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An optimization tool for the assessment of urban energy scenarios

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ABSTRACT

Energy demand and production of neighbourhoods are central issues in the development of integrated spatial-energy strategies in the framework of recent European Policies. This study provides a comprehensive tool that combines spatial and energy issues with optimization methods to support urban planners in the decision-making process for urban energy strategies. By adopting an integrated approach, optimized urban energy scenarios aimed at reducing CO_2 emissions are developed and results are shown in spatial-energy maps. Through the application of the proposed method, current urban energy demand is determined and potential local production of electrical energy due to the introduction of renewable energy systems is assessed. The insertion of renewable energy systems allows configuring a network of energy exchanges where buildings are considered able to share energy through physical connections. The optimization of energy exchanges among buildings is carried out by using a model based on complex networks and is represented in maps, developed in GIS, allowing the integration between energy evaluations and spatial planning. As case study, the method has been applied to a neighbourhood of the municipality of Catania in Southern Italy.

1. Introduction

The energy use in urban areas has a significant role in tackling the climate change [1]. Actually, cities are responsible for more than the 67% of the world's energy consumption and contribute for more than the 70% of global CO_2 emissions [2,3]. In addition, the world's population living in cities will increase from the actual 55% to the 66% by 2050, thus strengthening the impact of problem [4]. In this context, balancing the energy consumptions and the emissions is becoming one of the most important priorities when dealing with the concern of climate change. To deal with this point in question, focused actions should be designed for decreasing the emissions directly associated to the urban energy use.

In answer to this, European Policies address actions at urban level, as the recent Covenant of Mayors by which local authorities, voluntarily committed, implement EU climate and energy objectives on their territories [5]. Pathways to innovative sustainability actions also leverage on the concept of smart grids. One of the most impacting characteristics of the grid idea is the exploitation of renewable energy sources within urban territories for the production of energy and the chance to generate bi-directional exchanges between “prosumers”. Prosumers install renewable energy-based production systems with the primary objective of satisfying their own energy demands and, successively, to distribute to closer neighbours the produced energy not consumed [6,7]. However, the applicability of these policies requires an effort in terms of integrating the planning perspective with energy issues. Yet, the need for tools that facilitate action plans focusing on the assessment of both the outcomes of potential energy efficiencies measures and the introduction of renewable energy systems is unquestionable.

Numerous contributions in the current literature appraise and map the energy consumption of buildings and neighbourhoods to support the planners in integrating energy aspects on urban plans and policies [8,9]. As two examples of many, Rodriguez-Alvarez [10] proposes an estimation tool, the Urban Energy Index for Buildings (UEIB), for the assessment of the energy consumption of buildings in large urban areas. Ascione et al. [11] map heating and cooling energy demands of buildings at urban level by simplifying the national standard procedure; the model is applied to the historical centre of Benevento (IT). Whilst the cited researches refer to the assessment of the energy consumptions of buildings, just as many studies provide insights into their production potential. For instance, Santos et al. [12] use LIDAR data to assess the photovoltaic

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potential of buildings and compare it with the local electricity demand in order to support decisions on the investments in PV systems. Similarly, Redweik et al. [13] propose a method for the estimation of PV potential of all surfaces (roofs and facades) of buildings in urban landscapes.

The aforementioned works develop tools for the assessment of either urban energy demand or production but lack the inclusion of optimization features for future-oriented energy efficiencies scenarios. Actually, within the set of optimization models, some authors propose energy efficiency solutions dealing with the insertion of Distributed Energy Systems (DESs) on territory [14–18]. Among these, Prasanna et al. [17] propose a model for the minimization of the carbon emissions deriving from the electricity purchased from the grid and able to identify the PV production that can cover the electricity demand of the district. Tomc and Vassallo [18] study the interaction among renewable energy production, consumption and storage within a microgrid by also evaluating the impact of a central controller for the production and storage. Other authors deepen the aspect of the choice and the design of distributed technologies. In this respect, Li et al. optimize the design of distributed energy systems coupled with energy (heating, cooling and power) distribution networks in order to minimize the annual cost of investments and the emissions. Both costs of emissions and operations are treated in the optimization model developed by Maroufmashat et al. [19]. Similar approaches are proposed in the papers [20–23].

The so far mentioned papers do not consider the chance for consumers to distribute the own produced energy to their neighbours. This issue is tackled from the authors in Refs. [24–26] that optimize the energy exchanges among buildings in order to select the optimal distributed technology to install and design the distribution network. At this stage, however, the mentioned optimization models refer to a limited number of buildings both in fictitious and real small urban areas. In addition, they do not analyse how the spatial characteristics of the territory, such as the distance among buildings, may influence the results when dealing with the exchange of energy.

In summary, the listed literature treats the assessment of energy demands and production and the optimization of energy systems as separate topics. Nevertheless, an integrated approach is needed in order to support policy makers and urban planners in dealing with the energy issues in spatial planning. An integrated vision of planning and energy aspects is met in the studies of [27–33]. Among these, Hong et al. [28] develop a GIS-based optimization model for the estimation of the electricity produced by rooftop photovoltaic systems; Quan et al. [29] propose a procedure to get the energy use of every building in a city. Finally, Monteiro et al. [30] couple an optimal routing problem with a GIS-based mapping for the optimal selection of the routes of new power lines.

This paper differs from the scientific contribution cited so far essentially in three main points. As a first and leading consideration, the method presented in this paper join a spatial-energy model with an optimization procedure. As such, this paper aims at defining a useful tool able to support the decision process of urban planners when dealing with the insertion of renewable energy systems on urban territories. Secondly, the distribution network resulting from the chance to consumers to exchange the own produced energy is enlarged to comprehend large urban areas. Thirdly, the developed model is of general applicability regardless of both the characteristics of the urban area and of the typology of energy production system installed by the private consumers.

Along with the above consideration, it should be pointed out that the technological and electrical constraints for the basic infrastructure of the network of energy exchanges are assumed to be always satisfied. Actually, this work seeks to support planners on energy actions to be implemented on urban territories. As such, detailed features about electrical constraints, for which very exhaustive and targeted literature already exists [34–36], do not serve at this aim. In addition, several authors [25,26,37] neglect this aspect when dealing with the optimization of the energy flows within the network.

Therefore, this paper proposes a comprehensive method that integrates the knowledge of the territory-related energy demands and productions deriving from the data collection with the assessment of optimized urban energy scenarios for the reduction of CO_2 emissions. In particular, the collected data are elaborated for the optimization of scenarios of electrical energy distribution among buildings using an approach based on complex networks. Finally, the ultimate purpose of this work is to identify the role that buildings have in the neighbourhood when the insertion of renewable energy systems is considered and energy exchanges among installers are allowed.

The remainder of the paper is organized as follows. Section 2 introduces the proposed method In Section 3 the method is applied to a case study area in Italy and results are discussed. Finally, Section 4 provides the conclusions and discusses further directions of research.

2. Materials and methods

This study proposes a method based on the integration of a spatial-energy model and an optimization strategy. The spatial-energy model assesses the energy performance of urban areas for different energy conditions, also providing energy demand and production. The optimization strategy, framed within the complex network theory, uses the outcomes of the spatial-energy model as input data to build a model for the elaboration of optimized scenarios of energy distribution and exchange. The combination of these models allows to develop maps representing optimized urban energy scenarios, able to take into consideration both physical constraints and effective geographical characteristics. A general overview of the method is presented in Fig. 1.

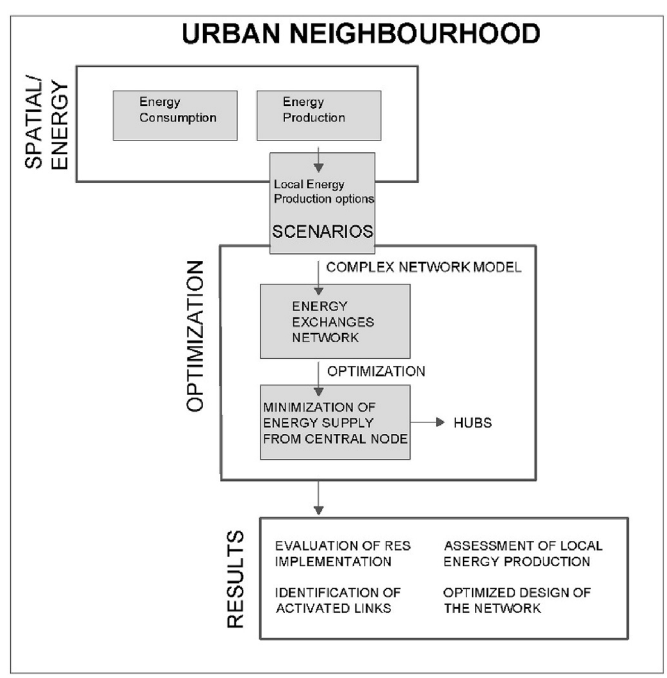

Fig. 1. Flowchart of the method for the assessment of urban energy scenarios.