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Energy Consumption and Space Density in Urban Area

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Abstract

Energy consumption is a technical issue or a spatial structure issue? Aim of this paper is to study the impact of population density and energy consuming density to space together on energy consuming with urban districts of Beijing. The author of this paper puts two kinds of factors including economic and technological ones, and urban space context factors with energy consuming together into a model. LMDI method will be employed to do the analysis. It is concluded that non-economic and non-technological factors were also significant to reduce energy consumption. Even population density did not contribute to reduction of energy consuming, when it was combined with energy consuming density to space together, the contribution was efficient. It indicates that compacted urban space with low-carbon city is the most efficient way to reduce energy consuming in urban areas.

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Keywords: Space density; Compact city; Energy consumption

1. Introduction

With urban areas enlarging, huge amount of energy has been consumed. While city transferring from industrial city to service one, energy consuming has been become complicated. Especially there are more and more mega cities emerging in China, where the population grows rapidly and the living standard has been improved very fast, the usage of energy is quiet different from traditional industrial city. In fact, urban space and the density of spatial utilization have already been caused for using more energy. However, the previous studies have discussed the consumption of energy mostly on second industry, which is obviously lagged the demand of city development. When low-carbon city has been encouraged, non-economic factors should be considered seriously. Space density such as population density and

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energy consuming density to space will be the main topic in this paper. They are very important factors to help us achieve the goal of energy saving and mitigation of carbon.

Newman and Ken Worthy believed that population density and urban land use were the main factors which influenced the energy usage in transportation system（Newman and Ken Worthy, 1990）[1]. Some scholars found that transit tools in different cities made a big difference for using energy, which improved that internal energy consumption should be connected to public transportation, as well as the pattern of city space（Paul Coevering, 2006；Schwanen, 2005；Stead, 2001) [1]. David Brown-stone made a joint model with combining living density with the use of vehicles and fuel in order to make a conclusion that if living density per square mile decreased by 1000 people, the car travel distance for family would correspondingly increased by 1200 miles（David Brown-stone，2009) [2]. Zheng et. also discovered a significantly negative correlation between the population density and taxi carbon emissions together with bus carbon emissions, namely if the living density per square mile increased by 1000 people, taxi carbon emissions of family would decrease by about 0.424 tons, which were about 0.837 tons for bus carbon emission（Zheng, Kahn, Wang and Glaeser, 2010）[3]. In the meantime, enlargement of urban space will stimulate the residents to choose more and more independent houses, which may finally lead to a rapid increase in carbon emissions. It is obvious that transit and land use in city affected energy consumption. However, they are difficult to describe the degree of effectiveness by combining factors together.

On average, energy consumption in city has a strong relationship with the growth of economy, population size and the space expansion. In fact, different factors have been mixed together and have made complex effects on each other in which some of them cancelled out each other while some reinforced each other. Pfaff, etc assumed that the influences of the growth of economy, expansion of population size and urban space expansion were mutually impacted each other (Pfaff, Alexander, el., 2004) [4]. They finally determined energy consumption in urban areas in an overall way. However, all the studies as above did not take those complex effects into consideration and only observed the influences on energy consumption from one aspect. Because urban space is somehow connected with transit utilization and resident living standard, the former was basic reason to consume more energy. As a result, the author of this paper will decompose aggregate energy consumption into economic and technological factors and factors of space density with population density and energy consuming density to space, and then put them into a combined model to observe the impact of these factors on energy consuming in order to compare the significant impact of urban space density with economic and technique factors.

Beijing has large energy consumption, ranking the second in China following Shanghai. Except for coal, the terminal consumption of energy consists of natural gas, liquefied petroleum gas, fuel gas, coal gas, electricity, heat, oil, geothermal energy, solar energy and other renewable energy. From 1995 to 2000, the growth rate of energy consumption per year was 2.6% while the rate was 5.3% during 2001-2009. Although the population in municipal districts had increased from 5.8603 million in 1985 to about 11.5808 million in 2008, population density declined. It is because the area had experienced an expansion from 2738 square miles in 1985 to 12187 square miles in 2008. As a result, density of energy consuming increased rapidly. Obviously population density and energy consuming density had negative relationship, it is necessary to be analyzed further for them.

2. Methodology and Data

Analysis of decomposition index will be adopted in this article to explain the contribution of urban space density with population density and energy consuming density to space to the total consumption of energy. Owing to be the requirement of one united expression with various variables, Logarithmic Mean

Division Index (LMDI) will be employed to satisfy this requirement and efficiently solve "remains" and "0" value problems during the process of decomposition.

When LMDI is used, two kinds of factors with five variables will be applied to do the analysis: one kind is economic and technological variables, which included: *Growth of Economy (GDP)*, *Energy Consumption of Each Output Value (ENEOV)*, *Energy Consumption of Per Capita (ECPP)*. Another kind is space density variables, which is: *Population Density (PD)*, whose increase can improve the spatial utilization, would reduce the consumption caused by distance as previous studies. However, increase of population in defined area will also expand the use of energy when population value is multiplied with it. The *Reciprocal of Spatial Density of Energy Consumption (RSDE)(*energy consuming density to space), namely if energy consumption is assumed a constant, more size of city space means higher rate of energy utilization, which indicates the way in which city residents make use of energy within considering the economy, the living standard and the facility and whether there is any change if habitants choose a low carbon lifestyle, as well as adjustment of urban industrial structure is also included in order to optimize the economic growth. The higher the value is, the saving development is. The value can be used as a comprehensive index to show the development stage of each city which influences the current consumption of energy. The contributions of second kind of variables to total energy consuming will be the topic of this paper.

While E is taken as total amount of energy consumption, P for the total population, A for the size of municipal districts and of course GDP for regional gross product. In the equation of LMDI, correspondingly with variables as above, δE represents the total change of energy consumption; δE_g represents the contribution of GDP makes to energy consumption; δE_{ep} represents the contribution of energy consumption per person (E/P); δE_{eg} indicates the influence of unit output value (E/GDP); δE_{pa} represents the contribution of population density (P/A) makes to energy consumption; δE_{ae} represents the effectiveness of energy consuming density to space to energy consumption. In order to make the affection comparable, all factors should be commuted into standard coal. Thus different industries and different types of energy are not necessary to be distinguished. The decomposition equation can be shown as follows.

$$E = (GDP\frac{E}{GDP}\frac{E}{P})(\frac{P}{A}\frac{A}{E}) \tag{1}$$

$$\delta E = E^t - E^0 = (\delta E_g + \delta E_{eg} + \delta E_{ep}) + (\delta E_{pa} + \delta E_{ae}) \tag{2}$$

Due to be urban energy consuming happened mainly in urban area, compared to other studies, statistic data of total population, the area and the regional GDP and corresponding data within Beijing's municipal districts since 1985(from eight districts at 1985 to 16 districts at 2008) have been employed in this paper. Total energy consumption is composed by electricity, fuel gas, liquefied petroleum gas (coal using mainly happen in suburbs which is not taken into account in this paper), and motor petrol used by buses and taxies are commuted into standard coal. All data source is from China City Statistical Yearbook, although some of them are adjusted by Beijing Statistical Yearbook. When it comes to motor petrol, 22560kg each bus and 8432kg each taxi have been used to calculate standard coal per year. Due to be data in the year of 1993 and 1994 were missed, the years of 1993 and 1994 will not be included during calculating.

3. Results of analysis

Since 1986, each year is used as t year of the year before, well each time t is 1 (data of 1993 and 1994 was missed. t is considered 3 from 1992 to 1995). After calculation variation each year compared to the year before, results will be shown as Table 1. Urban space was enlarged immediately during 1989-1990

and 2000-2001 owing to be administrative boundary adjusted. In order that the trends changed smoothly for describing the distribution of urban space density to energy using exactly (The administrative boundary is important to define urban space because of the authority), three periods will be classified (see Table 1).

Table 1 Annual average rates of contribution from two kinds of factors to energy consumption（%）

	δ Eg/ δ E	δ Eeg/ δ E	δ Eep/ δ E	δ Epa/ δ E	δ Eae/ δ E
1985-1989	331.19	-231.19	13.76	86.24	-100.00
1990-2000	190.32	-90.32	41.90	16.53	-58.43
2001-2008	553.02	-453.02	68.70	53.02	-121.73

Data source: China City Statistical Yearbook (1986-2009), Beijing Statistical Yearbook (1994-1995, 1998-2001)

Table 1 describes three periods of energy consumption. There are two kinds of factors, the former three ones indicate economic and technological effectiveness, the later two factors indicate space density ones. During the first period 1985-1989, economic and technological factors raised 113.76% of energy consuming annually (including 331.19% by GDP growth, -231.19% by technology progress and 13.76% by residents living improvement); while population density raised 86.24% and the contribution of energy consuming density to space was -100.00% yearly. The last one contributed energy consumption reduction obviously. During the second period 1990-2000, energy using values became smaller than at the first period. But the former three factors made 141.90% energy consumption, more ratio of energy consumption than at the first period. The later two factors made -41.90% of energy consuming, especially the contribution of energy consuming density to space to total energy consumption made more reduction of energy using than at the first period . During the third period 2001-2008 with preparing Olympic Games, the former factors made only 31.30% energy consumption raising, the later two factors made 68.71% of energy reduction, the last factor still made more reduction than at the previous periods.

No doubt that with low-carbon city, the factors which made reduction of energy consuming contributed more and the ones which made rising of energy consuming contributed less. While, the changes of factors contributed to reducing energy consumption were more significant than increasing energy consuming ones. Particularly, the last factor was interesting. When population density decreased, spatial density of energy consumption increased. However, when more population density made more energy using, more Reciprocal of Spatial Density of Energy Consumption (energy consuming density to space) contributed reduction of energy consuming. It was a double-sides indicator. The former indicated the space enlarging with less population density which contributed more energy consumption. The later indicates the low-carbon city with low-carbon life and clear production which contributed less energy consumption. When both the two factors have been combined together, it makes compacted city with energy-saving and low-carbon.

4. Conclusion

Growth of urban economy and improvement of residents' living standard are still the main factors affecting energy consumption. Anyway technological progress was main role in reducing energy consuming. Beside that, non-economic and non-technical ways have been more important to reduce energy usage.

4.1. Population density still increased energy utilization

Case of Beijing did not show the contribution of population density to reduction of energy using. It denoted that energy supply was not more enough to satisfy the demand of residents in Beijing. It can not provide evidence for the findings from Newman and Ken Worthy. But if combination of population density and space density to energy was considered, the result indicates that population and space density to reduction of energy using is effectiveness.

4.2. Compact City Is Necessary

Among the factors above, more significant factors of contributing reduction of energy consumption are contented urban space. When low-carbon city is discussed, the influence from these factors will become critical. Owning to be less investment and shorter term of return than economic and technique ways, a compact city by increasing the density of population and improving urban development in a smart way should be encouraged. Because low-carbon city can be achieved easily by urban planning, urban management, urban construction, and urban housing policy, etc. Therefore, multiple ways are always efficient than some sole ways. It is the mission of the whole city.

4.3. Low-carbon city is important

Low-carbon is highly potential for the reduction of greenhouse gas emissions by conserving energy. Low carbon production and life style will definitely be one of the most important way to save energy by advocating low carbon production and life style in all aspects such as change the ideological, the concept to survive and details in life, as well as improving the energy utilization by optimizing the structure of energy use.

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