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Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach

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ABSTRACT

Buildings are the principal energy consumer and greatest fraction of greenhouse gas emissions in Algeria. Therefore, energy consumption forecasting is a critical and it helps to make good planning, long term strategies, efficient initiatives to curb emissions and controlling energy usage in the building sector. In this work, a bottom-up model has been used in modeling and forecasting of energy consumption for Algeria residential buildings until 2040. For estimating annual energy consumption, Algerian territory is divided into climatic zones according to annual cost of energy consumption needed for cooling and heating in the residential sector. The annual heating and cooling requirements of buildings in different regions of Algeria (48 stations) are evaluated using the degree-days method. Then, Geographic Information System (GIS) technique is used to create the cartography of climatic zone. In each zone, the energy consumption for heating, cooling and domestic appliances is calculated. The results showed, the final energy consumption increased from 73.23 TWh in 2008 to 179.78 TWh in 2040. In addition, climatic zone in Algeria is delineated in seven zones. Zone 7 consumes 73% of the final energy in Algeria. Cooking, heating and hot water are the major energy consumers in Algerian residential sector.

1. Introduction

Energy is considered to be a key player in the generation of wealth and also a significant component in economic development. This makes energy resources extremely significant for every country in the world [1]. Energy production and consumption plays a vital role in deciding the energy conservation at every step of the economic development worldwide. Global total energy consumption has a direct influence on the economical and environmental development [2]. Energy consumption in buildings is a large share of the world's total end use of energy, it reaches about 40% of the world's energy use and it is the world's greatest fraction of greenhouse gas emissions [3]. In Algeria, the building sector consumes the most part of energy, namely 43%, followed by the transportation sector (36%) and the industry 21% [4]. The reasons that lead to the increase in energy demand are substantial increase of population and housing, low prices of conventional energy, increase number of electrical equipment in each house, use of non-economic electrical equipment such as incandescent lamps and cheap air conditioners, absence of awareness and lack of culture on the energy efficiency, growing desire of people to comfort [4,5]. With an expected increasing in the number of population and housing which are the main factors of the consumption in the residential sector, that demand supply problem can be even more dangerous. Thus, ever-increasing attention has been given to public policy in providing more aggressive and effective responses to reduce energy demand sustainably. Within this context, the development of energy efficiency standards for home appliances is part of the National Energy Efficiency Program of the Algerian Ministry of Energy and Mines [4]. The program aims to encourage the implementation of innovative practices and technologies, around thermal insulation of buildings. Adequate measures are scheduled at the architectural and design of housings phase. It also concerns to foster the massive introduction of efficient equipment and devices in the local market, as solar heater and economic lamps: the objective being the improving of interior accommodation of housings using less energy. Settling a local industry of thermal isolations and efficient equipment and devices (solar heaters, economic lamps) is an advantage for the

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development of the energy efficiency in that sector [6]. Therefore, the characterizing, modeling and forecasting of energy consumption in buildings are crucial if urban areas are to reduce their overall energy consumption. Accurate modeling and forecasting of building energy demand enables numerous energy management and efficiency applications such as: informing early stage design decisions, estimating improvements to building energy performance, optimizing building systems and urban energy infrastructure planning [7]. Techniques are used to the residential energy consumption model can broadly be grouped into two categories, "top-down" and "bottom up" which the terminology is referenced to the hierarchical position of data inputs as compared to the housing sector as a whole. Top down models utilize the estimate of total residential sector energy consumption and other pertinent variables to attribute the energy consumption for characterizing the entire housing sector. In contrast, bottom-up models calculate the energy consumption of individual or groups of houses and then extrapolate these results to represent the region or nation [8]. A number of works propose bottom-up techniques to model residential energy use. Gouveia et al. presented bottom-up model to project detailed energy end-uses demand in the Portuguese residential buildings until 2050, aiming to identify the parameters governing energy services demand uncertainty, through a sensitivity analysis. The main results show that technology can overweight behavioral practices and lifestyle changes for some end-uses as in space heating and lighting. Nevertheless, an important focus should be given to uncertain parameters related with consumer behavior, especially those on heating and other electric end-uses, as thermal comfort and equipment's use [9]. Papachristos et al. explored the effect of smart meter introduction, appliance efficiency and consumer behavior on reducing electricity consumption in the Netherlands. It does so by combining two perspectives: a sociotechnical approach and a bottom up simulation approach. The results show their effect on electricity consumption and suggest that further effort is required to control and reduce it. Insights from this paper suggest that future studies should disaggregate with respect to a number of factors [10]. Mastrucci et al. estimated the energy consumption of residential stocks across an entire city, using a bottom-up statistical methodology based on a Geographical Information System (GIS). Results are finally aggregated across the whole city for evidence based decision support in sustainable urban planning. The study provided relevant results to prioritize the implementation of energy retrofit measures for the residential stock of Rotterdam city, consisting about 300,000 dwellings. The methodology can be further applied to other contexts due to its generic nature [11]. Mattinen et al. presented a calculation and visualization approach for energy use and greenhouse gas emissions from residential stock using a bottom-up approach and geographical information system (GIS) techniques. The results obtained provide meaningful and detailed information about the energy performance and greenhouse gas emissions of the residential stock. The information can be, for instance, used in various hot spot analyses. Additionally, the impacts of energy efficiency measures and behavioral changes can be assessed. These types of analysis can be useful for policy makers in order to prioritize actions cost efficiently, such as carrying out renovations in the residential sector [12]. Abbaspour et al. discussed past trends and future scenarios to reduce greenhouse gas emissions in household sector in Tehran this sector. Using LEAP software and according to Iran's long term development policies, energy demand and its greenhouse gas emission were evaluated based on a baseline scenarios within a long term horizon (from 2011 to 2036). Energy demand was analyzed in the form of seven alternative scenarios. The obtained results indicated that natural gas consumption will increase to 21,084 MCM by the year 2036. In addition, the electricity consumption rate will grow to 21,084 million kWh over the studied period, if the current trend of consumption continues [13]. Chaturvedi et al. used a detailed technologically, service based building energy model nested in the long term, global, integrated assessment framework, Global Change Assessment Model (GCAM), to produce scenarios of the evolution of the Indian buildings sector up through the end of the century. The results support the idea that as India evolves toward developed country per-capita income levels, its building sector will largely evolve to resemble those of the currently developed countries (heavy reliance on electricity both for increasing cooling loads and a range of emerging appliance and other plug loads), albeit with unique characteristics based on its climate conditions (cooling dominating heating and even more so with climate change), on fuel preferences that may linger from the present (for example, a preference for gas for cooking), and vestiges of its development path (including remnants of poor rural that use substantial quantities of traditional biomass) [14]. This paper presents a bottom-up methodology for modeling and forecasting energy consumption in Algerian residential buildings until 2040. For estimating annual energy consumption, Algeria territory is divided into climatic zones according to annual cost of energy consumption needed for cooling and heating in the residential sector. The annual heating and cooling requirements of buildings in different regions of Algeria (48 stations) are evaluated using the degree-days method. Then, Geographic Information System (GIS) software is used to present the cartography of climatic zone. In each zone, the energy consumption for heating, cooling and domestic appliances is calculated.

2. Methodology and assumptions

Residential energy models rely on input data from which to calculate or simulate energy consumption [8]. This work presents a bottom-up approach for modeling and forecasting energy consumption in Algerian residential buildings until 2040. The starting point for developing projections for future energy consumption is establishing the useful energy demand for different end-uses in a base year (2008). For estimating annual energy consumption (see Fig. 1), Algerian territory is classified into climatic zones according to annual cost of energy consumption per unit area of wall surface needed for cooling and heating in the residential sector. In this study, the annual heating and cooling requirements of buildings in different regions (48 stations) of Algeria are obtained using the degree-days method. This method is the simplest and most intuitive way of estimating the annual energy consumption for heating and cooling of buildings. Then, Geographic Information System (GIS) is used to present the cartography of climatic zone. In each zone, the energy consumption for heating, cooling and domestic appliances is calculated. Energy used in the residential building is provided from the following energy carriers for different usage:

- Natural gas is used for space heating.
- Electricity is used as power for air conditioner system, hot water, fans, lighting and office appliances.

2.1. Modeling end-use energy consumption

The energy use in the residential sector can be best understood by focusing on specific end use functions and their drivers. The relevance of each end-use in the overall energy consumption is highly dependent on climate, physical dwelling characteristics, appliances and system characteristics, ownership, and occupancy behavior [9].

2.2. Energy for space heating and cooling

In the residential sector, the activity indicator is population, expressed as total population or as the number of households. An