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Research paper

Energy poverty vulnerability index: A multidimensional tool to identify hotspots for local action

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HIGHLIGHTS

- High spatial scale multi-faceted method for EP regional vulnerability assessment.
- Buildings energy performance gaps and socio-economic variables are combined.
- Tool for hotspots identification for local action and comparative analysis.
- Both space heating and cooling problems are highlighted for a Southern EU country.

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ABSTRACT

Energy poverty is a growing societal challenge that puts the welfare of many European citizens at risk. Several different indicators have been developed with the objective of assessing this phenomenon. The aim of this work is to develop a novel high-resolution spatial scale composite index, focusing on space heating and cooling, to map energy poor regions and identify hotspots for local action. The proposed index (EPVI) combines socio-economic indicators of the population (AIAM sub-index) with building's characteristics and energy performance (EPG sub-index). The method was tested for all 3092 civil parishes of Portugal and could be potentially replicated at Pan European scale. Results show a higher prevalence of significative EPVIs in the inland region and the islands, particularly in rural civil parishes. Although cooling EPVIs are generally higher, heating may be a more significant issue in terms of energy demand and health hazard. Energy poverty vulnerability assessment at such a disaggregated regional scale could bridge the gap between common overall country analyses and local-scale initiatives targeting vulnerable households. The outcomes of this paper support national and local energy efficiency policies and instruments while fostering better assessments and enabling local actions for tackling this problem.

1. Introduction

The European Commission addressed the concept of Energy Poverty (EP) for the first time in 2009, with the publication of Directives 2009/72/EC and 2009/73/EC, which instructed Member States to develop national action plans or other appropriate frameworks to tackle EP. The increasing costs of energy, combined with a stagnation in average household income has led to an increase in household energy expenditure, particularly among the most vulnerable, with lower incomes, raising the profile of this issue further.

Since then, there has been a strong imperative to properly define and measure EP in the European Union (EU), as also reflected in the EC's legislative proposal "Clean Energy for All Europeans" (EC, 2016a). Over the years, several EP definitions have been developed by countries (U.K., France, England, Scotland, Slovakia, and Ireland), projects and institutions. An extensive collection of different definitions can be found in EC (2016b), Rademaekers et al. (2016) and ASSIST (2018). There is also in the literature a wider debate between the mixed use of fuel poverty and energy poverty concepts and other energy deprivation terms (e.g. Li et al. (2014); Bouzarovski and Petrova (2015)). There is a European effort towards the interchangeable use of the two terms to explain the same issue — the difficulty of individuals and households to afford adequate access to energy services.

Policies addressing EP and promoting vulnerable consumers protection are beginning to be introduced throughout the EU, mostly in an unorganized manner conducted individually by each Member State (MS), either from a social perspective or through the energy sector (Dobbins and Pye, 2016). Pye et al. (2015) present a review of efforts across different MS to define and protect vulnerable consumers.

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Despite the elevated attention, EP is increasingly receiving in research (e.g. ENGAGER, 2017–2021), and in the EU (e.g. EPOV, 2016) and national policies' arena, around 50 million people in the EU are estimated to be experiencing EP, with evidence showing that different regions present individual their own EP inflected characteristics.

The most commonly used EP indicators are drawn by the EU Statistics on Income and Living Conditions (EU-SILC), with two of the prevailing indicators used to capture EP being self-reported with their inherent limitations and most of them using old data. In the EU, 8.7% of households are struggling to attain adequate warmth (2016 data), 19.2% of households are not comfortable during the summer (2012 data), and 8.1% of households cannot pay their utility bills on time (2016 data), resulting in other difficulties for low-income households and negatively affecting people's health and well-being (Eurostat, 2018). At a country level analysis, the indicators' results portray a wide distinction of the situation across the EU (Eurostat, 2018).

Other main data sources with relevant indicators for EP assessment are available on the Households Budget Surveys (HBS, 2010), European Building Stock Observatory (BSO, 2018) and Eurostat (2018) main database, however, there is missing information for several countries and insufficient information available at a lower spatial scale (regional, city level). Information available at a higher spatial resolution would foster better assessments and enable local actions for tackling this problem. In fact, Velte et al. (2013) highlight the relevance of EP assessment at a regional scale, so to clearly identify and analyse the social disparities in the root cause for this issue.

Additionally, it is widely recognized that the main drivers of EP are energy inefficient housing stock, elderly household occupants, low household income and high energy prices (e.g. Wright, 2004; Atanasiu et al., 2014; Desroches et al., 2015; Bouzarovski, 2017). Thus, EP is an issue of concern to policy-makers at all levels within the health, energy, social services, and housing.

Measuring energy poverty is important in understanding the extent and depth of the problem (at a national and regional level) and in assessing the impact of dedicated policies. The selection of appropriate indicators and approaches for application or development are factors which still surface in many debates (e.g. Rademaekers et al., 2016; Romero et al., 2018; Thomson and Bouzarovski, 2018). Besides, several authors have been exploring various dimensions of EP, focusing on the social and health dimension of the problem (e.g. Day et al., 2016; Gillard et al., 2017; Thomson et al., 2017a,b), economic and expenditure side (e.g. Hills, 2012; E-Control, 2013; ONPE, 2014), geography (e.g. Anusi and Owoyele, 2016; Robinson et al., 2018), and engineering perspectives (e.g. Fabbri, 2015; Gouveia et al., 2018).

Broadly, EP measurements are categorized into three types: those based on expenditure such as the Low Income High Costs (LIHC) (Hills, 2012), consensual approaches such as in the EU-SILC indicators and an alternative approach more focused on energy needs calculations (e.g. DECC, 2010; Sanchez et al., 2018), such as briefly surfaced by Rademaekers et al. (2016) and Bouzarovski (2017), but with increasing complexity and data needs.

Due to its multi-dimensionality, which is not easily captured by a single indicator, different authors have been following a more integrative perspective, calling attention to the importance of considering a broader range of indicators or a combination through an index development. Alternative methodologies were applied to the so-called Global North (as e.g. Herrero and Bouzarovski, 2014; Maxim et al., 2016; Okushima, 2017; Llera-Sastresa et al., 2017), while others were tested to the Global South (e.g. Nussbaumer et al., 2012; Sadath and Acharya, 2017).

Thus, in this paper, a novel EP index methodology founded on a core analytical tool to map and characterize EP at a regional level for a whole country is proposed. The index methodology advances current state of the art approaches by combining (i) socio-economic indicators of population (e.g. presence of elderly and young people; unemployed; income and education level) with (ii) climate variables (heating degree days, external outdoor temperature, heating and cooling seasons duration), (iii) energy consumption levels (e.g. electricity, natural gas, biomass), (iv) calculated energy demand for space heating and cooling (per square metre, per household), (v) climatization technologies details (efficiency, ownership) and (vi) construction characteristics of several building typologies (e.g. height, area, bearing structure, type of wall, windows, roofs) distinctive for each of the country's regions.

The designed index is used to map EP, addressing space heating and cooling separately, at a high-resolution spatial scale (tested for all 3092 civil parishes in Portugal), potentially to be replicated at a European scale. Our methodology also covers the assessment of relevant sub-indexes (buildings energy performance gaps (EPG) and the ability to implement alleviation measures (AIAM)). Its appraisal at such a disaggregated regional scale can facilitate the connection of common overall country analyses and local-scale initiatives targeting vulnerable households.

Portugal is suitable for testing this index for multiple reasons: (1) Poor ranking in most currently used EP indicators, with the 5th highest rate of people unable to maintain adequate warmth in their dwelling during the winter (22.5%) in 2016, and the 2nd highest percentage of people living in a dwelling which was not comfortably cool during the summer (35,7%, 2012 data), out of all 28 European member-states (Eurostat, 2018), (2) ageing building stock with low energy performance (74% of houses with energy performance certificate (EPC) below or equal to a C class (ADENE, 2018)); (3) decentralized low efficiency climatization systems and low ownership rates, mainly for cooling equipment — 15,7% (INE, 2017); (4) among the highest energy prices in the EU (both electricity and natural gas) (Eurostat, 2018), (5) low household income (INE, 2017), (6) despite the Mediterranean climate, one of the highest mortality rates in winter (Liddell et al., 2015) and (7) a dual problem regarding thermal comfort: both for space heating and cooling energy demand. All these factors increase the vulnerability and health risks of consumers under EP conditions and stress the need for increased research in these regions.

The implementation of the developed index and its achieved outcomes are a step further towards the accomplishment of United Nations sustainable development goals. Mainly SDG 1, 3 and 7 (UN, 2015), that set the basis for complementary analysis and sustainable energy transitions in the country, supporting the need for EP action plans development and implementation.

Section 2 details the methods and gives an overview of the selected case study's key relevant features. Section 3 provides a description of the obtained results, discussing the main lessons drawn from the empirical application. The main conclusions of our study are presented in the final section.

2. Methodology

In order to achieve the above-mentioned goal, research work was developed in three steps, with each part employing a different approach and depicted in two sub-indexes and one final composite index, as follows: (1) dwellings' energy performance gap sub-index, estimated with the buildings' energy demand and consumption; (2) assessment of the population's ability to implement alleviation measures sub-index, using several socioeconomic indicators; and (3) energy poverty vulnerability index calculation distinct for space heating and cooling, zooming in at a regional scale.

Fig. 1 summarizes the key components and methods envisaged in the proposed methodology. The adopted methodological

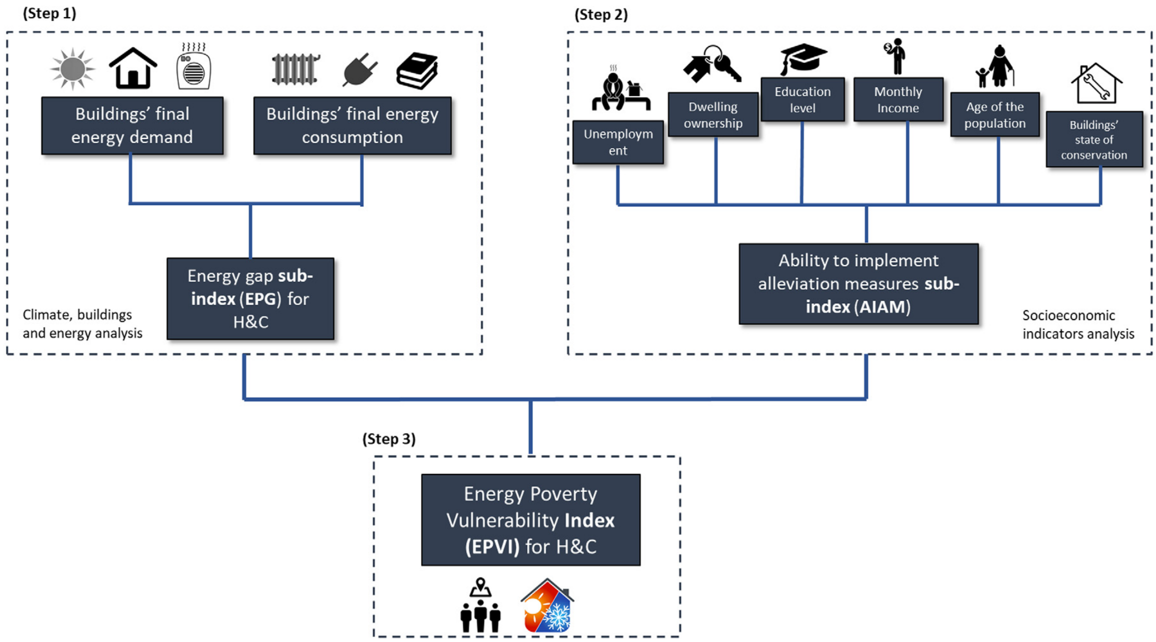

Fig. 1. Methodological Approach for building the multidimensional Energy Poverty Vulnerability Index.

framework evolves from the one proposed by Simoes et al. (2016), adapted from a climate change vulnerability concept framework (Fritzsche et al., 2014) The energy performance gap (EPG) sub-index represents the potential impact that combines the exposure and sensitivity; the ability to implement alleviation measures (AIAM) sub-index is analogous to the adaptive capacity; and the energy poverty vulnerability index (EPVI) corresponds to the vulnerability component. Each step of the methodology is described in the next sections, as well as the case study where the framework was tested.

2.1. Case study

Portugal was selected as a testbed to apply the proposed high regionally detailed methodology for energy poverty vulnerability evaluation. Portugal is located on the southwest region of the European continent, bordered by Spain to the north and east and by the Atlantic Ocean to the south and west. The country has a population of 10.3 million inhabitants (PORDATA, 2018) and a territory with an area of 92 226 km^2 (CAOP, 2016), divided into three different official circumscriptions: administrative regions/districts (#18), municipalities (#308), and civil parishes (#3092). The municipalities and civil parishes have low tier local governments.

The Portuguese climate is mostly temperate, with mild and dry summers in the north and coastal regions and east group of the Azores islands, and hot and dry summers in the south and centre inland, part of the northern inland region and in the Madeira islands. A small part of the southern inland region has a semi-arid or steppe climate, with hot and dry summers and cold dry winters. The westernmost group of Azores islands has an oceanic climate, with cold summers and mild winters. The annual average temperature ranges between 7 °C, in the mountainous region in the northeast, and 19 °C in the coastal areas of the Madeira islands. In the mainland area, the regions of Minho and Douro Litoral, located in the north coast, have the highest precipitation rates of the country, with values over 1200 mm, whereas Baixo Alentejo, a region located in the southern inland, has the lowest, below 600 mm (IPMA, 2018). On the island of Madeira, average annual temperature and precipitation vary respectively between 8° and 3300 mm, in the mountain regions, and 19 °C and 600 mm in the coastal areas. In the Azores, the average mean temperature and precipitation are respectively 13.8 °C and 987 mm.

In 2017, Portugal recorded the 3rd lowest number of heating degree days (HDD) and 6th highest number of cooling degree days (CDD) in the EU, respectively lower and higher than the HDD and CDD values of other southern European countries such as Spain, Italy, and Greece, which have similar climates (Eurostat, 2018). Furthermore, the energy consumption per dwelling for both space heating and cooling was lower compared to these countries. In 2013, space heating and cooling energy consumption accounted respectively for only 22.0% and 0.64% of all residential final energy consumption, a lower percentage compared to the other European countries (Odyssee-Mure, 2016).

2.2. Dwellings' energy performance gap (EPG) sub-index

Papada and Kaliampakos (2018) highlight in their research that most EP analyses presents one major weakness — being based on actual energy consumption of households and not on their corresponding required energy demand for thermal comfort, distorting the notion of EP and leading to underestimation of building energy demand. In order to overcome this research gap, the composite index includes the assessment of the country's building typologies energy demand combined with the final energy consumption through an energy performance gap assessment.

The dwelling's energy performance gap calculation builds upon previous work conducted by Lopes (2010) and Simões et al. (2015) and closely follows the methodology employed by Palma (2017). With the aim of assessing the potential heating and cooling energy savings of the Portuguese building stock, Lopes (2010) divided the Portuguese mainland territory into 16 different regions, according to similarity of residential building stock, in terms of different characteristics like area, walls, windows and bearing structure, as well as its representativeness and geographical proximity. Lopes (2010) established a total of 5 or 6 building typologies for each region. Simões et al. (2015) increased the representativeness of several of these regions, by adding more typologies to the group, with the goal of calculating the heating and cooling final energy demand of 26 Portuguese municipalities. Palma (2017) increased the building stock's representativeness even further, considering a total of 11 typologies for each region, with the purpose of estimating the heating and cooling gap of all 3092 Portuguese civil parishes. This work replicates Palma (2017) approach, considering the same building's typologies for every region of the country. Despite typologies being mostly differentiated by three main characteristics (the type of building, number of floors and year of construction), as building parameters of the same typology vary across regions, a total of 176 different typologies are considered herein. Other characteristics also defined each typology such as: wall type (from simple stone and mortar masonry wall, without insulation in older typologies; to double pierced brick wall with an air gap and insulation to more recent ones), wall thickness (from single 0.40 m to double 0.40m+0.10 m), wall insulation (none or EPS), type of roof (sloping or straight), roof slab thickness (0.10–0.20 m); type of glazing (double or simple); type of shutters (from roller blind to inside shutters), type of window frames (metal or wooden) and corresponding areas. The direction of the dwelling and solar irradiation were also taken into account.

For each typology, the useful energy demand for space heating and cooling was computed, according to the methodology defined in the most recent residential buildings' energy performance regulation of 2013, which derives from the EN ISO 13790 approach. This calculation considered the maintenance of an optimal inside temperature of 18 °C in the heating season and of 25 °C during the cooling season, for the whole useful area of the dwelling and during the total duration of the respective season. The space heating and cooling useful energy demand generic equations are respectively displayed in Eqs. (1) and (2).

$$N_{ic} = (Q_{tr,i} + Q_{ve,i} - Q_{gu,i})/A_p \qquad [\text{kWh}/(\text{m}^2\ \text{year})] \tag{1}$$

$$N_{vc} = (1 - \eta_v)\,.Q_{g,v}/A_p \qquad [\text{kWh}/(\text{m}^2\ \text{year})] \tag{2}$$

where $Q_{tr,i}$ represents the heat transfer through conduction between the building and the surroundings in [kWh]; $Q_{ve,i}$ is the heat transfer through ventilation [kWh]; $Q_{gu,i}$ represents the total useful heat gain in the heating season in [kwh]; A_p is the building's indoor pavement useful area in [m^2]. η_v is the utilization factor of the heat gains; $Q_{g,v}$ represents the heat gains in the cooling season [kWh]. Heat losses related to the elements connected with adjacent buildings and thermal bridges were not considered, due to the lack of detailed regional data. The dwellings in typologies from 1960–1980 in the northeastern region of the country have the highest heating useful energy needs, with 164 kWh/m^2, while the typologies from 2005–2011 in Algarve have the lowest useful energy needs, with 10 kWh/m^2. The dwellings in typologies from before 1919 in the central north region and from the period 1945–1960 in the central west region have the higher and lower cooling useful energy needs, with respectively 25 kWh/m^2 and 7 kWh/m^2 (Palma, 2017).

The final energy demand per civil parish was then calculated using: (a) the split of heating systems per civil parish from data collected from Statistics Portugal (INE, 2011), (b) split of cooling systems that is only available at a national level, (c) typical climatization systems' efficiencies, and (d) the number of occupied main residence dwellings per typology (INE, 2011).

Final energy consumption municipal data for the residential sector, per energy carrier, produced by national authorities (DGEG, 2017), was used to estimate the heating and cooling energy consumption per civil parish. The municipal consumption was disaggregated into energy consumption for heating and cooling, using representative municipal energy matrixes (Almada (AGENEAL and CMA, 2011), Bragança (Ferreira, 2012), Cascais (Selfenergy, 2012) and Porto (AdePorto, 2008) for each country's climatic zone, to obtain the percentage of final energy consumption per carrier for space heating and cooling. National shares from INE/DGEG (2011) were used if more detailed data was not available. Subsequently, the municipal heating and cooling consumption were apportioned per civil parishes using the number and area of dwellings.

Table 1
Energy performance gap classes and the corresponding EPG sub-index.

Gap classes (%)	EPG sub-index (1–20)
0–20	1
21–30	2
31–40	3
41–51	4
52–62	5
63–72	6
73–74	7
75–76	8
77–78	9
79–80	10
81–82	11
83–84	12
85–86	13
87–88	14
89–90	15
91–92	16
93–94	17
95–96	18
97–98	19
99–100	20

The heating and cooling performance gaps correspond to the percentage difference between the final energy demand (applying the buildings thermal regulation requirements) and the final energy consumption (derived from energy statistics), respectively for heating and cooling. Higher gaps refer to a higher thermal discomfort condition of the dwellings. Each percentage gap was then standardized into a sub-index that ranges from 1 (minimum gap) and 20 (maximum gap), according to the following classes shown in Table 1. The relationship between the variable and the sub-index is a segmented linear function, more precisely a "step" function, as described by Ott (1978).

2.3. Population's ability to implement alleviation measures (AIAM) sub-index

A literature review was conducted with the aim of identifying and selecting the most adequate socioeconomic variables to compose a sub-index (AIAM) that quantifies the regional population's ability to implement thermal comfort alleviation measures or take action to adapt and mitigate potential energy poverty conditions. Several authors (e.g. Liddell and Morris, 2010; Price et al., 2012; Thomson and Snell, 2013) highlight several indicators as relevant for energy poverty vulnerability assessment. The indicators were hence chosen to take into account their relevance, analytical soundness, timeliness and accessibility of data as a guarantee of quality, as indicated by OECD/JRC (2008), as well as avoiding data redundancy since the indicators will be aggregated into a sub-index. Figs. A.1 to A.4 in the Appendix depict the distribution of each of the indicators across Portuguese regions.

The selected indicators and the rationales that support their choice are the following:

- *Age of the Population* - particularly the share of the population with ages equal or lower than 4 years old or aged 65 and over. The underlying assumption is that these age groups are the most vulnerable to thermal comfort distress due to their lower adaptive capacity. Portugal has an ageing population, set to decrease to about 9.1 million by 2050 (Sievert et al., 2017). In 2017, approximately 428 thousand Portuguese inhabitants were children between 0–4 years old and about 2.2 million were aged 65 and over, representing respectively 4.2% and 21% of the population, compared to the EU average 5.1% and 19.4% (Eurostat, 2018).

Table 2
Socioeconomic indicators, their intervals, and classification segmentation.

Population with 4 or fewer years of age (%)	Class.	Population with 65 or more years of age (%)	Class.	Average monthly income (€)	Class.	Dwelling owned by the occupant (%)	Class.
>12%	1	>56%	1	>1800€	5	>91%	5
8%–12%	2	41%–56%	2	1427–1800€	4	78%–91%	4
4%–8%	3	25%–40%	3	1050–1426€	3	65%–77%	3
1%–4%	4	10%–24%	4	683–1050€	2	50%–64%	2
<1%	5	<10%	5	<683€	1	<50%	1
Population with a university degree (%)	**Class.**	**Unemployment (%)**	**Class.**	**Building State of Conservation (qualitative)**			**Class.**
>26%	5	>26%	1	No need for repair			5
19%–26%	4	19%–26%	2	Small repair			4
12%–18%	3	12%–18%	3	Medium repair			3
5%–11%	2	5%–11%	4	Big repair			2
<5%	1	<5%	5	Very degraded			1

Note: For the indicator "Building State of Conservation", the classification of each civil parish resulted from the weighted arithmetic mean of the different shares of buildings per state of conservation, in which the attributed classifications of each state of conservation (1–5) were the weighting factor.

- *Average Monthly per Capita Income* – refers to the financial capacity to implement thermal comfort improvement measures, namely through the purchase and use of heating and cooling systems and the application of retrofit measures. Data for this indicator is only available at a municipal level. In 2016, the annual monthly net income of a Portuguese worker was circa 880 euros, well below the EU average of 1573 euros (Eurostat, 2018).
- *Dwellings' Owned by the Occupant* – i.e. the proportion of residents who own the dwelling in which they reside. This alludes to the limited ability of a tenant to implement adaptation measures (Boardman, 2010) such as the installation of wall insulation or double glazing, given these interventions require consent from the landlord. In Portugal, in 2016, about 75.2% of the population lived in homes they owned themselves, differing from the EU average of 69.3% (Eurostat, 2018).
- *Education Level* – this indicator refers specifically to the share of the population with a university degree. The assumption is that a person with a university degree is potentially more aware and has better access to information on energy efficiency measures, including financing opportunities, social incentives, and other support actions for building retrofit, heating and cooling technology acquisition and installation. In 2017, 24.0% of the Portuguese population between 25–64 years old had a university degree, compared to an EU rate of 31.4%. (PORDATA, 2018).
- *Unemployment Rate* – assumes that generally unemployed people have more financial difficulties and less motivation to implement energy poverty alleviation measures. The unemployment rate of the Portuguese population stood at 8.9% in 2017 (PORDATA, 2018), while the EU rate was 7.6%.
- *Building State of Conservation* – a dwelling in a rundown building will require significant repair, more retrofit interventions and financial investment for indoor thermal comfort to be assured, compared to a dwelling in a well-preserved building. In 201, 28.9% of the Portuguese residential buildings needed some kind of repair (INE, 2011).

The seven indicators were also standardized according to a "step" segmented linear function, where each indicator was segmented in five intervals of values, according to the respective variable's distribution and its upper and lower end values in all country regions. Thus, an ability classification value between 1 (minimum ability) and 5 (maximum ability) was attributed to each interval, as illustrated in Table 2.

The population's ability to implement alleviation measures sub-index is the weighted linear sum of the aforementioned socioeconomic indicator values, and ranges between 1 (lowest ability) and 20 (maximum ability), in order to be consonant with the EPG sub-index. A group of 13 specialists of Nova University of Lisbon, ADENE (National Energy Agency), ICS (Social Sciences Institute) and DGEG (Directorate for Energy and Geology) were asked to set weights for each indicator, reflecting its relevance to the sub-index, varying from 0 (not important) to 2 (very important). The average resulting weights of the survey were standardized for their sum to be equal to 4 and consequently for the sub-index to range from 0 to 20. The average standardized weights of the survey (Table 3) were used for the sub-index computation.

Table 3
Average with used in each socioeconomic indicator.

Socioeconomic indicator	Average weights from 13 surveys
Population with 4 or fewer years of age	0.44
Population with 65 or more years of age	0.67
Average Monthly income	0.59
Dwelling Owned by the Occupant	0.27
Population with a University Degree	0.67
Unemployment rate	0.97
Building State of Conservation	0.39

2.4. Energy poverty vulnerability index (EPVI)

The energy poverty vulnerability index (separately for heating and cooling) is calculated from a linear equal-weighted average value between the EPG and AIAM sub-indexes, as described in Eq. (3). In order to maintain the consistency of the result's scale with the sub-indexes (in which 1 represents the lower gap and less ability to implement measures and 20 represents the maximum gap and the ability to implement measures), the symmetrical value of the AIAM sub-index was considered in the average calculation. Thereby, the EPVI ranges between 1 (the minimum value) and 20 (the maximum value). Higher energy poverty vulnerability derives from a combination of higher regional energy performance gaps and/or lower ability to implement thermal comfort measures of that regions' population. For every civil parish, two EPVI variations were therefore computed: one for space heating and another for space cooling, in order to evaluate the different impacts in a country with both vulnerability problems. The two indexes were mapped using the QGIS software (QGIS Desktop 2.18.18) for visualization and detailed spatial analysis.

$$EPVI = (EPG + (20 - AIAM))/2 \quad (3)$$

3. Results and discussion

In this section, the EPG sub-indexes for space heating and cooling, the AIAM sub-index, and the heating and cooling EPVI regionally explicit maps are presented by civil parish. The civil parishes' top 50 ranking for the heating and cooling EPVI can be found respectively in Tables A.1 and A.2 of the Appendix.

Each sub-index composing the EPVI addresses different drivers of energy poverty. The EPG sub-index evaluates building energy performance and the population's energy consumption. Different climatic conditions, construction characteristics and building bearing structure for assessing building typology energy needs, as well as ownership and use of space heating and cooling systems with related statistical data on final energy consumption, are taken into account. Thus, the developed EPG sub-index can be considered an indicator of the Portuguese building stock's energy efficiency, which is one of the main factors underlying energy poverty vulnerability, stressing or dismissing the need for increased energy consumption. On the other hand, the AIAM sub-index is a socioeconomic composite index, assessing the population's intrinsic ability, in the form of awareness, access to information, knowledge, motivation and financial resources, to adapt in case of thermal discomfort, which is directly linked to several enabling factors of energy poverty. Therefore, although distinct in nature and purpose, both sub-indexes complement each other and equally contribute to understanding and evaluating the different facets and complexities comprising the multidimensionality of energy poverty across EU countries.

3.1. Dwellings' energy performance gap (EPG) sub-index

Fig. 2 shows the sub-indexes for heating and cooling EPG mapped by civil parish. It is possible to denote that every civil parish has a heating and cooling EPG sub-index higher than 0, meaning that the final energy needed for keeping indoor temperatures as set by the residential buildings thermal regulation is always superior to the final energy consumption for these two end-uses. Approximately 97.5% of all civil parishes have a heating energy gap sub-index higher than 11, which results from heating gaps higher than 81%. With regard to cooling, the minimum sub-index of a civil parish (12) indicates that every civil parish has at least a cooling gap equal to or higher than 83%. About 98.9% of all civil parishes have a cooling gap higher than 90%.

The energy demand was computed according to the established methodology defined by the national energy performance regulation, which sets demanding standards, namely regarding the area and period of climatization, that differ widely from the Portuguese space heating and cooling habits for climatization. This is a key factor for explaining the significant discrepancy between energy demand and consumption. Another factor is the high percentage of ageing buildings (20% of the buildings were built before 1960) which, due to poor insulation and higher thermal conductivity materials in their structure (like stone masonry), have increased energy demand. The cooling EPG sub-index values are higher than the heating values due to the current low ownership rates of cooling systems. In Portugal, the use of natural ventilation and mixed ventilation systems is common (Pinto et al., 2016), resulting in lower cooling consumption levels. Notwithstanding, if the gaps are analysed in terms of absolute values, there is often a bigger discrepancy between the estimated annual heating final energy demand and final energy consumption (231 PJ) compared to the cooling (25 PJ).

The climate is the main driver of the sub-index regional variation. The higher heating sub-indexes are generally widespread throughout the territory but occur in higher concentration in the north and central Portugal, where outside temperatures are lower and the number of HDD is higher. The lowest gaps can be found in the Metropolitan area of Lisbon and Porto, as well as the Algarve region, where the winter climate is milder and energy consumption is higher. Although there are high cooling sub-indexes all over the country, the most significant cooling sub-indexes are also located in the north and centre region, as civil parishes in these regions have reduced energy consumption levels. In the south, the ownership rate of cooling systems is higher, which results in higher use of cooling equipment with higher consumptions and lower gaps.

3.2. Population's ability to implement alleviation measures (AIAM) sub-index

The sub-index map depicting the population's ability to implement thermal comfort measures sub-index map is shown in Fig. 3. It is important to emphasize that the seven indicators used to compute this sub-index have different weights, hence their influence has different magnitudes on the geographical variation of this sub-index. The "Unemployment Rate" is the most relevant indicator to the sub-index, whilst the "Dwelling Owned by The Occupant" was considered the less influential, probably due to the stakeholders' perceptions that most Portuguese dwellings are owner-occupied, and therefore significant regional differences are not identifiable. The civil parishes with a high sub-index (12.4+) are mainly located on the west coastline from north to south, but especially in the centre coastal region, and in the Azores islands in the middle of the Atlantic Ocean. The big urban areas like Lisbon, Porto, Coimbra, and Leiria constitute the bigger clusters of civil parishes with the highest AIAM sub-index classification, in other words, where a more significant proportion of the population will be able to react to thermal discomfort circumstances. This is mainly due to the fact that these areas have the highest proportion of people with a university degree, a lower rate of elderly people and among the highest salaries, which positively influence the sub-index result.

A number of civil parishes clearly stand out in the inland regions, but these regions encompass a significant frequency of civil parishes with lower sub-index results (<12.4), which is due to higher percentages of elderly people, who have low retirement pensions (income), and lower levels of education, as people over 65 years of age in Portugal seldom have a university degree. There is a considerable part of the northwest region where various civil parishes also have a low sub-index, as a result of high unemployment rates, a greater number of children in the households and lower rates of dwellings occupied by the owners. The islands have a considerable variation of sub-index values, due to the different shares of unemployed people, people with a university degree and income levels.

3.3. Energy poverty vulnerability index

Fig. 4 shows the heating and cooling Energy Poverty Vulnerability Index maps for the country split by civil parish. It is important to consider that this index does not provide information on where the energy poor consumers are and where they are not — as a matter of fact, it is safe to assume that there is population suffering from energy poverty all around the country, in every region. This index works on a basis of probability — it indicates the regions (civil parishes) where the share of the population at risk of energy poverty is higher and where the probability of finding energy-poor consumers is greater. In regard to heating, the most vulnerable civil parishes can be found all over the inland region of the country, many close to the border with Spain. In the north region of the country, high index civil parishes have a higher occurrence and are widespread throughout the whole region. This can be generally

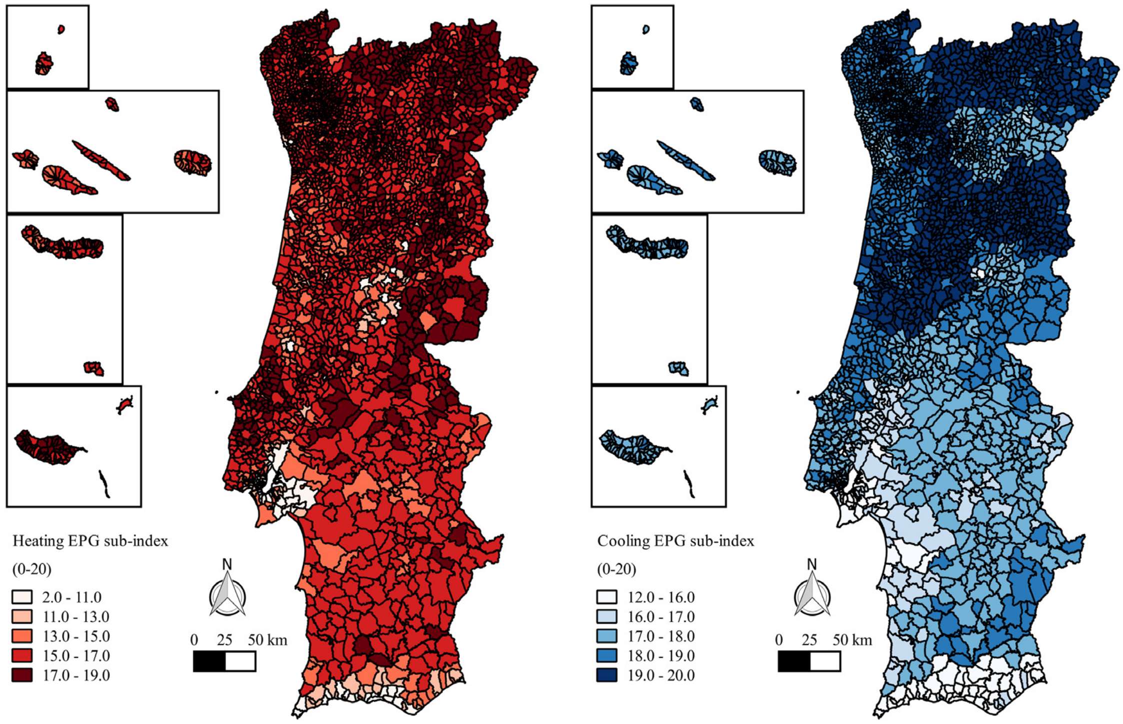

Fig. 2. Regional Heating and Cooling Energy Performance Gaps Sub-Indexes for Portugal.

explained by the lower AIAM sub-index, deriving from high unemployment rates and lower average income, and considerable higher energy performance gaps, related to a more severe winter climate (bigger number of HDDs and consequently, energy demand). In the centre region, aside from those in the east, close to the border, there is a big cluster of high index civil parishes in the Ribatejo region. The severe climate-related heating EPG sub-index and low AIAM sub-index are also the explanation for the magnitude of the heating EPVIs of this region. For the civil parishes close to the border, the low AIAM sub-index is related to low-income levels and a higher percentage of people over 65 years old, whilst in the Ribatejo region, it derives from a combination of a low rate of dwellings occupied by the owners, low share of population with a college degree and higher unemployment rates. Considerable EPVIs can also be observed in various islands' civil parishes, due to low energy consumption levels and high shares of unemployment, households with children and people without a university degree.

The lowest heating EPVIs are located in the Metropolitan Area of Lisbon and the Algarve region, as the heating EPG sub-index is lower in those regions, due to milder climate and higher heating equipment ownership rates and energy consumptions. In the Metropolitan Area of Lisbon, the ability to implement alleviation measures is more significant, which also contributes to the current lower EPVI index.

On a comparative analysis of both EPVI indexes, the cooling index represents a more serious issue, as the average magnitude of the cooling index (13.2) is superior to the heating (12.0), and the frequency of civil parishes presenting a higher cooling index is also higher. About 85% of all civil parishes have a cooling index above 12, whereas only 37% have a heating index superior to that number. The distribution of the high cooling index civil parishes is similar to heating, with most vulnerable civil parishes being located in the inland of the north and centre regions. Some civil parishes in the inland south and centre east region have the highest level of cooling-related energy poverty index, although their cooling gap sub-index is not the highest observed. This is due to the very low AIAM sub-index, deriving from a low percentage of people

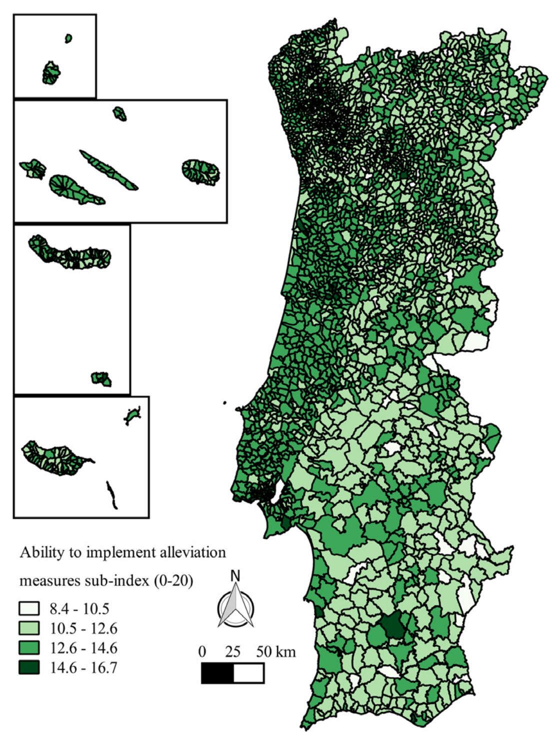

Fig. 3. Regional ability to implement alleviation measures sub-index in Portugal.

with a university degree, high shares of unemployment and elderly people and low average monthly wages.

Most of the inland civil parishes are situated in rural regions, whereas the coastal area is mostly constituted by urban civil parishes. As rural civil parishes have generally higher heating and cooling EPG sub-indexes and lower AIAM sub-index, there is a higher percentage of potentially vulnerable people in rural regions.

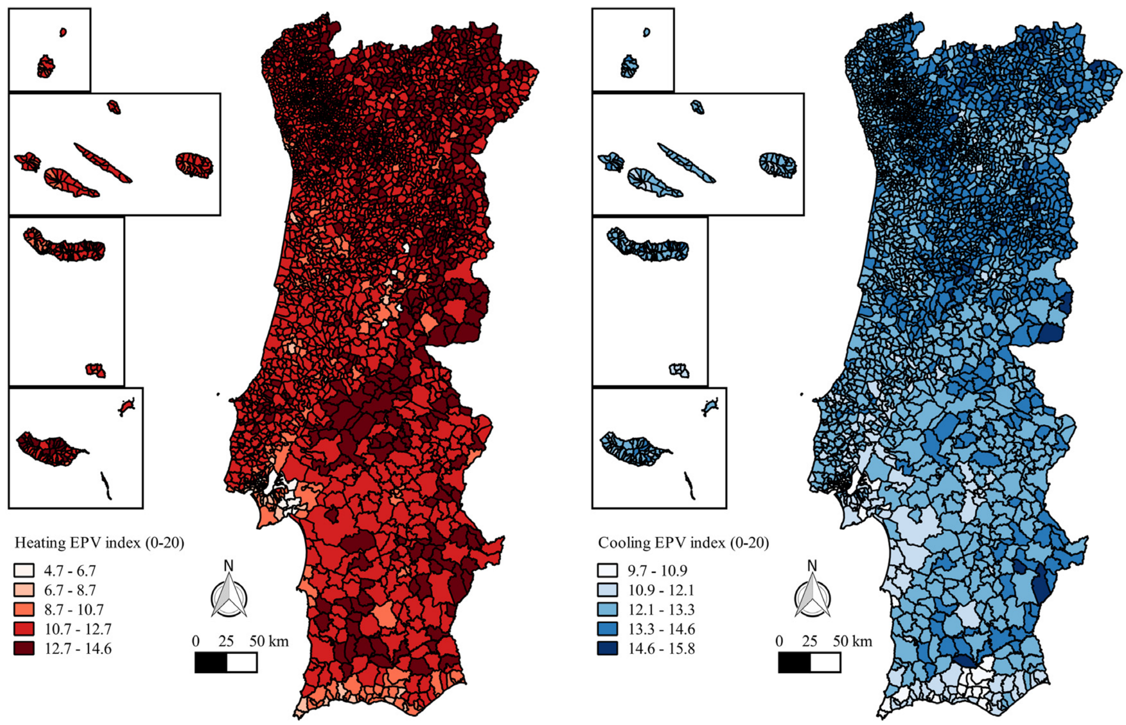

Fig. 4. Heating (left) and Cooling (right) Energy Poverty Vulnerability Index.

However, it is not correct to affirm that there is a greater number of energy-poor consumers in rural regions than in urban regions, as urban areas have a considerably higher number of inhabitants.

The two indexes results should be put in perspective, in terms of their relevance regarding the different spheres in which they can be analysed and how they should be used. At first glance, the heating EPG sub-index constitutes a less serious issue than the cooling, as the heating gaps are on average lower. If, however, the analysis is performed from the standpoint of the amount of energy necessary to offset these gaps, assuming that thermal comfort is assured if the aforementioned gaps are indeed offset, heating proves to be a more significant issue than cooling. Given the AIAM sub-index does not vary in reference to heating or cooling vulnerability analysis, a higher cooling EPG sub-index will result in a higher cooling EPVI, which indicates reduced ability to adapt and increased vulnerability of the population to higher temperatures. Greater vulnerability implies more considerable health risks for the population. Nevertheless, even though both high and low temperatures can have adverse effects on the population's well-being (Basu and Samet, 2002; Heutel et al., 2017), statistical evidence shows that cold weather is responsible for a significantly higher increase in mortality rates compared to hot weather (Healy, 2003; Gasparrini et al., 2015). Diaz et al. (2015) state that there are less prevention and adaptation measures for cold temperatures, resulting in increased mortality in the winter. Similarly, according to Liddell et al. (2015), Portugal recorded the second highest excess winter deaths index (28%) in the EU, estimated using data from 1980 to 2013. Almendra et al. (2017) found out a strong association between excess winter deaths and housing deprivation. Furthermore, PCS/Quercus (2017) recently conducted an online survey on thermal comfort in Portuguese households (for which they obtained 795 valid answers), where about 74% of the people consider their housing cold during the winter and 24% of the people consider their houses to be too hot during the summer. Only 1% report that their housing is at a temperature that provides comfort PCS/Quercus (2017).

Therefore, even though the indexes results might indicate otherwise, the inability to keep the house warm during the winter can arguably still be a more serious issue than cooling in terms of occupant health. In the future, due to climate change, average temperatures, as well as the number, duration, and amplitude of heat waves, are predicted to increase in the southern European region (including Portugal) (Gualdi et al., 2013; Ducrocq, 2016; Parente et al., 2018). This could further exacerbate cooling-associated vulnerability and potentially impact heating and cooling final energy consumption. Several studies indicate that heat-related excessive summer mortality will potentially increase in the future (Hajat et al., 2013; Li et al., 2018; Martinez et al., 2018). On the other hand, some authors claim that cold-related excessive mortality will only decrease slightly or not at all with warmer winters (Ebi and Mills, 2013; Hajat et al., 2013; Staddon et al., 2014; Kinney et al., 2015; Martinez et al., 2018). This both stresses the relevance of maintaining proper indoor thermal comfort and the future probable increase in the uncertainty of energy services' demand projections for heating and cooling (Gouveia et al., 2012).

All these consequences reinforce the need for increasing the ability of the population to adapt in both heating and cooling seasons, through dedicated energy poverty alleviation measures and intertwined energy efficiency and renewable energy policies. The only measure directly implemented to tackle energy poverty in Portugal is the social tariff on electricity and natural gas which, despite representing financial relief for the most vulnerable families, is an incomplete instrument addressing the needs of the population.

The EPVI is useful in the identification of hotspot regions for local action, allowing for more targeted and aggregated efforts that result in more effective tailored-made measures and policies focused on the most significant issues, which may differ from region to region. Interventions should be targeted to specific vulnerable groups, as these prove to be more effective in reaching the proposed objectives, compared to more general and wide-ranging efforts. Nevertheless, the integration of the proposed policies in urban and regional development and planning instruments is paramount, so their implementation can be followed, and its success assessed and put into a broader national perspective.

Since energy poverty is not fully explained by income levels and other socioeconomic conditions, and it is certainly related to infrastructure (buildings, climatization systems) fault and frailty, the EPVI can be used to identify both energy and social policy mechanisms that could alleviate the problem. The identified solutions should address energy efficiency in buildings and energy affordability and be supported and leveraged by social incentives and subsidies established by governance institutions, preferably at local or municipal scale. Examples include energy efficiency interventions aiming to decrease buildings' energy demand while assuring thermal comfort conditions. This can be achieved through passive measures that can range from no-cost energy consumption reduction behaviours such as natural ventilation optimization and proper use of shading devices; to more costly measures like the installation of double glazing, and external insulation, intrinsically improving the buildings' energy performance. Active measures like the purchase and use of more efficient space heating and cooling equipment such as heat pumps are also relevant for meeting increasing levels of thermal comfort but with energy consumption reduction.

Investment in decentralized renewable energy technologies can also assume a significant role in counteracting the high costs of electricity, particularly individual or neighbourhood scale technologies that might integrate local electricity grids, increasing the independence of local producers and consumers. Depending on the energy poverty drivers of a certain region, identified using the EPVI, interventions can correspond to only one or a group of these measures.

Besides identifying the most vulnerable regions and groups to whom the interventions should be channelled, the EPVI can also be used for both *ex-ante* and *ex-post* assessments of measures. It serves also as an instrument for raising awareness of the complexity and relevance of energy poverty problems not only for the population but among all the stakeholders involved, including relevant national institutions, that should actively participate and support the implementation of these measures through instruments such as tax incentives, low-interest banking loans, and non-refundable subsidies. Several of these instruments are already implemented but they are not particularly designed and targeted for vulnerable energy-poor consumers, which potentially reduces their effectiveness and efficiency in energy poverty alleviation. Schleich (2019) states that, in fact, dwelling owners with lower income have a lower tendency to adopt retrofit measures, hence it is particularly relevant to tailor these instruments to poor homeowners.

Notwithstanding its current merit and significant utility, the index only provides a snapshot of the national and regional situations. The number of uncertainties pertaining to the different methodological steps requires that index and sub-index are used parsimoniously, rather as a comparative tool between regions, than from an absolute values' standpoint.

An important step to advance this method would consist of moving towards the concept of a living index, where new and more time-sensitive datasets could be integrated. This would allow for a better evaluation of potential energy poverty alleviation measures. Thus, the EPVI may be further advanced if data is available, namely through the integration of (i) smart metre data, which would allow better incorporation of different levels of energy consumption and better understanding of regional consumption patterns, enabling the index to be zoomed to the neighbourhood and even individual house level; (ii) energy performance certificate data, that could provide more precise and detailed information on building stock and space heating and cooling equipment, hence improving the quality of the EPG sub-index and the final EPVI; (iii) indoor/outdoor temperature sensors that would foster a more realistic estimation of energy demand; (iv) include other indicators, such as the share of social housing, non-classic dwellings, and dwellings with social energy tariff, since these would increase the probability of accurately pinpointing the regions where the higher number of energy-poor consumers are residing. It would also be relevant to replicate the EPVI methodology in other European countries, to further validate its worth and adaptability, as well as to meet its purpose in pinpointing more hotspots for energy poverty vulnerability across the EU.

4. Conclusions

Energy poverty is a growing concern in the European Union, with visible detrimental consequences for the health, and well-being of the population, even going beyond the private domain of the home to larger economic and political problems. Living in an adequately heated and cooled home should constitute a civil right, as corroborated and enshrined by three of the United Nations Sustainable Development Goals (UN, 2015). UN-SDG 1 and 7 set the background for energy equity and EP eradication analysis across the EU. While underscoring universal energy access as a goal, through the implementation of more renewable energy technologies and increased energy efficiency, the UN supports 2 of the major solutions to the EP problem. SDG 3 is also directly linked to the issue, since households experiencing EP have high occurrences of physical ill, health and mental distress and resultant problems, such as children missing school and premature deaths among elderly people. Therefore, it is a societal issue that should be swiftly addressed, in order to avoid further damage in people's lives.

In this paper, we advance the development of a very high spatial scale multidimensional energy poverty composite index to map energy poverty at a regional level, addressing space heating and cooling separately. The empirical testing of the methodology was conducted for all 3092 Portuguese civil parishes (mainland and islands). The methodology combines socioeconomic indicators of the population with climate, energy consumption and buildings final energy demand, construction characteristics, and energy performance of different building typologies. Results show that the higher heating EPVIs are associated mainly with rural civil parishes located across the inland region of mainland Portugal, deriving mostly from higher unemployment rates, low income, elderly population, lower levels of education and a more severe winter climate. The higher cooling EPVIs can be found in inland north and central regions. This is also due to low AIAM sub-index levels and very low cooling energy consumptions related to low ownership rates of cooling equipment, which result in high cooling energy performance gaps, even though summer temperatures are generally milder in those regions. Cooling EPVIs are on average higher than the heating EPVIs, but the amount of energy required for space heating and the health effects of a cold home are more significant, which should make winter-related energy poverty the priority for the country.

The mapping and index jointly provide highlights to acknowledge two problems – energy poverty and poor indoor thermal comfort across the country – while identifying major hotspots for local action. The index (EPVI) and sub-indexes (EPG and AIAM) assessed at such a disaggregated regional scale could bridge the gap between common overall country analyses and local-scale evaluations targeting vulnerable households or consumers, while better-understanding EP enablers across different regions. Using the EPVI, it will be possible to put forward a more targeted and aggregated policy framework, with clear guidelines to policymakers and local authorities.

It is also paramount to integrate these policies in other regional instruments (e.g. climate mitigation and adaptation plans), in order to promote synergies with the process of mitigating concurrent and related issues like climate change, that in the future may

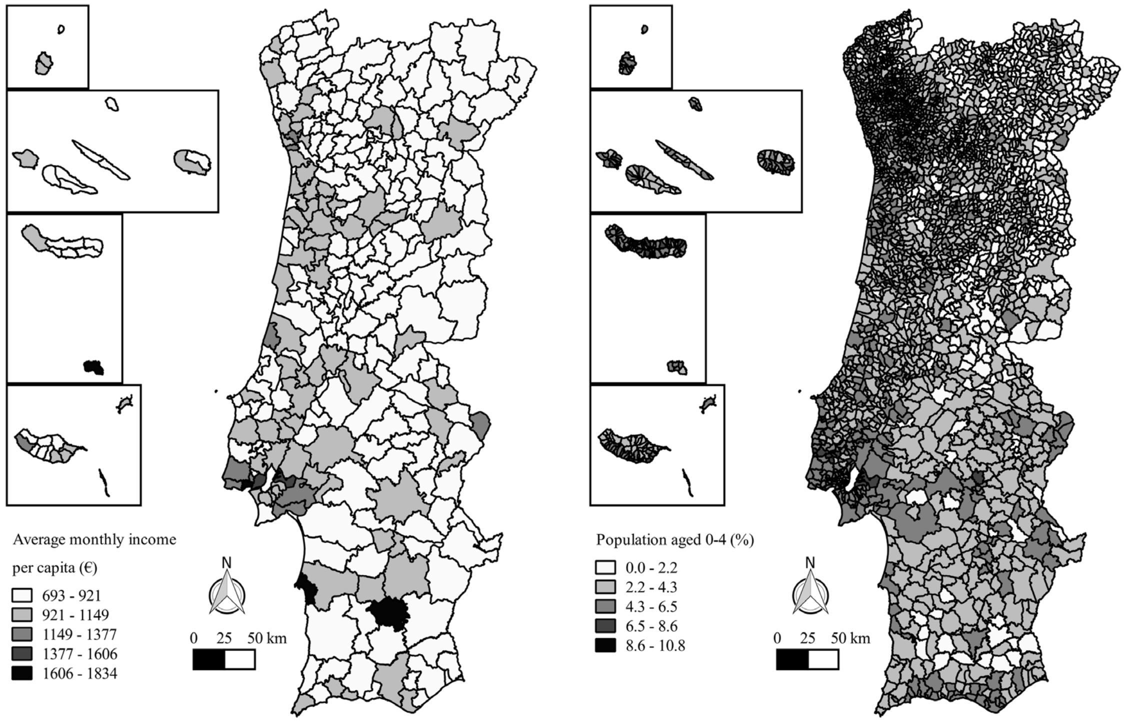

Fig. A.1. Average monthly income per inhabitant per municipality (left) and share of population with 4 or fewer years of age.

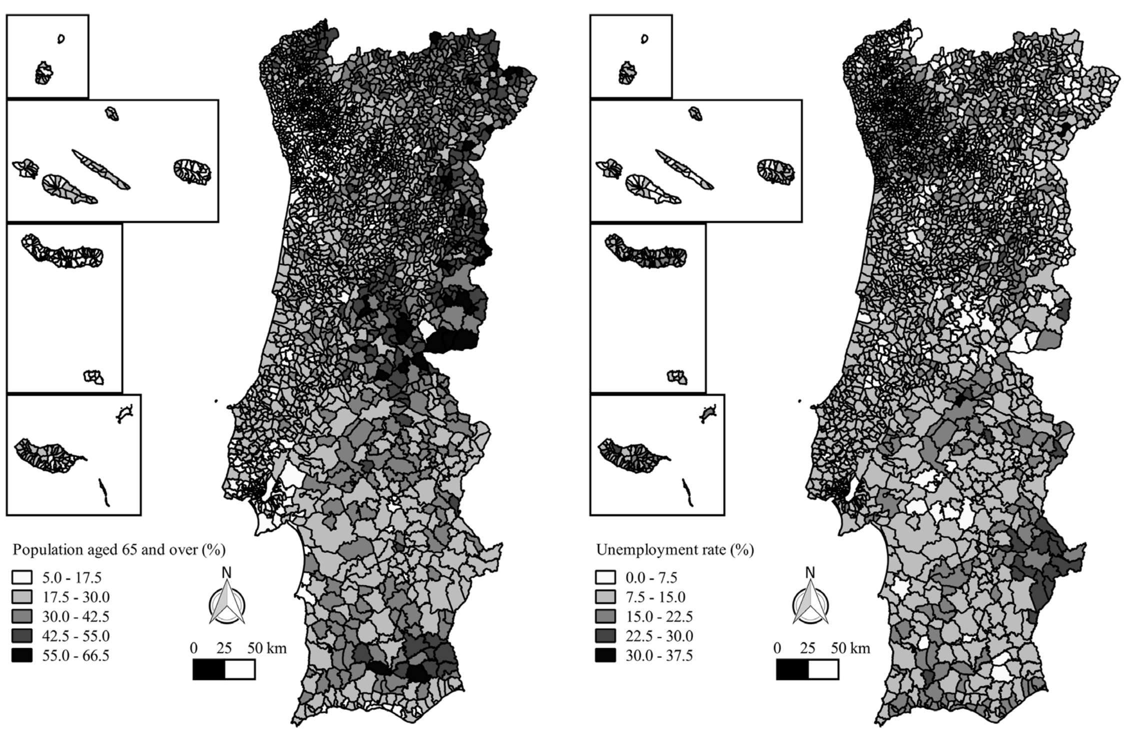

Fig. A.2. Share of population with 65 or more years of age (left) and Unemployment rate (right).

further stress the vulnerability of regions and households to energy poverty. It can also be used from the lens of housing and energy efficiency policies, to analyse the effectiveness of one or various measures to tackle energy poverty (e.g. buildings retrofit measures interventions, more efficient heating systems, income increase, residential energy-saving initiatives, and social and financial public incentives). The mapping also supports increased awareness of this topic among key national and local authorities such as the Covenant of Mayors, governmental bodies, NGO's, energy market players, social and health institutions, which prove to be fundamental to successfully address this problem.

Acknowledgements

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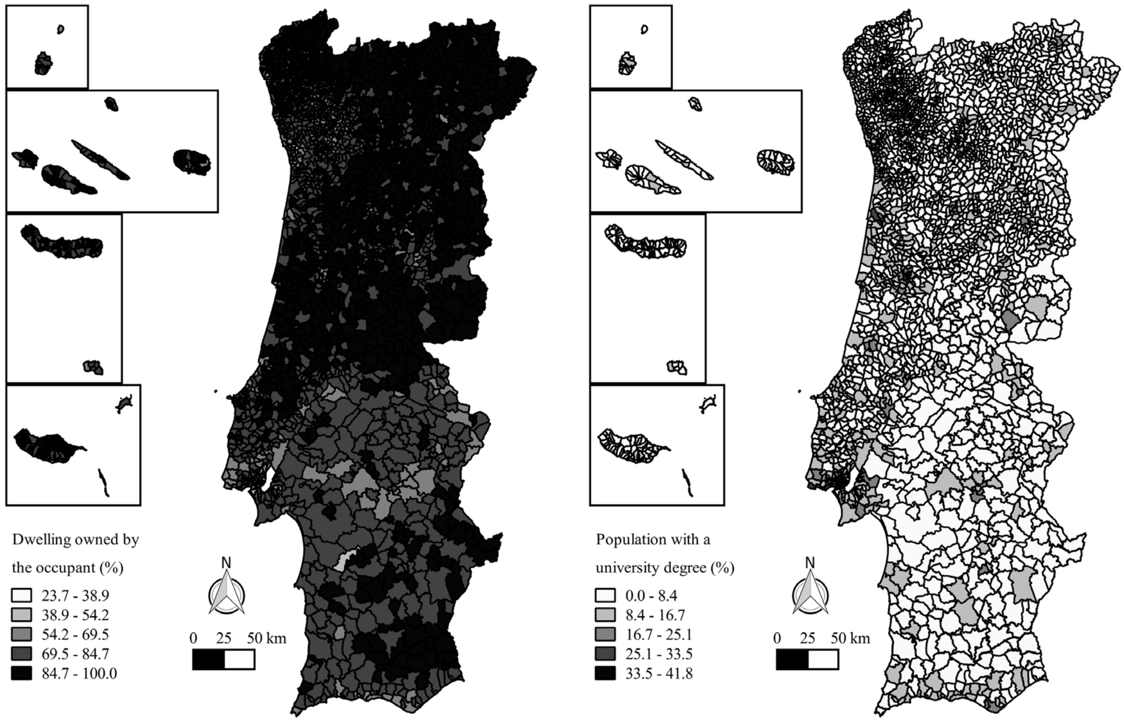

Fig. A.3. Share of dwellings owned by the occupant (left) and share of the population with a university degree (right).

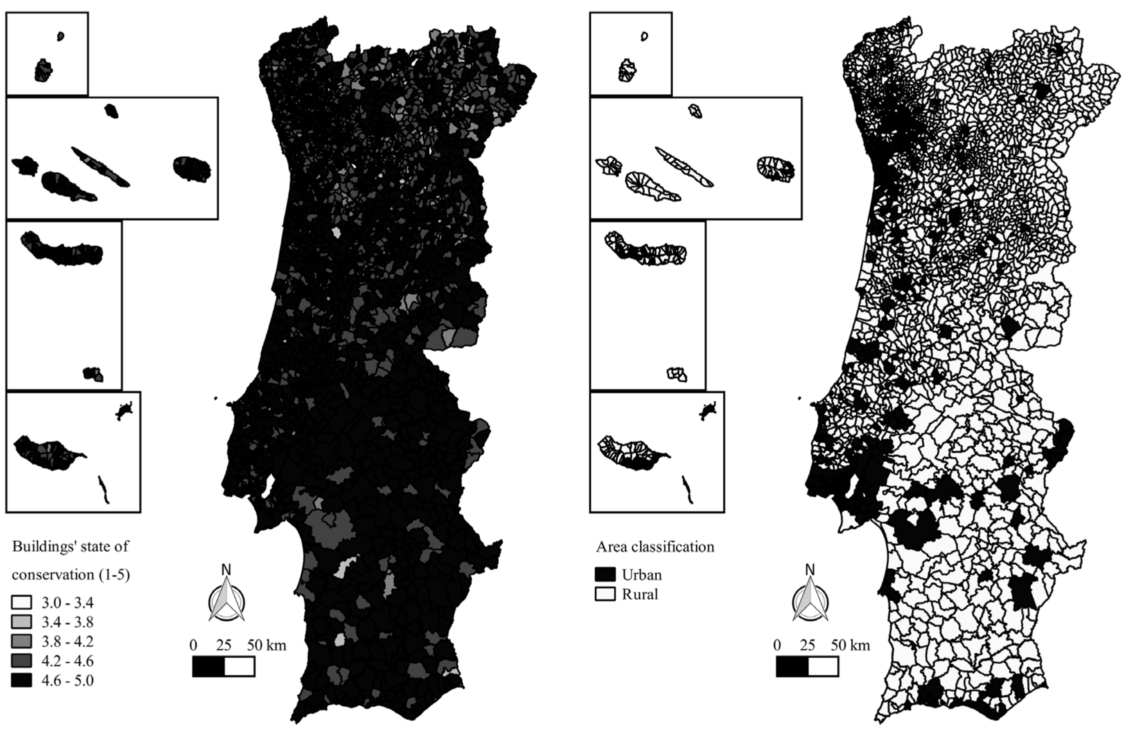

Fig. A.4. Buildings' state of conservation (left) and Area classification (right).

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Appendix

See Figs. A.1–A.4, Tables A.1 and A.2.

Table A.1
Heating EPVI Top 50 civil parishes.

Ranking	NUT2	NUT3	Municipality	Civil parish	Area classification	Heating EPVI
1	Centro	Beira Interior Sul	Idanha-a-Nova	União das Freguesias de Monfortinho e Salvaterra do Extremo	Rural	14.6
2	Centro	Beira Interior Norte	Guarda	Avelãs da Ribeira	Rural	14.5
3	Norte	Alto Trás-os-Montes	Mogadouro	Castelo Branco	Rural	14.4
4	Norte	Alto Trás-os-Montes	Chaves	Sanfins	Rural	14.4
5	Norte	Alto Trás-os-Montes	Chaves	Santa Leocádia	Rural	14.3
6	Centro	Beira Interior Sul	Idanha-a-Nova	Rosmaninhal	Rural	14.3
7	Norte	Alto Trás-os-Montes	Mirandela	União das Freguesias de Franco e Vila Boa	Rural	14.3
8	Centro	Cova da Beira	Covilhã	Verdelhos	Rural	14.3
9	Norte	Alto Trás-os-Montes	Chaves	Mairos	Rural	14.2
10	Centro	Serra da Estrela	Gouveia	São Paio	Rural	14.2
11	Alentejo	Alto Alentejo	Ponte de Sor	Longomel	Rural	14.2
12	Centro	Beira Interior Norte	Celorico da Beira	Baraçal	Rural	14.2
13	Norte	Douro	Vila Flor	União das Freguesias de Valtorno e Mourão	Rural	14.2
14	Norte	Tâmega	Ribeira de Pena	Santa Marinha	Rural	14.2
15	Norte	Ave	Guimarães	Barco	Urbano	14.1
16	Centro	Cova da Beira	Fundão	União das Freguesias de Póvoa da Atalaia e Atalaia do Campo	Rural	14.1
17	Norte	Alto Trás-os-Montes	Montalegre	União das Freguesias de Vilar de Perdizes e Meixide	Rural	14.1
18	Alentejo	Baixo Alentejo	Almodôvar	São Barnabé	Rural	14.1
19	Norte	Alto Trás-os-Montes	Vila Pouca de Aguiar	Bragado	Rural	14.1
20	Norte	Alto Trás-os-Montes	Vinhais	Candedo	Rural	14.0
21	Norte	Alto Trás-os-Montes	Mogadouro	Brunhoso	Rural	14.0
22	Centro	Beira Interior Norte	Manteigas	Vale de Amoreira	Rural	14.0
23	Centro	Beira Interior Sul	Penamacor	Vale da Senhora da Póvoa	Rural	14.0
24	Norte	Alto Trás-os-Montes	Bragança	França	Rural	14.0
25	Norte	Alto Trás-os-Montes	Bragança	União das Freguesias de Parada e Faílde	Rural	14.0
26	Centro	Beira Interior Norte	Guarda	Marmeleiro	Rural	14.0
27	Centro	Cova da Beira	Covilhã	União das Freguesias de Vale Formoso e Aldeia do Souto	Rural	14.0
28	Norte	Alto Trás-os-Montes	Chaves	Vilas Boas	Rural	14.0
29	Norte	Alto Trás-os-Montes	Chaves	Planalto de Monforte (União das Freguesias de Oucidres e Bobadela)	Rural	14.0
30	Norte	Alto Trás-os-Montes	Chaves	Anelhe	Rural	14.0
31	Norte	Alto Trás-os-Montes	Mogadouro	Vila de Ala	Rural	14.0
32	Centro	Beira Interior Norte	Guarda	Pega	Rural	14.0
33	Norte	Alto Trás-os-Montes	Macedo de Cavaleiros	União das Freguesias de Podence e Santa Combinha	Rural	14.0
34	Norte	Alto Trás-os-Montes	Bragança	Salsas	Rural	14.0
35	Centro	Cova da Beira	Covilhã	Dominguizo	Rural	14.0
36	Norte	Alto Trás-os-Montes	Chaves	São Vicente	Rural	14.0
37	Alentejo	Alto Alentejo	Gavião	Margem	Rural	13.9
38	Norte	Alto Trás-os-Montes	Montalegre	União das Freguesias de Venda Nova e Pondras	Rural	13.9
39	Centro	Cova da Beira	Covilhã	Peraboa	Rural	13.9
40	Norte	Alto Trás-os-Montes	Chaves	Águas Frias	Rural	13.9
41	Norte	Alto Trás-os-Montes	Bragança	Gondesende	Rural	13.9
42	Centro	Beira Interior Norte	Guarda	Ramela	Rural	13.9
43	Norte	Alto Trás-os-Montes	Bragança	União das Freguesias de Castrelos e Carrazedo	Rural	13.9
44	Norte	Grande Porto	Gondomar	Lomba	Rural	13.9
45	Alentejo	Alto Alentejo	Alter do Chão	Cunheira	Rural	13.9
46	Centro	Beira Interior Sul	Castelo Branco	Almaceda	Rural	13.9
47	Norte	Alto Trás-os-Montes	Montalegre	Reigoso	Rural	13.9
48	Alentejo	Baixo Alentejo	Moura	Póvoa de São Miguel	Rural	13.8
49	Centro	Beira Interior Norte	Guarda	Videmonte	Rural	13.8
50	Norte	Alto Trás-os-Montes	Vimioso	União das Freguesias de Vale de Frades e Avelanoso	Rural	13.8

Table A.2
Cooling EPVI Top 50 civil parishes.

Ranking	NUT2	NUT3	Municipality	Civil parish	Area Classification	Cooling EPVI
1	Centro	Pinhal Interior Norte	Pampilhosa da Serra	Pessegueiro	Rural	15.8
2	Norte	Alto Trás-os-Montes	Mogadouro	Castelo Branco	Rural	15.4
3	Centro	Serra da Estrela	Gouveia	São Paio	Rural	15.2
4	Centro	Beira Interior Norte	Celorico da Beira	Baraçal	Rural	15.2
5	Norte	Tâmega	Ribeira de Pena	Santa Marinha	Rural	15.2
6	Norte	Tâmega	Celorico de Basto	Vale de Bouro	Rural	15.2
7	Centro	Beira Interior Sul	Idanha-a-Nova	União das Freguesias de Monfortinho e Salvaterra do Extremo	Rural	15.1
8	Norte	Alto Trás-os-Montes	Montalegre	União das Freguesias de Vilar de Perdizes e Meixide	Rural	15.1
9	Norte	Tâmega	Cinfães	Tarouquela	Rural	15.1
10	Norte	Tâmega	Cinfães	União das Freguesias de Alhões, Bustelo, Gralheira e Ramires	Rural	15.1
11	Norte	Tâmega	Baião	Valadares	Rural	15.1
12	Norte	Alto Trás-os-Montes	Vila Pouca de Aguiar	Bragado	Rural	15.1
13	Norte	Alto Trás-os-Montes	Vinhais	União das Freguesias de Moimenta e Montouto	Rural	15.1
14	Norte	Tâmega	Cinfães	Ferreiros de Tendais	Rural	15.0
15	Norte	Alto Trás-os-Montes	Vinhais	Candedo	Rural	15.0
16	Norte	Alto Trás-os-Montes	Mogadouro	Brunhoso	Rural	15.0
17	Centro	Beira Interior Norte	Guarda	Avelãs da Ribeira	Rural	15.0
18	Norte	Alto Trás-os-Montes	Valpaços	Fornos do Pinhal	Rural	15.0
19	Norte	Alto Trás-os-Montes	Mogadouro	Vila de Ala	Rural	15.0
20	Centro	Beira Interior Norte	Guarda	Pega	Rural	15.0
21	Norte	Alto Trás-os-Montes	Macedo de Cavaleiros	União das Freguesias de Podence e Santa Combinha	Rural	15.0
22	Norte	Alto Trás-os-Montes	Montalegre	União das Freguesias de Venda Nova e Pondras	Rural	14.9
23	Norte	Tâmega	Baião	Viariz	Rural	14.9
24	Norte	Alto Trás-os-Montes	Montalegre	Reigoso	Rural	14.9
25	Norte	Alto Trás-os-Montes	Chaves	Santa Leocádia	Rural	14.8
26	Norte	Tâmega	Cinfães	Fornelos	Rural	14.8
27	Centro	Pinhal Interior Norte	Oliveira do Hospital	Lourosa	Rural	14.8
28	Norte	Alto Trás-os-Montes	Vimioso	União das Freguesias de Vale de Frades e Avelanoso	Rural	14.8
29	Centro	Beira Interior Sul	Idanha-a-Nova	Rosmaninhal	Rural	14.8
30	Centro	Serra da Estrela	Gouveia	Ribamondego	Rural	14.8
31	Norte	Tâmega	Cinfães	Souselo	Rural	14.8
32	Norte	Alto Trás-os-Montes	Vinhais	Edral	Rural	14.8
33	Centro	Serra da Estrela	Fornos de Algodres	União das Freguesias de Cortiçô e Vila Chã	Rural	14.8
34	Norte	Alto Trás-os-Montes	Miranda do Douro	Genísio	Rural	14.8
35	Norte	Tâmega	Cabeceiras de Basto	Faia	Rural	14.8
36	Norte	Alto Trás-os-Montes	Mogadouro	Castro Vicente	Rural	14.8
37	Norte	Alto Trás-os-Montes	Mirandela	União das Freguesias de Franco e Vila Boa	Rural	14.8
38	Centro	Serra da Estrela	Gouveia	Vila Cortês da Serra	Rural	14.8
39	Centro	Beira Interior Norte	Guarda	Meios	Rural	14.8
40	Norte	Alto Trás-os-Montes	Macedo de Cavaleiros	União das Freguesias de Talhinhas e Bagueixe	Rural	14.8
41	Norte	Tâmega	Cinfães	Travanca	Rural	14.8
42	Norte	Tâmega	Baião	Santa Marinha do Zêzere	Rural	14.8
43	Norte	Alto Trás-os-Montes	Chaves	Mairos	Rural	14.7
44	Norte	Alto Trás-os-Montes	Mirandela	Frechas	Rural	14.7
45	Norte	Alto Trás-os-Montes	Mirandela	Fradizela	Rural	14.7
46	Norte	Minho-Lima	Ponte da Barca	União das Freguesias de Touvedo (São Lourenço e Salvador)	Rural	14.7
47	Centro	Beira Interior Norte	Pinhel	Vale de Massueime	Rural	14.7
48	Centro	Beira Interior Norte	Guarda	União das Freguesias de Pousade e Albardo	Rural	14.7
49	Alentejo	Baixo Alentejo	Serpa	Brinches	Rural	14.7
50	Alentejo	Baixo Alentejo	Serpa	União das Freguesias de Vila Nova de São Bento e Vale de Vargo	Rural	14.7

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