ENERGY MANAGEMENT AND PLANNING IN SMART CITIES

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ABSTRACT

Smart cities provide citizens with information on various urban services and allow them to track the impact of their resource consumption on the overall sustainability of their city. 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. This paper introduces a theoretical planning and operation models within the smart city by classifying roles DSOs into six main intervention areas: parameters and resource availability, system costs, geolocation characteristics, energy prices, regulatory constraints and energy demand. More-complex urban energy models integrating more than one intervention area are also reviewed, outlining their advantages and energy demand, 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.

INTRODUCTION

The world population is expected to reach to nine billion in 2050. The population growth rate is more significant in developing countries. Accordingly, providing the basic needs of human beings such as space and basic materials to live implies a further increase in environmental impacts. However, Natural resources are limited. On the other hand, energy demands and costs are increased over time. Increasing usage of energy-intensive products and services directly affect greenhouse gas emissions and climate change. Since the beginning of 20th century, the global mean of surface temperature has increased by 0.6◦C. The northern hemisphere surface temperature has increased more in the 20th century than the previous 1,000 years. The warmest decade of the millennium was the1990s and the warmest year was 1998. The National Academy of Sciences (NAS) predicts a global mean surface air temperature increase of 2.5 to 10.4◦F between 1990 and 2100 due to increasing greenhouse gases [1].
Therefore, there is urgent need to a move towards urban sustainability and in particular planning and management energy consumption.
Today, countries have an increasing tendency towards smartening of cities, achieve on going improvement and innovation [2]. 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 [3].
Finally, since energy sector and electric power distribution companies in particular are infrastructures needed for smart cities, we need the most up-to-date and newest optimal models for energy management and planning in our smart cities. The main objective this paper 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. It Reviews current energy-modelling approaches for smart cities and proposes a methodology for energy-system planning and operation.

Smart City

Even though the term is relatively young, the operationalisation of what a Smart Cities, can vary dramatically depending on the approach. Several attempts have been made at formulating a definition of the Smart City, taking different perspectives. In an effort to be holistic, several areas a city should focus on in making itself “smarter” have been identified, such as competitiveness, social and human capital, participation, transport and ICT, natural resources and quality of life [4,5]. This was not only the case in sectors that are directly related to ICT or telecommunications, but also in various other sectors and industry branches beyond it e.g. health, culture, media, mobility, energy, government, policy etc. [6]. In spite of the many attempts at definitions, the Smart City concept remains elusive. However, it is an indication of the increasing need to develop new ways of looking at the city of the future and to think about structured approaches to provide answers for the diverse and complex questions companies, citizens and governments face there [7].

Rather than attempting a holistic and general definition of what a Smart City is we prefer to clarify our perspective on the concept in the follow in section. Generally, a smart city is a city which seeks to enhance citizens' life quality and to provide sustainable development using modern technology and IT. For a city to be entitled "smart", it must have certain dimensions and characteristics. Since "smart city" is a novel concept in today's world, different sources consider different dimensions for it. However, all of them pay special attention to the following two main goals: life quality enhancement and sustainable economic growth. Over the last few years, the concept of "smart city" has been put forward in different countries. On the other hand, numerous challenges have turned the concept of smart cities into a serious must; by 2013, over 140 cities in the world have started smartening plans, most of which are in North America, Europe, and East Asia [8].

SMART CITY ENERGY MANAGEMENT MODELS

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. 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.
Energy-system models have been around for several decades and are experiencing constant evolution to incorporate new technologies, paradigms, and externalities (such as environmental concerns) [3]. For the energy perspective only, this kind of model is commonly used for power system planning or for operation and management. An example of the former which presents a model for distribution network expansion planning, considering the sizing, placement, and timing of DG investments and network reinforcements. Similarly, optimal DG allocation in a distribution network [3].
The operation of power systems can be exemplified where a smart grid is simulated based on software agents; the simulation attempts to recreate the dynamic behaviour of a smart city, yet it considers only electricity. Other examples can be found in the distribution-network operation projects funded by the European Commission. According to [9], electric system modelling is normally carried out using some sort of stochastic programming, which involves minimizing an objective function subject to certain constraints. However, other techniques based on artificial intelligence, genetic algorithms, game theory, and so on, are also available.

Urban-planning models and energy

Besides the energy-based models for network planning and operation, the urban planning of a city (i.e., the land use and the design of an urban environment) can heavily influence its energy usage and the pollution it produces.
Indeed, urban infrastructure systems have extended lifespans and affect the inhabitants and the environment for long periods of time. Therefore, urban-planning models are of paramount importance for sustainable growth. For instance, [10] proposes a model to assess a site's potential renewable energy availability and urban energy-supply plants in order to determine the best places and type of generation to install given geographical constraints. A case study of a residential district in Korea is carried out to analyse its applicability. Similarly, [11] proposes solutions for urban-planning improvements to energy efficiency that rely on information technologies.
For instance, using geographic information systems (GIS) and 3-D modelling to design buildings Allows taking advantage of the terrain configuration (e.g., terrain slope: burying part of the building to reduce heating costs), orientation towards the sun(e.g., designing for greater sunlight Exposure so as to increase interior temperatures during winter), and wind effects(e.g., considering the direction of wind to promote natural ventilation, reducing air-conditioning costs),among other things.
many cities prioritize renewable energy or energy efficiency, as in the aforementioned examples; only a few cities Approach urban planning through on strategy that facilitates synergy in energy-related activities at different scales. Moreover, greenhouse-gas emissions are not always present in urban-planning models.
analyse the carbon footprint in industrial and Residential activities, respectively, and the possible prevention and mitigation solutions that can be carried out through urban-planning models. The former concludes that municipalities can have a decisive influence on the industrial carbon footprint because most reductions can be obtained through urban-planning Decision variables, such as the location of industrial plants, waste deposits, transport networks, use of non-organisable areas, and so on. The latter mentions that the greatest pollutant source is transport, followed by gas and electricity consumption, and concludes that policymakers can reduce greenhouse-gas emissions by managing the infrastructure design and by including sustainability design criteria in master urban plans.
As mentioned in [3], individual efforts (designing and Managing independent smart buildings, for instance) might not be Optimal overall, as these tend to overlook many interactions between facilities—hence, the importance of an inclusive urban-planning project that considers full energy cycles that cut across all the presented intervention areas.

Designing energy-system models in a smart-city context

It is clear from the review developed throughout this paper that modelling a complete urban energy system is a complex task. However, some elements in all the intervention areas stand out in importance. This section provides several guidelines for the adequate modelling of such systems and describes the elements that should be taken in to account.

Fig. 1 presents a general diagram of an energy-system model, including elements of all the intervention areas reviewed and the main required inputs(left) and expected outputs (right). Regarding the methodology for planning and operation, many approaches can be used, such as analytical, iterative, and hybrid methods.

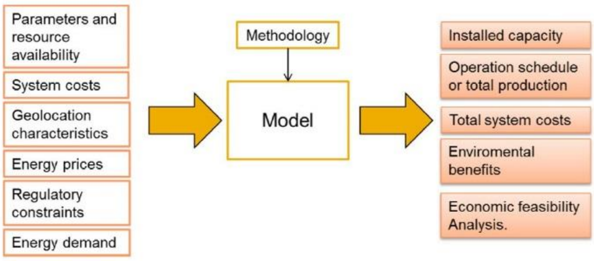

Fig. 1. General energy system design model.

- Parameters and resource availability: Performance parameters. (e.g. electric efficiency, thermal efficiency, power rating, losses) and availability of the resource when applicable (e.g. EV connection times, DG operation constrains)
- System costs: All the necessary costs to analyse economic feasibility of systems (e.g. cost per installed kW, operation and maintenance costs)
- Geolocation characteristics: natural sources information (e.g. solar irradiation, wind speed, rainfall)
- Energy prices: the cost of energy for comparative purposes (e.g. retail energy tariffs, fuel costs, price increment rate)
- Regulatory constraints: all relevant constraints and possibilities for the desired location (e.g. retailing conditions, selling energy back to the grid)
- Energy demand: energy demand characteristics for the desired application (e.g. load curves)

In [12], a classification of the different methodologies for distributed energy-resource dimensioning is provided. The input information used in the model considerably affects the quality of results; hence, special attention should be paid to its selection. Table 1 provides a description of the main inputs needed for the successful design of the energy systems and of how these Inputs affect the modelled system (e.g., in its profitability, in its performance). It is important to remark that despite the fact that certain inputs are more closely related to some aspects than others, all inputs are relevant to the final outcome.

Moreover, Fig. 2 presents some examples of the information Sources that can be used for each input. The list of typical information sources is not intended to be exhaustive but rather to serve as guidance and to suggest possible sources of information.

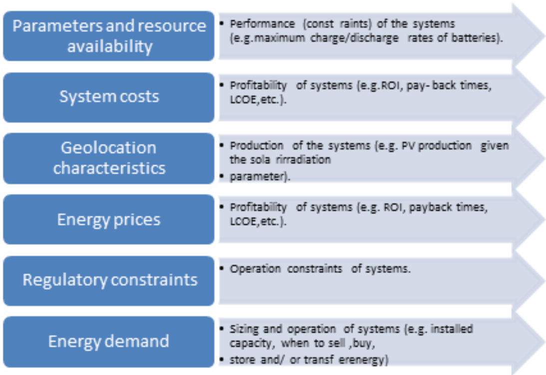

Fig. 2. energy system modelling and mainly impact on

CONCLUSION

In order to achieve optimal energy management in a very Complex system like a smart city, not only do most of its energy elements need to be identified and studied, but the implicit relations among them also have to be considered. Furthermore, detailed modelling and simulation are required to validate and improve existing and new systems.

In smart cities, comparative energy information on various urban services affect households' energy behaviour to improve urban environmental sustainability. The premise of smart cities is that with improved access to information on resource consumption, residents make better use of those resources, resulting in increased sustainability of the city. According to social learning and social cognitive theories, the information technologies of smart city impact positively on energy conservation. This paper undertakes an Extensive review of the existing approaches. On one hand, all the Proposed energy-intervention areas within the city and their relations are considered; on the other hand, different currently Available energy models and simulation tools are reviewed and compared.

Based on this study, some clear trends can be identified in all intervention areas. Benefiting from advances in technologies and Reduced prices, DG (including energy storage and renewable sources) will continue to gain presence in the coming years. Energy-efficient facilities are making their way into future smart cities with better devices, control systems, and demand-response schemes. Similarly, tendencies show that the micro grid and smart-grid paradigms will become the standard in the long term. With Respect to the transport sector, travel planners, parking assistants, and other similar system will be implemented, while EVs will surely find an important position in smart cities.

Models and simulators have been widely used in the urban Context for many decades. This kind of tool is normally used for the operation and management of the systems or for planning expansion or the construction of the new systems. Current models are normally designed with specific objectives in mind, such as implementing traffic control, planning urban development, planning the expansion of generation capacity or transmission lines, and so on. Therefore, the elements considered are limited and they do not take into account many important interactions within the system.

The necessity of a holistic and comprehensive smart-city model has been highlighted by many authors. Even though it might be extremely difficult to integrate all the elements into a single computational model, it should at least consider all the intervention areas studied in this paper and include the most relevant stakeholders and technologies. Furthermore, the model should be applicable to any kind of city and be adaptable to new technologies and systems.

As discussed in this paper, there are many elements that should be taken into account while modelling energy systems; however, some of them are more critical than others. Special attention should be paid to an adequate selection of the system parameters and energy constraints. Accurate geographical information about natural resources (wind, solar, etc.) is also important to the proper outcome of a planning process. Moreover, it has been demonstrated that the use of some sort of optimization algorithm considerably improves the expected benefits; hence, it is highly recommended that such approaches be followed. Lastly, considering the complexity of the systems, the objectives of the model should be clearly defined and prioritized. Addressing all these issues allows for the creation of a complete and adequate smart city energy model, one that will assist decision makers in both government and industry to develop, simulate, and implement the best systems at minimum cost, fostering smarter and more efficient cities.

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