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Co-Benefits Estimation for Building Rehabilitation Strategies in Portugal

Maria Filipa Monteiro Leal da Costa

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Supervisor(s): Prof. Dr. Carlos Augusto Santos Silva
Prof. Dr. Ilídio Pereira Lopes

Examination Committee

Chairperson: Prof. Dr. Carlos Manuel Dos Santos Rodrigues da Cruz
Supervisor: Prof. Dr. Carlos Augusto Santos Silva
Members of the Committee: Prof. Dr. João Carlos Carvalho de Sá Seixas
Dr. Cláudia Azevedo de Sousa Monteiro

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"The secret of change is to focus all of your energy, not on fighting the old, but on building the new."

Socrates

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Resumo

Em Portugal, edifícios residências representam 17% do consumo de energia no país e um sexto das emissões de gases de efeito de estufa. Simultaneamente, Portugal encontra-se entre os cinco países Europeus com uma maior taxa de pobreza energética, com 19.4% da sua população sem possibilidades económicas para garantir o seu conforto térmico nas suas casas.

Em 2018, a Diretiva Europeia sobre a performance energética dos edifícios, EPBD, foi atualizada, indicando que os estados membros deveriam desenvolver a integração e reforço de estratégias de reabilitação a longo prazo, promovendo a luta contra a pobreza energética, a redução das necessidades de consumo energético, a melhoria da eficiência energética e o aumento do uso de energias de fontes renováveis.

Este estudo explora e estima o extensivo alcance de benefícios consequentes de três cenários de reabilitação com eficiência energética e avalia a sua viabilidade económica, tanto do ponto de vista de um investidor privado como do governo. Para isso, foca-se na região da Área Metropolitana de Lisboa (AML) e em edifícios construídos entre 1960 e 1990.

Foi concluído que, contrariamente ao investidor que pretende reabilitar a casa para arrendar, do ponto de vista do investidor privado que pretende reabilitar a casa para vender, é um investimento bastante apelativo. Quanto ao proprietário típico, que quer renovar a casa onde vive, é concluído que por si só o investimento não é viável. Contudo, se o governo intervir dando um subsídio, um cenário destaca-se mais vantajoso do que os outros dois.

Palavras-chave: Eficiência Energética; Edifícios Residenciais; Reabilitações; Conforto Térmico; Pobreza Energética.

Abstract

In Portugal, residential buildings represent 17% of the country's energy consumption and account for one-sixth of the GHG emissions. Simultaneously, Portugal is in the top five European countries with the highest fuel poverty rate, with 19.4% of the population not being able to afford thermal comfort in their homes.

In 2018, the Energy Performance in Buildings Directive, EPBD, was updated, leading member countries to develop the integration and reinforcement of long term rehabilitation strategies, promoting the fight against fuel poverty, the reduction of energy consumption needs, the improvement of energy efficiency and the increased usage of renewable energy sources.

This study aims to fully explore and estimate the extensive range of consequential benefits that arise from three energy-efficient rehabilitation scenarios and assess the economic viability, both from a private investor and a government perspective. For that, a focus was made on the AML region and buildings with the construction from 1960 to 1990.

It was concluded that, contrary to the investor who renovates to rent the house, from the point of view of a private investor who wants to renovate and sell the house, it is a very attractive investment. On the other hand, as for the typical owner, who wants to renovate the home where he/she lives, it is concluded that the investment is not viable just by itself. However, if the government steps in and gives a subsidy, one scenario arises to be advantageous compared to the others.

Keywords: Energy-efficient; Residential buildings; Rehabilitation; Thermal Comfort; Fuel poverty.

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Acronyms & Symbols

ADENE	Agência para a Energia
AML	Area Metropolitana de Lisboa
AQS	AquaSmart
BCR	Benefit-Cost Ratio
CAGR	Compound Annual Growth Rate
CB	Cost-Benefit
COP	Coefficient of Performance
COPD	Chronic Obstructive Pulmonary Disease
DCF	Discounted Cash Flow
DGEG	Direção-Geral de Energia e Geologia
EAACEC	Estonian Association of Architectural and Consulting Engineering Companies
EAC	Equivalent Annual Cost
EBITDA	Earnings Before Interest, Tax, Depreciation and Amortisation
EPBD	Energy Performance in Buildings Directive
EPC	European Performance Certificate
EPS	Expanded Polystyrene
EU	European Union
EWD	Excess Winter Deaths
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IAQ	Indoor Air Quality
IMI	Property Tax
INE	Instituto Nacional de Estatística
IRC	Corporate Tax
IRR	Internal Rate of Return
IST	Instituto Superior Técnico
IVA	Value Added Tax

MIRR Modified Internal Rate of Return
NPV Net Present Value
PI Private Investor
PV Present Value
SBS Sick Building Syndrome
SNS Serviço Nacional de Saúde
UK United Kingdom
WHO World Health Organisation
WTP Willingness to Pay

Chapter 1

Introduction

1.1 Topic Overview - Contextualisation

1.1.1 Energy & Buildings

In a world that never stops, energy is a basic need for humanity's survival and evolution. Naturally, as the world progresses, the demand for energy increases. One of the main challenges today is to make this growth sustainable for the economy, environment and society.

The rapidly increasing demand for energy worldwide has raised concerns over the potential lack of supply, negative environmental impacts, and energy resources depletion [1]. Residential buildings account for around 25% of the total energy in the EU in 2015 [2, 3]. The upward trend in energy demand is likely to continue in the future. Some drivers are population growth, the increasing demand for thermal comfort and other building services, and the increasing time spent inside buildings [1]. For these reasons, energy-efficiency in buildings is a high priority topic for energy policy at regional, national and international levels [1].

Society and governments are increasingly shifting away from the concept that a good life is mainly connected to material goods and focuses on a broader concept of well-being, including healthy environments that promote residents' health, increase workplace productivity, and enhancement of natural environments. This paves the way for a healthier and more sustainable lifestyle, with public policy being an essential factor for this goal [4]. Inside the field of indoor environmental research, the home environment is a key topic, given that people in industrialised countries spend around 65% of their time in their homes [5].

Globally, buildings represent 40% of the world's energy consumption, more than in any other sector (see 1.1) [2], and account for one-third of the global greenhouse gas (GHG) emissions [6].

The residential buildings' share of total energy consumption in Portugal is lower than the EU's share, representing 17% of the country's total energy consumption, which is nevertheless a very relevant share [7]. When looking at Greenhouse Gas (GHG) emissions, it is also possible to conclude that residential buildings account for a meaningful proportion of developed countries' emissions, representing around one-sixth of GHG emissions [8]. Therefore, increasing energy efficiency in residential buildings can have a meaningful impact on reaching a sustainable future, with less energy consumption and less GHG emissions [9].

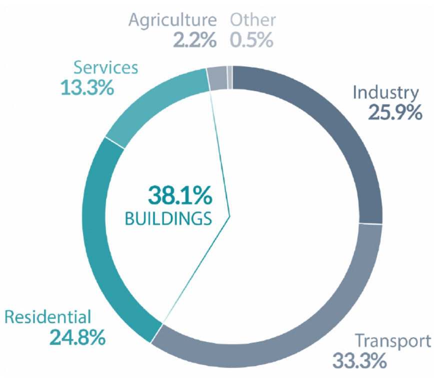


Figure 1.1: Energy consumption by sector in the EU-28 in 2014. Data source: Eurostat, 2014. [2]

Space heating represented around 65% of the energy consumption in residential buildings in the EU in 2015, while electricity for electrical appliances and lighting accounted for around 16%, water heating around 14%, and cooking around 5% [3]. When looking at Portugal individually, the results are quite different. According to an ADENE report in 2017, 44% of energy consumption in residential buildings was consumed by household appliances, 33% for lighting, 11% for water heating and 12% for space heating and cooling [10]. It is also relevant to mention that electricity represented 51% of monthly house expenses [10].

In 2016, Portugal was the 4th country with the highest electricity cost for medium-sized households across the European Union [11]. Simultaneously, a Lisbon survey showed that most of the inquired have to choose between keeping thermal comfort in their houses, paying rent, buying food and medicine, often opting to neglect thermal comfort [11].

1.1.2 Fuel Poverty

A Study [12] performed a Lisbon and Porto survey, which showed that 42% of people had no heating devices and about one-quarter of those who had not used it regularly during winter, concluding that 74% of the population enquired lived in temperature vulnerable houses.

Fuel Poverty is a significant problem for Europe. Between 50 and 125 million people do not have the means to afford adequate indoor thermal comfort [13]. Portugal, in particular, is among the five countries with the highest percentage of the population (19.4%) that are unable to afford thermal comfort in their houses [14] (see Figure 1.2).

Excess winter deaths[1] is a phenomenon throughout Europe. Due to the adverse impacts that temperature has on health, it can be considered an increasing concern due to population ageing and climate

[1] Excess winter deaths, the ratio between average daily deaths in December–March versus other month [15].

change [16]. The author of [15] presents an estimate that 65% of the Excess Winter mortality is due to cold and associated diseases, while between 30%-50% is due to housing conditions.

Even though Mediterranean countries have better weather, with milder conditions, it is in these countries that death seasonality is more evident, with Portugal having the second-highest excess mortality (see Figure 1.3). In fact, Portugal is the country in Europe with the highest correlation between death rates and outdoor temperatures in the winter and during heat waves in the summer, the same problem occurs [17] (see Figure 1.4). Poor housing conditions can potentially explain this public health problem in Portugal: lack of heating, poor thermal insulation, high energy prices, and overall lower economic power than other European countries [12, 18]. Around 90% of Portuguese houses have no central heating, while the EU average is 12% [11].

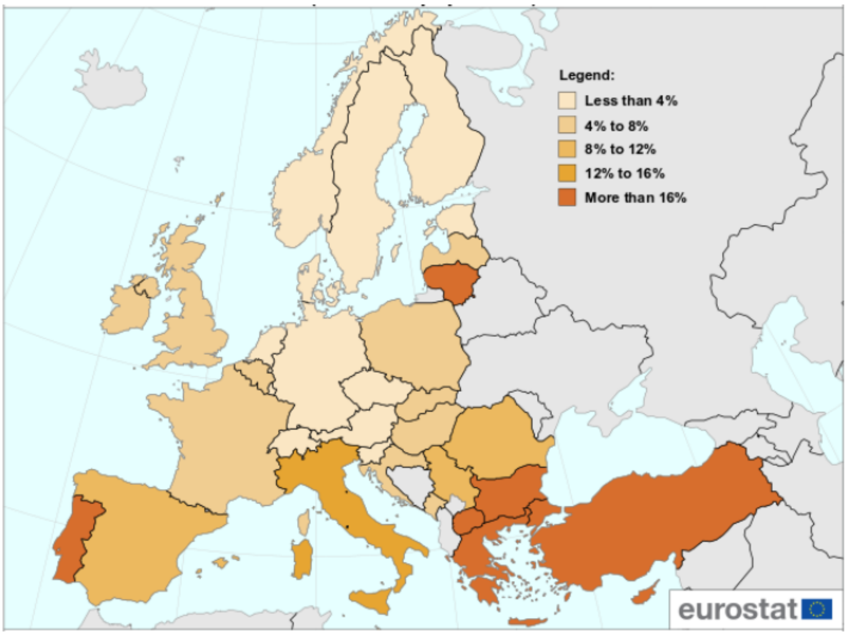


Figure 1.2: % of total population with the inability to keep home adequately warm in Europe in 2018. EU average = 7.3%. Source: [14].

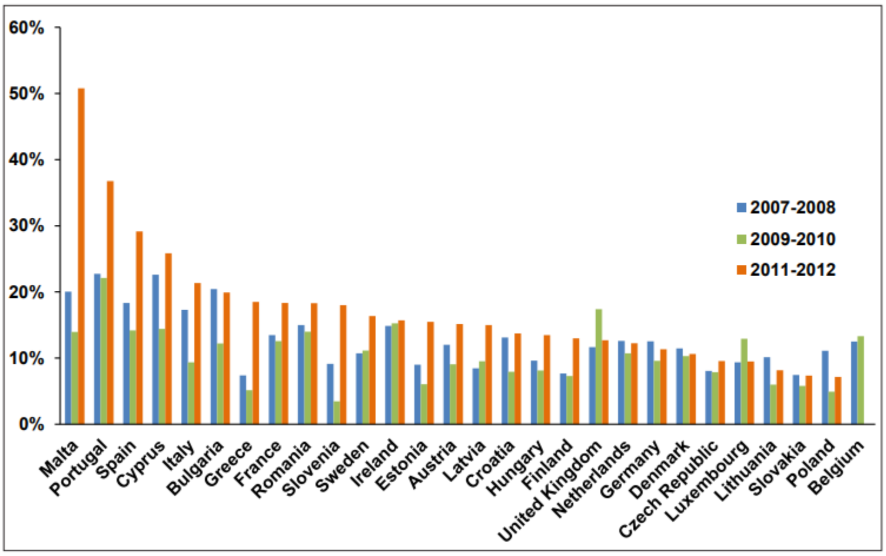


Figure 1.3: Excess winter deaths index (EWDI) between 2007 and 2012 in the EU-28. Source: [15].

In Portugal, counties with lower socioeconomic power tend to be more vulnerable to cold, with the bottom quintile having around 70% more probability of excess mortality in the winter. There is a significant increase in mortality in Lisbon when the temperature is below 16.5ºC, with 5.7% of deaths being statistically explained by the cold [11]. Daily hospital admissions in the Winter in Lisbon increase by 2.2% with a 1-degree drop in the Physiological Equivalent Temperature (measure expressed in Celsius degrees, that considers other factors, such as relative humidity) [12]. Moreover, study [11] states that the number of persons going to the hospital emergency departments increases by 10% in the winter. The increase in hospital admissions leads to a 4.5% cost increase in the National Healthcare Systems (SNS in the Portuguese acronym).

Furthermore, Figure 1.4 shows the general mortality in Portugal from 2009 to 2019[2] allows to conclude not only that there is a winter excess mortality as mentioned before, but also that there are some peaks in mortality in specific times when severe heat waves occurred. This data supports the conclusion that Portuguese houses are not well prepared for extreme climate conditions, having bad energy performance. This, together with the high prevalence of fuel poverty in Portugal, makes the population very vulnerable to extreme temperatures. It is no surprise that this phenomenon happens in Portugal.

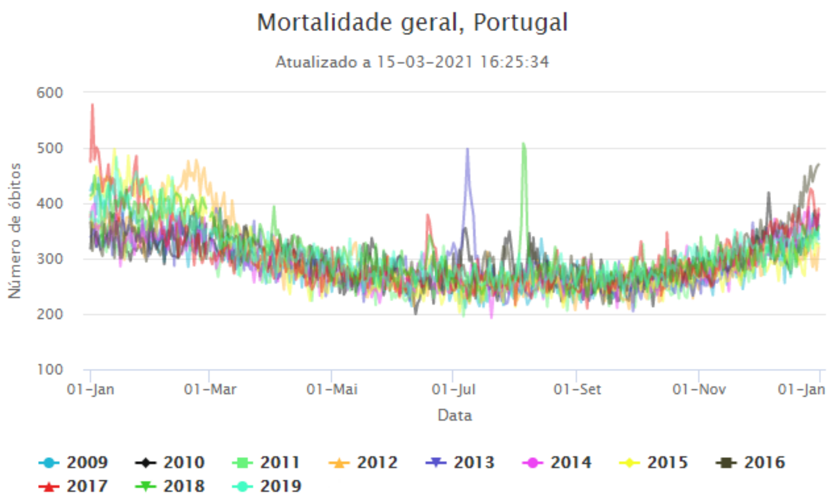


Figure 1.4: Mortality in Portugal in the past 10 years. Source: [19].

Nonetheless, it is worth mentioning that some external factors, such as the economic crisis between 2010 and 2013 and the N1H1 pandemic in 2009, may have affected the increment of mortality during these periods and are not directly related to housing conditions.

According to [20], in the districts of Lisbon and Setúbal, around 54% of existing buildings have an Energy Performance Label (EPC) lower than C, which is considered to describe the standard conditions. If Label C is taken into account, the previous value will go up to 89%, which is considerable, given that almost 90% of the Lisbon Metropolitan Area (AML) residencies have EPC labels equal to or lower than C.

The European building stock is ageing, and it is far from the energy efficiency requirements applied

[2]2020 and 2021 were excluded from this graph due to Covid-19, as it might induce wrong interpretations.

to new buildings. Figure 1.5 displays the age categorisation of the housing stock in Europe in 2021 [21]. In Portugal, as part of the South Countries, the share of new buildings is particularly low. Moreover, [6] states that Lisbon buildings are generally in a poor state of conservation, therefore having plenty of room for improvements.

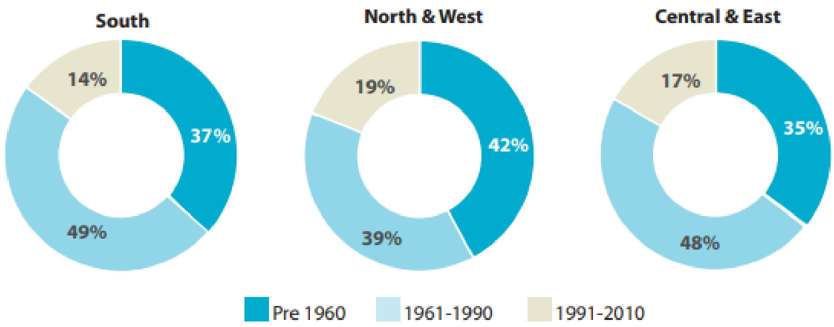


Figure 1.5: Age categorisation of housing stock in Europe. Source: [21].

1.1.3 Buildings & Health

Besides thermal comfort, other characteristics are relevant when taking renovation measures. A World Health Organisation (WHO) report from 1986 states that "energy-efficient but sick buildings often cost society far more than the gains by energy savings". Studies have supported this, suggesting that the financial benefits of improving occupant health and productivity can significantly exceed incremental costs of making buildings healthier [4].

When people live in unhealthy/poor condition houses, such as houses that have dampness or mould, the risk of having certain types of health issues increases, such as:

- **Respiratory diseases**, which are the third most common cause of death, and the fifth most common cause for hospital admissions in Portugal. In 2014, respiratory diseases were responsible for 17 thousand deaths and 70 thousand hospital admissions. Pneumonia is particularly concerning, with cases amounting to 150 thousand per year. Chronic Obstructive Pulmonary Disease (COPD), alongside Asthma, is one of the diseases estimated to have many more cases than those diagnosed. An estimate of 700 thousand people has the disease, but only 100 thousand people have been diagnosed. With this data in mind, it is important to remind that humidity problems in houses are a factor that contributes to respiratory diseases and that cold temperature in winter is responsible for up to 30% of deaths due to poor temperature conditions in houses [22]. While excess humidity coupled with increasing temperatures in the summer can also lead to problems, such as dust mites [23].

- **Sick Building Syndrome** (SBS), which can be defined as a group of non-specific symptoms that have increased prevalence in a population with a temporal connection to a particular building but with no specific or obvious cause [4]. Some associated health problems might be the prevalence of asthma, allergies, and non-specific symptoms from facial skin, eyes, and upper airways [5]. There is scientific evidence that shows the relationship between humidity levels in residential buildings and the emergence of fungi, asthma and respiratory symptoms [23]. According to the Associação Portuguesa do Ambiente, relative humidity below 25% is also associated with reduced comfort, mucous sensation, and dry skin, leading to cracked skin and rashes [24].

This is particularly problematic given that a report from the Observatório Nacional das Doenças Respiratórias in 2018 showed that 20% of Portuguese houses have humidity problems [23].

SBS is also correlated with building characteristics that are not obvious, such as light, ventilation, control of temperature, privacy, noise, layout and decoration and cleanliness, suggesting that SBS can also have a psychosomatic character [25].

Sick buildings' adverse effects can also be analysed from the cost they impose on its occupants. There is no strict list of these costs, but some examples are absence from work, lower productivity, increased building energy consumption and remedial expenses. For instance, [4] has found projects demonstrating that naturally ventilated or mixed-mode conditioning can achieve 0.8%-1.3% savings on health costs while also achieving significant productivity gains and energy savings.

Therefore, it is essential to ensure the best energy performance in houses and the necessary conditions not to be a negative factor to its occupants' health. When assessing if a building is healthy, it is vital to look at perceived health and include dangerous characteristics for health, such as asbestos or radon [25]. According to some literature, other dimensions contribute to human well-being in buildings. They, therefore, should be optimised and taken into account when classifying a building as healthy, including air, lighting, thermal comfort, colour, acoustic comfort, spaces, and texture [26]. This is supported by the fact that physical health is also impacted by psychological well-being since the human body is an interlinked biological system [4].

As previously mentioned, by applying properly designed interventions in buildings, with an adequate assessment, it is possible to improve energy efficiency and improve indoor air quality at the same time, leading to health benefits for occupants. The health benefits from these renovations can impact the individual occupants and public budgets. They can reduce healthcare expenses, reduce the number of sick days, and boost economic productivity, which will increase tax revenues.

1.2 Motivation & Objectives

1.2.1 EU Funds & the Energy Performance of Buildings Directive, EPBD

In this context, a new version of the Energy Performance in Buildings Directive (EPBD) appeared in 2018. This directive mandates the member states to develop the integration and reinforcement of long term rehabilitation strategies, promoting the fight against fuel poverty, the reduction of energy consumption needs, the improvement of energy efficiency and the increased usage of renewable energy sources, with the end goal being reaching decarbonisation in buildings by 2050 (reduce the EU GHG emissions in 2050 by 80–95% (compared to 1990) [27]. This directive also promotes other initiatives, such as automatic control in buildings, implementing infrastructures for e-mobility and introducing the Smart Readiness indicator. Lastly, it also puts a focus on overall comfort in buildings.

In line with the new EPBD version and looking forward to becoming the first climate-neutral continent by 2050, the EU commission presented, in 2019, the European Green Deal [28].

This ecological pact aims to be the ”green thread” for all future activities in Europe. It is accompanied by a roadmap of key policies for Europe, where implemented measures range from reducing emissions to investing in research and innovation and preserving Europe's environment. Moreover, this ambitious package will enable European citizens and businesses to benefit from a sustainable ecological transition, supported by investments in green technologies, sustainable solutions, and start-ups [28].

Part of the European Green Deal, was launched, in 2020, the renovation wave initiative, which intends to double Europe's renovation rate in the next ten years, contributing to making the continent carbon neutral by 2050. Its goals, among others, are strengthening information and incentives for renovations, tackling energy poverty, reinforcing more targeted funding, and creating a more sustainable built environment while creating green jobs and upskilling workers. All of this, with public buildings and social infrastructures showing the way [29].

1.2.2 Rehabilitation Potential Benefits

Considering the significant discomfort levels that Portugal encounters, and allying with the new directive, the green deal, the renovation way, and all of the investment mobilisation that the EU is experiencing, such as the PRR[3], it is urgent and pertinent to invest in energy-efficient houses sustainably. Improving energy efficiency can deliver a range of benefits to the environment, economy and society. Each member state is encouraged to produce their own rehabilitation assessment to study an incentive program's economic viability for the rehabilitation.

[3] The *Plano de recuperação e Resiliência* (Recovery and Resilience Plan) is part of the unprecedented effort made by the EU to emerge stronger from the COVID-19 crisis by enabling Portugal to promote ecological and digital transitions and strengthen the resilience and cohesion of EU members. [30]

There are several studies on this topic. However, there are always some limitations. For instance, an Estonian study [31], which was mainly based on secondary data collection from Estonian statistics, with validation by the Estonian Association of Architectural and Consulting Engineering Companies (EAACEC) and ten companies from the construction goods, analysed how many jobs were created and how much taxes paid per 1M€ of revenue as well how much were the costs per 1M€ of investment. It then calculated energy savings, net present value (NPV) and tax revenues, with a comparison of three different investment scenarios, in a cost-effectiveness analysis. However, this study did not consider environmental or societal benefits, which can be considered incomplete from a macroeconomic perspective.

Even though there are a lot of other studies on how energy-efficient residential buildings impact several sectors [31–34], there is none that sums them all in particular for Portugal. Moreover, energy efficiency programmes are most often evaluated only based on the energy savings they deliver. As a result, the total value of energy efficiency improvements in both national and global economies may be significantly underestimated [35], which makes most investors and owners reluctant to make such a big investment with so little return.

One of the most comprehensive studies in the literature is [36], which studies the macroeconomic and other benefits of energy efficiency policies at a European level, using a complex model [4] from Cambridge Econometrics [5]. Similarly to this thesis, that study estimates the direct and indirect benefits at a macroeconomic level. It includes in its model the social, environmental and economic interactions in a way that generates various economic outputs such as GDP and unemployment rate. Although it was not possible to use this methodology in this work due to the monetary costs and resource-demanding, [36] highlights the various potential benefits inherent to energetic rehabilitations. There are two types of benefits from energy-efficient housing rehabilitations: reduced costs due to reduced energy consumption and improved comfort levels. The latter, including improved indoor air quality, thermal comfort, and noise insulation [9]. Study [36] mentions several studies that have quantified the outcomes, some finding benefit to cost ratios as high as 4 when including health and well-being impacts.

The greatest environmental benefit is reducing the demand for fossil fuels, which makes GHG emissions diminish. Energy efficiency initiatives contribute up to 44% of the total carbon reduction required to reach the 2035 climate change targets [32]. A reduction in electricity costs can motivate the willingness to pay for energy savings. Thus, having energy efficiency induces a positive impact on property value [37]. Empirical evidence of the impact that energy efficiency has on the residential market in European countries suggests that there are, in fact, premiums for both the rental market and the acquisitions market [8, 38].

[4] E3Me model: https://www.e3me.com/
[5] https://www.camecon.com/

1.2.3 Thesis' Goal

Recently, a study for Portugal, ELPRE [39], was performed in a partnership between the *Direção-Geral de Energia e Geologia* (DGEG), *Agência para a Energia* (ADENE) e *Instituto Superior Técnico* (IST – IN+). The study's objective was to analyse the energetic requirements and the thermal comfort in Portugal's buildings and estimate the potential impact in terms of co-benefits and economic impact. The study showed that reduced energy consumption is not enough to generate a positive return from the required investments. The study also estimated in a back-of-the-envelope manner only 2 or 3 co-benefits, always from a private investor perspective.

This thesis, however, has a unique and differentiated objective, which is to fully explore and estimate the extensive range of benefits from improving the energy efficiency of residential buildings, both from a private investor and a government perspective. It will consider benefits like reducing unemployment, reducing GHG emissions, and increasing tax revenues for the government, allowing the government to run incentive programs in the country, which will increase the number of relevant rehabilitation, being a positive factor reaching the EPBD 2050 objectives. Incentive programs are generally financial incentives and can be done through different types of incentives (grants, subsidies, soft loans, etc.). These incentives are often used to incentivise energy efficiency rehabilitation by reducing the required initial investment [3].

This thesis's primary goal is to produce a framework and a high-level estimate of these measures' potential return. To get a precise estimate, an individualised comprehensive study for each of this study's segments should be performed, which becomes out of scope for this work. Therefore, the final quantitative results presented in this study should be addressed with caution. The main conclusion from this work is the qualitative interpretation made from this research.

1.3 Methodology & Data

The analysis performed in this study mainly relied on secondary data collection, which was done using various information sources for each of the benefits and costs. More recent data was prioritised (excluding 2020 due to being an atypical year due to the pandemic context). A regional focus on the AML was also prioritised when possible.

The estimation process used a method similar to the one described in [36]. The overall methodology was based on the one used in [40], given the time and resource limitations of this work.

1.4 Thesis Outline

This work was separated into six chapters. Chapter 1 includes a brief introduction to this thesis's topic, including its relevance.

In Chapter 2, the building type and regional focus used in this study and the motivation for these choices are described. The three different rehabilitation scenarios that will be analysed in this study are also presented along with the necessary assumptions used for the estimation phase. The methodology is presented, and lastly, essential mathematical and financial formulas are shown.

In chapters 3 and 4, the benefits and costs for the private investor and government are presented. Each scenario's estimate is performed for each benefit and cost, based on the existing literature of the benefit being estimated. It is relevant to mention that the state of the various specific subjects' art is performed in these two chapters.

In Chapter 5, the final results are presented and discussed for the cases of the investor and government investment in each scenario. Scenario analysis is also performed, varying the more uncertain estimates from Chapter 3 and 4 by 20% up and down to validate the results by analysing how the conclusions could potentially change given the 20% variation of those estimates.

In Chapter 6, the main findings of this study are summarised, and the limitations of the work and comparison to studies performed for other countries. Lastly, the future studies needed in this scope are presented.

Concluding this work, there are two appendixes. The first one explaining in depth the tax implications of these measures, and the second presenting graphs that improve the clarity of the results obtained in Chapter 5.

Chapter 2

Methodology

In this chapter, the building stock considered in this study is characterised, and the three rehabilitation scenarios are presented. Lastly, the methodology used is explained, and necessary mathematical and financial formulas are described.

2.1 Building Type & Climate Selection

According to the latest available Census (2011) [41], most of the residential buildings in Portugal and Lisbon were built between 1961 and 1990. This is explained by the fact that at a European level, there was a boom in construction from 1960 to 1990 when many countries doubled their housing stock during that period. However, 80% of these buildings in Portugal have an energy label C or less [6]. Although the Census data is from 2011 and there have likely been changed in the last years, the scope of this study will be focused on the residential buildings built in the above period, as they are more common than older buildings, on the one hand, and have more room for energy efficiency improvements than more contemporary buildings on the other hand, leading to a higher impact from a public intervention standpoint.

ADENE's study chose to focus on analysing buildings in 3 different climate types corresponding to Portuguese regions. However, in this work, the scope will also be limited to the Lisbon climate, given that it is the most moderate one, with less severe climate conditions in winter and summer. Therefore, it is more conservative to analyse the benefits in this region. The assumption is that if the strategies become a good investment in this region, it will also be good in the other regions with more severe climates. Another reason for choosing Lisbon is that it is the country's most populous region, with 2.8M residents in the AML [42]. In this region, according to the Census, there are 215 799 buildings built between 1961 and 1990, which represents 60% more than those built between 1991 and 2011 (127 900) [41].

Lastly, this study focuses on multi-family residential buildings, as the density of houses per building is high in the AML region, 3.3 compared to 1.7 for Portugal [43]. This choice is supported by [6], which aimed to study the reference building type for Portugal, choosing Lisbon as the central reference location. Based on ADENE's Energy Performance Certificates (EPCs) data, the investigation defines as Lisbon's reference household a 2-bedroom apartment, inserted in a building with two apartments per floor (which will also be used for this study) - Figure 2.1.

Building characteristics	Data (%)			
Net internal floor area (m^2)	75.8 (average)			
Clear height	2.7 (average)			
Number of rooms	2 (48.8%)	3 (22.8%)	1 (15.1%)	4 (6.6%)
Ventilation	Natural (99.4%)	Mechanical (0.6%)		
Existence of cooling (C) and heating (H) systems	C: no; H: no (87.0%)	C: yes; H: yes (8.5%)	C: no; H: yes (4.3%)	
Type of cooling and heating systems	Individual units (69.5%)	Centralized systems (22.0%)	Individual units + centralized systems (8.5%)	
Heating systems	Split (24.6%)	Electrical resistance (16.4%)	Multi-split (12.3%)	Conventional boiler (7.9%)
Cooling systems	Split (36.0%)	Heat pump (22.7%)	Multi-split (19%)	
Thermal inertia class (kg/m^2)	>400 (63.9%)	150–400 (35.7%)	<150 (0.4%)	

Figure 2.1: Characteristics of the Renovation Building type according to EPC's database provided by ADENE. Source: [6].

2.2 Rehabilitation Scenarios

Although ADENE's study has many different rehabilitation scenarios, this study focuses only on three of them. Each scenario has the measures from the previous one and some extra. Below is the description of each scenario.

2.2.1 Scenario 1 - Basic Comfort

This is the simplest scenario and also the one that requires the least investment. The goal is to reach at least the minimum energy performance that has been regulated. It is based mainly on improving the thermal insulation of the house by improving the walls and windows. The measures are presented below [44]:

- **Stone Wool Insulation**
  Stone wool has three essential qualities: it gives both thermal and acoustic insulation, it is incombustible and so serves as a fire break, and it maintains it is characteristics throughout time [44]. Acoustic insulation is vital for roofs of multi-family residential buildings. In ADENE's study, the price per m^3 is 71.16€, with a lifespan of 30 years and no need for maintenance.

- **EPS Insulation for walls**
  This material is ideal for double walls and building facades and has the three following essential characteristics: it is light, with a density around 10-30 kg/m^3; it is resistant; it is excellent for thermal insulation since it is 98% composed by still air and only 2% by polystyrene [44]. In ADENE's study, the price per m^3 is 103.81€, with a lifespan of 30 years and no need for maintenance.

- **Double Windows**
  The space between the two glasses is filled with dry air, a great acoustic and thermal insulator. This

system reduces the heat loss to half compared to ordinary glass, reducing water condensation, ice formation, and air currents. Lastly, it also improves natural light regulation and security [45]. In ADENE's study, the price m^2 is 198.65€, with a lifespan of 30 years and no maintenance costs.

2.2.2 Scenario 2 - All-electric

This scenario includes two additional measures that increase residential comfort but also the initial investment.

- **MultiSplit**
  It is a system that allows the thermal control of various rooms simultaneously, using only one outdoor unit and various indoor units distributed in different rooms. The different evaporators are independent among themselves [46]. Moreover, this system has a low energy consumption and produces low noise levels [47]. In ADENE's study, the price per standard unit is 1718€, with a lifespan of 15 years, requiring an estimate of maintenance costs equal to 1% of initial invested capital.

- **Heat Pump AQS (COP4)**
  Hot water heat pumps AquaSmart contributes to reducing energy costs and promotes environmental sustainability [48]. In ADENE's study, the price per unit is 135€, with a lifespan of 20 years, requiring an estimate of maintenance costs equal to 1% of initial invested capital.

2.2.3 Scenario 3 - Renewables + Self-sufficient

This final scenario goes beyond energy efficiency, focusing on being environmentally friendly and self-sufficient, using the energy generated from solar photovoltaic panels.

- **Solar Photovoltaic Panels**
  This system uses solar photovoltaic energy, with the excess energy being sold to the energy grid [49]. In ADENE's study, it has a price per kWp of 1 400€, with a lifespan of 25 years, requiring an estimate of maintenance costs equal to 5% of initial invested capital.

2.3 Private Investor Type(s)

According to a survey conducted by [50] in 2011[1], 13% of the residential houses are vacant in the Lisbon region, and 87% are being used. Out of those being used, 87% were primary residences, while 13% were secondary residences. Out of the primary residences, 67% were being used by the owner. This number is higher for Portugal, 73%. While out of the vacant houses, 24% were meant to be sold, and 17% were meant to be rented, Portugal's numbers were similar.

[1] AML may have slightly changed its housing distributions statistics with new foreign investors entering Portugal's Real Estate market during the last five years and many recent renovations.

Given the property ownership context in Portugal e in AML, this study contemplates three types of private investors: the most common type, which is the owner who lives in the house after the rehabilitation measures; the investor who rehabilitates the house to sell it; and the investor who rehabilitates in order to rent it. For tax purposes, it is assumed that all private investors are individuals and not collective entities.

2.4 Research & Data Analysis Methodology

This study uses a similar methodology to [40], by performing a cost-benefit (CB) analysis[2], starting from the existing literature about the different factors, monetising the relevant benefits so that a comprehensive quantitative analysis can be performed.

Due to imperfect access to data, it is impossible to maintain 100% consistency for all instances; in these cases, reasonable assumptions are made so that the overall analysis is still adequate.

With the CB analysis, the Capital Budgeting Approach is used to calculate the Net Present Value of each strategy to determine if it is a good investment, using other metrics to analyse it thoroughly. In this stage, it is assumed no government subsidy, and therefore the entire investment is private.

In the second stage, the optimal relationship between the value of the government's renovation subsidy for each scenario and its consequent adherence rate maximises its outcome. A higher subsidy will lead to lower required investment from the private investor, while benefits would still be the same, clearly creating a good incentive to increase the adherence rate, allowing more people (all in the best case) to live with better housing conditions. For the computation of the optimal relationship, it was also necessary to estimate the investors' willingness to pay for this type of rehabilitation, similar to the CB analysis estimates.

Lastly, a scenario analysis was performed, which allows to test the credibility and reliability of the results by verifying the impact that they would suffer from significant variations in the estimates that are more uncertain.

2.4.1 Capital Budgeting Approach

The Capital Budgeting approach is used to evaluate potential significant projects and investments. It consists of analysing the lifetime cash flows, including the initial cash outflow resulting from the initial investment. This approach's goal is generally to decide what investments should go forward, using potentially different metrics [52].

[2]consists of compiling a comprehensive list of all the incremental benefits and all the incremental costs [51].

Below are presented all of the metrics that will be used in this study, both for the estimates of the various benefits/costs, as well as the financial evaluation of each scenario for each type of investor and government. This last part's main focal point will be the Net Present Value, which measures value creation.

- **Net Present Value (NPV)**

  Net Present Value (NPV) consists of doing a Discounted Cash Flow Analysis (DCF), which is the sum of all cash flows (including the initial investment) discounted to the Present Value at a risk-adjusted discount rate [53]. A project should be undertaken when the NPV is larger than 0, meaning it adds value. It is calculated with the formula below:

$$\text{NPV} = \sum_{n=0}^{N} \frac{\text{CF}_n}{(1+i)^n} \tag{2.1}$$

  where n is the time of the cash flow, i is the discount rate, which should be the same as the one for investment with similar risk, and CF_n is the net cash flow for period n.

- **Modified Internal Rate of Return (MIRR)**

  Internal Rate of Return (IRR) is the discount rate that would make the NPV of all cash flows equal to zero [54]. An IRR higher than the discount rate i means that the project should be undertaken, meaning that it generates more return than it is expected from its level of risk. To calculate IRR, the below equation should be solved:

$$0 = \text{NPV} = \sum_{n=0}^{N} \frac{\text{CF}_n}{(1+\text{IRR})^n} \tag{2.2}$$

  Where IRR substitutes the i from the traditional NPV formula.

  There is an important limitation of IRR. When there is more than one sign change in the cash flows, it can happen that there are multiple IRRs and the interpretation is not clear, as a high IRR has the impact of discounting future positive cash flows at a higher rate, but the same for future negative cash flows [55–57]. Thus, IRR will not be used in this study due to the reinvestment costs in future years. Therefore, this study will use an IRR adaptation that does not have this issue, the Modified IRR (MIRR).

  The interpretation of MIRR is the same as IRR, a MIRR higher than the discount rate i means that the project should be undertaken. The difference from IRR is that in this method, all positive intermediate cash flows are assumed to be reinvested at a defined reinvestment rate, while all negative cash flows are discounted to present value at the financing rate, the MIRR being the discount rate that makes NPV equal to 0 with these assumptions [55]. In this study, both the reinvestment rate and financing rate will be assumed to be equal to the discount rate i.

$$MIRR = \sqrt[n]{\frac{FVCF}{PVCF}} - 1 \tag{2.3}$$

where FVCF is the future value of positive cash flows discounted at reinvestment rate and PVCF is the present value of negative cash flows discounted at the financing rate, and n is the number of periods.

- **Benefit-Cost Ration (BCR)**

  The Benefit-cost Ratio (BCR) is the ratio between the present value of incremental positive cash flows and the present value of incremental negative cash flows, discounted at a risk-adjusted discount rate [58]. A BCR higher than one means that the project should be undertaken, as the benefits outweigh the costs. It can be calculated through the following expression:

$$\text{BCR} = \frac{|\text{PV(Benefits)}|}{|\text{PV(Costs)}|} = \frac{\sum_{n=0}^{N} \frac{|\text{CF}_n\text{(Benefits)}|}{(1+i)^n}}{\sum_{n=0}^{N} \frac{|\text{CF}_n\text{(Costs)}|}{(1+i)^n}} \tag{2.4}$$

  where n is the time of cash flow, i is the discount rate of return for investment with similar risk, CF_n (Benefits) is the positive cash flow for period n, and CF_n (Costs) is the negative cash flow for period n.

- **Compound Annual Growth Rate (CAGR)**

  The Compound Annual Growth Rate (CAGR) is similar to a geometric mean. It gives the constant annual rate of growth/return that would be required from the initial amount (IV) to get the final amount (FV) in a given number of years (n), with compounding effect included [59]. The following expression gives it:

$$\text{CAGR} = \left(\frac{FV}{IV}\right)^{\frac{1}{n}} - 1 \tag{2.5}$$

  where FV and IV are the final and initial values, respectively.

- **Equivalent Annual Cost**

  The equivalent annual cost [60] is beneficial when the period being studied is shorter than the lifetime of the investment, which will be the case further on this investigation. It is calculated through the following expression:

$$\text{EAC} = \frac{\text{Asset Price} \times \text{Discount Rate}}{1 - (1 + \text{Discount Rate})^{-n}} \tag{2.6}$$

  where the discount rate is the return required to make the project worthwhile and n the number of years.

2.5 Assumptions for Data Collection

This section will study the evolution of the parameters evolution needed in the following chapters to forecast the data until 2050. To define the best value, both literature review and past data will be taken into account. As this study focuses on the AML, detailed focused data will also be considered and prioritised to Portugal's average's data. For this research, some values will be considered constant until 2050.

2.5.1 Number of Inhabitants per Residency

According to the study [61], the average number of inhabitants per residency at AML was 2.1 in 2001, 1.9 in 2011 and 1.9 in 2019. Considering the change that has been happening over the last eighteen years, it will be then considered the number of inhabitants per residency constant and equal to 1.9 throughout the next 30 years.

2.5.2 Average Area per Residency

The net internal floor area considered in this study was 75.8m^2. This value, presented in Figure 2.1, was found by [6] and aimed to study what the reference building type for Portugal. Although space energy needs don't grow linearly with the floor area, for simplicity in this study, it will be considered as so.

2.5.3 Inflation Rate

According to the study [62], the average inflation rates for different sectors over the last 5 years (2015-2019) in the Metropolitan Area of Lisbon were: 1.44% in housing, water, electricity, gas and other fuel costs; 0.32% in health care costs; the global inflation rate was 0.78%.

However, [63] shows that the average correspondent values for Portugal over the last 5 years were respectively: 0.74% in housing, water, electricity, gas and other fuels costs; 0.42% in health costs; and lastly, the global inflation rate was 0.76%.

Even though AML's housing, electricity, gas and other fuels inflation rate was significantly above the Portuguese average and it would be more conservative to use the lower values since they would imply lower future cost savings, in this study, the author has decided to use the AML inflation rates, since the whole study is focused only on this area. The assumption that rates in this area will remain constant until 2050 is made. Additionally, 2020 inflation rates were actively excluded when making forecasts, given that it was an atypical year due to the various macroeconomic impacts coming from the Covid-19 pandemic and its response.

2.5.4 Discount Rate

The discount rate used in this paper is the nominal discount rate, given that inflation is also factored in forecasted energy and health prices. To calculate the nominal discount rate, the following formula is used [64, 65]:

$$1 + \text{Nominal Discount Rate} = (1 + \text{Inflation})(1 + \text{Real Discount Rate}) \quad (2.7)$$

Given the very low-risk nature of these projects, it is assumed zero risk premium, and therefore the real discount rate is the real risk-free rate, which gives us:

$$\text{Discount Rate} = (1 + \text{Inflation Rate})(1 + \text{Risk Free Rate}) - 1 \quad (2.8)$$

The inflation rate that has been used was the last five-year AML average of 0.76%, and the real risk-free rate used was 1%, in line with ADENE's study, giving us a discount rate of 1.79%. The low nature of this value is explained by this being a low-risk investment since it is almost certain that the various savings from this investment will occur.

2.5.5 1961-1990 Residential Building Stock

According to [41], in the AML, in 2001 and 2011, there were, respectively, 221 830 and 215 799 buildings built between 1960 and 1990 that were still active. Assuming a constant annual demolition rate of existing buildings, the geometric average was computed to get the compounded annual growth rate, CAGR, which was -0.275%. This CAGR was also used for forecast years, allowing the author to extrapolate the number of buildings built in 1961-1990 that were still active each year until 2050. Lastly, to get the forecast of residences built-in 1961-1990 for 2020 to 2050, the extrapolated number of buildings was multiplied by the ratio of residences per building.

2.5.6 Resident Population Growth

According to the survey [66] conducted in 2018, in the base case scenario, in 2080, the population is forecasted to be 8.2M in Portugal and 3.1 M in AML, representing a 2.1M decline of the Portuguese population and a 0.2M increase of the AML population. For this study, it is relevant to forecast the AML population up until 2050. The linear interpolation method was used with 2019 and 2080 as the reference points to establish the interception and slope of the equation of the type $y = mx + b$ (where y is the population and x is the year), which is adequate given that INE's projections show a relatively linear increase in population up until 2080. After making the calculations, the 2050 AML population is forecasted to be 3.0M.

Chapter 3

Cost-Benefits Estimation: Private Investor

This Chapter presents the cost-benefit analysis from the private investor's perspective. A literature review is performed to estimate the benefits and costs for the different scenarios and each type of investor based on available data.

3.1 Benefits

3.1.1 Energy Consumption Cost savings

The cost savings from the energy consumption reduction were taken from the ADENE's study. The results are represented in the following tables (3.1, 3.2 and 3.3), which describe each scenario's yearly energy savings in 2020. The savings for the next 30 years will take into account the energy price inflation. The inflation rate that is used is the same used in ADENE's study: 1.50% for electricity, 1.00% for gas, 0% for biomass and 3.4% for diesel. This study did not consider the side effect of the insulation of solar panels, which helps keep houses cooler during the summer when installed on the roof.

	Energy Savings [kWh]	Baseline price [€/kWh]	Economical Energy Savings [€]
Electricity	0.8768	0.2246	0.1969
Gas	0.0284	0.0759	0.0022
Biomass	0.0926	0.0500	0.0046
Diesel	0.0019	0.1080	0.0002
TOTAL	–	–	**0.2039**

Table 3.1: Baseline yearly energy savings per m^2 for scenario 1. Data source: ADENE.

	Energy Savings [kWh]	Baseline price [€/kWh]	Economical Energy Savings [€]
Electricity	1.239	0.225	0.278
Gas	15.434	0.076	1.171
Biomass	0.109	0.050	0.005
Diesel	0.016	0.108	0.002
TOTAL	–	–	**1.457**

Table 3.2: Baseline yearly energy savings per m^2 for scenario 2. Data source: ADENE.

	Energy Savings [kWh]	Baseline price [€/kWh]	Economical Energy Savings [€]
Electricity	2.544	0.225	0.571
Gas	15.434	0.076	1.171
Biomass	0.109	0.050	0.005
Diesel	0.016	0.108	0.002
TOTAL	–	–	**1.750**

Table 3.3: Baseline yearly energy savings per m^2 for scenario 3. Data source: ADENE.

3.1.2 Asset Value/Property Value

- **Housing Prices**

  In theory, there should be a strong relationship between energy efficiency and housing prices since the markets should internalise the future energy savings benefit in housing prices. Energy-efficient houses should be more expensive, based on the rationale that they will have lower energy bills. However, this relationship is not so simple. In practice, there are market failures. This benefit is not always fully internalised in housing prices, leading homeowners to invest less in energy performance than ideally. This market failure generally occurs because buyers typically focus on the house's characteristics with a more immediate impact and only benefit from the difference that energy efficiency measures provide when using the house [67].

  To estimate the value-added that improved energy efficiency brings in the future, it is necessary first to estimate the price appreciation that would happen without the energy efficiency rehabilitation measures.

  The inflation rate used for housing prices is 1.44%, as presented in the previous Chapter 2.5.3. Using this inflation rate and applying it to the average housing price bank valuation in 2018 [68] - 1 459€/m^2 - we estimate that the prices for the next 30 years will reach 2 305€/m^2 in 2050.

  The author of [67] studied how the energy efficiency, based on the EPC label, impacted the Portuguese housing prices. Even though the study's scope is not limited to the AML region, many of the houses used in this study come from this region, where most of the EPC have been issued. That study uses data from administrative records and property tax purposes for housing prices and the EPC label information from ADENE and includes a large sample of 256 000 transactions. This work will use [67] study to estimate the housing price impact that the rehabilitations will have on scenarios 2 and 3.

The results (figures 3.1 and 3.2) are in line with results obtained from other authors [69, 70]. The results show an average price increase of 12.5% for the energy-efficient apartments (i.e. the ones with an EPC label of A or B), with an increasing trend over the years. Moreover, it is possible to see that the energy efficiency impact varies along with the price distribution, throughout time and according to the dwelling type [67].

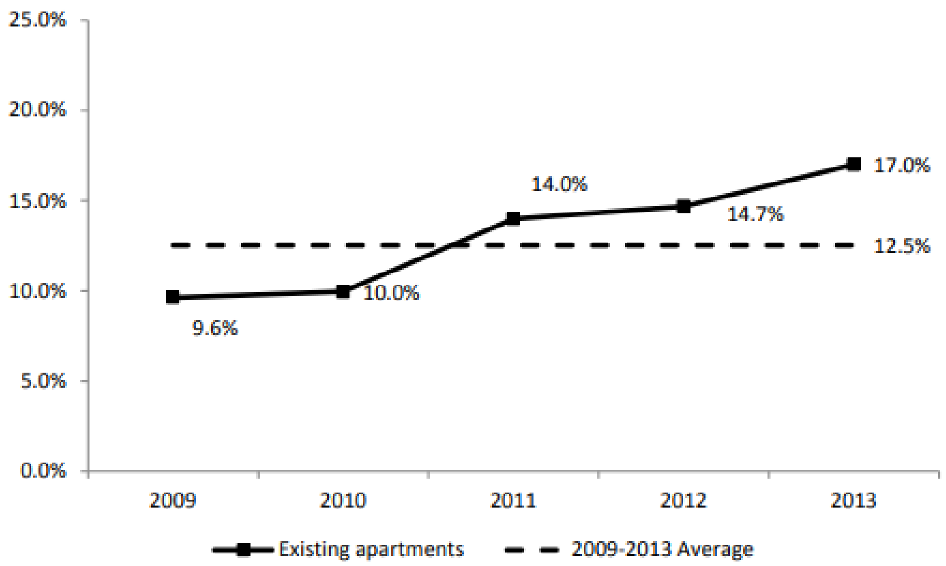


Figure 3.1: Effect of Energy efficient on apartment prices. Source: [67].

Transaction price quartile group	1st	2nd	3rd	4th	All
(1) Existing apartments	11.9	21.1	33.8	51.0	29.4
(2) New apartments	49.0	67.4	76.0	83.1	69.0
(3) Existing houses	13.8	13.2	22.2	34.4	20.9
(4) New houses	18.7	32.3	43.5	53.1	39.9

Figure 3.2: Most energy efficient properties (A nd B EPCs) with premium percentage by price quartile group - 1st is the least priced quartile apartments. Source: [67].

According to Figure 3.2, we can see that the lowest average premium across the four quartiles is 11.9% for existing apartments and corresponds to the lower-cost apartments. To be conservative, and since this study's scope is focused on apartments that already have at least 30 years, this study assumes 11.9% as the house price premium only if all scenario 3 rehabilitation measures are fully applied.

For scenario 1, this work will use [71] study, which also studies the impact of energy efficiency on EPC labels on Portuguese housing prices. The main difference to the previous study is that it also includes a label of C in the energy-efficient group. Therefore it assumes lower energy efficiency than [67], which is assumed to be more appropriated for scenario 1. In this case, the estimated housing price premium is only 5.9% for houses with labels of A, B or C. For scenario 2, an average of the premiums from scenario 1 and 3 is used (8.9%).

Given that the housing price for 2020, without rehabilitations is 1 501€/m^2, it is estimated that the rehabilitation measures will increase 2020 prices by 89€/m^2 in scenario 1, 134€/m^2 in scenario 2 and 179€/m^2 in scenario 3 (see Table 3.4).

- **Rental Yields**

  Given that there is no literature on the impact that energy efficiency has on Portuguese rental prices, this study reviews other European countries' literature. Sweden shows the highest premium in the reviewed literature, which equates to 5% for green buildings [38]; in Germany, the premium is 1.7% [37]; in Ireland, the premium is 1.8%-1.9% [8, 38]. To be conservative and given that the Portuguese weather is closer to the German and Irish weathers than the Swedish one (even though not similar), this study assumes an average premium of 1.8% for the apartments with higher EPC labels for the three scenarios.

  The inflation rate used for renting prices is 1.44% from the previous Chapter 2.5.3. Using this inflation rate and applying it to the average rental prices in 2019 [61], 8.07€/m^2, we estimate the prices for the next 30 years to reach 12.57€/m^2 in 2050. In this way, the average rental premium in 2020 is estimated to be 0.15€/m^2, and in 2050 to be 0.23€/m^2 (see Table 3.4).

	Scenario 1	Scenario 2	Scenario 3
House Price Premium	89.18€	133.92€	178.66€
Rent Price Premium	0.15€	0.15€	0.15€

Table 3.4: House and rent price premiums for each scenario per m^2.

3.1.3 Healthcare Costs Savings

Although most of the health costs have been assumed to be borne by the government (see Chapter 4), in this section, the reduced income associated with taking sick days will be studied. When a person takes sick leave, they receive only part of the salary. Through social security, the government is the institution that pays the salary during the sick leave days. The value of the sickness's subsidy is a percentage based on the last six months of salary and depends on the number of sick leave days taken [72].

In 2018, [73] analysed the diseases associated with temporary incapacity certificates [1] and the respective time duration. It was concluded that out of the people in the study, 6.2% were due to the flu and 8.1% due to acute infection of the respiratory system, with respective average time durations of 5.6 days and 4.6 days. Simultaneously, pneumonia was the cause of 2.2% of the certificates and had an average time duration of 13.5 days. To simplify and get to one value, the weighted average of the time durations was calculated. It was concluded that the three respiratory diseases have an average time duration of 6 days and represent 16.5% of the temporary incapacity certificates.

Study [73] shows that 90% of the people who asked for temporary incapacity certificates due to respiratory problems took less than 12 days. For these reasons, in this study, the subsidy of sickness will be assumed at 55%, given that this is the subsidy for sick leaves below 30 days [72]. According to [74], the average Portuguese gross salary in 2020 was 1 326€/month, which equates to a reference value of 44.2€/day and, therefore, a daily subsidy of sickness of 24.3€ [72].

However, the subsidy is only paid starting on the 4^{th} sick day for employees and starting on the 11^{th} sick day for independent workers. Considering an average of six sick day leave, for an employee, the average cost per temporary certificate is 192.3€, total loss of income in the first three days and 45% on the following 3. For an independent worker, the average cost per temporary certificate is 265.2€, total loss of income for the six days [75].

In 2019, only 16.5% of workers were independent workers [76]. Therefore the weighted average cost is 204.3€ per worker who takes sick days due to respiratory diseases.

In 2019, 179 247 workers in the AML resorted to the subsidy of sickness [77], so it can be estimated that 29 575 are due to respiratory diseases. Moreover, 74% of people with respiratory diseases live in vulnerable houses [11, 12]. Using the 74%, plus the 16.5%, plus the fact that 20% of Portuguese houses are vulnerable, as concluded before, and conditional probability properties, it can be calculated that the probability of having respiratory diseases when living in a good house is only 5.4%. So it can be concluded that the rehabilitation measures will lower the percentage by 11.1 percentage points. This implies that almost 20 000 sick leaves in the AML could be avoided with better housing conditions; this represents an annual cost of 5.3M€ in the AML.

The 5.3M€ in the AML, represents an average cost of 1.86€ per resident in the region [78]. Knowing that there are on average 1.9 people per house (see 2.5.1), this equates to an expense saving of 3.54€ per house and 0.05€/m^2 for the house type used in this study.

[1] It is necessary to have this type of certificate to receive the subsidy of sickness.

3.1.4 Comfort Value

One of the main reasons why owners who live in the property make renovations in their homes is to increase their comfort level. For instance, when deciding to build a swimming pool, the objective is not to get positive cash flows from that but rather to increase the comfort/leisure of the house.

To quantify the increase in comfort, this study resorts to the formula that the government uses to calculate property value for IMI purposes, which includes a coefficient of quality and comfort [79].

$$V_t/A = V_c \times C_a \times C_l \times C_v \times C_q \tag{3.1}$$

where Vt/A is the property value per square meter, V_c is the base value, which was 615€ in 2019 [80], C_a is the coefficient related to the type of property, which is 1 for apartments, C_l is the coefficient of location, the average for the AML region being 1.7 [81], C_v is the coefficient related to the building age, which is on average 0.65 for the type of buildings in this study, and lastly, C_q is the coefficient of quality and comfort.

The coefficient of comfort is calculated by adding and subtracting points depending on if the house has certain things or not; in particular, if the house has a central system of climatisation, it increases by 0.03, and there can be up to 0.15 points attributed to the quality of construction, which depends on the materials used [79]. In this study, it is assumed that doing the measures from scenario 1 would increase the quality of construction by 0.05 points while adding the MultiSplit in scenario 2 would check the central system of climatisation box, adding another further 0.03 points.

By differentiating the equation with respect to C_q, we can then understand that an increase of 0.05 in C_q would have an impact of $0.05 \times V_c \times C_a \times C_l \times C_v$ in the property value per square meter, while an increase of 0.08 would have an impact of $0.08 \times V_c \times C_a \times C_l \times C_v$. Since the increased comfort is not instantaneous but rather a continuous benefit, the equivalent annual cost method is used, obtaining the values expressed in Table 3.5. of 1.33€/m^2 for scenario 1 and 2.12€/m^2 for scenarios 2 and 3.

	Scenario 1	Scenarios 2 & 3
Comfort Value	1.33 €/m^2	2.12 €/m^2

Table 3.5: Economic value of extra comfort due to renovations done.

3.2 Costs

3.2.1 Initial Investment Cost

The initial investment cost for each scenario's rehabilitation in this study comes from ADENE's study. The values for each measure and the total for each scenario are displayed in Table 3.6.

It is relevant to note that the additional measures from scenarios 2 and 3 will need full reinvestment

Rehabilitation Measure	Scenario 1	Scenario 2	Scenario 3
Stone Wool Insulation	12.32€	12.32€	12.32€
EPS Insulation for Walls	4.33€	4.33€	4.33€
Double Windows	39.05€	39.05€	39.05€
MultiSplit	–	39.97€	39.97€
Heat Pump AQS (COP4)	–	13.69€	13.69€
Solar Panels	–	–	10.29€
TOTAL	**55.70 €**	**109.37 €**	**119.66 €**

Table 3.6: Total initial investment cost per m^2 for each scenario and each rehabilitation measure. Data source: ADENE.

within the 30 year period since the measures' lifespan is lower than 30 years (see Table 3.7). MultiSplit will need reinvestment in 2035, the Heat Pump AQS will need reinvestment in 2040, and the solar panels will need reinvestment in 2045. Given that the last two have a lifespan that will last longer than 2050, but the analysis made in this project only runs until 2050, the Equivalent Annual Cost method is used, with the values being 0.82€/m^2 each year for the Heat Pump AQS from 2040 to 2050 and the value for the Solar Panels being 0.51€/m^2 each year from 2045 to 2050.

Re-investment	year	Scenario 2	Scenario 3
MultiSplit	2035	39.97 €	39.97 €
Heat Pump AQS	2040	13.69 €	13.69 €
Solar Panels	2045	–	10.29 €

Table 3.7: Re-investment needed per m^2 for scenarios 2 and 3 until 2050. Data source: ADENE.

3.2.2 Maintenance/Operational Costs

The annual maintenance costs are deduced from ADENE's study. The measures from the first scenario do not require any maintenance. In contrast, maintenance costs from the additional measures from scenarios 2 and 3 are summarised in Table 3.8 (the costs shown are for 2020, and the inflation rate is used to estimate maintenance costs in future years).

Rehabilitation Measure	Scenario 2	Scenario 3
MultiSplit	0.40 €	0.40 €
Heat Pump AQS (COP4)	0.14 €	0.14 €
Solar Panels	–	0.51 €
TOTAL	**0.54 €**	**1.05 €**

Table 3.8: Yearly maintenance costs per m^2 for scenarios 2 and 3. Data source: ADENE.

3.2.3 Taxes Balances

Although many people do not think of taxes as a potential cost or benefit, it is relevant to study the impact that the measures have on taxes, as on one side, the measures lead to less energy consumption taxes, on the other, they lead to increased taxation on the value of the property. Table 3.9 summarises the fiscal balance analyses for each type of private investor's scenarios. Appendix A shows in more detail how the values in the Table were calculated.

Taxes	**to live in** Scenario 1	Scenario 2	Scenario 3	**to rent**	**to sell** Scenario 1	Scenario 2	Scenario 3
IVA	0.03€	0.31€	0.35€	-	-	-	-
Energy	0.00€	0.17€	0.18€	-	-	-	-
Property	-0.30€	-0.46€	-0.61€	-0.35€	-1.78€	-2.68€	-3.57€
TOTAL	**-0.28€**	**0.03€**	**-0.09€**	**-0.35€**	**-1.78€**	**-2.68€**	**-3.57€**

Table 3.9: Tax balances for the three investors types. Positive value means incremental savings, whereas negative means incremental expense. Values per m^2.

Chapter 4

Benefits Estimation: Government

Similarly to Chapter 3, the benefits and costs of the government will be analysed. The impact that energy efficiency has on the public budget is quite complex. There is a high degree of uncertainty in estimating such impacts. For instance, impacts on public health budgets are a good example of the complexity: while having houses that are more energy efficient will have a positive impact on reducing public expenditure on health by reducing health problems among occupants, it will also prolong the life expectancy of the occupants, which can lead to more expenditure in the future for other health problems and also to more Social Security expenditure for retirement [36].

The main impacts that energy efficiency has on public budgets identified in the literature were summarised by [36], shown in Figure 4.1.

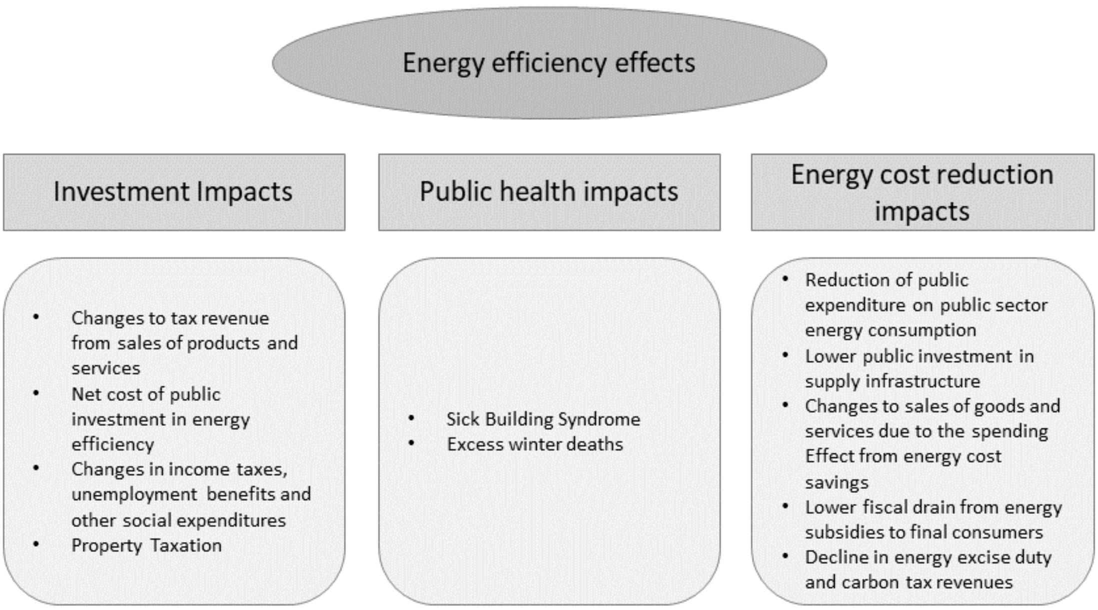


Figure 4.1: The effects of energy efficiency on public budgets. Source: [36].

Given that it would be a somewhat complex and endless exercise to study all the possible impacts that would require a comprehensive and exhaustive macroeconomic model [36], this study will focus on the most direct and relevant impacts coming from the rehabilitation measures, such as the reduced health care expenses from improved health, the increase in tax revenues from the rehabilitation measures and the decrease in tax revenue due to less energy consumed.

Whenever no distinction is specified between the different scenarios, it is assumed that the results are the same for the three scenarios.

4.1 Economical & Societal Benefits

4.1.1 Construction Market & Employment

The values calculated in this subsection do not correspond directly to the benefits. Instead the values calculated are the before tax values that will be used for the calculation of tax revenues coming from this sector due to the rehabilitation measures.

- **Construction Market**

  To estimate the incremental IRC tax that the government would receive, this study estimates the incremental taxable income that companies that implement the rehabilitation measures make. It is assumed that these companies make a 10.6% margin on these projects, meaning that the incremental taxable income will be 10.6% of the measures' price before IVA. This assumption is based on the average of the 2018 and 2019 EBITDA margins for the relevant segments of the three construction companies that are in the Portuguese stock exchange (Teixeira Duarte[1] - Construction Segment [82], Mota-Engil[2] - Engineering & Construction Segment [83] and Conduril[3] [84]). Although these segments also include activities beyond rehabilitations and housing construction, these public companies were still preferred to smaller more rehabilitation oriented firms, as their financial results are more transparent and credible, since they must disclose them to public shareholders. This implies an incremental taxable income of 5.24€/m^2 for scenario 1, 10.28€/m^2 for scenario 2 and 11.25€/m^2 for scenario 3.

- **Employment**

  To estimate the impact that the rehabilitation would have on employment, experts of two companies that implement this kind of rehabilitation measures were consulted, Tecniart[4] and Pinetree[5], reaching a consensus of the required number of workers and time for each of the measures as shown in Table 4.1.

[1]Website: https://www.teixeiraduarte.pt/
[2]Website: https://www.mota-engil.com/
[3]Website: https://www.conduril.pt/
[4]Website: https://www.tecniarte.pt/pt/
[5]Website: http://pinetree.pt/

Therefore, for job creation estimates, it is assumed that the scenario 1 rehabilitation employs

Rehabilitation measure	# days	# workers	**# Days x # Workers**
Stone wool insulation + EPS Insulation for Walls	5	3	**15**
Double Windows	2	3	**6**
MultiSplit	3	2	**6**
Heat Pump AQS (COP4)	0.5	2	**1**
Solar Panels	2	2	**4**

Table 4.1: Jobs creation due to each rehabilitation measure per residence (2 bedroom, 75.8 m^2 apartment).

the equivalent to 1 person for a month; scenario 2 employs the equivalent to scenario 1 plus 7 days (approximately a month and a third); scenario 3 employs the equivalent to scenario 2 plus 4 days (approximately a month and a half). Considering that in Portugal, the total number of holiday days typically add up to around a month, it can be estimated that a scenario 1 rehabilitation employs 0.09 people per year entirely dedicated to this, a scenario 2 rehabilitation employs 0.12 people and a scenario 3 rehabilitation employs 0.14 people. The average salary in the construction sector is 967€/ month [74], which equates to an annual gross salary of 13 538€, implying for scenario 1 an incremental gross salary equivalent to 16.24€/m^2, for scenario 2 an incremental gross salary of 21.40€/m^2 and for scenario 3 an incremental gross salary of 24.35€/m^2.

In this study, it is assumed that the employment created by the measures is directly taking people out of unemployment. This might be a reasonable assumption, as even though the work might come from people who were already employed in a construction company, putting the workers on these projects opens up space for more workers to be recruited for other projects. Furthermore, in reality, all renovations will be done during an extensive period of time (even though not considered for simplicity in this study), having more permanent effects in the construction market.

4.1.2 Healthcare Expense Savings

Most energy efficiency measures will improve indoor temperatures, mould and dampness and, by choosing renovation measures that also improve indoor air quality, health benefits can be obtained through fewer incidences of disease, such as reduced mortality. Some other collateral benefits may be higher productivity or even overall improvement of life quality. Although some benefits accrue to society in general, public budgets may also be improved through reduced healthcare expenses, fewer sick days and increased tax revenues resulting from increased economic production [36].

To estimate and quantify the major impacts that improved energy efficiency performance has on public health, this study focused on the following issues: ability to keep houses at adequate temperatures; decrease of mould and dampness, which are generally related to respiratory problems that represent the third most common cause of death in Portugal and the fifth most common cause of hospital admissions [22]; and fewer sick days leave. The cost savings on preventive health such as medical appointments and exams are not being considered in this study as there is not enough data on those subjects to make reliable estimates.

A summary of the government healthcare savings is made in Table 4.2.

	Asthma	Extreme Weather	Sick Days	**Total**
government Savings	0.103€	0.539€	0.011€	**0.653€**

Table 4.2: Government healthcare savings per m^2.

1. **Sickness costs associated with sick building syndrome – case of Asthma**

   As explained in Chapter 1.1.3, the sick building syndrome is associated with problems that come due to poor housing conditions, high levels of humidity are correlated with asthma and other respiratory problems. In this section, the cost savings are studied by analysing the current incidence rate and costs associated with the diseases and how much the incidence rate would decrease due to the housing rehabilitation. The cost savings result from the difference between the incidence rates multiplied by the costs.

   In 2016, according to [85], around 6.8% of Portugal's residents had asthma. It is estimated that the incidence rates differ by age group, being 11% in the [6,7] years old group, 11.8% in the [13,14] group and 5.2% in the [20,44] group [85]. Assuming that the incidence for the [6,7] age group applies to the [5,9] group and that the incidence of the [13,14] group applies to the [10,14] group, and that the rates for Portugal also apply to AML, the incidence rate for the [5,14] group was calculated based on the population sizes by age group in AML [78]). The final value is 11.4%.

   Due to the lack of more data, more assumptions had to be made to estimate the incidence rate among the 65+ age group. In particular, the 11.4% obtained previously also applies to the [0,19] age group and that the incidence of the [20,64] group is equal to the 5.2% of the [20,44] group, which leads to an estimate of 7.0% for the 65+ age group.

   Using data from 2010, [86] has studied the costs associated with adults' asthma, estimating that each adult with asthma costs an average of 708.2€ per year, representing a total annual cost of 386M€, equivalent to 2.0% of the total Portuguese healthcare expenditure in 2010. Of this value, 93% are direct costs - such as acute care usage (30.7%), treatment (37.4%) or medical appointments - and 7% are indirect costs, e.g. decreased productivity [86].

   Regarding children, each child with asthma costs an average of 929.4€ per year, leading to a total of 161M€. Of this value, 75% are direct costs, and 25% are indirect costs (including sick leaves taken by parents to take care of their children) [87].

Assuming that the costs estimated for children apply to the 0-19 age group and that adults' costs apply to the rest of the population, the average cost per asthmatic person was calculated - 784.6€ per year and 547M€ for the total population. It is relevant to mention that these costs are spread out between the patients, the government and health insurance companies [86]. However, it is assumed that indirectly, the government bore all these costs and hence reducing them is a benefit for the government. It is a reasonable assumption as most people have health insurance of some kind and as these are benefits for society, and the government's objective is to maximise the welfare of society (in the case of this representing cost savings for private insurers and not for individuals, it can be argued that these cost savings would lead to cheaper insurance premiums, therefore passing the cost savings to the individuals).

It is suggested by [88] that people who live in a damp or mouldy house are 40% more likely to have asthma. Besides that, it is consensual in the literature that around 20% of Portuguese houses have damp or mould [11, 22, 23]. Equation (4.1) computed a probability of 6.3% of a person having asthma when living in a house with no damp nor mould.

$$6.8\% = 0.2 \cdot (1.4 \cdot x) + 0.8 \cdot x \iff x = 6.3\% \tag{4.1}$$

Given that the general probability of a person having asthma is 6.8%, it is assumed that this probability will fall by 0.5 percentage points with the rehabilitation measures.

The 547M€ expense in asthma in Portugal in 2010, represents an average of 51.8€ per resident in Portugal [78]. Knowing that in the AML region, there is an average of 1.9 residents per house (see Chapter 2.5.1), this leads to an average cost of 98.4€ per house. Assuming linear costs reduction, by decreasing the incidence by 0.5 percentage points, there would be cost savings equal to 40.2M€, equivalent to 3.8€ per resident in Portugal, which leads to 7.2€ per house in the AML region. In 2010, this value represents 7.8€ per house in 2020, which is the same as 0.10€/m^2 in this study's housing type.

2. **Sickness costs associated with extreme weather condition derived from poor insulation**

The relationship between cold temperatures and increased hospital admissions and deaths is consensual in the literature and consistent across Europe, particularly in Portugal [11, 17, 89].

Between 2000 and 2009, there were 85 952 EWDs, Excess Winter Deaths[6], (8% of the total mortality), mainly through circulatory (39 972) and respiratory (18 116) diseases [11]. In Portugal,

[6]calculated as: Winter deaths – non-winter deaths /2

73% of the population lives in regions with high winter vulnerability to respiratory mortality and 60% in regions with high winter vulnerability to circulatory mortality [11]. Given the quantitative nature of this study and the focus on financial returns, it will focus only on the excess hospital admissions and costs from that (i.e. this study has deliberately opted not to put an economic value on deaths).

The author of [11] has conducted various studies about health, its relationship with poverty and geographical correlation, and health's economic impacts. He concluded that emergency rooms have increased by 10% during the winter for the period between 2013 and 2016; other authors have shown similar values [90, 91]. This 10% increase leads to an incremental cost of 227M€ for the SNS, 5.7% of the hospital admission costs in Portugal, and an average cost of 2 749€ per excess winter hospitalisation. It is worth mentioning that these values align with studies done in the UK by other authors [11].

This incremental cost for the SNS, represents an average annual cost of 21.5€ per resident in Portugal [78]. Knowing that in the AML region there are 1.9 people per house (see Chapter 2.5.1), this equated to an average cost of 40.8€ per house and 0.54€/m^2 for the type of houses used in this study. Given that this is an extra cost coming directly from poor housing conditions, it is assumed in this study that the rehabilitation measures will lead to completely saving this value.

3. **Fewer sick days**

   Besides the health costs mentioned above, it is also relevant to mention the subsidy that the government, through social security, pays to people who take sick leave due to poor housing conditions. The cost savings will be calculated using the rationale used in Chapter 3. Therefore, subsidy for independent workers is assumed to be 0€, and the subsidy for employees is assumed to be 72.9€ on average, resulting in a weighted average of 60.9€ per person who takes temporary incapacity certificates. This value equates to a total cost of 1.2M€ in the AML for the government due to poor housing conditions, representing an average cost of 0.43€ per resident in the AML. Knowing that there are on average 1.9 people per house (see Chapter 2.5.1), this equates to a cost of 0.81€ per house and 0.01€/m^2 for the house type used in this study.

4.2 Tax Balances

According to [36], a large part of the revenues coming from rehabilitation measures come from its taxes, such as IVA, income tax receipts, social contributions, corporate taxes, property taxes, and other taxes.

In this study, it is assumed that the tax rates will remain unchanged, and therefore, tax revenues and costs will only depend on the variation in salaries or profits. Movements between tax bands are also be excluded in this analysis, as it is used a single rate. This is a reasonable assumption as, for example, the jobs that will be created from the rehabilitation measures include high and low skilled workers, and so it is reasonable to assume that the average tax rate will not change.

Moreover, only taxes relevant to this study will be discussed (i.e. only taxes impacted by the rehabilitation measures).

In Table 4.3, it is possible to see the summarised balance of possible taxes from the rehabilitation measures. Appendix A shows in more detail what is included in each category and how the values for the Table were calculated.

Taxes	Scenario 1	Scenario 2	Scenario 3
IVA	6.38€	12.37€	13.61€
Energy	0.00€	-0.17€	-0.18€
Property	2.13€	3.18€	4.22€
Workforce	20.49€	27.72€	31.45€
TOTAL	**29.00€**	**43.09€**	**49.11€**

Table 4.3: Tax balances for the government, separated by category and rehabilitation scenario. Values per m^2.

4.3 Environmental Benefits

Improving energy efficiency has a positive impact on the environment through multiple factors. In terms of climate change, there is also less fossil fuel consumption by decreasing energy consumption, which leads to less greenhouse gas emissions [36].

Greenhouse gas emissions do not directly impact the government's budget but rather a long-term indirect impact on society as a whole. Therefore, to estimate the benefit of reducing greenhouse gas emissions, this study uses the concept of Social Cost of Carbon, a concept often used in cost-benefit analysis. The Social Cost of Carbon is the indirect cost that greenhouse gas emissions (particularly carbon) impose on society as a whole and is often used in Benefit-Cost Analysis [92]. In economics theory, this type of indirect cost imposed on others is called a negative externality and can be tackled via a cap and trade mechanism, which sets the cap of production for the companies and allows them to trade rights to produce (in this case pollute), this system leads to an optimal solution where the quantity produced is equal to the social optimal quantity and the price of the rights to produce is equal to the negative externality so that this indirect cost becomes internalised [93]. Given that this system already exists in the EU, through the EU Emission Trading System, even though only applied to some industries [94], this study uses the market value of the permits from this system as the benefit that the government has from reducing greenhouse gas emissions. The average market value of the permits for March 2021 was 40€ per tonne of CO_2 [95]. The average of the last month was used to remain current, but at the same time avoid small market fluctuations.

The emission factor considered for a diesel generator, biomass, natural gas and electricity was 1.27 $kgCO_2/kWh$ [96], 0.35 $kgCO_2e/kWh$ [97], 0.20 $kgCO_2e/kWh$ [97] and 0.40 $kgCO_2/kWh$ [98], respectively.

The greenhouse gas emission savings were calculated, and the following tables (4.4, 4.5 and 4.6) present the yearly savings for each scenario in 2020. Since it is a tax, the savings for the 30 years will consider global price inflation, which is 0.78%.

	Energy Savings [kWh]	CO_2 emissions savings [kg]	Expenses Savings [€]
Electricity	0.8768	0.3507	0.0140
Gas	0.0284	0.0057	0.0002
Biomass	0.0926	0.0324	0.0013
Diesel	0.0019	0.0024	0.0001
Total	–	**0.3912**	**0.0156**

Table 4.4: CO_2 emissions savings per m^2 for scenario 1 in 2020. Data source: ADENE.

	Energy Savings [kWh]	CO_2 emissions savings [kg]	Expenses Savings [€]
Electricity	1.2391	0.4956	0.0198
Gas	15.4344	3.0869	0.1235
Biomass	0.1093	0.0383	0.0015
Diesel	0.0156	0.0199	0.0008
TOTAL	–	**3.6406**	**0.1456**

Table 4.5: CO_2 emissions savings per m^2 for scenario 2 in 2020. Data source: ADENE.

	Energy Savings [kWh]	CO_2 emissions savings [kg]	Expenses Savings [€]
Electricity	2.5439	1.0175	0.0407
Gas	15.4344	3.0869	0.1235
Biomass	0.1093	0.0383	0.0015
Diesel	0.0156	0.0199	0.0008
TOTAL	–	**4.1625**	**0.1665**

Table 4.6: CO_2 emissions savings per m^2 for scenario 3 in 2020. Data source: ADENE.

Chapter 5

Results and Discussion

In this chapter, the financial results based on the estimates from chapters 3 and 4 are presented. The final Net Present Values (NPVs) for each investor type and government and each scenario over the 30 years time-frame are presented. In the case of private investors (PI), the respective benefit-to-cost ratios (BCRs) are also shown. Following that, the willingness to pay for each scenario is estimated, which, together with the NPV, allows the calculation of the optimal subsidy that maximises the government outcome, based on the adherence rate and NPV per adherence. Lastly, a scenario analysis is performed. The more uncertain estimates are changed by 20% up and down so that the results obtained can be validated and that the conclusions are credible and relevant for the Portuguese government.

5.1 Results

The Private Investors' values were calculated based on the Equation (2.1), where the present value of the cash flows of each year was calculated. The benefit-to-cost ratio was also calculated based on the Equation (2.4) for each investor type.

The final NPV values are shown in tables 5.1 and 5.2. It is also possible to see the evolution of NPV for each scenario and investor type/government in the Appendix B (see figures B.1 and B.2).

	PI Live			**PI Rent**			**PI Sell**		
Scenario	S1	S2	S3	S1	S2	S3	S1	S2	S3
NPV [€/m^2]	-24.9	-68.7	-89.1	-61.5	-170.0	-200.0	31.7	21.9	55.4
BCR	0.55	0.54	0.44	0.0	0.0	0.0	1.57	1.20	1.46

Table 5.1: Private investor financial metrics before subsidy.

The BCR values in Table 5.1 allows making two conclusions. The first is that for the investor who lives in the home and rents it, the present value of future cash flows is not enough to outweigh the costs associated with the measures for all three scenarios. In fact, the annual future cash flows for the investor that rents are negative, as the IMI tax is expected to rise higher than the gain in rent prices, and therefore

	from PI - Live			from PI - Rent			from PI - Sell		
Scenario	S1	S2	S3	S1	S2	S3	S1	S2	S3
NPV [€/m^2]	53.0	75.0	87.5	54.2	76.2	88.7	54.7	77.7	91.1

Table 5.2: Government financial metrics before subsidy.

BCR is 0. In comparison, the investor that sells the house will have higher expected benefits than costs for all three scenarios. The second conclusion is that scenario 1 has a higher BCR for both types of investors, meaning that the first rehabilitation measures are the ones that add more value relative to its cost.

Regarding NPV from tables 5.1 and 5.2, two first conclusions can be taken. The first is that for the first two types of investors, the NPV is negative for all scenarios, and therefore, at least theoretically, the measures are not attractive for them (at least without government subsidies). In contrast, the opposite is true for the investor that intends to sell. The second conclusion is that the NPV is always positive for the government and relatively stable across the different types of investors for each scenario.

When comparing the NPV of the two tables, more conclusions can be obtained. If the investor rents the house, the NPV for the government is well below what would be necessary to outweigh the negative NPV of the private investor. Therefore there is no room for a subsidy that would lead to a mutually beneficial situation. For this reason, the study will not focus on this type of investor for the rest of the chapter.

Contrary to the investor who rents the house, selling has a positive NPV even without subsidy. For this reason, and given that subsidising this type of investors can lead to real estate speculation, which is not desirable from the government point of view, this study will not focus on this type of investor for the rest of the chapter.

In this way, the only private investor that will be studied is the one that lives in the house. In this case, the NPV for the government is enough to outweigh the negative NPV of the private investor, meaning that there is room for a subsidy level that will lead to a mutually beneficial outcome. The rest of this Chapter will study the optimal subsidy amount that the government should give for the private investor that will live in the house in each scenario in order to maximise its own expected return, which is impacted by the adherence rate and the NPV per renovation (already including the cost of the subsidy).

5.2 Willingness to Pay

To find the optimal subsidy amount that the government should provide for the rehabilitation measures, it is necessary to better understand how the different subsidy levels will affect the number of houses renovated. Thus, the next step is to calculate the willingness to pay (WTP) for the different measures.

There is no extensive literature on this topic for Portugal. It is important to analyse the Portuguese WTP specifically since it can be widely different for different countries due to different factors, such as different income levels, climate, and cultures.

An analysis of the WTP in Portugal for a hybrid system that provides heating/cooling and domestic hot water for residential buildings was made by [99]. Given that this system contains Solar PV panels and Heat Pumps and that it provides the same functions as the extra measures from scenarios 2 and 3, it will be assumed in this study that the WTP for this system is the same as the WTP for scenario 3 (excluding the measures from scenario 1). The study [99] is based on surveys and does not give an exact WTP function, but rather three important points, 10% of people are willing to pay more than 6000€, 25% are willing to pay between 3000€ and 6000€ and 65% of people are willing to pay between 0€ and 3000€. Dividing by 75.8 to get the values per meter and assuming a constant proportion of the WTP to the PV of the total lifetime investment cost of the measures, the points for the same percentages were calculated for the three scenarios. For instance, the Present Value of the investment cost of the difference between scenario 3 and scenario 1 is 116.05€/m^2, while the PV of the cost of scenario 1 is 55.70€/m^2. In this way, to get to the point where only 10% are willing to pay, the calculations are $(6000€/75.8) \times (55.70/63.96) = 37.99€$, while to get to the point that 35% are willing to pay, the calculation is $(3000€/75.8) \times (55.70/63.96) = 19.00€$, the third point being the one where 100% are willing to pay, which is when the price is 0€. Even though this shows that some private investors would be willing to invest even with negative NPV, this is not unreasonable, given that homeowners generally do not apply this methodology when making a decision, and they often also value other factors that are not being accounted in the NPV calculation, such as having a positive impact on the environment, as shown in [100] where the reduction of GHG emissions is something that Korean homeowners are highly willing to pay for.

Having three points for each of the three scenarios (Table 5.3) and using R[1] programming, a demand function was estimated in Equation (5.1) (see Figure 5.1 and Table 5.4) by the interpolation of the points through a logarithmic function:

$$P = a + b \cdot log(Q) \tag{5.1}$$

where P is the price to the investor, Q is the percentage of households that adhere to the rehabilitation measures, and a and b are the parameters of each scenario's interpolation (see values in Table 5.4).

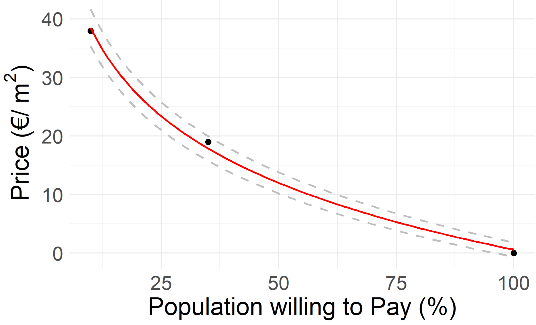
5.3 Subsidy Optimal Value

As government's primary goal is to maximise the number of rehabilitations done (Q) while minimising the subsidy (S) given, it was necessary to find the relationship between Q and S. With the demand function

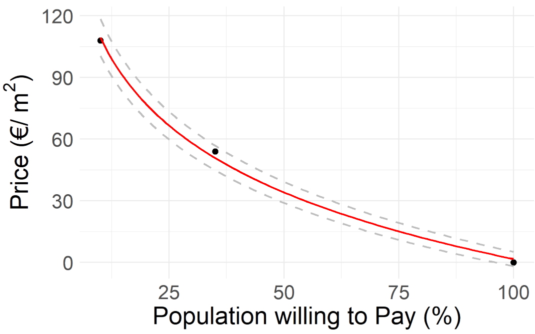
[1] https://www.rstudio.com/

	Price WTP [€/m^2]			Adherence Rate [%]
	Scenario 1	Scenario 2	Scenario 3	
Point 1	0.0	0.0	0.0	100
Point 2	19.0	54.0	58.6	35
Point 3	38.0	108.0	117.1	10

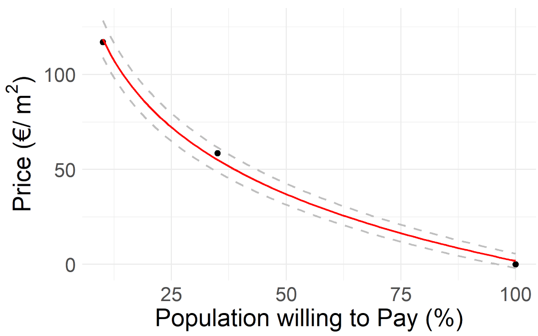
Table 5.3: Adherence rate for rehabilitation measures given certain prices - used to interpolate WTP function.



(a) Scenario 1.



(b) Scenario 2.



(c) Scenario 3.

Figure 5.1: Percentage (%) of the population willing to pay for each renovation scenario. Interpolation made through points shown in Table 5.3.

already defined (see Equation (5.1)) and taking into account that the price paid by investors (P) will be equal to the difference between the Present Value (PV) of the lifetime investments and the PV of the lifetime of the subsidy, it was possible to obtain Equation (5.2).

$$\begin{cases} Q = e^{\frac{P-a}{b}} \\ P = Investment - S \end{cases} \implies Q = e^{\frac{Investment-S-a}{b}} \tag{5.2}$$

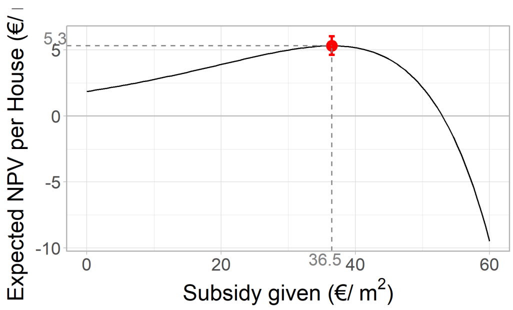
The next step was to maximise the government NPV, that is, maximising NPV per rehabilitation multiplied by the number of rehabilitations by choosing the optimal subsidy. Given that reinvestment will be required for some of the measures in scenarios 2 and 3, it was assumed that subsidies would also be given in the same proportion in the future. The subsidy impacts both the NPV per rehabilitation, which will be equal to NPV without subsidies – PV of lifetime subsidy, and the quantity function (Equation (5.2)).

Therefore, using the two functions, the function to be maximised is written in Equation (5.3), with the parameters from Table 5.4. In Table 5.5, the optimal initial subsidies are presented, as well as the NPV for the government per rehabilitation and for the private investor in each scenario and the % of people willing to pay given that subsidy level. Initial subsidy being calculated as the PV of lifetime subsidy $\times$ % initial investment on the lifetime investment PV.

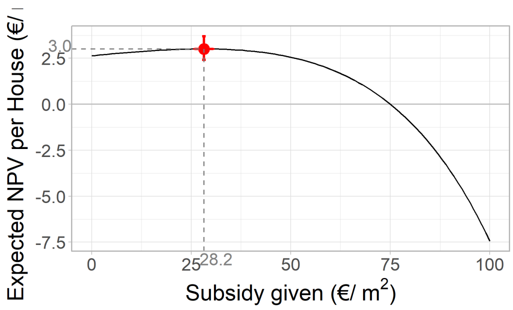
$$\textbf{max TOTAL NPV}^{*} = (NPV - S) \cdot Q = (\mathbf{NPV} - \mathbf{S}) \cdot \mathbf{e}^{\frac{\mathbf{Investment} - \mathbf{S} - \mathbf{a}}{\mathbf{b}}} \tag{5.3}$$

	Scenario 1	**Scenario 2**	**Scenario 3**
a	0.6±1.2	1.7±3.5	1.9±3.8
b	-16.5±0.8	-46.8±2.4	-50.7±2.6
Investment [€/m^2]	55.7	158.4	171.8
Government NPV without subsidy [€/m^2]	53.0	75.0	87.5

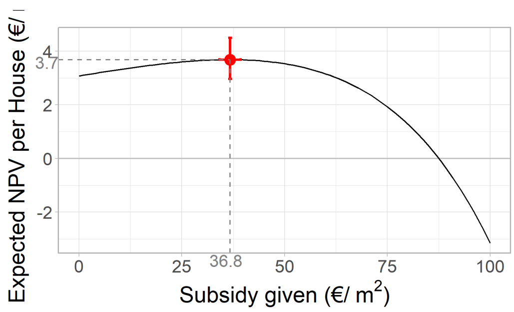
Table 5.4: Computed parameters for the optimal solution of equation (5.3) for each rehabilitation scenario.



(a) Scenario 1.



(b) Scenario 2.



(c) Scenario 3.

Figure 5.2: Subsidy optimal value calculation for each scenario - optimisation of Equation (5.3) with parameters from Table 5.4.

	Scenario 1	Scenario 2	Scenario 3
Optimal Lifetime Subsidy [€/m^2]	36.5C0.8	28.2±2.4	36.8±2.6
Initial Subsidy [€/m^2]	36.5±0.8	19.5±2.4	25.6±2.6
Adherence Rate at Optimal Subsidy [%]	32.3±2.9	6.4±0.6	7.3±0.6

Table 5.5: Optimal subsidy and corresponding adherence.

5.4 Final Results after Subsidy is taken into account

Table 5.6 shows PI and government final financial metrics after the government subsidy is taken into account. Only scenario 1 leads to a positive final NPV for the PI, as the amount of subsidy is not enough to outweigh the negative pre subsidy NPV. This happens because scenarios 2 and 3 are not as beneficial for the government as scenario 1 concerning the initial investment, which leads to less margin for the government to subsidise.

Regarding BCR, the investor has a much higher BCR in scenario 1 than in scenarios 2 and 3, which is no surprise, given the higher subsidy. It is also worth mentioning that the investor's BCR for scenario 1 with a subsidy is more than triple than it was before the subsidy, being now higher than 1, meaning that the benefits outweigh costs.

When looking at MIRR (see Section 2.3), the same conclusions can be taken since only scenario 1 has a higher MIRR than the private investor's discount rate, therefore being the only scenario that is theoretically worth investing in.

As for the government, due to the higher relative subsidy paid in scenario 1, this is the one that has the lowest return on the subsidy per rehabilitation as can be seen by the MIRR and BCR, while the return on the subsidy for scenarios 2 and 3 are roughly similar. It is possible to see that the optimal solution for scenario 1 is, in fact, sacrificing the return on the subsidy to get a higher adherence a much higher adherence rate.

	PI Live			Government		
Scenario	S1	S2	S3	S1	S2	S3
NPV [€/m^2]	11.6±0.7	-40.4±0.7	-52.3±0.8	16.5±0.7	46.8±0.7	50.7±0.8
BCR	1.61	0.66	0.57	1.45	2.66	2.38
MIRR [%]	3.41	0.37	-0.11	3.06	5.16	4.77

Table 5.6: PI live and the government financial metrics after subsidy.

5.5 Scenario Analysis

Given that this study is highly based on future forecasts and estimations, which are not precise numbers by nature, it is important to understand how the outcomes would change if some of the main assumptions change. Therefore, this section studies how the NPV, BCR and MIRR change if the more uncertain estimates that are cash-flow negative go up by 20% and the more uncertain estimates that are cash-flow positive go down by 20%; this being called the pessimistic case. At the same time, it also studies the opposite, which will be called the optimistic case. The variation of 20% was chosen as it is sufficiently significant and believed to encompass all of the real values.

The estimates changed in this section were chosen due to being the most uncertain and harder to estimate, and, for that reason, the author decided not to include the inflation rate nor discount rate.

For the Private Investor that lives in the house, the estimates that will be changed are the improvement in comfort, the savings from fewer sick days and the IMI tax (given that the impact on property value is highly uncertain). The impact that varying these estimates by 20% has on the financial metrics is displayed in Table 5.7.

As it is visible, even though there is a significant range from the Optimistic case to the Pessimistic case, the conclusions regarding if the investment is worth it for the Private Investor are unchanged by the 20% variations for all three scenarios, as the NPV is positive, BCR above one and MIRR above the discount rate for all three cases in scenario 1 and the opposite for scenarios 2 and 3.

For the government, the changed estimates were all the health-related savings, the IMI tax, the cash flows related to more economic activity and the carbon savings benefit. The impact that varying these estimates by 20% has on the financial metrics is displayed in Table 5.8.

As it is clearly seen, with these Subsidy levels, the rehabilitations are beneficial for the government in all three scenarios and respective cases, as NPV is always higher than 0, BCR is always higher than 1, and MIRR is always higher than the discount rate.

	Scenario 1			**Scenario 2**			**Scenario 3**		
Case	Optimistic	Base	Pessimistic	Optimistic	Base	Pessimistic	Optimistic	Base	Pessimistic
NPV [€/m^2]	20.1	11.6	3.2	-27.3	-40.4	-53.6	-38.3	-52.3	-66.4
BCR	2.05	1.61	1.17	0.77	0.66	0.54	0.68	0.57	0.45
MIRR [%]	4.25	3.41	2.31	0.90	0.37	-0.26	0.51	-0.11	-0.87

Table 5.7: PI live financial metrics scenario analysis.

Case	Scenario 1 Optimistic	Scenario 1 Base	Scenario 1 Pessimistic	Scenario 2 Optimistic	Scenario 2 Base	Scenario 2 Pessimistic	Scenario 3 Optimistic	Scenario 3 Base	Scenario 3 Pessimistic
NPV [€/m^2]	25.9	16.5	7.0	60.4	46.8	33.2	66.2	50.7	35.2
BCR	1.71	1.45	1.19	3.14	2.66	2.18	2.80	2.38	1.96
MIRR [%]	3.63	3.06	2.38	5.74	5.16	4.46	5.34	4.77	4.09

Table 5.8: Government financial metrics scenario analysis.

Thus, after the scenario analysis, it is possible to conclude that the results of this study hold, even though there is some variability in terms of the absolute values, the decision that each financial metric indicates for each scenario is constant. Lastly, error propagation is not mentioned in this section, as its small size would not impact in these findings.

Chapter 6

Conclusions

6.1 Findings & Achievements

The economic viability of three rehabilitation scenarios was studied from the point of view of the government and three investors types – the one who lives in the renovated house, the one who rents it and the one who wants to sell it. The first rehabilitation scenario delivers a basic comfort level, where only wall insulations and implementation of double windows are made. The second one, besides the measures from the first, also includes some extra level of comfort, with a MultiSplit and a heat pump AQS. Lastly, the final scenario taken into account in this study goes beyond energy efficiency, as it also adds solar panels, trying to be as environmentally friendly as possible.

For each rehabilitation scenario and PI type/government, a cost-benefit (CB) analysis is performed. In order to estimate each cost and benefit, it was necessary to have an estimation approach similar to [36]. Regarding the three types of PIs, the benefits estimated were energy consumption costs savings, increased property value/rent, healthcare cost savings and increased comfort levels, whereas the considered costs were an initial investment, maintenance & operational costs and finally increased taxes. Although property's value increases substantially (from 5.9% to 11.9% in scenarios 1 and 3, respectively) with the rehabilitations, except for the investor who wants to sell the property after the renovations, there is no cash involved in this benefit. For this reason, costs out weight benefits for the other two private investors.

During the CB analysis, all initial investment is considered to be entirely private, meaning that it was assumed no government subsidy, so the government had no costs, only benefits. These benefits were employment creation due to the construction market's growth (its impact on taxes and subsidies), healthcare expense savings, taxes, and reduced greenhouse gas emissions. More concretely in healthcare expense savings, it was studied the particular case of asthma, as well as sicknesses associated with extreme weather and sick leave days compensation, all of three giving the government a total savings of 0.653€/m^2. The tax balance study (see Appendix A) was very complex to do, once there are many taxes involved in the rehabilitations' world. However, it was extremely necessary, as it is the main source of revenue for the government, delivering up to a total of 29.45€/m^2 for scenario 1 and 50.08€/m^2 for scenario 3 in the first year. This shows that, even though the government diminishes the energy-related tax revenues, the others rise enough to more than make up for the losses. Lastly, as there is no direct cost/revenue for the government associated with savings of GHG emissions, the concepts of the social cost of carbon and negative externality were used, applying the market value of CO_2 to find the economic value of the emissions savings per m^2.

After the cost-benefit analysis, a Capital Budgeting approach was used to calculate the NPV of each initiative to assess if each scenario is a good investment for each type of PI. From that, it was possible to note that for the PIs who live in and rent the house, scenario 1 present the highest NPV compared to the others, followed by scenario 2 and finally scenario 3, which demonstrates the lowest value of NPV. However, NPV for scenario 1 is far from ideal, as it is negative for the both type of investors (-24.9€/m^2 and -61.5€/m^2, respectively). As for the PI who sells the renovated house, it seems like a very good investment, having the highest NPV of 55.4€/m^2 for scenario 3, followed by 1 (31.7€/m^2) and then 2 (21.9€/m^2). Regarding the government and considering that there were no costs for it, its NPV is not surprisingly positive. Moreover, it is very similar for every PI type when talking about the same scenario, averaging 55€/m^2 for scenario 1, 83.3€/m^2 for scenario 2 and 97€/m^2 for scenario 3.

Even though NPV gives an idea of how good or bad an investment might be, it is also relevant to complement it with an analysis of the benefit-cost ratio. As there were no costs for the government, this calculation only made sense for the three PIs. BCR for the PI who lives in the house ranges from 0.44 (in scenario 3) to 0.55 (in scenario 1). For the PI who rents the house, BCR is zero for all scenarios. This result is due to negative cash flows for this investor, as IMI taxes will increase further than expected gain in rent prices. Lastly, for the PI who sells the house, BCR is, as expected, above one for all scenarios, ranging from 1.2 in scenario 2 to 1.57 in scenario 1.

From this first set of results, two main findings were possible to conclude. Given that all three scenarios have positive NPVs for the private investor that aims to sell his/her house after the rehabilitation, the energy-efficient renovations are a very attractive investment for this investor type. The same cannot be said about the other two types of investors, as their NPVs are negative for all three scenarios. For the Private Investor who wants to rent the renovated house, it is particularly unfavourable as its NPV are much lower than what the government benefits from it. This makes it difficult for the government to help financially this type of investor and makes it not economically interesting for the owner to make such an investment. While the case of the private investor who owns and lives in the renovated house is somewhere between the previous two investors. Its NPVs are not positive as it is the case of the investor who wants to sell, but at the same time is not as negative as for the private investor who rents, giving a larger margin for the government to financially help and generate returns at the same time.

The next step was to calculate the best subsidy the government could give as a way to incentivise the private owner to invest in his/her house. After assessing the willingness to pay for the PI who lives in the house for each scenario, the demand function (equation (5.1)) was defined. The maximum of the total new NPV was found using R programming. The optimal subsidy values of 37.6€/m^2, 35.2€/m^2 and 44.7€/m^2 were found for scenarios 1, 2 and 3, respectively. Table 5.6 presents the government and the PI's final financial metrics after the subsidy is taken into account. It is relevant to affirm that the government is willing to subsidise much more, in relative terms, of scenario 1 than the others. This might be because the investment costs increase faster than the government's benefits when going from scenario 1 to 2 and from 2 to 3. With that being said, after the subsidy, the PI only has a positive NPV for scenario 1, although the other two are about half as they were previously the subsidy. It was also possible to calculate BCR and MIRR for both the PI and government. From those values, It is possible to resume that theoretically, the only scenario worth investing is scenario 1. However, there are some other non-math related key factors that might play a relevant role when making a decision. These might be the feeling a PI gets of energy security and sustainability in case of scenario 3 and a more luxurious comfort in scenario 2. Furthermore, with the possible addition of other unmentioned benefits, scenario 2 and 3 might become more attractive.

Following this second set of results, it is possible to note that for scenarios 2 and 3, the government's subsidy is rather limited, as it is not enough to generate a positive NPV for the investor. However, given that most owners who are in the decision process of renovating their homes tend to be less strict when it comes to economic metrics, the government's subsidy might just be enough to convince some owners to rehabilitate their houses. Anyhow, it is necessary to note, that that is only possible if the owner has the financial means to do it, as if he/she struggles financially, it might be impossible to make such investments. Nonetheless, the results for scenario 1 are reassuring, as the subsidy given by the government, allows for the generation economic return for both the owner and the government. This, allied with the fact that the scenario 1 secures basic comfort level for its occupants and it's the minimum energy-efficient renovation that EPBD compels, makes this conclusion preeminent.

Lastly, a scenario analysis was made, changing most uncertain estimates by 20% positively and negatively, with its results being displayed in tables 5.7 and 5.8. By this final analysis it was possible to assume that this study's findings hold, with its financial metrics similar, even with some changed estimates and different absolute values. With this in mind, it would be valuable to study the economic benefit of lower rates of energy poverty in the context of a ”private investor” who is a public entity and who rents its dwellings to people in need.

It is worth mentioning that when comparing with ELPRE's analysis [39], the benefits estimated in the present thesis are substantially lower, which is mainly due to the author's conservative approach and the fact that some significant ELPRE's benefits were not included in this study due to the lack of relevant data.

6.2 Future Work

One of the most complicated challenges in this work was finding relevant studies, with scopes similar to this work, in a way that reasonable assumptions could be made. Therefore, the lack of studies regarding some of the costs and benefits, namely willingness to pay for these measures, warrants a more profound analysis to be performed for each benefit and cost, with a particular focus on the rehabilitation measures from this work and in the climatic/geographic regions of interest. Moreover, when studying the willingness to pay, other external factors should be considered, for example, implementation barriers, as people living in flats need their neighbours to agree on particular renovations that include the whole building.

Other studies should be made regarding heating and cooling needs separately, as there might be considerable differences. Furthermore, to better understand the influence of the macroeconomic environment, it would also be interesting to add other variables in the scenario analysis, such as inflation and discount rates. In this study, the Covid-19 pandemic context was not included, given that it is assumed to be only temporary and this study having a focus on a 30 years time-frame. Nevertheless, it would be interesting to analyse benefits related to this context, given that people spend more time in their homes, such as even higher health benefits and increased productivity, since [36] linked productivity gains to better indoor air quality (productivity increased by 3%-8% due to indoor air quality).

Although this study is quite comprehensive, due to the complexity, some benefits were not taken into account, such as energy security and spillover effects from economic growth. The former being a highly important benefit for the government, as Portugal would become more self-sufficient and therefore depend less on other countries in terms of energy in the residential sector. This would be particularly focused on scenario 3, as besides consuming less energy, the measures also create renewable energy. It would also be interesting to study in the future what would be the impact that the new demand for energy and increased self-sufficiency would have on energy prices [101].

Another unstudied effect is that the energy cost savings will allow households to have more disposable income, which they can use to consume or invest in other sectors, contributing to economic growth. With this in mind, it would be valuable to study the economic benefit of lower rates of energy poverty in the context of a ”private investor” who is a public entity and who rents its dwellings to people in need.

Additionally, in conformity with [15], poor housing conditions can influence households negatively in many more ways than just financially. In step with [102], a correlation between mental health and housing have been examined. Based on [103], mental well-being and social contact can be affected by fuel poverty and the development of children. Inadequate housing indirectly affects children’s educational attainment and emotional well-being. By contrast, good housing conditions, while providing other benefits, improve children’s performance at school [15].

In future studies that aim to study more complex relationships, it is important to consider the rebound effect. While it is also crucial to be clear on the interaction between different benefits to avoid double-counting the same benefit [36]. Additionally, it would be beneficial to consider a phased investment instead of focusing on one year, as it has more lasting economic benefits. Lastly, it would also be interesting to analyse possible compensations for the private investor who rents it. For example, understanding whether tax benefits, such as IMI exemption or even support programs for long term rents after renovations works, would be enough to change the economic perspective of the private investor who rents their apartment.

Other perspectives on the potential of incentivising rehabilitations can be taken. For instance, according to [104], there is a positive correlation between education level and housing comfort. If the plan has a more long-term focus, one way to indirectly incentivise might therefore be to invest in measures that promote the education of the population, particularly on this topic. It is suggested by [3] other possibilities, such as financial facilities to encourage private capital investments, fiscal incentives that may indirectly reduce the cost of investments, measures addressing vulnerable consumers and fuel poverty or even measures addressing landlord-tenant problems. In fact, private investors who rent their place could be encouraged to do renovations through some fiscal benefits such as paying less rental and property taxes.

Lastly, in a future study, it would be interesting to use a macroeconomic model similar to the one used in [36], since it automatically estimates the complex relationships between the different variables in the study, which is particularly beneficial for the factors that affect public budgets, as the impacts are numerous and complex. This would be interesting both at the private investor and at a government and society level.

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Appendix A

Taxes Calculations

A.1 Tax on Energy

The taxes on this section are paid by the final consumer, which means that it is the private investor paying for the government.

A.1.1 IEC – Special Tax on Consumption of Combustible Natural Gas

This tax is integrated as a subcategory of *imposto sobre os produtos petrolíferos e energéticos*/ tax on petroleum and energy products (ISP). It is a variable tax that depends on the natural gas consumption. In 2020 the value was 0.00589 € per kWh [105].

To calculate the decrease in this tax, the change in gas consumption was multiplied by the tax per kWh.

A.1.2 TOS – Tax on Underground Occupation

This tax on Natural Gas is defined by each municipality and has both a fixed (€/ day) and a variable term, with the latter depending on the Natural Gas consumption (€/ kWh). The fixed tax rates are not relevant for this study as the rehabilitation measures will have no impact on them [105, 106].

Below are the rates the variable component for the different AML Municipalities [107, 108]:

- <u>Alcochete:</u> no tax
- <u>Almada:</u> 0.00283633€ per kWh
- <u>Amadora:</u> 0.00161642€ per kWh
- <u>Barreiro:</u> 0.00487195€ per kWh
- <u>Cascais:</u> 0.018887€ per kWh
- <u>Lisboa:</u> 0.00291628€ per kWh
- <u>Loures:</u> 0.00416305€ per kWh
- <u>Mafra:</u> 0.00732961€ per kWh
- <u>Moita:</u> 0.01070919€ per kWh
- <u>Montijo:</u> 0.00519616€ per kWh

- Odivelas: 0.00340152€ per kWh
- Oeiras: 0.00375301€ per kWh
- Palmela: 0.00322486€ per kWh
- Seixal: 0.00773145€ per kWh
- Sesimbra: no tax
- Setúbal: no tax
- Sintra: 0.0086931€ per kWh
- Vila Franca de Xira: 0.00620083€ per kWh

A weighted average of this tax was used, with the weights being the population size [78]. Obtaining a value of 0.0052€ per kWh.

To calculate the decrease in this tax, the change in gas consumption was multiplied by the tax per kWh.

A.1.3 IEC – Special Tax on Electricity Consumption

This tax is integrated as a subcategory of *imposto sobre os produtos petrolíferos e energéticos*/ tax on petroleum and energy products (ISP). It is a variable tax that depends on the electricity consumption. The value for mainland Portugal is 0.001 € per kWh [105].

To calculate the decrease in this tax, the change in electricity consumption was multiplied by the tax per kWh.

A.2 Tax on Workforce & Corporations

A.2.1 IRS (A) – Tax on Individual Person Income (Category A)

This category of IRS is a tax that is applied to an individual person's income from employment and paid by the person. It is a progressive tax, having several brackets that increase with increasing income. Various different factors can impact the tax rate paid, such as number of children, marital status and long-term disease. To simplify, in this study, the Table for the general IRS (A) [1] tax rate in 2020 is used, as shown below (see Table A.1).

To calculate the IRS for a given Income, the formula is IRS (A) = Income · Marginal Tax - To subtract [111].

As mentioned in Chapter 4.1.1, the annual income for the people that are employed by the rehabilitation measures is 13 538€, therefore landing on the 28.5% marginal tax rate. To get to the incremental IRS received by the government by one rehabilitation, the yearly IRS for this type of worker is multiplied by the number of jobs created by the rehabilitation.

Since some of the measures need full reinvestment within the 30 year period, the same rationale that

[1] To check simplified Table go to [109] and complete Table [110]

Annual Income [€]	Marginal Tax	To Subtract [€]
$<$ 7 112	14.5%	-
7 112 - 10 732	23.0%	604.52
10 732 - 20 322	28.5%	1 194.79
20 322 - 25 075	35.0%	2 515.66
25 075 - 36 967	37.0%	3 017.27
36 967 - 80 882	45.0%	5 976.61
$>$ 80 882	48.8%	8 401.21

Table A.1: IRS table considered for the calculation of IRS tax. Source: [111].

was used in Chapter 3.2.1 for cost is used here for employment creation, including the Equivalent Annual Cost method.

A.2.2 IRC – Tax on Collective People's Income

This is the corporate tax rate, which is applied to the companies' taxable income and paid by the companies. The relevant rate for this study is 17% on the first 25 000€ of taxable income and 21% on income higher than 25 000€. While there is an extra tax rate (*Derrama Estadual*) of 3% on income from 1.5M€ to 7.5M€, 5% on income from 7.5M€ to 35M€ and 9% on incomes above 35M€ [109, 111].

To calculate the incremental IRC received by the government, the incremental taxable income generated from the rehabilitations is multiplied by the marginal IRC tax rate, which is assumed to be 21%.

A.2.3 TSU – Social Security Tax

This is a tax on income from work and represents the Social Security Contributions. It is part paid by the employee and part by the employer. The portion paid by the employee is 11% of his gross income, while the employer pays 23.75% of the employee's gross income [111, 112].

To get to the incremental TSU that the government receives by one rehabilitation, the yearly annual income of rehabilitation workers is multiplied by the sum of the two TSU rates and then by the number of jobs created by the rehabilitation.

Since some of the measures need full reinvestment within the 30 year period, the same rationale that was used in Chapter 3.2.1 for cost is used here for employment creation, including the Equivalent Annual Cost method.

A.3 IVA – Imposto sobre o Valor Acrescentado / Value Added Tax (VAT)

This is an indirect tax that is applied to most sales of products, goods, and services. There are three different tax rates, the general one is 23%, the intermediate is 13% and the reduced is 6%. Which rate to use depends on what is sold. This tax is paid only by the final consumer [111].

A.3.1 IVA on Energy

The value added tax rate on electricity is 13% for consumption until 100 kWh per month. and 23% for any consumption exceeding that. For simplicity, only the 13% will be used in this study, this is a reasonable assumption given that, according to the Portuguese government, 86% of electricity contracts use less than 100 kWh per month [113].

The value added tax for the variable component of natural gas is 23% [114]. While it is also 23% for Biomass and Diesel [115, 116].

To calculate the decrease in IVA, the change in energy consumption by type was multiplied by the respective tax rate.

A.3.2 IVA in Rehabilitation

The value added tax rate on the service provided for a housing rehabilitation is 6%, while the value added tax on the building materials used for a housing rehabilitation is 23% [117].

Given that the construction prices provided by ADENE already include IVA, the IVA was calculated by calculating what the price would be without IVA and calculating the difference.

A.4 Unemployment Benefits

The unemployment subsidy is paid by the government and is equal to 65% of the gross income that the worker has received in the last year divided by 12, with the maximum being 1 097€ and the minimum 439€ [118].

The cost savings for the government generated by the rehabilitations is calculated as the number of jobs created by each rehabilitation multiplied by the subsidy that they would be receiving, which is assumed to be the average salary of construction workers multiplied by the subsidy rate [74].

Since some of the measures need full reinvestment within the 30 year period, the same rationale that was used in Chapter 3.2.1 for cost is used here for employment creation, including the Equivalent Annual Cost method.

A.5 Property Taxes

In this section, only the taxes that are impacted by the rehabilitation measures will be mentioned. Meaning, that only taxes that depend on either the property value or the income coming from the property will be discussed.

A.5.1 IMI – Imposto Municipal sobre Imóveis / Municipal Tax on Properties

This is a yearly tax that property owners must pay as a percentage of the value of their property. It is defined by each municipality and can range from 0.030% to 0.45% [119].

Below are the values for 2020 for each Municipality of the AML region [108, 120]:

- Alcochete: 0.38%
- Almada: 0.36%
- Amadora: 0.30%
- Barreiro: 0.38%
- Cascais: 0.34%
- Lisboa: 0.30%
- Loures: 0.37%
- Mafra: 0.45%
- Moita: 0.37%
- Montijo: 0.37%
- Odivelas: 0.36%
- Oeiras: 0.30%
- Palmela: 0.35%
- Seixal: 0.365%
- Sesimbra: 0.40%
- Setúbal: 0.44%
- Sintra: 0.30%
- Vila Franca de Xira: 0.30%

A weighted average of this tax was used, with the weights being the population size [78]. Obtaining a value of 0.34%, which was multiplied by the increase in property value.

A.5.2 IRS (F) – Imposto sobre os Rendimentos Singulares (Categoria F) / Tax on Individual Person Income (Category F)

This category of IRS is a tax rate applied to an individual person's income from renting a property. The tax rate is flat at 28% [119].

To calculate the increase in this category of IRS, the increase in rent prices is multiplied by the tax rate.

A.5.3 IMT – Imposto Municipal sobre a Transmissão Onerosa de Imóveis / Municipality Tax on Transaction of Properties

This tax is applied as a percentage of purchase value, when buying a property. It is a progressive tax, with several different brackets that increase with increasing purchase price. The Table below displays the tax rates:

Purchase Price [€]	Marginal tax	To Subtract [€]
$<$ 92 407	0%	0
92 407 - 126 403	2%	1 848.14
126 403 - 172 348	5%	5 640.23
172 348 - 287 213	7%	9 087.19
287 213 - 574 323	8%	11 959.32
574 323 - 1 000 000	single tax - 6%	
$>$ 1 000 000	single tax - 7.5%	

Table A.2: IMT Table considered for the calculation of IMT tax. Source: [121].

To calculate the IMT for a given purchase price, the formula is IMT = Purchase Price · Marginal Tax - To subtract [121].

On top of this, there is a 0.8% tax on the purchase price, called *Imposto de Selo*/ Stamp Tax (1% if the purchase price is above 1 000 000€) [119].

To calculate the increase in IMT, the value of IMT before and after the rehabilitation for the typical house was calculated. With the difference being the increase in IMT.

A.5.4 Tax Balances

The following tables summarise the calculations above described for each scenario, investor type and government.

Taxes	Scenario 1 [€/m^2]	Scenario S2 [€/m^2]	Scenario S3 [€/m^2]
IVA investment	6,40787	12,58202	13,76585
IVA maintenance	0,00000	0,10117	0,19797
IVA Electricity	0,02560	0,03618	0,07428
IVA Gas	0,00050	0,26944	0,26944
IVA Biomass	0,00106	0,00126	0,00126
IVA Diesel	0,00005	0,00039	0,00039
EIC Gas	0,00017	0,09177	0,09177
TOS	0,00015	0,08107	0,08107
EIC Electricity	0,00088	0,00125	0,00256
IMI	0.30445	0.45719	0.60993
IMT	1,78357	2,67836	3,57315
IRS (rent)	0,04126	0,04126	0,04126
IRC	1,09965	2,15918	2,36234
IRS (workers)	3,19446	4,21088	4,79169
TSU	5,64219	7,43743	8,46328
Unemployment subsidy	10,55373	13,91173	15,83059

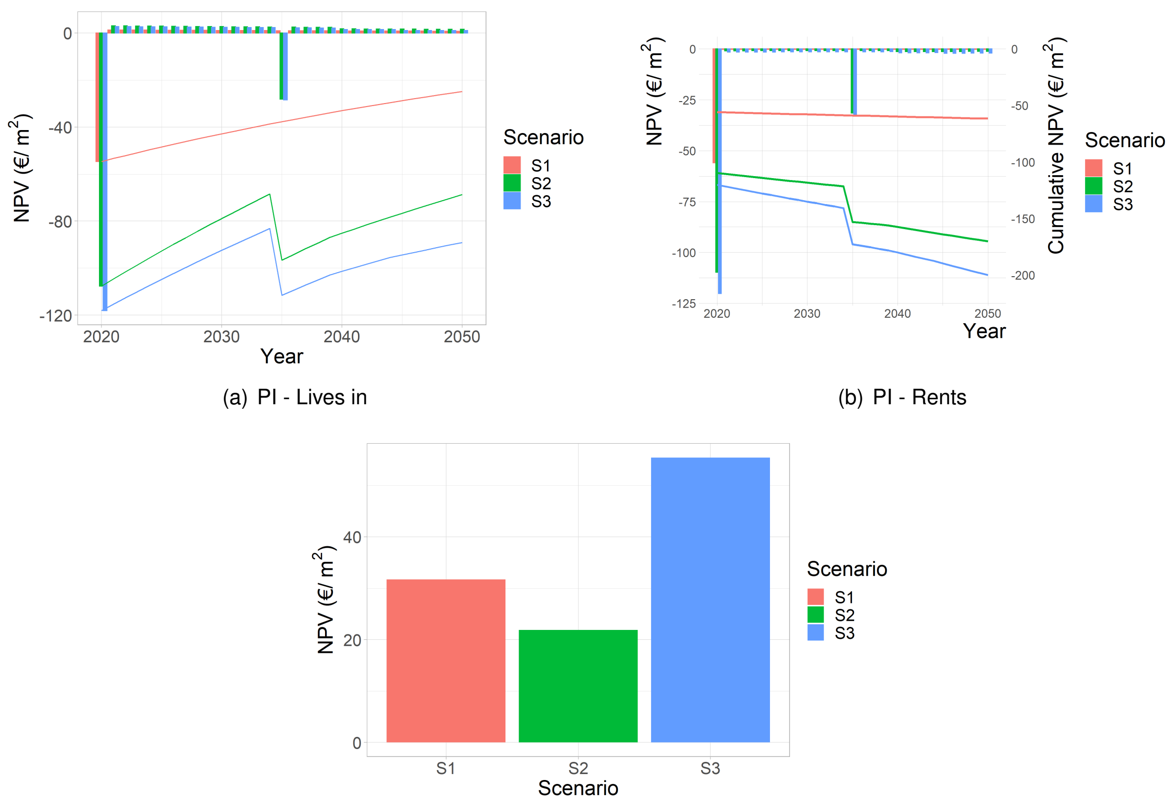
Table A.3: Summary of calculated taxes for all of scenarios

Taxes	government	Investor lives in	Investor to rent	Investor to sell
IVA investment	+1	0	0	0
IVA maintenance	+1	0	0	0
IVA Electricity	-1	+1	0	0
IVA Gas	-1	+1	0	0
IVA Biomass	-1	+1	0	0
IVA Diesel	-1	+1	0	0
EIC Gas	-1	+1	0	0
TOS	-1	+1	0	0
EIC Electricity	-1	+1	0	0
IMI	+1	-1	-1	0
IMT	+1	0	0	-1
IRS (rent)	+1	0	-1	0
IRC	+1	0	0	0
IRS (workers)	+1	0	0	0
TSU	+1	0	0	0
Unemployment subsidy	+1	0	0	0

Table A.4: Impact of each tax for the government and for the three investors type. Legend: -1 for negative impact; 0 for no impact; +1 for positive impact.

Appendix B

Yearly NPV Results

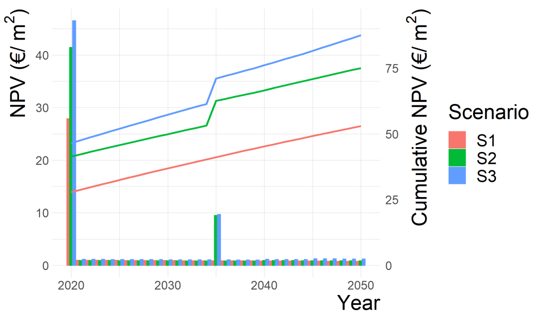


(a) PI - Lives in

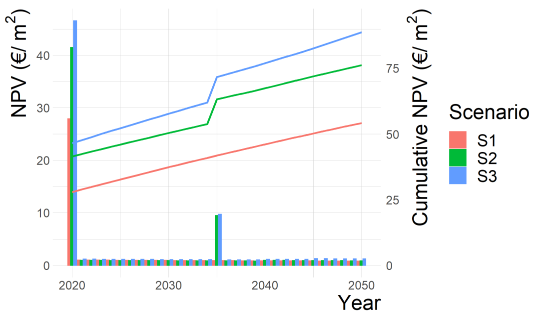
(b) PI - Rents

(c) PI - Sells

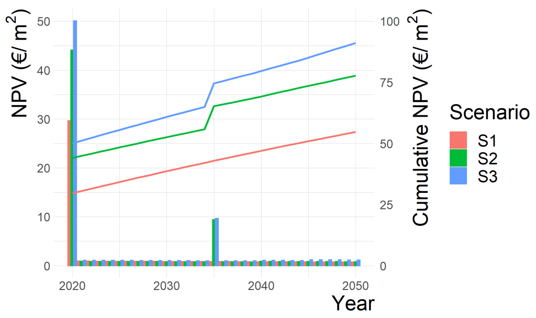
Figure B.1: Yearly NPV for each one of the private investors types for each scenario.



(a) PI - Lives in



(b) PI - Rents



(c) PI - Sells

Figure B.2: Yearly NPV for the government from each one of the private investors types for each scenario.