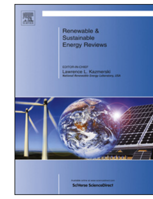
Renewable and Sustainable Energy Reviews 55 (2016) 273–287

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Energy management and planning in smart cities

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ARTICLE INFO

Article history:
Received 20 February 2015
Received in revised form
16 August 2015
Accepted 26 October 2015

Keywords:
Smart city
Renewable sources
Energy storage
Smart grid
Distfributed energy resources
Transport systems

ABSTRACT

A *smart city* is a sustainable and efficient urban centre that provides a high quality of life to its inhabitants through optimal management of its resources. Energy management is one of the most demanding issues within such urban centres owing to the complexity of the energy systems and their vital role. Therefore, significant attention and effort need to be dedicated to this problem. Modelling and simulation are the major tools commonly used to assess the technological and policy impacts of smart solutions, as well as to plan the best ways of shifting from current cities to smarter ones.

This paper reviews energy-related work on planning and operation models within the smart city by classifying their scope into five main intervention areas: generation, storage, infrastructure, facilities, and transport. More-complex urban energy models integrating more than one intervention area are also reviewed, outlining their advantages and limitations, existing trends and challenges, and some relevant applications. Lastly, a methodology for developing an improved energy model in the smart-city context is proposed, along with some additional final recommendations.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.10.133
1364-0321/

1. Introduction

The *smart city* is a relatively new concept that has been defined by many authors and institutions and used by many more. In a very simple way, the smart city is intended to deal with or mitigate, through the highest efficiency and resource optimization, the problems generated by rapid urbanization and population growth, such as energy supply, waste management, and mobility. Many classifications of smart-city intervention areas can be found in the literature, as in [1,2]. A drawback of these classifications is that they categorize energy mainly based on the smart grid, overlooking other relevant energy elements, like transport and facilities.

Cities' energy requirements are complex and abundant. In consequence, modern cities should improve present systems and implement new solutions in a coordinated way and through an optimal approach, by profiting from the synergies among all these energy solutions. The intermittency of renewable sources, the increasing demand, and the necessity of energy-efficient transport systems, among other things, represent important energy challenges that are better addressed as a whole [3] rather than separately, as is usually the case.

Simulation models have been developed to assist stakeholders in understanding urban dynamics and in evaluating the impact of energy-policy alternatives. However, very often these efforts address energy areas separately, lacking the "full picture" and, therefore, producing suboptimal solutions. A comprehensive smart-city model that includes all energy-related activities while keeping the size and complexity of the model manageable is highly desirable in order to successfully meet the increasing energy needs of present and future cities.

This work proposes five main energy-related activities that have been called *intervention areas* (see Fig. 1): generation, storage, infrastructure, facilities, and transport (mobility). All these areas are related to each other but contribute to the energy system in different ways: generation provides energy, while storage helps in securing its availability; infrastructure involves the distribution of energy and user interfaces; facilities and transport are the main final consumers of energy, as they need it to operate. Energy systems' implementations are supported by three main layers: intelligence (control/management), communication, and hardware (physical elements and devices). Hence, multidisciplinary solutions are expected. This research mainly focuses on the hardware and intelligence layers.

This paper has two main objectives. The first is to develop insight into the complexity of the energy-related activities in a smart-city context by reviewing advances and trends and by analysing the synergies among different intervention areas. Moreover, some of the most typical applications found in the literature for the various energy areas, as well as operation and planning tools, are reviewed. The second objective is to assist stakeholders and policymakers in the design of energy solutions for smart cities by providing strategies for the effective modelling and management of energy systems and by reviewing existing projects and software tools. These strategies include the most relevant elements and common sources of information required for their mathematical modelling.

This paper comprises two parts: the first (Sections 2–6) presents a review of the research developed in the proposed intervention areas involving energy in smart cities. Section 2 addresses advances in energy generation in a smart-city context, Section 3 reviews several storage systems and their applications, Section 4 analyses the actual state of the technology and perspectives in the area of infrastructure, Section 5 presents energy-related technologies and systems implemented in facilities, and Section 6 analyses the advances in energy consumption of transport systems. The second part comprises Section 7; it reviews current energy-modelling approaches for smart cities and proposes a methodology for energy-system planning and operation. Finally, concluding remarks and recommendations can be found in Section 8.

2. Generation

From an energy-generation perspective, two main research lines are attracting the most attention. On one hand, renewable-energy sources entail a mid- to long-term investment for energy self-sufficiency without compromising future generations [3], although other non-renewable sources, such as combined heat and power (CHP) with natural gas and biomass generation (considering that these alternatives are less polluting than conventional generation [20,98]), can also be a suitable short-term alternative for reducing emissions and meeting the energy demand [4]. On the other hand, distributed generation (DG) is gaining interest as a tool to increase efficiency and to support grid reliability and resiliency [5]. The benefits and requirements of DG have been studied widely [6,8].

It is important to note that the smart city should gradually migrate to a full renewable-energy scheme, a goal that can be facilitated by DG. Hence, although conventional generation will still be present in smart cities in the short to medium term, it is not addressed in this section.

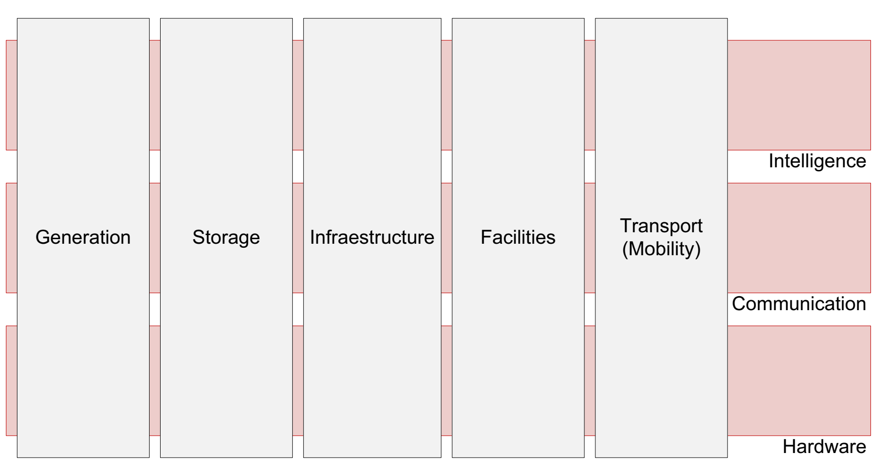

Fig. 1. Classification of energy intervention areas in the smart city.