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Urban energy consumption mapping for energy management

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HIGHLIGHTS

- We develop a model for calculating location-specific energy consumption for cities.
- The methodology couples different approaches to the traditional energy planning.
- As a result, we produce maps of the spatial distribution of energy consumption.
- Those maps allow the evaluation of the impacts of energy consumption on urban areas.

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ABSTRACT

The amount of energy consumption of individual buildings is a widely discussed theme. However, there are few studies that have analyzed the consumption of energy by groups of buildings. This work aims to develop a model able to estimate the energy consumption by residential sectors, in different areas inside a city, through the adoption of an energy planning methodology using the city of Belo Horizonte, Brazil as a case study. In this model, the most important variables of consumption behavior are related to the economy. The methodology coupled different approaches. Its first step was to survey the ownership of appliances and the socioeconomic profile of households in each region inside of the city, through the statistical analysis of census data. The second step was to characterize the average energy consumption by typical residential equipment. Then, it was possible to compute the energy consumption according to equipment and region. Finally, the modeled municipal energy consumption was compared with that recorded by the energy utility company. As a result, maps of energy consumed by end use are presented for the years 1991, 2000, and 2007. The conclusions of this work can be applied in energy planning projections and in local urban planning.

1. Introduction

The number of urban dwellers is increasing rapidly. By 2030, the global urban population is expected to reach five billion or 60% of the total population (United Nations Population Fund (UNFPA), 2007). Therefore, energy demand in cities should be a dominant issue in energy supply planning. Increasing energy consumption by urban populations could endanger economic development because the consumption of energy by the residential sector, which does not generate wealth, could limit the amount of resources available to the productive sectors, which use energy to produce goods and services.

Growing cities face specific energy supply challenges. Metropolises can experience intense periods of settlement and vertical growth. However, infrastructure often fails to keep pace with this growth, and energy demand in cities can put pressure on the energy system, threatening supply and occasionally increasing costs.

Because of increasing family income and decreasing poverty over the past two decades, there has been a significant increase in the ownership of household appliances in Brazil. While this increase has led to significant improvement in the quality of life, large Brazilian cities have faced constant problems related to energy use. The richest regions of Brazilian cities have experienced blackouts in their power supply systems, especially during peak hours of consumption and on the hottest days of summer. The poorest regions, such as the slums, have faced security problems that should be further discussed.

Currently, there are no subsidies for purchasing liquefied petroleum gas (LPG), which is the main fuel used for cooking in Brazilian cities. For the residential sector, LPG is sold in 13-kg canisters, which contain 31.5 l of LPG and cost approximately US $25. This cost might be too high for families earning an income near the minimum wage, which is established by law. Thus, LPG is

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often substituted with ethanol-based improvised systems, especially in large cities. These improvised systems are precarious and often explode, causing burns to children and women or even fires. Another cause of fires in the low-income areas of large cities is the high number of illegal access points to the power grid.

Both the power supply problems in richer areas and the fires in low-income areas have been frequently reported in the Brazilian media. These facts highlight the problem of the lack of consumption management in the residential sector and system planning to ensure that the necessary infrastructure is supplied to satisfy the growing demand. In the context of energy consumption in large cities, this research investigated how the energy demand of the residential sector can be spatially differentiated.

Several studies discuss issues related to residential sector consumption, but most of these studies do not address the differences within cities, which are more pronounced in the cities of developing countries (Shimoda et al., 2007; Koomey et al., 1999; Sanchez et al., 1998).

The spatial approach is crucial for enabling decision makers to consider the impacts of the development of areas or activity sectors and adopted policies. However, only a few studies have mapped the residential sector consumption in cities; among these studies, those of Jones et al. (2000) and Gadsden et al. (2003) are discussed below.

Based on provided and collected data, Jones et al. (2000) developed a GIS interface that was able to quantify the energy consumption of different sectors and urban areas. The developed numerical model is called energy and environmental prediction (EEP). Gadsden et al. (2003) subsequently described the methodology underlying the solar energy planning system (SEP) for planners and public policy makers. Such studies are based on land use and occupation data, such as the size and type of construction, the use and age of a building, and the ownership and use of energy consumption equipment. Furthermore, some information is obtained through fieldwork and statistical studies. As a result, the energy consumption of different industry sectors and geographic areas can be quantified, and a baseline for energy consumption can be established. Furthermore, the greenhouse gas emissions associated with these energy consumption values can be calculated.

The studies of Jones et al. (2000) and Gadsden et al. (2003) propose an approach that can be used as a basis for elaborating on an urban-scale energy planning model in Brazil. However, the model cannot be directly applied to the Brazilian scenario because of the many distinctions between Brazilian and European cities, such as the heterogeneity of the land use and occupation of Brazilian cities, the large socioeconomic differences existing within cities, and user profiles. Furthermore, the aforementioned studies were developed based on extensive and detailed surveys on urban consumption data (Ratti and Richens, 2000; Shorrock and Dunster, 1997; Jones et al., 2000), and there are no similar studies for Brazilian cities.

Thus, this paper introduces an urban energy consumption study focused on the Brazilian context. Specifically, the objective of this study is to develop a model for calculating location-specific energy consumption. Because the distribution of the variables associated with energy consumption in cities is heterogeneous and complex, the proposed model adopts the Geographic Information System (GIS) to organize the information as well as to process and present the results. The model is based on the intersection of land use and occupation data, socioeconomic data, and the ownership and use of energy consumption devices drawn from census surveys and statistical studies. Thus, the proposed model allows the energy consumption of different urban areas to be quantified and displayed in the form of maps, facilitating data use by planners and decision makers. Because of the complexity and multitude of factors associated with urban energy consumption, only the residential sector of the Belo Horizonte municipality was considered.

In this article, a brief description of the study area and the objectives of the study are presented. In Section 2, the spatial data used to map energy consumption are presented. The procedures for calculating intra-urban energy consumption by source and end use are described. The results from the proposed model and a comparison to recorded consumption data are included in Section 3. Finally, the conclusions of this study are given in Section 4.

1.1. Study area

Belo Horizonte is a Brazilian municipality, founded on 12 December 1887 as the political and administrative capital of the state of Minas Gerais. The municipality is located at 19°55′S and 43°56′W and has an area of 331 square kilometers. The locations of the state and the municipality are shown in Fig. 1.

According to the 2010 Census, the population of the municipality is 2375,444, which is approximately 12% of the total population of Minas Gerais. It is the sixth most populated city in the country and the executive municipality of the Belo Horizonte Metropolitan Region (RMBH), which consists of more than 32 municipalities and has a total population of 4830,451 (IBGE, 2010). This city was chosen because a substantial amount of consolidated

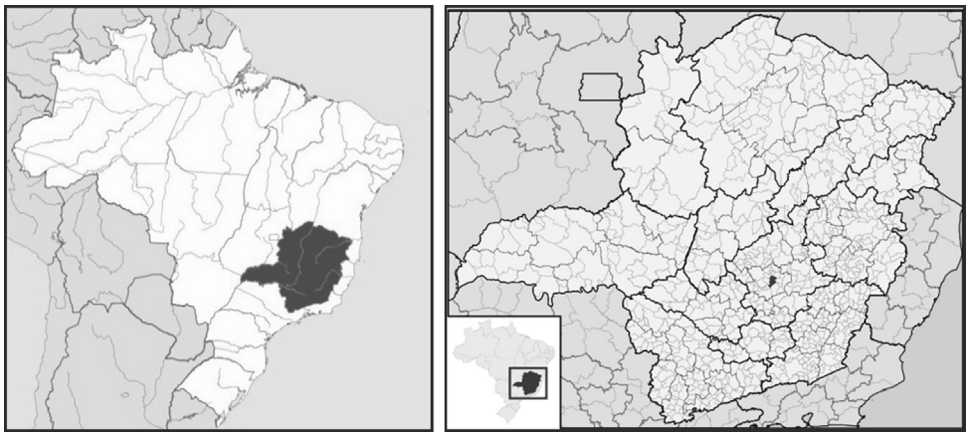

Fig. 1. Locations of Minas Gerais (Retrieved from http://pt.wikipedia.org/wiki/Ficheiro:Brazil_location_map.svg#filehistory.) and Belo Horizonte (http://pt.wikipedia.org/wiki/Ficheiro:MinasGerais_Municip_BeloHorizonte.svg.) in Brazil.