Clean energy utilization technology in the transformation of urban existing residence in China

Li Zhao
China Academy of Building Research
Wei Chen
North China University of Science and Technology
Qiong Li (hdliqiong@163.com)
North China University of Science and Technology https://orcid.org/0000-0001-9199-9865
WeiWei Wu
China Academy of Building Research

Research

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Abstract

Clean energy substitution technology of existing residential buildings in cities is an inevitable choice for sustainable development and low-carbon ecological city construction. In this paper, the current status of energy-saving renovation and renewable energy application of existing residential buildings in various cities in China is summarized by using statistical method. The geographical distribution of clean energy power generation in primary energy production has been deeply explored in China. According to different climatic division of urban existing residence, the clean energy production and consumption are analyzed and predicted based on STIRPAT model. The results shows that the energy consumption of urban residential buildings in 2016 has increases by 43.6% compared with 2009. Clean energy has also increased from 7.9% to 13.4%. Different climate regions have different advantages in clean energy. Nuclear power generation is ahead of other regions in hot summer and warm winter regions, and wind power and solar power generation are strong in severe cold and cold regions. The results can provide basic data support for planning and implementation of clean energy upgrading and transformation system in urban existing residences in China.

1. Introduction

With climate change and economic development, Low-carbon communities in cities has become an important choice for all countries to achieve sustainable development[1]. At the general debate of the 75th session of the United Nations General Assembly, President Xi Jinping said that China aims to see its carbon dioxide emissions peak before 2030 and achieve carbon neutrality before 2060. According to the energy development target announced by the State Council, non-fossil energy accounts for 15% of total primary energy consumption by 2020. Revolutionary strategy on energy production and consumption in China (2016-2030) proposed that the demand for clean energy and the proportion of non-fossil energy to generate electricity will be 50% by 2030 [2]. In the future, China has a clear strategic goal and direction to replace fossil energy with clean energy. Clean energy includes renewable energy and some non-renewable energy. Renewable energy refers to energy that can be fully replenished after energy consumption, and produces no or only a small amount of pollutants, mainly including wind energy, water energy, solar energy, biomass energy, geothermal energy, etc.; Some non-renewable energy is also a clean energy that minimizes the production of pollutants or has been cleaned with specific technologies in the process of energy generation and consumption, mainly including nuclear energy, natural gas, clean coal, and clean oil. In recent years, the renovation of existing buildings has effectively promoted in China [3-7]. But there is a lack of applicable standards for the renovation in urban existing residence. The clean energy transformation in urban existing residence need to achieve standardization and large-scale.

At present, residential energy consumption accounts for a large proportion in all countries. By 2018, U.S. residential energy consumption has been the third largest end use sector since 1950. This year, the U.S. residential sector consumed almost equal amounts of natural gas (43%) and electricity (42%)[8]. The final energy consumption of industry, transportation and housing in German is about 25%; the energy consumption of residential sector in France is 36,870,000 toe, ranking the second in all industries[9]. In

2016, building energy consumption in China accounted for 20.6% of the total energy consumption[10]. In order to reduce the dependence on fossil energy, various countries and regions have successively promulgated clean energy. Clean coal technology is one of the effective methods to address coal associated pollution[11].The building clean energy substitution is a new requirement of green development in the process of urbanization in China. The energy consumption of urban residential buildings in China mainly includes heating energy consumption in northern cities, residential building energy consumption in cities across the country and air conditioning energy consumption In northern China[12-13]. The energy consumption of residential air conditioning in China is far lower than that in America. Through the detailed investigation of typical residential buildings in China and the United States, it is found that this huge energy consumption is mainly caused by "part time and part space" air conditioning [14]. Therefore, the existing alternative technologies of clean energy in urban residential areas mainly include renewable energy utilization and key technologies of cold and heat sources of existing buildings, clean power system and gas application technology of existing buildings.

Scholars have previously attempted to investigate energy consumption with statistical method and prediction model. In the 1970s, Ehrlich, an American scholar, proposed the IPAT (I = impact, P = population, A= fluency, T= Technology) equation to express the quantitative relationship between economic growth and resources and environment. Later, the above formula has been widely used in various fields [15-16], and at the same time, it shows certain limitations because of its few influencing factors [17-18] built STIRPAT model on the basis of IPAT model to supplement this deficiency. The model is revised by York et al[19]., and driven index data is obtained by statistical regression to support model prediction and analysis. STIRPAT model not only retains the relationship between driving forces in IPAT model, but also takes population, economy, technology and other driving forces as the main factors affecting the change of environmental pressure[20]. Ridge regression is a kind of biased estimation regression method for collinear data analysis to deal with the collinearity of independent variables. When the covariates are highly collinear, ridge regression has become the standard treatment method[21]. Many scholars have applied ridge regression in literature [22-25] to solve multicollinearity in practical problems.

In summary, the demand for alternative technologies of clean energy in urban existing residence is a new requirement for the development of ecological civilization in China. In this paper, statistical method is used to summarize the current situation of energy-saving transformation and clean energy application in urban existing residence in China under different climate division. The energy consumption of existing urban residential buildings is analyzed and predicted based on STIRPAT model, and the regression analysis of the functional relationship between the energy consumption of existing residential buildings and the influencing factors is carried out by using R software. An engineering application in Changdao, Shandong Province is addressed based on the clean energy efficient alternative technology in urban existing residence. The results provide basic data support for the planning and implementation of clean energy upgrading system in urban residential areas in China. The direction of clean energy utilization in low-carbon communities can be clarified and guided in the future.

The rest of this paper is organized as follows: Section 2 provides the materials and methods of survey and data analysis method. Section 3 presents the results and the model validation. Section 4 presents the analysis on an engineering application that is a demonstration project in Changdao, Shandong Province. Section 5 presents the conclusion and future directions.

2. Materials And Methods

2.1. Survey and research process

The types and quantity of clean energy are investigated in urban existing residence divided by different climate region. The outdoor environment and relevant clean energy potential data are collected and analyzed. Furthermore, important factors in the forecasting model of the strategy of efficient use of clean energy are determined in the urban existing residence. The survey and research process are shown in Figure 2-1.

2.2. Data analysis method

2.2.1. Architecture climate division in China

In order to adapt to local environmental conditions, the building area is divided according to climate. In the General design of civil buildings, the Architecture climate area in China is divided into seven main regions. In this paper, five climatic regions is simplified to divide the clean energy distribution, which shown in the Figure 2-2.

2.2.2. Prediction model

The influencing factors of building energy consumption in urban existing residence is established by STIRPAT model ,and ridge regression analysis is conducted on the model with R software. STIRPAT model is shown as:

$$I = a \cdot P^b \cdot A^c \cdot T^d \cdot e \qquad (1)$$

Because it is a nonlinear model. Take logarithm on both sides of the model equation.it is shown as:

$$LnI = Lna + bLnP + cLnA + dLnT + Lne \qquad (2)$$

where in Equation (2), *I* is energy consumption; *P* is population; *A* is economic development level; *T* is science and technology. *a* is model coefficient; *b, c and d* is the driving indexes of population, economy and science respectively; and *e* is the model error.)

3. Results

3.1The energy-saving transformation in urban existing residence

The construction area of old residential area in 31 provinces in China is 3.491 billion m^2, which in the severe cold region and cold region is 151,165.9 million m^2 before August 2015. After the large-scale application and promotion of project achievements, the energy saving and carbon dioxide emission reduction amount of in old residential areas in cold areas is only 10% of the existing old residential area in the severe cold region and cold region. The goal to reduce the building energy consumption ratio set as 10% compared with the guidance value, 600,000 tons of standard coal can be saved annually, 1.5 million tons of CO_2 can be reduced, 45,000 tons of SO_2 can be reduced, 400,000 tons of carbon dust can be reduced, and economic benefits and ecological efficiency can be achieved. Meanwhile, it significantly improves the livability level of urban existing residence.

the total annual utilization of renewable energy will be 730 million tce, including the utilization of commercial renewable energy will be 580 million tce by 2020, according to the 13th Five-Year plan for renewable energy development [26],issued by the NDRC in December 2016. By the end of 2017, the installed capacity of electric power in China was 1.78 billion kilowatts, of which the installed capacity of renewable energy power generation reached about 650 million kilowatts, which increased from 33.1% in 2015 to 36.6% in 2017. Wind power and solar photovoltaic power generation account for more than 10% of the power generation in Inner Mongolia, Gansu, Qinghai and other provinces, and become an important new power source.

The statistics of energy-saving renovation area of existing residential buildings in China during 2017-2018 are shown in Figure 3-1 From the Retrofitting of Existing Buildings Yearbook of 2018 [27]. In order to promote the revolution of energy production, consumption, and the construction of ecological civilization, the National Energy Administration organized various regions to prepare the development plan of new energy demonstration cities and new energy application demonstration industrial parks, which can give full play to the role of renewable energy in adjusting the energy structure and protecting the environment. The number of key development and utilization of renewable energy demonstration projects recommended by new energy demonstration cities in each province is shown in Figure 3-2. In different cities, the advantages of energy resources are different. The renewable energy mainly considered for development includes solar photovoltaic and heat utilization, shallow geothermal energy, biomass energy (waste power generation, etc.), wind power generation, air energy, marine energy, hydropower, etc.

3.2Energy load in urban existing residence

According to the statistical method of China Building Energy Conservation Association for the energy consumption of existing urban residential buildings, the energy consumption of urban residential buildings is mainly composed of the electricity consumption of household appliances and the consumption of natural gas, which is related to the level of urban development, the level of energy technology, the mode and concept of energy consumption of residents. The per capita energy consumption reflects the basic energy consumption of urban residents, which is positively related to the energy consumption of urban residential buildings.

As shown in Figure 3-3 and 3-4, the per capita usage of electricity and natural gas is increasing, while the per capita usage of coal is decreasing year by year. The per capita use of natural gas has increased by 142.4% since 2009. The per capita energy consumption of the whole country and cities is increasing, and the per capita energy consumption of the cities is higher than that of the whole country, but with the gap decreases , the per capita energy consumption of the whole country is higher than that of the cities in 2017. It can be seen that energy-saving transformation of urban buildings and utilization of clean energy technology have achieved initial results. Figure 3-5 shows that coal is the main source of fossil energy consumption in different region, while electricity and natural gas consumption is the most in cold region.

3.3. Clean energy power production by climate division

The clean energy data changes in the past years according to CHINA ENERGY STATISTICAL YEARBOOK 2018[28]. Specifically, it includes national power generation, nuclear power, wind power, solar photovoltaic power generation, and natural gas production. Data maps and Line charts are provided to explore the advantages of clean energy resources in various regions, providing support for the next step of alternative application of clean energy in urban existing residence.

As shown in Figure 3-6 and 3-7, the electricity generation in each region shows an upward trend. From high to low, the power generation is in the order of cold region, hot summer and cold winter region, severe cold region, hot summer and warm winter region and temperate region. Power generation in cold area is the highest, and the average electricity generation in cold region is 2.7 times higher than that in temperate region.

As shown in Figure 3-8 and 3-9, the hydropower generation in various regions has tended to grow slowly and steadily in recent three years. In hot summer and warm winter region, hot summer and cold winter region, and temperate region, the hydropower generation is more developed than that in other regions. Yunnan and Sichuan province are the best hydropower development due to geographical advantage, which located in the upper reaches of the Yangtze River Basin with huge terrain drop.

As shown in Figure 3-10 and 3-11, the nuclear power generation is mainly concentrated in coastal provinces, including Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan. From the perspective of climate division, nuclear power generation is the most abundant in the hot summer and warm winter region, with an increase of 73.3% from 2015 to 2017.

As shown in Figure 3-12 and 3-13, the wind power generation is mainly concentrated in Inner Mongolia, Xinjiang, Gansu, Ningxia, Hebei, Liaoning, Yunnan and other regions. From the perspective of climate division, the wind power generation is the most abundant in severe cold region, the wind power generation in severe cold region increased by 45.8% from 2015 to 2017.

As shown in Figure 3-14 and 3-15, Inner Mongolia, Xinjiang, Gansu, Ningxia and Qinghai are major provinces of solar photovoltaic power generation. From the perspective of climate division, solar photovoltaic energy resources are abundant in severe cold region and cold region, and the solar photovoltaic power generation capacity in the cold region increased significantly in 2017, with an increase of 261.9% compared with 2015.

In summary, it can be seen that: 1) the nuclear power generation capacity in hot summer and warm winter region is ahead of other regions, and the power generation capacity is increasing notably; 2) the wind power generation and solar photovoltaic power generation capacity are strong in severe cold region and cold region, and the power generation capacity is also increasing year by year; 3) the clean energy power generation in each region accounts for a small proportion of the total power generation; 4) the clean energy power generation in each region is positively related to the total power generation.

As shown in Figure 3-16 and 3-17, the natural gas supply areas exceeds $150\times10^{8}m^{3}$ in 2017 include Sichuan, Guangdong, Jiangsu and Beijing. The energy departments in Sichuan Province are encouraged in urban residential buildings to use multi-complementary mode of consumption, such as natural gas preferential price can be reduced to 2.2~2.3 yuan/m^3.Natural gas supply in each region shows an upward trend. Natural gas supply in each region ranks from high to low as cold area, cold area, hot summer and cold winter area, hot summer and warm winter region and temperate region. Therefore, the natural gas supply in cold region is the absolute advantage.

3.4 Regression analysis of urban residential energy consumption

The main influencing factors of urban residential energy consumption are total population, per capita energy consumption, GDP and energy consumption per unit of GDP. In this paper, the proportion of clean energy in the terminal energy consumption is added. According to the STIRPAT model in Section2.2.2, the energy consumption model of urban buildings is established as shown in Figure 3-18. Regression analysis is carried out with data from 2009 to 2016. Specific data are obtained from CHINA ENERGY STATISTICAL YEARBOOK 2018 [28], Statistical yearbook of urban and rural construction in China 2018.Beijing: China [29], 2012-2018 Annual Research Report on China’s Building Energy Consumption. Beijing: China [30], as shown in Table 3-1.

Table 3-1. Data for the model

year	Energy consumption of urban residential area (10^4tce)	Total urban population (10^4)	Gross Domestic Product (10^8yuan)	Energy consumption per unit of GDP (10^4yuan/10^4tce)	Urban per capita energy consumption (10^{-4}tce)	Proportion of clean energy in end energy consumption（%）
2009	23600	64512	349081	1.16	328	7.9
2010	24300	66978	413030	0.88	320	9
2011	25300	69079	489301	0.86	331	9
2012	26800	71182	540367	0.83	344	9.9
2013	28800	73111	595244	0.79	357	10.7
2014	30100	74916	643974	0.76	364	11.7
2015	32000	77116	689052	0.63	377	12.3
2016	33900	79298	743586	0.6	395	13.4

Firstly, multiple linear regression is performed on the data, and the multicollinearity of the data is obtained by Klein discriminant method. Therefore, multiple linear regression cannot be used, ridge regression is used as mentioned above. Ridge regression is a biased estimation regression method which is specially used in the analysis of collinear data. After running, the ridge trace is shown in Fig. 3-19.According to the value principle of *K* value (lambda value), this paper takes *K* value (lambda value) recommended by R software. $K = 0.01215678$，The regression equation is as follows:

$$
\begin{aligned}
Lny = 0.023898LnP + 0.006304LnGDP - 0.006651LnEPG + 0.058895LnEP \\
+ 0.037602LnCE + 10.235879
\end{aligned}
\tag{3}
$$

where, *P* is Total urban population, *GDP* is Gross Domestic Product, *EPG* is Energy consumption per unit of *GDP*, *EP* is Urban per capita energy consumption, *CE* is Proportion of clean energy in end energy consumption.

The results show that the coefficient of determination R^2 (multiple R-squared) is 0.9984 and 0.9950 after correction. The model has high goodness of fit and the model is established in Equation 3. The result is from large to small in order to their influence is per capita energy consumption, proportion of clean energy in energy terminal consumption, total population, energy consumption per unit of gross product and total population. The fitting results show that this factor accounts for a large and significant proportion in the influencing factors of existing urban residential buildings, which means that the utilization technology of clean energy will be a very important direction for the transformation of urban existing residence. Previous data analysis shows that the energy consumption of urban residential buildings increases year by year with the increase of GDP and energy consumption per capita. Compared with 2009, the energy consumption of urban residential buildings increases by 43.6% in 2016.Natural gas has also increased from 7.9% to 13.4%. But this still cannot meet the demand of energy consumption in urban residence.

4. Engineering Application

Our project team will further discuss the climate characteristics, energy resources, building types, use rules and control performance of urban existing residence. According to the principles of energy conservation and local conditions, the specific clean energy alternatives of urban existing residence in typical cities will be reasonably determined to meet the goals of Energy and Production and Consumption Revolution Strategy (2016-2030). At the same time, the clean energy utilization rate in the future transformation should be reasonably predicted.

As shown in Figure 3-20, the clean energy efficient alternative technology in urban existing residence is the first large-scale engineering application in Changdao, Shandong Province, which is divided into cold regions. The Changdao project contains 17 residential communities and an urban area of 2.45 million square meters. The demonstration area is approximately 4 square kilometers. According to figures 3-9, 11, 13 and 15, Shandong Province's dominant renewable energy resources include solar photovoltaic energy, geothermal energy, marine energy and biomass energy. Therefore, the efficient utilization strategy of clean energy in the urban existing residence in Changdao County is formulated, and the renewable energy is fully used as the heating source, that is, the renewable low-grade heat source combining the air source energy tower and the sea water source heat pump is used to realize the high-efficiency utilization of clean energy.

In addition to clean heating, Changdao County has electricity demand for household appliances, cooking, elevators, etc. It is recommended to comprehensively utilize clean power generation technologies such as solar photovoltaic power generation, wind power generation, and nuclear power generation to realize existing urban residential areas. The district energy supply of clean and the power system is upgraded.

5. Discussion

The geographical distribution of clean energy power generation in primary energy production has been deeply discussed in China. The proportion of clean energy in end-use consumption is increasing to meet the aims of carbon dioxide emissions peak before 2030. The proportion of clean energy consumption reflects the level of national energy technology. The statistical analysis of clean energy utilization in urban existing residence has been completed. The clean energy demand prediction model has been established, and the clean energy contribution rate in the urban energy consumption is analyzed based on the ridge regression method. The clean energy potential value analysis method has been clearly proposed based on the climate division.

However, clean energy usage in urban existing residence project application is not enough popular. The demand for clean energy is being measured and investigated in 2020. Based on the dynamic load characteristics of typical existing urban residential areas, combined with energy-saving and environmental indicators, a clean energy replacement technology that is applicable and efficient in urban existing residence is proposed, and a strategy for the efficient use of clean energy in urban existing residence is formulated aims of carbon dioxide emissions.

Declarations

Author Contributions: Conceptualization, Li Zhao.; methodology, Wei Chen. investigation, Qiong Li; writing—original draft preparation, Wei Chen.; writing—review and editing, Qiong Li.; visualization, Li Zhao. All authors have read and agreed to the published version of the manuscript.

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Figures

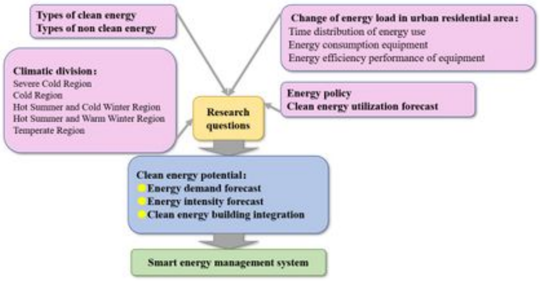

Figure 1

Figure 2-1：Survey and research process

Figure 2

Figure 2-2. Architecture climatic division in China

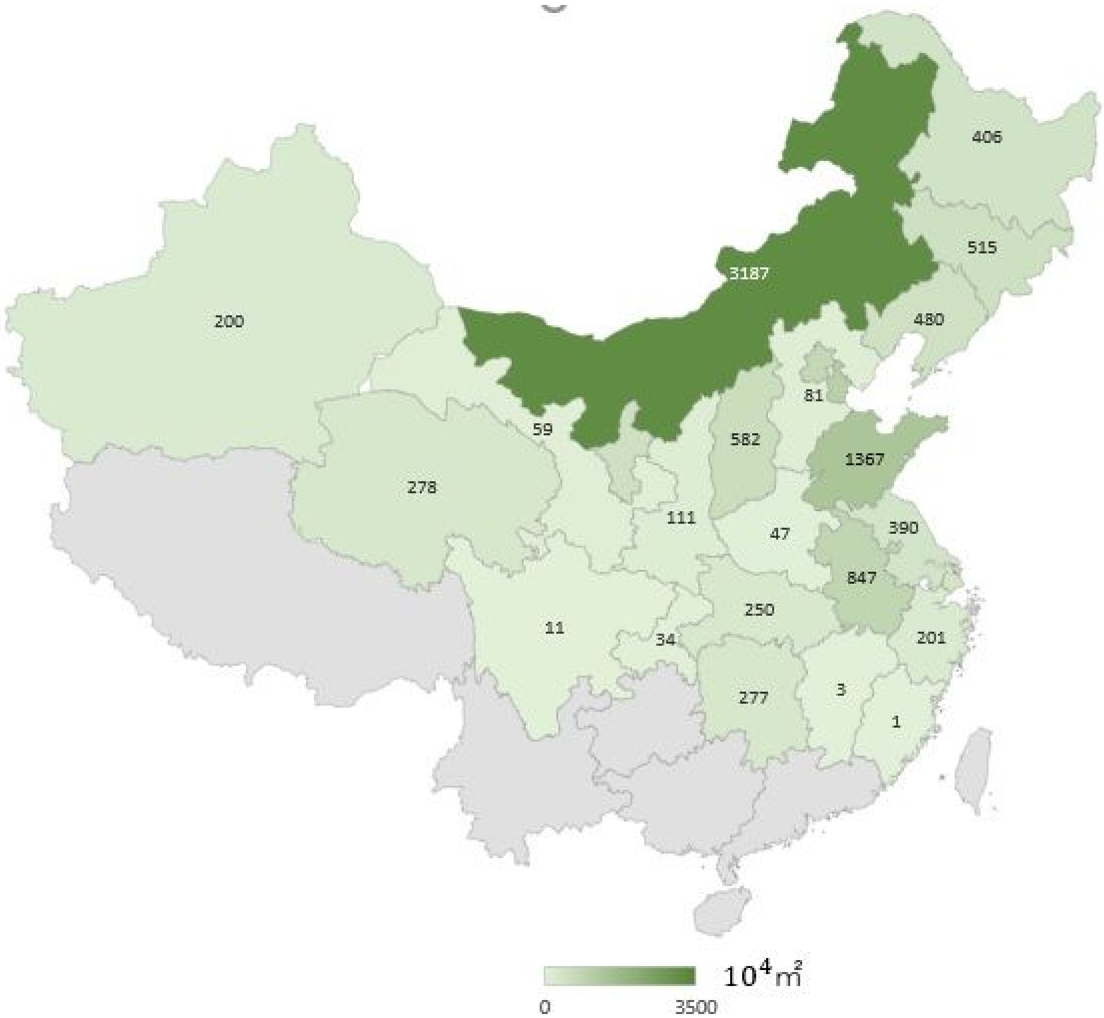

Figure 3

Figure 3-1 2017-2018 cumulative energy-saving reconstruction area of urban existing residential buildings in China. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

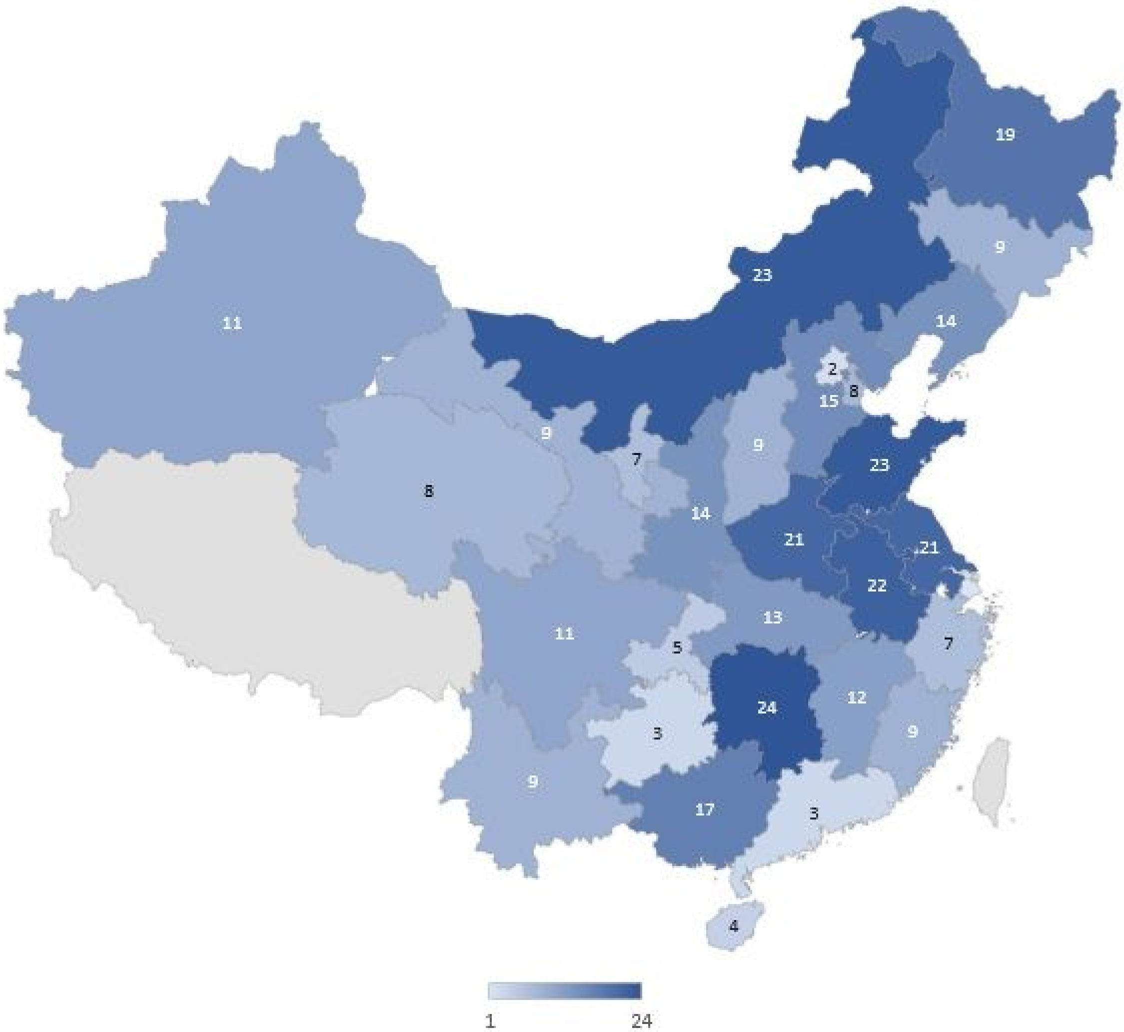

Figure 4

Figure 3-2 Number of renewable energy application demonstration projects in each province in 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

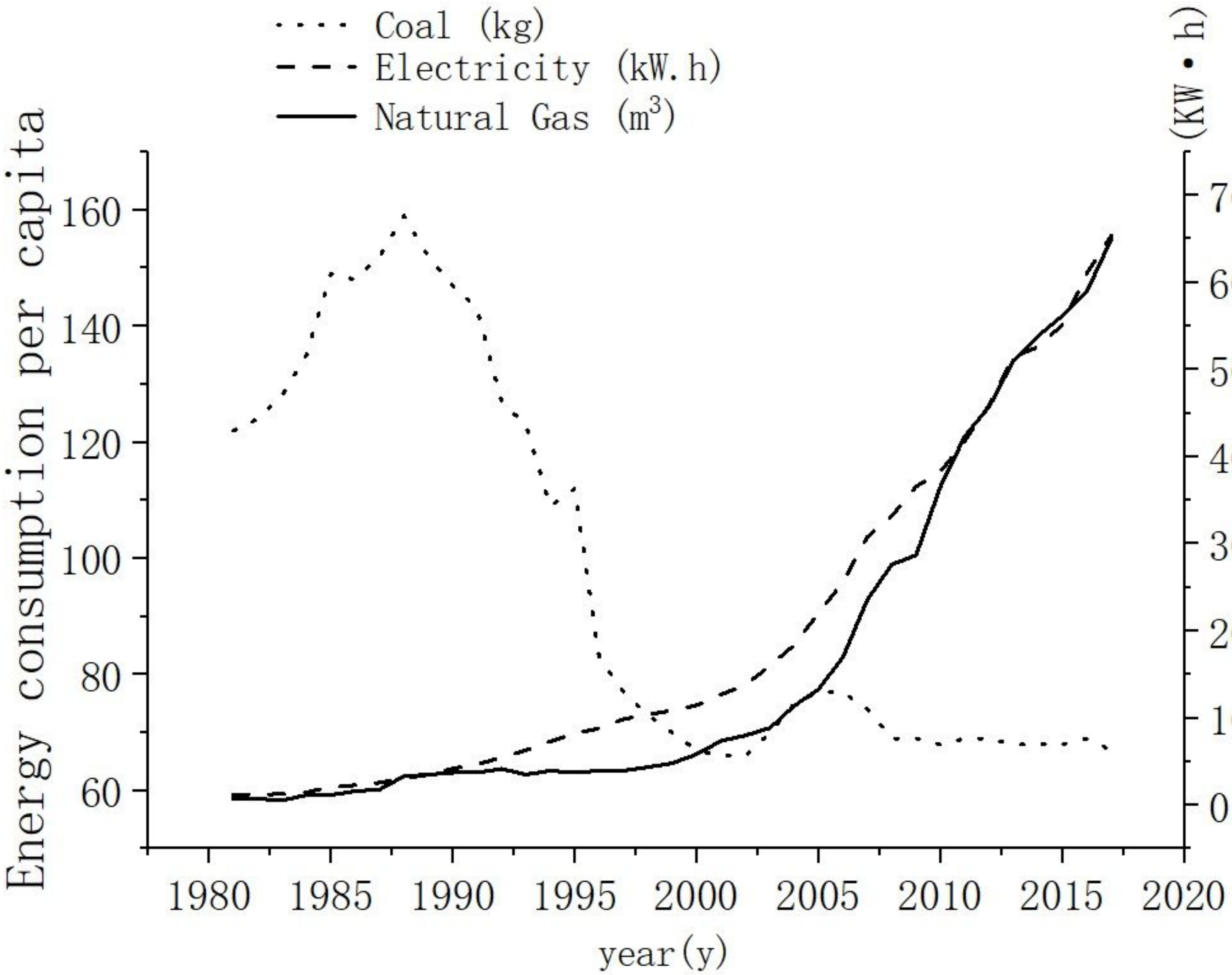

Figure 5

Figure 3-3 Per capita use of different types of energy

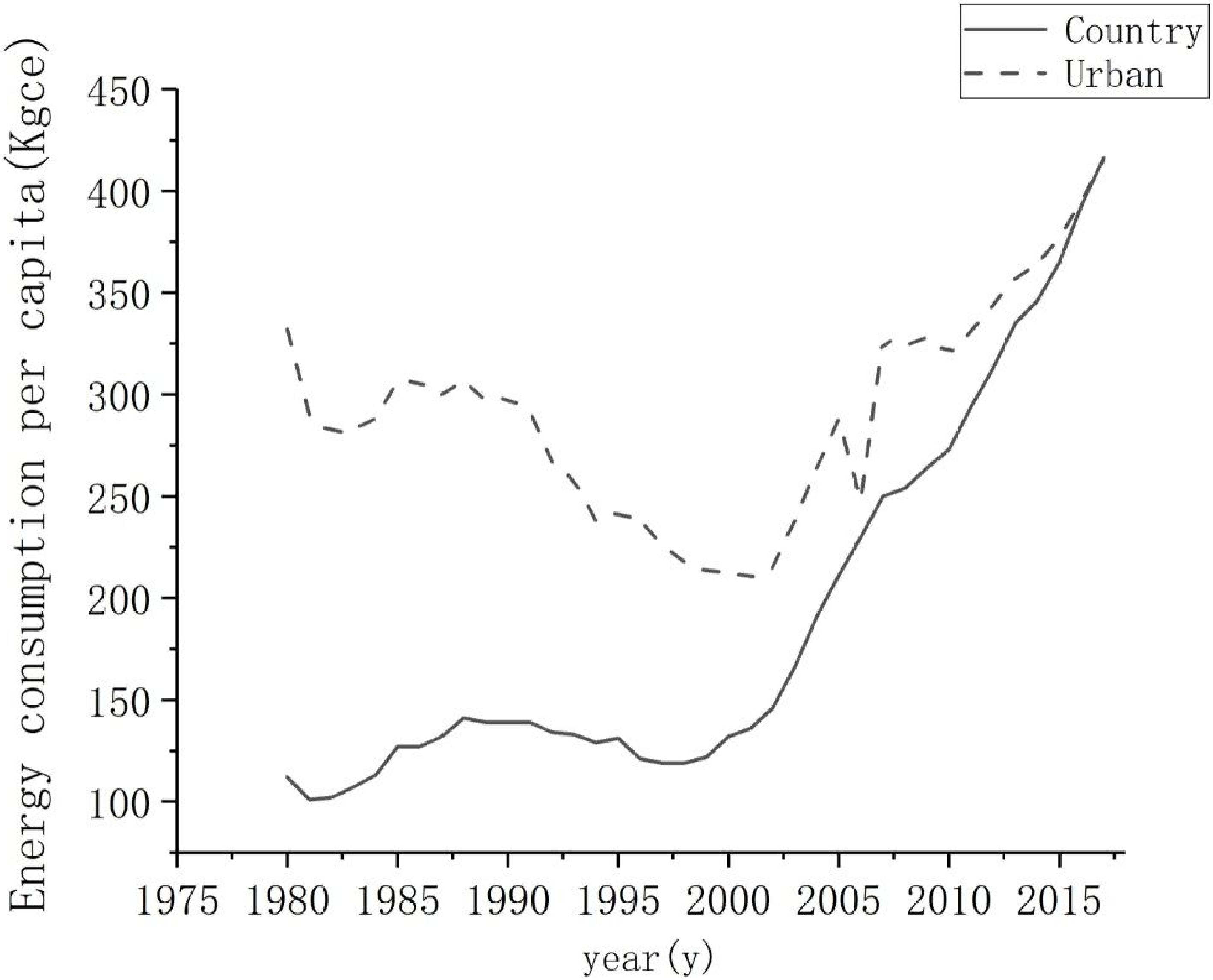

Figure 6

Figure 3-4 Country and Urban per capita energy use

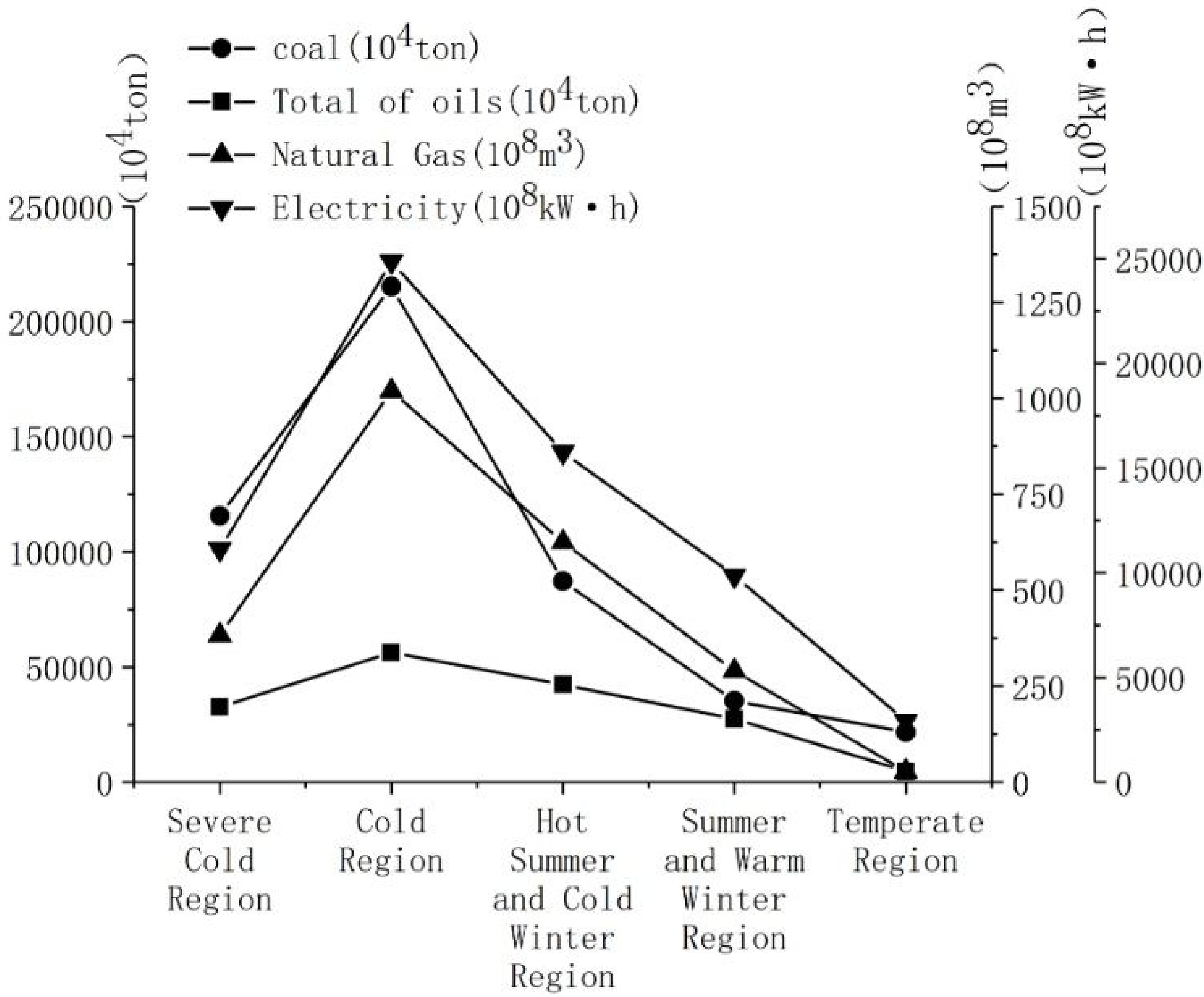

Figure 7

Figure 3-5 Different energy consumption in different climate region

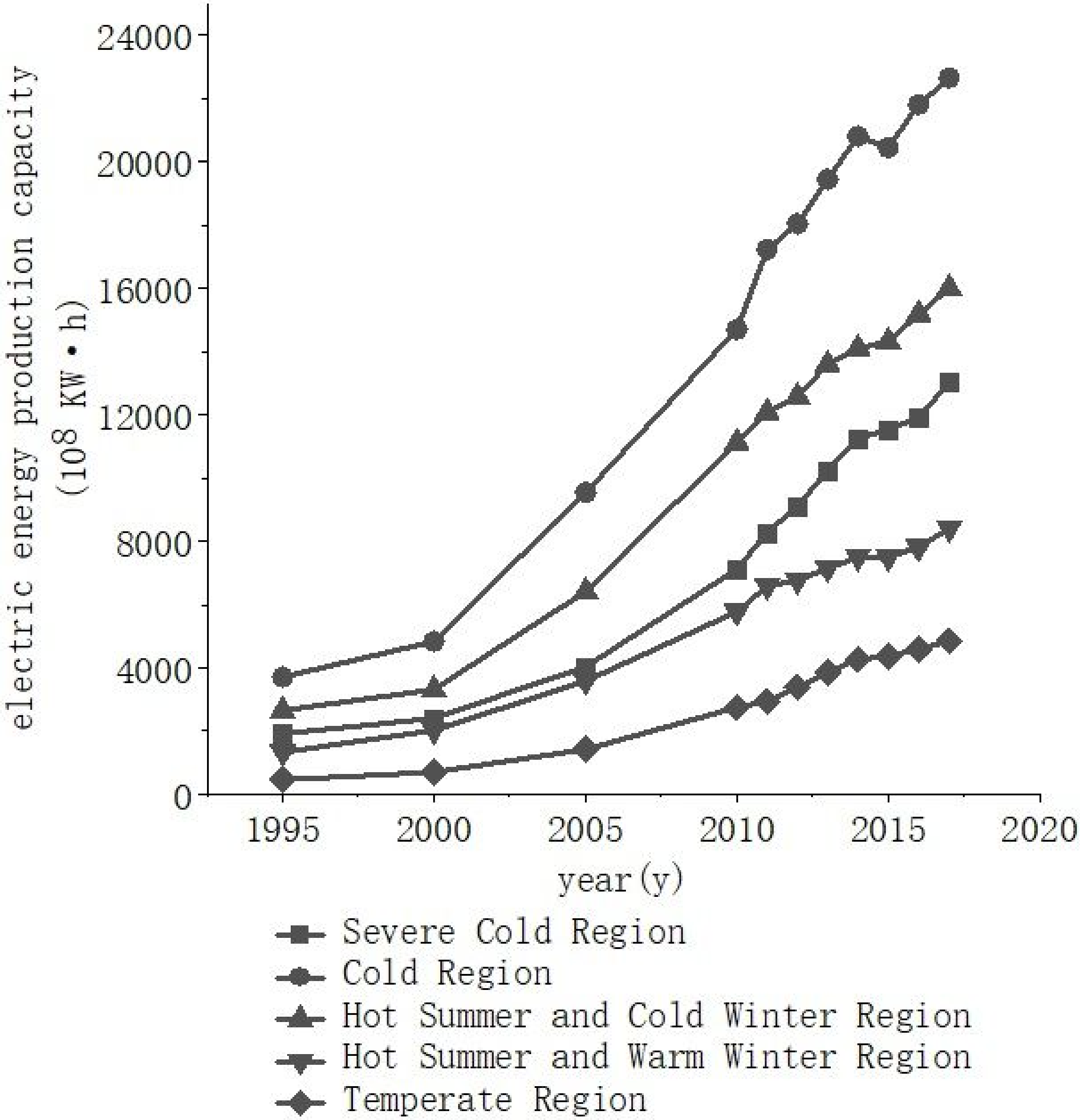

Figure 8

Figure 3-6 Power generation by region

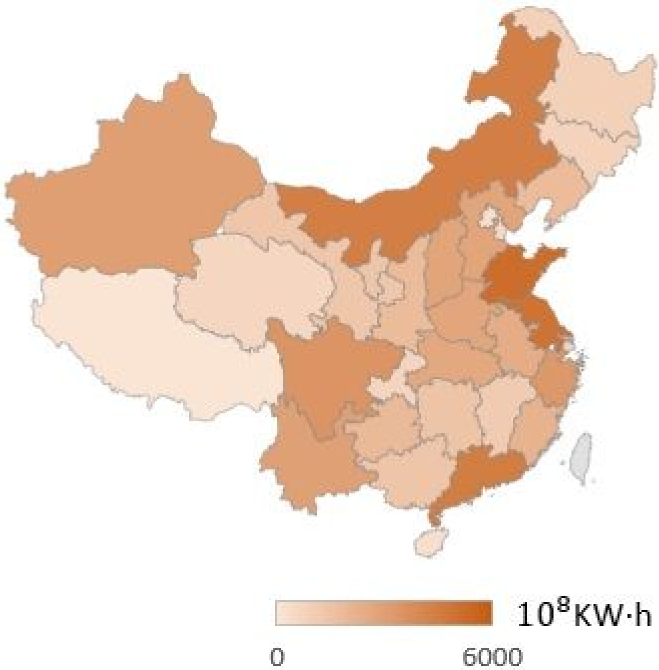

Figure 9

Figure 3-7 Electric energy production capacity of 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

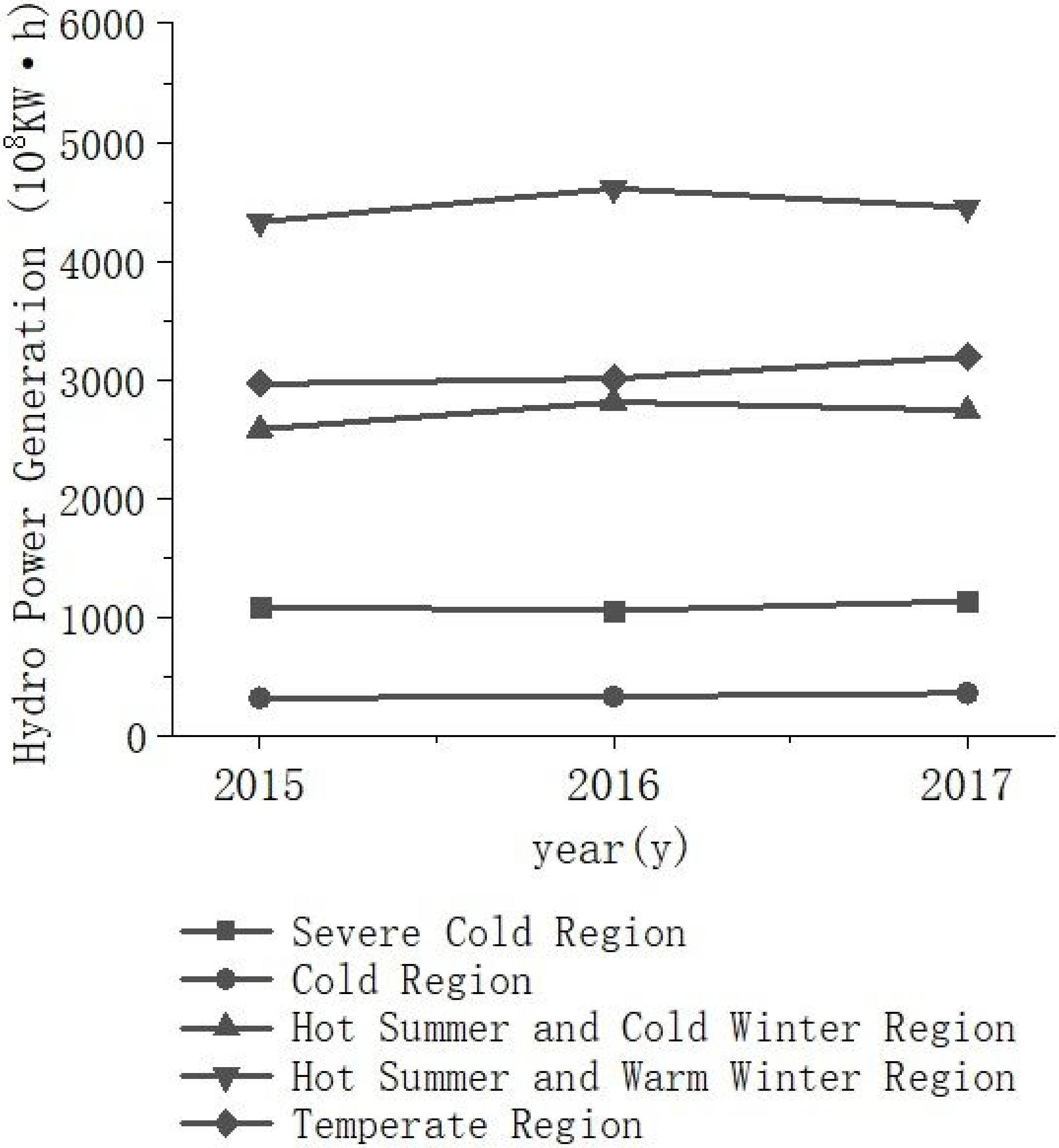

Figure 10

Figure 3-8 Hydropower generation by region

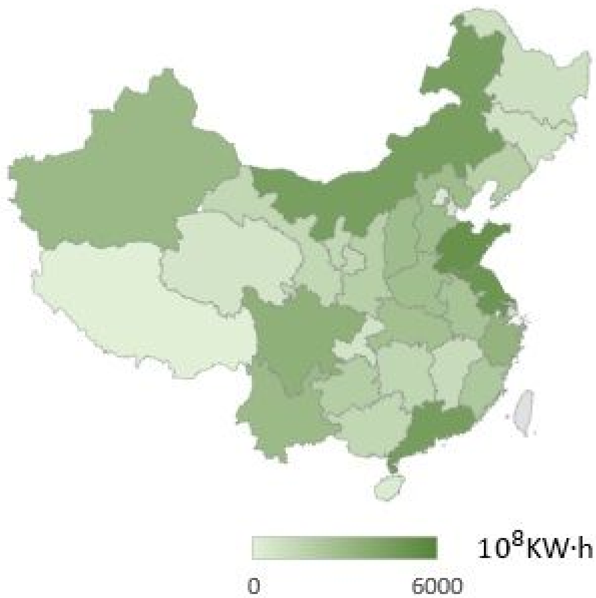

Figure 11

Figure 3-9 Hydro Power Generation of 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

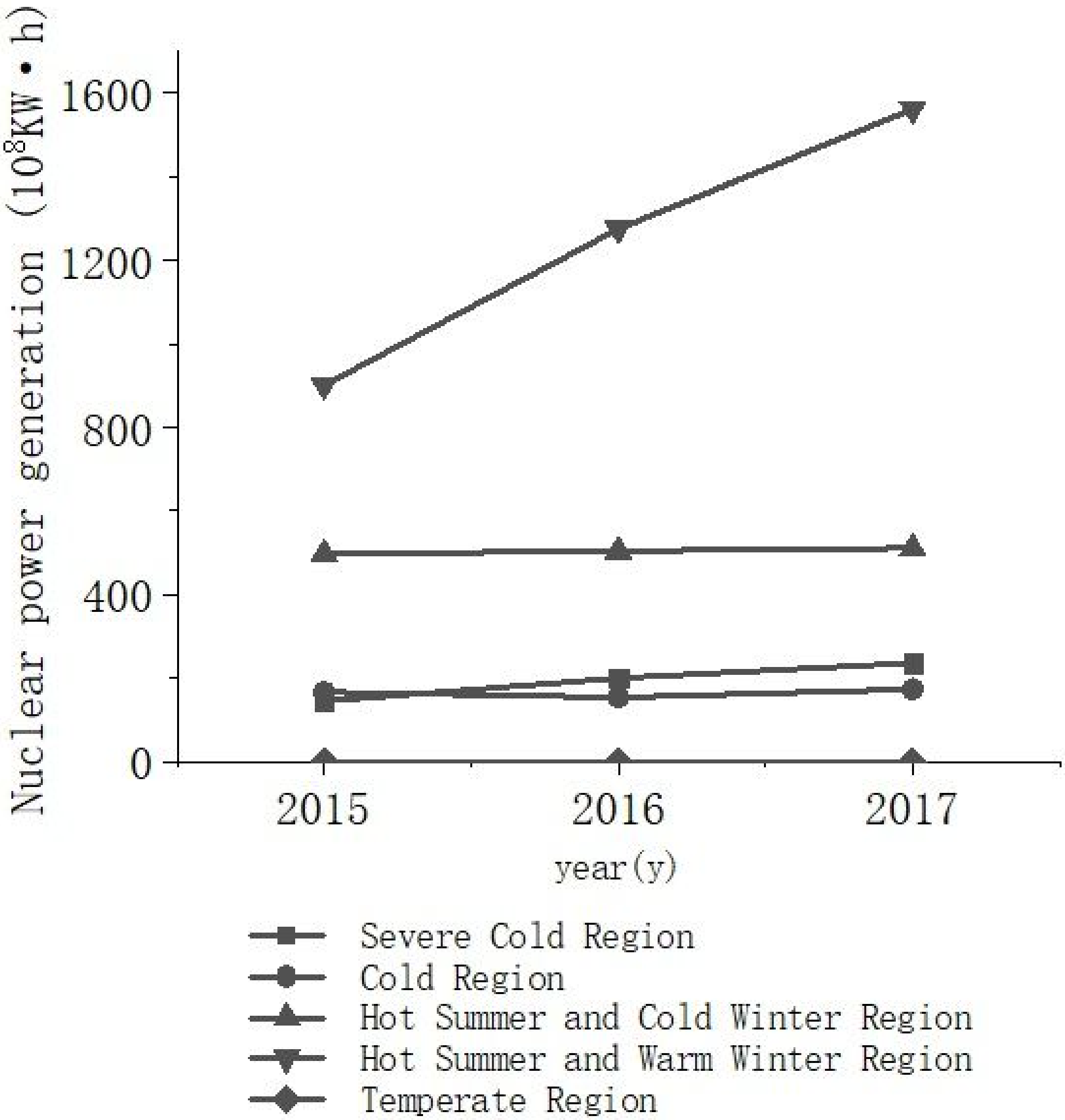

Figure 12

Figure 3-10. Nuclear power generation by region

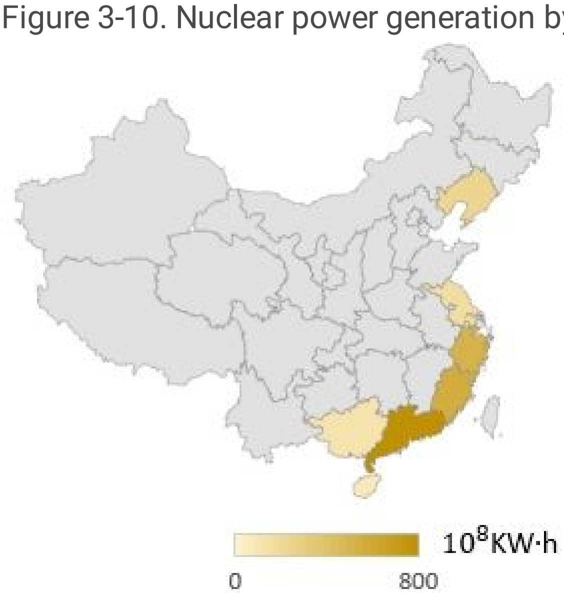

Figure 13

Figure 3-11. Nuclear power generation of 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

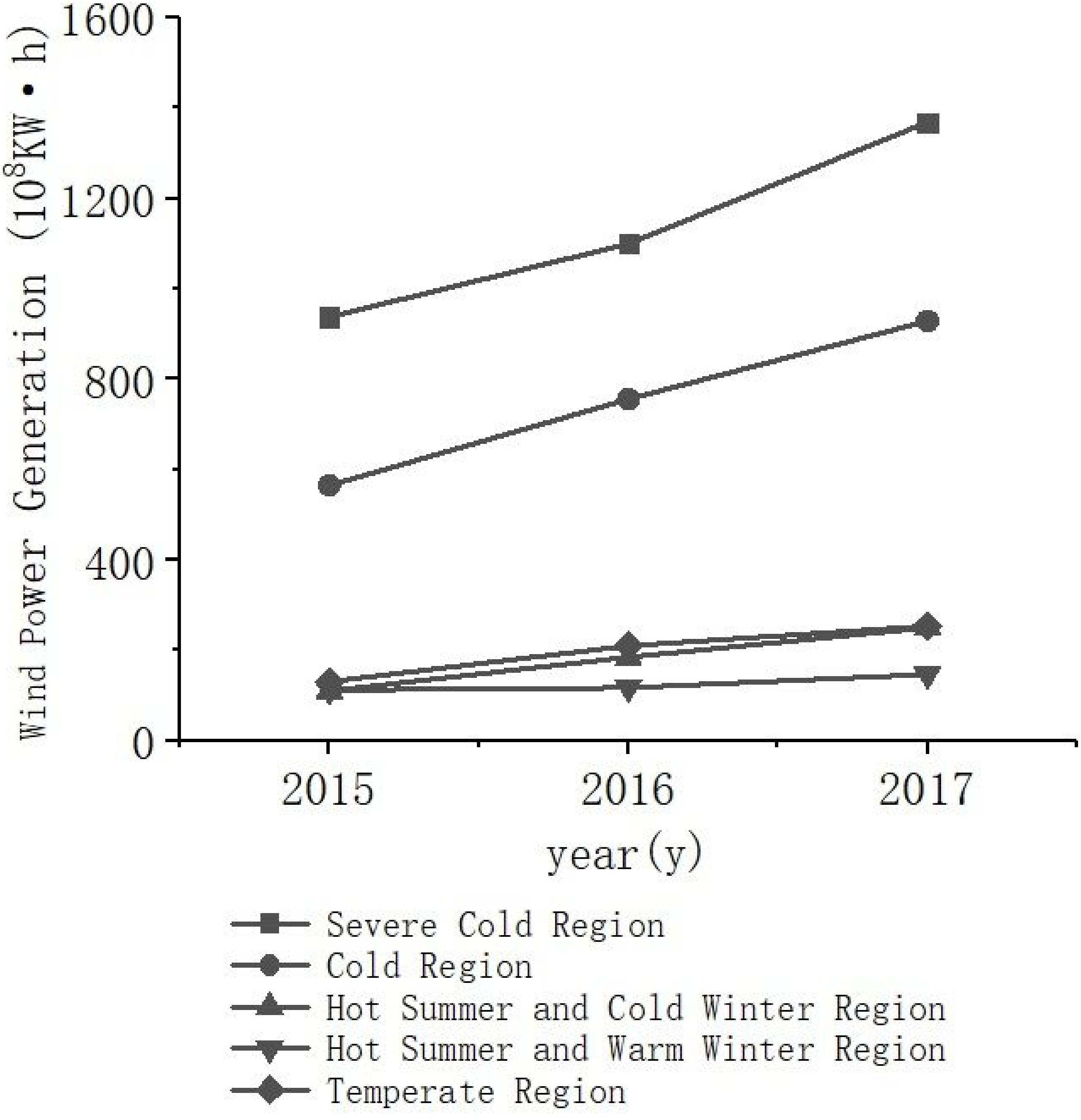

Figure 14

Figure 3-12. Wind power generation by region

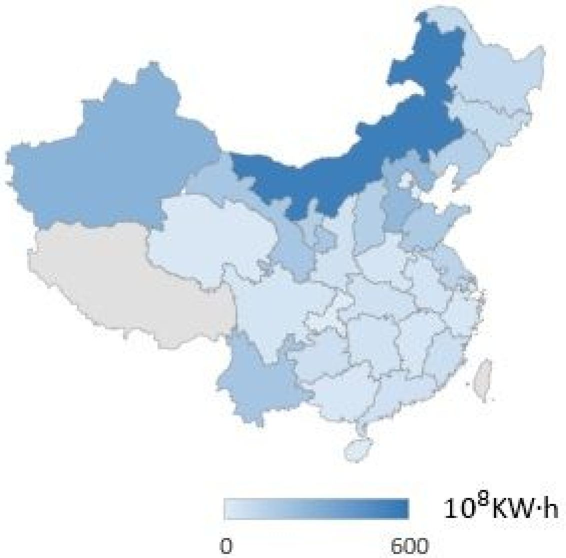

Figure 15

Figure 3-13. Wind Power Generation of 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

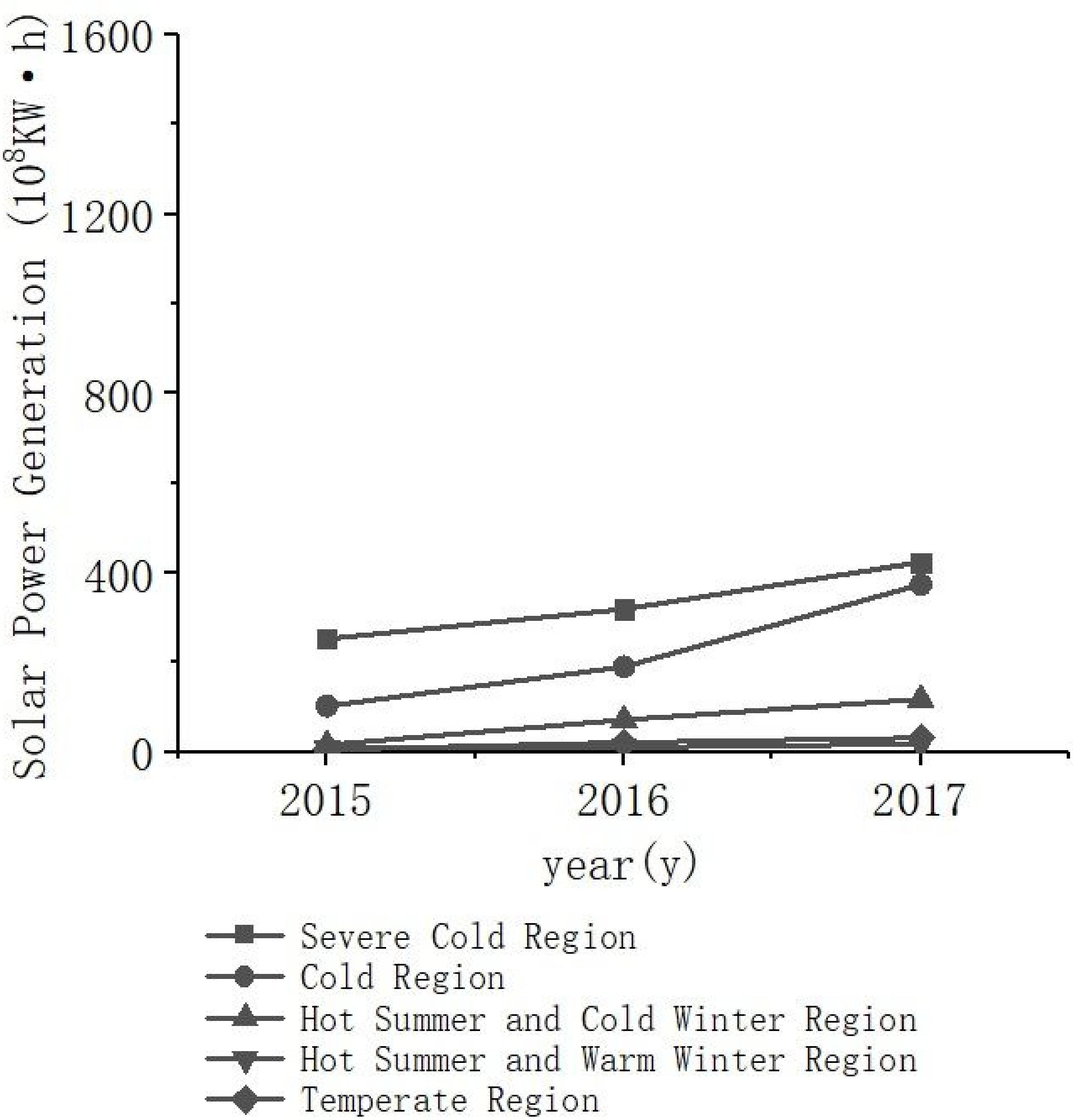

Figure 16

Figure3-14.Solar photovoltaic power generation

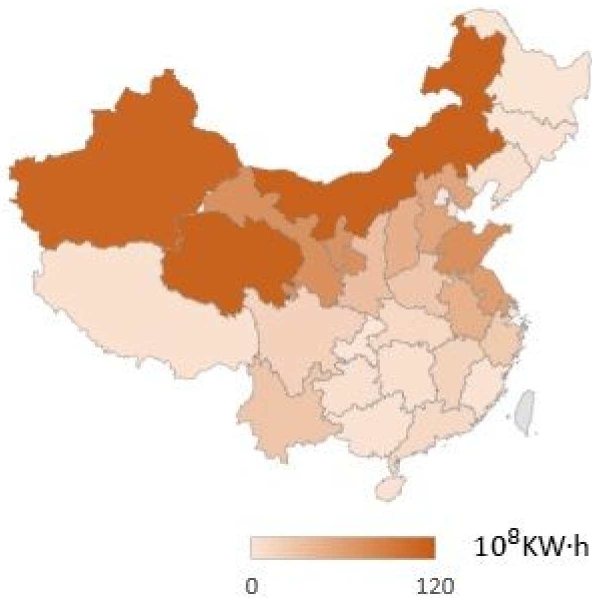

Figure 17

Figure3-15.Solar photovoltaic Power Generation of 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

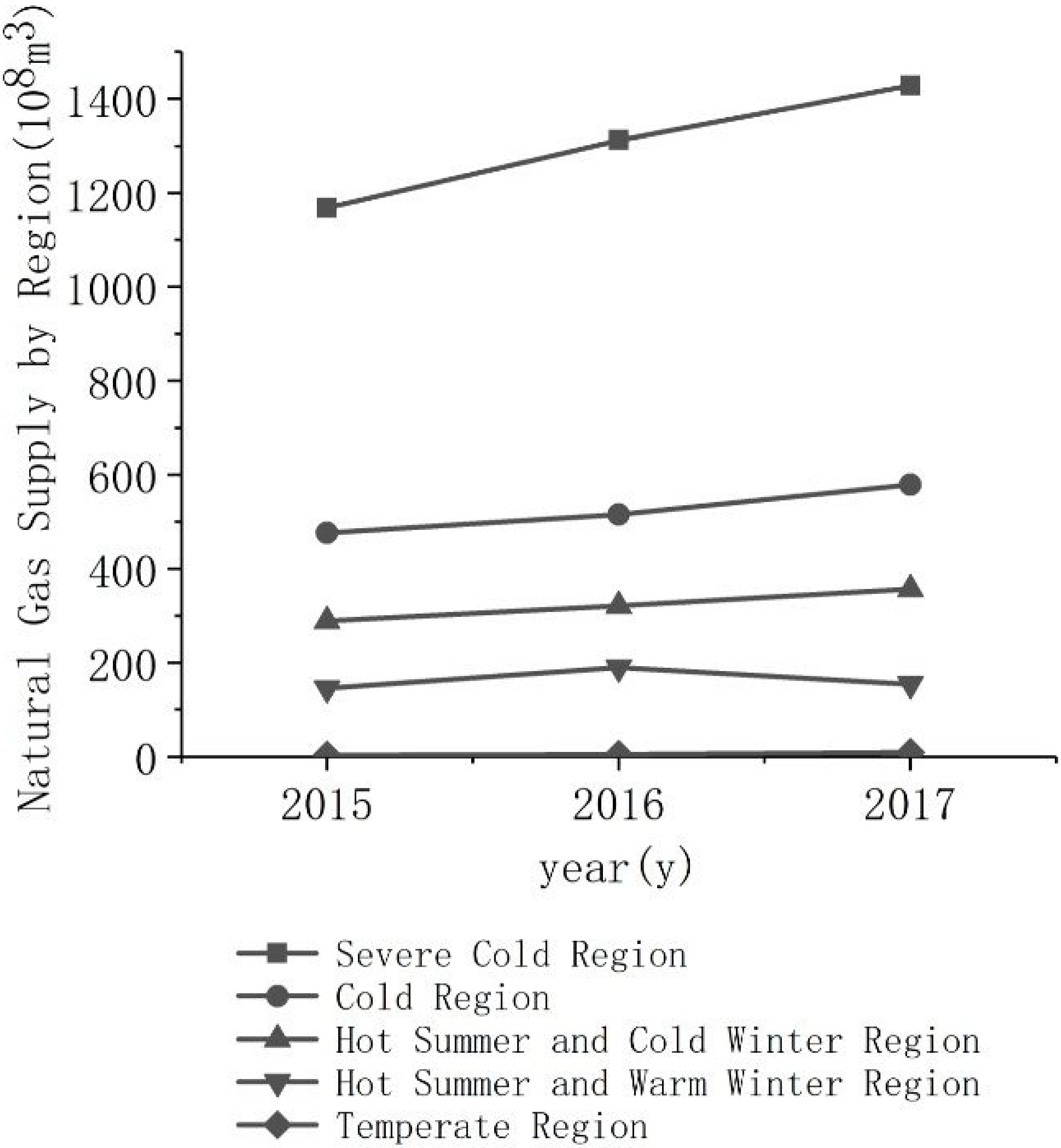

Figure 18

Figure 3-16.Natural Gas Supply by region

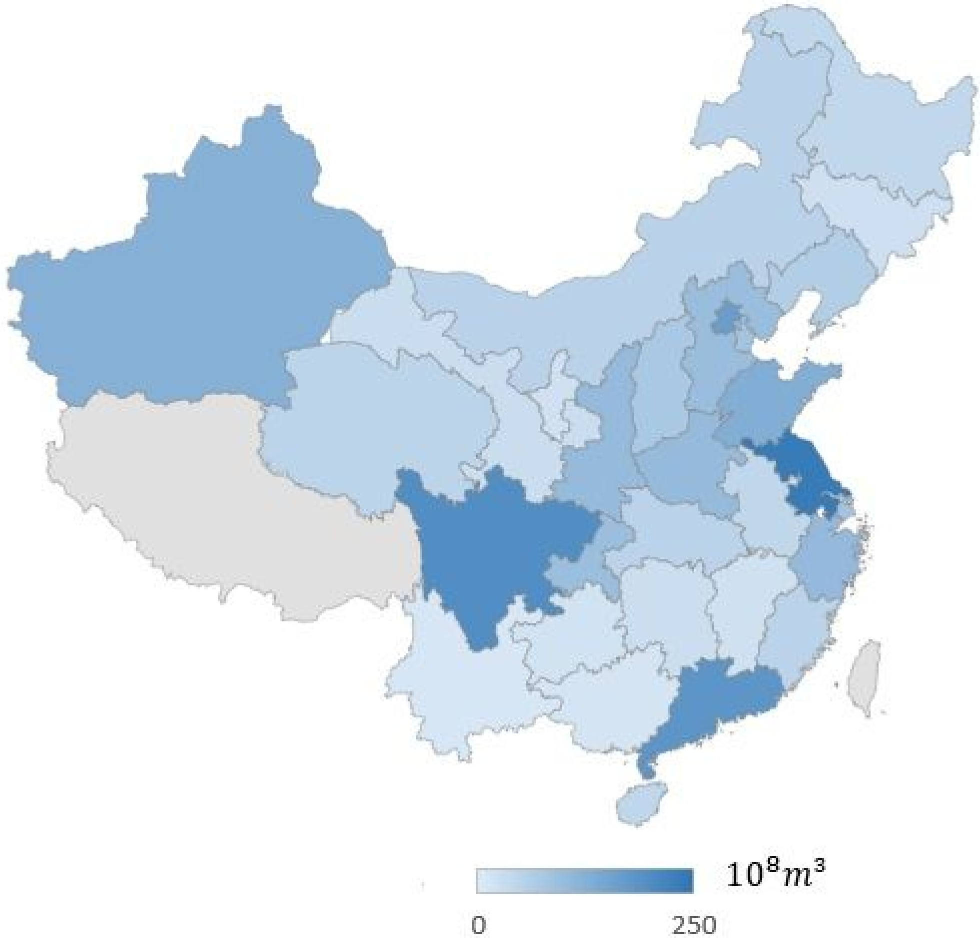

Figure 19

Figure 3-17.Natural Gas Supply. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

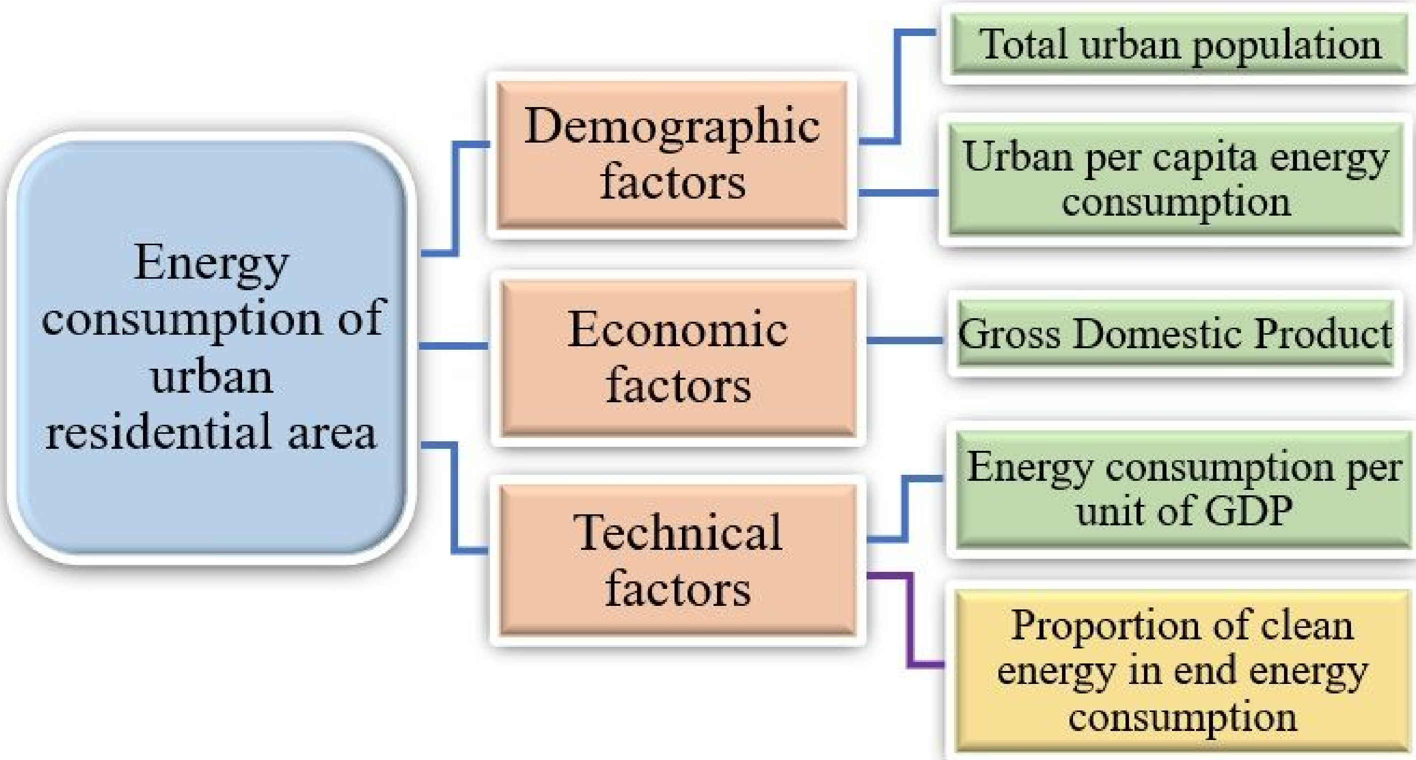

Figure 20

Figure 3-18. energy consumption model of urban buildings

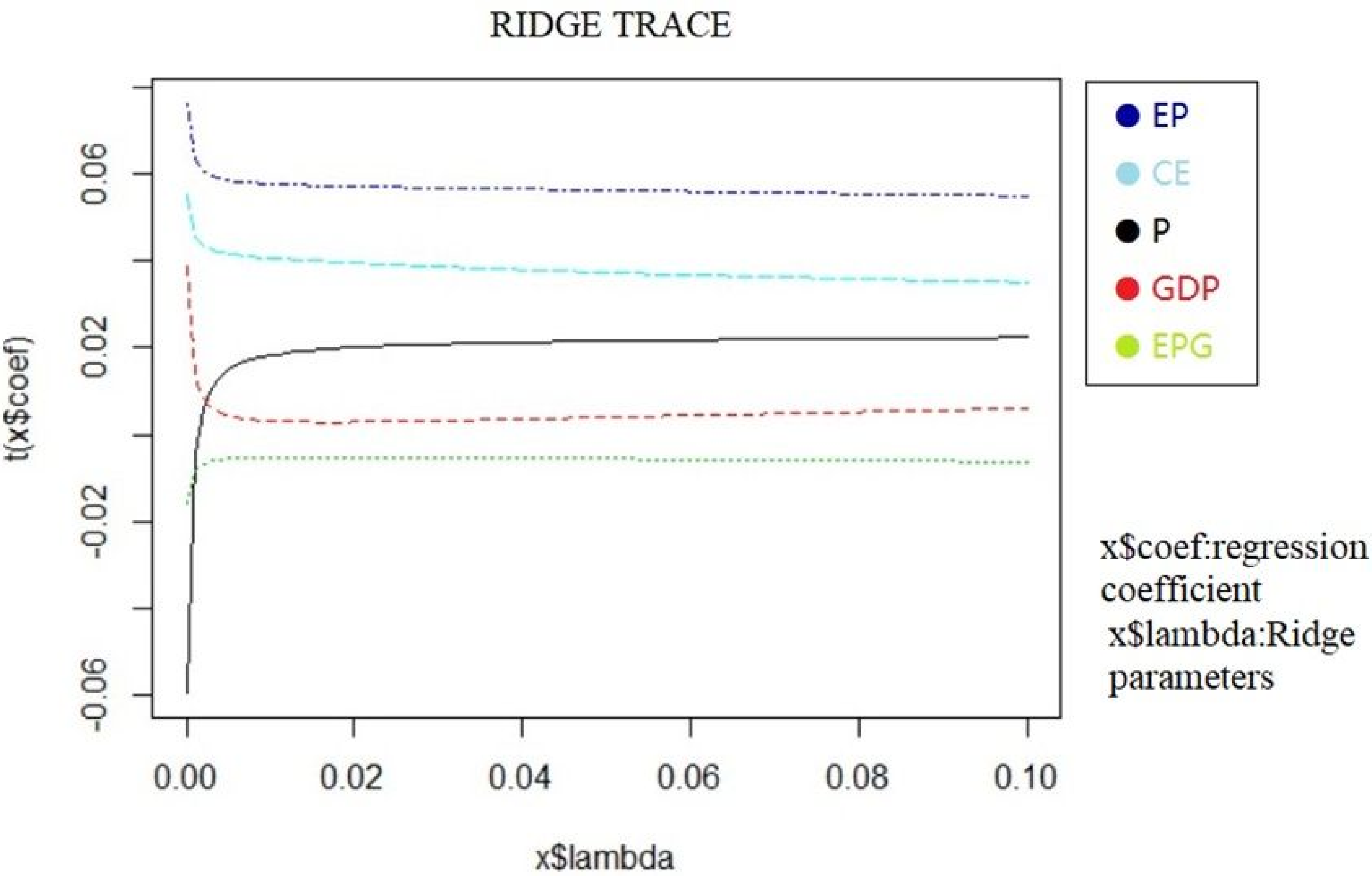

Figure 21

Figure 3-19. RIDGE TRACE(EP: Urban per capita energy consumption, CE: Proportion of clean energy in end energy consumption, P: Total urban population, GDP: Gross Domestic Product, EPG: Energy consumption per unit of GDP)

Figure 22

Figure 3-20.Engineering application in Changdao, Shandong Province. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.