UNIVERSIDADE D COIMBRA

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ASSESSING ENERGY POVERTY IN PORTUGAL
A NEW METHODOLOGY APPROACH

Dissertation submitted to the University of Coimbra for the Master of Science Degree in Energy for Sustainability, within the scope of Energy Systems and Energy Policies - supervised by Professor Patrícia Pereira da Silva, Ph.D., and co-supervised by Professor Rita Martins, Ph.D.

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The world is very different now. For man holds in his mortal hands the power to abolish all forms of human poverty and all forms of human life.

John F. Kennedy

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In 2015, I began attending classes for a Management Degree at the Faculty of Economics at the University of Coimbra. Were it not for its structures to absorb me for years, the UC was almost my first home and not merely a university. From my role at the Presidency of the NEG/AAC to acting as Academic Start UC Ambassador, General Counsellor, Book in Loop, Intern and Collaborator at the DITS and the World Health Summit, several challenges have led me to write these words. The end of this chapter is near, and I will miss what I regard as the best years of my life. It remains for me to give thanks for this experience.

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Resumo

No "Terceiro relatório pan-europeu sobre pobreza energética do Observatório da Pobreza Energética da UE", Bouzarovski et al. (2020) reconhecem que "a pobreza energética em Portugal é um fenómeno amplamente negligenciado", reforçando como têm sido parcos os esforços envidados pelo país no sentido de dar resposta a este assunto. Em 2013, o UE-SILC indicava que 20% e 29% dos agregados familiares portugueses se encontravam a viver em condições de pobreza energética (Simões et al., 2016). Sete anos mais tarde, o Governo português continua sem definir este conceito e a sua forma de medição.

A presente dissertação aborda o conceito de pobreza energética, analisando o trabalho desenvolvido nos quatro países da União Europeia, ao qual está subjacente um conceito oficial e forma de medição oficiais. Leva também a cabo uma revisão dos indicadores existentes na literatura para cálculo ou estimativa da pobreza energética e respetivas características. Face à inexistência de dados oficiais em Portugal, foi desenvolvida para este país uma metodologia de cálculo/estimativa da pobreza energética. Esta metodologia introduz um inovador recurso a dados relativos ao consumo de energia, considerado ideal para que o agregado familiar viva em conforto térmico, o que permite eliminar todos os casos omissos de agregados familiares que não consomem energia por anteciparem a sua incapacidade de assumir o respetivo encargo. A metodologia baseia-se no uso do Simulador de Eficiência Energética para Edifícios, do Portal CasA+, sendo os resultados obtidos posteriormente conjugados com três indicadores de pobreza energética (10%, MIS e LIHC). Estes indicadores incluem nas suas variáveis elementos que caracterizam cada um dos 16 diferentes tipos de agregados familiares da Região Centro de Portugal.

A partir dos 864 diagnósticos realizados e tendo por base o indicador de 10%, conclui-se que 50,7% desses agregados vive em pobreza energética, ao passo que, segundo o indicador MIS, a percentagem de agregados em pobreza energética sobe para 65,6%. Por outro lado, se for utilizado o indicador LIHC, a percentagem de famílias pobres em termos energéticos passa a ser de 17,4%. Esta análise permitiu também concluir que os equipamentos usados para aquecimento das habitações são os que mais influenciaram os resultados.

Palavras-chave: Pobreza energética; Agregados familiares; Conforto térmico; *Minimum Income Standard*; Simulador Portal CasA+

Abstract

In the "Third Pan-European Report on Energy Poverty of the EU Energy Poverty Observatory" Bouzarovski et al. (2020) recognize that "energy poverty in Portugal is a largely neglected phenomenon", reinforcing how little has been done by the country within this scope. In 2013, EU-SILC indicated that Portugal had between 20% and 29% of its households living in energy poverty (Simões et al., 2016). Seven years later, the Portuguese Government has not yet defined the concept nor how it is supposed to be measured.

This dissertation explores the concept of energy poverty by scrutinizing efforts carried out in the four countries of the European Union as regards an official concept and method of measurement. It also reviews the existing indicators in literature focused on measuring energy poverty and its features. Given the lack of official data in Portugal, a methodology was deveoped for measuring energy poverty in the country. This approach innovates in using data on what each household's energy consumption can ideally amount to in order to achieve thermal comfort, which allows discarding all the missing cases of households that do not consume energy because they anticipate their inability to assume the burden thereof. The methodology is based on data retrieved from the *Portal CasA*+'s Energy Efficiency Simulator for Buildings, the results obtained later being combined with three selected energy poverty indicators (10%, MIS, and LIHC). These indicators include elements that characterize each of a set of 16 different types of households within the Mid-Portugal territory.

Based on 864 diagnoses made and on the 10% indicator, one may conclude that 50.7% of these households live in energy poverty conditions while, according to the MIS indicator, the percentage of rises to 65.6%. If the LIHC indicator is used, the percentage of energy-poverty households is 17.4%. This analysis has also allowed us to conclude that the equipment used for heating the houses is the one that most affected the outcome.

Keywords: Energy poverty; Households; Thermal comfort; Minimum Income Standard; *Portal CasA*+ Simulator

Acronyms

ADEME – French Environment and Energy Management Agency

ADENE – Portuguese Energy Agency

AEA – Austrian Energy Agency

AIAM - Ability to Implement Alleviation Measures

ANRE - Romanian Energy Regulatory Authority

ASECE – Social Tariff on Energy and Supplementary Social Support for Energy Consumers

AT – Austria

BE – Belgium

BG – Bulgaria

CENSOS - General Census of the Population of Portugal

CEPI – Compound Energy Poverty Index

CRES - Centre for Renewable Energy Sources

CY – Cyprus

CZ – Czech Republic

DCENR – Department for Communication, Climate Action & Environment

DE – Germany

DECC –Energy & Climate Change Department

DECO - Portuguese Consumer Defence

DENA - German Energy Agency

DGEG – Directorate-General for Energy and Geology

DK – Denmark

EC – European Commission

EE – Estonia

EHS – English Housing Survey

EIHP - Energy Institute Hrvoje Pozar

ELPRE - Long Term Strategy Deadline for Renewal of Buildings

ENE – National Energy Strategy

ENEA – Italian Agency for New Technologies, Energy and Sustainable Economic Development

EnR – European Energy Network

ENSE – National Entity for the Energy Sector

EPG - Energy Performance Gap

EPI – Energy Poverty Index

EPOV – Energy Poverty Observatory

EPVI - Energy Poverty Vulnerability Index
ERSE - Energy Service Regulatory Authority
ES – Spain
EST - Energy Saving Trust
EU – European Union
EU-SILC - European Union Statistics on Income and Living Conditions
FI – Finland
FR – France
GR – Greece
HEP – Hidden energy poverty
HEPURA - Hungarian Energy and Public Utility Regulatory Authority
HR – Croatia
HU – Hungary
IDEF – Expenditure Survey for Portuguese Households
IDGAE – Inter-Departmental Group on Affordable Energy
IE – Ireland
IEA – International Energy Agency
INE –National Institute for Statistics
ISTAT - Italian National Institute of Statistics
IT – Italy
LIHC – Low income high cost
LT – Lithuania
LU – Luxembourg
LV – Latvia
MIBEL – Iberian Electricity Market
MIS – Minimum income standard
MT – Malta
NL – Netherlands
OFGEM - Office for Gas and Electricity Markets
ONPE – French National Observatory for Energy Poverty
PEES - Economic and Social Stabilization Program
PNEC - National Energy and Climate Plan
PL – Poland
PT – Portugal
RECS – Energy Performance Regulation for Trade and Service Buildings
REH – Energy Performance Regulation for Residential Buildings

RO – Romania

SCE – National Energy Certification System

SDG – Sustainable Development Goals

SE – Sweden

SEAI – Sustainable Energy Authority of Ireland

SEDA - Sustainable Energy Development Agency

SGEIE – Management Systems for Intensive Energy Consumption

SI –Slovenia

SK – Slovakia

UK – United Kingdom

UMVI – Mission Unit for Inner Valuation

UN – United Nations

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1. Introduction

1.1. Contextualization

Energy and its sustainable use have become the top priority for both developing and developed countries (Pereira, 2013).

Access to energy is crucial, among other aspects, to reduce poverty, provide good quality healthcare and education, and enable a higher standard of living. In this context, Hills (2012) considered that energy poverty in developed countries is a severe problem liable to affect poverty, health, and energy efficiency.

After the recent economic crisis in Europe (2008), which led to an increase in the amount of households experiencing unexpected economic hardship, governments started regarding energy poverty as a crucial problem in need of urgent resolution (Herrero, 2017; Scarpellini et al., 2015; Boemi and Papadopoulos, 2017).

1.2. Motivation

Energy poverty is a subject that has received growing attention from the scientific community. In 2019, several publications were written about Energy Poverty in Portugal (Gouveia et al., 2019; Horta et al., 2019; Kyprianou et al., 2019; Rodrigues et al., 2019; Silva, et al., 2019). Around the same time, Portugal was ranked by European Union as one of the countries with more citizens potentially living in energy poverty conditions.

Besides all studies, Portugal still lacks an official definition of Energy Poverty and its respective calculation method. The absence of suitable metrics (namely those based on the reality of each country's territory) is keeping the Portuguese Government from establishing a strategy to address this issue. In addition, the level of energy illiteracy of the Portuguese population as a whole does not assist the chief decision makers in valuing energy poverty and, consequently, prevents thorough guidelines from being implemented to fight the phenomena by, for instance, encouraging the improvement of buildings' energy efficiency.

1.3. Goals

The first goal of this dissertation was to understand how governments in France, Ireland, United Kingdom and Slovakia managed to define the concept of energy poverty and its associated indicator, and then assess what the best indicator to estimate energy poverty in Portugal might be. During the research process, one could realize that the process used by those four countries to define the concept and choose its relevant indicator was not clear nor straightforward enough.

Additionally, Portugal has no official data on energy poverty, which increases the difficulty in coming up with a unique or unquestionable way to measure it. The purpose of this dissertation emerges from within the following scope of things: proposing a methodology to estimate/calculate energy poverty in Portugal, based on a household's ideal energy consumption in order to live in thermal comfort conditions. The *Portal CasA+*'s Energy Efficiency Simulator for Buildings (an initiative of ADENE, the Portuguese governmental entity in charge of activities related to energy) introduces the major innovation of this methodology: to account for energy poverty based on the ideal energy consumption level for a household to be in perfect thermal comfort conditions. This innovation would thus avoid omitting all cases of households that do not consume all the energy that they recognize in advance is unaffordable for them. So, a sample of households from the Mid-Portugal territory was chosen, taking into account the most representative types of households and dwellings in the area.

1.4. Structure

Regarding the structure, this dissertation is organized into six different chapters (and includes references and annexes). Chapter 1 is the starting point, providing the contextualization, motivation, and purpose of this dissertation.

Chapter 2 addresses the concept of energy poverty, exploring the countries of the European Union with an official definition of energy poverty, It also proceeds to survey how energy poverty can be measured through distinctive indicators (and introduces the European Union report on this subject).

The methodological approach is presented in Chapter 3. The focus here is the case study, with a small description of the Portuguese energy system and the variables that may influence Portugal's energy poverty, like weather conditions, demography, socioeconomics, and building features. Chapter 4 sets about adjusting the *Portal CasA+*'s Energy Efficiency Building Simulator to the data collection on energy poverty in Portugal, in order to better fit our main goal. Then, each scenario's results are described in Chapter 5.

Chapter 6 beholds the key outcomes obtained and reflects on possible future work to be undertaken in the field of energy poverty in Portugal, aggregating the main outputs of all research carried out. This chapter also mentions the most typical hindrances to the research development process.

2. Energy poverty conceptualization and ways of measurement

In 2011, the UN Secretary-General Ban Ki-Moon launched the “SEforALL- Sustainable Energy for All” initiative, which is now an international organization. This initiative is about working with leaders in government, the private sector, and civil society to drive further, faster action toward the achievement of the Sustainable Development Goal (SDG) 7 (Seforall, 2020).

The SDG was later defined by the United Nations (UN) in 2015, as everyone’s mind became set on a better and more sustainable future (such an enterprise should be achieved by 2030). When considering the access to energy, the "SDG 7 - Accessible and Clean Energy" is the directly concerned SDG. However, there are also other goals concerning the topic, such as "SDG 1 - No Poverty", "SDG 2 - Zero Hunger", "SDG 3 - Good Health and Wellness", "SDG 4 - Quality Education", "SDG 5 - Gender Equality", "SDG 8 - Decent Work and Economic Growth", "SDG 9 - Industry, Innovation and Infrastructure", and "SDG 11 - Sustainable Cities and Communities" (IEA, 2017).

The energy problem has become more noticeable as the concepts of clean energy and sustainable energy were introduced, since poorer populations use polluting fuels more frequently, with adverse effects on the health of users and the environment (Neacsa et al., 2020). In 2017, the International Energy Agency (IEA) estimated that 1 billion people fail to have access to electricity. According to the defined SDG, this number should decrease to 674 million until 2030 (IEA, 2017). This chapter will address the different definitions of energy poverty, its consequences and ways of measuring it.

2.1. The concept of energy poverty

Despite the growing attention devoted to this issue, there is still a lack of consensus on the definition of energy poverty, making it difficult to know precisely how many people are living in energy poverty conditions. Looking at EU surveys, it is possible to see that the number of people living in energy poverty conditions varies between 50 and 160 million, depending on the definition and the indicator used (European Union, 2017).

Energy poverty is often known as the “*inability to keep homes adequately warm*” (EC, 2014); however, every country/area/territory has different features likely to affect how energy poverty prevails.

To better explore this concept, is it crucial to understand the difference between energy poverty and fuel poverty, often mistakenly used as synonyms. Regarding this problem, the European Commission (2010) explained that energy sources included in fuel poverty are electricity, natural gas, liquefied petroleum gas, oil, coal, district heating, and other solid fuels included in a broader group than those considered in energy poverty references made in the internal energy market legislation, which only include electricity and gas. This work draws attention to how using energy sources (electricity and gas) exclusively would exclude consumers that use fuels other than electricity and gas to heat their homes. From a macro perspective, both concepts have almost the same implication, which is why many authors do not advocate a distinction (Papada and Kaliampakos, 2016; Simões et al. 2016). However, some propose to tell these concepts apart, having in consideration some variables as: i) definition focus; ii) measured approach; iii) research target; or iv) research organization (Kang Li et al. 2014).

In 2014, a study requested by the European Union allowed the creation of a concept map, which we can see in Figure 1.

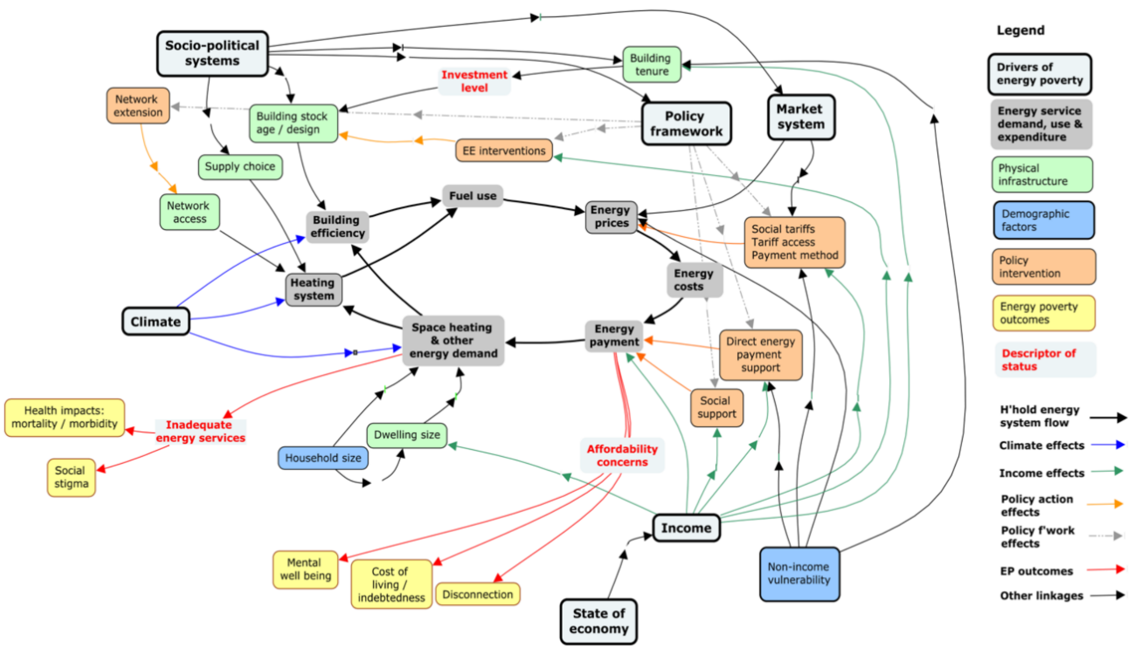


Figure 1: Conceptual map of the drivers, causes and effects of energy poverty (Trinomics, 2016)

To better understand the map, it is essential to look into the author's explanation of the image caption. The map is divided as follows:

a) "Drivers of energy poverty" are the drivers that impact the affordability of household energy services and could lead to energy poverty: i) Socio-political systems; ii) Policy framework; iii) Market system; iv) Climate; v) Income; and vi) the State of Economy;

b) The household energy system's demands, use and expenditure: i) Building efficiency; ii) Fuel use; iii) Energy Prices; iv) Energy Costs; v) Energy payment; vi) Space heating and other energy demands, and; vii) Heating system.

c) Key factors influencing or causing energy poverty, specifically relating to: i) physical infrastructure; ii) policies; and iii) demographic factors.

Based on the map, it is possible to understand how complex it is to find a definition (and metrics) liable to combine all the components and that is also adaptable for every country. For this dissertation, the expression used will be energy poverty. It will be use because of the focus of this research (which excludes transport costs). Another reason for choosing it has to do with the concept used by the European Commission in the Energy Poverty Observatory (2020), where energy poverty is described as the inability to guarantee the presence of "*adequate heat, cooling, lighting and energy for electrical appliances are essential services necessary to ensure a decent standard of living and the health of citizens*".

Along with energy poverty, comes the definition of vulnerable consumer. However, it is essential to realize that *vulnerable consumers* and *energy poor consumers* are not synonymous. The different definitions of vulnerable consumer are grounded on criteria concerning uneasy access to social support and to service energy (low income or high expenses) or presence of faults and other specific socioeconomic groups (Pye et al., 2015). Energy poverty and vulnerable consumers have been acknowledged in European legislation (Romero et al., 2018), by the Directives 2009/72/CE of July 13th 2009 and 2009/73/CE of July 13th 2009 (electricity and gas, respectively). In Directive 2009/72/CE (2009), the European Union requires all the Member States choose an official definition - a goal that hasn't been achieved yet. In Directive 2009/72/CE (53) (2009), it is further claimed that:

> "Energy poverty is a growing problem in the Community. Member States which are affected and which have not yet done so should therefore develop national action plans or other appropriate frameworks to tackle energy poverty, aiming at decreasing the number of people suffering such a situation. In any event, Member States should ensure the necessary energy supply for vulnerable customers".

Each country is required to define and list the concept, as we can see on Directive 2009/72/EC (2009), chapter II, article 3, (7):

> "Member States shall take appropriate measures to protect final customers, and shall, in particular, ensure that there are adequate safeguards to protect vulnerable customers. In this context, each Member State shall define the concept of vulnerable customer, which may refer to energy poverty and, inter alia, to the prohibition of disconnection of electricity to such customers in critical times".

In 2015, Pye et al. proposed the different definitions of the concept of vulnerable consumer, as shown in Table 1:

Table 1: Categorization of Member States' definitions of vulnerable consumers (Pye et al., 2015)

Definition type	Member state (MS)
Energy affordability (low income / high expenditure)	FR[2], IT, SE
Receipt of social welfare	BG, CY, DE, DK, EE, FI[1], HR, HU, LT, LU, MT[4], PL, PT, SI[3,6]
Disability/health	CZ, NL, SK, IE
Range of socio-economic groups	AT, BE, ES, GR, RO, UK[5]
Not available / Under discussion	LV

More than forty percent (14 in 30) of the member state countries use social transfer measures to combat energy poverty. Ireland and Slovakia consider vulnerable consumers as the households that include people with disabilities or health problems. Latvia is the only country without an official definition of vulnerable consumers.
The Portuguese case will be addressed in chapter 3.

2.2. Consequences of energy poverty

The consequences of energy poverty are the most significant concern of governments, because not only they occur at various levels, but also because of the long-term influence that they may have on people's lives, the economy, health, and maybe the environment. This section explores the many potential effects and the existing data regarding each.
González-Eguino (2015) summarized three types of impacts:

1) Impacts on health: The World Health Organization (2018) estimates that 3.8 million people a year die prematurely from illness attributable to household air pollution

caused by the inefficient use of solid fuels and kerosene for cooking. Among these 3.8 million deaths, 27% are due to pneumonia, 18% to stroke, 27% to ischemic heart disease, 20% to chronic obstructive pulmonary disease and 8% to lung cancer.

2) Impacts on the economy: Energy poverty affects all business sectors and limits development potential, especially in agriculture. The access to and consumption of energy has a potentially deep impact at various levels: a) In education, where statistics show that households with better and easier access to electricity and street lighting have higher literacy rates (Khandker et al., 2014); b) In health, where the availability of transport is often a determining factor in providing effective medical treatment in a timely manner, and; c) The access to information and communication technologies could encourage people to set up their own micro companies, allow people free access to high-quality online training courses, and drive towards empowerment in society.

3) Impacts on the environment: Energy poverty and the environment are somehow connected, mainly through land use change. As indicated by the author, traditional biomass provides the main source of energy for poorest people, and its over-exploitation leads to increased deforestation, desertification and land-degradation. However, detailed worldwide studies in many areas have documented that the main cause of deforestation lies not in the consumption of traditional biomass (representing 6%), as sometimes is assumed. Instead, it is due to the expansion of farmland for crops and livestock and illegal logging. Moreover, the loss of woodland has significant implications for the populations in question: not only do they lose firewood but many of the services provided by the relevant ecosystems will vanish with them, including sources of food and water, thus forcing populations to migrate.

The Energy Poverty Observatory (EPOV) reinforces the multiple benefits of fighting energy poverty. Among them are: less money spent by governments on health, less air pollution, better comfort and well-being, better family budgets, and greater economic activity. The negative impacts of the prevalence of energy poverty on a population are intertwined in a cause-effect relationship. Thus, fighting energy poverty at various levels (improvement of buildings, efficient equipment, among others) is the first step towards reducing energy poverty, lowering the impacts caused by it, and consequently reducing state expenditure on solving this problem.

2.3. Energy Poverty definition in some EU countries

In the EU, the United Kingdom, Ireland, France, and Slovakia are the only countries with an official definition of energy poverty (Sammer and Wüstenhagen, 2006; Pye et al., 2015). The complexity of finding variables that support each country's own differences is very high. Some of them are i) geographic features; ii) weather conditions; iii) architectural features of the houses; and iv) population's socioeconomic reality. Additionally, other variables may be defined by each country. In the following sections, actual case processes for the official definition of energy poverty in those countries will be presented.

2.3.1. United Kingdom

When this research began, the UK was still part of the EU. However, it was decided to keep the in-context survey of this country in this research project, despite the fact that BREXIT was decided in October 2019 and formalized by the EU on January 31st 2020 (Council Decision (EU) 2019/1750).

Boardman (1991) proposed the first formal definition of energy poverty as follows: "*[a] home would be energy poor if its expenditure in energy services exceeds 10% of its total income*", commonly known as "*10% indicator*" (as cited in Romero et al., 2018). Following the review of the fuel poverty policy, Hills (2012) proposed a new definition, the Low-Income High Cost (LIHC) measure, stating that "*a household is fuel poor if it has lower than average income and higher than fuel costs*" (as cited by Middlemiss, 2017). Strakova (2014) used data from England in 2009, and compared the use of the 10% indicator and the LIHC indicator. The numbers (using the 10% indicator) showed that more than 1.3 million households were living in energy poverty conditions in England.

The 10% indicator definition is still used in Scotland, Wales and Northern Ireland but is to be replaced in Scotland, as mentioned in the EnR Position Paper on Energy Poverty in the European Union (EnR, 2019). This can be explained by the availability of the data needed to calculate the 10% indicator. In a similar perspective, these countries also recognized the 20% indicator, which rates as extremely energy-poor households those that expend more than 20% of their income in energy (Basterra, 2018).

2.3.2. Ireland

In 1942, Ireland took the first step in supporting energy-poor families with a "*social welfare support for energy*" via the Cheap Fuel Scheme, which has remained in place under many guises to this day (DCENR, 2016). In 2000, the Sustainable Energy Authority of Ireland (SEAI) introduced the first national scheme - the Better Energy Warmer Homes Scheme - to improve the energy efficiency of households living in energy poverty conditions. The Inter-Departmental Group on Affordable Energy (IDGAE) was created to develop an energy poverty strategy for Ireland and, in 2011, published the first-ever national Affordable Energy Strategy, named "Warmer Homes", with 48 priority actions. These actions have resulted in the implementation of: new area-based models for providing energy efficiency interventions to clusters of homes at risk of energy poverty; new legislation to guarantee legal protection to electricity and gas consumers; an online repository of affordable energy information for householders in Ireland; and legal requirements incumbent on all energy suppliers to address the energy poverty issue. In 2009, 317,000 households were potentially energy poor, equivalent to 20% of all households in the state. However, there are limitations to the 10% indicator as the amount "*people actually spend on energy may deliver an inadequate picture of energy poverty since many of those (...) may be living in homes that are inadequately heated*" (DCENR, 2016).

Ireland is still using the 10% indicator to estimate energy poverty in the scope of a planned strategy defined by the Department of Communications, Energy & Natural Resources. The government has also explained that:

> "The Low Income/High Costs model is an attempt to address the limitations of a pure expenditure-based model of energy poverty. Under this model to be considered in energy poverty, a household must have both a low income and face high-energy costs (defined as twice-median energy costs). This is an attempt to ensure that statistics on energy poverty do not capture those households that are not income poor but choose to live (in a home) with poor energy efficiency. Some objections have been raised to this methodology, it appears to have caused some confusion among consumers and there is, as yet, no evidence to suggest that the new definition is improving targeting of supports." (DCENR, 2016).

Recently, the Roadmap for Social Inclusion, published in January 2020, includes all existing initiatives and policies to tackle energy poverty, as well as housing-related contents, such as:

1) The Climate Action Plan (August 2019) that includes provisions on energy poverty and monitoring mechanisms.
2) Social Justice Ireland, an independent think tank and advocacy group which has developed a growing interest on energy deprivation. Initiatives include the Warmth

and Wellbeing pilot scheme in Dublin, developed by the Department of Communications' Climate Action and Energy Action and the Sustainable Energy Authority of Ireland, which aims to improve the living comfort of vulnerable families suffering from chronic respiratory problems. (Bouzarovski et al., 2020)

2.3.3. France

According to the *Observatoire National de la Précarité Énergétique*, someone who is hard pressed to provide himself/herself enough energy supply to satisfy elementary needs is regarded as living in energy poverty conditions. However, this definition is not official in the entire country (ONPE, 2014), and the problem of understanding what the definition best suiting the French context might be still remains (Dubois, 2018).

Legendre and Ricci (2014) used three partly-subjective criteria: i) ability to afford keeping one's home warm; ii) presence of dampness, leaks and mould in the accommodation; and iii) arrears on electricity, gas and water bills. According the authors, depending on which subjective criteria you use, the definition of a fuel-poor household differs significantly, failing on the general characterization.

Many projects are being developed in France, such as the RAPPEL program (founded in 2007), which keeps on being the key actor both in the fight against energy poverty and the provision of 'decent housing,' with the collaboration of the ONPE. The *Habiter Mieux* programs are at the heart of the State's aid programs via the National Housing Agency and financed by Energy Saving Certificates (Bouzarovski et al., 2020).

Dubois (2018) used data from the national housing survey to compare both the 10% indicator and the LIHC. The percentage of households in energy poverty conditions differed by 0.1% (corresponding to 0.4 million people), when using one indicator or the other. This small variation, as well as proving more straightforward to calculate, can be what accounts for the fact that France goes on using the 10% indicator.

2.3.4. Slovakia

Slovakia was the last country in EU to define the energy poverty concept. This step was taken by implementing the Third Energy Liberalization Package into the Slovak law (Strakova, 2014). According to the Law No. 250/2012, Coll. Of Laws, of July 31st 2012, energy poverty "*is a status when average monthly expenditures of household on the consumption of electricity, gas, heating and hot water production represent a substantial share of the average monthly income of the household*."

In Slovakia, the expression *"energetická chudoba"* incorporates two English terms: energy poverty and fuel poverty (Strakova, 2014), excluding the difference between these terms mentioned earlier. In 2012, estimates showed that, if the 10% indicator were applied, all the Slovak households would live in energy poverty conditions. However, Data from the EU SILC Indicators of poverty and social exclusion (2012) demonstrate that almost 13.2 % of households live in energy poverty conditions.

In Slovakia, in February 2020, the Office for the Regulation of Network Industries (ÚRSO) submitted to the Government a report on the 'Concept for the Protection of Customers Meeting the Conditions of Energy Poverty', proposing a definition and several solutions (Bouzarovski et al., 2020).

2.4. European Energy Network

The European Energy Network (EnR) is a voluntary network currently numbering 24 national European energy-management agencies. They mostly have responsibility for the planning, management, or review of national research, development, demonstration or dissemination programs in the fields of energy efficiency, renewable energy, and climate change abatement (EnR, 2019). The Italian Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) took the EnR Presidency in February 2018, and chose *Energy Poverty* as the focus of activities. To achieve this goal, an *ad hoc* Task Force was established, involving experts from eleven EnR Members: ADEME (France); ADENE (Portugal); AEA (Austria); ANRE (Romania); CRES (Greece); DENA (Germany); EIHP (Croatia); ENEA (Italy); EST (United Kingdom); HEPURA (Hungary); SEDA (Bulgaria). This group agreed (except Austria and Slovakia) to circulate a survey to obtain an overview of energy poverty definitions, an idea of how it is measured, and knowledge of what policies are being implemented in tackling the issue in each country.

The survey included four sections: 1) Definition, measurements, roles, and mandates; 2) Description of the energy poverty measurements; 3) Policy measures in force; and, 4) Political action. The results obtained by the task force provided the following guidelines:

a) Introducing a unique EU energy-poverty calculation method, which could be a LIHC measure, and complement it with country-specific indicators set according to country-specific characteristics.
b) Promoting energy efficiency measures as critical solutions to the energy poverty problem, by allowing for multiple benefits and structural changes and by acting locally.

c) Developing an integrated approach to tackle energy poverty and to draft nation-wide policy responses.
d) Examining energy poverty implications in terms of the cost distribution underlying the measures adopted, in order to achieve the long-term energy and environmental goals.
e) Acknowledging that training and information campaigns are essential to obtain a behavioural change and then boost dwelling energy-renovation rate when it comes to households in energy poverty conditions.

The most crucial question as regards these guidelines is understanding the different needs felt by each country that is taking *point a)* into account. It is of the utmost importance that the measures implemented in the fight against energy poverty are not only economical but also permissive of an energy-efficiency development of buildings, with expense reduction being a natural consequence of the process.

2.5. Measuring Energy Poverty

Energy poverty definitions are directly related to the indicator chosen to quantify the issue. Boardman (1991) proposed that energy poverty could be measured by the percentage of households that have to spend 10% or more of their income on energy services. This metrics, called the 10% indicator, was the only available calculation method for some time (Herrero, 2017).

Since then, Moore (2012) proposed the use of the Minimum Income Standard (MIS) indicator, considering that this indicator is more focused on energy poverty and more adaptable to different standards in Europe (Romero et al., 2018).

In MIS, a household is considered energy-poor if "*after deducting their actual housing costs, they have insufficient residual net income to meet their total required fuel costs*[1] *after all other minimum living costs*[2] *have been met*". In a more streamlined way, in MIS, a household is energy-poor "*if it does not have enough income to pay for its basic energy costs, after covering housing and other needs*" (Romero et al., 2018). For the definition to take place, the following equation (1) must be verified:

$$(1)\quad [Fuel\ Costs\ (EHS)] > [Net\ household\ income\ (LHIC)] - [Housing\ Costs\ (EHS)] - [Minimum\ Living\ Costs\ (MIS)]$$

[1] As estimated by the EHS.
[2] As defined by the MIS.

John Hills (2012) proposed the Low Income High Cost (LIHC) indicator, that seeks to assess energy poverty based on what the household income amounts to, stating that a household is energy-poor if the costs are higher than the energy expenditure threshold defined for that income level, as explained below (Romero et al., 2018).
To calculate this indicator, Hills proposed the following equations (2) and (3):

$$(2)\ [Household\ expenditure\ on\ energy] > [Median\ expenditure\ on\ energy]$$

$$(3)\ [Household\ income] - [Household\ expenditure\ on\ energy] < 60\%\ [Median\ Household\ income]$$

Figure 2 shows four quadrants, in which the variables are the "Income Threshold" and the "Cost Threshold". For the calculation of the LIHC indicator, we should look at the lower left quadrant of Figure 2, which establishes the necessary conditions for an individual or household to be classified as energy-poor. It also includes the population that is not normally considered energy-poor according to standard definitions, but is pushed into energy poverty by its high energy needs (DECC, 2013).

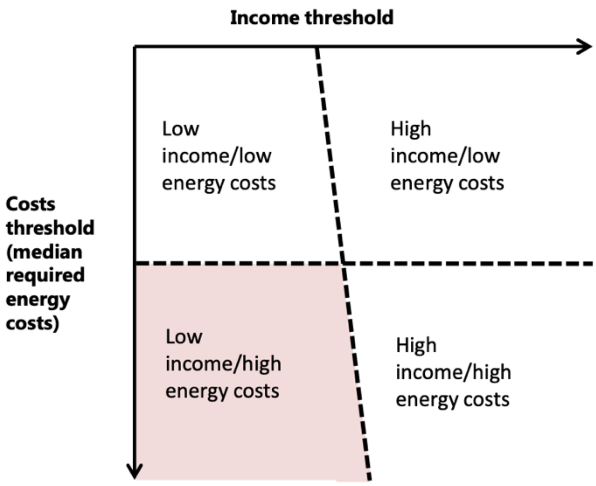


Figure 2: Representation of LIHC calculation quadrants (DECC, 2013:pp 9)

One important notion to have in mind is what is called the fuel poverty gap (Figure 3), calculated as the difference between a household's required fuel costs and what these costs would have to amount to in order for the concerned household not to be in fuel-poverty conditions. This is referred to as the fuel poverty gap, and gives an indication of how severe this problem can be from one household to another (DECC, 2013:pp 9).

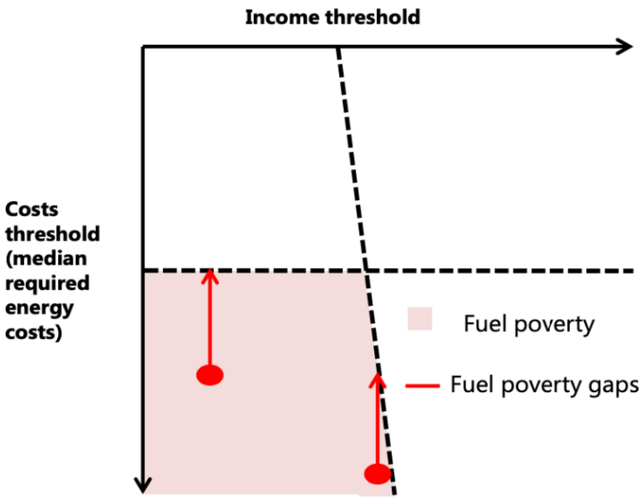


Figure 3: The fuel poverty gap (DECC, 2013:pp 9)

Bouzarovski and Herrero (2015) proposed a different approach. Using the *Energy Poverty Index* (*EPI*), they divided countries by three clusters with different energy-poverty levels and dynamics, as defined by equation 4:

$$(4)\ EPI = (0{,}5 \times Inability + 0{,}25\ Arrears + 0{,}25 \times Housing\ Faults) \times 100$$

The *EPI* uses the EU-SILC percentages of people who have reported:

1) being unable to keep their homes adequately warm (*Inability*),
2) having arrears in utility bills (*Arrears*), and
3) living in a house with a leaking roof or the presence of dampness and corrosion (*Housing faults*).

The component *Inability* has a higher weight because the authors considered that the difficulty in keeping dwellings adequately heated is directly related to energy poverty.
Maxim et al. (2016) further developed the idea implied in the equation proposed by Bouzarovski and Herrero (2015), by defining the Compound Energy Poverty Index (*CEPI*):

$$(5)\ CEPI = (0{,}3 * Not\ warm + 0{,}2 * Not\ cool + 0{,}1 * Not\ Dark + 0{,}2 * Arrears + 0{,}2 * Leaks) * 100$$

The *CEPI* (Maxim et al., 2016) uses the percentage of the population who have reported:

1) living in a dwelling not comfortably cool during summertime (*Not cool*);
2) considering their dwelling as too dark (*Dark*);

3) being unable to keep their homes adequately warm (*Not warm*);
4) having arrears in utility bills (*Arrears*); and
5) living in a house with a leaking roof, or the presence of dampness and corrosion (*Leaks*)

Romero et al. (2018) summarized the pros and cons of the 10% indicator, the MIS and the LIHC, based on the views of several authors, as Table 2 demonstrates.

Table 2: Summary of pros and cons of income-based energy poverty indicators (Romero et al., 2018)

Indicator	Pros	Cons
10%	1. Simple to calculate 2. Easy to communicate 3. Relatively versatile from a pragmatic point of view	1. Excessive sensitivity to energy prices 2. Arbitrary selection of the threshold at 10% 3. Lack of any reference to the household income
MIS	1. Robust when measuring objective income-based energy poverty by addressing the problem from its very economic root	1. Difficulty to determine the minimum income on an objective basis
LIHC	1. Corrects the 10% indicator by considering not only the expenditure on energy but also an income threshold	1. Overly complex and not transparent indicator 2. Difficulty to find out those households that can come out of energy poverty by way of reducing their energy costs 3. Doubly-relative character which makes very difficult to isolate causes and effects when analyzing time series

In the last indicators shown (EPI and CEPI) the variables include household-response data. Although these indicators happen to be more complete, they require an elaborate data collection operation. They are based on what each household reports on the subject, and the responses given may not stand for reality.

Betto et al. (2020) proposed a new approach, developing a new hidden Energy Poverty (hEP) indicator, which allows lessening the amount of energy-poverty cases found to be missing from the previously analysed indicators. The indicator identifies a household in hidden energy poverty conditions, then adds two constraints related to the household's absolute poverty and the considered household's building construction period. The hEP is represented in equation (6):

$$(6)\ [(H_i)_{j,k} > ((\frac{1}{n}) \cdot \sum_{i=0}^{n} (H_i)_{j,k}] \cap [(RP)_i = 1] \cap [(AP)_i = 1] \cap [(CP)_i < const]$$

where I = 0, ..., n, i.e. the *i*th household, j = 1, ..., 6, i.e. the amount of household members, and k = B, D, E, i.e., the climate zones defined. Additionally, H_i is the energy expenditure of the *i*th household, $(RP)_i$ is the relative poverty condition of the *i*th household, and "n" is the number of households with the same amount of members (j) and living in the same climate zone (k) of the *i*th household. The threshold value is calculated as $((\frac{1}{n}) \cdot \sum_{i=0}^{n}(H_i)_{j,k}$ and represents the mean value of the energy expenditures of those households with the same member amounts (j) and living in the same climate zone (k) of the ith household. Relative poverty (RP) is a discrete variable of the Italian National Institute of Statistics (ISTAT) data that contains only the integers 0 and 1, hence "$(RP)_i = 1$" means that the *i*th household is in relative poverty conditions, while "$(RP)_i = 0$" means that the *i*th household is not in relative poverty conditions. AP_i is the absolute poverty condition of the *i*th household, CP_i is the construction period of the building where the *i*th household lives, and the constant named "*const*" is the reference year (i.e., 1979). As with *relative poverty* above, *absolute poverty* is a discrete variable of the ISTAT data that contains only the integers 0 and 1, hence "$(AP)_i = 1$" means that the *i*th household is in an absolute poverty condition, while "$(AP)_i = 0$" means that the *i*th household is not in an absolute poverty condition. Although there is evidence of a reduction in omission cases, this indicator does not discard all cases, since no ideal consumption is established for each type of family and dwelling, as the methodology proposed in this dissertation does.

2.6. European Union report

Thompson and Bouzarovki (2018) provided an overview of the energy poverty outlook in the EU, from November 30th 2016 to July 31st 2018. The authors argued that energy poverty should be viewed as a multi-dimensional concept, which implies the use of a suite of indicators simultaneously. Firstly, the authors divided the indicators (Annex 1) as primary and secondary, according to the data source:

1) Primary indicators – those that capture various aspects of energy poverty - are applied elsewhere in policy and research;
2) Secondary indicators – the reasons for a secondary classification are twofold. Perhaps these indicators captures aspects of energy poverty but fail to meet the indicator quality criteria listed above. They are relevant in the context of energy poverty but are not a direct indicator of energy poverty itself.

In the report, five primary indicators were studied. The results are summarized in the following table:

Table 3: Summarized indicators study (Thomson and Bouzarovski, 2018)

Indicator	Description	EPOV Data Source	EU households living in Energy Poverty (average)
Inability to keep home adequately warm	This indicator encompasses the prevailing qualitative definition of energy poverty and captures self-reported thermal discomfort issues.	EU – SILC (2004-2016)	8.7%
Arrears on utility bills	This indicator captures potential financial difficulties, and is an important indicator as households unable to keep up to date with energy bill payments may experience disconnection of supply. Note, however, that it covers all utility bills, including those beyond energy. In addition, arrears are not possible for some energy carriers, such as heating oil and wood pellets.	EU – SILC (2004-2016)	8.1%
High share of energy expenditure in income (2M)	Proportion of the population whose share of energy expenditure in income is more than twice the national median share.	2010 HBS Data Source	16.3%
Hidden energy poverty (HEP)	Share of population whose absolute energy expenditure is below half the national median, *i.e.*, abnormally low.	2010 HBS Data Source	15.1%
Summertime issues	Dwelling equipped with air conditioning facilities (yes/no)	EU-SILC ad- hoc modules 2007	10.8%
	Dwelling not comfortably cool during summertime (yes/no)		25.8%[3]

As mentioned by EnR (2019), promoting the use of a single indicator to measure energy poverty would allow the European Union to have actual data on household conditions in each EU country. This data information allows the definition of goals for each country, with measures to tackle energy poverty and the ensuing improvement in energy efficiency.

[3] In 2012, this figure decreases to 19.2, according to information from EU-SILC data.

However, this is not possible if one concept or definition is not consensual, as it will not allow for comparisons among EU countries. The European Union Report (2018) analyses different indicators, showing that a variation in results ranging between 8.1% and 25.8%. As regards vulnerable consumers, the EU has assigned Member States the task of providing a definition and measures to fight energy poverty. A definition and a calculation method should also be established in this case.

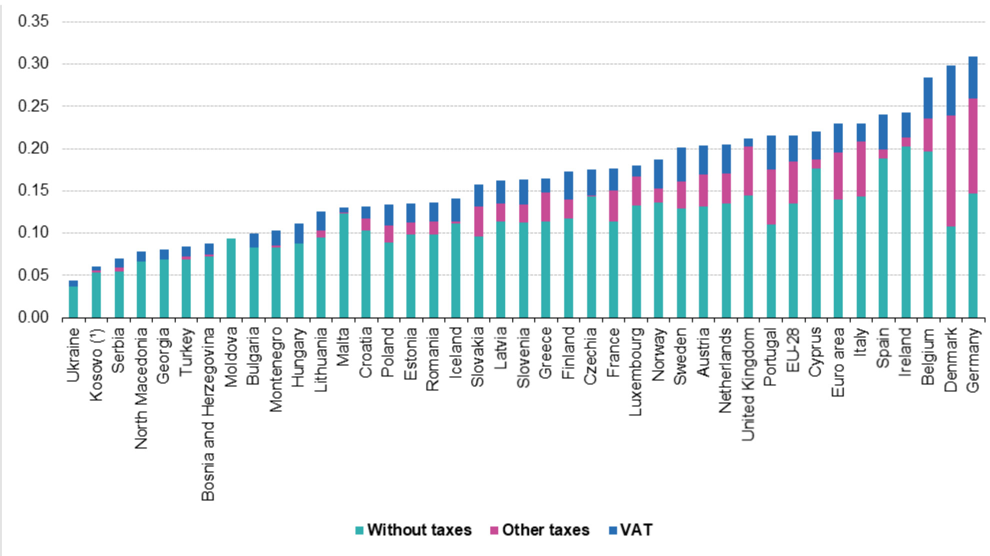
However, these measures should present *a priori* standardized rules, such as the variables that must be mandatorily included. These measures should be based on an ideal energy consumption for each household, thus avoiding the omission of all households that do not consume energy they cannot afford. That is why the next chapters of this dissertation propose a new methodology for estimating energy poverty, by designing a completely new approach to how three existing indicators are to be used (10%, MIS and LIHC). This is because the data introduced in the variables corresponding to energy consumption will not deliver the actual consumption. It will instead deliver the ideal consumption for a household to be in thermal comfort conditions, according to the concerned dwelling's features. This is possible by means of the *Portal CasA+'s* Simulator.

3. Drivers of Energy Poverty in Portugal

In Portugal, the energy sector is regulated by the Regulatory Authority for Energy Services (ERSE) and the DGEG (General Directorate of Energy and Geology) is the licensing entity. ERSE is in charge of all inspection procedures (2020).

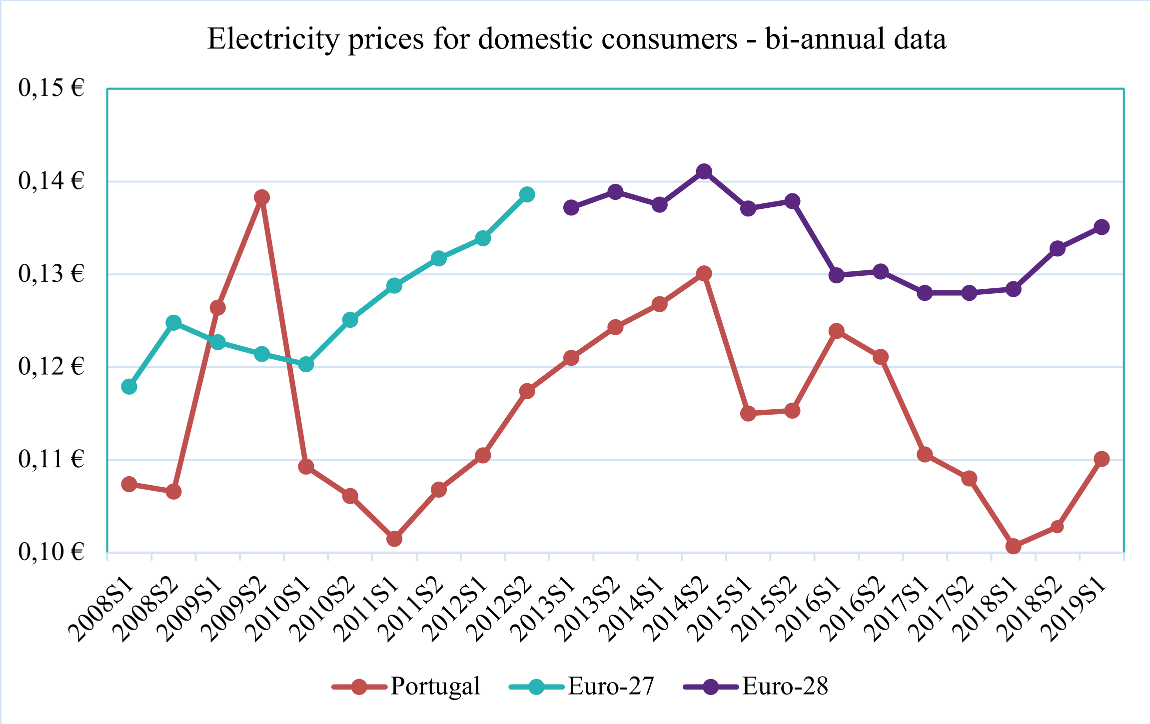
ADENE is the National Energy Agency with the mission of driving public interest action in the scope of energy, efficient use of water and energy efficiency in mobility. It is responsible for managing a number of initiatives, such as the National Energy Certification System (SCE), and the "*Portugal Energia*" (a platform that includes programs such as the Management System for Intensive Energy Consumption (SGCIE), the Energy Information Center "*Cinergia*", the Energy Observatory, and also the "*Poupa Energia*" Platform).

In recent years, Portugal has evidenced one of the higher energy bills in the EU. Compared to other countries (looking at data related to band DC: 2500kWh < Consumption < 5000 kWh), the Portuguese pay the eighth-highest bill, despite being one of the countries with the lowest purchasing power, as is shown on Graphic 1. It is also possible to see the percentage of taxes and levies included in the energy bill.



Graphic 1: Electricity prices for household consumers, in the first half of 2019 (Eur/kWh), with all taxes and levies included). Source: Eurostat

However, this trend has not been maintained on recent years. In 2008 and 2009, electricity prices in Portugal were much higher than the average prices in the EU, something that concurs with the economic crisis of 2008. The lowest value was recorded in the first half of 2018, but costs have been increasing since then. Graphic 2 shows how the energy bill has been evolving in Portugal and the EU.



Graphic 2: Electricity prices evolution in Portugal and the EU (EU-27 from 2008 to 2013 and EU-28 after 2013 and up to 2019)

Expensive energy bills makes many households unable to afford the energy consumed. In 2010, the Decree-Law no. 138-A/2010, of December 28th 2010, was published and it set about defining the first criteria for qualifying as a vulnerable consumer in Portugal. Motivated by the Program of the 18th Constitutional Government and aligned with the National Energy Strategy 2020 (ENE 2020), there was an important focus on the creation of the internal energy market and the completion of the Iberian Electricity Market (MIBEL). The Decree-Law also mentions the trend towards a price increase, the volatility of energy costs internationally, and the intention to further coordinate things within the energy market, which validates the sort of constructive policymaking liable to protect the most economically-vulnerable consumers. Decree-Law 172/2014 of November 14th 2014 is the most recent update to these policies, establishing the following requirements to benefit from the Social Energy Tariff and the Complementary Social Support for Energy Consumers (ASECE):

1) The client must benefit from at least one of the following social supports: a) Solidarity complement for the elderly; b) Social inclusion income; c) Unemployment benefit; d) Family allowance; e) Social disability pension; f) Old-age social pension; or
2) The client must receive an annual income lower than the Maximum Annual Income (RAM) defined under the Decree-Law no. 138-A / 2010 of December 28th 2010, even if he does not benefit from any of the social supports above. For this purpose, the total income recorded in the relevant tax domicile is to be considered, according to the amount of persons living in that household. Currently, the following RAM values apply.

In the second option described above, a person is eligible to receive the benefit if the household's yearly earnings do not exceed the threshold of 5,808 euros, plus 50% for each member that does not earn any salary, up to a maximum of 10 members (Silva et al., 2019). In 2016, Law no. 7-A/2016, of March 30th 2016, amended the Decree-Law no. 138-A/2010 and the Decree-Law no. 101/2011. The access to the social energy tariff benefit was to occur through an automatic recognition mechanism. This mechanism made the numbers increase by 283% between the 2nd and the 3rd quarter of 2016 (Martins et al., 2019). In 2011, 73, 550 households received a social energy tariff, a number that would increase to 812, 680 in the 3rd trimester of 2018.

Despite this effort, the acknowledgement of and support to vulnerable consumers does not solve the structural problems underlying energy poverty. Thus, the next sub-chapters address the variables that allow the characterization of the Mid-Portugal territory, such as weather conditions, buildings, and households.

3.1. Weather conditions characterization

The Official Administrative Map of Portugal (CAOP) of 2018 indicates that Mainland Portugal has 89, 015 square kilometres, a number that does not include the Azores and Madeira archipelagos[4].

According to data from the Portuguese Climate Portal, the average temperature recorded in the period from 1972 to 2000 was approximately 13.6º C (Figure 4).

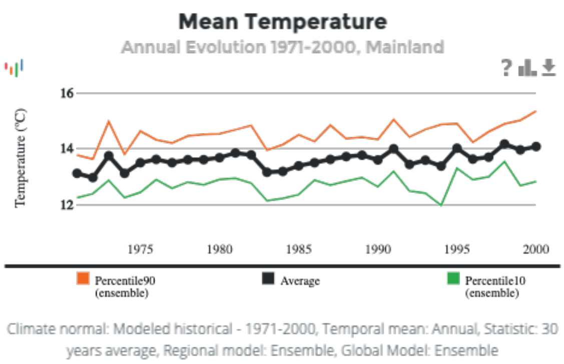


Figure 4: Mean temperature from 1971 to 2000 in Portugal
Source: Portuguese Climate Portal, 2019

[4] Since these archipelagos are Autonomous Regions with some variations in their own legislation, they will not be included in this work.

Its distribution during the year can be observed in Figure 5.

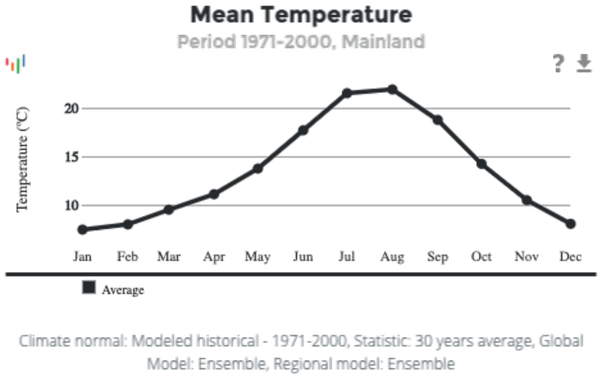


Figure 5: Mean annual temperature evolution from 1971 to 2000 in Portugal (Portuguese Climate Portal, 2019)

The variation in geographic characterization leads to differences in atmospheric conditions. Therefore, data was aggregated considering the NUTS 2 exclusively (excluding the archipelagos), in Table 4.

Table 4: Average temperature and thermal amplitude between 1971 and 2000 and prediction to 2041-2070 by NUTS II (Portuguese Climate Portal, 2019)

Region	Average Temperature		Thermal Amplitude[5]	
	(1971-2000)	(2041-2070)	(1971-2000)	(2041-2070)
Northern Portugal	11.3º C	12.8º C	8.9º C	9.2º C
Mid Portugal	12.9º C	14.4º C	9.2º C	9.4º C
Lisbon Metropolitan Area	15.3º C	16.6º C	8.8º C	9º C
Alentejo	15.3º C	16.8º C	10.6º C	10.3º C
Algarve	16º C	17.4º C	9.4º C	9.5º C

In all regions, an increase is forecasted in average temperatures between 1.3º C and 1.5º C. The Thermal Amplitude is expected to vary between 0.1º C and 0.3º C for the years between 2041 and 2070.

According the Long Term Strategy Deadline for Renewal of Buildings (ELPRE) (European Parliament, 2020):

> Two thirds of the national building park in Portugal was built before the introduction in 1990 of energy efficiency requirements for new buildings (Decree-Law No. 40/90 of June 2, however revoked), which is reflected, in many cases, in high energy needs and even in situations of energy poverty with an impact on thermal comfort and the health of the occupants. The Portuguese built park is an aging park, particularly in the residential sector".

[5] Thermal Amplitude: daily difference between the minimum and maximum temperature

That is why it is possible to predict that Portuguese households in old buildings will increasingly be subject to thermal discomfort, since their homes are not prepared for the existing variations of temperature (Palma et al., 2019).

3.2. Demography and socioeconomic characterization

Portugal has a population of 10.562.178 (Censos, 2011). 30.81 % of the population (3.254.177 inhabitants) lives in cities with a population of more than 20.000. Table 5 shows the population density by region (NUTS II), according to data referring to the population per square kilometre.

Table 5: Population density by region - NUTS II (INE, 2019)

Portuguese Regions (NUTS II)	Average number of individuals per square kilometre
Northern Portugal	167.9
Mid Portugal	78.6
Lisbon Metropolitan Area	946.8
Alentejo	22.3
Algarve	87.8
Portugal mainland	110

Lisbon Metropolitan Area is clearly different from the rest of the country, when looking into population density.

In terms of age profile, in 2011, there were 164.1 older people per 100 young people and 48.7 older people per 100 people in working age, which characterizes Portugal as a country with a significant aging population. Table 6 shows age characterization by region.

Table 6: Aging index and elderly dependency ratio by NUTS II (INE, 2019)

Portuguese Regions (NUTS II)	Aging index[6]	Elderly dependency ratio[7]
Northern Portugal	162.7	31.1
Mid Portugal	201.4	38.5
Lisbon Metropolitan Area	138.2	35.3
Alentejo	204.6	41.1
Algarve	145.4	34.4
Portugal mainland	161.3	34.2

[6] Number of elderly people per 100 young people

[7] Elderly people per 100 in working age

After Alentejo, Mid Portugal has the most significant aging value. The National Program for the Territorial Cohesion Report (2017) demonstrates that demographic processes and socio-economic development are generally uneven: "*The increase in territorial disparities announces marked differences in social conditions, competitiveness, and prosperity, and pose challenges for national cohesion and cooperation policies*." (UMVI, 2016).
Table 7 shows the different amounts of people recorded as unemployed, the difference between national minimum wage and average monthly base salary, and the purchasing power by region.

Table 7: Summarized values of the socio-economic variables by NUTS II (INE, 2016,2017)

	Northern Portugal	**Mid Portugal**	**Lisbon Metro. Area**	**Alentejo**	**Algarve**
Recorded unemployed by% of resident population aged 15 to 64 years (2016)	7.6%	5.3%	5.9%	6.3%	5.5%
Difference between national minimum wage and average monthly base salary (2016)	-304	-276	-621	-283	-264
Purchasing power (2017)[8]	92.1	88.3	124.1	90.1	99.1

Northern Portugal is where the highest percentage of unemployed people is recorded, and the lowest unemployment value is found in Mid Portugal. Algarve is the region with the worst average salary (when compared with the minimum salary). In terms of purchasing power, Mid Portugal has the worst value and the Lisbon Metropolitan Area is the region with the highest value, which is significantly higher than the other areas.

3.3. Building features

A building's features may seriously affect the energy efficiency of each dwelling, as it happens to be one of the major influences on a household's thermal comfort. In addition,

[8]Data on purchasing power is not available for the year 2016

heating, ventilation, and air conditioning systems play a remarkable role as regards the energy consumption of buildings (Silva et al., 2016).

By screening the latest data concerning the Building Aging Index (BAI) (*Instituto Nacional de Estatística and Direcção-Geral de Energia e Geologia*, 2011), Portugal is found to have an aging index of 1.76 (its Mid-Territory region has a 1.86 aging index). According to *Datacentro* (2011), the BAI allows knowledge of the amount of buildings built before 1960 per each building built after 2001, which is calculated as follows:

$$BAI = \frac{Buildings\ built\ before\ 1960}{Buildings\ built\ after\ 2001}$$

This means that, in the Mid-Portugal territory, 1.86 buildings were built before 1960 for each building built after 2001. On average, household condition is poorer and there is a greater difficulty in keeping the ideal temperature. A study by Simões et al. (2016) showed that "*In average terms, 22% of the inhabitants are potentially fuel-poor regarding the satisfaction of their dwellings' heating needs and 29% regarding cooling needs*", after going over 679 civil parishes. This occurs because old buildings are not well fitted for temperature fluctuations, as stated above.

Since 2002, the EU has been introducing regulations on buildings' energy certification. Addressing the energy performance of buildings, Directive no. 2002/91/CE of December 16th 2002, by the European Parliament and the European Council, was transposed into the national legal system through Decree-Law no. 78/2006 of April 4th 2006, which rendered official the National System for Energy Certification (SCE). It was replaced by Directive no. 2010/31/EU of May 19th, which the European Parliament and European Council transposed to the national law by the Decree-Law no. 118/2013 of August 20th, as explained below. This replacement made it possible to widen the scope of the energy certification system and its regulations (while at the same time rendering it more systematic). It also enabled national demands to be aligned with what it explicitly seemed to be imposing. All this is included in a single document: the Energy Certification System for Buildings (SCE), the Energy Performance Regulation for Residential Buildings (REH) and the Energy Performance Regulation for Trade and Services Buildings (RECS).

The update of national legislation already brought into force involved changes at various levels, particularly as regards: a) simplifying the legislation in a single document; b) distinguishing between the REH and RECS implementations, the first focusing exclusively on residential buildings and the latter on commercial and services buildings; and 3) acknowledging the SCE certificate as a technical certification (adapted from Decree-Law no. 118/2013 of August 20th). Scope 4 of Article 3, Chapter II of Decree-Law no. 118/2013, of August 20th, specifies that:

> "All buildings are still covered by the SCE or fractions existing from the moment of its sale or donation in fulfilment or after the entry into force of this law, except in the cases of: a) sale or donation in compliance with co-owner, the lessee, in executive proceedings, or the expropriating entity, for total demolition confirmed by the competent licensing authority; (b) the rental of the landlord's usual place of residence for less than four months; (c) the lease to whoever is already the lessee of the leased thing."

An increase in energy certifications demonstrates the actual state of things regarding energy efficiency in buildings, since the primary sales and rental actions depend on the issue of an SCE certificate. The Decree has now been amended six times: Decree-Law no. 68-A/2015, Decree-Law no. 194/2015, Decree-Law no. 251/2015, Decree-Law no. 28/2016, Law no. 52/2018 and Decree-Law no. 95/2019, with some specific changes concerning energy performance, special regimes, and others. Currently, 1, 299, 496 certificates have been issued, out of which 1, 144, 156 are from residential buildings. This number represents 34.88% of the total residential buildings in Portugal (when compared to the 3.991.156 residential buildings recorded in 2011) (INE, 2011).

In July 2020, the *Portal CasA+* (an initiative of ADENE) had a record of 1, 953, 177 houses, with 1, 218, 174, 562 € in savings for the households, resulting from a total of 2, 796, 880 improvement measures proposed by the Portal to their users. In this portal, the users provide information about their property and update it with new data and information about housing features. The project aims to inform citizens about energy efficiency and determine the energy class of their dwellings. One of the principles underlying the simulator that integrates the project is the assumption that households are in the right temperature conditions throughout the year (18º C in winter and 25º C in summer). Therefore, the results corresponding to each dwelling result from the feature input by the user. This tool allows the identification of energy-efficiency improvement measures based on the features of the dwelling, which can lead to a reduction in energy consumption. In the portal, we may find three simulators that provide information about the energy efficiency of a certain home such as a) Housing Simulator; b) Household Appliances Simulator; and c) Lighting Simulator.

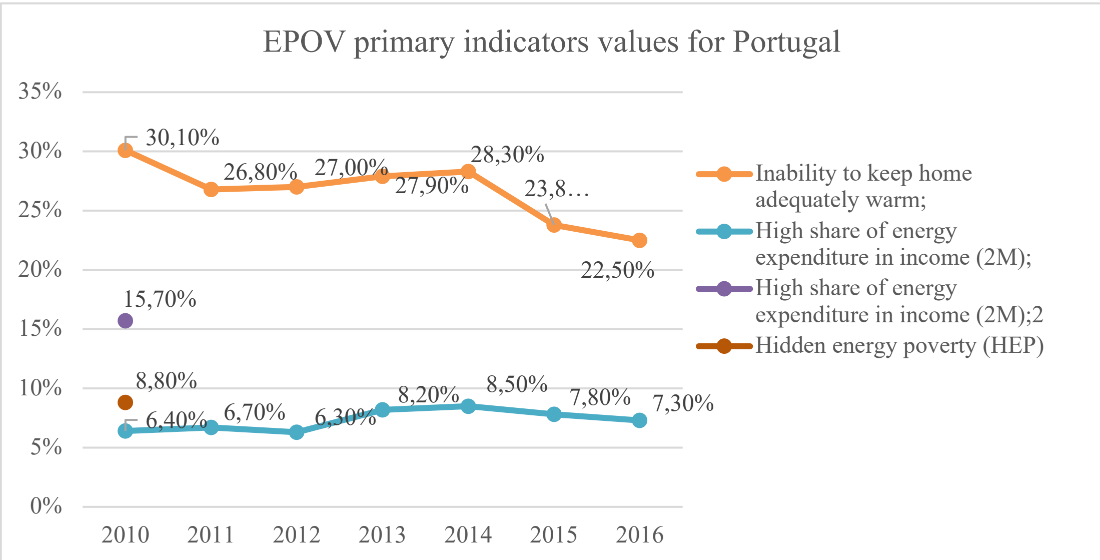
According to ADENE, "*This tool is not intended to replace the in-depth work of a qualified expert, but to raise consumer awareness based on statistical averages of the potential and dynamics of energy efficiency improvements in private homes*."

In summary, Portugal has a high rate of aged population. Mid Portugal, specifically, has the second-worst value of both the aging index and the elderly dependency ratio. Despite being the Portuguese territory with the lowest unemployment rate, it is ranked with the worst national purchasing power and the second-worst average salary.

Regarding dwellings, Mid Portugal gets a high score when it comes to aging buildings (1.86), well above the national average of 1.76. This is particularly concerning since the territory's average annual thermal amplitude is 9.2º C, which is expected to increase to 9.4º C until 2041.

3.4. Previous studies

Over the years, some organizations have tried to estimate the percentage of the population living in Energy Poverty conditions. In 2016, the INE estimated that 25.10% of the Portuguese population lived in such conditions. More recently, Matos proposed 25,00% (2017). Graphic 3 shows the different results, depending on the metrics and sources used.



Graphic 3: Different EPOV primary indicator values for Portugal between 2010 and 2016 (adapted from Simões et al., 2016; Matos, 2017; EnR, 2019)

More recently, Rodrigues et al. (2019) made available a study about Energy Poverty in Portugal, commissioned by EDP.

The authors mainly use 2015/2016 data from a national household-expenditure survey - *Inquérito às Despesas das Famílias* (IDEF). The approach used three different methods to assess energy poverty, each with different indicators:

1) The household perception approach;
    a. The proportion of individuals considered unable to afford a warm house;
2) The expenditure approach or energy expenditure;
    a. Energy cost ratio higher than 10%
    b. LIHC (1) - the indicator tested for Portugal, although strongly inspired by the methodology developed for the UK, still boasts the possibility of different options regarding the definition of the reference threshold for energy expenditure and the reformulation of the poverty line to consider energy costs. The energy-expenditure reference threshold is defined as a relative value (not an absolute one). It is defined as the median value of how much of the household income is spent on energy (as advanced by the IDEF). The economic poverty line is redefined to include the energy expenditure benchmark, i.e., the economic poverty line is now defined as the 'official' economic poverty line plus the median of declared energy expenditure.
    c. Energy cost rate higher than the median value of households with similar features;
3) The direct approach or direct measurement;
    a. LIHC (2) – as used in England;
    b. Economically-poor households whose energy expenditure is less than adequate;

The research group found that the proportion of energy-poor individuals varies between 8.1 % and 18.9 %, depending on the estimation considered. 22.5% of the individuals are energy-poor according to at least one estimation, and 5.4% are poor whatever the indicators considered. The percentage of households regarding themselves as unable to afford a heated house was 42.7%.

In addition, Gouveia et al. (2019) combined the population's socioeconomic indicators with climate, energy consumption, building's final energy demand, construction features, and energy performance of different building typologies. Figure 6 summarizes the key components and methods envisaged in the proposed methodology.

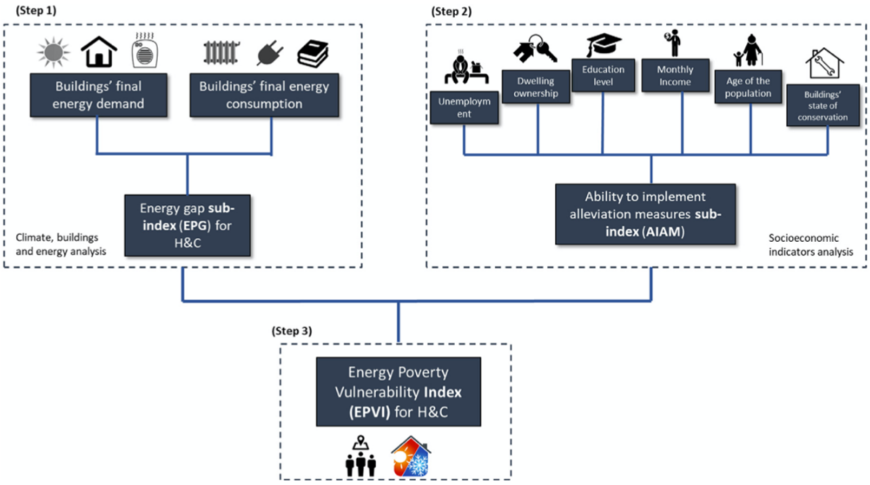


Figure 6: Methodological Approach for conceiving the multidimensional Energy-Poverty Vulnerability Index (Gouveia et al., 2019)

The research project proposed the index (EPVI) and sub-indexes (EPG and AIAM), testing the methodology in 3,092 Portuguese civil parishes (mainland and islands).

Using the indicators referring to the building features and household's features, the authors calculated the EPVI, whose results are shown in Figure 7. On the left side (red), the heating-related EPVI is shown, and the right side (blue) shows the cooling-related EPVI.

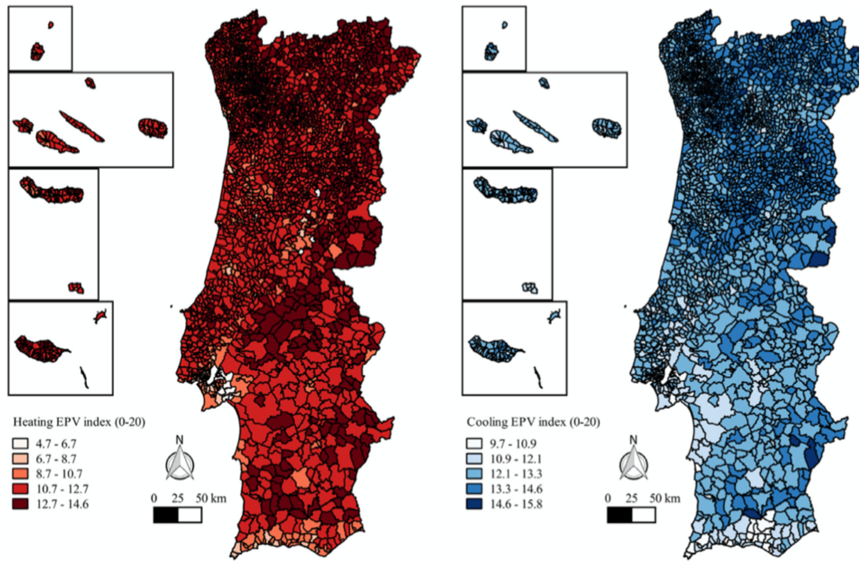


Figure 7: Heating (left) and Cooling (right) EPVI (Gouveia et al., 2019)

Recently, several programs on energy efficiency have been introduced and should have an impact on energy poverty reduction, such as:

1) *Casa Eficiente 2020* (Efficient House 2020) aims to promote dwellings more energy-efficient, providing soft loans to operations that promote the improvement of private housing's environmental performance, with a particular focus on energy and water efficiency, as well as urban waste management. The interventions may focus on the building envelope and its systems. It was co-financed by the European Investment Bank;
2) ADENE and the University of Porto are partners in the Interreg's Sudoe Energy Push project on social housing in the north of Portugal, aiming to identify innovative solutions for socially-minded energy management, in order to assess and quantify the cost effectiveness of energy efficiency measures;
3) The consumer organization DECO is also a partner in the Horizon 2020 STEP project to develop a simple, innovative and replicable model of measures to address energy poverty. The goal behind it is to cover some of the countries with the highest rates of energy poverty in Europe. These are Bulgaria, Cyprus, Czech Republic, Latvia, Lithuania, Poland, Portugal, Slovakia and the United Kingdom.

More recently, the Environmental Fund opened a call for tenders ("Support Program for More Sustainable Buildings"), included in the Economic and Social Stabilization Program (PEES) approved by the Council of Ministers' Resolution 41/2020 of June 6th 2020. The main goal is to assist all citizens in contracting interventions in buildings, aiming at their sustainability and energy rehabilitation. Measures like this are among the ones with the greatest multiplier effect on the economy, generating employment and wealth at a local and national level. The fact that there is such a program, although very interesting when improving the energy efficiency of buildings, may exclude households that live in energy poverty conditions. This is because, despite the support given by the government, there is always a percentage of investment that is ensured by the household (i.e. the placement of efficient windows (class A+ or higher) is granted a participation rate of 70% up to the limit of 1,500 euros), which will limit households with no budget availability for an investment. Despite all the projects, the National Energy and Climate Plan 2021-2030 (PNEC 2030) has defined the following measures at Line of Operation 8.2. "*Combating energy poverty and improving vulnerable customer's protection instruments*":

a) 8.2.1. Promoting a long-term strategy to combat energy poverty. [Scheduled date: 2019-2021]

b) 8.2.2. Establishing a national energy poverty assessment and monitoring system, including the number of family members in energy poverty conditions. [Expected date: 2020-2021]
c) 8.2.3. Pursuing mechanisms to protect vulnerable consumers and study the introduction of new mechanisms. [Expected date: 2019-2030]
d) 8.2.4. Developing programs to promote and support energy efficiency and the integration of renewable energy to mitigate energy poverty. [Expected date: 2020-2030]
e) 8.2.5. Promoting and supporting local strategies to tackle energy poverty. [Expected date: 2020-2030]
f) 8.2.6. Disseminating information to mitigate energy poverty. [Expected date: 2020-2030]

In the next Chapter, the methodology used to measure energy poverty in Portugal implies usage of the *Portal CasA+*'s Building Simulator. It consists of a ground basis for obtaining an ideal energy consumption for each type of housing chosen. To this simulator will be added data from different types of households of Mid Portugal, according to the three indicators chosen (10%, MIS and LIHC).

4. Methodology

To apply the various energy-poverty measurement indices, multiple data are required, regarding not only household incomes, but also energy consumption.

Considering the short time during which this project took place, it was not possible to conduct an actual-data household survey. In this sense, *Portal CasA+*'s Energy Efficient Simulator was used, by which one gains knowledge of the ideal energy consumption (according to building characteristics of each household) in order to reach thermal comfort. This will demonstrate that energy poverty classifications that consider the ideal consumption of energy to reach thermal comfort will exclude all the omitted energy-poverty cases, since discarding will then occur of households that do not consume energy because they know *a priori* that they cannot afford it.

Figure 8 shows the map of interactions regarding potential actions underway.

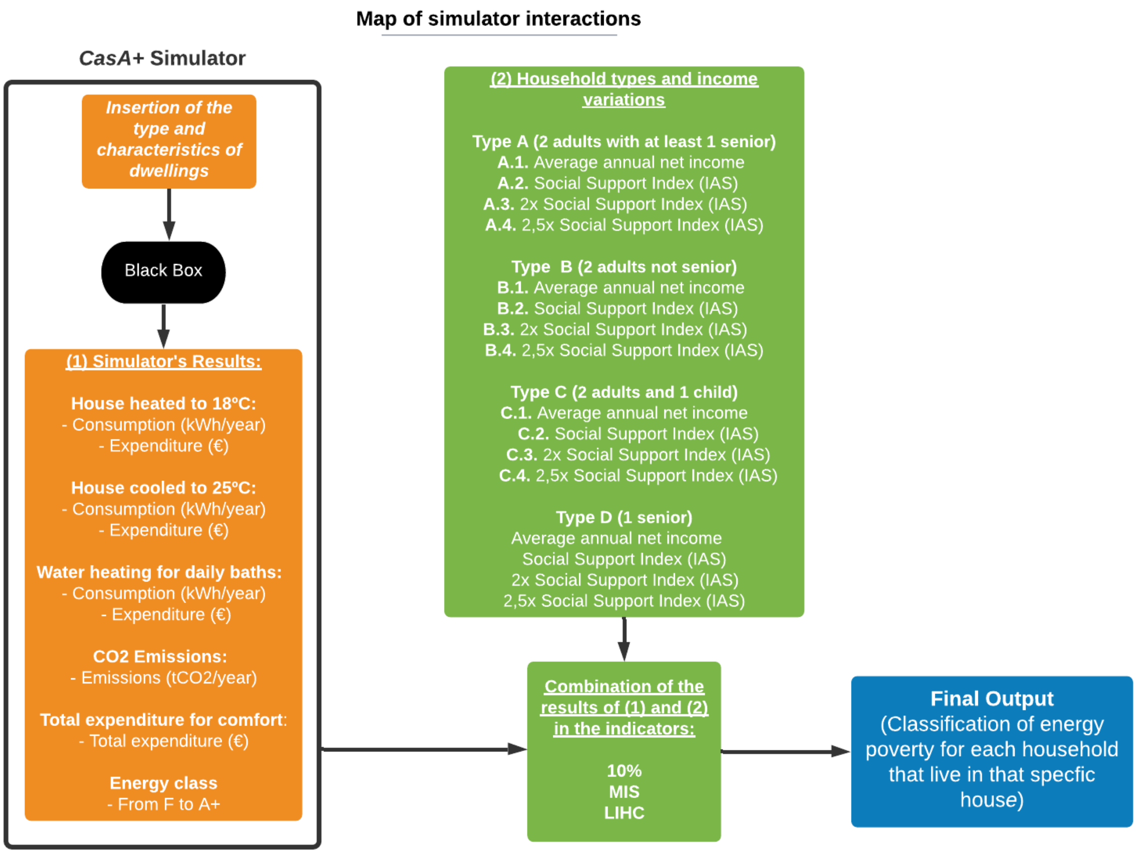


Figure 8: Map of the simulator's interactions

In the first stage, two types of scenarios will be defined: 1) for flats and 2) for detached houses. Each scenario will have eight variations relative to the base scenario, allowing us to consider the changes in detail according to window typology, heating source, and other features. This information will be added to the *Portal CasA+*'s Building Simulator. It is unknown how the simulator processes the information, which is why the "black box" mechanism is referred to in the map.

These results will be added to the variables corresponding to each energy poverty indicator. As regards each household typology (A to D) and relevant income levels (1 to 4), information from each will be added to the three different indicators. The result is 864 diagnoses of energy poverty.

The result of the 10% indicator is shown in percentage. MIS and LIHC are shown as being true for a case of energy poverty or false.

Subsection 4.1 submits the indicators chosen to measure energy poverty and the relevant source of data that is used. This information is coupled with the simulator's data. Subsection 4.2 sets forth the definition of scenarios and households' types. At this stage, two sets of information are put forward: 1) two-based scenarios and eight variations of each, representing the features and specific variations of dwellings, and; 2) four different types of households (A to D) with four different income levels (1 to 4). The simulator will be described in subsection 4.3.

4.1. Selecting Indicators

For the simulation, three indicators were used to make an estimate of Portugal's energy poverty based on the study undertaken by Romero et al. (2018): 10% indicator, MIS, and LIHC, with the following data sources.

Table 8: Energy-poverty indicators' data source

Indicator	**Formula**		**Data source**	**Geographic source**
10%	Fuel Costs/ Net household income > 10%	Fuel Costs	*Portal CasA+*	Coimbra Area
		Net household income	IDEF 2015/2016 (INE, 2016)	National scale
MIS	[Fuel Costs (EHS)] > [Net household income (EHS)] – [Housing costs (EHS)] – [Minimum living costs]	Fuel Costs	*Portal CasA+*	Coimbra Area
		Net household income	IDEF 2015/2016 (INE, 2016)	National scale

		Housing costs	IDEF 2015/2016 (INE, 2016)	National scale
		Minimum living costs	(Pereirinha, 2017)	National scale
LIHC	[Household expenditure on energy] > [Median expenditure on energy]	Household expenditure on energy	*Portal CasA+*	Coimbra Area
		Median expenditure on energy	IDEF 2015/2016 (INE, 2016)	Mid Portugal
	[Household income] – [Household expenditure on energy] < 60% [Median Household income]	Household income	IDEF 2015/2016 (INE, 2016)	National scale
		Household expenditure on energy	*Portal CasA+*	Coimbra Area
		Median Household income	IDEF 2015/2016 (INE, 2016)	National scale

4.2. Scenarios definition

Based on the Survey on Energy Consumption in the Portuguese Domestic Sector (ICESD) (INE, 2011), it was possible to retrieve data on the type and features of dwellings. Unfortunately, these are the most recent data available, with previous surveys dating from 1989 and 1996.

Thus, two scenarios were chosen, with eight variations, each allowing us to grasp the differences in consumption for each dwelling attribute.

Base scenarios (1 and 2) took into account the most representative options, according to what is explained below. The eight different variations start from the base scenarios and appear with small changes (such as heat source, the kind of materials used in construction, etc.), which show us how the consumption values can vary (Annex 2).

Results are given in kWh/year, the tCO2/year are shown on a scale of 0-20, and the total costs are in euros.

As for households, four types were chosen according to their representativeness in Mid Portugal, as established by IDEF 2015/2016 (INE, 2016):

A) 2 adults[9] with at least 1 senior[10] (22.9%);
B) 2 adults and no senior (19.7%);
C) 2 adults and 1 child (18%), and;
D) 1 senior (14.3%).

This study did not consider the possibility that only 1 member of the household is unemployed, nor did it take into account any circumstances of a retirement due to disability. The four typologies were defined in the standard format, and are shown below, in Table 9.

Table 9: Data available for the simulation

Data	Source	Household Type A	Household Type B	Household Type C	Household Type D
Average annual net income	IDEF 2015/2016 (INE, 2016)	23, 459€	23, 548€	26, 037€	11, 543€
Housing costs	IDEF 2015/2016 (INE, 2016)	34.6% of 18, 894€	34.6% of 20, 500€	28.8% of 23, 363€	34.6% of 10, 459€
Minimum living costs	(Pereirinha, 2017)	1283.5€[11]	1, 299€	1, 796€	634€
Median Expenditure on energy[12]	IDEF 2015/2016 (INE, 2016)	1, 416€	1, 416€	1, 416€	1, 416€

The Minimum Living Costs were used based on the Pereirinha et al. (2017) study that combined the consensus method of budgetary standards ("what people think") with the normative approach of experts ("the expert opinion") to estimate adequate income levels in Portugal for different types of households. This methodology was adapted from the method used for determining a Minimum Standard Income in the United Kingdom.
For each type of household, four income levels were defined, as described in Table 10.

[9] Adult is a person aged above 18 years.
[10] Senior is a person aged above 65 years.
[11] This value is not available in the Pereirinha (2017) study, so it has been calculated considering half of the value of household type B and half of household type D (0.5*1,299€ + 0.5*634€)
[12] The data submitted refers to average values. It is not possible to know the values by household typology

Table 10: Types of household by income

	Average annual net income	Social Support Index (IAS)	2x Social Support Index (IAS)	2.5x Social Support Index (IAS)
Household Type A	A.1	A.2	A.3	A.4
Household Type B	B.1	B.2	B.3	B.4
Household Type C	C.1	C.2	C.3	C.4
Household Type D	D.1	D.2	D.3	D.4

IAS is the Social Support Index in Portugal. Since most of the data available corresponded to the year 2016, the IAS value was used for that year (419, 22 €), based on the national limit of 2.5 IAS that one person can earn in Portugal.

4.3. *Portal CasA+*'s Simulator

The simulator is divided into five broad groups: a) Geographic location; b) Building features; c) Configuration; d) Materials used, and; e) Equipment.
From Table 11 to Table 15, it is possible to observe what questions and possible answers are available in which group.
The first input for the simulator is the geographic location and altitude, which influence the weather conditions that buildings are exposed to. By default, the altitude is 149 meters, but the parameter changes automatically after defining the city where the building is sited.

Table 11: Geographic location options (SCE, 2020)

Geographic location	District	18 districts of Portuguese Mainland
	Municipality	Municipalities in Portuguese Mainland
	Altitude of building place	By default, the altitude is 149 meters

The next inputs have to do with building features such as those referring to age, type, and typology.

Table 12: Building features (SCE, 2020)

Building features	Year of construction	Before 1918 1919-1960 1961-1990 1991-2005 2006-2013 After 2013
	Type	Flat or Detached house
	Typology	T0; T1; T2; T3; T4; T5; T6; or T6+
	Floors / floor	Floors: 1; 2; or 3+ Floor: r/c;1st ;2nd; 3rd; 4th;5th; 6th to 10th, 10th+

The configuration is about the position of the dwelling (e.g. in a row with other houses), and its position regarding another flat, garage or business.

Table 13: Building configuration (SCE, 2020)

Configuration	What is the position of your house on the block?	Isolated Row house (corner) Row house (on top); Row house (intermediate).
	The flat	Intermediate flat between flats; Over business/service facilities; On the ground floor; Top floor; Above garage.

The inputs concerning the materials used check into the composition and features of the walls, roof, pavement, windows, and shading.

Table 14: Materials used (SCE, 2020)

Materials used	**Walls**	Composition	Stone; Stone and brick; Single brick masonry; or Double brick masonry.
		With thermal insulation?	Yes or no.
		Does it have inner walls in partitioning or plasterboard?	Yes or no.
	Roof (if applicable)	Features	Horizontal on terrace; sloping on roof; under bare roof, attic or similar;
		What is the colour of your house cover?	Light; Medium; Dark
		With thermal insulation?	Yes or no.
		Does it have a false ceiling?	Yes or no.
	Pavement	Pavement with thermal insulation?	Yes or no
		Pavement on coal, shop, garage or the like?	Yes or no
		Floor on another autonomous fraction?	Yes or no
		Do you have a floating floor or a carpet floor?	Yes or no
	Windows	Type	Wood; plain aluminium; aluminium with thermal cut; pvc
		Does it have double glass?	Yes or no

Materials used		What is the proportion of windows in the walls of your house?	Small proportion of windows; Average windows ratio; Large proportion of windows.
	Shading	Type	No shading. Curtains, Blinds, Shutters.
		Sunscreens from outside?	Yes or no
		How much of the window space in your house is shaded by sun visors or other buildings?	The whole; Most of them; Part of them; None or almost none;

The last group concerns features of the equipment that is used for heating, cooling, and hot water.

Table 15: Equipment (SCE, 2020)

Equipment	Heating	Type	Open fireplace; Stove/heat stove; Electric heater; Boiler; Air conditioning/heat pump; Don't have/do not know.
		Is the equipment more than 10 years old?	Yes or no
	Cooling	Type	Air conditioning; Don't have / don't know
		Is the equipment more than 10 years old?	Yes or no
	Hot water	Type	Gas heater; Electric water heater; Heat pump; Boiler; Don't have/do not know.
		Is the equipment more than 10 years old?	Yes or no

Equipment		If you choose "gas heater" or "boiler"	Natural gas; Butane gas; Propane gas;
		Do you have showers with water efficiency class A or higher?	Yes or No

After inserting all the parameters, the user will receive a possible energy classification for the house. The results, as Table 8 showed previously, provide a general idea of the costs that a household must incur to live with thermal comfort. In addition, it is possible to gain knowledge of what the house's energy classification happens to be and thus make the required changes to improve energy efficiency conditions. The process also allows the household to spend less money on bills and, ultimately, decrease CO2 emissions.

5. Discussion of Results

Once the results of the housing-typology simulator are obtained, we cross-check them with the household typologies for each indicator.

The complete results can be seen from tables 24 to 31 in Annex 3. The values that represent a household living in energy poverty conditions are marked in red.

A summary of the most relevant results can be seen on Table 16.

Table 16: Summary analysis of results

	Income Levels with Highest EP indices	Energy Poverty in Scenario 1	Energy Poverty in Scenario 2	Notes
Type A (Household with 2 adults with at least 1 senior)	A.2	24.1% (26 in 108)	277% (30 in 108)	
Type B (Household with 2 adults and no seniors)	B.2	21.3% (23 in 108)	42.6% (46 in 108)	In scenarios 2.1, 2.2, 2.3 and 2.5, even the household with the highest incomes may be at risk of energy poverty. Although there is small variation as to their position, the number of floors, and the double glasses, all houses have in common the use of an electric heater leading to an overly-high energy consumption.
Type C (Household 2 adults and one child)	C.2	40.7% (44 in 108)	60.2% (65 in 108)	In scenarios 2.4, 2.6, 2.7, 2.8, and 2.9, there is an open fireplace, which can explain a lower number of households living in energy poverty.
Type D (Household with 1 senior)	D.2	48.1% (52 in 108)	70.4% (76 in 108)	Scenario 2 was the one with the highest energy-poverty rating. Several factors are determinant in this classification: first, this dwelling's household is composed of one person; then, the average salary of this type of household is low. Finally, presence of certain housing features ends up leading to a higher energy consumption. Even in scenarios with an open fireplace or double glass, this household is considered energy-poor.

The scrutiny of results highlights the households with the maximum incidence of energy poverty conditions. The income figures A.2, B.2, C.2 and D.2 correspond to households with an income level of 1 IAS (419, 22€) per employee.

Comparing the results of scenarios 1 (flats) and scenarios 2 (detached houses), it is possible to see that the flats have fewer energy poverty cases. This situation can be explained by the dwellings' direct contact with other homes, which reduces the dwelling's heating and cooling needs. Heating equipment represents the variable mostly responsible for classification differences, which is evidenced by the use of an open fireplace (that helps reduce the numbers). Table 17 shows the summary of results by indicator used.

Table 17: Summary of the results

		10%	MIS	LIHC
Type A (Household with 2 adults with at least 1 senior)	Scenario 1 (living in a flat)	22.2%	41.7%	8.3%
	Scenario 2 (Detached house)	58.2%	58.3%	16.7%
Type B (Household with 2 adults and no seniors)	Scenario 1 (living in a flat)	25%	30.6%	5.6%
	Scenario 2 (Detached house)	58.3%	47.2%	22.2%
Type C (Household with 2 adults and one child)	Scenario 1 (living in a flat)	22.2%	91.7%	8.3%
	Scenario 2 (Detached house)	58.3%	100%	22.2%
Type D (Household with 1 senior)	Scenario 1 (living in a flat)	63.9%	72.2%	8.3%
	Scenario 2 (Detached house)	97.2%	83.3%	30,6

Looking at the indicators, it can be seen that when using the LIHC to assess energy poverty, the percentage of people living in energy poverty conditions is lower in almost all scenarios (only scenario 2 of household type A is excluded) than the figures obtained when the other indicators are used. The worst results are obtained from the MIS in most scenarios (6 out of 8), which can be explained by the fact that this indicator includes expenditures on housing costs and minimum living costs. Regarding the types of households composed of one senior (Type D) and households composed of two adults and one child (Type C), scenario 2 is the one where the phenomenon of energy poverty is most visible, when the 10% indicator is used.

If one accepts that LIHC is the indicator with the highest amount of variables and making use of more information, it is possible to say that, on average, between 5.6% and 8.3% of households living in a flat are in energy poverty conditions and between 16.7% and 30.6% of households living in detached houses are in energy poverty conditions.

6. Conclusions

This dissertation started out expanding on how European countries define the concept of energy poverty and the associated in measurement indicator, in order to provide a basis to outline the metrics of energy poverty in Portugal. Obtaining information on the decision making of countries with formal definitions of energy poverty was found impossible and furthermore there were severe constraints in obtaining data for Portugal. Because of that, the goal of the dissertation was to propose a methodology to estimate energy poverty, considering the amount of energy consumption found to be ideal for a household to live in a state of thermal comfort.

Departing from an existing simulator, inputs were coupled based on the economic and social features of illustrative households of Mid Portugal. With this methodology, the measurement of energy poverty in Portugal gains a new perception, since the physical conditions of buildings have allowed to gain knowledge of how much a household should spend to live in thermal comfort. This action enables to overcome the gap resulting from not regarding as energy-poor the households that do not consume the adequate levels of energy because they are unable to afford the ensuing expenses. The *Portal CasA+*'s Energy Efficiency Building Simulator can be considered an opportunity to generate data, generally regarded as one of the most significant existing limitations (Palma, Gouveia, & Simões, 2019). This approach appears to be pioneering, to the best of our knowledge. Using three current indicators reported in the literature, three results for each simulation performed were obtained. 864 diagnoses of energy poverty were made, testing a set of 16 typical households over 18 building types.

From the results obtained, it was possible to conclude that:

a) Regarding their features, the households with the highest rate in energy poverty classifications were the ones whose working members receive 1 IAS. Households consisting of only one senior (Type D) had the worst results, with energy poverty percentages between 48.1% and 70.4%, which can be explained by several factors, such as: the meagre composition of the household, its income and housing features leading to higher energy consumption.
b) Of all scenarios looked into and comparing the flats and the detached houses, it is possible to conclude that the households living in flats have fewer energy poverty

cases. This situation can be explained by the dwellings' direct contact with other homes, which reduces the dwelling's heating and cooling needs. From all variables of the simulator, the heating equipment was the one that most affected the classification. As a proof of this, it was found that the use of an open fireplace stands out, because the scenarios that include this heating option do not have such high energy-poverty ratings, and;

c) When assessed by different indicators, energy poverty appears to be a phenomenon with a different magnitude. The results obtained for the households considered in this dissertation reveal that, according the 10% indicator, 47.2% live in energy poverty in Mid Portugal. 61.8% of households are energy-poor according to the MIS indicator, while only 15.3% of people live in energy poverty in Mid Portugal, if the LIHC indicator is used.

d) The energy poverty results obtained are higher when compared to other studies, for example Rodrigues et al. (2019), mainly because this dissertation made use of the ideal energy consumption to live in a thermal comfort state, instead of using the actual households' energy consumption.

Regarding omission of energy poverty cases, the proposed methodology foresees the elimination of them, avoiding the creation and use of new additional indicators to discard the omission cases, as happens with the indicators created by Betto et al. (2020).

In summary, this research project addressed a gap in the definition, namely as to how energy poverty should be classified and monitored. Secondly, the issue of measuring energy poverty was addressed, and several indicators were studied. The chosen indicators evidenced considerable differences as to the data required for their calculation, which is the kind of complex, hard-to-obtain data. This uncovers a void in national and some local platforms (that could otherwise turn out to be valuable governmental decision-making tools). The use of three comparative indicators provided more robust information, as they are designed around different assumptions. One advantage of the proposed methodology is the adaptation of the simulator that allows obtaining an energy poverty classification with data that already exists or that can be collected without the need of an additional census.

6.1. Future work

In Portugal, and unlike other countries, the government lacks the sort of definition of energy poverty that allows the establishment of indicators to measure energy poverty. Attention should be paid to the indicators chosen, since the data for their use may be challenging to obtain. Only with robust data are we able to know which measures are to be chosen in order to tackle this problem in each country's region.

The methodology developed in this dissertation can be expanded and implemented as a prototype to address this vital matter. More scenarios can be further explored to bring the values of energy poverty closer to the reality of the country. The implementation of other indicators could also be considered, in order to understand which indicators are best suited to the Portuguese case.

Addressing new policies (beyond those dealing with social tariffs, for instance) is likewise crucial, since this policy aims to support families but does not solve actual structural problems (such as building conditions).

Once the efforts to combat energy poverty have been implemented, it will make sense to study how reducing the number of people living in energy poverty conditions is very likely to benefit those individuals' health and well-being (and the country's economy).

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Annex 1

Indicator name	Data source	Data year(s)	Primary/Secondary	Description
Inability to keep home adequately warm	EU-SILC	2004-2016	Primary	Based on question "Can your household afford to keep its home adequately warm?" This indicator encompasses the prevailing qualitative definition of energy poverty and captures self-reported thermal discomfort issues. It is a recommended indicator by Rademaekers et al. (2016).
Arrears on utility bills	EU-SILC	2004-2016	Primary	Based on question "In the last twelve months, has the household been in arrears, i.e. has been unable to pay on time due to financial difficulties for utility bills (heating, electricity, gas, water, etc.) for the main dwelling?" This indicator captures potential financial difficulties, and is an important indicator as households unable to keep up to date with energy bill payments may experience disconnection of supply. Note, however, that it covers all utility bills, including those beyond energy. In addition, arrears are not possible for some energy carriers, such as heating oil and wood pellets.
High share of energy expenditure in income (2M)	HBS	2010	Primary	The 2M indicator presents the proportion of population whose share of energy expenditure in income is

Figure 9: Summary of EPOV indicators – part 1 (EPOV, 2018)

				more than twice the national median share. This suggests the prioritisation of energy costs over other household costs. The 2M threshold was established on the basis that this represents disproportionately high expenditure. It is a recommended indicator by Rademaekers et al. (2016).
Hidden energy poverty (HEP)	HBS	2010	Primary	The HEP indicator presents the share of population whose absolute energy expenditure is below half the national median, in other words abnormally low. HEP is a relatively new indicator that has been used in Belgium to complement other expenditure and self-reported indicators. It is a recommended indicator by Rademaekers et al. (2016).
Fuel oil prices	BSO	2004-2015	Secondary	Average household prices per kWh generated from fuel oil.
Biomass prices	BSO	2004-2016	Secondary	Average household prices per kWh generated from biomass.
Coal prices	BSO	2004-2016	Secondary	Average household prices per kWh generated from coal.
Electricity prices	Eurostat: nrg_pc_204	2007-2016	Secondary	Electricity prices for household consumers, band DC 2500-5000 kWh/yr consumption, all taxes and levies included.
Gas prices	Eurostat: nrg_pc_202	2007-2016	Secondary	Natural gas prices for household consumers, band 20-200GJ

Figure 10: Summary of EPOV indicators – part 2 (EPOV, 2018)

				consumption, all taxes and levies included.
Presence of leaks, damp, rot	EU-SILC	2004-2016*	Secondary	Share of population with leaks, damp or rot in their dwelling, which can be seen as an indirect proxy of housing quality and living conditions. *However, from 2020, this indicator will no longer be collected annually; rather it will take place every 3 years.
Dwelling comfortably cool during summer time	EU-SILC ad-hoc modules	2007 and 2012**	Secondary	Share of population, based on question "Is the cooling system efficient enough to keep the dwelling cool?" and/or "Is the dwelling sufficiently insulated against the warm?" **From 2020, this indicator will no longer be collected.
Dwelling comfortably warm during winter time	EU-SILC ad-hoc modules	2007 and 2012**	Secondary	Share of population, based on question "Is the heating system efficient enough to keep the dwelling warm?" and "Is the dwelling sufficiently insulated against the cold?" **From 2020, this indicator will no longer be collected.
Equipped with air conditioning	EU-SILC ad-hoc module	2007***	Secondary	Share of population living in a dwelling equipped with air conditioning facilities.

Figure 11: Summary of EPOV indicators – part 3 (EPOV, 2018)

				***Collection of this indicator stopped after the 2007 ad-hoc module.
Equipped with heating	EU-SILC ad-hoc modules	2007 and 2012**	Secondary	Share of population living in a dwelling equipped with heating facilities. **From 2020, this indicator will no longer be collected.
Number of rooms per person (owners, renters, total)	Eurostat: ilc_lvho03	2004-2016	Secondary	Average number of rooms per person in owned, rented, and all dwellings.
Dwellings in densely populated areas	BSO	2004-2014	Secondary	Share of dwellings located in densely populated areas (at least 500 inhabitants/km2).
Dwellings in intermediately populated areas	BSO	2004-2014	Secondary	Share of dwellings located in intermediately populated areas (between 100 and 499 inhabitants/km2).
Risk of poverty or social exclusion	Eurostat: ilc_peps01	2004-2016	Secondary	People at risk of poverty or social exclusion (% of population).
Energy expenditure for electricity, gas and other fuels as a share of income, split by income decile	Eurostat: hbs_str_t223	2005, 2010 and 2015	Secondary	Consumption expenditure for electricity, gas and other fuels as a share of income, by income decile.
Excess winter mortality	BSO	2005-2014	Secondary	Share of excess winter mortality.

Figure 12: Summary of EPOV indicators – part 4 (EPOV, 2018)

Annex 2

Table 18: Scenario 1 characterization

Geographic location	**District**		**Coimbra**	**-**
	Municipality		Coimbra	-
	Altitude of building place		Coimbra: 67 m (by default)	-
Building features	Year of construction		1961-1990;	(ICESD, 2010)
	Type		Flat;	48.7% of national houses; (IDEF 2015/2016 (INE, 2016))
	Typology		T2;	4.3 living rooms is the average in Mid Portugal (IDEF 2015/2016 (INE, 2016))
	Square metres		130 m^2	130.1 m^2 is the average in Mid Portugal (IDEF 2015/2016 (INE, 2016))
	Floors / floor		2^{nd};	19.2% of national houses. IDEF 2015/2016 (INE, 2016))
Configuration	What is the position of your house on the block?		Isolated;	Without available data.
	The flat		Intermediate flat between flats;	Without available data.
Materials used	**Walls**	Composition	Single brick masonry;	Without available data.
		With thermal insulation?	No.	In just 21.1% of national houses. (ICESD, 2010)
		Does it have inner walls in partitioning or plasterboard?	No.	Without available data.
	Roof (if applicable)	Features	-	Without available data.

Materials used		What is the colour of your house cover?	-	-
		Does it have thermal insulation?	-	-
		Does it have a false ceiling?	-	-
	Pavement	Pavement with thermal insulation?	No	Without available data, we figured that if the walls don't have it, then the floor won't, as well.
		Pavement on coal, shop, garage or the like?	No	Without available data.
		Floor on another autonomous fraction?	Yes	Without available data.
		Do you have a floating floor or a carpet floor?	Yes	Without available data.
	Windows	Type	Plain aluminium;	Without available data. However, it is the most used in windows with no double glass;
		Does it have double glass?	No.	More than 70% of national houses. (ICESD_2010)
		What is the proportion of window space on the walls of your house?	Average windows ratio;	Without available data. However, we came up with an average.
	Shading	Type	Shutters;	Most used in houses built between 1961 and 1990;
		Sunscreens from outside?	No	Without available data.

		Which part of the windows in your house are shaded by sun visors or by other buildings?	Almost none;	Without available data.
Equipment	**Heating**	Type	Electric heater;	13.9% of houses in Portugal. (ICESD_2010) 63.3% of houses in Mid Portugal (IDEF 2015/2016 (INE, 2016))
		Is the equipment more than 10 years old?	No	Without available data.
	Cooling	Type	Don't have / don't know	10.2% of houses have this equipment in Mid Portugal. (IDEF 2015/2016 (INE, 2016))
		Is the equipment more than 10 years old?	No	Without available data.
	Hot water	Type	Water gas heater;	63% of households. (IDEF 2015/2016 (INE, 2016))
		Is the equipment more than 10 years old?	No	Without available data.
		If you choose "gas heater" or "boiler"	Butane gas;	81.9% of houses; (ICESD_2010)
		Do you have showers with water efficiency class A or higher?	No	Without available data.

Table 19: Scenario 1 variations

Scenario 1		1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
Geographic location	District	=	=	=	=	=	=	=	=
	Municipality	=	=	=	=	=	=	=	=
	Altitude	=	=	=	=	=	=	=	=
Building Features	Floor	=	1st	1st	9th	=	=	=	=
Configuration	Position	Row house (intermediate) [RHI]	[RHI]	=	[RHI]	=	=	[RHI]	[RHI]
	The Flat	=	=	Over business/ service area	Top Floor	=	=	=	=
Materials used	Walls	=	=	=	=	=	=	=	Double brick masonry with isolation
	Roof	=	=	=	=	=	=	=	=
	Pavement	=	=	=	=	=	=	=	=
	Windows	=	=	=	=	=	With double glass [WDG]	PVC and [WDG]	[WDG]
	Shading	=	=	=	=	=	=	=	=
Equipment	Heating	=	=	=	=	Open fireplace [OF]	=	=	[OF]
	Cooling	=	=	=	=	Air Conditioned	=	=	=
	Hot water	=	=	=	=	=	=	=	=

Table 20: Scenario 2 characterization

Geographic location	**District**	**Coimbra**	**-**
	Municipality	Coimbra	-
	Altitude of building place	Coimbra: 67 m (by default)	-
Building features	Year of construction	1961-1990;	(ICESD, 2010)
	Type	House	51.3% of national houses; (IDEF 2015/2016 (INE, 2016))
	Typology	T2;	4.3 living rooms is the average in Mid Portugal (IDEF 2015/2016 (INE, 2016))
	Square metres	130 m^2	130.1 m^2 is the average in Mid Portugal (IDEF 2015/2016 (INE, 2016))

	Floors		one;	49.4% of houses in Mid Portugal. IDEF 2015/2016 (INE, 2016))
Configuration	What is the position of your house on the block?		Isolated;	Without available data.
	The flat		-	-
Materials used	**Walls**	Composition	Single brick masonry;	Without available data.
		With thermal insulation?	No.	Just 21.1% of national houses has. (ICESD, 2010)
		Does it have inner walls in partitioning or plasterboard?	No.	Without available data.
	Roof (if applicable)	Features	Sloping on roof;	Without available data.
		What is the colour of your house cover?	Medium	Without available data.
		With thermal insulation?	No	Just 17.1% of national houses (ICESD, 2010)
		Does it have a false ceiling?	No	Without available data.
	Pavement	Pavement with thermal insulation?	No	Without available data. We figured that if the walls don't have it, then the floor won't, as well.
		Pavement on coal, shop, garage or the like?	No	Not applicable.
		Floor on another autonomous fraction?	No	Not applicable.
		Do you have a floating floor or a carpet floor?	Yes	Without available data.

Materials used	**Windows**	Type	Plain aluminium;	Without available data. However, it is the most used in windows with no double glass;
		Does it have double glass?	No.	More than 70% of national houses. (ICESD_2010)
		What is the proportion of window space on the walls of your house?	Average windows ratio;	Without available data. However, we came up with an average.
	Shading	Type	Shutters;	Most used in houses built between 1961 and 1990;
		Sunscreens from outside?	No	Without available data.
		Which part of the windows in your house is shaded by sun visors or other buildings?	Almost none;	Without available data.
Equipment	**Heating**	Type	Electric heater;	13.9% of houses in Portugal. (ICESD_2010) 63.3% of houses in Mid Portugal (IDEF 2015/2016 (INE, 2016))
		Is the equipment more than 10 years old?	No	Without available data.
Equipment	**Cooling**	Type	Don't have / don't know	10.2% of houses have this equipment in Mid Portugal. (IDEF 2015/2016 (INE, 2016))
		Is the equipment more than 10 years old?	No	Without available data.

	Hot water	Type	Water gas heater;	63% of households. (IDEF 2015/2016 (INE, 2016))
		Is the equipment more than 10 years old?	No	Without available data.
		If you choose "gas heater" or "boiler"	Butane gas;	81.9% of houses; (ICESD_2010)
		Do you have showers with water efficiency class A or higher?	No	Without available data.

Table 21: Scenario 2 variations

Scenario 2		2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
Geographic location	District	=	=	=	=	=	=	=	=
	Municipality	=	=	=	=	=	=	=	=
	Altitude	=	=	=	=	=	=	=	=
Building Features	Floor	=	2 floors	=	=	=	=	=	=
Configuration	Position	Row house (intermediate) [RHI]	[RHI]	=	=	=	[RHI]	[RHI]	[RHI]
	The Flat	=	=	=	=	=	=	=	=
Materials used	Walls	=	=	=	Double brick masonry with isolation	=	Double brick masonry with isolation	=	=
	Roof	=	=	=	=	=	=	=	=
	Pavement	=	=	=	=	=	=	=	=
	Windows	=	=	=	With double glass [WDG]	[WDG]	=	[WDG]	Aluminium with thermal cut and [WDG]
	Shading	=	=	=	=	=	=	=	=
Equipment	Heating	=	=	Open fireplace [OF]	=	[OF]	[OF]	[OF]	[OF]
	Cooling	=	=	=	=	=	=	=	=
	Hot water	=	=	=	=	=	=	=	=

Annex 3

Table 22: Results for households type A in scenario 1 and its variations

Scenario 1		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
A.1	10%	7%	4%	4%	4%	10%	3%	6%	4%	2%
	MIS	True	False	False	False	True	False	True	False	False
	LIHC	False	False	False	False	False	False	False	False	False
A.2	10%	15%	10%	10%	10%	22%	6%	14%	9%	4%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	False	False	False	True	False	True	False	False
A.3	10%	8%	5%	5%	5%	11%	3%	7%	4%	2%
	MIS	True	False	False	False	True	False	True	False	False
	LIHC	False	False	False	False	False	False	False	False	False
A.4	10%	6%	4%	4%	4%	9%	3%	6%	4%	2%
	MIS	False	False	False	False	False	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False

Table 23: Results for households type A in scenario 2 and its variations

Scenario 2		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
A.1	10%	21%	19%	13%	7%	20%	7%	6%	6%	6%
	MIS	True	True	True	True	True	True	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False
A.2	10%	43%	37%	25%	14%	39%	14%	11%	13%	12%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	True	True	True	True	True	False	True	True
A.3	10%	21%	19%	13%	7%	20%	7%	6%	6%	6%
	MIS	True	True	True	True	True	True	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False
A.4	10%	17%	15%	10%	6%	16%	6%	4%	5%	5%
	MIS	False	False	False	False	False	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False

Table 24: Results for households type B in scenario 1 and its variations

Scenario 1		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
B.1	10%	8%	5%	5%	5%	11%	3%	7%	4%	2%
	MIS	False	False	False	False	True	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False
B.2	10%	15%	10%	10%	10%	22%	6%	14%	9%	4%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	False	False	False	True	False	True	False	False
B.3	10%	8%	5%	5%	5%	11%	3%	7%	4%	2%
	MIS	False	False	False	False	True	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False
B.4	10%	6%	4%	4%	4%	9%	3%	6%	4%	2%
	MIS	False	False	False	False	False	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False

Table 25: Results for households type B in scenario 2 and its variations

Scenario 2		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
B.1	10%	21%	19%	13%	7%	19%	7%	6%	6%	6%
	MIS	True	True	True	False	True	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False
B.2	10%	43%	37%	25%	14%	39%	14%	11%	13%	12%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	True	True	True	True	True	False	True	True
B.3	10%	21%	19%	13%	7%	20%	7%	6%	6%	6%
	MIS	True	True	True	False	True	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False
B.4	10%	17%	15%	10%	6%	16%	6%	4%	5%	5%
	MIS	False	False	False	False	False	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False

Table 26: Results for households type C in scenario 1 and its variations

Scenario 1		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
C.1	10%	7%	4%	4%	4%	10%	3%	6%	4%	2%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False
C.2	10%	15%	10%	10%	10%	22%	6%	14%	9%	4%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	False	False	False	True	False	True	False	False
C.3	10%	8%	5%	5%	5%	11%	3%	7%	4%	2%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False
C.4	10%	6%	4%	4%	4%	9%	3%	6%	4%	2%
	MIS	True	True	True	True	True	False	True	False	False
	LIHC	False	False	False	False	False	False	False	False	False

Table 27: Results for households type C in scenario 2 and its variations

Scenario 2		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
C.1	10%	19%	17%	11%	6%	18%	6%	5%	6%	6%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False
C.2	10%	43%	37%	25%	14%	39%	14%	11%	13%	12%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	True	True	True	True	True	False	True	True
C.3	10%	21%	19%	13%	7%	20%	7%	6%	6%	6%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False
C.4	10%	17%	15%	10%	6%	16%	6%	4%	5%	5%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False

Table 28: Results for households type D in scenario 1 and its variations

Scenario 1		1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
D.1	10%	16%	10%	10%	10%	23%	6%	15%	9%	4%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False
D.2	10%	31%	20%	20%	20%	44%	13%	29%	18%	8%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	False	False	False	True	False	True	False	False
D.3	10%	15%	10%	10%	10%	22%	6%	14%	9%	4%
	MIS	True	True	True	True	True	True	True	True	False
	LIHC	False	False	False	False	False	False	False	False	False
D.4	10%	12%	8%	8%	8%	18%	5%	11%	7%	3%
	MIS	False	False	False	False	False	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False

Table 29: Results for households type D in scenario 2 and its variations

Scenario 2		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
D.1	10%	44%	38%	26%	15%	40%	14%	11%	13%	13%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	False	False	False	False	False	False	False	False	False
D.2	10%	44%	37%	25%	14%	39%	14%	11%	13%	12%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	True	True	True	True	True	True	True	True
D.3	10%	43%	37%	25%	14%	39%	14%	11%	13%	12%
	MIS	True	True	True	True	True	True	True	True	True
	LIHC	True	False	False	False	True	False	False	False	False
D.4	10%	34%	30%	20%	12%	31%	11%	9%	10%	10%
	MIS	True	True	False	False	True	False	False	False	False
	LIHC	False	False	False	False	False	False	False	False	False