. The last category, 50% charging at home and 50% charging away from home, is for users who regularly make longer trips away from home.

Table 3 compares the savings from electric versus gasoline and diesel charging under different charging scenarios showing that the savings are significant, particularly when charging at home. Charging the electric vehicle exclusively at home can result in savings of up to 77% for gasoline and 73% for diesel, depending on the tariff plan. However, charging at public stations can be costly due to the high fees charged to provide the necessary power. It is therefore clear that charging at home is more economical and cost-effective for electric vehicle users.

Table 3 – Comparison of savings from an electric charge versus gasoline and diesel fuel in different situations[59]

Fuel	Petrol	Diesel
Charging 100% home	Normal tariff:77% Bi-hourly tariff:85%	Normal tariff:73% Bi-hourly tariff:82%
Charging 80% home and 20% public	Normal tariff:71% Bi-hourly tariff:77%	Normal tariff:64% Bi-hourly tariff:71%
Charging 50% home and 50% public	Normal tariff:60% Bi-hourly tariff:64%	Normal tariff:51% Bi-hourly tariff:55%

4.4. Car tax

Currently, there are several tax incentives for the purchase of electric vehicles. These incentives focus heavily on the taxes charged to the owner of the vehicles. The main taxes are on the purchase and the single circulation tax that is charged annually to the owners of the vehicles.

As mentioned before there is a great incentive to purchase this type of vehicle, since a buyer can save up to 4000€ in the purchase of an electric vehicle up to a maximum ceiling of the purchase cost of the vehicle of 62500€, but these incentives have a limit that after being exceeded new buyers will not have such benefit.

The single circulation tax (IUC) is calculated by factors such as engine type, engine size and CO_2 emissions. This is a policy to encourage people to buy electric vehicles by giving them an IUC exemption until 2030. Another incentive for change is the increase in taxes on internal combustion cars, larger and more polluting cars will pay more tax.

A great advantage in relation to internal combustion vehicles is this type of tax incentive with support for the purchase of new vehicles with a tax reduction of 4000€ and then the exemption of the single circulation tax at least until 2030[53].

4.5. Maintenance and servicing

Every vehicle that travels on public roads needs careful maintenance that allows the vehicle to travel on the road in acceptable safety conditions. Not only does this ensure the longevity of the vehicle, but it also allows the occupants to be protected in the event of an emergency. Maintenance is light for electric vehicles, unlike an internal combustion vehicle that requires changing engine oil, oil filters, and fuel filters, among others. Since an internal combustion vehicle is a vehicle with numerous moving parts, it will wear out more than an electric vehicle, so the cost of maintenance and repair will be higher.

A comparison was made at the Nürtingen Institute of Industry in Germany, where it was found that the repair costs of electric vehicles are about 30% less expensive than a vehicle with an internal combustion engine[60]. This is due to the fact that electric vehicles have fewer moving parts and simpler systems, resulting in fewer repairs and less maintenance needed over time. In addition, electric vehicles have regenerative braking systems, which reduce wear and tear on the brakes and prolong their lifespan. This makes owning an electric vehicle a more cost-effective option in the long run, despite the initial investment in purchasing the vehicle and installing a home charging station.

4.6. Conclusion of the total cost of ownership

The thesis aims to determine the feasibility of switching from internal combustion vehicles to electric vehicles. A comprehensive analysis of the necessary infrastructure for the electric car market was conducted, followed by a basic comparison mainly focused on economic factors across different regions. While government subsidies have been generous and continue to increase, they are set to end by 2030, providing an incentive to adopt electric vehicles before this deadline. Even without subsidies, the cost of some electric models is becoming increasingly competitive with internal combustion vehicles.

Table 4 shows the costs of purchasing and owning a gasoline-powered Golf versus an e-Golf for a period of 10 years. It is important to note that this sample period represents a realistic time frame for the average lifespan of a vehicle. The table demonstrates that while the initial purchase price of an e-Golf is significantly higher than that of a gasoline-powered Golf, the electric vehicle incurs lower recurring costs. Only after 10 years of ownership does the e-Golf really start to pay off in total costs such as acquisition and maintenance.

Table 4 – Cost Comparison of 10 years of use

Cost Factors		Golf 1.0 TSI 110hp Sportline Gasoline	e-Golf
One-off costs	Purchase price	27 831,20 €	40 500,00 €
	Charging infrastructure	0,00 €	1 100,00 €
	Subsidy/purchase premium	0,00 €	-4 000,00 €
Recurring costs (per year)	Consumption	18 150,00 €	7 000,00 €
	"IUC" Unique circulation tax	1 440,00 €	0,00 €
	Insurance	9 690,00 €	12 600,00 €
	Maintenance	7 440,00 €	5 220,00 €
Total costs		64551.20 €	62420,00 €

In this analysis, a gasoline-powered vehicle was compared with an electric vehicle in the context of the Portuguese market, using the Volkswagen Golf as a model for both versions. The Volkswagen Golf is a popular car that is available in both gasoline and electric versions.

Performance and Driving Experience:

The gasoline-powered Volkswagen Golf comes with different engine options, offering varying levels of power and performance. The entry-level Golf has a 1.0 TSI engine that delivers 110 hp, while the GTI version has a 2.0 TSI engine that produces 245 hp. Gasoline engines generally offer good acceleration and are suitable for drivers who enjoy an engaging driving experience.

On the other hand, the electric Volkswagen Golf has an electric motor that provides a maximum power output of 204 hp. Although it may not have the same rapid acceleration as the most powerful gasoline-powered Golf, the electric motor delivers instant torque, providing a smoother and more responsive driving experience. In addition, the electric Golf has a unique feature called "one-pedal driving," allowing the driver to accelerate and decelerate the car using only the accelerator pedal. When the driver takes their foot off the accelerator, the car automatically slows down, recovering energy to charge the battery.

Economy and Energy Efficiency:

The gasoline-powered Volkswagen Golf has an average fuel consumption of around 5.5 liters per 100 km, depending on the model and driving conditions. On the other hand, the electric Volkswagen Golf has an average energy consumption of around 17.5 kWh per 100 km, which translates to an average cost of around 2 euros to travel 100 km.

Based on the current gasoline prices in Portugal, which are around 1.65 euros per liter, and the average electricity prices, which are around 0.20 euros per kWh, it can be concluded that the electric Golf is significantly more economical in terms of energy costs.

Furthermore, the electric Golf is much more efficient in terms of CO_2 emissions. While the gasoline-powered Golf emits around 125 g/km of CO_2, the electric Golf emits zero exhaust emissions, making it a zero-emission vehicle. However, it's worth noting that the electricity used to power EVs is often generated from fossil fuel sources. This means that while the EVs themselves produce no emissions, the overall carbon footprint of an EV depends on the mix of electricity generation in the region where it is charged. In regions with a high proportion of renewable energy, such as wind or solar power, the carbon footprint of EVs is significantly lower than in regions where electricity generation is heavily dependent on fossil fuels.

Maintenance and Costs:

Generally, electric vehicles have fewer moving parts and are simpler to maintain than gasoline-powered vehicles. For example, the electric Golf does not have a starter motor, alternator, or complex transmission system, which means there are fewer things that can go wrong. Moreover, the cost of electricity is usually lower than the cost of gasoline, meaning that the electric Golf has a lower long-term usage cost. However, the initial cost of the electric Golf is significantly higher than the cost of the gasoline-powered Golf, which could be a barrier to adoption for some consumers.

In conclusion, the Volkswagen Golf is an excellent example of how gasoline-powered and electric vehicles compare in the Portuguese market. While gasoline-powered vehicles offer good performance and driving experience, electric vehicles are more economical, efficient, and require less maintenance in the long run. As electric vehicle technology continues to improve and become more affordable, it is likely that they will become more prevalent on the roads of Portugal in the future.

5. REPLACEMENT OF GAS SYSTEMS WITH ELECTRIC SYSTEMS IN BUILDINGS

As the world focuses more on reducing carbon emissions, there is a growing interest in the transition from traditional gas-based systems to electric systems in buildings. Replacing gas-based systems with electric systems has the potential to significantly reduce carbon emissions and help achieve decarbonization goals [62].

Electric systems, such as heat pumps and electric boilers, can provide efficient heating and hot water without producing direct emissions. This means that by transitioning to electric systems, buildings can reduce their carbon footprint and contribute to a cleaner, more sustainable environment. Another significant step toward reducing greenhouse gas emissions is the replacement of gas systems with electric systems in buildings. The use of gas in heating and hot water systems is a significant source of greenhouse gas emissions, and the transition to electric systems is a crucial step in reducing emissions. Replacing the use of gas in equipment such as stoves, boilers and water heaters systems with electric ones also has the added benefit of improving indoor air quality by eliminating fossil fuel combustion inside buildings. A study by the International Energy Agency concluded that replacing gas boilers with electric heat pumps could reduce $CO2$ emissions by up to 70% in some countries [61]. Additionally, the following chapters will analyze the replacement of gas systems with electric systems in buildings, evaluating the costs and benefits of such a transition.

However, there are also challenges associated with this transition. One major challenge is the initial cost of replacing existing gas systems with electric systems. This can be a significant investment for building owners and may require financial incentives or subsidies to make it economically feasible[62]. Another challenge is the need for a reliable and resilient electricity supply to power these electric systems. Additionally, there is a significant need for skilled labor to perform this installation upgrade, which could pose a challenge if there were to be a large-scale program of nationwide replacement. Moreover, ensuring a reliable and resilient electricity supply to power these electric systems remains a significant challenge. Investment in grid infrastructure and potential upgrades to transformers and local distribution systems are necessary to support the increased demand for electricity. However, these investments require significant resources, and it may take time to build the necessary infrastructure to support the transition.

Despite these challenges, there are potential solutions that can help ease the transition to electric systems in buildings. These include financial incentives, regulatory policies, and public education and awareness campaigns to promote the benefits of electric systems[63]. Overall, this chapter will explore the benefits and challenges of replacing gas systems with electric systems in buildings and highlight potential solutions to facilitate this transition.

5.1. Benefits of Replacing Gas Systems with Electric Systems

Replacing gas systems with electrical systems in buildings offers numerous benefits. Perhaps the most significant of these benefits is the reduction in carbon emissions. Gas-based heating systems are responsible for a significant amount of greenhouse gas emissions, which contribute to climate change. By replacing gas systems with electric systems, the carbon footprint can be significantly reduced and help mitigate the impacts of climate change [64].

In addition to reducing carbon emissions, replacing gas systems with electric systems can also improve indoor air quality. Gas heating systems produce indoor air pollutants such as carbon monoxide, nitrogen dioxide, and particulate matter, which can be harmful to human health. Electric heating systems, on the other hand, produce no indoor air pollutants and can help improve indoor air quality [65].

Another benefit of replacing gas systems with electric systems is reduced maintenance costs. Gas heating systems require regular maintenance, including annual safety checks and the replacement of parts such as pilot lights and thermocouples. Electric heating systems, on the other hand, have fewer moving parts and require less maintenance, leading to lower maintenance costs over time.

Finally, replacing gas systems with electric systems can increase energy efficiency. Electric heating systems are often more efficient than gas systems, since they do not lose heat through a chimney or flue. This increased efficiency can lead to lower energy bills and lower energy consumption.

In conclusion, the benefits of replacing gas systems with electric systems in buildings are numerous, including reduced carbon emissions, improved indoor air quality, reduced maintenance costs, and increased energy efficiency. However, there are also challenges to making such a transition, including the need for new infrastructure and the higher upfront costs of electric systems. With careful planning and implementation, however, the benefits of this transition can far outweigh the challenges [66].

5.2. Challenges of Replacing Gas Systems with Electric Systems

While replacing gas systems with electric systems can bring several benefits, it also presents significant challenges. One of the main obstacles to this transition is initial costs. Electric systems, such as heat pumps, can require a significant initial investment compared to traditional gas-based systems, which can deter building owners from making the switch.

Another challenge is the limited capacity of the electrical grid. As more buildings and infrastructure switch to electric systems, the demand for electricity will increase, putting a strain on grid capacity. Without adequate investment in upgrading the grid infrastructure, this could lead to power outages or system failures[67].

Compatibility with existing infrastructure is also a concern when it comes to replacing gas systems with electric systems. Many buildings are not designed to accommodate electrical systems, and retrofitting can be costly and disruptive. In addition, electrical systems may require larger equipment, such as heat pumps or electric boilers, which can take up more space and require more substantial electrical connections.

Dependence on the electricity supply is another challenge to consider. Electric systems rely on a constant supply of electricity from the grid. This reliance on the grid can lead to problems in the event of power outages, and building owners may need to invest in backup power sources or battery storage systems to ensure uninterrupted operation.

To overcome these challenges, building owners and policymakers must work together to create policies and incentives that support the transition to electric systems. This includes investing in modernizing the electricity grid infrastructure, providing financial support to building owners to make the switch, and promoting energy-efficient design and retrofit practices[68].

5.3. Potential Solutions for Replacing Gas Systems with Electric Systems

While there are challenges associated with replacing gas systems with electric systems in buildings, there are also potential solutions that can help overcome these challenges. This section will explore some of these potential solutions. One potential solution is to offer financial incentives and support for building owners who make the switch to electric systems. This could come in the form of tax credits, rebates, or low-interest loans. Such incentives like environmental funds can help offset the upfront costs of purchasing and installing new electrical systems and more efficient systems, which is often a major barrier for building owners [69].

Another potential solution is to expand the electric grid infrastructure to accommodate the increased demand for electricity in the buildings. This could involve upgrades to the existing grid, as well as the installation of new infrastructure in areas where demand is expected to be high. Such investments could help ensure that electric buildings have reliable access to the electricity they need. Investment in energy storage technologies is also a potential solution. Energy storage technologies can help address the issue of dependence on electricity supply by storing electricity during periods of low demand and making it available when demand is high. This can help smooth out fluctuations in electricity supply and demand, which is particularly important for buildings that rely on electricity for both heating and cooling [70].

Finally, the collaboration between building owners, energy providers, and policymakers is essential for the successful transition to electric systems. Building owners need to be willing to make the switch, energy providers need to be prepared to meet the increased demand for electricity, and policymakers need to create an enabling policy environment that supports the transition to electric systems. In conclusion, while there are challenges associated with replacing gas systems with electric systems in buildings, there are also potential solutions that can help overcome these challenges. By offering financial incentives and support, expanding the electric grid infrastructure, investing in energy storage technologies, and collaborating between building owners, energy providers, and policymakers, we can work towards a more sustainable and decarbonized future[71]

5.4. Benefits and Challenges of Replacing Gas Systems with Electric Systems

The benefits and challenges of replacing gas systems with electric systems have been discussed in the previous sections. In this section, we will explore some successful case studies of gas-to-electric system conversions in residential and commercial buildings in Portugal, as well as lessons learned and best practices.

In Portugal, the majority of buildings still rely on fossil fuels for heating and hot water. However, there are some examples of buildings that have successfully made the transition to electric systems. For instance, in Lisbon, a residential building installed electric boilers to replace gas boilers, resulting in a 50% reduction in CO_2 emissions and a significant reduction in energy costs [72]. In another case, a commercial building in Porto switched from gas to electric heating, resulting in a 65% reduction in CO_2 emissions and a 20% reduction in energy costs [73].

One of the main reasons for the success of these case studies is the high efficiency of electric boilers. Compared to gas boilers, electric boilers can convert up to 99% of the energy they use into heat, while gas boilers are typically only 90% efficient [74]. Additionally, electric boilers have a lower carbon footprint and zero risk of CO_2 leaks, making them a safer and more environmentally friendly option.

Another advantage of electric boilers is their compatibility with solar panels, allowing buildings to generate their own renewable energy and reduce their reliance on the grid. Furthermore, electric boilers require little maintenance and have a longer lifespan than gas boilers, resulting in lower maintenance costs over time as shown in Fig. 13.

While electric systems offer many advantages, there are some challenges to consider when making the switch. For instance, the upfront costs of installing electric systems can be higher than those of gas systems. Additionally, the dependence on electricity supply may be a concern in areas with limited grid capacity. However, with the expansion of the electric grid infrastructure and investment in energy storage technologies, these challenges can be overcome.

In conclusion, the case studies discussed in this section demonstrate that the transition from gas to electric systems is not only possible but also beneficial in terms of reducing carbon emissions and energy costs. While there are challenges to consider, the advantages of electric systems make them the best option for avoiding emissions in the long term.

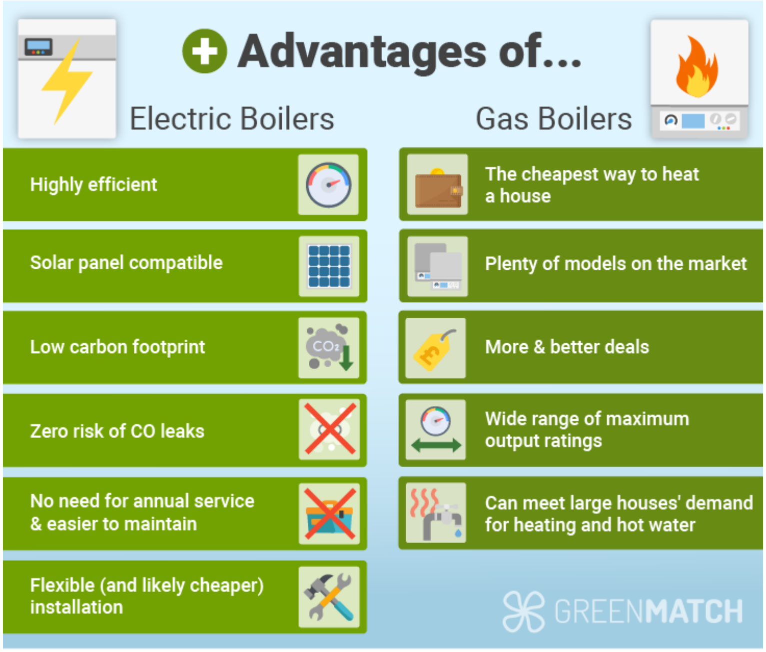

Fig. 13 – Electric boilers vs gas boilers comparison [75]

6. ECONOMIC EVALUATION OF HEATING ELECTRIFICATION

The electrification of residential heating systems is a crucial step towards a more efficient and sustainable energy system. To ensure a reduction of greenhouse gas emissions and prevent further global warming, the electrification of heating systems can become an ally to this cause, with important reductions in carbon footprint, due to the higher potential to incorporate renewable generation in electricity generation. However, the transition to such electric heating systems, for both sanitary water heating and cooking, involves a significant investment, and it is essential to analyze and evaluate the economic feasibility of such a change.

This chapter provides an economic evaluation of the electrification of residential heating, assessing the costs and benefits associated with the transition from traditional heating systems such as gas to electric. The assessment considers the different factors that affect the economics of heating electrification, including initial investment costs, operating costs, and maintenance expenses. In addition, the chapter explores the potential barriers to the adoption of electric heating systems and examines ways to overcome them.

The following sections begin by discussing the various factors that contribute to the cost of electrification, including the cost of equipment, installation, and ongoing maintenance. It then looks at the economic benefits of electrification, decreased maintenance costs, and potential financial incentives. Finally, the chapter will address the challenges and barriers to electrification, namely the availability and cost of electricity and the lack of infrastructure to support widespread nationwide adoption.

6.1. Electric and Gas Heating Systems

In Portugal, electric heating, such as water heaters or heat pump systems, and gas heating boilers are two of the most popular methods for providing heat to the newest homes. Both of these options have their advantages and disadvantages, but it is important to understand the real cost differences between them in order to make an informed decision. It is typically common to use rather inefficient electrical heating equipment, such as oil heaters or resistance heaters. However, for this study, this point of view will not be observed due to the fact that they are easy to replace as they are only used with a connection to a conventional socket. This section will compare the costs associated with electric heating systems and gas heating boilers in Portugal and provide a representation of the real values for comparison.

When comparing heat pump systems with gas heating boilers, there are several factors to consider, primarily their efficiency, initial purchase cost, maintenance costs, and direct impact on the environment. It is also important to consider equivalent equipment and an important factor to understand what BTU is. BTU (British Thermal Unit) is a measure of energy used to determine the heating or cooling capacity of a system.

It is also important to consider the Coefficient of Performance (COP), which is a measure of the efficiency of heating systems. It represents the ratio of the amount of heat produced by a system to the amount of energy consumed. A higher COP indicates a more efficient heating system. Gas boilers typically have a COP of around 0.9, which means that they can produce approximately 0.9 kW of heat for every kW of energy consumed [76]. In contrast, the COP of an electric heating system depends on the type of system being used. In this case, the heat pump has a COP of 4.62, while a traditional electric heater may have a COP of around 1.0 [77]. A heat pump uses a refrigerant to extract heat from the ambient air, which is then used to heat the water. This type of system is more efficient than traditional electric heaters, as it can produce more heat output per unit of energy consumed. However, the initial cost of installation can be higher than traditional electric heaters or gas boilers.

The average installation cost for a gas boiler can be approximately 267 € [78], while the cost of installing an electric heating system can cost on average 827€ [79].

The acquisition cost of electric heating pump systems is usually higher than a gas heating boiler. However, the initial acquisition cost of the boiler can vary significantly depending on the size of the building and the specific system chosen. The acquisition cost for a gas boiler can cost around 368€ [79] and an electric heat pump can cost about 2500 € [80]. This comparison is made considering an identical BTU value, where in both devices there is a capacity of 12000 BTU. Although the initial cost of electric heating systems is higher, they are more efficient than gas heating boilers as explained earlier[81].

According to the Department General of Energy and Geology (DGEG) the average price of electricity in Portugal is 0.22€/kWh, while the average cost of natural gas is 0.16€/kWh or an equivalent of 1.68€/m^3[82].

For a heat pump, an average annual consumption of 750 kWh can be expected for the pump under discussion. Considering the cost of electricity in Portugal the heat pump can cost 165€ per year[83]. Through a gas boiler, they can expect an annual consumption of about 3125 kWh and for the price in 2023, it will be on average 500€ per year [84].

For electric heating systems typically maintenance costs are generally lower, as it has fewer moving parts which in turn require less maintenance when compared to a gas boiler. A gas boiler can normally require annual maintenance that can cost around 70 € depending on how demanding the equipment is. On the other hand, electric heating systems only require periodic maintenance, considering a change of filters which may cost around 50 euros per year [85].

With environmental impact being a factor, electric heating systems are more environmentally friendly than gas-fired boilers, since they produce no direct greenhouse gas emissions during operation.

Another crucial factor to consider is the environmental impact in terms of carbon emissions. Although the cost of electricity is generally higher than gas in Portugal, it is important to evaluate the carbon footprint associated with each option. Gas heating contributes to carbon dioxide emissions, with an average emission rate of 0.186 $kg\ CO_2/kWh$ consumed[86]. On the other hand, electric heating pumps powered by the grid have an average emission rate of 0.175 $kgCO_2$/kWh [87].

To have a comparative perspective, considering the values calculated above: a gas heating consuming around 3125 per year, and an electric pump consuming 750 kWh per year. Assuming the average emission rate, the gas heating would result in 581 kg of CO_2emissions, while the electric pump would contribute 131 kg of CO_2 emissions annually[88].

Based on this estimate, it is clear that grid-powered electric pumps, especially when coupled with low-carbon electricity sources, can significantly reduce carbon emissions compared to gas heating. This highlights the potential environmental benefits of transitioning from gas to electric pumps, despite the higher energy costs associated with electricity. It is crucial to consider long-term sustainability and environmental impact along with economic factors when making informed decisions about heating systems.

Although electric heating pump systems have a higher initial cost, they can provide significant savings in energy costs compared to gas heating boilers. This shifting from gas to electric systems is only economically feasible if the government begins to provide tax incentives and if the price of electricity becomes more competitive through renewable sources. The price of gas has also been very volatile which can be a favorable factor for the adoption of electric systems.

The Portuguese government's Environmental Fund offers a financial incentive to households seeking to install heat pump systems. This incentive is currently set at a maximum of €2,500 if the price is higher than 2500 €. If the price is lower, the incentive is 80% of the price and is available to homeowners who wish to replace their current heating system with a heat pump. This incentive aims to encourage families to switch to more sustainable and efficient heating options, reducing their carbon footprint and contributing to Portugal's efforts to combat climate change [89]. In this case, the incentive will be 2000€.

Tabel 5 – Cost comparison of 10 years of use

Cost factors	Gas Boiler	Heat Pump
Acquisition	368€	2500€
Installation cost	267€	827€
Consume per 10 years	10950€	1650€
Maintenance	700€	500€
Incentive	0	-2000€
Total cost	12285€	3477€

When considering the cost comparison between a gas boiler and a heat pump over a 10-year period, it becomes evident that the overall cost is higher for the gas boiler. Taking into account factors such as acquisition, installation, annual energy consumption, and maintenance, the total cost for a gas boiler amounts to 12285€, whereas for a heat pump, it reaches 3477€. However, it is important to consider that the cost of the electrical infrastructure may need to be considered, particularly for older homes that may require upgrades to support high-energy consumption equipment.

It is important to acknowledge that these cost calculations are subject to variations based on factors such as local energy prices and the specific models of heating systems being compared. Additionally, while the initial investment for a heat pump is higher, it is important to consider the long-term benefits of its higher energy efficiency and lower environmental impact. Moreover, in cases where the price of gas exhibits volatility or experiences an unusual increase, the advantages of replacing a gas boiler with a heat pump become more compelling.

Ultimately, the decision to switch from a gas boiler to a heat pump should consider not only the financial implications but also the potential environmental benefits and the specific circumstances of the household. Conducting a comprehensive evaluation that accounts for factors beyond the scope of this table, including electrical infrastructure requirements and potential government incentives, can provide a more accurate assessment of the cost-effectiveness and suitability of each heating system option.

6.2. Electric and Gas Cooking Systems

In Portugal, gas cooking systems are the most common type of equipment used in households. Both types, gas and electric cooking have their own advantages and disadvantages, and it is important to evaluate them in order to determine which is the most cost-effective and efficient. This section will provide a comprehensive evaluation of the cost comparison between electric and gas cooking systems in Portugal.

When it comes to cooking, gas stoves have long been the preferred choice in Portugal. Gas stoves have the advantage of heating up quickly, and they allow for more precise temperature control. However, electric stoves are gaining in popularity, as they are easier to clean, have a more modern appearance, and do not emit harmful gases.

The cost comparison between electric and gas cooking systems is a complex issue that involves several factors. The first factor to consider is the initial purchase price. In general, electric stoves are more expensive to purchase than gas stoves. However, the price difference may not be significant, and the overall cost of the stove may be offset by other factors.

Another crucial factor to consider is the energy consumption of electric and gas stoves. In Portugal, the cost of electricity is usually higher than that of gas, which can lead to the perception that electric stoves are more expensive in the long run. However, it is important to note that electric stoves are generally more energy efficient than gas stoves, resulting in lower overall energy consumption. Despite higher energy prices, the energy efficiency of electric cooktops can help offset the increased cost, making them a more cost-effective option in the long run. This fact highlights the importance of considering not only the initial cost and energy prices, but also the energy efficiency of the appliances when making a comprehensive evaluation.

The maintenance costs of the two systems should also be considered. Electric stoves require less maintenance than gas stoves, as they have fewer moving parts. Gas stoves require regular cleaning and maintenance of the burners, which can be costly over time.

The environmental impact of the two systems should also be taken into account. Electric stoves do not emit harmful gases during operation, while gas stoves release carbon monoxide and other pollutants into the air. These gases are responsible for almost 10,000 cases of asthma among children in Portugal [90]. Therefore, electric stoves are generally considered to be more environmentally friendly than gas stoves.

When comparing the cost of acquisition, a gas stove is relatively more affordable, with a price of 155€ [90]. However, it is important to consider the monthly consumption and electricity price of induction stoves. For the same output power (7 kW) for an induction stove it can cost around 380€, the initial cost of an induction stove is higher. Despite the higher initial cost, other factors such as energy efficiency, installation, consumption and long-term savings should be considered [91], [92].

Regarding installation costs, a gas stove requires an investment of 221€, while installing an induction stove cost on average 266 €. This means that the installation cost of the induction stove is slightly higher. However, it is important to note that both types of cooktops may require professional installation to ensure proper operation and safety [93], [94].

In the case of gas stoves, the annual consumption can be estimated at 876 kWh, assuming a gas price of 0.16€/kWh [95] with an average monthly usage of 30 hours, the approximate cost is 140€ per year [96][97]. On the other hand, an induction hob, with an average monthly use of 30 hours and average power of 1 kW, consumes about 360 kWh per year, with an electricity price of 0.22€/kWh resulting in an annual cost of about 80€. This significant difference in energy consumption and cost demonstrates the greater efficiency of induction hobs, which can lead to long-term savings on energy bills[98].

Maintenance costs have been omitted from this comparison as they are generally insignificant for both gas stoves and induction stoves. These appliances often have a long lifespan and are built to withstand regular use without requiring frequent repairs or maintenance. While occasional maintenance might be necessary, the associated costs are typically minimal and do not significantly impact the overall cost comparison between the two technologies within one year of use. It is worth noting that the longevity and durability of these appliances contribute to their value and make them reliable choices for households seeking long-term cooking solutions.

Table 6 – Cost comparison of 10 years of use

Cost factors	Gas Stove	Electric Stove
Acquisition	155€	380€
Installation cost	221€	266€
Consume of 10 years	1400€	800€
Maintenance	0€	0€
Government Funds	0	0€
Total cost	1776€	1446€

When all the cost factors, including acquisition, installation, consumption, maintenance, and government funds, are taken into account, the total cost of the electric stove over a 10-year period amounts to 1446€, while the total cost of the gas stove reaches 1776€. This indicates that the electric stove offers a more economical option for households in the long run.

Therefore, choosing an electric stove not only contributes to reducing carbon emissions but also proves to be a financially advantageous decision over an extended period of use. By considering the long-term cost savings and environmental benefits, households can make a sustainable and economically prudent choice by opting for an electric stove.

Another crucial factor to consider is the environmental impact in terms of carbon emissions. Although the cost of electricity is generally higher than gas in Portugal, it is important to evaluate the carbon footprint associated with each option. A gas stove contributes to carbon dioxide emissions, with an average emission rate of 0.186 $kg\ CO_2/kWh$ consumed [86]. On the other hand, electric stoves powered by the grid have an average emission rate of 0.175 $kg\ CO_2/kWh$ [87].

To have a comparative perspective, considering the values calculated above: a gas stove consuming around 876 kWh per year, and an electric stove consuming 360 kg of CO_2. Assuming the average emission rate, the gas stove would result in 162.92 kg of CO_2 emissions, while the electric stove would contribute 63 kg of CO_2 emissions annually [88].

The lower emissions associated with the electric stove can be attributed to the decreasing carbon intensity of electricity generation. As renewable energy sources, such as wind, solar, and hydroelectric power, continue to replace fossil fuel-based electricity generation, the carbon footprint of the electric stove further diminishes.

It is important to note that the emissions from electricity generation can vary depending on the energy mix of a particular region. However, the advantage of the electric stove lies in its potential for utilizing renewable energy sources. By supporting the transition to renewable energy and investing in clean electricity, households can significantly reduce their carbon emissions and contribute to a more sustainable future.

It is crucial to recognize that mitigating the environmental impact of cooking systems goes beyond merely evaluating economic factors. The shift towards electric stoves aligns with the broader goal of transitioning to a cleaner and more sustainable energy future. Governments, policymakers, and individuals must consider the long-term environmental implications when making choices about cooking appliances, and prioritize solutions that help combat climate change and preserve our planet for future generations.

The cost comparison between gas stoves and electric induction stoves clearly demonstrates the advantages of the latter, both from an economic and environmental standpoint. While gas stoves may have a lower initial acquisition cost, lower installation cost and significantly greater annual energy consumption make them less cost-effective in the long run. On the other hand, electric induction cooktops have a higher upfront price but offer substantial savings in energy consumption, resulting in lower annual operating costs. Moreover, induction stoves provide precise temperature control, rapid heat-up times, and easier cleaning compared to gas stoves.

From an environmental perspective, electric induction stoves are the preferred choice as they produce no direct emissions during operation. However, gas stoves release carbon monoxide and other pollutants, contributing to air pollution and potential health risks. Additionally, induction stoves are more energy-efficient, converting a higher percentage of the supplied electricity into usable heat. An induction hob heats the cookware and food more efficiently because it heats the cookware directly. Consumer Reports found that induction hobs can boil water 20-40% faster than gas hobs tested [99]. This efficiency helps reduce overall energy consumption and reliance on fossil fuels.

In conclusion, the comprehensive cost comparison favors electric induction stoves over gas stoves. Their higher initial investment is offset by significant savings in energy costs, making them a more viable option over time. Additionally, their superior environmental performance, precise cooking capabilities, and ease of cleaning further solidify induction stoves as the better choice for households seeking efficient, environmentally friendly, and cost-effective cooking solutions.

7. CONCLUSIONS

7.1. Conclusions

This thesis has explored the multifaceted options of sustainable transitions, aiming to address the pressing need for reducing greenhouse gas emissions and mitigating the effects of climate change. By focusing on three pivotal areas: the replacement of internal combustion vehicles with electric vehicles (EVs), the substitution of gas water heaters with heat pumps, and the shift from gas stoves to electric induction cooktops, the objective was to explore alternative pathways toward a low-carbon future. Throughout this research, the primary objective has been to shed light on the potential environmental and economic benefits that arise from embracing cleaner technologies and practices, ultimately fostering a more sustainable and resilient society.

The transition from internal combustion vehicles to EVs has been identified as a crucial step toward reducing greenhouse gas emissions and combating climate change. Through advancements in battery technology and increased charging infrastructure, EVs offer a promising solution for achieving a more sustainable transportation sector. While challenges such as limited driving range and higher upfront costs have posed barriers in the past, ongoing developments and government incentives are making EVs increasingly viable and attractive to consumers.

In a 10-year cost comparison between the gasoline model Volkswagen Golf 1.0 TSI 110hp Sportline and the electric e-Golf, the electric model currently has a higher purchase price, internal charging infrastructure installation and insurance costs than the gasoline model, but at the end of a 10 year period the e-Golf benefits from a lower consumption and maintenance cost and have as well a 4,000 Euro subsidy from the Portuguese government on the purchase of the electric vehicle. Despite the higher initial cost, the total cost of the e-Golf over 10 years is slightly lower 62,420€ than the gasoline model 64,551€. This means that it is only after a long 10-year period that the long-term economic and efficiency advantages of electric vehicles, supported by subsidies, lower recurring costs and tax breaks, begin to be revealed. As the technology of EVs advances and becomes more affordable, they are expected to gain popularity in the Portuguese market, offering environmental benefits and cost savings to consumers.

The substitution of gas water heaters with heat pumps represents another significant opportunity for energy efficiency and emissions reduction. Heat pumps utilize energy that can be produced by renewable sources and can provide efficient heating and cooling solutions for residential and commercial buildings. By reducing the reliance on fossil fuels and maximizing the use of renewable energy, heat pumps contribute to a more sustainable and environmentally friendly approach to water heating. The economic analysis carried out clarifies the differences between electric heating systems, namely heat pumps, and gas heating boilers in Portugal. The comparison considered factors such as efficiency, initial purchase and installation costs, annual energy consumption, maintenance expenses and environmental impact. The results show that while gas heating boilers may have a lower initial purchase cost, the long-term cost savings associated with electric heat pumps make them a more cost-effective choice. Electric heat pumps, characterized by higher Coefficient of Performance (COP) values and lower maintenance costs, prove to be more energy efficient and environmentally friendly options. The cost comparison clearly indicates that over a 10-year period, the total cost of a gas boiler amounts to 12285€, while a heat pump costs significantly less at 3477€. These results highlight the potential financial benefits of transitioning from gas to electric heating systems. In addition, the availability of government incentives, such as the Environmental Fund financial incentive of up to 2500€ for heat pump installations, further supports the economic viability of electric heating systems. Although the initial investment of a heat pump may be higher, these incentives help to reduce the cost difference between the two systems. In addition, the potential to use low-carbon electricity sources and the reduced carbon emissions associated with electric heat pumps offer long-term sustainability benefits.

Similarly, the replacement of gas stoves with electric induction cooktops offers numerous benefits in terms of energy efficiency, precise temperature control, and reduced emissions. Induction cooktops utilize electromagnetic technology to heat cookware directly, resulting in faster heating times and minimal energy waste. While the initial cost of induction cooktops may be higher, their long-term benefits, including lower energy consumption and improved safety, make them an attractive option for eco-conscious households. When all the cost factors, including acquisition, installation, consumption, maintenance, and government funds, are taken into account, the total cost of the electric stove over a 10-year period amounts to 1446€, while the total cost of the gas stove reaches 1776€. This indicates that the electric stove offers a more cost-effective option for households in the long run. Throughout this study, it was evaluated the economic feasibility, energy efficiency, and environmental impact of these sustainable alternatives. It is important to note that the viability of each option may vary depending on individual circumstances, such as upfront costs, availability of infrastructure, and energy prices. Therefore, a comprehensive analysis should consider these factors when making decisions regarding the adoption of cleaner technologies.

In conclusion, the findings of this thesis highlight the importance of embracing sustainable alternatives in various aspects of daily life. While not all options may be immediately viable from an economic standpoint, it is essential to recognize the long-term benefits in terms of reduced carbon emissions, energy efficiency, and overall environmental sustainability. Government support through incentives and policies, along with technological advancements and increased public awareness, are crucial in facilitating the widespread adoption of these alternatives. By actively choosing and promoting sustainable practices, individuals and communities can contribute to mitigating climate change and safeguarding the planet for future generations. It is our collective responsibility to embrace cleaner technologies, support renewable energy sources, and make environmentally conscious choices in order to create a more sustainable and resilient future.

7.2. Future Work

In future research, a valuable direction to explore is the electrification of technologies in other sectors, such as the service and industrial sectors. Investigating the feasibility and benefits of transitioning from traditional gas-powered systems to electric alternatives in these sectors would provide insights into the potential for energy efficiency improvements and emissions reductions on a larger scale. Analyzing the economic viability, technological requirements, and environmental impacts of electrifying different technologies in these sectors would offer valuable information for decision-making and policy development aimed at achieving a more sustainable and low-carbon society.

By focusing on the electrification of technologies in service and industrial sectors, future research can provide valuable insights into the potential for reducing greenhouse gas emissions and achieving a sustainable energy transition beyond the residential sector. This line of investigation will contribute to a more comprehensive understanding of the challenges, opportunities, and strategies associated with electrification and will support the development of effective policies and practices for a sustainable and resilient future.

Furthermore, studying the integration of electric technologies with energy management systems in service and industrial settings can optimize energy use, demand-response strategies, and grid interactions. By exploring how electric systems can be integrated into smart grid infrastructures and adaptive energy management systems, research can contribute to improving energy efficiency, reducing peak demand, and enhancing the overall resilience and sustainability of these sectors.

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Annex A

1. THE ELECTRIFYING MOBILITY: COMPONENTS AND CHARGING MODES OF EV'S

Nowadays, EVs are seen as an extraordinary technological advance that is becoming viable day by day. This technological option aims at decarbonizing the passenger transport sector and in turn the heavy-duty sector as well. However, EVs have faced great historical challenges with several barriers. Although this type of vehicle has a growing trend, it is still a small representation in the world [100].

The life stories of EVs, this is a type of car with a few years of history. The first ones to be developed appeared at the end of the 19th century, and their main components, such as batteries and electric motors were experimental and underdeveloped. With the discovery of the diesel engine, its performance, and the low cost of a barrel of oil, EVs were pushed aside.

The high price of fossil fuels, climate change, and the high development of the processes and performance of electric batteries and motors brought about a new phase of electric investment in the automotive sector. These days it is also noticeable that the political effort to direct large automobile companies to follow an EV path has been noticed, with the vast majority of them forbidding the construction of new internal combustion vehicles [101].

The fundamental principle that drives EVs is the flow of current. This current creates magnetism in such a way that spins a rotor by opposing or repelling the magnetic poles. These cars are composed of the basic components:

- Battery storage in DC
- Invertor to change DC to AC
- AC Electric induction motor
- Energy recovery system

This electric current can reach the vehicle through Direct Current (DC) by a fast charger or Alternating Current (AC) charger [102]. After production, the current is sent through the electricity grid to the charging points as shown in **Erro! A origem da referência não foi encontrada.**. If the current arrives in DC it will be stored directly in the battery that only works in DC. If it is charged by AC it will be converted internally by an inverter and only then stored. At the time of operation, the AC induction motor requires the inverting DC to AC[103].

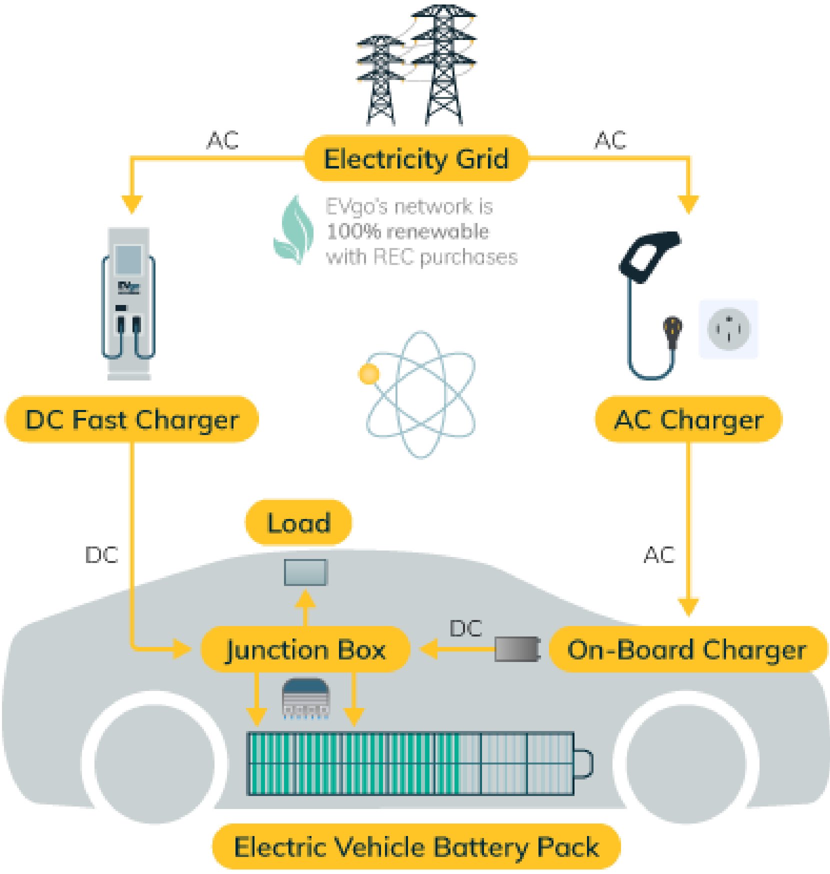

Fig. 14 – The journey of electrons[103]

Fig. 14shows all the components of an EV. First, the electricity is received by a charging port (1) on a charging station. The Battery Pack (2) is made up of hundreds or thousands of small lithium-ion cells and can be stored by DC, as well as powering its loads in DC. The inverter (3) serves the purpose of converting the DC electricity from the battery into AC electricity for the induction motor. The Electric Motor (4) through the passage of electrons produces a rotating magnetic field. The Drivetrain (5) only transmits the motor power to the vehicle's wheels. In newer models, it is also possible to regenerate the regenerated braking energy by Regenerative Braking (6)

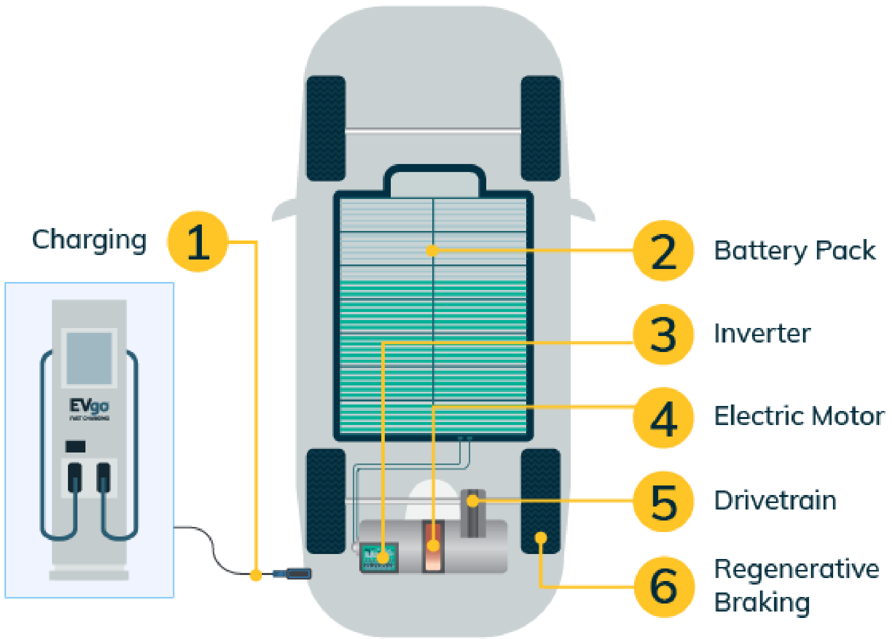

Fig. 15 – The componentes inside an EV[103]

Electricity is essential for an EV, it requires an external power source to charge the batteries inside the vehicle. It is therefore important to understand which is the most efficient way to use for charging. There are 4 different charging modes. The need for different purposes or cars drives the need for each charging mode [104].

Mode 1 is when a normal socket is used for charging an electric vehicle, usually a household socket (Schuko). Its simplicity is demonstrated in **Erro! A origem da referência não foi encontrada.**Fig. 15 since only a simple cable connection to the vehicle is required. This mode is advised for smaller vehicles of low power. It is not the ideal mode for a medium vehicle because it needs about 6-8h of charging and also requires adequate protection of the electrical installation avoiding overloads to the vehicle. This protection in Portugal is regulated by national legislation and the circuit breaker curve should be (C or D)[105].

Fig. 16 - Charging Mode 1[106]

Mode 2 is also considered slow charging like the previous one with a power of less than 3.7 kW. The vehicle is connected to the grid through a specific charging cable since it also has a control system attached that is capable of protecting the installation and the vehicle as shows in **Erro! A origem da referência não foi encontrada.**. This system communicates with the vehicle resulting in electric efficiency-oriented management.

Fig. 17 - Charging Mode 2[106]

Fig. 18show the Mode 3 that is oriented toward semi-rapid charging with the protection of the electrical installation and the vehicle. It requires a charging station usually called a Wall-box. It is powered by AC current like the previous modes and allows charging up to 7.4 kW with a duration of 3-4h. This type of charging is usually the most used because of its balance of speed and charging cost price.

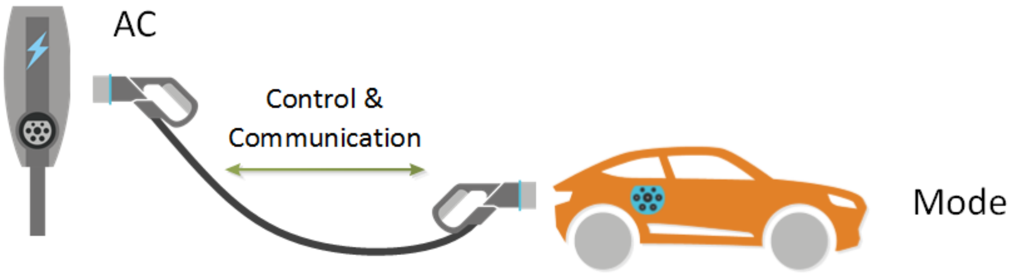

Fig. 18 - Charging Mode 3[106]

The main function of mode 4 is speed as it shows on **Erro! A origem da referência não foi encontrada.**. This mode is considered from 50 kW which results in 20-30min charging time. This mode requires more expensive installation equipment since it needs cables prepared for the DC voltage level. It has been studied that fast charging compromises the integrity of the battery in the long term, so it is not advisable to charge this type of charger every day.

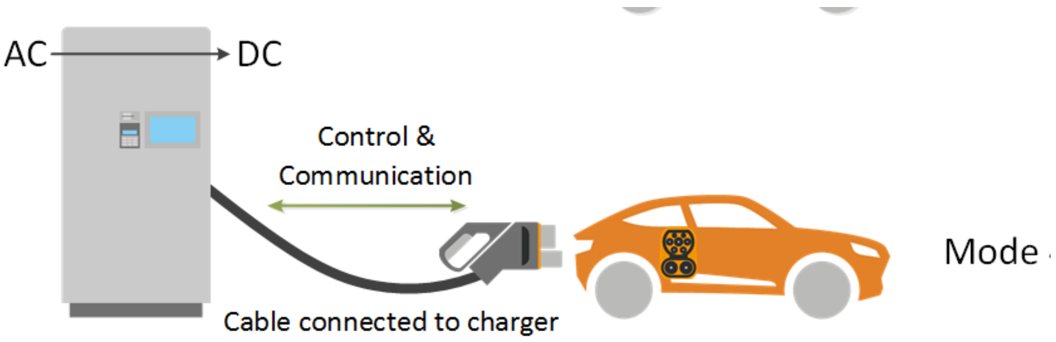

Fig. 19 - Charging Mode 4[106]