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Impact of urban residences on energy consumption and carbon emissions: An investigation in Nanjing, China

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ABSTRACT

This paper analysed the energy consumption of urban households in Nanjing and the influencing factors in this energy consumption. The households studied were located in three urban districts of Nanjing: the city centre, a spontaneous residential area around the old city, and a planned satellite town. A questionnaire was used to obtain information on building characteristics, household characteristics, use of domestic appliances, and fuel oil consumption. Energy use was analysed by conversion into CO_2 emissions. The study found that household use and transport were the two main contributors to domestic energy consumption. Household electricity consumption showed obvious seasonal characteristics (higher in summer than in other seasons), while transport energy consumption showed geographical characteristics (the old town had lowest transport energy consumption). Highly efficient devices may not render buildings more energy-efficient, so architects should seek to reduce the need for such devices. Energy consumption and income were generally positively correlated. Family structure also influenced energy consumption, with high-income families and small families consuming more energy per capita. Economic and social factors were found to be equally important to technical factors for energy efficiency. Based on the findings, some possible policies are recommended.

1. Introduction

Sustainable strategies for energy can be considered from two sides – energy production and consumption. Fig. 1 shows that from the production side, the focus is on alternatives to fossil fuel, while on the consumption side the focus is on energy efficiency. The strategies from energy producers are more influential than those dealing with energy consumption, because energy providers are much more centralised compared with thousands of consumers. However, there are two reasons why we cannot overlook energy efficiency in energy consumption. One is that existing technologies for renewable energy are not yet sufficiently economically efficient, which prevents them from replacing fossil fuels. It is impossible to generate enough energy by solar technology at the local site in Asia's high-density cities (Close, 1996). Another reason is that the amount of energy produced is determined by energy demands. Thus the effect of reducing energy demands is marked in terms of carbon emissions reduction, especially in the coming decades.

China's energy consumption and CO_2 emissions have increased very rapidly in the past 30 years and especially in the past decade, making China the second largest energy consumer and the largest CO_2 emitter in the world (Chinanews.com, 2011; IEA, 2010). Responding to growing challenges on energy demand and CO_2 emissions, the Chinese government has been trying to develop strategies on sustainable energy in recent years (Xu, Sun, Wennersten, & Brandt, 2010). For the first time, the Chinese urban population exceeded the rural population in 2011. In that year the urban population reached 690.79 million, representing 51.27% of the total population, while the rural population was 656.56 million, representing 48.73% of the total (National Bureau of Statistics of China, 2012b). In general, energy consumption in urban cities is an important part of strategies on sustainable energy, since urban cities are currently the main energy consumers worldwide (Crompton and Wu, 2004). In addition to architectural design and spatial planning, the pattern of energy consumption in households due to human activities is important for the total energy demand and associated CO_2 emissions in urban cities (Chen, Yoshino, & Li, 2010; Mihalakakou, Santamouris, & Tsangrassoulis, 2002; Hickman and Banister, 2007). Therefore, it is necessary to analyse household energy consumption in urban areas of Chinese cities and apply this knowledge in devising strategies on sustainable energy and climate change.

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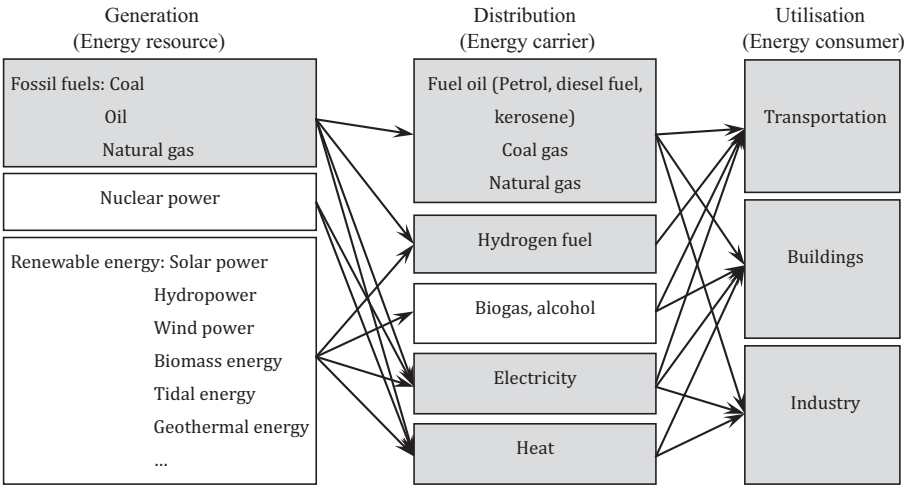

Fig. 1. Diagram of energy flow from generation to utilisation, showing that fossil fuels cannot be quantified at the consumption side of the chain. Source: Made by Zhenhong Gu).

Roughly a billion Chinese (or more than 90% of the population) live in only a little more than 30% of China's land area (Heilig, 1999). Fig. 2 illustrates the geographical concentration of the Chinese population and the increasing concentration of population in the eastern portion of the country since its rapid growth began in the mid-20th century (Wang & Wei, 2010).

Apart from a few megacities such as Beijing, Shanghai, Chongqing and Guangzhou with a population of over 10 million, the majority of China's major cities, i.e. provincial capitals and cities specially designated in the state plan, have a population of 5–10 million. With 8 million permanent population on 11 November 2010, Nanjing, the capital city of Jiangsu Province and located in the Yangtze River delta region, is a representative large city (Nanjing Statistic Bureau, 2010). Nanjing City is located at 32°02′38″ N, 118°46′43″ E, in a region where the coldest monthly temperature in January is 2.4 °C and the hottest monthly temperature in July is 27.8 °C, with an annual average of around 15.5 °C. The average relative humidity is 77% (CDC, 2011). Fig. 3 shows mean monthly temperature in Nanjing during the period 1971–2001.

In general, China can be divided into seven zones according to climate characteristics (Fig. 4). The climate in Nanjing is characterised by hot summers and cold winters, the typical weather in Zone III in Fig. 4 (Ministry of Construction of China, 1993). The coldest month of the year is January, with an average temperature of 2.4 °C, and the hottest month is July, with an average temperature of 27.8 °C. As in Zone II, both indoor cooling in summer and heating in winter are needed in Nanjing according to national standards (Ministry of Construction of China, 1993).

Before China's reform and opening-up policy in 1978, most residential buildings were constructed in the former Soviet Union style to meet basic living needs (Ma, 2002). However, most of these old buildings have now been reformed or replaced and it is difficult to find any surviving examples.

In the period 1976–1990, new residential buildings were constructed to meet higher living standards, but such development was mainly restricted to the old city, an area of 44.65 km^2 within the Ming Dynasty city wall (Nanjing Urban Planning Bureau, 2006a). In the 1990s, some large residential communities, e.g. Longjiang and Zhongbao, were developed outside Nanjing's old city without careful planning. The lack of business and commercial buildings means that the residents of these areas have to work in Nanjing downtown (Yeh and Yuan, 1986).

After 2000, new satellite towns and residential areas began to be developed outside the old city and urban planning was applied appropriately in this development (Nanjing Local Chronicles Compilation Committee, 2011). Hexi is a new town that was planned to be the second centre of Nanjing due to its location close to the old town. The first two of Nanjing's subways were constructed across this area, and many business and commercial buildings were planned for the central area of Hexi (Nanjing Urban Planning Bureau, 2006b). A large quantity of residential communities were planned and constructed in Hexi during the first decade of the 21st century.

Our survey on energy consumption was carried out in three different urban areas, representing the three phases of residential development in Nanjing since 1978. These areas were: Zhujiang Road (Site A) in the old city, Longjiang area (Site B) in the unplanned residential area, and Hexi area (Site C) in the planned satellite town (Fig. 2). Basic information about the households and their energy consumption was collected in the three areas. Various

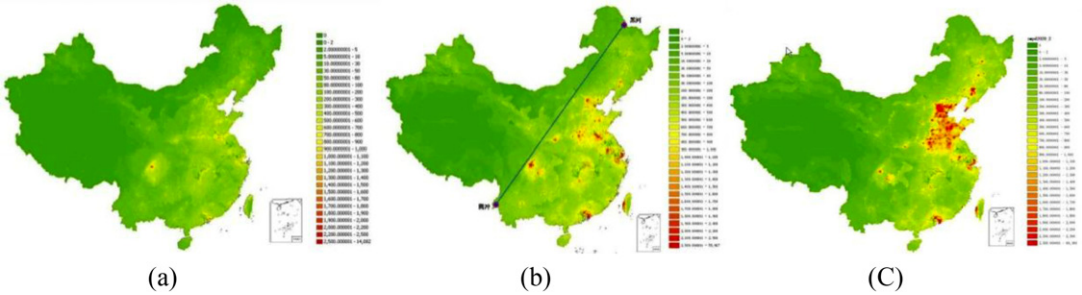

Fig. 2. Changes in population density in China showing an obvious trend of population concentration in eastern coastal regions (Wang & Wei, 2010,). (a) Density in 1949; (b) density in 2000; and (c) density in 2020 (projected).