

Assessing energy performances: A step toward energy efficiency at the municipal level



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ABSTRACT

At present, energy efficiency represents one of the foremost challenges to achieve the transition toward a low-carbon society. Reducing energy use spans a broad range of technical issues and spatial scales: from building to districts, from cities to rural areas, and from energy power plants to electricity grids. In this frame, the challenge of enhancing energy efficiency can be understood as an extremely relevant topic for planning at the municipal level. Nevertheless, recent studies provide evidence that significant gaps exist in the enhancement of energy efficiency within municipal boundaries. The present research recognises that a comprehensive assessment of municipal energy performances is an essential starting point to facilitate local planning in enhancing energy efficiency. However, how can this challenge be translated into practice and applied to the implementation of local planning? As new models result from the transformation of existing ones, the development of a methodology associated with a case study in Portugal was deemed the most appropriate approach to contribute to knowledge in these fields. The primary objective of this study is to move toward more integrated process of planning for energy efficiency, supporting the definition of priorities and strategies to address energy saving improvements at municipal level. The assessment process involves a statistical analysis that using Geographical Information System, is combined and translated into spatial models to determine needs and set priorities within a Municipal Master Plan review. Based on this top-down approach, it becomes clear that energy efficiency is a cross-cutting issue interrelated with a blend of various disciplines: geography, spatial planning, urbanism, architecture, and civil engineering. The results enable us to understand why municipalities should be called upon to enhance energy efficiency by first looking at a comprehensive energy performance assessment. Embracing the whole municipal territory rather than only urban areas, is key to articulate energy efficiency and geographical, social, environmental and economic factors that are at the core of local planning.

1. Introduction

From the Brundtland Report in 1987 to the 2015 Paris Climate Conference – COP21, international concern has been expressed regarding how best to combat global warming to achieve more sustainable development. One of the lessons learned from these three decades of reflexive debates is that “environment-development” and “climate-energy” represent two bilateral relationships, interconnected in a critical cause-and-effect loop. Energy is a driving force for modern civilization development (Afgan, Gobaisi, Carvalho, & Cumo, 1998). Since the Industrial Revolution, however, economic and population growth, underpinned by globalization and capitalism processes, has increased emission of greenhouse gases, primarily stemming from fossil fuel combustion and land use changes (Clack & York, 2005). Thus, the threat of global climate change arises as an outcome of

progress and social conquests (Laughlin, 2012) in a blend of “burn out”, “collapse” and “overshoot” catastrophic scenarios, as noted by Rob Hopkins (Hopkins, 2008; Neves & Leal, 2010; Hopkins, 2008:33). Sustainable development and energy must progress together, bringing about a desired transition towards the efficient energy use and the switch to renewables, (Boyle, 2012; García-Álvarez, Moreno, & Soares, 2016; Hopkins, 2008; Süsser, Döring, & Ratter, 2017;).

In this framework, Smart Cities (Calvillo, Sánchez-Mirallas, & Villar, 2016), Net-Zero Energy Buildings (Kolokotsa, Rovas, Kosmatopoulos, & Kalaitzakis, 2011), Internet of Things (Atzori, Iera, & Morabito, 2016), Information and Communications Technologies (Battarra, Gargiulo, Pappalardo, Boiano, & Oliva, 2016) represent significant solutions being implemented, but, they currently result in planning approaches mainly focused on urban contexts.

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Table 1
Synthesis matrix of review studies.

Scale	Level	Main themes and cross cutting issues	Barriers/gaps	Insights	Ref.
City	Urban Planning and Energy Conservation	Rethinking Sustainable Cities: Multilevel Governance Urban Politics of Climate Change. Urban planning's new requirements and goals to tackle energy issues.	There are few policies, initiatives or measures related to energy conservation in the majority of strategic planning documents or development control decisions. EU insights and guidelines do not explicitly describe how energy and urban planning processes should be integrated. Methods and the tools have not yet been combined to manage all of the integrated energy planning processes and tasks.	Energy considerations should be taken into account, for policy planning guidance.	(Bulkeley and Betsill, 2005)
City	Local energy planning	Review of the existing planning processes and methods and the tools taken.		The pressing issues related to energy might represent a convenient opportunity to rethink how such tools could be used to inform planning. Planning procedure can be divided into four phases with several interlinked sub-activities and tasks.	(Cajot et al., 2017)
City and territory	Integrated Energy planning	Assessment of municipal energy plans.	The necessary institutional framework for energy saving is largely absent and/or that it has not entered general local planning practice.		(Mirakyan and De Guio, 2013)
Municipality	Municipal energy planning	Assessment of municipal energy plans.	Energy-planning has not been a prioritized subject in comprehensive municipal planning-processes. Lack of political support; Lack of engagement of the planning profession; The misframing of the problem as one that can be 'solved' at local level.	There is a fundamental need to restructure current energy planning system in order for strategic municipal energy planning to be effective in practice. In the newer plans, efficiency in the whole municipal energy system is considered. The new generation of plans is meant to take a broader, more spatial and integrated view	(Sperling et al., 2011)
Municipality	Municipal energy-Local planning	Review of local development plans.			(Nilsson and Mårtensson, 2003) (Wilson, 2006)
Municipality	Urban planning	Municipal involvement in the markets for energy services and energy efficient equipment.	Vague definition of local government tasks.	Municipal authorities can implement energy efficiency by enforcing building codes.	(Rezessy et al., 2006)

The multi-dimensionality of energy transition (Sovacool & Geels, 2016) leads us to consider a global energy balance equation in which planning for both energy efficiency, i.e. less consumption, and renewable energy, i.e. a cleaner supply, has to move beyond urban boundaries to focuses on the whole energy system (Poggi, Firmino, & Amado, 2015). There is growing consensus that local scale and cross-scale dynamics play an important role in addressing and understanding energy-environmental issues (Pasimeni et al., 2014). Here, energy efficiency is a key aspect of rethinking cities and territories, in light of the local planning process (Mirakyan & De Guio, 2013).

Nevertheless, a literature review provides evidence that significant gaps exist in the form of enhancing energy efficiency within municipal boundaries. Reducing energy use spans a broad range of technical issues and spatial scales: from building to districts, from cities to rural areas, and from energy power plants to electricity grids. In this frame, the challenge of enhancing energy efficiency can be understood as an extremely relevant topic for planning at the municipal level. The value of this perspectives is an effective sustainable management of resources that integrates energy needs in a comprehensive territorial planning strategy (Cosmi et al., 2015).

This ways of thinking confirms what Patrick Geddes wrote in 1915 on “Survey Before Plan (Süsser et al., 2017:340)”, “the collaboration of rustic and urban points of view, of county and rural authorities (Süsser et al., 2017:352)” and “the full utilisation of local and regional conditions (Süsser et al., 2017:352)”. These arguments provide highly topical insights on the relevance of local action and top-down and bottom-up approaches to planning. Geddes’s theories seem to be important for enhancing energy sustainable planning so long as this challenge shows itself to be less and less the result of single initiative and more the kind of a local planning action. Following Geddes’ thought, this paper aims to contribute to the debate on why enhancing energy efficiency at the local scale and the importance of the “survey before plan” concept in this process. The main objective behind the energy performance assessment carried out in Arraiolos (Portugal) is to give directions to the Municipal Masterplan (MMP) review. This step aims to set up an adequate framework for a planning process capable of enhancing energy efficiency among different municipal domains and spatial scales: the functional allocation of economic activities, on the basis of a potential balance between energy consumption and production; the association of energy savings, firstly, with local bioclimatic conditions and urban forms and morphologies and, secondly with building types and materials; the modernization of electricity system through smart technologies; and planning grid expansion, considering topological optimization within new and existing urban areas.

2. Framework

Energy efficiency constitutes a strategic development vector in rapid evolution, with different sectors as its target, namely, population behaviour (Jia, Srinivasan, & Raheem, 2017), transportation (Karan, Mohammadpour, & Asadi, 2016), industry (Abdelaziz, Saidur, & Mekhilef, 2011), agriculture (Li, Baležentis, Makutėnienė, Streimikiene, & Kriščiukaitienė, 2016) and the building/construction sector (Gellings, 2009). Indeed, energy efficiency is currently being promoted through several approaches, such as public awareness programmes, measures aimed at the construction of new buildings and improvement of existing ones (Ruparathna, Hewage, & Sadiq, 2016), sustainable mobility solutions (Goldman & Gorham, 2006), and the reconfiguration and renewal of local planning process for the territory (Bulkeley & Betsill, 2005; Rosa & Neves, 2010). Without neglecting any of the aspects mentioned, the present research seeks to contribute to the last category. This section aims to review the theoretical and practical approaches that are currently related to the task of enhancing energy efficiency at municipal scale.

The review process was based on the analysis of peer-reviewed studies published between 2003 and 2017 and indexed by Scopus and ISI Web of Knowledge databases. According to an inductive approach,

Table 2
Synthesis matrix of empirical studies.

Scale	Level	Methodology /Approach	Gaps	Outputs	Ref.
Municipality	Municipal Energy-planning process	Three steps methodology to develop the municipal energy plan.	Municipal energy-planning process should be more widespread.	Bottom-up approach to assess municipal energy consumption is the first and fundamental step to be applied at the beginning of the energy-planning process.	(Brandoni and Polonara, 2012)
Municipality	Energy planning processes	Indicators in the assessment of energy sustainability and in energy planning processes at the level of municipalities. Energy matrix	Current practices using indicators are still lacking a holistic approach; Lack of a comprehensive assessment of the overall impact of local energy use.	Indicators have also the potential to be used as a planning tool.	(Neves and Leal, 2010)
Large Towns	Municipal energy planning	Background information; Statement of purpose; Information on regional/national and municipality's strategic vision;	Absence of policy; Need for information/baseline data to support decision-making.	The structure of strategic planning processes presents significant variations between the municipalities.	(Fenton, Gustafsson, Ivner, & Palm, 2015)
Medium-sized Municipalities		Local process, targets, measures and plans for monitoring and evaluation.			
Small municipalities					

Table 3
Synthesis matrix of applied studies.

Scale	Level	Theory/Approach	Actions/Tools	Outputs	Ref.
City and territory	Integrated energy planning	Elaboration of a generic four phases energy planning process based on literature background.	Preparation and orientations Model design and detailed analysis. Prioritization and decision. Implementation and monitoring.	Planning tasks and activities have been presented and organized in a systematic and holistic way	(Mirakyan and De Guito, 2013)
Municipality	Municipal energy policy development	Municipal energy policies constitution and integration process within the municipal energy system (MES).	Review of present energy policies; In-depth analysis of present MES; Addressing features of sustainable MES.	Municipalities could be appointed as the micro accelerators on the local level for future development of energy systems.	(Kostevšek et al., 2016)
Community	Territorial planning strategy	Characterization of energy systems of policy background, energy uses, infrastructures, market behaviour and community attitude for sustainable development.	Advanced Local Energy Planning; SWOT analysis; Political, Economic, Social and Technological analysis.	Energy issues at national and local scale should be evaluated from a multiple point of view.	(Cosmi et al., 2015)
Towns	Energetic relocalisation movement; Local authorities	Transition processes enhances our capacity to analyse the relocalisation movement within the context of socio-geographic responses to peak oil.	Education Sustainable Building Code Ecotourism Waste Energy Rating Scheme	Small towns are "natural" spatial scale for relocalisation	(Bailey et al., 2010)

the selection of relevant research covered the following keywords: “local energy transition”; “municipal energy planning”; “energy efficiency in local planning”; “energy efficiency assessment municipal scale” and “energy efficient territories”. Given the complex and inter-related natures of these issues; selected research has been divided into three categories.

1. Review studies that examine the comprehensive state of the art of energy efficiency and the local planning framework and highlight current knowledge gaps yet to be addressed (Table 1); 2. empirical studies that explain both the process and outcomes of existing methodologies and approaches already adopted or implemented by local governments (Table 2); and 3. applied studies that present new theories, approaches and tools, aimed at supporting or improving the current municipal energy planning process (Table 3).

This cross-disciplinary revision process led to the construction of the following three synthesis matrixes, which illustrate a range of energy efficiency and planning relationships, through a top-down analysis: city, city and territory, and municipality and community.

The first important evidence that emerges from the three matrixes is that the process of enhancing energy efficiency involves different scales and levels of intervention. Here local governments play the role of both stakeholders and policy makers in implementing the energy-saving initiatives (Rezessy, Dimitrov, Urge-Vorsatz, & Baruch, 2006; Brandoni & Polonara, 2012). Shifting from “government” to “governance”, municipalities emerge as the micro accelerators on the local level for future development of energy systems (Kostevšek, Petek, Klemeš, & Varbanov, 2016).

Indeed, review studies focused on the city scale confirm that energy efficiency improvements can be more effective if challenged by working across and beyond urban boundaries (Cajot et al., 2017). Despite the importance of such challenge, there are many studies that highlight the interrelated gaps and barriers but few provide empirical facts.

One example is that of Denmark, where energy saving at local scale is a focus area for which an institutional framework is under development or insufficient and for which local planning practices are incoherent (Sperling, Hvelplund, & Mathiesen, 2011). Sperling et al. (2011) claim that, to achieve successful implementation of municipal energy plans, it is necessary to restructure the energy planning system.

A second example is Nilsson and Mårtensson’s review, which documented the past and the present energy challenges in Sweden. Here, energy-planning has not been a prioritized subject in municipal plans, inducing vague goals and uncertainties (Nilsson & Mårtensson, 2003). These examples have been chosen to introduce another alarming issue related to EU insights and guidelines that do not explicitly describe how energy and urban planning processes should be integrated (Cajot et al., 2017).

At this point, it is important to note that municipal energy planning has to deal with barriers whose nature seems operational. However, how should such planning be done? The translation of theories into practices, leading the way towards an energy-efficient municipality, is still emergent. There are, however, pioneering studies that are trying something new.

Cosmi et al. (2015) argue that self-assessment analysis is a basic step for the successful implementation of strategic energy policy and measures. The promotion of both renewable energy production and energy efficiency depends on the coordination of all the involved aspects and has to be supported by a comprehensive territorial planning strategy (Cosmi et al., 2015). Mirakyan and De Guio (2013) present an integrated energy planning procedure that is divided into four phases with several interlinked sub-activities and tasks (Mirakyan & De Guio, 2013). Nevertheless, the lack of empirical and applied foundations of this study has led to the need and opportunity to develop more practice-oriented approaches to energy efficiency.

However, as Hopkins (2008) points out: “how this is explored and developed in practice will be different in each settlement: rather than offering perspective solutions, the Transition Movement aims to act as catalyst for a community to explore and come up with its own answers

(Hopkins, 2008: 88)”. In this vein, the author provides an interesting “energy descent” (Hopkins, 2008:37) vision to promote social and political change, based on the concept of resilience and permaculture lessons (Bailey, Hopkins, & Wilson, 2010). Hopkins’s perspective emphasizes the need to start a comprehensive reduction in oil dependency through community-scale initiatives. Sustainable planning practices have been applied in Kinsale (Ireland) and Totnes (England). The experience of these projects provides insights towards a more holistic way of how local planning can articulate the energy descent process through various sectors, such as education, sustainable buildings, ecotourism, food, transport, waste, and energy rating scheme (Kinsale, 2005).

The recognition that current planning practices and tools do not contribute to enhancing energy efficiency at the municipal scale is a considerable gap that has to be addressed to yield new operative perspectives. In this context, the Municipal Masterplan (MMP) review emerges as an opportunity to implement actions in the field of energy efficiency. In line with the aforementioned framework, this paper tries to look at planning energy-efficient municipality. It does so by focusing on the first important step highlighted by Cosmi et al. (2015) and Mirakyan and De Guio (2013): the assessment of municipal energy performances.

This train of thought leads to the rediscovery of Geddes’s “survey before plan”, simultaneously conjuring up Hopkin’s vision of local energy transition with the aim to projecting the insights of the past toward reliable practices in the future.

3. Methodology



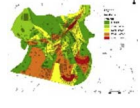
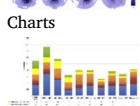
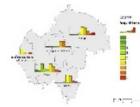
Today, planning for energy efficient municipalities is not an end in itself, but rather a critical challenge to the elaboration of proposals capable of reducing energy consumption and introducing renewable energy sources at local scale. This consideration underlines the importance and opportunity of scientific studies applied to municipal planning process, focusing on the treatment of the energy efficiency in local development plans that have to be revised and replaced (Wilson, 2006).

In tackling these challenges, the present research recognises that increased energy efficiency forms part of different stages of defining and drawing up the municipal planning process. To this end, a comprehensive energy performance assessment of the whole municipal territory, capable of informing the following planning phases is developed. The case study method has been adopted to closely examine the data within a specific context: the municipality of Arraiolos in Portugal.

In this way, the assessment framework is concerned with four core dimensions of physical and functional municipal system: economic activity sectors, electricity distribution grids, the built environment and residential buildings. This clearly reflects a top-down approach that aims to analyse parameters, variables and indicators to assess energy performance at the municipal level. From a methodological point of view, the assessment process consists of five steps:

- Step 1 identifies economic activity sectors and provides a statistical analysis and quantitative information in terms of global electricity consumption patterns (Cosmi et al., 2015).
- Step 2 determines the spatial location of activity sectors with electricity consumption using Corine Land Cover. Here the traditional concept of zoning is associated with the concept of energy balance between the production from existent and future renewable energy plants and the demand from the electricity consumption cells, across the whole municipal territory. On this basis, local electricity distribution grids and electricity consumption zoning were overlapped to assess the spatial and functional coherence between territorial model and energy infrastructures.
- Step 3 focuses on the built environment with respect to the relationship between urban morphologies and bioclimatic factors.
- Step 4 considers the relationships between energy consumption,

Table 4
Synthesis of the methodology for assessing energy efficiency.

Steps	Objective	Parameters, variables and indicators	Outputs
1 STATISTICAL ANALYSIS OF ELECTRICITY CONSUMPTION PATTERNS	This step analyses electricity consumption trends at municipality level. Here statistical data treatment leads to design a set of graphics for a quantitative interpretation of economic and social local dimensions.	Electricity Consumption by Sector of Activity (DGE, 2015); Resident population trends based on the final Census 2011 (INE, 2015);	Charts 
2 MUNICIPAL ELECTRICITY CONSUMPTION ZONING	This step involves the definition of municipal electricity energy consumption zoning based on Corine Land Cover. The objective is to understand how electricity grids correlate with spatial consumption cells delimited across municipal territory.	Electricity distribution system (polylines) (EDP distribuição, 2014); Corine Land Cover 2007 level 2, (Arraiolos Territorial Planning Department, 2014); Buildings (urban settlements polygons) (Arraiolos Territorial Planning Department, 2014).	Maps 
3 MORPHOLOGICAL ANALYSIS OF URBAN SETTLEMENTS	This step involves the identification of urban morphology patterns and their articulation with local bioclimatic factors. The objective is to understand what morphologies have the highest overall consumption of electricity and investigate the reasons/determinants.	Information Reference Geographical Base (BGR) of annual domestic electricity consumption per capita (Instituto Nacional de Estatística, 2011); 1 K and 2 K urban settlements contour map (Arraiolos Territorial Planning Department, 2014); Weather file (U.S Department of Energy's and Building Technologies Office, 2017).	Maps & Diagrams 
4 STATISTICAL AND SPATIAL ANALYSIS OF BUILT ENVIRONMENT	This step develops a statistics and spatial analysis on the built environment. Here, the distribution of buildings for each parish is interpolated according to period of construction and materials.	BGRI of period of construction and materials (Instituto Nacional de Estatística, 2011).	Charts 
5 SPATIAL ANALYSIS OF CERTIFIED RESIDENTIAL BUILDINGS	This step makes a substantial contribution to mapping existing certified residential buildings and statements of regulatory compliance from the energy certification systems.	Buildings certified by the Portuguese Agency for Energy (ADENE, 2015).	Maps & Charts 

local construction systems and building materials.

- Step 5 provides a detailed analysis of energy efficiency classes of buildings, parish by parish, to assess, on average, the energy performance of the residential sector.

The following Table 4 table summarizes aforementioned steps, highlighting the objectives, data sources and outputs.

It is worth noting that this methodology integrates Geographical Information System to elaborate an energy efficiency-related database capable of connecting electricity energy consumption patterns with the multitude of parameters, variables and indicators expressed by the territory. As such, the approach promotes the analysis and correlation of top-down informative levels on energy and territory in a geographical manner.

4. Case study

This section presents a case study in Portugal to closely examine the practical application of the methodology within a specific context. Before moving to the energy-related issues, a brief introduction of the Portuguese planning system is given, followed by a description of the case study itself.

In Portugal, the system of planning currently in force is organized around a coordinated interacting framework relating to national, regional, intermunicipal and municipal levels and concerning the nature and territorial incidence of public interests involved (Lei no 31/2014 de 30 de Maio, 2014). Among these, of note is the importance of the Municipal Master Plan which has been shown to be one of the most effective territorial management instruments for the design, control and respective implementation of development at the local level (Fidélis, 2001). In this context, the revision phase of the MMP provides an opportunity and a need to draw up methodologies and implement actions promoting sustainable development. Indeed, this is why the first author has been involved in various MMP reviews, addressing a sustainable energy planning model to aid municipalities in planning for renewable

energy in rural areas and enhancing energy efficiency at the municipal level (Amado, Poggi, & Amado, 2016; Poggi et al., 2015).

As new models result from the transformation of existing ones, the development of a methodology associated with a case study was deemed the most appropriate approach to provide a contribution to knowledge in these fields.

Arraiolos is a predominantly rural municipality located in the Alentejo Region. It consists of seven parishes and has a surface area of approximately 693 km² (Fig. 1).

The council created the MMP review in 2013. Here, one of the most predominate themes underlying the aspirations of local authorities was minimizing the use of energy by enhancing energy efficiency at municipal level.

From the outset, the assessment of the municipal energy performances involves understanding its relationship with the economic and social context, land use and cover, the configuration of infrastructures and the built environment.

By analysing energy consumption indicators per energy source, it can be seen that electricity is the main source of energy used in the Arraiolos Municipality. In this context, the graph in Fig. 2 shows the development of electricity consumption as related to the demographic dynamics verified in the Arraiolos Municipality between 1994 and 2012.

It is possible to see how the increase in electricity consumption between 1994 and 2007 corresponded to a reduction in the resident population, a fact which can be explained through the considerable impact due to the increase in the demand for thermal comfort and the growth in the number of electrical devices placed in homes (Inquérito ao Consumo de Energia no Sector, 2011). However, a reversal in the upward trend in electricity consumption can be seen from 2010 onwards, reflecting, on the one hand, the consequences of the 2008 economic crisis and the 2009 economic recession and, on the other, the effects of the entry into force of energy efficiency measures as laid down by the Energy Efficiency Action Plan 2008–2015.

The weighting of electricity consumption in the energy balance of

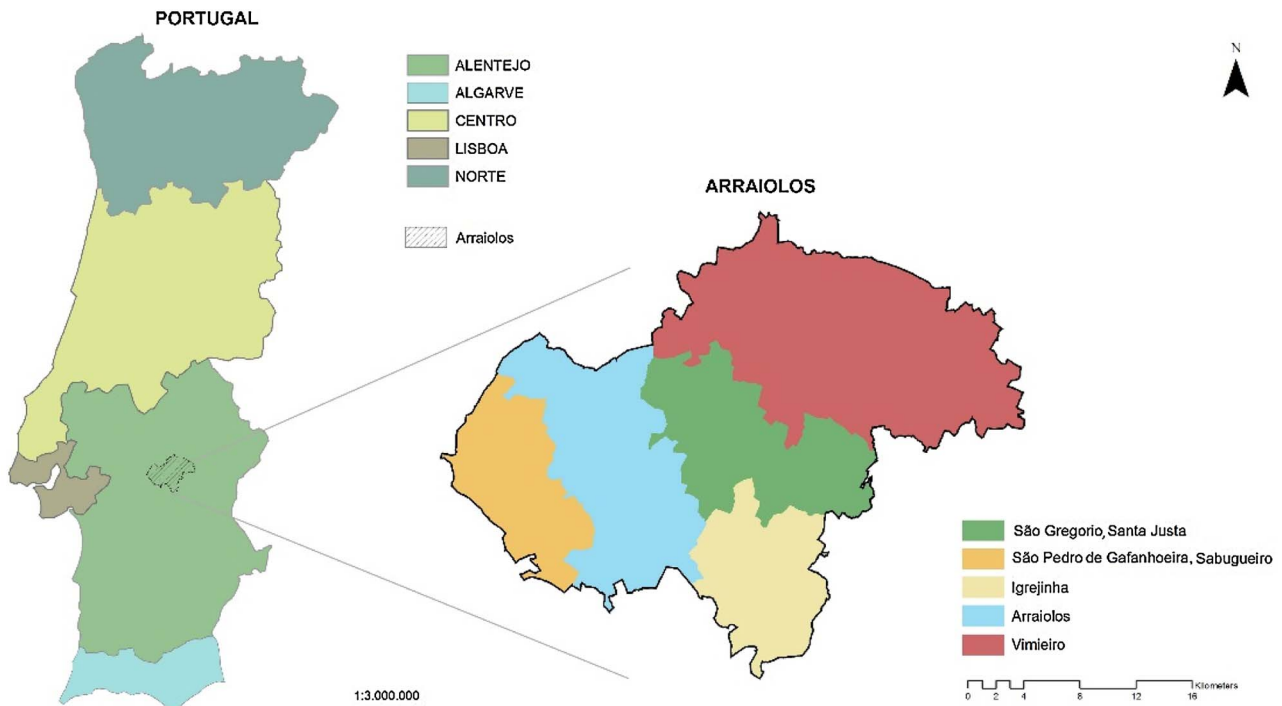


Fig. 1. Arraiolos Municipality location and parish boundary reference map.

the municipality is demonstrative of the gradual increase in energy demand in the main activity sectors, particularly domestic, trade and services, agriculture, industry, and in the public sectors, such as roads and state buildings lighting (Fig. 3).

Fig. 3 highlights the high electricity consumption of the domestic sector, taking up around 41% of the total electricity used in the municipality. The non-domestic sector, included in the Portuguese Classification of Economic Activities, 3rd Rev, shows a highly significant share of consumption (20%), followed by the agricultural sector, which represents 17%. Among the different sectors of activity present in the urban settlements, electricity consumption in residential, trade and public administration buildings constitutes an important reference in understanding the interactions characterising the energy performance of a municipality. The incidence of these sectors of activity can be translated into a spatial model associated with the transportation, distribution and use of electricity (Fig. 4).

Electricity consumption cells result from the delimitation of the continuous urban fabric, concentrated in 11 urban settlements, and scattered economic activities in rural areas. The spatial configuration of

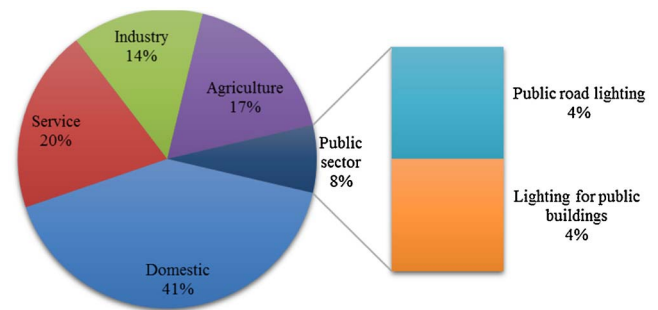


Fig. 3. Electricity consumption by sector of activity in 2012.

the electricity distribution grid in relation to such consumption cells, reveals a model valuable to both urban planners and electricity operators. It should be noted that the electricity distribution grid presents a reticular network topology that has to be assessed considering the implementation of future renewable electricity power systems (Morvaj,

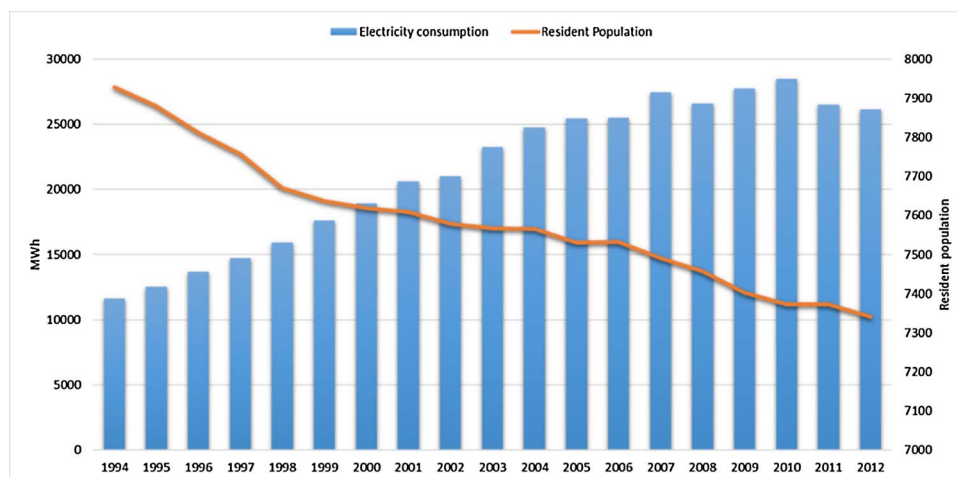


Fig. 2. Electricity consumption trend in relation to the resident population in the Arraiolos Municipality.

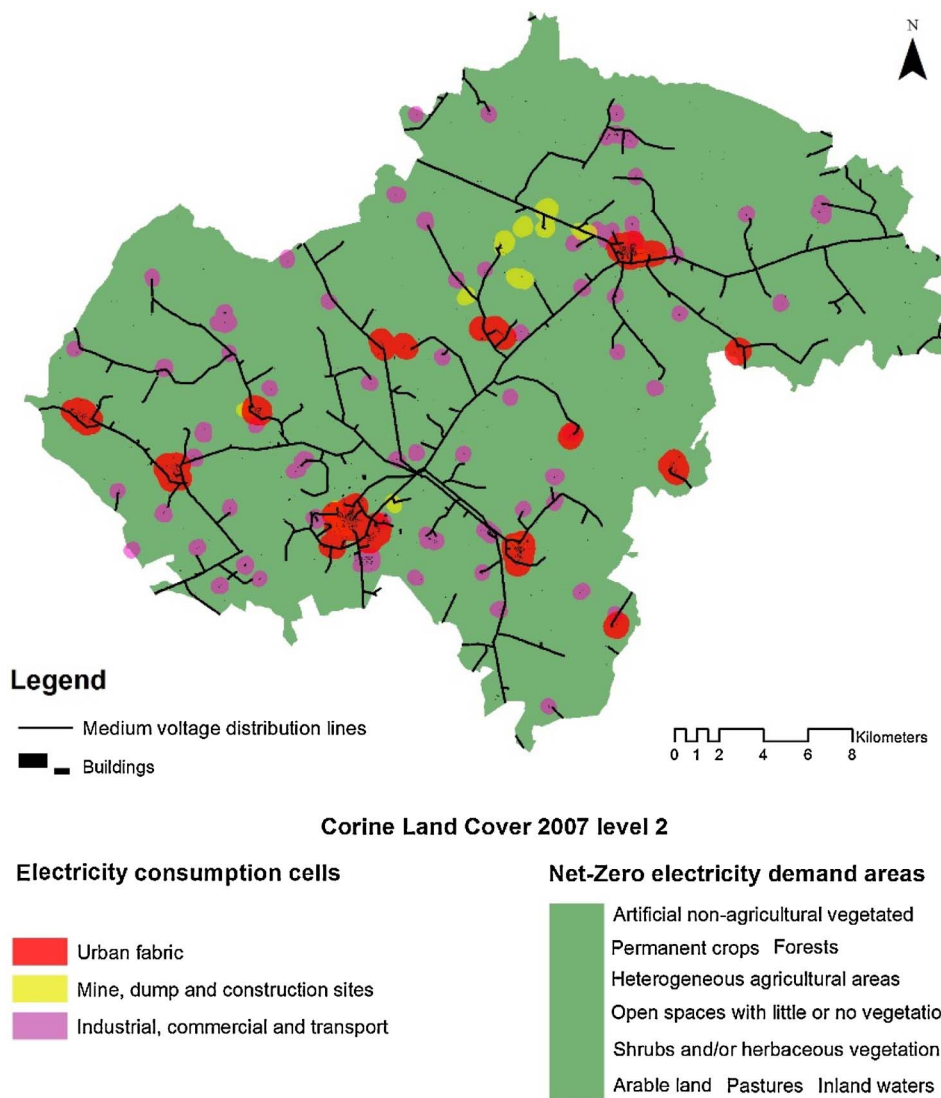


Fig. 4. Spatial configuration of medium voltage distribution grid in relation to electricity energy consumption cells.

Evins, & Carmeliet, 2017), and the integration of smart technologies in the conventional grid (Colak, Kabalci, Fulli, & Lazarou, 2015).

Due to the high demand for electricity in the domestic sector and its weight in the overall energy balance of the municipality, an in-depth analysis of urban settlements plays a key role in assessing the energy efficiency.

As such, the annual domestic electricity consumption per capita, which in Arraiolos is 1460 kWh (INE, 2015), is correlated with the number of inhabitant of each statistical subsection. 1 K and 2 K contour maps supplied by the territorial planning department were used to explore the relationships between urban morphology and residential energy consumption, as suggested by Ratti, Baker, and Steemers (2005) (Fig. 5).

From the study shown in Fig. 5, it is possible to identify urban morphologies which have the worst performance overall (Fig. 6). They are located along the organic linear road patterns and are characterised by small-sized buildings, with 1–2 floors throughout the municipality, with an occasional maximum of 3–4 floors in the main urban area of Arraiolos.

Here, it is important to reflect on local bioclimatic variables as well as the incidence of the construction periods of buildings and the respective construction systems and materials in terms of energy efficiency.

The location of the Arraiolos Municipality in a I1-V3 climate zone strongly influences the consumption of energy in the buildings to satisfy

cooling needs in the summer and ensure thermal comfort during the 5.7 month heating season in winter (Decree-Law No. 80/2006). Furthermore, it is worth highlighting that the orientation of existing buildings, due to their exposure to the sun, influences their energy efficiency, naturally favouring better thermal performance in the winter, but increasing the indoor temperature in the summer.

In this regard, Fig. 7 shows the best theoretical building orientation simulated by Ecotect Weather Tool.¹ By comparing this reference diagram with Fig. 6, it is possible to understand that the current orientation of urban morphologies may be one of the determinant factors of highest overall electricity consumption.

On the other side, local wind direction and frequency prevail from N-NNE and S-SSW during the Spring and the Autumn seasons, from NNW in the summer and SE-NW in the Winter (Fig. 8). Here it is important to observe the direct link between urban morphologies and natural ventilation of buildings, which, due to local annual wind variation, can determinate impacts in terms of energy requirement for heating and cooling.

Moving the assessment down to the scale of the built environment, residential buildings emerge as a connecting thread between the local

¹ The Evora weather file was used for the simulations (Lei no 31/2014 de 30 de Maio, 2014). It should be noted that Evora is located approximately 25 km south of the Arraiolos municipality. Such minimal difference in latitude between Arraiolos and Evora can be considered as not influential in terms of the solar path.

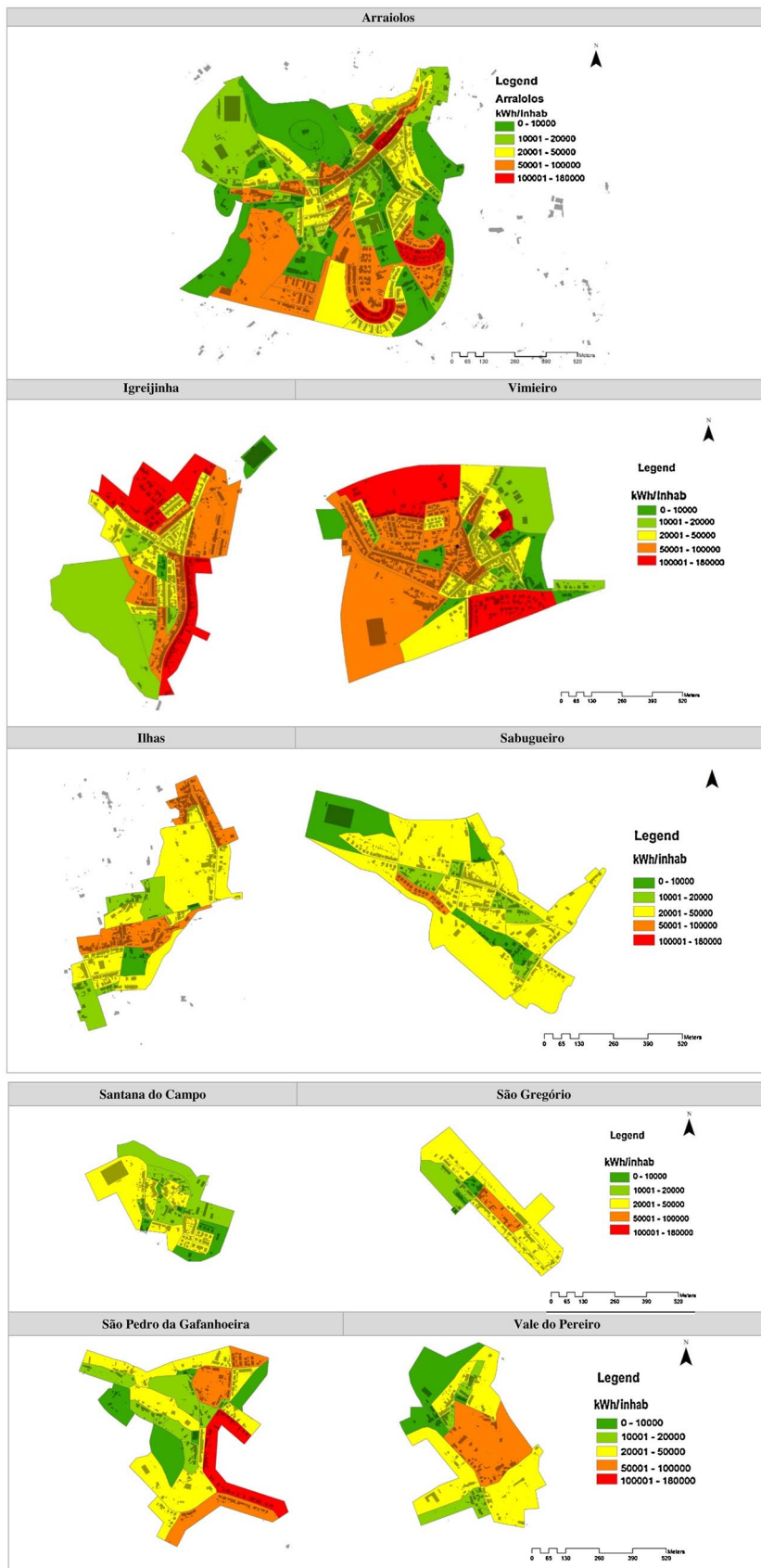


Fig. 5. Annual domestic electricity consumption per capita in the main urban settlements of the municipality (kWh/inhab).

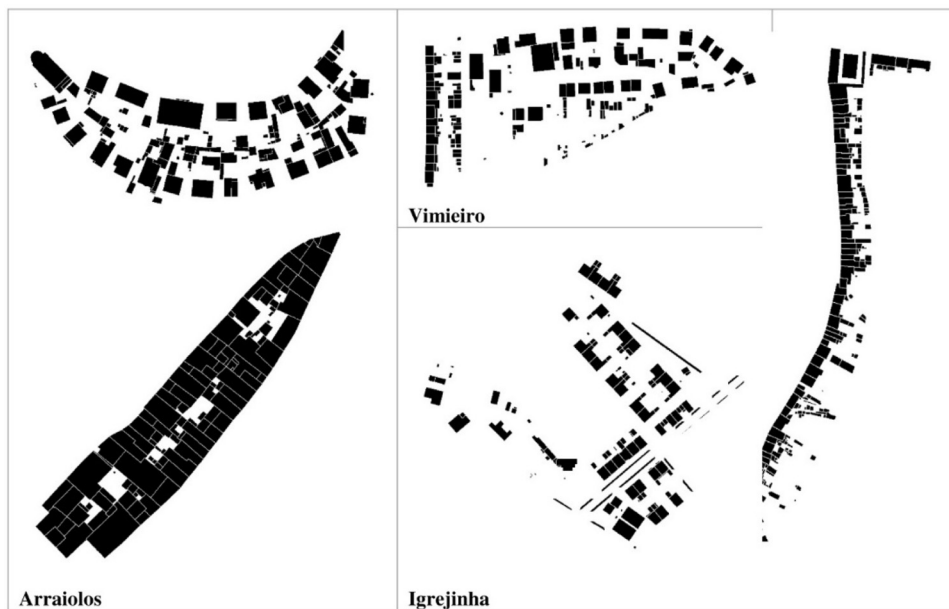


Fig. 6. Urban morphologies that have the highest overall consumption of electricity.

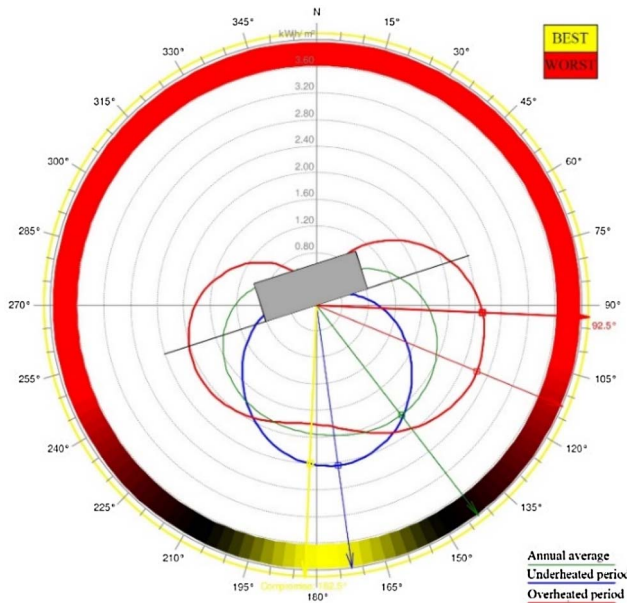


Fig. 7. Diagram of the best theoretical building orientation.

and global scale of municipal energy performances. Indeed, the residential sector is the largest energy consumer (see Fig. 3) and one of the main fields of local planning action. Moreover, the energy performances of residential buildings affect the local population’s well-being and health. As such, they are a focal point of this assessment process.

In this framework, it is worth highlighting that the period of construction of buildings is an important energy performance indicator (Csoknyai et al., 2016).

Fig. 9 shows how the buildings constructed before the 1960s play a dominant role in all parishes given that this situation negatively influences the overall energy performance in the existing construction within the municipality.

Buildings with plate² structure form the highest percentage of buildings in the municipality, coinciding in large part with the

² The plate structure adopts masonry as the main structural material, but with a small slab of reinforced concrete on the rear of the building.

buildings constructed in the period between 1919 and 1945 (Fig. 10).

What is more, the parish of Vimieiro has buildings from more recent periods mainly with concrete structures, whereas the masonry and stone/adobe structures are distributed in a uniform manner among all the parishes of the municipality without being significant in terms of the number of buildings.

By analysing the building structure, it is possible to state that the masonry have the worst energy performance due to their low thermal inertia and the existence of thermal bridges in the constructed envelope, their lack of insulation and the presence of windows with metal frames and single glazing.

The buildings with the stone/adobe structure ensure a better indoor level of comfort due to the greater thermal inertia of their walls; however, it should be mentioned that the overall performance result is lowered by the type of windows, with wooden or metal frames and single glazing.

The buildings with a masonry structure and reinforced concrete, built in more recent periods, reflect improved energy performance resulting from the introduction of new rules to the design and construction laid down by the Regulations on Characteristics of the Thermal Behaviour of Buildings (RCCTE), which have been in force since mid-2006.

As an example, Fig. 11 shows the evolution of building typologies in the municipality, according to the variation in their respective energy performance level.

Considering the major impact of residential buildings on municipal energy performance, we decided to strengthen this assessment process by mapping the buildings certified by the Portuguese Agency for Energy (Agencia para a Energia – ADENE). To carry out this study, data were used from the ADENE online platform referring to March 2015 (ADENE, 2015). The map of Fig. 12 permits us to analyse the spatial distribution of the certified buildings and their respective energy class as recorded in the Arraiolos parishes.

According to the legislation in force in the National System for Energy Certification for Buildings, such information is characterised as the performance evaluation of the buildings, on a scale of 9 classes from class A+ (the most efficient) to G (least efficient). Table 5 below shows with greater detail that approximately 65% of the certified residential buildings have energy classes between C and E and that the set of buildings with classes above B are only recorded in the parish of Arraiolos.

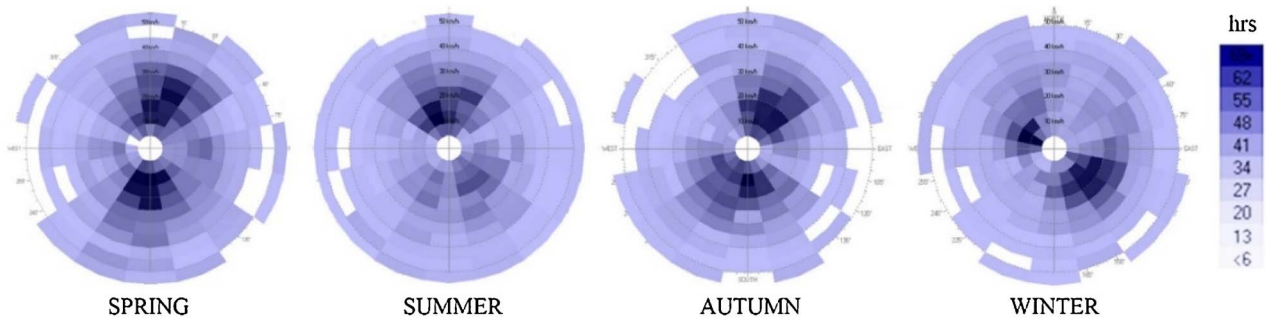


Fig. 8. Annual prevailing wind direction and frequency (hours).

Fig. 9. Distribution by parish of the number of buildings according to period of construction.

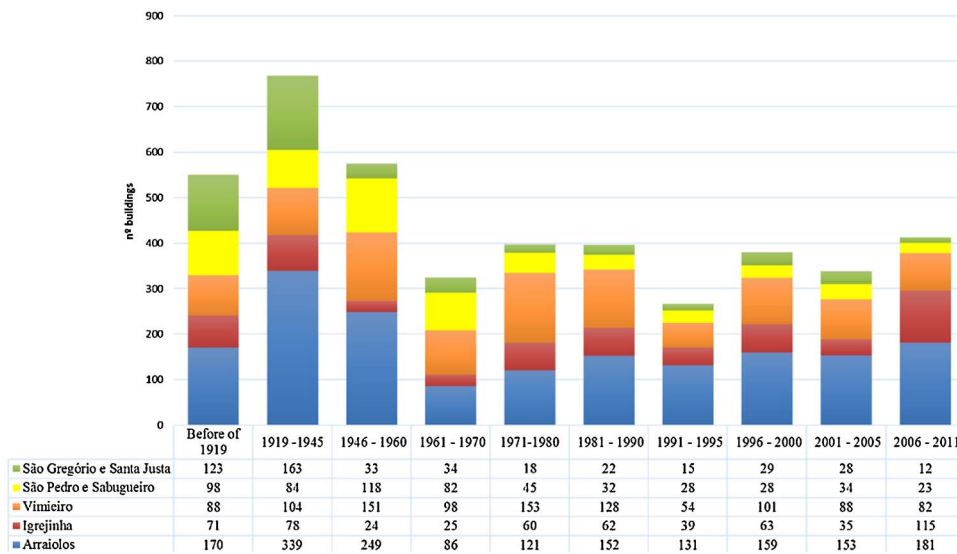
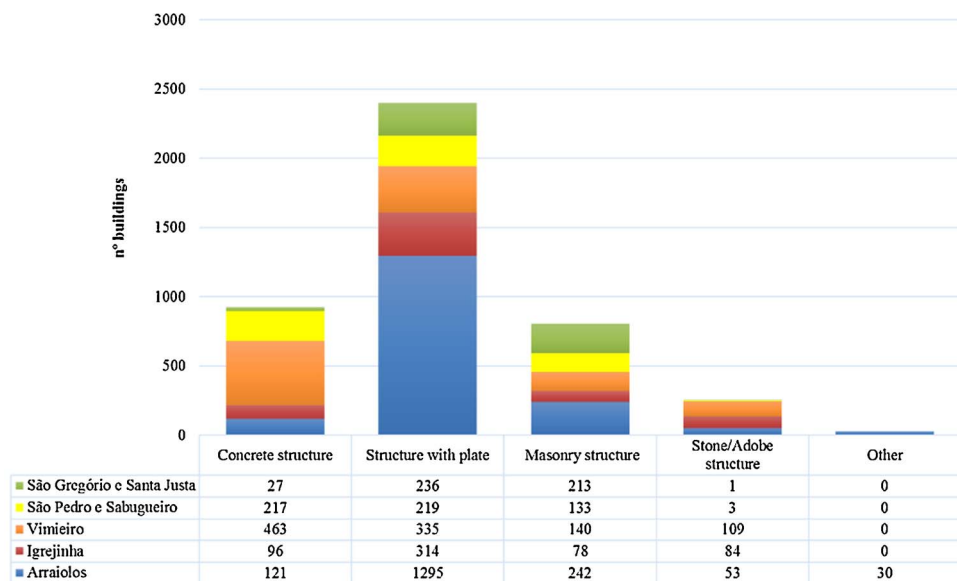


Fig. 10. Distribution by parish of the number of buildings according to structure.



5. Discussion and conclusions

According to European Union climate and energy policies, regional and local governments are encouraged to adopt energy efficiency plans that contain specific energy saving and efficiency objectives and actions. Nevertheless, the literature review highlights a considerable gap in the elaboration of practice-oriented approaches capable of aiding

local authorities in the preparation of development plans where energy efficiency goals are covered. The limited number of empirical and applied studies evidences a lack of a linear municipal energy planning process, in which a sequence of steps is taken from problem formulation through analysis, diagnostic and implementation to evaluation and feedback.

The results of this research refer to a comprehensive assessment of

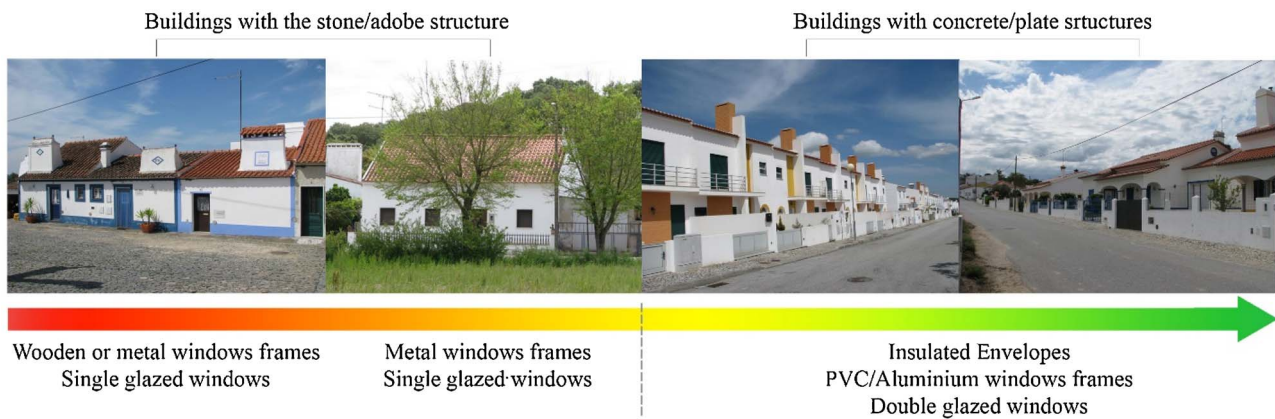


Fig. 11. Evolution of the different typologies of buildings in the municipality and their respective energy performance level.

parameters, variables and indicators associated with municipal energy performance.

From the correlation between statistical energy consumption patterns and the spatial incidence of economic activity sectors, it was possible to identify electricity consumption cells that permit the planning of functional allocation of economic activities on the basis of a potential balance between energy demand and production poles. It is at this level that the modernization of the electricity system, through smart technologies, can provide local planners with meter information to manage energy balance within municipal boundaries. Here, energy performances-informed land use zoning can enhance energy efficiency by interconnecting higher density areas with more compact and mixed uses with a surplus of on-site generation to share. New scenarios, will also characterize electricity grid expansion, considering topological optimization within new and existing urban areas to improve energy efficiency.

The study of urban morphology provides insights into various planning and design domains: how do patterns repeat themselves at different spatial scales, what physical parameters characterize historic and oldest areas in different settlements, how does the built environment shape and how do dimensions influence thermal comfort conditions in public space. Indeed, the analysis of urban morphologies and local bioclimatic conditions represents a powerful tool for the

determination of the fundamental parameters that local planning has to follow to achieve settlements with better energy performances. Here, local planning coupled with urban design, plays a key role in relating bioclimatic concepts with the layouts of streets and public spaces, the dimension and form of the lots, the orientation and volume of buildings, and so on, creating energy-efficient urban morphologies.

“From urban settlement to built environment”, residential buildings emerge as a core field for local planning intervention promoting energy efficiency. As a matter of fact, the construction and retrofiting of buildings is regulated by the local administration through its municipal code and land use standards. The period of construction allows a relationship to form between the building structure, the materials and thermal insulation systems used in the buildings. It should be added that these factors strongly interfere with indoor levels of thermal comfort and, consequently, with the energy performance of a building. Indeed, these considerations have important implications for energy policy design. An example is the case of residential buildings that can be classified according to the period of construction:

- i. . buildings that are part of the historic and monumental heritage;
- ii. . buildings constructed in the 50’s, 60’s and 70’s;
- iii. . buildings constructed in the 80’s and 90’s;
- iv. . buildings constructed after the 00’s.

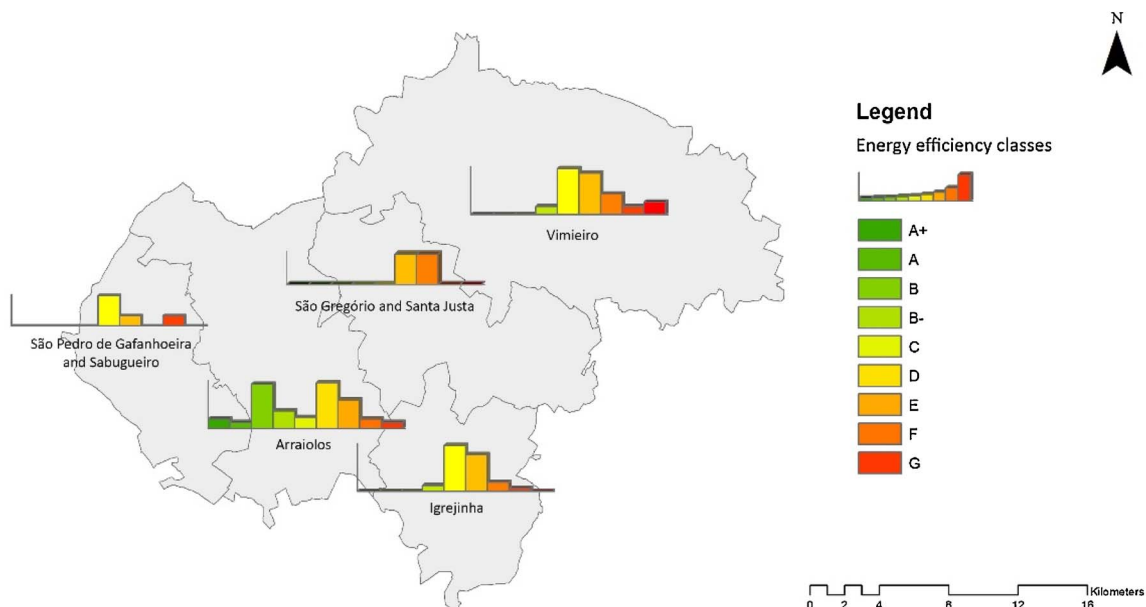
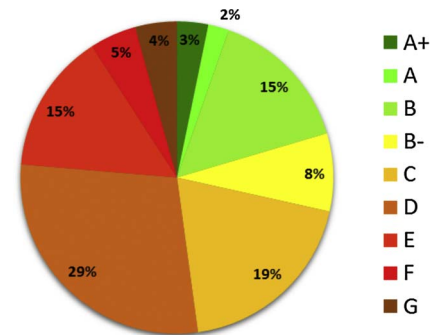


Fig. 12. Map of certified buildings and respective energy efficiency class per parish.

Table 5
no. of buildings and respective energy classes per parish.

	A+	A	B	B-	C	D	E	F	G
São Gregório and Santa Justa parishes	–	–	–	–	–	1	1	–	–
São Pedro de Gafanhoeira and Sabugueiro parishes	–	–	–	–	3	1	–	–	1
Vimieiro	–	–	–	2	11	10	5	2	3
Igrejinha	–	–	–	2	15	12	3	1	–
Arraiolos	6	4	28	11	7	29	18	6	4
Total	4	4	28	15	36	53	27	9	8



Such a classification, developed in GIS environment, can provide significant contributions as a decision-making tool in supporting rehabilitation, regeneration and retrofitting programmes that can be organized at the neighborhood level by adopting specific energy savings measures.

The municipal energy performances assessment presented in this paper aims to provide the basis for setting fields of interventions and priorities. From this top-down approach, it is possible understand that energy efficiency is a cross-cutting issue interrelated to a blend of various disciplines: geography, spatial planning, urbanism, architecture, and civil engineering. The discussion of results enables us to understand why municipalities should be called upon to enhance energy efficiency by first looking at a comprehensive energy performance assessment. Embracing the whole municipal territory rather than only urban areas is key to articulating energy efficiency and geographical, social, environmental and economic factors, which are at the core of local planning. Tackling these issues, the developed methodology may be a valuable contribution especially within the MMP revision process, given that the former incorporates energy concerns and adjusts them to the current challenges for sustainable development. It is here that municipalities, through their local plan, must take the lead addressing a comprehensive “energy descent” vision.

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