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Supporting Local Authorities to Plan Energy Efficiency in Public Buildings: From Local Needs to Regional Planning

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Abstract: The support offered to local authorities in this work consisted of technical and economic training on the integration of energy efficiency measures as well as the development of tools (guidelines, a decision support tool, databases and a visualization platform) that allow local authorities to prepare their building renovation plans. These tools are found very useful for local authorities, particularly in the case of Teruel province, characterised by many small municipalities whose local governments do not have the technical staff to undertake this type of planning. As a result of this work, an energy action plan was elaborated for the implementation of 96 energy efficiency measures in public buildings of Teruel province. The execution of this plan would allow energy savings of 1.3 MWh/year and 245 tonsCO_{2e}/year of CO_2 emission reduction, involving an investment of EUR 1.2 M. The close collaboration with public authorities made it possible to assess the strengths and weaknesses of using the developed tools. One of the barriers found is the availability of accurate building data (e.g., regarding envelope features) necessary for the decision support tool.

Keywords: capacity building; energy efficiency; public authorities; public buildings; renewable energy technologies

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1. Introduction

Public buildings represent 10% of the overall building stock, and usually consume large amounts of energy due to their specificities. The renovation of public buildings is key to achieve a carbon-free economy as foreseen by the EU Green Deal [1], but it is hindered by scarce or even lack of competencies of public authorities in energy planning, along with a lack of financial resources in most cases. There is a need to improve the competencies of public authorities, as well as to enhance the energy production systems and sustainability in rural and urban environments [2]. This work is an extended version of the paper presented at the 16th Sustainable Development of Energy, Water and Environment Systems (SDEWES) Conference [3].

Several numerical models for building energy demand simulation have been developed over the years, in an attempt to predict heating and cooling demands and unveil potential EE measures [4]. However, many of these available models are developed for research purposes, making difficult their use for building designers, likely because of the required time and knowledge to use these tools, and the cost and time of the simulations [5]. Steady-state models that do not consider the inertia effect are usually used for long-term calculations as they are faster, especially for preliminary design and analysis of several EE measures in different scenarios [4,6]. A well-known and simple approach used to obtain a first idea of the building's heating and cooling demands is the degree-days (DD) method [6–8]. This approach assumes that the energy consumption is proportional to the difference between the external and internal temperatures for long-term calculations [4]. Depending on the data availability of outdoor air temperature, there are different methods for calculating DDs. The hourly method produces a more accurate estimate [9], but hourly data is not always available.

In recent years, examples of the coupling of building energy models and GIS methods have proliferated in the scientific literature [10–13] with different purposes. One of the advantages of the GIS methods is their flexibility to be coupled with different approaches [10], both top-down approaches, such as to represent regional energy use employing data from aggregated levels, and bottom-up approaches, for example, to scale up the energy performance simulation of a building to the urban or regional level. This last approach has proliferated in comparison with top-down studies in recent years [11]. The availability of disaggregated datasets and extensive computational resources have allowed the expansion of these bottom-up GIS methods. Nevertheless, the diversity of this type of tools (energy building model coupled to GIS techniques) is very large attending to input data (energy performance certificates, spatial climate data, building dimensions and characteristics, shading), uncertainty analysis, scale, accuracy, validation or the final purpose of the tool.

Previous authors [12] developed a method based on large scale GIS to model building heat demand of large regions with a high temporal resolution. Building dimensions, shading, spatial climate data, uncertainty and statistical treatment of data were considered for the elaboration of the method in which GIS techniques were linked to a heat demand model (SIA 380/1 [12]). The final model was validated against a database of 120 buildings, achieving average goodness of fit (R2) of 0.6. Other authors [13] carried out a similar approach. They used a GIS and multiple linear regression techniques (to correlate variables such as area and height of the buildings or period of construction with energy consumption) to evaluate the building energy consumption in a medium-sized Italian city.

However, these detailed tools require a large amount of reliable spatial data (such as climatic data, geometric parameters of the buildings or construction materials) and, also, comprehensive building energy modelling [10,11]. Furthermore, despite this, the accuracy obtained is limited since the number of factors that influence the energy demand in a building is large.

This has motivated the integration of Energy Performance Certificates (EPCs) with GIS techniques and building energy modelling. In this line, previous work [14] mapped the EPCs of an Italian city, Ferrara (old town), to obtain energy indicators useful to develop local energy efficiency plans. A similar approach is found in Ref. [15], in which, apart from EPCs and GIS techniques, the energy building model is fed with statistical data to elaborate local energy plans and also, to boost energy measures on the private building stocks. These allow obtaining more realistic energy consumption since EPCs report the energy consumption in standard conditions but not the actual energy consumption [16]. Further, statistical data were used when EPCs were not available or EPCs data were considered unreliable. As a result, they obtained indicators for each building such as current energy consumption, the technical potential of energy savings, obsolete windows or walls, planning restrictions or number of owners [15]. This information was represented on a GIS allowing the identification of particular buildings, their quantification and their distribution.

A similar approach has been found in a more recent work [17], where a model called DECoRuM was developed, consisting of a GIS-based energy model with the capability to estimate current energy CO_2 emissions and test the effectiveness of several best practice energy efficiency measures in homes. The background calculations of DECoRuM are performed by BREDEM-12 (Building Research Establishment's Domestic Energy Model) and SAP 2009. The input data are based on EPCs, dwelling statistics, external observations and, ideally, where possible, occupant energy surveys. The authors applied this model to a neighbourhood of Bicester (UK) [17]. As a result of the DECoRUM application in this neighbourhood, recommendations for energy retrofit were made in the form of improvement packages, such as insulation packages or heating packages. Further, the visual effectiveness of GIS techniques was very valuable to engage householders and community groups to support the installation of energy efficiency measures. These semi-empirical approaches (based on EPCs as input data) allow faster implementation and, therefore, have more practical applications than detailed models.

The incorporation of the spatial dimension, very important for issues such as the aggregation of energy efficiency measures, and the increase in the analysis capacity, are important features that allow GIS-based support tools to contribute to the development of local energy plans. Furthermore, the visual effect provided by GIS techniques is a relevant asset to boost retrofitting measures in buildings among stakeholders. Nevertheless, a lack of economic analysis has been observed in all the aforementioned tools found in the literature; they mainly provide energy and environmental results, without considering economic factors such as fuel and electricity prices, or the estimated cost of different energy efficiency (EE) measures.

The European Energy Efficiency Directive enforces the State Administration to perform the energy renovation of at least 3% of the surface of its public buildings, annually. However, this obligation does not apply to the regional or local administrations. This incoordination between national and regional administrations causes a lack of information and commitment about the energy renovation processes of public buildings at the local level.

The work presented in this article made it possible to answer questions about how the public sector, specifically local administrations, face the renovation of their public buildings. Particularly, one of the aims of this work was to research this topic, to find answers to questions such as: What are the decision-making processes for the energy renovation of public buildings at regional and local levels? Is there long-term planning? Is there coordination between different levels of Public Administration (local, regional, national)? What are the barriers? Is the transition to sustainability one of the main priorities, or are other aspects more pressing for local authorities? What is the current status of public buildings in terms of energy efficiency? Which are the energy efficiency measures most often implemented? Is there a more common renovation measure needed in public buildings? Which measures are more cost-effective?

The answers to these questions can help the decision-making process to improve the energy renovation of public buildings in the local Administrations. This is particularly important in the current context of the renovation wave, which aims to double annual energy renovation rates in the next 10 years.

The primary aim of the tool developed in the PrioritEE project was to support local authorities to implement EE measures in the public buildings of their municipalities. The objective was to allow public authorities to make their calculations, considering measures such as windows' replacement, increasing insulation in walls or roofs, or replacing the boiler, simply based on the building EPC. As a result, the user obtains energy savings, CO_2 emissions reduction and, more importantly, a simple economic analysis of each potential EE measure, including economic savings, required investment and payback time (PBT) [18,19]. Therefore, the results of this tool can be used as the first step in a decision-making process, which should be followed by a more detailed technical and economic analysis of the selected EE measures.

There are numerous articles on barriers to private building renovation, but there is a lack of articles studying such barriers for public buildings [20]. Although the public and private sectors share many barriers for building renovation, the public sector has specific barriers such as budget restrictions, the coordination and cooperation between different levels of the public Administration or the dependence on electoral cycles [20].

This article presents the work developed to support the public authorities of Teruel province (Spain) in the implementation of EE measures and the integration of renewable energies in municipal public buildings. The work was developed in three main phases: (1) Analysis of the status quo (current status, opportunities, barriers and decision-making procedures) of the Teruel province regarding the energy efficiency of its public buildings; (2) Development of tools within the PrioritEE project to train the public authorities in decision-making on the implementation of energy efficiency measures in their public buildings; (3) Training of public authorities and elaboration of energy action plans.

The strategy followed is an excellent example of how to support public authorities in planning the renovation of their public buildings. Additionally, as it was developed simultaneously in five countries within the PrioritEE project (Italy, Portugal, Spain, Greece and Croatia), it is easily replicable [19]. Furthermore, the results obtained allow describing the barriers that public authorities face in implementing energy efficiency measures and quantifying the existing potential for energy savings in public buildings.

In this work, we present the analysis of the status quo of Teruel province regarding the energy efficiency of its public buildings. Subsequently, we briefly describe the tools developed in the PrioritEE project and how the training of public authorities was performed. Then, the techno-economic analysis of different energy efficiency measures is detailed, and the energy action plan is described. Finally, the main conclusions are summarized, answering the above questions. Most of the findings of this work can be extended to the local administrations in other countries of the European Union, as we have seen in the PrioritEE project that the processes and problems faced for the energy renovation of buildings are common in most countries.

2. The Case of Teruel Province: Status Quo

Teruel Province is located in the Autonomous Community of Aragón, located in the North East of Spain. It has a total surface of 14,800 m^2 and 136,000 inhabitants living in 236 municipalities. Despite Spain's climate being predominantly Mediterranean, there is a range of micro-climate conditions and local variations. In particular, Teruel Province has a transitional climate between Continental and Mediterranean, with cold winters (down to −10 °C) and hot and dry summers (up to 35 °C).

In general, municipalities are small (median of 162 inhabitants) and sparsely populated. As shown in Figure 1, most of the municipalities (215 in total) have less than 1000 inhabitants, 19 municipalities have between 1000 and 10,000 inhabitants and only 2 municipalities have 10,000 and 50,000 inhabitants. Therefore, one of the most severe problems of Teruel province is depopulation, which added to the ageing population, makes it a challenge to plan energy efficiency in buildings.

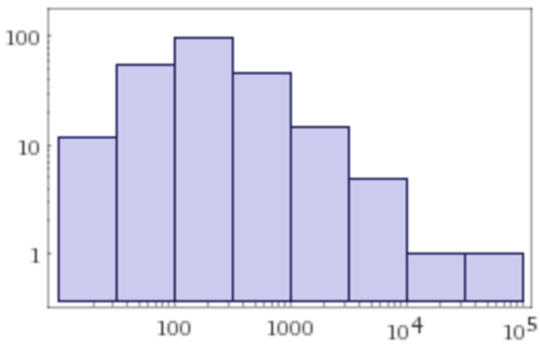
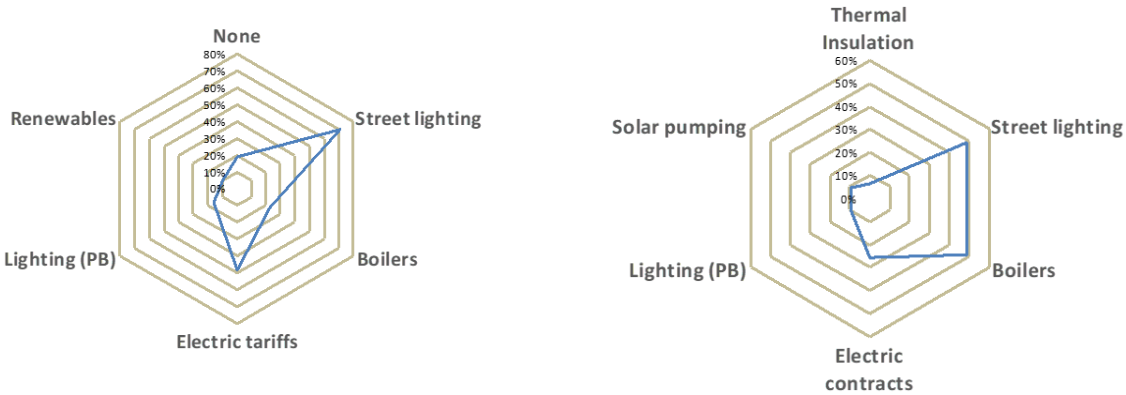


Figure 1. Logarithmic distribution of the population in the municipalities of Teruel province.

Another challenge for the planning of energy efficiency in buildings is the lack of data. A PrioritEE budget line was dedicated to financing the issuance of EPCs for public buildings in Teruel province. Here, it should be highlighted that most of the buildings do not meet the criteria that require an EPC (a surface area larger than 250 m^2 and frequent occupation). For this reason, the majority of public buildings in Teruel do not have an EPC. Without data with which to evaluate energy efficiency, it was very difficult to develop any energy planning. This was one of the first barriers faced in the implementation of the PrioritEE project in Teruel province.

There is a very limited number of energy capacity building or deployment projects in the province. A recent survey showed that in 2016, the Teruel Provincial Government commissioned energy audits for 78 municipalities. The audit scope varied depending on the municipality and the energy auditor, but in general, the audits were focused on electricity consumption, not addressing other energy sources (such as natural gas or light fuel oil). The main goal was to identify inefficiencies in the energy contracts, and the potential economic savings of switching tariffs or suppliers, or by amalgamating contracts. Only in a few cases, other energy efficiency aspects were examined, including building envelopes, replacing street lighting, installing solar water pumping, or replacing boilers feed with light fuel oil with biomass boilers (see Figure 2 left). These energy efficiency interventions often quantified energy savings as well as economic cost benefits.



(**a**) Prior EE studies (**b**) Implemented EE measures

Figure 2. (**a**) Type of energy efficiency (EE) studies and (**b**) implemented EE measures.

The results of the survey performed [21] showed that the main energy efficiency interventions executed in Teruel province included (see Figure 2 right):

- The replacement of lighting: 48% of the municipalities reported street lighting replacement and 16% building lighting replacement.
- The replacement of boilers, often with biomass boilers (pellets or wood chips). This was reported by 48% of municipalities. The results were generally positive, but some high-profile hiccups resulted in a very cautious approach in other municipalities.
- Modifications in the electricity supplier contract: often quoted as a major positive measure (26% of municipalities). While this measure does not directly lead to energy savings, the economic savings freed some of the annual budgets which could be used in other energy-saving measures.
- Solar water pumping was implemented in 10% of the municipalities.
- Only 6% of the municipalities made interventions in the building envelope, but 39% reported the need to implement such interventions (see Figure 3 left).

(**a**) Demanded EE measures (**b**) Source of EE advice

Figure 3. (**a**) Type of energy efficiency measures demanded by the municipalities and (**b**) the source of advice for the energy efficiency assessment.

Only 19% of the surveyed municipalities resort to some form of (presumably) paid-for professional advice. Most of the advice is informal (40%), or from the suppliers of the equipment (29%). Meanwhile, 10% of the municipalities reported that they do not have any advice (see Figure 3 right).

The ELENA project [22] entailed a major drive to introduce energy efficiency measures in Teruel province, as this project intended to provide upfront capital to fund energy interventions. The capital, provided by the European Investment Bank, should be paid back over time using the economic savings of the interventions. However, the upfront funds were computed as public debt at a time when, due to the exceptional national financial hardships, municipalities were not allowed to increase their debt. As a consequence, the project ended without any practical outcome. Still, it is believed that it is a good model to be replicated if and when the financial restrictions are lifted.

2.1. Target Buildings

In Spain, the national-based infrastructure database [23] gathers public buildings organised by building typology. It details, for each of them, surface area, current status, location (municipality), owner and operator. Public buildings in Teruel province have a wide diversity of uses. This variety reflects the special nature of the Province as it is composed of small municipalities that need to provide a wide range of services to their citizens. In large municipalities, some of these services are often provided by the private sector. However, in small municipalities, there are no economies of scale that provide a viable framework for the private sector.

Five main types of buildings have been identified: school, residential centre, multiservice building, sports centre and council/doctors' office. The use of many of these buildings is discontinuous both throughout the day and annually; for instance, the main use of the sports centre in terms of energy, is often for the annual local fair. The building energy consumption is not systematically recorded (other than in their energy bills), except for the electricity consumption, which was subject in many municipalities (but not in all) to systematic scrutiny as a part of the ELENA project mentioned before.

2.2. The Decision-Making Process on Energy-Related Issues

In the small municipalities of Teruel province, the energy-related decisions are usually made directly by mayors and councillors, who are often citizens with an external, full-time job, sometimes in agriculture, farming or the services sector. Few of them have technical expertise in energy or any other branches of engineering. Most of the municipalities do not have technical support on energy issues, even at a county or provincial level. Some counties (but not all) have an environmental expert who, in general, does not have the relevant technical knowledge on energy issues. Therefore, public authorities usually make the decisions guided by positive experiences in neighbouring municipalities (and word-of-mouth), or by the advice from the supplier of the energy efficiency intervention.

The first source of information highpoints the value of the success stories prepared in the PrioritEE project as a catalyser for energy efficiency interventions (see the section below). However, it should be highlighted that negative experiences have a comparable negative effect. For instance, when a biomass boiler malfunctioned in winter at a school, negative word-of-mouth and even press reports tainted all biomass boilers as a viable carbon-neutral approach for other municipalities for a long time.

The second source, advice from the supplier, involves a dangerous pathway because the supplier of the intervention does not necessarily have the municipality interests as a priority; while the municipal authorities rely on their opinion because they often lack the technical knowledge, the resources, or the incentives to compare alternative solutions or suppliers.

An additional challenge is that the installed equipment should be maintained by the existing technicians in the region. However, in these sparsely populated municipalities, a boiler in a school or day-care centre cannot be out of service for days waiting for repairs or maintenance.

In addition, municipal budgets are tight, with a sizeable portion going towards expenditure in social programmes (notably, services to senior citizens, given the ageing population). This, together with the restrictions to increase municipal debt, severely limit the availability of choices for non-essential interventions. Therefore, usually, the main decision-making criterion is that the intervention should be self-funded with its annual savings. Meanwhile, major interventions are often postponed when the equipment to be replaced (e.g., a boiler) is obsolete or broken.

2.3. Barriers and Opportunities

Bearing in mind the aforementioned findings, the main barriers for a larger deployment of energy efficiency measures in the public buildings of Teruel province are the following:

- Lack of data about the energy performance of public buildings. There are few buildings with energy data and this information is not centralised. Therefore, it is complicated to develop provincial plans to improve the energy efficiency of public buildings, which is poor (according to the findings of this work).
- The decision-making authorities rarely have a technical background, or the time or support required to make informed decisions.
- For this reason, decisions are often limited to the portfolio of solutions available from local providers. Continuity-of-service is critical (e.g., boilers), and it further constrains the available choices.
- There is no budgetary slack to make a substantial investment in energy efficiency without external funding. Even partial external funding as high as 50% may be not enough due to budget limitations.
- Any technical tool needs to be designed for non-technical users to be valuable in these types of municipalities.
- The concept of energy efficiency is often bundled with economic savings. For instance, the negotiations of energy supply contracts are often cited as [energy] saving initiatives. Further, energy usually means only electricity, as it is the main energy carrier in the municipalities.
- Non-building energy expenditure is often the major component of the energy budget in these municipalities because the buildings themselves are sparsely and discontinuously used. For instance, street lighting is nearly always the major energy expense in small, underpopulated municipalities. Water pumping also comes often as a relevant cost.

Table 1 shows a summary of the SWOT analysis performed in Teruel province.

Table 1. SWOT analysis.

Strengths	**Weaknesses**
Awareness and positive attitude Good renewable resources, biomass particularly (also solar energy)	Lack of skilled technical personnel Very restricted budgets and debt ceilings Geographical isolation Buildings are often not the main expense
Opportunities	**Threats**
Ageing infrastructure (e.g., boilers) may force interventions Funding from regional, national, European programmes Employment opportunities	Depopulation

3. Materials and Methods

3.1. Development of the Prioritee Toolbox

One of the main project outcomes is the PrioritEE toolbox, which can be used by local administrations to manage and monitor energy consumption, assess the cost-effectiveness of a predefined set of energy efficiency and renewable energy measures, and prioritize investments. The PrioritEE toolbox was tested on five pilots in the aforementioned countries, focusing on a varied portfolio of local priorities, covering different key energy efficiency issues [18].

The toolbox consists of five main components: (i) a technological analytical database, (ii) a decision support tool (DST), (iii) a set of How-to Briefs, (iv) a repository of good practices, and (v) an open data and knowledge access infrastructure.

The **technological analytical database** incorporates more than 150 solutions to improve energy efficiency in buildings involving: lighting, space heating, space cooling, water heating and cooking. The database also includes energy efficiency measures to improve the building envelope as well as different renewable energy technologies. It provides information about the solution features, investment, operation and maintenance costs, and estimated energy savings, among others [24]. The **How-to Briefs** are easy-to-use guides for the implementation of selected best practices for energy efficiency in buildings. The **repository of good practices** aims to enhance sustainable energy awareness and foster behavioural changes. The **open data and knowledge access infrastructure** gathers all the above components on the PrioritEE website to be easily and freely accessed [25].

The **decision support tool (DST)** aims at assessing the cost-effectiveness of a predefined set of energy efficiency measures and renewable energy interventions and prioritizing investments across several technological options [26]. There are two levels of inputs, basic and advanced. The basic inputs allow users that do not have detailed information of the building characteristics to have a first estimation of potential energy efficiency interventions. Meanwhile, advanced inputs include information of the EPC that allow a more accurate analysis of the potential energy savings. The DST contains a database of country-specific data for different building typologies, namely offices, educational buildings, cultural buildings, social centres, sports facilities and swimming pools. Available background data include climate data (e.g., solar irradiation levels, heating and cooling degree days), energy prices, energy consumption breakdown per energy source (e.g., natural gas, electricity, biomass, light-fuel oil) and energy end-use split (e.g., for space heating, cooling, lighting, water heating). This information was collected during the project and is used when no detailed information is provided by the DST user. The DST calculations when advanced inputs are introduced follow the energy performance certification methodology. More details can be found in previous work [18,26].

The interventions analysed include improving the building envelope (windows, façade, roof and/floor), replacing the heating, cooling and/or hot water systems with more efficient units, and replacing the lighting system with LED units. The renewable energy technologies assessed involve the installation of solar thermal collectors for domestic hot water provision, the installation of a biomass boiler and the integration of PV panels on the building roof [18]. The DST provides an overview of results ranked by energy savings, investment costs and payback time for each building. It also allows the evaluation of a combination of energy efficiency measures, and to aggregate several buildings. The DST is freely available and can be accessed through the PrioritEE project website [27].

3.2. Capacity Building and Knowledge Transfer

Local living labs were performed in different municipalities of Teruel province to engage target groups in the project activities, foster energy awareness and implement selected good practices within the local communities [28].

The first living lab focused on potential funding for the implementation of energy efficiency measures in public buildings. The main objective was to provide public authorities and other local stakeholders with an overview of the Covenant of Mayors for

Climate & Energy of the EU, as well as of national and European funding available for the implementation of energy efficiency projects in municipalities. The aim was to guide public authorities on ways to implement these types of projects.

The second living lab focused on success stories within the province of Teruel. The main objective was to present success stories about solutions to improve energy efficiency in public buildings.

The third living lab focused on different technologies and energy efficiency solutions available on the market. The main objective was to present how to obtain biomass resources to use them to heat municipal public buildings. Another objective was to provide basic knowledge about energy certification, and its importance to guide stakeholders on energy efficiency measures in municipalities.

In total, more than 100 stakeholders attended these events, including mayors, local authorities, municipal staff and energy managers. The main outcome of the events was that in general there is a lack of knowledge about available funding to help implement energy efficiency projects, as well as about potential measures that can be implemented to save energy. Meanwhile, there is an important willingness to implement energy efficiency measures. Thus, the attendants were very interested in the PrioritEE project and specifically in the tools developed within the project.

In parallel, training materials were developed to provide public authorities with basic concepts on energy efficiency in buildings. The training material includes the main building components that influence its energy consumption, a summary of the main technological options for each energy service, and different alternatives to increase energy efficiency in buildings, involving the building envelope, HVAC systems, lighting, and renewable energy integration, among others. The economics of energy efficiency and how this reflects on the utility bills are also addressed in the training materials, to show public authorities how to quantify and compare economically different energy efficiency measures.

In addition, three local workshops were organized covering several regions of Teruel province to involve key stakeholders and provide an effective transfer of knowledge with the final aim to develop local energy action plans. The first workshop helped to establish the status quo in Teruel province and to collect requirements from local authorities on energy efficiency, as shown in the previous section. In the second workshop, the developed training materials were tested to receive feedback from public authorities. Finally, in the third workshop, public authorities tested the toolbox and were trained to develop local energy action plans.

In total, 90 stakeholders attended these workshops, including mayors, local authorities, municipal staff and energy managers. The feedback received in these workshops was very positive. Public authorities considered very useful the availability of a user-friendly tool such as the proposed DST to perform energy efficiency calculations and, also, the capacity building provided with the training course. Further, it was found that public authorities are keen to do their own calculations and therefore, that the type of tools developed in the PrioritEE project can achieve a very good acceptance by public authorities.

The following section shows a summary of the energy action plan of Teruel province.

4. Results and Discussion

In this section, we describe the main results obtained in this work. First of all, the quantitative evaluation of the energy performance of a representative sample of public buildings in Teruel province is shown. Then, the techno-economic results of the implementation of different efficiency measures obtained with the aforementioned DST are detailed. Finally, the developed energy plan is outlined.

4.1. Assessment of the Current Situation of the Public Building Stock

In the framework of the PrioritEE project, 59 EPCs were issued, thanks to the funding provided by the Teruel Provincial Government. Figure 4a shows the distribution of the buildings by typology. It is observed that 78% of the buildings were built before 2000 when the energy efficiency regulation in buildings was less demanding than the current one (see Figure 4b)

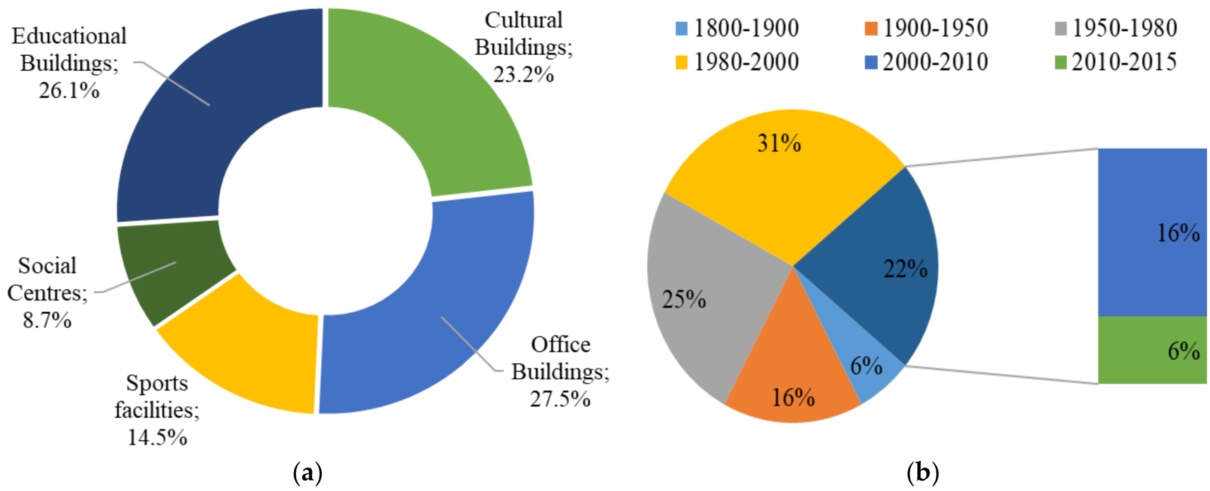


Figure 4. (**a**) Distribution of the buildings by building typology (**b**) by year of construction.

The EPCs show that 51% of the buildings have an energy label F or worse (in an A–G scale) in terms of total CO_2 emissions (Figure 5a). Figure 5b shows that the predominant fuel used is light fuel oil (in 45% of the total heated area) so there is a significant potential of CO_2 emissions reduction with the replacement of the heating system.

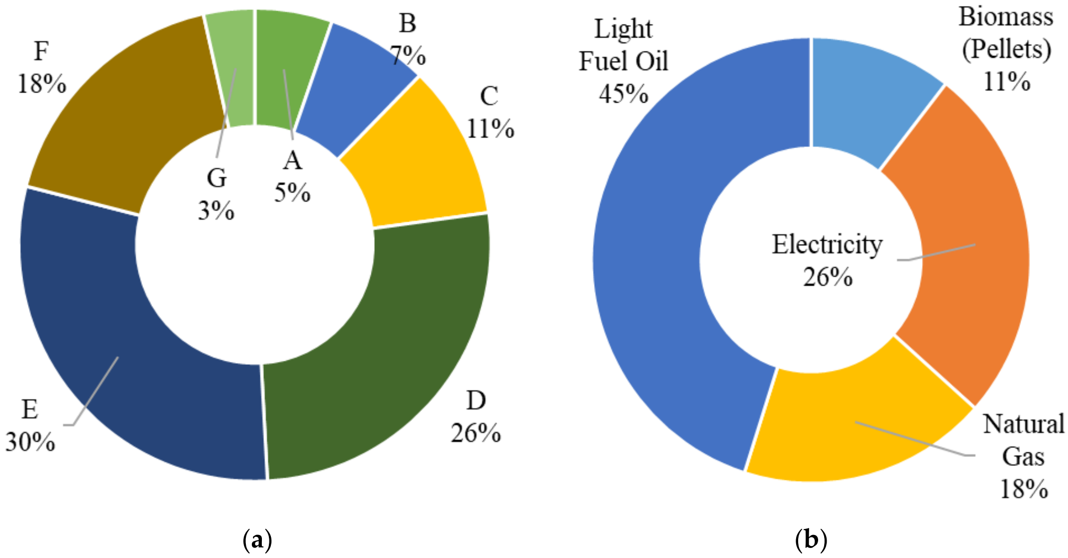


Figure 5. (**a**) Distribution of the EPC energy label regarding the CO_2 emissions and (**b**) share of the fuel used for the heating system per total heated area.

Regarding the heating demand, 98% of the buildings have an energy label of D or worse, 32% of the buildings have a G energy label and 34% have an F energy label (Figure 6a). This is attributed to the age of buildings (more than 90% were built with building regulations from 1979), and thus, the envelope and insulation are very inefficient. The better energy label in CO_2 emissions (Figure 5a) compared to the label of heating demand is due to the installation of biomass boilers in several public buildings (see Figure 5b). Thus, it is possible to conclude that there is also considerable room to improve the energy efficiency of these buildings, in particular the building envelope.

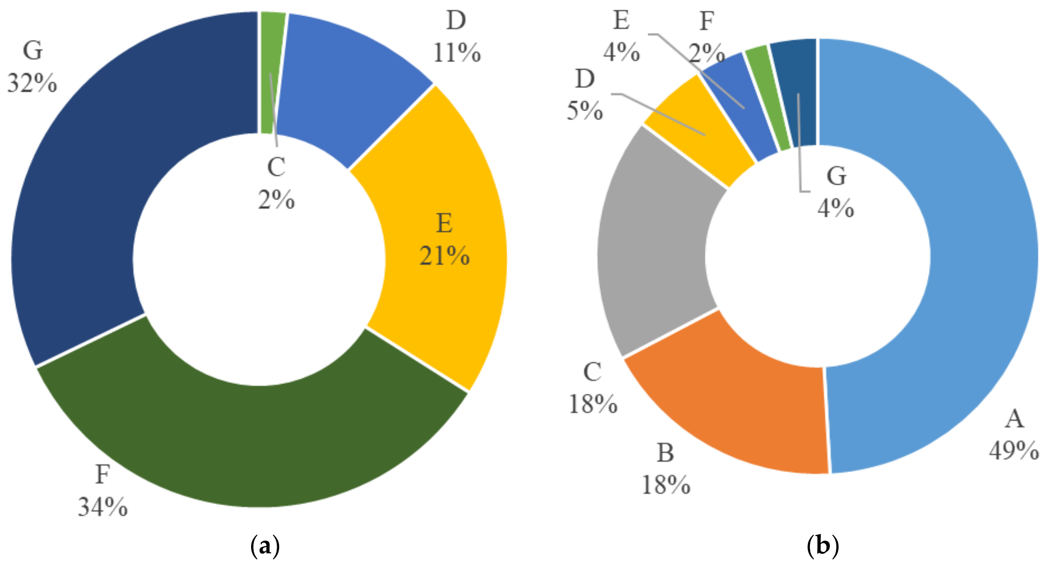


Figure 6. (**a**) Distribution of the EPC energy label regarding the heating demand and (**b**) the cooling demand.

Better results are found regarding the cooling demand, with an A energy label in almost half of the buildings (Figure 6b), which is attributed to the mild summer weather in these regions, with very few days with high temperatures.

4.2. Energy Action Plan

The first step in the energy action plan is to analyse the current energy consumption of the building stock, to have the overall picture of the current situation and assess which buildings have more potential energy savings. Figure 7 shows the aggregated fuel consumption and total electricity consumption for the different buildings typologies of public buildings assessed in this work. The predominant fuel used in all the building typologies, except in the social centres, is light fuel oil. In social centres, more than half of the total fuel consumption is biomass, while light fuel oil accounts for less than 10% of the total. Cultural and office buildings have an important use of electricity, while sports facilities predominantly consume natural gas.

It is observed that sports facilities have the largest total fuel consumption, despite this type of building only represents 14% of the total number of buildings analysed in this work. Therefore, there is an important potential for energy savings in sports facilities. Meanwhile, cultural buildings have the largest total electricity consumption, which is partially attributed to the use of electricity for heating purposes.

As mentioned in the methodology, the PrioritEE DST proposes potential energy efficiency measures and renewable energy interventions and estimates the energy savings, investment costs, CO_2 emission reduction, and payback time for each building. Depending on the current status of each building, different interventions might be suitable. It is also possible to apply a combination of different measures to a specific building, and the different combinations can also be applied to all or several buildings.

It is necessary to select some criteria to prioritise the most suitable interventions. In this local action plan, in the short-term, energy efficiency interventions that do not require a considerable investment, have important energy (and associated costs) savings and hence have short payback time, are prioritised, because the available budget of local authorities is limited. It is planned to use the economic savings achieved with the short-term interventions to implement the medium-term interventions. These interventions can have slightly higher investment and payback times. Finally, the most expensive interventions are planned for the long-term, when the local authorities have saved enough money thanks to the previous interventions to implement the most expensive ones. Only interventions with a payback time shorter than 30 years have been considered.

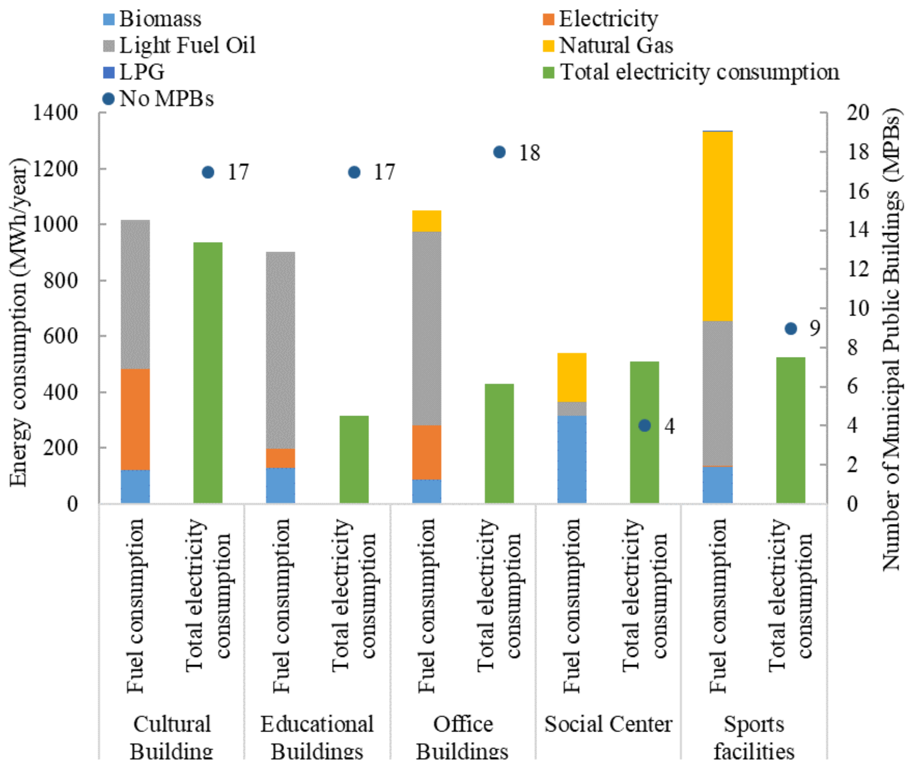


Figure 7. Aggregated fuel consumption and total electricity consumption of the different buildings typologies assessed in this work.

Figure 8 shows that in all types of buildings, except in educational buildings, there are important potential energy savings if the current lighting system is replaced with LEDs; although it also implies a considerable investment. Sports facilities have the largest energy-saving potential with this measure. The reason is that the current lighting system is mainly composed of inefficient fluorescent lamps and in some cases even incandescent lamps. In most of the buildings, the total installed lighting power (W/m^2) is higher than the maximum installed power according to the UNE-EN 12464-1: 2003 normative [29]. As a consequence, when these lamps are replaced by LEDs, the total installed lighting power is considerably reduced, meeting the aforementioned normative, and the associated electricity consumption is also significantly reduced.

Meanwhile, in educational and cultural buildings, as well as in sports facilities, the roof renovation would lead to important energy savings; but the investment is considerable in this case.

The most promising energy efficiency measure in terms of energy-saving potential in office buildings is the renovation of external walls, followed by the installation of a new ventilation system with heat recovery. This is attributed to the low insulation level of the current walls in office buildings. Most of these buildings are historical buildings, built before 2000 when the energy efficiency regulation in buildings was less demanding (see Figure 4b). As a consequence, the heating demand in these buildings is large (see Figure 6a), and thus a considerable amount of energy is required to main the comfort setpoint temperature. The renovation of external walls would involve an improvement of the thermal insulation, and thus a reduction in the heating demand (and corresponding energy consumption). The installation of a new ventilation system with heat recovery would allow recovering part of the heat that otherwise would be lost with natural ventilation, and thus would also lead to a reduction in the building energy consumption due to heating.

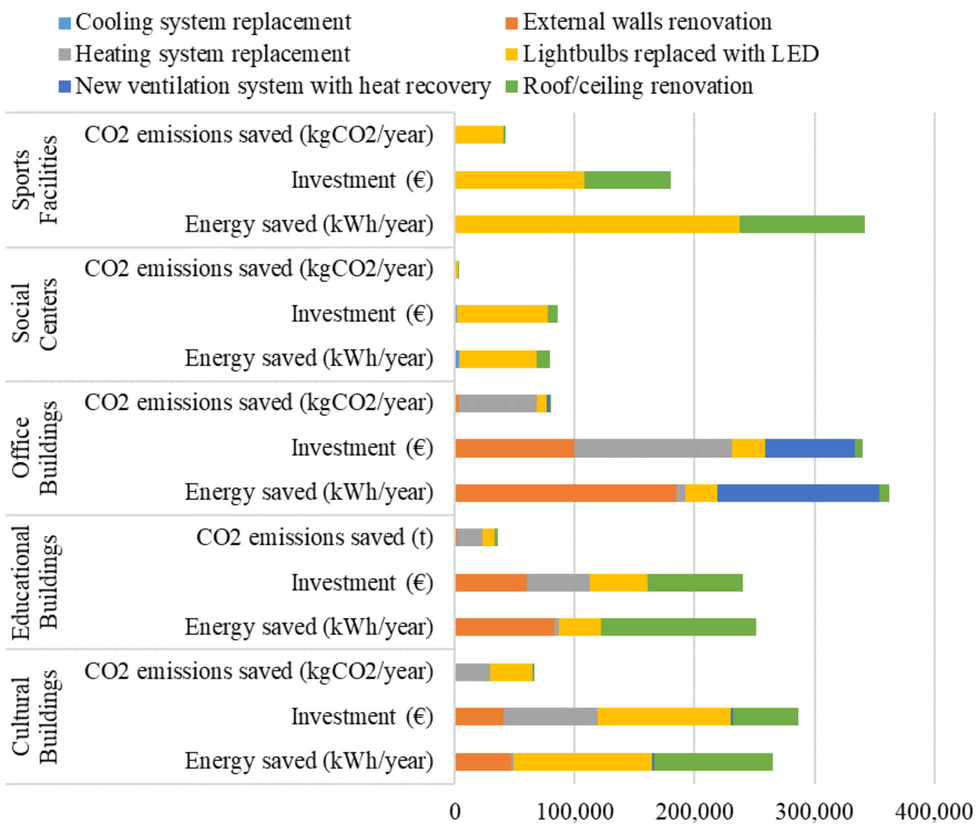


Figure 8. Summary of potential energy savings, investment and CO_2 emission savings of the selected actions to improve EE and renewable energies in the buildings, classified per building typology.

It is observed that the heating system replacement leads to the largest CO_2 emissions reduction in office, educational and cultural buildings, while the energy savings are lower than with other measures. This is attributed to the fact that the boiler replacement usually leads to a slight improvement in energy efficiency, but the heating demand remains the same, so the final fuel consumption is only partially reduced. Instead, if the roof or external walls are renovated, the heating demand will decrease, and thus the associated fuel consumption. Still, the large CO_2 emissions reduction emission thanks to the replacement of the heating system is attributed to the new type of boiler, a biomass boiler. Biomass has an almost negligible emission factor compared with the high emission factor of light fuel oil (0.018 Kg CO_2/kWh vs. 0.331 Kg CO_2/kWh of final energy, respectively, in the case of Spain [30]).

It is estimated that the combination of selected energy efficiency interventions would lead to 1.3 MWh/year of energy savings and 245 tonsCO_{2e}/year of CO_2 emissions reductions. The total foreseen investment costs are EUR 1.2 M.

Figure 9 shows the CO_2 emission reduction vs. the payback time of the proposed energy efficiency interventions. The size of the circles represent the investment of the measure, so bigger circles mean larger investment. In the upper part of the figure on the left, there are interesting measures as they achieve a large CO_2 emissions reduction with short payback times. For instance, it is observed that the lighting replacement requires a larger investment than other measures, but thanks to the high energy savings, the CO_2 emissions reduction are considerable and the payback time is less than 15 years in most cases. Meanwhile, the heating system replacement requires lower investment, but have longer payback times. Similarly, the renovation of the external walls has longer payback times (see the lower part of Figure 9 on the right).

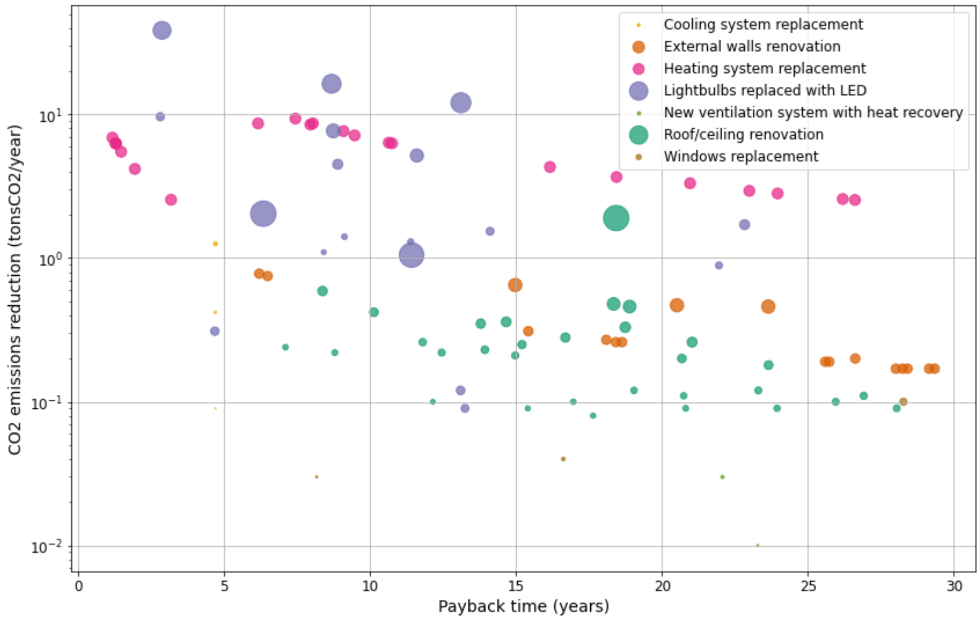


Figure 9. Payback time vs. CO_2 emission savings of the selected actions to improve energy efficiency and renewable energies in the buildings. The circle size represents the investment of the measure.

5. Conclusions

This article describes the application of the PrioritEE project in the Teruel province. The methodology followed is replicable in other territories to support public authorities to develop action plans for the renovation of their public buildings. The strategy consists mainly of three phases: analysis of the current situation, development of tools adapted to public authorities skills and training of public authorities. Thanks to this strategy, results were obtained throughout the process of preparing an energy action plan.

Throughout the capacity building activities performed within the project several technical, social and governance factors were identified that hinder the implementation of energy efficiency measures in public buildings, particularly in small municipalities such as in Teruel province. Governance factors include the electoral cycles, since priorities may change depending on the political party in power, the need for tedious procurement processes to perform energy interventions and budget constraints. Furthermore, in general, there is a lack of knowledge about available funding to help implement energy efficiency projects, as well as about potential measures that can be implemented to save energy. Social factors comprise the existence of other needs with higher priority (e.g., social assistance), particularly in the case of depopulating, ageing regions, such as in most of the municipalities of Teruel province. Finally, technical factors include the lack of expert staff and the lack of data about the building energy performance.

This information can be used to improve the energy policies and the institutional infrastructure to support the local authorities in Teruel province in the renovation of their public buildings. Furthermore, the depopulation and ageing population represent additional barriers, as explained above.

The work performed in the PrioritEE project allowed answering the questions presented in this article about the energy renovation processes of public buildings in small municipalities, such as the ones of the Teruel province presented here.

Decisions related to energy interventions are made directly by local authorities, which in many cases do not have the required technical training or skills. In general, these decisions are based on positive experiences in neighbouring municipalities or technicians' advice from local companies related to the energy efficiency sector. Most local administrations do not have technical personnel who can help them in this decision-making process.

Another barrier found in this research is the total lack of planning. Projects for the implementation of energy efficiency measures are performed based on the personal initiative of local authorities or existing subsidies. There is even an excessive dependence on subsidies (or a dangerous incentive) since, in general, the implementation of EE measures is based on the subsidies available (but sometimes not particularly in the real needs). Furthermore, the self-financing of the EE measures (even by ESCOs) is rarely considered by local authorities.

Coordination between the different levels of the public Administration (local, provincial, regional) is, in general, quite poor. There are public buildings owned by the regional Administration but managed by the local Administration (for example, schools). In these cases, the implementation of energy efficiency measures can become very complicated because both Administrations must agree.

Of course, the lack of financing is a major barrier, but, also, the lack of technical personnel to support decision-making, planning, and implementation of energy efficiency measures. The lack of technical data of the buildings is a significant barrier since it complicates the development of long-term strategies. Many of the public buildings considered in this work (because of their size and low occupancy) do not need to have EPCs. Additionally, local authorities are generally reluctant to spend money on EPCs, as most of the time they do not see the use of the EPC. Consequently, it is very complicated to find quality data about the energy performance of public buildings.

The energy performance of public buildings has a relevant margin for improvement (considering the representative sample of buildings analyzed in this work). Regarding the heating demand, most buildings have ratings above E. In addition, a considerable number of buildings have light fuel oil boilers, which undoubtedly cause high CO_2 emissions from public buildings. This energy diagnosis of buildings coincides with the energy efficiency measures that public authorities usually implement: changes in the lighting system and, to a lesser extent, change from fossil fuel boilers to biomass boilers. In general, it is observed that large interventions in public buildings are avoided, such as changes to the envelope, which could certainly generate significant energy savings, but whose payback is relatively high (at least compared to the electoral cycle).

The resulting energy action plan includes a series of energy efficiency measures applied to 59 representative buildings of Teruel province. It is estimated that the implementation of this plan would save 1.3 MWh/year of energy, reducing 245 tons_{CO2}/year, and it would require an investment of around EUR 1.2 M. The results show that the replacement of the current lighting system with LEDs involves the largest CO_2 emission reduction potential and the lowest payback time. The replacement of the current heating system (commonly, light fuel oil boilers) with biomass boilers also appears as a cost-effective measure (in general, around 5–10 years payback time). The improvement of the envelope insulation is revealed as one of the measures that achieve a significant reduction in energy consumption, as this measure leads to a reduction in the heating demand and thus the energy required to heat the building. However, envelope interventions have higher payback times (more than 10 years). Finally, window renovations have large payback times and lower energy savings.

It is concluded that improving the energy efficiency of public buildings will require more significant interventions than those being currently performed.

Based on these barriers, the following solutions are proposed: (1) improving the coordination between the different Administration levels is essential; (2) Long-term planning is needed (3) Energy managers (technical staff) that support the municipalities in its pathway to sustainability would facilitate the energy transition. Additionally, an appropriate level of funding availability is also needed to implement energy efficiency measures.

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