



Improving policy making and strategic planning competencies of public authorities in the energy management of municipal public buildings: The PrioritEE toolbox and its application in five mediterranean areas

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ABSTRACT

Making public buildings smarter and more energy efficient requires tailored solutions to overcome the barriers in implementing suitable technology options in a large variety of building types. The PrioritEE project aimed to strengthen the policy-making and strategic planning competencies of local and regional public authorities in the energy management of Municipal Public Buildings, gaining experience in five local pilots in the Mediterranean area. This paper focuses on the PrioritEE toolbox, describing both the “soft components” and the technical components. These components are widely applicable and replicable in all European cities for supporting local administrations in improving energy efficiency and the use of renewable energy sources in municipal public buildings. The Energy Technologies and Building Retrofit Database is a technology repository of energy efficiency measures and renewable energy technologies, providing the main reference data on costs, technical performance and lifetime. With the Decision Support Tool users can assess current building stock energy performance, evaluate different efficiency and renewable interventions, and compare, rank, and prioritize technical options through a set of key performance indicators. A sample of the results to date in the five partner regions are also presented, comparing the main individual characteristics in order to derive replicable solutions for local authorities. This project also highlighted how crucial stakeholder involvement is for tool improvement, capacity building and enabling knowledge transfer.

1. Introduction

Buildings are responsible for approximately 40% of energy consumption and 36% of CO₂ emissions in the European Union (EU) [1], where about 35% of the buildings are over 50 years old and 75% of the overall stock is energy inefficient [2]. Additionally, commercial buildings are more energy intensive than residential ones [3]. Enhancing adaptive and mitigative capacity to deal with climate change is a pressing challenge for cities across the planet [4] and is among the

United Nations Sustainable Development Goals (SDGs) [5]. A specific analysis for 885 cities in the EU [6] (building from Refs. [7]) has highlighted the need for local authority capacity building in Europe, particularly for certain EU countries such as Italy [8]. A range of suitable solutions already exist [9], however these are not always available to local decision-makers. A recent assessment by the International Energy Agency (IEA) regarding the status of the global building sector according to the SDGs identifies that “emissions from buildings appear to have risen again in 2018 for the second year in a row” due to “several factors, including extreme weather that raised energy demand for heating and cooling” and

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Nomenclature	
CIMLT	Intermunicipal Community of Lezíria do Tejo in Portugal
CO ₂	Carbon Dioxide
CoM	Covenant of Mayors for Climate and Energy
DOE	Department of Energy
DST	Decision Support Tool
EE	Energy Efficiency
EED	Energy Efficiency Directive
EPA	Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
GHG	Greenhouse Gases
GPs	Good Practices
ICT	Information Communication Technology Service
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LED	Light Emitting Diode
LL	Living Labs
LLL	Local Living Labs
LPG	Liquefied Petroleum Gas
MPB	Municipal Public Building
MS	Member States
NECP	National Energy and Climate Plan
NEEAP	National Energy Efficiency Action Plan
NLTS	National Long-Term Strategy
PrioritEE	Prioritize energy efficiency measures in public buildings: a decision support tool for regional and local public authorities
PV	Photovoltaics
REGEA	Regionalna Energetska Agencija Sjeverozapadne Hrvatske (<i>North-West Croatia Regional Energy Agency</i>)
RES	Renewable Energy Sources
ROI	Return Of Investment
SDG	Sustainable Development Goal
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
WS	Local Workshop

that “enormous potential remains untapped due to the widespread use of less-efficient technologies, a lack of effective policies and insufficient investment in sustainable buildings” [10].

The untapped energy saving potential of buildings on the path to decarbonizing energy systems is underlined by EU directives in response to the climate challenge set by the Paris agreement [11], adopted by the United Nations Conference of the Parties COP21 in 2015 and ratified on November 2016 by 187 parties, which aims to restrict global warming to 2 °C and encourages a further limitation to 1.5 °C.

To cope with this demanding issue, the EU has set binding climate and energy targets for 2030: reducing greenhouse gas emissions by at least 40%, increasing energy efficiency by at least 32.5%, and increasing the share of renewable energy to at least 32% of EU energy use [12]. The “Clean Energy for All Europeans package” [13] includes a set of legislative measures to facilitate the transition of the European Community towards “a resilient Energy Union with a forward-looking climate change policy” [14]. This set includes, in particular: 1) the revised Energy Efficiency Directive (EED) (2018/2002) [15], in which the Article 5 requires national governments to put in place measures to renovate 3% of public buildings or provide equivalent savings (in response to this request some Member States have already carried out inventories of public buildings); 2) the new Energy Performance of Buildings Directive (EPBD) (2018/844) [16], which promotes the implementation of comprehensive long-term national roadmaps for the decarbonization of buildings and encourages the use of smart technologies; 3) the Regulation on the Governance of the Energy Union and Climate Action (2018/1999) [17], which requires Member States to prepare integrated National Energy and Climate Plans to 2030 (NECPs) and National Long-Term Strategies to 2050 (NLTS). Several studies have been conducted to support these strategic national plans, for instance showing the technical energy efficiency potentials in the different EU Member States by 2030 [18], and analysing alternative decarbonization scenarios to 2050 [19].

Taking into account the complex framework and the large variety of buildings, a careful planning of interventions is required to pursue the energy performance objectives of public buildings promoted by the EU, accelerating renovation of the existing stock and moving towards nearly-zero-energy and nearly zero carbon emissions buildings [20], in accordance with the National Energy Efficiency Action Plans (NEEAPs) and the NECPs. Energy benchmarking, rating and classification of buildings are basic requirements for the adoption of energy certification schemes and regulatory measures, to promote energy efficiency and to

assess the reduction of consumption, in compliance with the EU Directives [21]. New approaches have also been designed to identify renewable energy options to make buildings more efficient, cost-effective, environmentally friendly and technologically advanced [22] and to identify the factors that can affect building renewal.

Energy renovation is a key measure for energy saving and reducing CO₂ emissions in public buildings with the added benefit of reducing building operation costs. Despite these advantages, there are still many barriers [23] in promoting energy efficiency (EE) investments and renewable energy sources (RES) use in existing public buildings. For example the lack of financial resources for investments [22] is a problem which is particularly relevant for public buildings [23]. Another important barrier is that local decision-makers [24] and commercial building owners [25] often lack the technical expertise necessary to promote technology innovation and demonstrate the profitability of such investments. This is further hampered by complex legal, regulatory or institutional frameworks, in some cases associated with a multi-level governance structure with shared competencies and responsibilities.

The main barriers and challenges are particularly evident at the local level, where public authorities have to manage diverse building stocks and have to evaluate various building stock development pathways [24].

In this context, improving the energy efficiency of Municipal Public Buildings (MPBs) is one of the actions focused on both reducing greenhouse gases emissions [26] and reducing local authority energy bills. This is also one of the pillars of the Sustainable Energy (and Climate) Action Plans (SEAP/SECAP) that the signatories of the Covenant of Mayors for Climate and Energy (CoM) initiative must prepare within two years to describe the steps towards, respectively, their 2020 or 2030 targets [27]. The CoM’s guidelines on SEAP/SECAP implementation highlight the need for a local authority to adopt a systematic approach “in order to ensure a coherent and efficient energy policy covering the entire building stock over which the local authority exercises control” [28]. Nevertheless, in most cases, public authorities have insufficient knowledge of building features, energy consumption, and of the most potentially effective options for the improvement of energy performance.

A substantial number of computer-based models and tools have been developed to perform energy analyses of buildings [29]; to model the building energy systems [30]; to support energy planning [31] (choosing a tool suitable for the specific purpose [32]); and to analyse the integration of renewable energy into energy systems [33], some of which can be accessed through common platforms (such as [34]).

Specifically, existing models and tools facilitate energy audits for single buildings [35], allow for a comprehensive simulation of the energy system [36] and provide an integrated assessment of building operational status [37]. These tools also contribute to energy efficiency benchmarking with a focus on the operational conditions of the building stock [38]. The tools also estimate costs of electricity for integration of PV in buildings [39]. Models can also conduct statistical analysis approaches regarding the effectiveness of refurbishment measures [40] and have applications specifically designed for the analysis of energy retrofit in buildings [25]. Simulations based on life-cycle analysis [41] and monitored data [42], can be used to provide estimations of the building's thermal load. Typically these account for climatization factors [43] and draw on algorithms to evaluate if specific industrial and commercial buildings can become net-zero energy by deploying RES [44]. However, most of these models and tools are too complex and remain unknown to municipalities and local governments [45], hindering their utilization in supporting strategic decision-making. Moreover, more studies (and tools) based on “real” operational data from existing buildings instead of generic datasets are needed [46]. In operational terms, there is a strong need for simplified EE assessment tools which can operate based on the available information (e.g. the Energy Performance Certificates - EPCs [47]). A current operational challenge is, therefore, to develop user-friendly, open-source tools that can be easily transferred to energy planners, policymakers, and local administrators, after a short “hands-on” training, supporting policy design, implementation, and assessment.

In addition to the measures identified above local authorities and civil society must be informed, trained and motivated to reduce their energy consumption by changing behaviour. This implies the implementation of a series of actions “to approach building users and motivate them to change their behaviours and engage in energy-related initiatives” [48].

It is therefore necessary to strengthen the institutional capacities of local public bodies in the sustainable management of public buildings and, in particular, in the field of EE and use of RES [24]. This is underlined by Annunziata et al. [24], who pointed out how capacity building through training courses and technical support provided by energy audits can positively affect the adoption of EE in municipal buildings. Ruparathna et al. [49], evaluated the existing body of knowledge on improving EE in the management of commercial and institutional buildings, noting that existing studies have focused mainly on technical progress while neglecting the encouragement of behavioural changes.

The PrioritEE project “Prioritize energy efficiency measures in public buildings: a decision support tool for regional and local public authorities” [50] aimed at supporting more efficient energy management of MPBs in five Mediterranean countries (Croatia, Italy, Greece, Portugal and Spain). The core of the approach is the development of a comprehensive and generally applicable set of tools (which constitutes the PrioritEE toolbox) aimed at professionals and experts from different levels, including energy managers, energy planners, and decision-makers. Moreover, awareness-raising initiatives and capacity building activities were carried out throughout the project to involve key target groups, familiarise them with the PrioritEE toolbox and to ensure it was suitable for application in the five local pilots. One relevant feature of the PrioritEE toolbox is that it focuses explicitly on several types of public service building (e.g. cultural buildings, health centres, sports centres, schools), as well as office buildings. This progresses current literature a step further, where previously it has mainly focused on office buildings [46].

This paper focuses on the main outcomes of this multifaceted collaborative effort aimed at increasing the capabilities of local and regional public authorities in the strategic management of their public building stock. The main aim is to present the methodological approach used for developing, testing and applying the PrioritEE toolbox under different local conditions and to illustrate how the toolbox can be

adapted to meet specific end-user needs. The paper is structured as follows: Section 2 illustrates the methodological approach, describing the toolbox components, the pilot case studies and how to move towards local action plans. Concrete examples of toolbox application (in pilot format) in the five Mediterranean regions are presented in Section 3. Section 3 specifically focuses on the various aspects of the analysis for each case study as well as on different features and assessment options of the toolbox. Section 4 provides a critical discussion of the research findings, and the paper concludes with further possible improvements, main common strategies and policy recommendations.

2. Methods and tools

One of the main objectives of this research was to create and test a toolbox to support the management of energy consumption and increase energy efficiency and renewable energy use in municipal public buildings (MPBs). The toolbox is aimed at a wide range of professionals, experts, and local administrators who can benefit from using one or more of its components.

The design and implementation of the toolbox was driven by, tested and refined through five local pilots in the Mediterranean area. Its application in different local conditions led to the development of local action plans for energy efficiency using a transparent and common methodological platform.

The main components of the toolbox, the characteristics of the pilot cases and the structure of the target local action plans for increasing energy efficiency in public buildings are described in the following sections. The toolbox design follows the known factors affecting building energy consumption and carbon emissions as described in Ref. [46].

2.1. Overview of the toolbox

The PrioritEE toolbox consists of four main components including both analytical and “soft” tools, as introduced in Ref. [51] (see Fig. 1):

- A spreadsheet-based *Energy Technologies and Building Retrofit Database* which includes EE and RES measures collected through literature review, expert interviews and national energy certification systems;

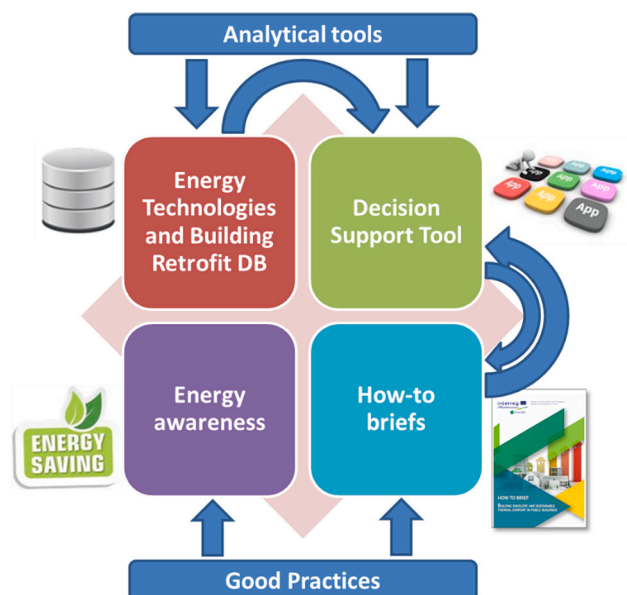


Fig. 1. Main components of the PrioritEE toolbox.

- A web-application *Decision Support Tool (DST)* for comparing and ranking a portfolio of EE/RES interventions on the overall set of MPBs of a given local authority,
- A collection of *Good Practices (GPs)* to enhance sustainable energy awareness and foster behavioural changes,
- Seven *How-to briefs* on energy efficiency related topics.

All these components are linked and are available through the project's website [52].

2.1.1. Energy technologies and Building Retrofit Database

One of the analytical components of the PrioritEE toolbox is the Energy Technologies and Building Retrofit Database which incorporates solutions to improve EE and RES utilization in MPBs with a focus on cultural buildings, office buildings, social centres, educational buildings, sports facilities and swimming pools.

The main goal of this repository is to provide quick and user-friendly data including, among others, technological parameters, investment/operation/maintenance costs and energy savings. Another objective is to support energy benchmarking and the identification of different alternatives for energy savings.

More than 150 energy devices and measures are catalogued for five end uses (lighting, space heating, space cooling, water heating and cooking), as represented in Fig. 2. It also includes passive measures and improvements on the building structure to reduce the energy losses through the envelope (such as window replacement, external and internal insulation of walls, thermal improvement of floors and roofs). The database also includes decentralized, small-scale RES technologies that could be used at building level (i.e. solar PV systems and micro-wind turbines).

The main data sources include international and national reports and information from retailer websites, regarding, for example, the application of insulation materials and building techniques [53] and their costs in different countries [54]; different lighting technologies [55]; energy-efficient products and buildings under the ENERGY STAR joint program of the Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) [56]. This extensive search and organization of data in a common database benefited from the local knowledge provided by the different country partners and from the assessment, when available, of the building's EPC recommendations.

The database was developed for the five pilots in a user-friendly

excel-based structure, designed to be easily accessible to the municipalities and local agents, while also allowing for future updates. The database is organized in a matrix style with sheets per building type and energy service in order to select those measures that could be targeted or used in a specific building typology, or in a specific country.

The database is a useful support tool for decision-makers, city administration officials or employees who are not energy experts, permitting the completion of an initial evaluation of several technological possibilities. The values included in the database are, however, generally representative for Mediterranean countries, therefore, estimates of costs or energy savings may not be accurate for a specific public building.

The complete Energy Technologies and Building Retrofit Database is available for download on the project website [57]. Alternatively, it is possible to download technological options for different end uses as separate pdf files.

2.1.2. Decision support tool

The other analytical component of the toolbox is the Decision Support Tool (DST) for assessing the cost-effectiveness of a predefined set of EE and RES measures and for prioritizing investments across several technological options [58]. A comprehensive set of key indicators constitutes an integral part of this tool and it is useful to compare different intervention scenarios and to assess the effects of the proposed strategies.

The development of the PrioritEE DST was driven by the following main requirements outlined by the city governments and local stakeholders that were involved since the early stages of the project [59]: i) easy and user-friendly interaction; ii) free online availability of both the English version and translated version in the languages of the partner countries; iii) focus on building project development and implementation evaluation; iv) flexibility in data input (limited key data but ability to apply more extensive data, if available); v) ranking of EE measures and RES solutions under several key performance indicators.

The first step consisted of thorough research, characterization and comparison of selected existing tools for energy efficiency decision-making, as extensively described in Ref. [59]. The second step focused on the assessment of their suitability for use by local authorities, according to the five main requirements mentioned above. Based on these requirements a new tailor-made DST was created, drawing upon an existing spreadsheet tool (the Energy Efficiency Database - EED) made

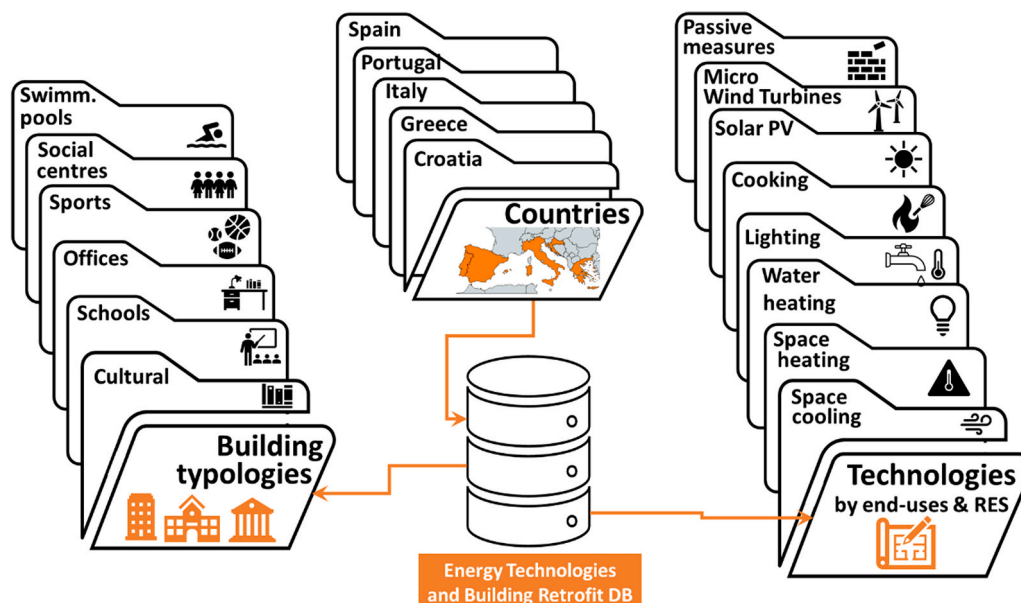


Fig. 2. Building typologies, end-uses and country regions included the Analytical Database.

available by the project partner REGEA, the North-West Croatia Regional Energy Agency. The tool was further developed to: include national specific information (e.g. on climate, emissions factors, energy prices and taxes); consider electricity and LPG use for space heating; address space cooling, solar thermal hot water, solar PV and three different levels of insulation thickness (low, medium and high).

Table 1 provides an overview of the 12 tools fully available at the time of the analysis (January 2018) characterized by a specific scope on the Building level and a comparison with the main characteristics of the final PrioritEE DST.

In a further step, to make the PrioritEE DST user-friendly and widely applicable, the DST was transferred from Excel to a web-based application, which was tested in the five local pilots to gather feedback from local authorities and improve its user-friendliness. The web application is available in English, Portuguese, Croatian, Italian, Spanish and Greek. In addition, a PowerPoint presentation is available for download in each language on the project website [60] and serves as a tutorial. Through the creation of an account and the country specifications of the user, the DST automatically applies the relevant database for the chosen country. This can be changed in the account settings.

The basic structure of the PrioritEE DST is composed of different input layers divided among basic information, information from energy certificates, as well as information regarding energy consumption, the building envelope and the different energy consumption systems (ventilation, lighting, heating and cooling), as represented in Fig. 3.

The first step in using the DST involves *data input*: users input information through several tabs where core data for calculations are gathered. The DST allows a tailored approach where users can provide numerous assumptions and database information and quantify different technical and financial parameters for their specific buildings. Using the tabs, users can select the building typology, insert information about energy consumption and relevant energy cost, specify the current state of the building envelope analysed and the parameters for its technical systems. In addition, users can select the desired level of energy renovations, such as the new preferred technical systems, the desired options for the building envelope and the inclusion/exclusion of certain measures from the calculations. In a dedicated input tab (calculation options), users can modify the calculation processes that have the greatest influence on financial parameters (energy costs, investment value, return of investment). This means that users directly influence the results – the more detailed the inputs, the more accurate the results. In the case of buildings with an Energy Performance Certificate (EPC) it is possible to use this information to obtain a detailed characterization for inclusion in the DST. Otherwise, if users are unable to provide certain information, the calculations are based on average values for each country contained in the database, which were derived during the project from national EPC, standards and reports from each pilot case. The geographical location of the buildings added to the DST application is represented on a map, which provides an overview of all the buildings that have been entered and their respective basic information (energy class and expected energy saving potential).

Once the data entry phase is completed, the *calculation module* allows the computation of the main impacts of the selected EE and RES interventions per each of the MPBs analysed. The DST calculates energy savings and costs for interventions, e.g. improving the building envelope, replacing heating, cooling and hot water systems with more efficient and/or RES-based systems (among those selected by users), and replacing lighting devices with more efficient LED ones. Among RES technologies, solar thermal collectors and PV panels are the main options included in the DST.

The next step is *results analysis*. Results are provided as indicators per building and per type of measure and allow a customized ranking (and prioritization) of EE and RES interventions in each MPB as well as in the entire stock of MPBs under analysis. This customization is undertaken through a dynamic sorting of the list of measures, based on different criteria, namely: annual energy savings (kWh), annual primary energy

Table 1

Comparison between the PrioritEE DST and other available tools (based on the information contained in Ref. [59]). The grey cells and the bold font highlight the main weaknesses (according to the PrioritEE objectives) that caused the exclusion of each tool.

Name Weblink (Developer/ Funding)	Type of Tool	User Friendliness	Availability	Data Needs
CHES UP Simulation Model www.chess-setup.net/simulation-software (EU H2020 - CHES UP)	Software for a preliminary sizing and economic analysis of RES only.	High	Online & free	Medium
CITYNVEST One Stop Shop www.cityinvest.eu/ (EU H2020 – CITYNVEST project)	Mainly guidelines for financing energy retrofitting.	High	Online & free	Low
Economic Assessment Tool http://comm.onenergyproject.eu/ (EU FP7 CommONEnergy)	Targeted for managers and owners of shopping centres located in the EU and Norway.	High	Online & free	Medium
EIS Zagreb https://eis.zagreb.hr/ (KONČAR - Elektronika i informatika d.d)	Energy Information System for all public buildings owned by the City of Zagreb. Available only in Croatian.	Medium	Not free	High
Energy Plus https://energypus.net/ (U.S. DOE, BTO, NREL, etc.)	Simulation program for the whole building.	Low	Online & free	High
FMAT (Financial Mechanism Assessment Tool) (not available) (Interreg - MED MARIE project)	A spreadsheet-based tool to assess the profitability of investments focusing on the financial aspects.	High	Not available	Medium to High
IMPULSE Web based System https://impulse.interreg-med.eu/ (Interreg MED – IMPULSE project)	Excel-based tool with energy performance indicators and definition of buildings' classification.	Medium to High	Online & free	Medium
PROITACA Family www.proitaca.com/family/	A questionnaire-based tool that calculates the energy expenditure of a building. Available only in Italian.	High	Online & free	Low
REPUBLIC MED MCDA Building www.republ ic-med.eu (Interreg MED - REPUBLIC MED project)	Toolkit for multiple-criteria decision-making. A methodology for conducting complete	Medium to High	Free	Medium

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Table 1 (continued)

Name Weblink (Developer/ Funding)	Type of Tool	User Friendliness	Availability	Data Needs
SCORE www.scoremed.eu/ (Interreg MED – SCORE project)	techno-economic studies for the refurbishment of public buildings and open spaces. An eco-construction tool to support energy-efficient choices for new buildings, conversion & renovation/retrofitting in fragile coastal and rural MED areas.	High	Online & free	Low
TEE-KENAK http://portal.tee.gr/portal/page/portal/TEE/TCG (Technical Chamber of Greece)	The official national calculation tool of the energy performance of buildings in Greece, to issue Energy Audits. Available only in Greek	Low	Not free	High
Energy efficiency database (EED) (Not available) (REGA)	Excel-based tool for identifying potentially “good” energy efficiency and renewable energy projects concerning: several public building typologies, different end uses and technical measures. Available only in Croatian	Medium	Free	Medium to high
PrioritEE DST https://prioritee.interreg-med.eu/toolbox/decision-support-tool/ (Interreg MED – PrioritEE project)	A web-based application. Available in English, Croatian, Greek, Italian, Portuguese and Spanish.	Low	Online & free	Low to High

savings (kWh), annual energy cost savings (€), investment (€) and annual reduction of CO₂ emissions (tons/year). Calculation options can be changed quickly and different measures can be easily included/excluded so that the total values for a single building are automatically updated. Finally, the results are also presented through a set of indicators relevant for the benchmarking of different MPBs, before and after the selected EE and RES interventions. A benchmarking section of the DST allows users to compare multiple selected buildings and extract a report for the selected buildings. Apart from calculations, the PrioritEE DST also allows the exportation of a report for a single building or for more selected buildings providing an overview of input and results.

In summary, this interactive online calculator [60] provides users with a relatively easy and quick calculation of energy and financial savings in public buildings by applying different EE measures and RES

interventions. Users can create their accounts which allow them to enter an unlimited number of buildings, to use the large database available for the countries involved in the PrioritEE project and identify the buildings with the highest potential for energy (and financial) savings.

2.1.3. Good practices and how-to briefs

The first “soft” component of the toolbox consists of a repository of actions to enhance sustainable energy awareness and foster behavioural change, which include the main *Good Practices* (GPs) identified in scientific literature, within national/international projects and those reported by partners through a tailor-made online questionnaire. The main aim was to inspire local administrators and other target groups with energy efficiency activities based on concrete experience. Some of the identified actions were also tested in the local pilots. This is the case, for instance, of the Green Schools Competition [61], which has been carried out for several years by the Province of Treviso (Italy) to reduce electricity consumption in State High Schools and the EURONET 50/50 MAX [62] a “roll-out 50/50 initiative to unlock energy saving in schools and other public buildings”. Both of these initiatives were included in the Potenza’s Schools4energy experimental laboratory [63].

Good practices are sorted according to the targeted type of MPB and building users. Each compiled action is accompanied by key information (area of implementation, time period, main references and contact person) as well as by a short description of the aims, developed activities and the main local impacts.

The fourth and last component of the toolbox is represented by the *How-to Briefs*, which are a set of short documents that compile the best practices already achieved in energy efficiency and other relevant topics in a transparent and easy-to-use manner. These documents are focused on public buildings and are of interest to professionals and experts from different organisational levels, including users and managers of MPBs. The topics include: Engaging the stakeholders, Creating a Sustainable Energy Action Plan, Innovative financing of energy efficiency measures in public buildings, Roof-top uses for more efficient public buildings, Building envelope and sustainable thermal comfort in public buildings, Promoting behavioural changes for increased energy efficiency in public buildings, and Centralized energy management and ICTs in public buildings. These how-to briefs encompass the three phases of energy planning: the pre-intervention phase, the intervention phase and the post-intervention phase, providing a balance between technological and non-technological measures.

2.2. Pilot case studies

The idea behind the selection of the pilot case studies was to develop a toolbox that can be widely used. To this end, the case studies had to represent the variety of climate, culture, social characteristics and administrative structures that can be found in the Mediterranean area. Hence, the PrioritEE toolbox was developed and tested to meet the requirements of each case study. Based on this, the project’s activities focused on five local pilots in the Mediterranean area that were characterized (Table 2) in terms of:

- *main policies and plans* at national, regional and local level affecting the adoption of EE and RES measures in existing and new public buildings;
- *main data sources, models, databases and reports* developed or used by local administrations and which contain useful information to further characterize the MPB and lay the foundations for the development of the toolbox;
- *current use of analytical tools* to support energy management and decision-making at the municipal level.

As shown in Table 2, the five pilot case studies are characterized by seven different climates (Cfa, Cfb, Csa, Csb, Dfb, Dsb, Bsk) according to the Köppen climate classification [64], belonging to three main climate

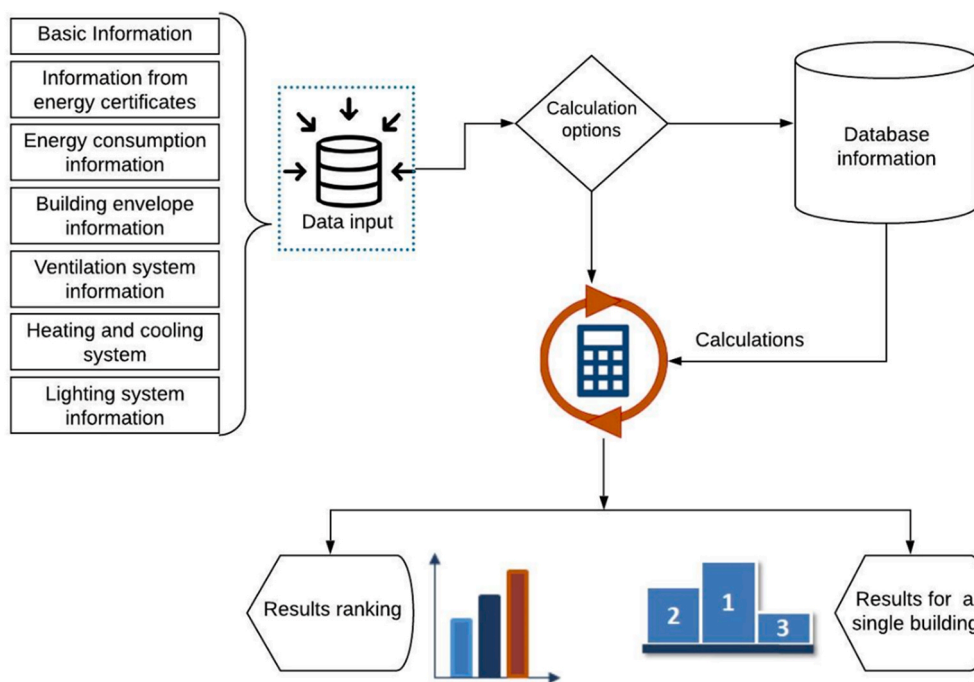


Fig. 3. Basic structure of the PrioritEE Decision Support Tool.

Table 2
Main characteristics of the five local pilots.

	Karlovac	Potenza	Teruel	Lezíria do Tejo	West Macedonia
Involved municipalities	City of Karlovac	Municipality of Potenza	Teruel Province	Almeirim, Alpiarça, Azambuja, Benavente, Cartaxo, Chamusca, Coruche, Golegã, Rio Maior, Salvaterra de Magos, Santarém	Municipal Region of Kozani, Municipal Region of Ptolemaida, Municipal Region of Amyntaion
Region (Country)	Karlovac (Croatia)	Basilicata (Italy)	Aragón (Spain)	Lezíria do Tejo (Portugal)	Western Macedonia (Greece)
Area	400 km ²	173 km ²	14,800 km ²	4275 km ²	9541 km ²
Number of inhabitants (year)	55,705 (2011)	67,211 (2016)	133,344 (2019)	247,453 (2011)	283,689 (2011)
Population density	140 (Inhabitants/km ²)	388 (Inhabitants/km ²)	9 (Inhabitants/km ²)	58 (Inhabitants/km ²)	30 (Inhabitants/km ²)
Climate (description and Köppen climate classification [64])	Moderate continental with hot summers and cold winters with snow (Cfa, Cfb)	Mountain Mediterranean climate, warm and dry in summer and cold and snowy in winter (Csb)	Transitional climate between continental and Mediterranean (Bsk, Csa, Cfb, Dfb, Dsb)	Warm and temperate climate, with more rainfall in the winter than summer (Csa, Csb)	Transitional climate between the continental and the Mediterranean one (Cfa, Csa, Csb, Dfb, Dsb)
Availability of expert staff in energy management	Yes	Yes	No	No	Yes
Responsible for the implementation of EE measures	Heads of technical departments	Heads of technical departments	Mayors of municipalities	Mayors of municipalities	Heads of technical departments
Pre-existing use of analytical tools	Informational System for Energy Management (ISGE) for monthly monitoring of energy consumption of MPBs	Internal software to monitor, on a monthly basis, electricity and gas consumption and carry out energy benchmarking analysis of MPBs	No energy performance assessment tool, although in Spain there are several official tools available to obtain the EPC	No energy performance assessment tool, two main studies available on the replacement of energy technologies in MPBs (solar thermal and PV in sports pavilions/schools, and LED lighting)	Use of the Greek nationally adopted software (TEE-KENAK) to calculate the energy performance of buildings

groups: dry (B), temperate (C) and continental (D). The population density is also very different across the case studies, varying from 9 inhabitants/km² of Teruel (with many municipalities with less than 150 inhabitants) to 401 inhabitants/km² of Karlovac.

The municipal public building stock is relatively similar in all case studies (schools, public offices, sports installations, cultural buildings) but the technologies employed vary. For instance, district heating is common in Karlovac and Western Macedonia but it does not exist in Lezíria do Tejo or Teruel. The administrative capabilities also vary

across the case studies: Karlovac, Potenza and Western Macedonia have technical departments in charge of the energy management of public buildings and the implementation of energy efficiency measures. On the other hand, Teruel and Lezíria do Tejo lack technical staff and the mayors of the municipalities (without sufficient technical knowledge) make decisions on the implementation of EE measures. A varied state-of-the-art among pilots in terms of local data sources and tools is also observed, with two local administrations monitoring monthly energy consumption of MPBs (Karlovac and Potenza) and one authority using a

tool to calculate the energy performance of buildings (West Macedonia).

This variation in technical knowledge within the relevant Public Administrations highlights that a key challenge in designing the PrioritEE toolbox is making it accessible to users with limited technical expertise.

Following the initial characterization of the pilots, a set of individual MPBs was evaluated using the PrioritEE toolbox. Therefore, each building was characterized in terms of area, number of staff, work/operational schedules, existing infrastructures for the production/use of thermal energy and electricity, as well as the main problems related to energy efficiency.

Specific objectives of the five pilots were initially elaborated during the first workshop (as described in Ref. [51]) and then refined during an iterative collaborative process throughout the entire project:

- *City of Karlovac (Croatia)*: development of an energy management software for the planning and execution of energy renovation of public buildings, creation of a detailed database on the energy characteristics of public buildings in the city of Karlovac.
- *Municipality of Potenza (Italy)*: improvement of the energy performances of public schools and offices also by promoting behavioural changes; identification and selection of key performance indicators for energy benchmarking; capacity building and technical support in the decision making process on EE and RES interventions.
- *Province of Teruel (Spain)*: reduction of the overall annual impact of energy on the budget; technical support to unqualified public authorities on EE decisions; increased ability to respond to calls for proposals for funding energy interventions through a set of technically justified measures that could be implemented; establishment of local plans and methods to prioritize EE investments in public buildings and encourage the adoption of EE good practices.
- *Intermunicipal Community of Lezíria do Tejo (Portugal)*: increase the knowledge of all MPB features, set up an energy consumption database, adopt a tool that allows a good understanding of the possible EE measures for each MPB, with expected cost, energy savings and investments.
- *Region of Western Macedonia (Greece)*: evaluation of energy intervention measures in MPBs, particularly in the selected pilot buildings; support for municipal energy policy, SEAP/SECAP development and long-term energy planning; adoption of the PrioritEE DST by the municipality during the process of energy interventions on the municipal public building stock; implementation of the developed DST and alignment with the SEAP/SECAP actions; prioritization of the EE measures in MPBs interventions.

From this starting point, key target groups in each of the local pilots were involved through several *capacity building and knowledge transfer activities*. These included, in particular, three rounds of *Local Living Labs* to engage target groups in the project's activities, foster energy awareness and implement selected good practices within the local communities. *Local Workshops* (WSs) were organized in each pilot to complement these activities, involving key stakeholders and providing knowledge transfer for the development of the toolbox and in the implementation of local plans and policies.

2.3. Local action plans

One of the main outputs of the PrioritEE project was the development of a methodology and supporting tools to assist Local Authorities in the writing of a Local Action Plan for the improvement of energy efficiency and the employment of renewable energy sources in municipal public buildings. This plan can serve as a basis for the development of a SECAP in compliance with the related guidelines on data compilation and reporting framework [65], as it specifically targets one of the key sectors: public buildings.

Common guidelines were provided within the project to help local

public authorities and energy planners to move from the application of the DST to the planning phase, based on the following steps:

1. Inventory of public buildings in the municipality and data gathering, in particular regarding the characteristics of the buildings, energy consumption and energy production from renewable energy technologies;
2. Analysis of the current public building stock;
3. Use of the PrioritEE DST to analyse potential energy efficiency measures and renewable energy technologies in public buildings of interest;
4. Prioritization of the key actions to be undertaken based on several key parameters;
5. Elaboration of a Local Action Plan to accelerate energy efficiency and renewable energy use in public buildings, based on the information above.

To classify the implementation timeframe of each selected intervention, a ten-year period was considered, divided into three periods: immediate (1–2 year), intermediate (3–5 year), and long-term (6–10 year).

An overview of the main features of the 5 pilots and some sample results focusing on different aspects of the application of the proposed DST as part of the Local Action Plan are described in the following sections. More detailed information is provided in the project deliverables [66–70].

3. Results

The various results of the project involved an active and lasting commitment from stakeholders and target groups both at municipal and provincial/regional level. An increase in the “soft” and technical capacities of the partnership and local level actors was also necessary.

These activities were principally driven by the demand for user-friendly decision-support tools, which can be widely used by professionals with different levels of technical knowledge. The PrioritEE toolbox and, in particular the Decision Support Tool, as described in the following sections, were co-designed and developed, they were then transferred locally and made available to a wider audience through the project website [60].

3.1. Awareness raising activities

The Living Lab [71] methodology is commonly used to develop, test and evaluate innovative solutions in a real-environment, helping to support social and technological innovation, as well as promoting new governance schemes. Living Labs are said to increase the capacity and willingness of both public authorities and citizens to implement policy measures. Living Labs also allow for transparent and objective assessment of alternative solutions.

Based on this methodology, *Local Living Labs (LLs)* were set up in each of the five pilots, to promote energy awareness initiatives and more conscious behaviours. Each pilot defined specific local energy actions to improve energy use and capacity building, targeting different building typologies and identifying key stakeholders (Table 3).

Various activities were performed throughout three rounds of LLLs in the five pilots. For example in the Municipality of Potenza (Italy) the Schools4energy Living Lab [72] was created with the aim of achieving, measuring and rewarding energy savings in schools by promoting energy awareness and changing behaviour.

In addition to the Local Living Labs, two *Case Study Exchange Visits* were organized for partners and local administrators to facilitate knowledge exchange. These Labs resulted in an overall enrichment in terms of information acquisition, shared experience, and commitments for new approaches. The sites visited included buildings characterized by innovative technical solutions on energy efficiency and RES

Table 3
Summary of the LLL activities in the pilots (based on [72]).

Target Area	Title and Aim	Stakeholders
Potenza Municipality (IT)	Schools4energy: experiential activities for awareness-raising and energy saving in schools	- Mayor and Municipal Staff - Headmasters, Teachers & Students - Environmental organizations
Region of Western Macedonia (EL)	Success Stories and Good Practices on energy efficiency: implementation in the municipally-owned Public Buildings.	- National and Local Stakeholders - Representatives of the technical departments of the municipalities
City of Karlovac (HR)	Success Stories and Good Practices on energy efficiency: implementation of selected good practices and awareness-raising measures within the community.	- Mayors - Municipal Staff - Other public stakeholders - Civil society
Teruel Province (ES)	Success Stories adapted to rural areas: implementation of customized solutions to improve EE in Municipal Public Buildings.	- Mayors/local authorities - Municipal Staff - Energy managers
Leziria do Tejo Intermunicipal Community (PT)	Training on the implementation of good practices and awareness-raising measures: hands-on session on the energy management software recently installed on 46 MPBs and implementation of selected good practices for promoting behavioural changes in the target communities.	- Mayors - Energy managers - Municipal Staff

utilization and/or exemplary activities to encourage behaviour change for saving energy.

3.2. Capacity building activities

Selected target groups were involved in the development of the PrioritEE toolbox from the beginning of the project through *Local Workshops (WSs)*. These workshops aimed to effectively transfer the knowledge gained through the project to the local authorities engaged. Three technical workshops were organized in each of the pilots, and thus 15 workshops took place throughout the project. The first round of workshops (WS1 - *requirements*) was organized to establish the status quo in each of the five pilots and to collect requirements from local authorities on EE, a necessary step to design the PrioritEE toolbox [51]. The second round of workshops (WS2 - *training*) was aimed at training public authorities to use the decision support tool developed within the project in response to the requirements specified at the previous events. During the third set of events (WS3 - *transferring*) public authorities tested the toolbox and were trained to develop a local plan for improving EE in public buildings, providing feedback on these activities. Approximately 256 municipal technicians attended these sessions and gained enhanced competencies in the energy field.

In parallel to the above, training materials were developed to provide step by step guidance on how to apply the PrioritEE toolbox. These materials were used as part of Workshop 2 to communicate to the public authorities the need to be quantitative for a rigorous assessment of EE measures. The results of the workshops showed that this is possible with proper training and adequate tools. Public Authorities found the availability of a user-friendly tool to perform energy efficiency calculations very useful.

3.3. Implementation of the decision support tool

This section aims to show how the DST has been usefully applied to the different building stocks in the five pilots, despite their variable contexts and features. Results were obtained for energy and emissions savings as well as for investment needs. Given the aforementioned variation in building stocks these results are presented individually for each pilot, in each case focusing on the most relevant aspects and employing the most suitable data visualisations. This approach demonstrated the adaptability of the DST in terms of data analysis according to the specific needs of the end-user.

The Decision Support Tool (DST) was implemented in 229 municipal public buildings (MPBs) across the five pilots. In total, 344 EE and RES measures were identified within all the MPBs, the associated costs and energy savings were estimated in each case. Each pilot developed a local action plan, identifying the EE and RES measures, an implementation timeline and the necessary associated financial and human resources were also provided. These plans identified the largest consumers among MPBs in each pilot, as well as the most suitable investments for energy savings and cost reduction in the MPBs.

The main identified measures included: floor, wall and/or roof renovation; window replacement; implementation of LED lighting; replacement/integration of cooling systems; replacement of heating systems; and integration of PV panels and solar thermal collectors. As shown in Table 4, overall, the proposed measures throughout the five pilots accounted for 8.03 GWh/year potential energy savings due to EE interventions (as obtained from the DST application across all pilots), and a potential reduction of circa 2.42 kton/year in CO₂ emissions (if all the EE and RES measures are implemented). An increase of circa 936 MWh/year in RES generation (mainly PV panels) was also estimated. The total implementation cost of these measures was estimated at 12.96 million euros. Table 4 shows a summary of the main results from the Local Action Plans developed for the five pilots.

In the following sub-sections, the different types of assessments and results available in the DST are shown, along with more detailed results of the implementation of the DST in the different pilots.

3.3.1. Teruel Province (Spain) – comparing energy efficiency options for municipal public buildings

Teruel has a wide diversity of MPBs and each of them usually has several uses, with occupancy rates and energy use being fairly inconsistent both throughout the day and throughout the year. Overall, 59 MPBs were analysed, with a total of 1388 users, of which 28% are Council/Doctors' offices, 26% Schools, 22% Multiservice buildings, 14% Sports centres and the remaining 10% Residential centres. Although the age of the buildings in the sample varies, the majority are over 30 years old. The Energy Performance Certificates of the MPBs showed that over 34% of the buildings are energy class "F", and 32% are energy class "G" for heating demand, highlighting the opportunity to increase the energy efficiency of the buildings in the pilot.

Fig. 4 shows a comparison of the current thermal energy and electricity consumption of five types of MPBs in a municipality in the Teruel Province, obtained by applying the PrioritEE DST. This information was not previously available to the municipalities, and the DST simplified the generation of these figures for MPB comparison.

By applying the DST to each building, several EE interventions were proposed. As an example, Fig. 5 shows five EE interventions for the city hall/offices of a municipality of Teruel Province, as obtained from the DST. The figure shows that the EE measure that results in the greatest energy savings (lightbulb replacement) does not necessarily lead to the greatest CO₂ emissions savings or monetary savings. In this case, the EE intervention with the shortest return of investment (ROI) is the replacement of space heating systems, as the current system is a conventional boiler firing light fuel oil. Its replacement by a biomass (pellet-fired) boiler would lead not only to considerable CO₂ emissions savings (Fig. 5 top-right), as pellets have negligible CO₂ emissions (in the case of

Table 4
Summary of results of the Local Action Plans based on the application of the DST in the five pilots.

	Karlovac Municipality	Potenza Municipality	Teruel Province	Intermunicipal Community of Lezfría do Tejo	Region of Western Macedonia	Total
N° buildings	36	25	59	97	12	229
N° measures identified	66	67	66	97	48	344
Energy Savings (MWh/yr)	1770	2050	1331	1600	1280	8031
CO ₂ e emission reduction (t CO ₂ e/yr)	465	644	245	620	447	2421
Increase in RES (MWh/yr)	350	486	0	100	0	936
Investment costs (million euros)	4.4	1.73	1.17	3.27	2.39	12.96

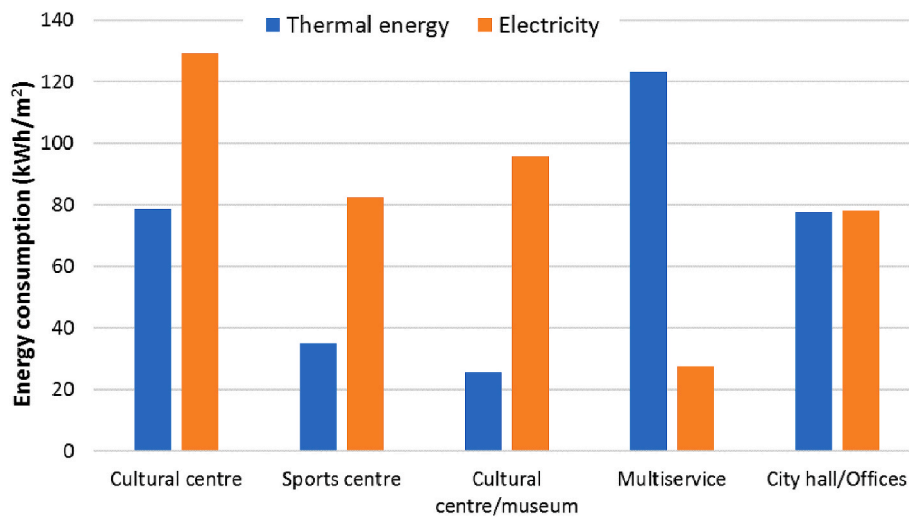


Fig. 4. Thermal energy and electricity consumption (kWh/m²-year) for five different MPBs of a municipality of Teruel Province, direct output from the DST.

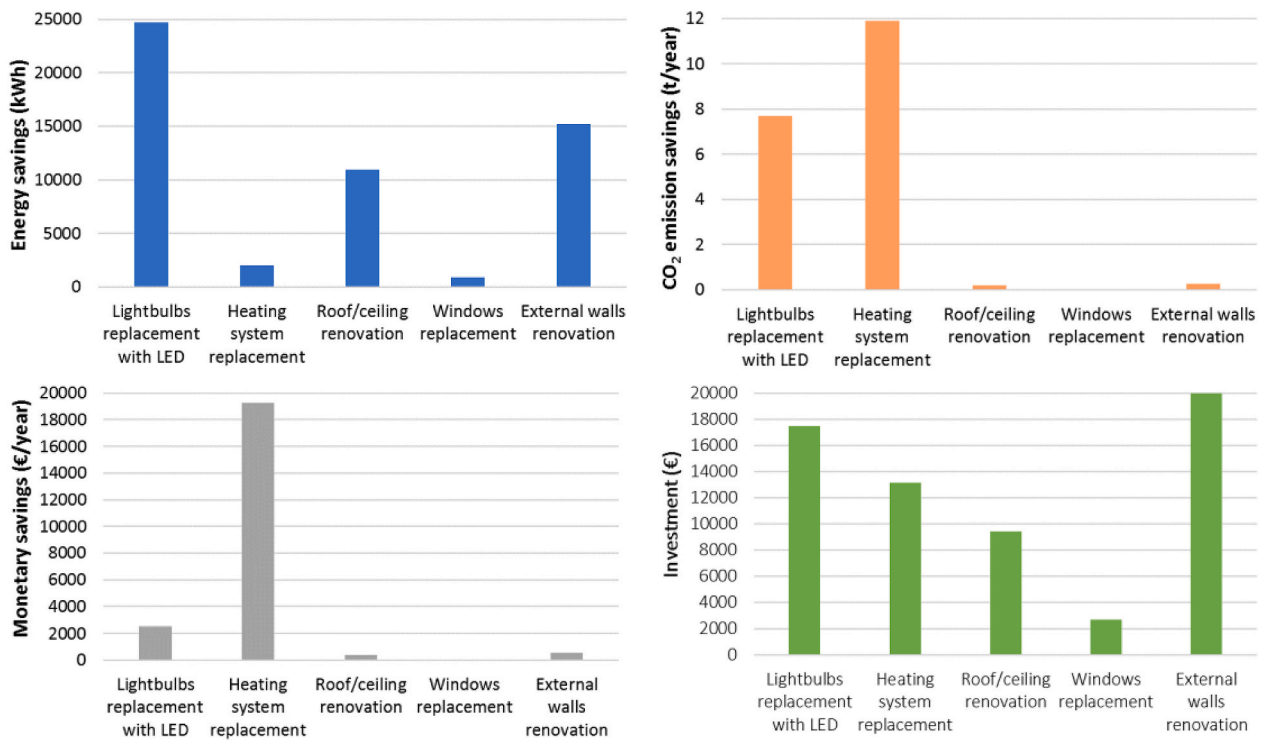


Fig. 5. (Above-left) potential energy savings (kWh/year); (above-right) potential CO₂ emission savings (tons CO₂/year); (below-left) potential monetary savings (€/year); (below-right) estimated investment (€) of the proposed EE interventions for the city hall/offices of a municipality of Teruel Province. This data is a direct output of the DST.

Spain its conversion factor is 0.018 kg CO₂/kWh, compared to the 0.331 kg CO₂/kWh of light fuel oil [73]), but also to significant economic savings (Fig. 5 bottom-left), as pellets are a much more economical fuel than oil. Average values from the literature were used to calculate the investment costs for technology replacements.

The selection of the most suitable interventions to be implemented through the PrioritEE Local Action Plan was based on the following criteria: Return of Investment (ROI), investment, energy savings and associated CO₂ emissions savings. The cost savings achieved with the short-term (1–2 year) interventions are designed to contribute to the payment of the medium-term (3–5 year) interventions, as these interventions can have slightly higher investment costs and longer ROIs. Finally, the most expensive interventions were staged for the long-term (6–10 year), so that the savings from previous interventions can pay for the implementation of the more expensive ones.

3.3.2. Municipality of Potenza (Italy) – assessing CO₂ savings

In Potenza, the DST implementation was focused on energy benchmarking for 21 buildings belonging to two main typologies, office buildings and schools: the 4 buildings hosting the city hall, offices and services as well as the 7 Lower Secondary Schools (LSS). In total, these selected MPBs are used by approximately 5724 users. These building had different construction ages, previously identified varied refurbishment interventions, and different heating systems.

Figs. 6 and 7 show the CO₂ emissions reduction that can be achieved, respectively, in the analysed municipal offices and schools by different combinations of technical interventions (i.e. replacement of current lighting systems and windows, improvement of the insulation of walls or roofs). The purple bar represents the combination of all measures and represents the best-case scenario in which the maximum benefits are achieved both in terms of energy saving and CO₂ emissions reduction. This simple comparison among bars of different colours for different buildings allows decision-makers to easily determine which buildings and municipalities will benefit the most from the proposed interventions. Relevant examples include the Mobility Centre (Fig. 6) and the Savio Lower Secondary School (Fig. 7).

The involvement of City officials and employees in the project's activities contributed to an in-depth energy characterization of the overall

MPB stock. Specifically, this input contributed to the identification of optimal investments for MPBs in terms of energy saving and cost; as well as increasing capacity building in the energy sector. Finally, this also resulted in the diffusion of energy saving practices from schools to households. Four of these schools were voluntarily involved in the Schools4energy Living Lab (as described in Section 3.1) with the aim of quantifying the effects of behavioural changes on energy consumption, thus fostering an energy awareness culture.

In the Local Action Plan, the most suitable interventions were selected by prioritizing the investment-to-energy-savings ratio, accounting for CO₂ emissions saved. This analysis focused on buildings and interventions which demonstrated consistent energy savings, investment and ROI values, in order to evaluate the long term effectiveness of the energy efficiency actions. The list of measures chosen for improving the selected MPBs was grouped into 3 actions in a 3-year action plan. More details on the Potenza case study can be found in Ref. [74].

3.3.3. Region of western Macedonia (Greece) – prioritization of interventions

In the region of Western Macedonia, 12 MPBs were analysed: 8 educational buildings (3759 users), 1 sports facility (150 users), 2 office buildings (360 users) and 1 cultural building (300 users). The selected 12 MPBs represented 22% of the electricity consumption and 24% of heat consumption in all the MPBs of the Kozani Municipality (values referring to 2016). It should be noted that none of these MPBs has obtained an energy performance certificate to date.

Based on the EE and RES a number of possible interventions were provided by the DST (not shown here for the sake of brevity), a range of criteria were selected to prioritize the most suitable interventions for implementation in the Local Action Plan. In this pilot, the following criteria were followed: 1) reduction of CO₂ emissions, 2) energy savings and 3) increase in renewable energy generation.

In this pilot, most buildings are connected to central district heating, therefore renewal of the heating system is not necessary. The selected MPBs were built in the 1980s and have a low level of thermal insulation, thus thermal insulation is the most important measure, including improving the envelope and the renovation of windows and doors.

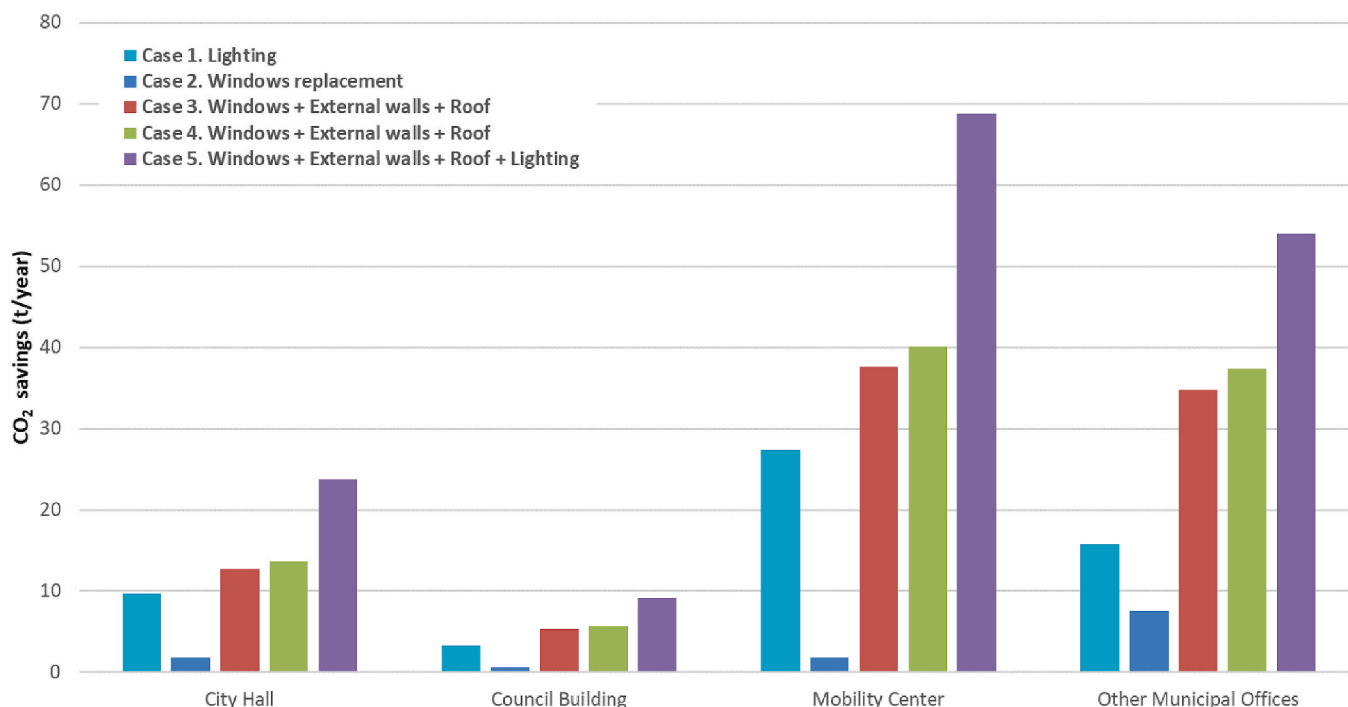


Fig. 6. CO₂ savings for four administrative municipal buildings in Potenza per type of intervention, direct output of the DST.

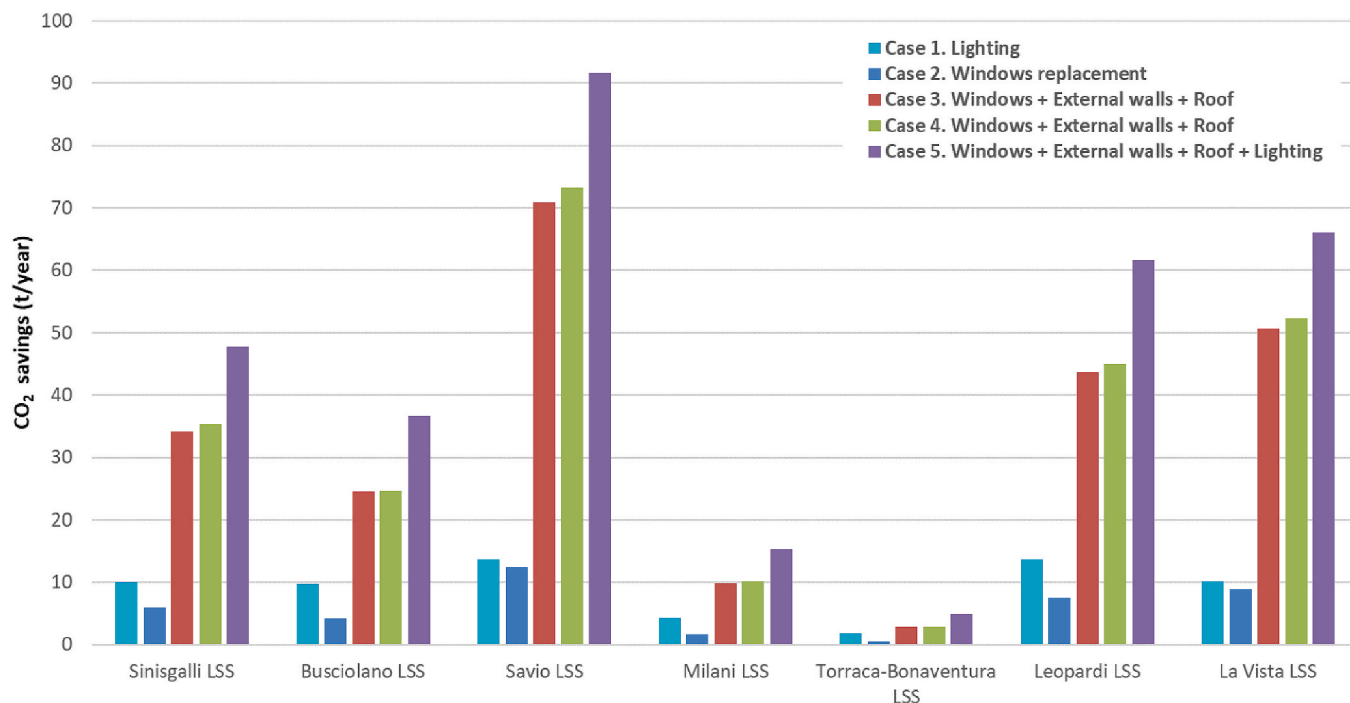


Fig. 7. CO₂ savings for seven schools in Potenza per type of intervention, direct output of the DST.

Another important intervention is the replacement of the lighting system (Table 5).

An implementation timeframe was defined in the Local Action Plan for each selected intervention following the approach described in Section 2.3 (Table 5). The immediate timeframe means that the intervention is considered a higher priority for the Municipality. The energy and the corresponding economic savings achieved through the implementation of these interventions would be used for the implementation of the measures in the intermediate timeframe, and likewise for the longer-term interventions.

3.3.4. Intermunicipal Community of Lezíria do Tejo (Portugal) – visualizing a ranking of energy efficiency options for a large municipal public building stock

In the case of CIMLT, consisting of 11 municipalities, assessing the large MPB stock as a whole was important in order to facilitate comparisons between the different interventions recommended for the different typologies. In particular, the stock in question included 88 MPBs, comprising 20 schools (4410 users), 16 sports facilities (2113 users), 11 swimming pools (3405 users) and 41 other buildings (2032 users). The selected 88 MPBs represent 2.85% of electricity consumption in the tertiary sector in the pilot (in 2017), 13 of these MPBs have an energy certificate (23% in class C, 38% in class E).

By applying the DST (Fig. 8), it was possible to assess the greatest saving potential for heating, electricity and total energy savings for each building type, and for alternative interventions. In Fig. 8, energy savings for each type of intervention (e.g. walls, ventilation, heating, PV panels) are represented in the central columns and savings values are coloured from green to red, where green represents higher savings and red lower savings for the entire MPB stock. Total energy savings are represented in the column on the right-side and the ranking is defined based on percentage savings with respect to the total annual consumption. Finally, the ROI is provided for each MPB.

For this pilot, the greatest total energy savings in absolute terms are obtained in swimming pools by replacing heating systems with more efficient ones and by installing solar PV systems. This is followed by improvements in office buildings, particularly in city halls via the installation of solar PV and improved insulation of walls. In terms of the

percentage of total annual energy consumption, the highest savings are obtained in some specific schools and offices (savings around 40–50%). In terms of ROI (here represented in years and not considering subsidies or taxes), a large variety of values from 17 years to more than 100 years, in one case, can be observed.

This DST allows public authorities in the CIMLT region to analyse the effects of a different set of measures (for example removing PV panels), and to view how these measures can affect the ranking. This process allowed a better knowledge of the energy consumption in CIMLT municipal public buildings.

3.3.5. Municipality of Karlovac (Croatia) – implementing RES in public buildings

In the municipality of Karlovac, there are 61 buildings owned or managed by the City, which include administrative, educational, cultural and sports buildings. 38 of these buildings are public institutions and have an energy performance certificate. In total, 7736 users visit these buildings.

The Decision Support Tool was tested on 36 buildings and results were used to determine which buildings will be considered for energy renovation projects, undertaken mainly through various financial funds (private, regional, EU).

As previously discussed, the DST also provides interventions that involve the implementation of renewable energy technologies in buildings. Fig. 9 shows a summary of the RES interventions proposed by the DST for the public buildings in the municipality of Karlovac. Three types of measures were taken into account: integration of photovoltaics (PV), integration of solar thermal collectors, and replacement of the heating system by a biomass boiler. For each of the proposed interventions, Fig. 9 shows the results of the DST application in terms of avoided CO₂ emissions (green column, on the left axis), renewable energy generation (light-blue column, on the left axis), Return of Investment (ROI, red column, on the left axis), and investment costs (dots, on the right axis). Proposed measures regarding solar hot water and PV are calculated based on the available roof area, estimating the heat and electricity that can be produced, using simplified analytical models. The corresponding investment costs are calculated based on average prices (€/m² or €/kW) sourced from a set of real projects.

Table 5
Implementation timeframe (including estimated start and end date).

Interventions	Implementation timeframe		
	Immediate (1–2 years)	Intermediate (3–5 years)	Longer-term (6–10 years)
Lightbulbs replacement with LED - Educational Buildings	✓ (2021–2023)		
External Wall Renovation – Educational Buildings		✓ (2021–2026)	
Window Replacement – Educational Buildings		✓ (2021–2026)	
Floor & Roof/Ceiling Renovation – Educational Buildings			✓ (2021–2028)
Lightbulbs replacement with LED – Sports Facilities	✓ (2021–2023)		
Windows Replacement – Sports Facilities	✓ (2021–2023)		
External Walls Renovation – Sports Facilities		✓ (2021–2026)	
Floor & Roof/Ceiling Renovation – Sports Facilities		✓ (2021–2026)	
Lightbulbs replacement with LED – Office Buildings	✓ (2021–2023)		
Cooling System Renovation – Office Buildings	✓ (2021–2023)		
Windows Replacement – Office Buildings		✓ (2021–2026)	
External Walls Renovation – Office Buildings		✓ (2021–2026)	
Floor & Roof/Ceiling Renovation – Office Buildings			✓ (2021–2028)
Lightbulbs replacement with LED – Cultural Buildings	✓ (2021–2023)		
Floor & Roof/Ceiling renovation – Cultural Buildings		✓ (2021–2026)	
External Wall Renovation – Cultural Buildings		✓ (2021–2026)	
Window Replacement – Cultural Buildings		✓ (2021–2026)	

Fig. 9 shows that the replacement of the heating system involves the least investment, while the ROI is similar or even higher than the integration of solar thermal collectors in some primary schools. The highest investments involve the installation of PV systems, especially in some primary schools.

These results demonstrate the value of the DST as a means of visualizing key indicators and representing the consequences of the different technical choices. The DST also helps to identify priorities in the implementation of different EE and RES measures based on the decision criteria defined by the local public authorities.

4. Discussion and further steps

Despite the significant number of tools and information sources which tackle energy planning and energy efficiency, a specific need remains for guidance in the definition and implementation of energy strategies for municipal public buildings. This is particularly relevant given that decision support tools developed by researchers and academics are not commonly used by public authorities, especially at a local level [51], [75]. Successful identification of the most suitable tool within this significant pool of information can be overwhelming for local policymakers. Overcoming this reluctance regarding the use of analytical tools which assess alternative local development pathways, is essential for supporting local authorities in the strategic steps of the planning cycle [76,77]. Furthermore, the proposed solutions need to be adapted

to the various regional contexts accounting for different implementing conditions such as: climate, urbanization degree, types of building construction, different usage (i.e. swimming pools, health centres, sports centres, schools, office buildings), energy services (e.g. space heating and cooling, water heating, lighting, other electric equipment), as well as different consumption profiles (number of users and type of users). The general underuse of analytical tools and indicators to design and implement local EE policy is attested by the local public authorities involved in this research.

Public administration of EE and RES measures in the Mediterranean area is characterized by a wide variety of administrative requirements, sometimes presenting a barrier to the implementation of these measures. These administrative processes presented the most significant challenge in the development of the PrioritEE toolbox. The involvement of local stakeholders in the development of the toolbox and the following tests in five real, very different case studies (in terms of size, number of inhabitants, climate, type of buildings, energy consumption patterns, administrative structures and technical capabilities of public staff) has rendered the toolbox widely applicable and transferable, especially in the Mediterranean area.

The toolbox received very positive feedback from more than 100 users involved in the final local workshop activities. The workshop was held in each in each pilot and included a project survey which identified several difficulties, strengths, weak points, lessons learned and implications for policy-making.

4.1. Strengths, weaknesses and general problems

The results of this survey showed that the main challenge which occurred during the implementation of the pilot was overcoming initial resistance and bias from municipal technicians with regard to the use of the Decision Support Tool (DST). Very different levels of skills and competencies were found within the local authorities involved: while some of them are very experienced, others lack staff with in-depth knowledge of energy efficiency problems. It was, therefore, necessary to develop flexible approaches suitable for users of all skill levels. The collection of data for the characterization of energy consumption and MPB features presented a further difficulty, as the data is usually scattered among the different offices of the same municipality with poor cross departmental communication. A further complexity entailed including different energy technologies and practices normally applied across the five different pilots (e.g. cooling or district heating are not common in some countries) which required substantial efforts in the translation and validation of the developed tools.

On the other hand, several strengths of the PrioritEE Toolbox were identified by the survey. It is relatively easy to use and provides useful information to make informed and cost-effective choices. The DST is the core of PrioritEE toolbox and represents a useful tool for screening analyses based on indicative results. In particular, the possibility of defining priorities for energy efficiency interventions using only basic data and taking advantage of average national data was considered a strength of the DST. It was considered particularly valuable for driving investments in energy efficiency, for supporting local action plans, and for demonstrating the benefits of single and/or combined interventions. The tool was also valuable for comparing multiple interventions in terms of energy efficiency and cost-benefits for various combinations of technologies. Its further value is demonstrated in its ability to perform benchmarking both for types of measures and for specific buildings. The tool also provides a common and transparent repository of technical data on public buildings and a transnational energy baseline. Finally, it is used to monitor the effects of the intervention on the MPBs introducing ex-post data. A critical review of the results identified some weaknesses to be taken into consideration for further improvements in the whole toolbox and project follow-up, such as the introduction of searching features both in the Good Practices Repository and the Energy Technologies and Building Retrofit Database.

Building Name	Building Typology	Heat energy savings (kWh)	% saved heat	Position in heat savings ranking	Electricity energy savings (kWh)	% saved electricity	Position in electricity savings ranking	Total energy savings (kWh)	% saved energy	Position in ranking	ROI (year)
Centro Escolar dos Charcos, Almeirim	Schools	8,603	63%	18	19,339	16%	11	27,942	21%	16	17.6
Centro Escolar das Fazendas, Almeirim	Schools	7,336	73%	9	24,690	54%	1	32,026	58%	2	24.4
Pavilhão ABC, Almeirim	Sports buildings	4,987	52%	20	29,596	45%	3	34,583	46%	3	11.5
Cineteatro, Almeirim	Culture buildings	2,500	70%	16	366	1%	20	2,865	7%	20	25.5
Centro Cultural das Fazendas, Almeirim	Culture buildings	6,559	73%	11	8,643	34%	4	15,203	44%	4	29.5
Piscinas Municipais, Almeirim	Swimming pool	8,797	54%	19	16,262	8%	15	25,059	12%	18	13.3
Paços de Concelho, Almeirim	Offices	11,774	72%	12	23,202	13%	13	34,976	17%	17	12.3
Biblioteca Municipal, Almeirim	Offices	8,721	74%	8	1,008	1%	19	9,729	9%	19	28.1
Benavente	Sports buildings	8,860	64%	17	11,454	25%	7	20,314	34%	10	24.1
Pavilhão INATEL, Cartaxo	Sports buildings	2,594	71%	13	4,283	53%	2	6,877	59%	1	49.9
Centro Escolar de Alcanede, Santarém	Schools	22,702	75%	6	17,989	27%	6	40,691	42%	6	20.3
Piscinas Municipais, Alpiarça	Swimming pool	186	41%	21	4,281	4%	16	4,468	4%	21	12.8
Biblioteca Municipal, Azambuja	Offices	24,333	73%	10	218	0%	21	24,551	23%	15	17.7
Biblioteca de Alcoentre, Azambuja	Offices	4,500	74%	7	289	2%	17	4,789	24%	14	17.5
EB1 Aveiras de Cima, Azambuja	Schools	10,780	70%	15	5,715	17%	10	16,495	33%	11	23.5
Prim./Pré-pri. Foros Charneca, Benavente	Schools	4,112	75%	5	1,396	12%	14	5,507	31%	12	24.6
Cent. Cult. Samora Correia, Benavente	Culture buildings	14,538	81%	2	5,606	14%	12	20,144	35%	9	25.6
Palácio do Infanteado, Benavente	Culture buildings	25,019	79%	3	985	1%	18	26,004	25%	13	19.8
Centro Cultural de Benavente, Benavente	Culture buildings	7,466	82%	1	5,148	25%	8	12,614	43%	5	28.4
Biblioteca de Salvaterra	Offices	18,567	71%	14	15,852	27%	5	34,420	41%	7	9.6
Secção Adm. Samora Correia, Benavente	Offices	3,154	76%	4	2,199	24%	9	5,354	40%	8	32.4

Fig. 8. Another example of a direct output from the DST - a visualization of excel table with the full ranking for some of the CIMLT MPBs regarding heat, electricity, total energy savings and ROI in years. For each type of estimated energy savings, a ranking is shown per each building coloured from green to red, where green represents higher savings (and red lower savings) as a percentage of annual consumption before the intervention. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.2. Lessons learned and policy implications

Several lessons and recommendations can be derived from this experience. First, investments in energy efficiency should not be considered by Public Authorities as a debt for local public institutions. They are often reluctant to increase the debt of their institutions; even though the return of investment (ROI) is reasonable as shown in this work. The implementation of the DST in 229 municipal public buildings (MPBs) across the 5 pilots has made it possible to identify a total number of 344 measures of energy efficiency and renewable technologies which would lead to 8.03 GWh/year of potential energy savings, an increase of 936 MWh/year in RES generation, and 2.42 kton/year of avoided CO₂ emissions with an estimated cost of 12.96 million euros.

Second, in smaller and rural municipalities there is a substantial lack of human resources and know-how in energy efficiency: often a single staff member must deal with all environmental and energy-related issues and this leaves little room for strategic planning or, in the case of the application of the PrioritEE Decision Support Tool, for compiling and analysing the data available for the entire stock of municipal public buildings. Therefore, information and recommendations on the energy certificates are often not used. It would be useful to implement a policy and/or programme that brings together local and central/regional authorities to share information and develop capacities.

Third, the actions of local authorities to promote energy efficiency primarily respond to existing funding and the preparation of funding applications is highly bureaucratic and time-consuming. It would be highly beneficial to simplify these processes to ensure a wider involvement of small municipalities.

Fourth, with specific reference to Mediterranean countries, it is believed that language barriers are still very significant, thus all activities (and the material) need to be available in national languages for effective communication. Moreover, in considering the promotion of energy efficiency in public buildings, it is necessary to consider the fact that in some countries (e.g. Portugal) municipal public buildings have extremely low thermal comfort, i.e. they are not heated or cooled enough due to their poor conditions, cultural context and lack of funding. Therefore, the promotion of energy efficiency in public buildings (in

particular, in schools) can lead to the implementation of passive measures, which are highly desirable but might not lead to energy savings. These measures will improve the comfort of building's occupants, but they are not likely to lead to significant energy savings if there has been no effective heating/cooling of the building from the beginning.

In terms of policy implications, this experience has shown that capacity building is an effective means of increasing energy efficiency and should be strengthened among professionals and staff from local and regional public authorities in the Mediterranean region. To this end, selected knowledge transfer activities and communication channels should be promoted, in particular, to take into account the specific problems of smaller and rural areas (i.e., elderly population, limited education, poor knowledge of English). In this regard, participatory approaches such as the Living Labs are a very effective means of promoting the active involvement of users by increasing their motivation and promoting a lasting change in habits that leads to energy savings.

5. Conclusions

A decision-making process capable of systematically supporting the management of the entire public building stock involves a series of complexities. This is mainly due to the complexity of the individual components of local energy systems, how these systems interact with one another and to a general lack of detailed data. Additionally, the decision-making process is often multilevel and poorly co-ordinated. Furthermore, energy savings and emissions reduction targets can be achieved at lower costs if behavioural changes occur, proving that "soft measures" are an essential lever for the implementation of "hard" technological measures.

Considering these needs and the challenges involved in improving energy management of MPBs, the PrioritEE toolbox was co-developed, tested and subsequently finalized based on concrete experiences in five pilots in the partner regions, focusing on a diversified portfolio of local priorities and covering several key energy issues. Local decision-makers were provided with adequate (and simple) tools capable of providing a benchmarking scenario. These tools assessed the effectiveness of policies and measures and facilitated the careful planning of local

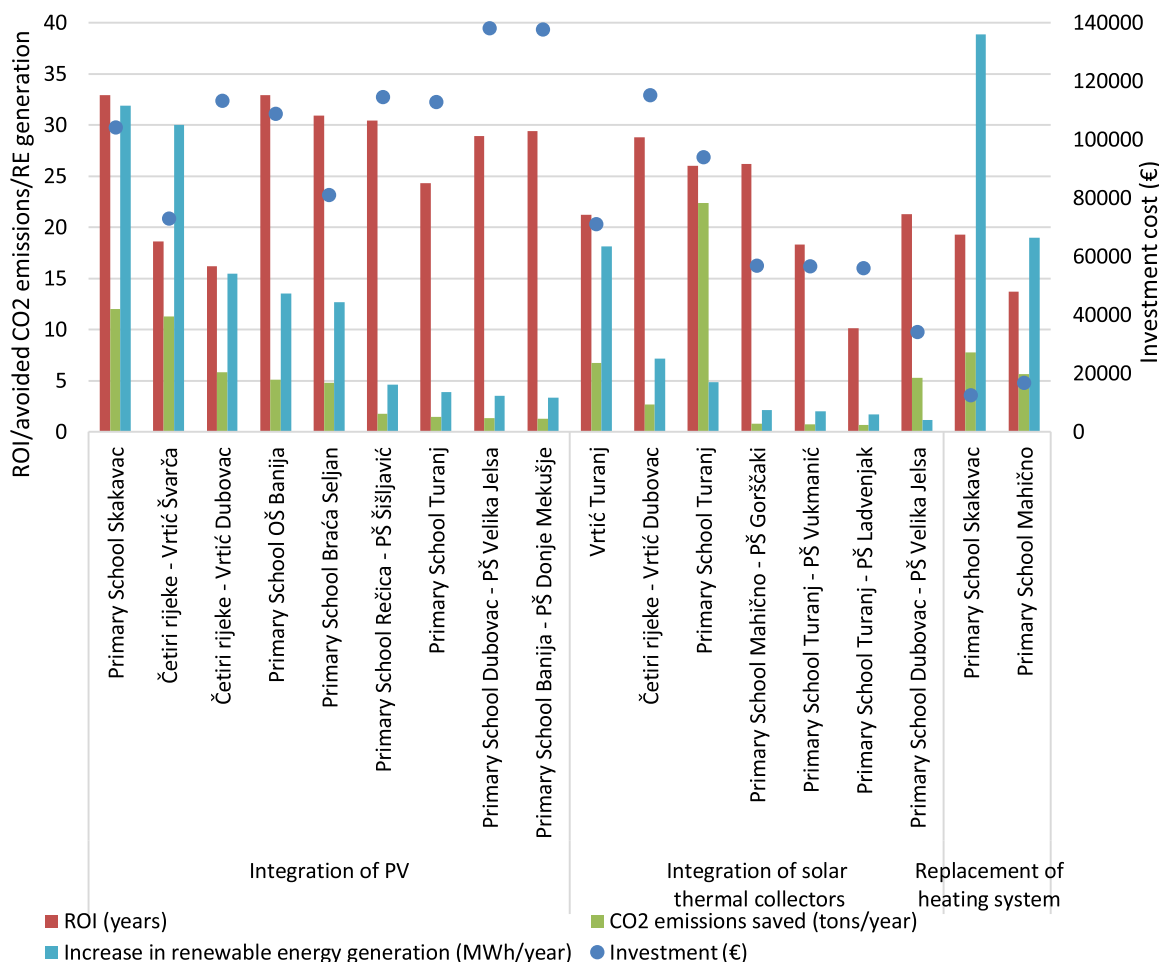


Fig. 9. Results of the implementation of renewable energies in the public buildings of the municipality of Karlovac in terms of Return of Investment (ROI), avoided CO₂ emissions, renewable energy generation, and investment costs.

investments by comparing different alternatives while accounting for key performance indicators. These tools were also very important for supporting capacity building for non-energy experts working in the technical departments of local authorities, who often need to outsource technical work for EE decision-support. The results provided the basis for the development of local action plans in the partner regions. These plans are a valuable resource to support/improve/update/monitor current and future SEAPs/SECAPs and retain a specific focus on the municipal public building stock, energy efficiency and integration of renewable energy sources.

This paper also proves how cooperation projects between academics, researchers, local agencies and public authorities can help to tackle common local challenges and needs. These groups can learn from each other and can also develop a shared language. Capitalizing on this experience, and more particularly continuing to improve and disseminate the developed toolbox, is currently one of the priorities for the project partners and is a small step towards more climate-resilient cities.

Credit author statement

Monica Salvia: Supervision, Conceptualization, Writing - original draft (Methodology, Results, Discussion, Conclusions), Writing - review & editing, Sofia G. Simoes: Conceptualization, Investigation and Visualization, Data collection and curation, Writing - original draft (Methodology, Discussion, Conclusions), Writing - review & editing, María Herrando: Conceptualization, Investigation and Visualization, Data collection and curation, Writing - original draft (Introduction, Results,

Discussion), Writing - review & editing, Marko Čavar: Investigation and Visualization, Data collection and curation, Writing - original draft (Methodology, Results), Writing - review & editing, Carmelina Cosmi: Conceptualization, Writing - original draft (Introduction), Filomena Pietrapertosa: Investigation and Visualization, Data collection and curation, Writing - original draft (Introduction), João Pedro Gouveia: Investigation and Visualization, Data collection and curation, Writing - original draft (Methodology, Results), Norberto Fueyo: Conceptualization, Writing - original draft (Discussion, Conclusions), Writing - review & editing, Antonio Gómez: Investigation and Visualization, Data collection and curation, Writing - original draft (Methodology), Kiki Papadopoulou: Investigation and Visualization, Data collection and curation, Writing - original draft (Results), Elena Taxeri: Investigation and Visualization, Data collection and curation, Writing - original draft (Results), Karlo Rajić: Investigation and Visualization, Data collection and curation, Senatro Di Leo: Investigation and Visualization, Data collection and curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- European Commission. EeB Factsheet. The Energy-efficient Buildings PPP: research for low energy consumption buildings in the EU. 2013. https://ec.europa.eu/research/press/2013/pdf/ppp/eeb_factsheet.pdf. [Accessed 15 April 2019].
- European Commission. Energy efficient buildings. 2019. <https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings>. [Accessed 15 April 2019].
- Lu M, Lai J. Review on carbon emissions of commercial buildings. *Renew Sustain Energy Rev* 2020;119:109545.
- Rosenzweig C, Solecki W, Romero-Lankao P, Mehrotra S, Dhakal S, Bowman T, et al. Climate change and cities: second assessment report of the urban climate change research network. 2018.
- United Nations Development Programme - Undp. Goal 11: sustainable cities and communities. 2020. <https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-11-sustainable-cities-and-communities.html>. [Accessed 13 March 2020].
- Reckien D, Salvia M, Heidrich O, Church JM, Pietrapertosa F, De Gregorio-Hurtado S, et al. How are cities planning to respond to climate change? Assessment of local climate plans from 885 cities in the EU-28. *J Clean Prod* 2018;191:207–19.
- Reckien D, Flacke J, Dawson RJ, Heidrich O, Olazabal M, Foley A, et al. Climate change response in Europe: what’s the reality? Analysis of adaptation and mitigation plans from 200 urban areas in 11 countries. *Climatic Change* 2014;122:331–40.
- Pietrapertosa F, Salvia M, De Gregorio Hurtado S, D’Alonzo V, Church JM, Geneletti D, et al. Urban climate change mitigation and adaptation planning: are Italian cities ready? *Cities* 2019;91:93–105.
- Calise F, Vicidomini M, Costa M, Wang Q, Østergaard PA, Duić N. Toward an efficient and sustainable use of energy in industries and cities. *Energies* 2019;12:3150.
- International Energy Agency. Tracking buildings 2019. 2019. Paris.
- The Paris agreement | UNFCCC. Paris agreem. <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>. [Accessed 18 December 2019].
- European Commission. 2030 climate & energy framework | Climate Action. 2019. https://ec.europa.eu/clima/policies/strategies/2030_en#tab-0-0. [Accessed 12 December 2019].
- European Commission. Clean energy for all Europeans package. 2018. <https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans>. [Accessed 1 April 2019].
- European Commission. A resilient energy union with a forward-looking climate change policy. 2019. https://ec.europa.eu/commission/sites/beta-political/files/euco-sibiu-energy_union_and_climate_change_policy.pdf. [Accessed 15 April 2020].
- European Union. Directive 2012/27/EU of the European parliament and of the Council of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EU and repealing directives 2004/8/EC and 2006/32/EC. *Official Journal of the European Union*; 2012.
- European Union. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. *Off J Eur Union* 2018;156:75–91. *Europe: Official Journal of the European Union*; 2018.
- Regulation (EU) 2018/1999 of the European parliament and of the Council. 2018.
- Knoop K, Lechtenböhmer S. The potential for energy efficiency in the EU Member States – a comparison of studies. *Renew Sustain Energy Rev* 2017;68:1097–105.
- Fragkos P, Tasios N, Paroussos L, Capros P, Tsani S. Energy system impacts and policy implications of the European Intended Nationally Determined Contribution and low-carbon pathway to 2050. *Energy Pol* 2017;100:216–26.
- Buildings Performance Institute Europe (BPIE). Principles for nearly Zero-energy Buildings. Paving the way for effective implementation of policy requirements. 2011.
- Nikolaou T, Kolokotsa D, Stavrakakis G. Review on methodologies for energy benchmarking, rating and classification of buildings. *Adv Build Energy Res* 2011;5:53–70.
- Rezaie B, Esmailzadeh E, Dincer I. Renewable energy options for buildings: case studies. *Energy Build* 2011;43:56–65.
- Buildings Performance Institute Europe (BPIE). Europe’s buildings under the microscope. 2011.
- Annunziata E, Rizzi F, Frey M. Enhancing energy efficiency in public buildings: the role of local energy audit programmes. *Energy Pol* 2014;69:364–73.
- Hong T, Piette MA, Chen Y, Lee SH, Taylor-Lange SC, Zhang R, et al. Commercial Building Energy Saver: an energy retrofit analysis toolkit. *Appl Energy* 2015;159:298–309.
- Commission of the European Communities. SEC(2011) 278 final. Europe: Energy Efficiency Plan 2001; 2011.
- Covenant of mayors for climate & energy. 2018. <https://www.covenantofmayors.eu/>. [Accessed 5 May 2020].
- Covenant of Mayors. How to develop a sustainable energy action plan. SEAP) - Guidebook; 2010.
- Petrichenko K, Aden N, Tsakiris A. Tools for energy efficiency in buildings - a guide for policy-makers and experts. 2016. <https://c2e2.unepdtpu.org/wp-content/uploads/sites/3/2016/11/2016-11-tools-energy-efficient-buildings.pdf>. [Accessed 18 April 2019].
- Harish VSKV, Kumar A. A review on modeling and simulation of building energy systems. *Renew Sustain Energy Rev* 2016;56:1272–92.
- Jebaraj S, Iniyan S. A review of energy models. *Renew Sustain Energy Rev* 2006;10:281–311.
- Ringkjøb H-K, Haugan PM, Solbrenke IM. A review of modelling tools for energy and electricity systems with large shares of variable renewables. *Renew Sustain Energy Rev* 2018;96:440–59.
- Connolly D, Lund H, Mathiesen BV, Leahy M. A review of computer tools for analysing the integration of renewable energy into various energy systems. *Appl Energy* 2010;87:1059–82.
- Climate-smart planning platform. 2019. <https://www.climatesmartplanning.org/index.html>. [Accessed 15 April 2019].
- SENTECH Inc. Review of selected home energy auditing tools. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy; 2010.
- National Renewable Energy Laboratory. Cities-LEAP PROJECT. City-Level Tools 2016;1.
- Costa A, Keane MM, Torrens JI, Corry E. Building operation and energy performance: monitoring, analysis and optimisation toolkit. *Appl Energy* 2013;101:310–6.
- Wei Z, Xu W, Wang D, Li L, Niu L, Wang W, et al. A study of city-level building energy efficiency benchmarking system for China. *Energy Build* 2018;179:1–14.
- Talavera DL, Muñoz-Cerón E, De La Casa J, Ortega MJ, Almonacid G. Energy and economic analysis for large-scale integration of small photovoltaic systems in buildings: the case of a public location in Southern Spain. *Renew Sustain Energy Rev* 2011;15:4310–9.
- Barbiero T, Grillenzoni C. A statistical analysis of the energy effectiveness of building refurbishment. *Renew Sustain Energy Rev* 2019;114:109297.
- Ardente F, Beccali M, Cellura M, Mistretta M. Energy and environmental benefits in public buildings as a result of retrofit actions. *Renew Sustain Energy Rev* 2011;15:460–70.
- Zhou Z, Zhang S, Wang C, Zuo J, He Q, Rameezdeen R. Achieving energy efficient buildings via retrofitting of existing buildings: a case study. *J Clean Prod* 2016;112:3605–15.
- Ceballos-Fuentealba I, Álvarez-Miranda E, Torres-Fuchslocher C, del Campo-Hitschfeld ML, Díaz-Guerrero J. A simulation and optimisation methodology for choosing energy efficiency measures in non-residential buildings. *Appl Energy* 2019;256:113953.
- Bandeiras F, Gomes M, Coelho P, Fernandes J. Towards net zero energy in industrial and commercial buildings in Portugal. *Renew Sustain Energy Rev* 2020;119:109580.
- Cosmi C, Salvia M, Pietrapertosa F, Di Leo S. Energy and climate planning: the role of analytical tools and soft measures. In: Bianco V, editor. *Anal. Energy syst. Manag. Plan. Policy*. Taylor & Francis Group, LLC; 2017. p. 13–47.
- Lu M, Lai J. Review on carbon emissions of commercial buildings. *Renew Sustain Energy Rev* 2020;119:109545.
- Herrando M, Chordá R, Gómez A, Fueyo N. The challenges for energy efficient public buildings in a depopulating mediterranean Region : a GIS-based support tool. 13th Conf. Sustain. Dev. energy, water Environ. Syst. 2018;1–13.
- Interreg Central Europe Together project. Training material on energy efficiency in public buildings - DSM aspects. 2017. <https://www.interreg-central.eu/Content.Node/TOGETHER/Training-material-on-DSM-aspects-1.pdf>. [Accessed 8 February 2019].
- Ruparathna R, Hewage K, Sadiq R. Improving the energy efficiency of the existing building stock: a critical review of commercial and institutional buildings. *Renew Sustain Energy Rev* 2016;53:1032–45.
- Interreg Med PrioritEE project. prioritise Energy Efficiency (EE) measures in public buildings: a decision support tool for regional and local public authorities. 2019. <https://prioritee.interreg-med.eu/>. [Accessed 15 April 2019].
- Salvia M, Simoes S, Fueyo N, Cosmi C, Papadopoulou K, Gouveia JP, et al. The PrioritEE approach to reinforce the capacities of local administrations in the energy management of public buildings. *Int. Symp. New metrop. Perspect. ISHT 2018 new metrop. Perspect.* Cham: Springer; 2019. p. 601–8.
- PrioritEE Interreg med project. PrioritEE - toolbox overview. 2019. <https://prioritee.interreg-med.eu/toolbox/toolbox-overview/>. [Accessed 12 December 2019].
- DECO. Isolamento. Térmico - conforto com mais poupança. *Proteste* 356. <https://it.scribd.com/document/407418173/PT356-026029-pdf>. [Accessed 28 April 2020].
- Boneta MF. Cost of energy efficiency measures in buildings refurbishment : a summary report on target countries. D3.1 of WP3 from Entranze Project. 2013.

- [55] California Lighting Technology Center (CLTC). 2015 lighting technology overview. 2015.
- [56] U.S. EPA and DOE. Energy STAR. 2016. <https://www.energy.gov/energysaver/energy-saver>. [Accessed 28 April 2020].
- [57] PrioritEE - analytic database. 2019. <https://prioritee.interreg-med.eu/toolbox/analytic-database/>. [Accessed 12 December 2019].
- [58] Gouveia JP, Simoes SG, Cavar M, et al. A decision support tool to rank energy efficiency options in services buildings. 4th Int. Conf. Energy Environ. bringing together Eng. Econ. Guimarães, Port. 2019;16–17 May. 2019.
- [59] PrioritEE Interreg MED project. PrioritEE Report D3.2.2 Preliminary study on available methods and tools: review and screening of existing tools, methods and good practices. 2018. https://prioritee.interreg-med.eu/fileadmin/user_upload/Sites/Efficient_Buildings/Projects/PrioritEE/Library/Deliverables/WP3/D322_PrioritEE_Preliminary_Study_31_01_2018.pdf. [Accessed 11 June 2020].
- [60] PrioritEE Interreg Med Project. PrioritEE - decision support tool. 2019. <https://prioritee.interreg-med.eu/toolbox/decision-support-tool/>. [Accessed 12 December 2019].
- [61] Province of Treviso. Green schools competition. 2019. <http://www.greenschools.eu/home.aspx>. [Accessed 12 December 2019].
- [62] Euronet 50/50 MAX. 2019. <http://www.euronet50-50max.eu/en/>. [Accessed 12 December 2019].
- [63] Cosmi C, Pietrapertosa F, Sarricchio G, Giordano M, Proto M, Tancredi M, et al. Schools4Energy: a living laboratory for energy awareness in schools 2018.
- [64] Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen-Geiger climate classification. *Hydrol Earth Syst Sci* 2007;11:1633–44.
- [65] Covenant of Mayors for Climate & Energy. The covenant of mayors for climate and energy - reporting guidelines. 2016. https://www.covenantofmayors.eu/1MG/pdf/Covenant_ReportingGuidelines.pdf. [Accessed 12 December 2019].
- [66] Dimitriou A, Sidiropoulos A. Interreg MED PrioritEE project D3.9.1 “report on pilot n.5” (region of western Macedonia, Greece). 2019.
- [67] Tomé S. Interreg MED PrioritEE project D3.8.1 report on pilot n.4. Intermunicipal Community of Lezíria do Tejo, Portugal); 2019.
- [68] Herrando M, Gómez A, Chordá R, Fueyo N. Interreg MED PrioritEE project D3.7.1 “report on pilot n.3” (diputación de Teruel, Spain). 2019.
- [69] Tancredi M, Giordano M, Pepe A, Salvia M, Pietrapertosa F, Cosmi C. Interreg MED PrioritEE project D3.6.1 “report on pilot n.2”. Municipality of Potenza, Italy); 2019.
- [70] Juričić D, Metulj K, Čavar M, Hrupački M. Interreg MED PrioritEE project D3.5.1 “report on pilot n.1” (municipality of karlovac, Croatia). 2019.
- [71] European Network of Living Labs. <https://enoll.org/about-us/>. [Accessed 5 April 2019].
- [72] Cosmi C, Pietrapertosa F, Sarricchio G, Giordano M, Proto M, Tancredi M, et al. Schools4Energy: a living laboratory for energy awareness in schools. *Res. Innov. Conf. Proc. Brussels: ENoLL Office*; 2018. p. 272–86.
- [73] de España Gobierno. Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España. 2016.
- [74] Pietrapertosa F, Tancredi M, Giordano M, Cosmi C, Salvia M. How to prioritize energy efficiency intervention in municipal public buildings to decrease CO2 emissions? A case study from Italy. *Accept Publ Spec Issue “Climate Chang Mitig Strateg Int J Environ Res Public Heal* 2020;17:12–4434.
- [75] Beccali M, Ciulla G, Lo Brano V, Galatioto A, Bonomolo M. Artificial neural network decision support tool for assessment of the energy performance and the refurbishment actions for the non-residential building stock in Southern Italy. *Energy* 2017;137:1201–18.
- [76] Cosmi C, Salvia M, Di Leo S, Pietrapertosa F, Loperte S. Interregional cooperation as a key tool for the achievement of strategic-energy and climate targets: the experience of the INTERREG IVC RENERGY and SEE RE-SEETies projects. 2017.
- [77] Salvia M, Leo S Di, Nakos C, Maras H, Panevski S, Fülöp O, et al. Creating a sustainable and resource efficient future: a methodological toolkit for municipalities. *Renew Sustain Energy Rev* 2015;50:480–96.