

Research Article

Strategy of Energy Conservation and Emission Reduction in Residential Building Sector: A Case Study of Jiangsu Province, China

Tingting Jiang ¹, Hongyang Li ^{1,2,3}, Peng Mao ⁴, Tongyuan Wu ⁵,
Martin Skitmore ⁶ and Nima Talebian ⁷

¹Business School, Hohai University, Nanjing 211100, China

²School of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510641, China

³State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510641, China

⁴College of Civil Engineering, Nanjing Forestry University, Nanjing 210037, China

⁵Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong SAR, China

⁶University Professorial Fellow, Faculty of Society and Design, Bond University, 14 University Drive, Robina QLD 4226, Gold Coast, Australia

⁷Faculty of Society and Design, Bond University, 14 University Drive, Robina QLD 4226, Gold Coast, Australia

Correspondence should be addressed to Hongyang Li; li.terryhy@yahoo.com

Received 30 June 2022; Revised 31 August 2022; Accepted 2 September 2022; Published 31 January 2023

Academic Editor: Yibin Ao

Copyright © 2023 Tingting Jiang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The building sector is the second-largest energy consumer in China. With the proposal to reach a carbon peak by 2030 and achieve carbon neutrality by 2060, China attaches more importance to the energy conservation and emission reduction of the residential sector. To study the connection between socioeconomic factors and residential energy consumption (REC), this paper collects the data of 13 prefecture-level cities in Jiangsu Province, China, from 2001 to 2019 to explore the REC impact factors by the STIRPAT model. The factors for modeling are identified from relevant studies and weighted by the independent weight coefficient method (IWCM). The regression result shows that the average number of persons per household, per capita housing construction area, urbanization rate, and cooling degree days have a significant positive impact on REC, while a negative correlation is found between per capita housing construction area, residential water consumption, and residential liquefied petroleum gas (LPG) consumption. Strategies of energy conservation and emission reduction in residential building sector are explored based on the demonstration of the future REC pattern evolution and the changes in its impact factors.

1. Introduction

The continually increasing world energy consumption is creating many challenges to the ecology [1, 2] through its contribution to climate change, with the IPCC's (2018) report on the impact of global warming of 1.5°C above preindustrial levels, for example, being of major concern. Residential energy consumption (REC) is a significant contributor, accounting for 21% of the world's total energy consumption according to the latest global energy data from the International Energy Agency (IEA).

Along with the rapid development of its economy, China's energy consumption has continued to grow rapidly in recent decades [3], surpassing the United States to become the world's largest energy consumer, with 20.3% of the world's energy consumption since 2010 [4, 5] and with its REC accounting for 16.8% of total national energy consumption and 16.4% of global REC [6]. While REC will continue to increase in the future, related studies have pointed out that per capita REC will increase at an average annual rate of 1.5% before 2040 and subsequently slow to 0.94% [5].

To help limit global warming to 1.5–2°C by 2100, China has committed to having its CO₂ emissions peaking around 2030 [7, 8] and achieving carbon neutrality by 2060 [9]. As the residential sector is one of the most potential energy-saving sectors [10, 11], the Chinese government has proposed to change household energy to be cleaner and more efficient in its clean energy strategy [5]. The effective control of REC is a crucial part of China's CO₂ emissions peak and carbon neutralization plan.

In response, this study analyzes the REC in Jiangsu Province, China, as a case study. Jiangsu is a rapidly developing economy over the past two decades that has been at the expense of high energy consumption [12], which is a typical development pattern for most developing regions. Based on the STIRPAT model, panel data of 13 of the province's cities from 2001 to 2019 are explored to understand the influence mechanism underlying the high growth of REC and establish the impact factors involved. The results show that the average number of persons per household, per capita housing construction area, urbanization rate (urbanization in this paper refers to the process of transforming rural population into urban population), and cooling degree days have a significant positive effect on REC, while per capita housing construction area, residential water consumption, and residential liquefied petroleum gas (LPG) consumption have a significant negative effect. The results of this study reveal the change of REC and its impact factors, helping to control energy consumption in residential sectors from the city level, which could be used for reference to other cities both in China and around the world.

2. Literature Review

2.1. Bibliometric Analysis on REC. VOS viewer, a computer program for constructing and viewing bibliometric maps, is used to make a bibliometric analysis and network analysis of the articles collected by the Web of Science Core Collection bibliographic database to analyze the main research areas in the field of REC. The query used was TS=(“residential energy consumption” OR “residential energy use” OR “household energy consumption” OR “household energy use”), which identified 1,179 relevant articles published before 2021. The terms extracted from the title and abstract of the publications are filtered for a minimum of 30 occurrences through the text mining function of the VOS viewer software [13]. The terms in the same cluster are marked in the same color (see Figure 1).

The VOS viewer groups are termed into three categories by cluster analysis, where each cluster is marked with a different color. Cluster 1 (marked in red) focused on the occupant behavior as well as its interfering factors. Du et al. [14], for instance, explored the impact of occupant behaviors on energy consumption in high-rise residential buildings, while Wolske et al. [15] examined recent findings on social influence in energy behavior and discussed how this can result in peer effects. Cluster 2 (marked in blue) mainly contains studies of the raw material of residential energy, including fuel and LPG; Chen et al. [16] proposed set of regression models to quantify fuel consumption for the

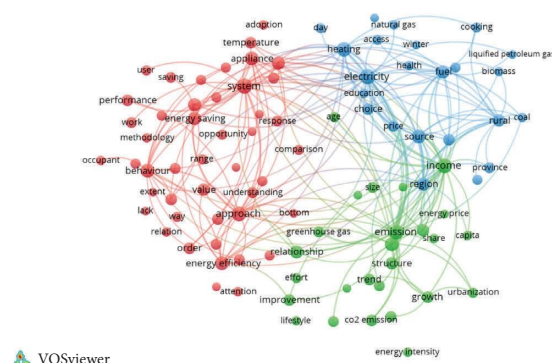


FIGURE 1: Co-occurrence of terms clusters by a VOS viewer. Note: the size of node represents the number of occurrences of a term, and the length of the connection between the two nodes represents their relationship.

residential sector based on temperature-related variables and socioeconomic parameters, and Bhandari and Pandit [17] used a Long-range Energy Alternative Planning System (LEAP) tool to analyze the LPG demand for residential cooking from 2015 to 2035. Cluster 3 (marked in green) concerns not only on energy saving but also on emission reduction. This includes the study of Fan and Lei [18] accessing the key factors that affect the residential CO₂ emissions in Beijing from 1995 to 2015, based on a newly built decomposition model with generalized Fisher index and MP model to find that energy consumption intensity is a decisive factor in inhibiting residential CO₂ emission, and Zhang et al.'s [19] quantification of the indirect effects on energy usage and PM 2.5 emissions of urban and rural residents' lifestyles in China during 2005–2015.

2.2. Methods Used to Analyze REC. The methods used to analyze REC can be divided into two different but complementary categories, i.e., top-down models and bottom-up models. The bottom-up method analyzes regional and national REC by the data for a representative set of individual houses [20]. The accuracy of the bottom-up model results depends heavily on the quality of the data source, which is difficult to test. Compared to the bottom-up models, the top-down models use national or regional time-series data [21], reflecting the macroeconomic situation.

A STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) theory, first proposed by Richard York, has been widely used in the study of building energy consumption to analyze the factors impacting on energy consumption [22]. The STIRPAT model is a typical top-down model used to analyze REC at the macrolevel, analyzing the impact of population, affluence, and technological level. Hasanov and Mikayilov [23] use the STIRPAT model to demonstrate the relationship between different population age groups and residential electricity consumption in Azerbaijan over the period of 2000–2012, and Liddle [24] estimates the residential electricity consumption, using the STIRPAT model to analyze the U.S. state-based panel data. The STIRPAT model is also used to explore the impact of urbanization on the energy

consumption of the residential sector, transportation sectors, industrial sectors, and commercial sectors, based on data from the Association of South East Asian countries over the period of 1995–2013 [25]. With the promotion of energy conservation and emission reduction in China, REC has aroused much research interest in the country's academic field, and an increasing number of studies use the STIRPAT model to analyze REC. Wang and Yang [26], for instance, use the balanced panel data of 29 Chinese provinces from 1998 to 2014 to investigate the nonlinear relationships between urbanization and REC based on the STIRPAT framework, and Dong et al. [27] combine an extended STIRPAT with a seemingly unrelated regression to explore the determinants of urban REC per capita and rural REC per capita based on 2007–2016 China provincial data.

All the articles reviewed above are at the national, provincial, or state level, however, with no analysis of REC by the STIRPAT model at the city level, resulting in the lack of a comparatively microscopic perspective to cope with REC issues. More specific studies focusing on the city-scale REC are therefore needed.

3. Methods

3.1. The Study Area. The focus of this study is on Jiangsu Province located in the eastern coastal center of the Chinese mainland (see Figure 2) and one of the most developed areas in China [28]. As with many other Chinese provinces, since the turn of the 21st Century, its economy's continued rapid development [29] has created serious ecological problems [30], which have led to the need to consider the issue of saving energy and protecting the environment when pursuing economic development.

Referring to other studies using the STIRPAT model [31–33], the number of impact factors is set to six. Due to this limitation, some of the factors extracted from the literature need to be deleted. The specific process is as follows.

3.2. Research Workflow. The main work includes the extraction of influential factors, weight calculation, and modeling analysis (see Figure 3). The REC impact factors are extracted from the related literature, and then their weight is calculated based on the panel data of 13 cities in Jiangsu Province by the IWCM. Finally, the STIRPAT model is built to analyze the impact of these factors on REC.

3.3. The STIRPAT Model. The IPAT model reflects the influence of human activities on the environment and is a widely accepted formula for analyzing the impact of population, affluence, and technological level on the environment [34, 35]. The equation is as follows:

$$I = P \times A \times T, \quad (1)$$

where I represents the environmental impact, P represents the population, A represents the affluence, and T represents the technology.

The IPAT theory tacitly accepts that the contribution of different factors to the environmental is the same, that is, different factors affect environmental quality in proportions, and the various factors are mutually independent. However, according to references [35, 36], these assumptions are too idealized and the relationship between the various factors and environmental quality is not simply linear but often involves interactions or superposition nonlinear effects.

The STIRPAT model introduces the exponential form into the model so that it can study the nonproportional effects of different factors on the environment [35, 37]. The model is as follows:

$$I = aP^b A^c T^d e, \quad (2)$$

where a is the proportional constant term; b , c , and d are the elastic coefficients of population, affluence, and technology; and e is the residual value. Taking the natural logarithm on both sides of equation (6) gives the following equation:

$$\ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e, \quad (3)$$

where the regression coefficient reflects the elastic relationship between the explanatory variable and the explained variable. The value of the regression coefficient is the percentage change in the dependent variable caused by a 1% change in the independent variable when the other independent variables remain unchanged [37–39].

Based on the literature review and understanding of the knowledge of the REC impact factors (see Table 1), cooling degree days (CDD) and heating degree days (HDD) are added to the original three dimensions of the STIRPAT model [40–43] to give the following equation:

$$\begin{aligned} \ln(EC_{it}) = & \alpha + \beta_1 \ln(AP_{it}) + \beta_2 \ln(pCA_{it}) \\ & + \beta_3 \ln(UR_{it}) + \beta_4 \ln(R\&D_{it}) + \beta_5 \ln(CDD_{it}) \\ & + \beta_6 \ln(HDD_{it}) + \varepsilon_{it}, \end{aligned} \quad (4)$$

where EC_{it} denotes the energy consumption per household, AP_{it} is the average persons per household, pCA_{it} is the per capita housing construction area, UR_{it} is the urbanization rate, $R\&D_{it}$ is the rate of the expenditures on research and development to GDP, and CDD_{it} and HDD_{it} are the CDD and HDD of the city i in year t , respectively (see Table 2). α is the intercept term, ε is the model error term, and β is the regression coefficient. When the independent variable changes 1%, the dependent variable will change $\beta\%$.

3.4. Independent Weight Coefficient Method. As some of the impact factors selected from the literature are related to each other to a certain extent, the factors containing information coincidence are deleted by the IWCM. This is an objective weighting method, which reflects the amount of information contained in the index according to the collinearity between each index and other indexes, so as to calculate the weight of each index [64]. IWCM mainly judges the correlation between one variable and other

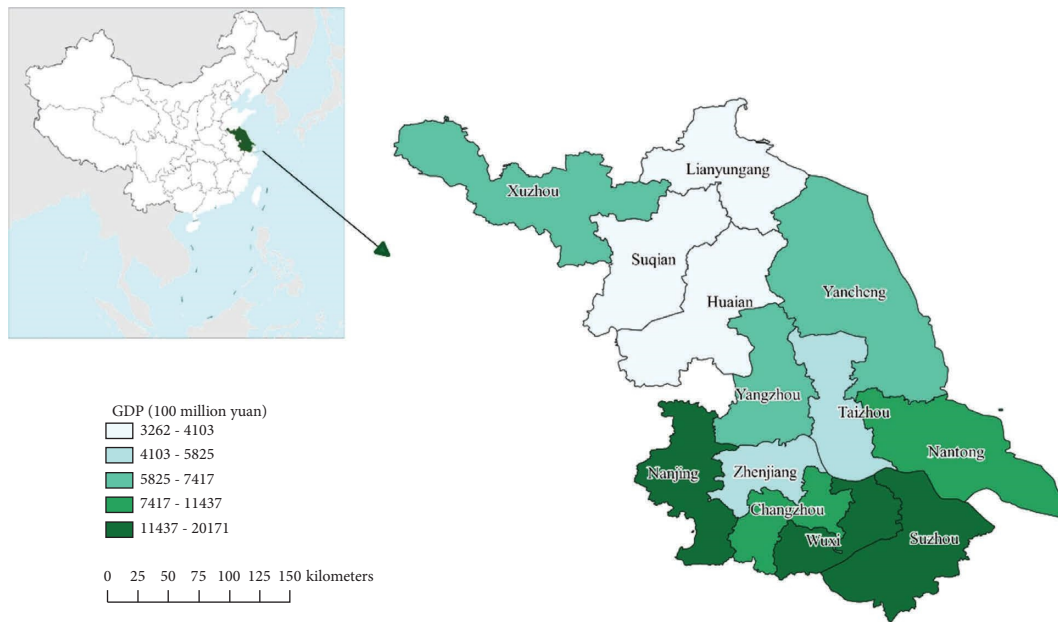


FIGURE 2: The administrative division of Jiangsu province and the gross domestic product (GDP) of its prefecture-level cities in 2020.

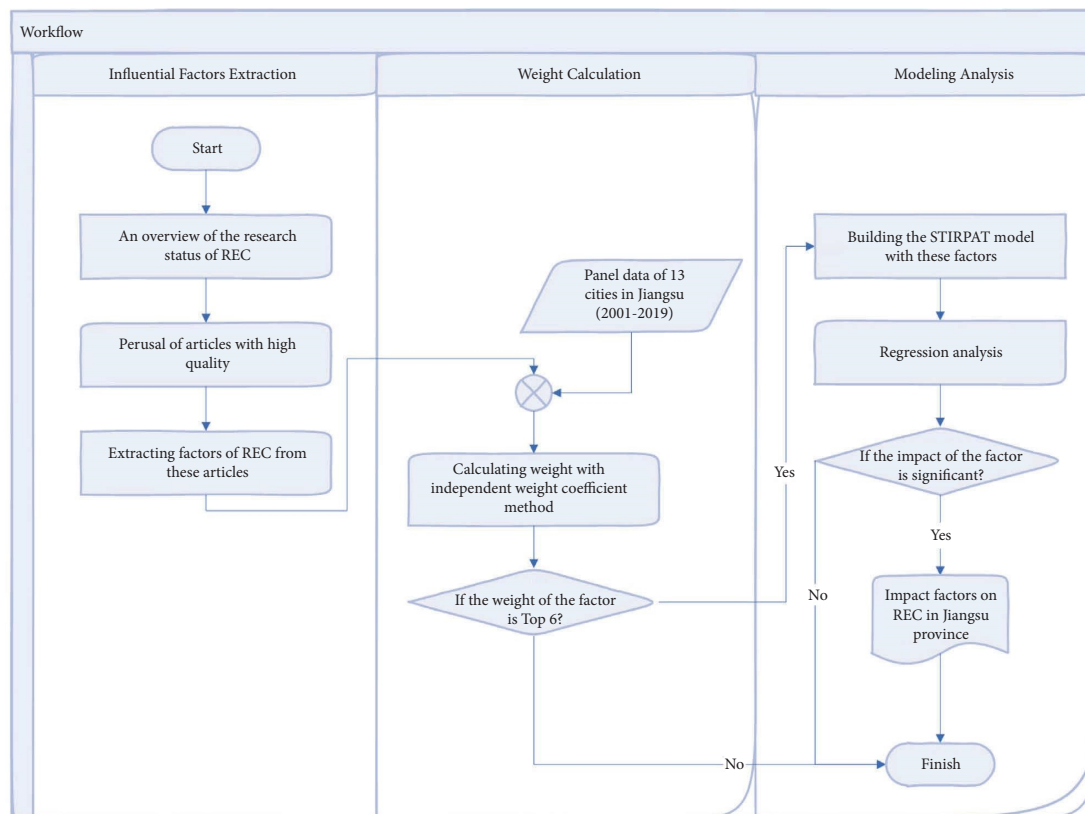


FIGURE 3: The workflow of the research.

variables by calculating the complex correlation coefficient R value [64]. The stronger the correlation between one variable and other variables, the greater the complex correlation coefficient R value from the regression analysis, indicating that the index is more

collinear with other indicators. The strong collinearity represents a high degree of information repeatability, and it will be given a lower weight.

The equation for calculating the complex correlation coefficient R is as follows:

TABLE 1: Preliminary table of REC cluster factors.

Factors	Population			Affluence			Technology			Environment	
	Average number of persons per household	Permanent population	Registered population	Per capita GDP	Per capita housing construction area	Per capita disposable income of residents	Urbanization rate	Energy consumption per unit building area	Rate of expenditure on research and development to GDP	CDD	HDD
Fan et al. [44]		✓	✓		✓		✓				
Nie and Kemp [45]			✓		✓			✓			
Zhang and Peng [46]		✓		✓			✓			✓	
Herreras et al. [47]		✓									
Lu et al. [48]					✓			✓			
Zhao et al. [49]		✓				✓					
Berrill et al. [50]					✓			✓			
Zhang et al. [51]	✓		✓		✓			✓			
Levy and Belaid [52]	✓							✓			
Karatasou and Santamouris [53]	✓				✓	✓			✓	✓	✓
Fan, Zeng [43]			✓			✓					
Li et al. [54]					✓	✓		✓			
Liu and Zhao [55]	✓	✓		✓		✓		✓			
Iraganaboina and Eluru [56]					✓				✓		
Wang et al. [57]				✓			✓	✓			
Yang et al. [58]							✓				
Zhang et al. [59]				✓						✓	✓
Anser et al. [60]											
Alola and Yildirim [61]			✓	✓		✓	✓				
Wang et al. [62]				✓						✓	✓
Berrill, Gillingham [50], Craig and Feng [63]											✓

TABLE 2: Description of the STIRPAT model variables.

Abbreviations	Variables	Definitions	Units
AP	Average persons per household	Dividing the total population by the number of households	Person
pC/A	Per capita housing construction area	Per capita residential building area of residents	m ² /person
UR	Urbanization rate	The proportion of urban population in the total population	%
R&D	Rate of the expenditure on research and development to GDP	The rate of expenditures on research and development to the gross domestic product	%
CDD	Cooling degree days	The summation of temperature differences between the daily mean temperature and 26°C for the day whose mean temperature is higher than 26°C in a year	°C • d
HDD	Heating degree days	The summation of temperature differences between the daily mean temperature and 0°C for the day whose mean temperature is lower than 0°C in a year	°C • d
EC	Energy consumption per household	The average energy consumption per household of the city in a certain year	Kgce/household

$$R_i = \frac{\sum (y - \bar{y})(\hat{y} - \bar{\hat{y}})}{\sqrt{\sum (y - \bar{y})^2 \sum (\hat{y} - \bar{\hat{y}})^2}}. \quad (5)$$

The reciprocal of the complex correlation coefficient R_i is recorded as follows:

$$r_i = \frac{1}{R_i}. \quad (6)$$

The impact factor weight W_i is converted into a decimal value in the range $[0, 1]$ by normalization, with

$$W_i = \frac{r_i - r_{\min}}{r_{\max} - r_{\min}}. \quad (7)$$

Before using IWCM to calculate the weight of each factor, it is necessary to standardize the data by

$$F_{ij}' = \frac{F_{ij}}{F_{\max}}, \quad (8)$$

where F_{ij} is the j th initial value of the i th impact factor, F' is the standardized value, and $F_{\max}$ is the maximum value of F .

IWCM is then used to select the impact factors to be analyzed by the STIRPAT model (see Figure 4).

To avoid the situation where the estimation result is distorted or the model is unable to be estimated accurately because of a high correlation between explanatory variables, it is necessary to test the multicollinearity of the constructed regression model [65]. The variance inflation factor (VIF) is often used for this purpose. It is generally believed in statistics that there is a positive relationship between the VIF value and multicollinearity, recognizing that the regression model may have the problem of multicollinearity if the VIF value is more than 10 [66].

The unit root test judges the stability of the panel data by checking whether there is a unit root in the panel data series. If the data have a unit root, it is a nonstationary time series [67]. If the data cannot pass the stability test, there is a great possibility that there will be t -test failure and pseudoregression, in the analysis of the multiple linear regression models. Here, the LLC test is used to test the stability of the panel data.

3.5. Data Source. Given that the official statistical yearbook of each region is only updated to 2020, the time range of this study is from 2001 to 2019. The original data are derived from the Jiangsu Statistical Yearbook (2001–2019) and the 2001 to 2019 statistical yearbooks of the province's prefecture-level data. To unify the physical unit measurement of different energy, the collected energy consumption is converted from physical quantities to standard coal equivalents [68, 69]. The climatic data of the cities refer to the daily average temperature data of urban meteorological stations. The CDD and HDD are calculated according to the ASHRAE Handbook [70].

4. Results

4.1. IWCM Results. According to the weight, the average persons per household, per capita housing construction area,

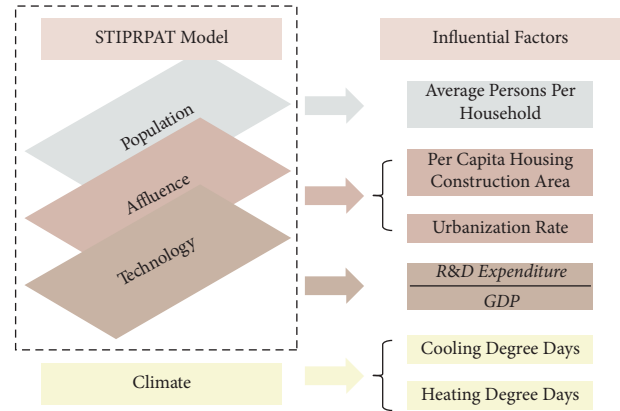


FIGURE 4: REC factors in Jiangsu Province based on the STIRPAT model.

urbanization rate, the rate of the expenditures on research and development to GDP, CDD, and HDD are selected as the variables of the STIRPAT model (see Table 3).

4.2. Panel Data Overview. The time variable of panel data is from 2001 to 2019, and the panel variable is 13 prefecture-level cities in Jiangsu Province with 247 samples in total. The mean, standard deviation, minimum, and maximum values of variables are shown in Table 4.

4.3. Results of the Multicollinearity and Stability Tests. All the VIF values of the explanatory variables are less than 10, and therefore the regression model passed the multicollinearity test (see Table 5).

Data for the variables in the multiple linear regression models are stable (see Table 6).

4.4. Model Results. The value of R^2 is 0.911, meaning that the model's degree of fit is high (see Table 7).

These results show that the average number of persons per household, per capita housing construction area, urbanization rate, and CDD have a significant impact on REC, while the rate of expenditure on research and development to GDP and HDD are not significant. It is shown that when the average number of persons per household, per capita housing construction area, urbanization rate, and CDD increased by 1%, the average energy consumption per household increases by 0.72%, 0.64%, 2.15%, and 0.25%, respectively.

5. Discussion

5.1. Implications for the Evolution of REC in Developing Regions. It is apparent that Jiangsu's REC has an obvious increasing trend from 2001 to 2019 (see Figure 5). The residential electricity and natural gas consumption of each city all increased significantly during this period, while the residential liquefied petroleum gas gradually declined. The changing pattern of REC in Jiangsu Province is the epitome of the energy conservation and emission reduction process

TABLE 3: IWCW weights of identified impact factors.

Factors	Multicorrelation coefficient (R)	Reciprocal of multicorrelation coefficient (1/R)	Weights (%)
Average persons per household	0.691	1.447	9.65
Permanent population	0.972	1.028	6.86
Registered population	0.973	1.028	6.85
Per capita GDP	0.989	1.011	6.74
Per capita housing construction area	0.931	1.075	7.16
Per capita disposable income of residents	0.989	1.011	6.74
Urbanization rate	0.945	1.058	7.05
Energy consumption per unit building area	0.972	1.029	6.86
Rate of expenditures on research and development to GDP	0.394	2.537	16.91
Cooling degree days	0.598	1.672	11.15
Heating degree days	0.475	2.104	14.03

TABLE 4: Descriptive statistics of the STIRPAT model variables.

Variables	N	Min	Max	Mean	Std. err
AP	247	2.65	4.00	3.12	0.32
pCA	247	15.19	60.40	36.68	9.55
UR	247	27.6	83.20	58.34	12.56
R&D	247	0.20%	26.06%	1.59%	1.92%
CDD	247	247.00	33.50	373.60	166.16
HDD	247	247.00	0.00	140.30	21.81
EC	247	62.38	1034.97	297.77	188.96

TABLE 5: Multicollinearity test results of the STIRPAT model variables.

Variables	VIF	1/VIF
ln AP	1.38	0.73
ln pCA	1.47	0.68
ln UR	3.01	0.33
ln R&D	2.54	0.39
ln CDD	1.34	0.75
ln HDD	1.12	0.89

TABLE 6: LLC unit root test results of the STIRPAT model variables.

Variables	Statistics
ln AP	-4.0837***
ln pCA	-0.3833**
ln UR	-4.8868***
ln R&D	-6.4481***
ln CDD	-0.5740**
ln HDD	-4.4486***

** and *** in the table indicate that the original hypothesis of unit root is rejected at the significance level of 5% and 1%, respectively.

in the most developing regions in the globe, with a continuous and significant increase in REC and a tendency to be cleaner and more sustainable in the early-middle stage [11], [71]. The experience of Jiangsu has a certain referential value for the developing regions, and this section analyzes the REC in Jiangsu as a case to provide implications for the evolution of REC in the developing regions.

Jiangsu is a typical hot summer and cold winter province in the middle and lower reaches of the Yangtze River [72, 73], and air-conditioning is used for cooling and heating

in most areas of the province [74]. This means that domestic electricity consumption accounts for a large proportion in the REC structure. This dependence on electric heating in winter has attracted extensive attention from the country's social circles recently, suggesting the need to start a pilot demonstration project of clean and low-carbon heating in some of the province's cities, which may change its REC structure.

Although natural gas is not a satisfactory energy type for most countries that have achieved carbon peaking and carbon neutralization, its degree of exploitation and utilization in China is relatively low and coal is still the main source of energy supply. As a transitional energy type, natural gas can reduce SO₂ and dust emissions by nearly 100%, CO₂ emissions by 60%, and N₂O emissions by 50% [75]. Natural gas helps to reduce acid rain, slow the greenhouse effect, and fundamentally improve the quality of the environment [76, 77]. Therefore, to realize the goal of carbon peaking and carbon neutralization in China, it is suggested that full play is given to the role of natural gas as a bridge. The use of natural gas by the residential sector can reduce the consumption of coal and oil and greatly alleviate the problem of environmental pollution. Natural gas was not very popular until the national promotion of natural gas in the Eleventh Five-Year Plan (2006–2010), when some new-built residential buildings began to use pipeline natural gas instead of canned LPG for cooking. The proportion of natural gas consumption in the province's REC structure has increased, gradually replacing that of LPG since 2006 (see Figure 6). The province has basically realized the popularization of natural gas use, and the priority in energy saving and emission reduction will change in the future. To release the stress on the environment, therefore, the province could promulgate policy to promote the use of renewable energy [11] and limit residential natural gas consumption [78].

5.2. Analysis of the Impact Factors. The positive impact of the average number of persons per household on REC is also found in other studies [53, 79–82]. Population growth will increase the demand for energy in the residential sector, and more residents consume more energy in daily life.

Consistent with Zhang and Li [28], Fan et al. [44], and Chen et al. [83], a positive relationship is found between the

TABLE 7: Regression results of the STIRPAT model.

Variables	Coef	Std. err	t	$P > t $	95% conf	Interval
ln AP	0.7266635	0.1485319	4.89	0.000	0.4340709	1.019256
ln pCA	0.6279793	0.0513353	12.23	0.000	0.5268541	0.7291045
ln UR	2.109613	0.0888053	23.76	0.000	1.934676	2.284551
ln R&D	0.0209468	0.0257684	0.81	0.417	-0.0298143	0.071708
ln CDD	0.1592412	0.0292094	5.45	0.000	0.1017016	0.2167808
ln HDD	-0.0025082	0.003717	-0.67	0.500	-0.0098303	0.0048138
_cons	-6.883501	0.4653904	-14.79	0.000	-7.800272	-5.966729

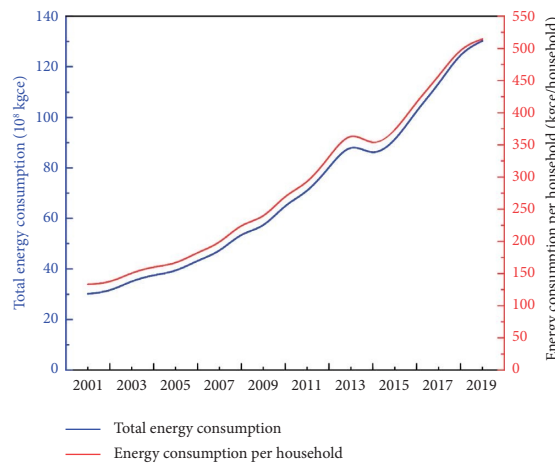


FIGURE 5: Jiangsu's 2001–2019 REC and REC per household.

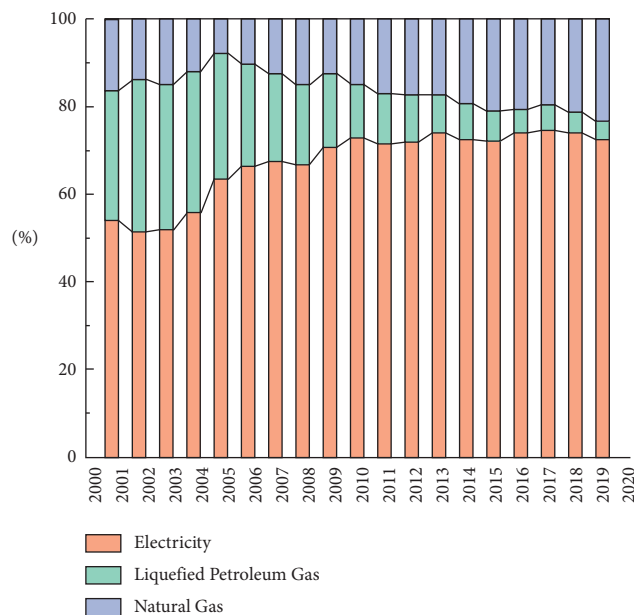


FIGURE 6: 2001–2019 structural change of Jiangsu's REC.

urbanization rate and REC in the present study. The influence of the urbanization rate on REC is related to economic development and the degree of urbanization [26, 84]. Based on the study of 136 countries, Wang and Lin [84] argued that if the process of urbanization is not accompanied by corresponding economic growth, the increase in urbanization rate will even lead to the reduction of REC.

When the urbanization rate reaches a certain level, its impact on REC will no longer be significant [44, 84]. Jiangsu Province has maintained a rapid speed of economic development over the past two decades [12], and so there is a positive relationship between urbanization rate and REC. Therefore, as the province's urbanization rate has reached 72%, its impact on REC is expected to gradually decrease in the future.

Per capita housing construction area that has a significant positive impact on REC is also found in other studies [43, 85]. This has a significant impact on lighting and air conditioning [53, 86], and together with the number of residents, has a significant impact on the number and use intensity of household appliances (e.g., lighting and air conditioning) [87], leading to more energy being consumed to meet work needs [53]. Moreover, when the per capita housing construction area increases to a certain extent, its impact on REC will be negative because of houses becoming vacant: Thonipara and Runst [86] demonstrated that the floor area has an inverted "U" effect on REC, finding that REC decreases when the floor area exceeds about 100 m². Therefore, as Jiangsu's per capita housing construction area has increased continually since 2000, the increase of per capita housing construction area is expected to have a negative impact on REC when it reaches a certain value in the future.

According to Li et al.'s study of the impact of climate change on REC in China [88], the impact of hot summers on REC is more significant than cold winters, owing to the differences of heating systems and temperature tolerance of residents in different areas. A higher humidity has a negative effect on the thermal comfort of the human body [89], and compared with residents in hot and humid areas, those in hot and arid areas have a higher tolerance of the thermal environment [90]. Jiangsu Province is in the ecotone of temperate and subtropical zones [91], and its air humidity is high [92]. Therefore, the temperature tolerance of Jiangsu's residents is low, and they tend to consume more energy to improve the thermal comfort of the living environment when they feel hot.

5.3. Impact on Specific Residential Consumption. To investigate the influence of the selected factors on specific residential consumption, this study builds the STIRPAT models for Jiangsu's 2001–2019 domestic electricity consumption, domestic water consumption, household LPG consumption, and natural gas household consumption (see Figure 7).

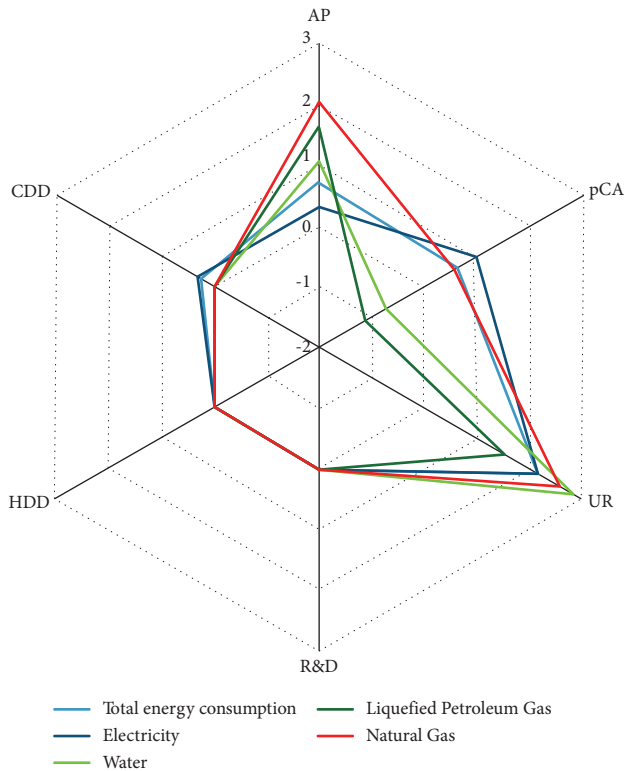


FIGURE 7: Summary of the regression coefficients. Note: the factors with nonsignificant regression coefficient are set to 0.

The results show that CDD has a significant impact on only domestic electricity consumption, which is because residents often use air conditioners to improve thermal comfort [93] and the running time of air conditioners has a direct impact on the daily electricity consumption. Water is mainly used for cooking, cleaning, and drinking, while LPG and natural gas are mainly used for cooking in Jiangsu's residential buildings. A high temperature may change people's living habits and have a certain impact on water consumption, LPG consumption, and natural gas consumption. With the improvement in the living standards, people often use air-conditioning cooling to obtain a suitable temperature environment, and so CDD has no significant effect on water household consumption, LPG household consumption, and natural gas household consumption. It has been recognized above that electricity consumption accounts for a large proportion in Jiangsu's REC structure, and so CDD has a significant effect on REC because of its significant effect on electricity consumption.

The average number of persons per household and urbanization rate positively affects domestic electricity consumption, water household consumption, LPG household consumption, and natural gas household consumption. The impact of per capita housing construction area on electricity consumption and LPG consumption is positive, while negative on water consumption and natural gas consumption. There is no significant impact of the rate of expenditures on research and development to GDP and HDD on electricity consumption, water consumption, LPG consumption, and natural gas consumption.

6. Conclusions

This innovative study develops an extended STIRPAT model to identify the factors with a significant impact on RED at the city level based on the data of 13 cities in Jiangsu Province, China, from 2001 to 2019, and several new findings are obtained. The model results show that when the average number of persons per household, per capita housing construction area, urbanization rate, and CDD increased by 1%, the energy consumption per household will increase by 0.72%, 0.64%, 2.15%, and 0.25%, respectively. CDD has a significant impact only on domestic electricity consumption and no significant effect on water consumption, LPG consumption, and natural gas consumption. Per capita housing construction area has a negative effect on the household consumption of LPG and natural gas.

In addition to the results of the STIRPAT model, it is also found that (1) domestic electricity consumption accounts for a large proportion of REC structure, but its energy consumption structure is likely to change in the future; (2) the proportion of natural gas in the REC structure is expected to gradually replace that of LPG; (3) Jiangsu's urbanization rate has reached 72% at present, and the impact of urbanization on REC is expected to gradually decrease in the future; (4) the impact of per capita housing construction area is also forecasted to change when the area reaches a certain value because of its inverted "U" effect on REC; and (5) the impact of hot summers on REC is found to be more significant than cold winters in temperate and subtropical zones with high air humidity.

For the regions that has almost realized the cleaning transforming of its energy consumption structure in residential sectors, the next step to improving REC quality is to promote the use of renewable energy and develop appropriate technologies. Since the increase in urbanization rate and per capita housing construction area will not lead to a significant increase of REC after reaching a certain value, a policy to improve residents' living standards would be beneficial for energy conservation and the felicity index of residents.

The study is limited by not considering amount of straw, coal, firewood, and other carbon emitters consumed in rural residential buildings as it is not contained in official statistics (although unlikely to be significant). Its scope is also limited to Jiangsu Province, China, which means that there will also be some limitation of the generalizability of its findings. Furthermore, similar studies are therefore needed to examine the extent of this as well as further expanding the scope of the research and analyzing REC from such different perspectives as macro and micro and long- and short-term.

Data Availability

The original data are derived from the Jiangsu Statistical Yearbook (2001–2019) and the 2001–2019 statistical yearbooks of the province's prefecture-level data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Fundamental Research Funds for the Central Universities (B210201014); Innovation and Entrepreneurship Talents Program in Jiangsu Province, 2021 (Project Number: JSSCRC2021507 and Fund Number: 2016/B2007224); “13th Five-Year” Plan of Philosophy and Social Sciences of Guangdong Province (2019 General Project) (GD19CGL27); State Key Laboratory of Subtropical Building Science, South China University of Technology, China (2020ZB17); and National Natural Science Foundation of China (72071115).

References

- [1] Z. Mi, J. Meng, and D. Guan, “Chinese CO₂ emission flows have reversed since the global financial crisis,” *Nature Communications*, vol. 8, 2017.
- [2] Y. Shan, H. Zheng, and D. Guan, “Energy consumption and CO₂ emissions in Tibet and its cities in 2014,” *Earth’s Future*, vol. 5, no. 8, pp. 854–864, 2017.
- [3] Z. Mi, J. Zheng, J. Meng et al., “China’s energy consumption in the new normal,” *Earth’s Future*, vol. 6, no. 7, pp. 1007–1016, 2018.
- [4] K. M. Uby, C. F. He, B. Trapido-Lurie, and N. Moore, “The changing structure of energy supply, demand, and CO₂ emissions in China,” *Annals of the Association of American Geographers*, vol. 101, no. 4, pp. 795–805, 2011.
- [5] H. Han and S. Wu, “Rural residential energy transition and energy consumption intensity in China,” *Energy Economics*, vol. 74, pp. 523–534, 2018.
- [6] A. International Energy, *International Energy Agency World Energy Statistics*, UK Data Archive, Colchester, UK, 2020.
- [7] F. Dong, Y. Hua, and B. Yu, “Peak carbon emissions in China: status, key factors and countermeasures—A literature review,” *Sustainability*, vol. 10, no. 8, 2895 pages, 2018.
- [8] J. Zong, L. Sun, W. Bao, and Iop, “Situation analysis and development suggestion regarding carbon emission peaking,” in *Proceedings of the 2020 4th International Workshop on Renewable Energy and Development*, Sanya, China, April 2020.
- [9] Y. Li, S. Lan, M. Ryberg, J. Perez-Ramirez, and X. Wang, “A quantitative roadmap for China towards carbon neutrality in 2060 using methanol and ammonia as energy carriers,” *iScience*, vol. 24, no. 6, Article ID 102513, 2021.
- [10] A. Salehi, I. Torres, and A. Ramos, “Experimental analysis of building airtightness in traditional residential Portuguese buildings,” *Energy and Buildings*, vol. 151, pp. 198–205, 2017.
- [11] M. D. P. Pablo-Romero, R. Pozo-Barajas, and R. Yniguez, “Global changes in residential energy consumption,” *Energy Policy*, vol. 101, pp. 342–352, 2017.
- [12] Y. H. Wang, T. Y. Xie, and S. L. Yang, “Carbon emission and its decoupling research of transportation in Jiangsu Province,” *Journal of Cleaner Production*, vol. 142, pp. 907–914, 2017.
- [13] M. E. Bireselioglu, M. H. Demir, B. Solak, A. Kayacan, and S. Altinci, “Investigating the trends in arctic research: the increasing role of social sciences and humanities,” *Science of the Total Environment*, vol. 729, Article ID 139027, 2020.
- [14] J. Du, C. Yu, and W. Pan, “Multiple influencing factors analysis of household energy consumption in high-rise residential buildings: evidence from Hong Kong,” *Building Simulation*, vol. 13, no. 4, pp. 753–769, 2020.
- [15] K. S. Wolske, K. T. Gillingham, and P. W. Schultz, “Peer influence on household energy behaviours,” *Nature Energy*, vol. 5, no. 3, pp. 202–212, 2020.
- [16] H. Chen, Y. Huang, H. Shen et al., “Modeling temporal variations in global residential energy consumption and pollutant emissions,” *Applied Energy*, vol. 184, pp. 820–829, 2016.
- [17] R. Bhandari and S. Pandit, “Electricity as a cooking means in Nepal—a modelling tool approach,” *Sustainability*, vol. 10, no. 8, 2841 pages, 2018.
- [18] F. Fan and Y. Lei, “Index decomposition analysis on factors affecting energy-related carbon dioxide emissions from residential consumption in Beijing,” *Mathematical Problems in Engineering*, vol. 2017, Article ID 4963907, 14 pages, 2017.
- [19] M. Zhang, S. Ding, J. Pang, and W. Wang, “The effect of indirect household energy consumption on PM_{2.5} emission in China: an analysis based on CLA method,” *Journal of Environmental Management*, vol. 279, Article ID 111531, 2021.
- [20] A. Zerroug and E. Dzelzitis, “A study of modeling techniques of building energy consumption,” *Engineering, Technology & Applied Science Research*, vol. 10, no. 1, pp. 5191–5194, 2020.
- [21] D. Wiesmann, I. Lima Azevedo, P. Ferrao, and J. E. Fernandez, “Residential electricity consumption in Portugal: findings from top-down and bottom-up models,” *Energy Policy*, vol. 39, no. 5, pp. 2772–2779, 2011.
- [22] M. D. Ma, R. Yan, and W. G. Cai, “An extended STIRPAT model-based methodology for evaluating the driving forces affecting carbon emissions in existing public building sector: evidence from China in 2000–2015,” *Natural Hazards*, vol. 89, no. 2, pp. 741–756, 2017.
- [23] F. J. Hasanov and J. I. Mikayilov, “The impact of age groups on consumption of residential electricity in Azerbaijan,” *Communist and Post-Communist Studies*, vol. 50, no. 4, pp. 339–351, 2017.
- [24] B. Liddle, “Accounting for nonlinearity, asymmetry, heterogeneity, and cross-sectional dependence in energy modeling: US state-level panel analysis,” *Economics*, vol. 5, no. 3, p. 30, 2017.
- [25] P. Minh Khuong, R. McKenna, and W. Fichtner, “Multi-level decomposition of ASEAN urbanization effects on energy,” *International Journal of Energy Sector Management*, vol. 13, no. 4, pp. 1107–1132, 2019.
- [26] Q. Wang and X. Yang, “Urbanization impact on residential energy consumption in China: the roles of income, urbanization level, and urban density,” *Environmental Science and Pollution Research*, vol. 26, no. 4, pp. 3542–3555, 2019.
- [27] F. Dong, B. Yu, Y. Hua, S. Zhang, and Y. Wang, “A comparative analysis of residential energy consumption in urban and rural China: determinants and regional disparities,” *International Journal of Environmental Research and Public Health*, vol. 15, no. 11, 2507 pages, 2018.
- [28] M. Zhang and P. Li, “Analyzing the impact of urbanization on energy consumption in Jiangsu Province,” *Natural Hazards*, vol. 76, no. 1, pp. 177–190, 2015.
- [29] S. J. Wang, G. H. Hua, and L. Z. Yang, “Coordinated development of economic growth and ecological efficiency in Jiangsu, China,” *Environmental Science and Pollution Research*, vol. 27, no. 29, pp. 36664–36676, 2020.
- [30] C. Li, R. H. Wang, F. M. Zhang, Y. J. Luo, and Y. Huang, “Relationships between ecosystem services and urbanization in Jiangsu province, eastern China,” *Sustainability*, vol. 11, no. 7, 2073 pages, 2019.

- [31] W. E. Kilbourne and A. Thyroff, "STIRPAT for marketing: an introduction, expansion, and suggestions for future use," *Journal of Business Research*, vol. 108, pp. 351–361, 2020.
- [32] M. Roy, S. Basu, and P. Pal, "Examining the driving forces in moving toward a low carbon society: an extended STIRPAT analysis for a fast growing vast economy," *Clean Technologies and Environmental Policy*, vol. 19, no. 9, pp. 2265–2276, 2017.
- [33] L. Wen and H. Shao, "Analysis of influencing factors of the carbon dioxide emissions in China's commercial department based on the STIRPAT model and ridge regression," *Environmental Science and Pollution Research*, vol. 26, no. 26, pp. 27138–27147, 2019.
- [34] T. Dietz and E. A. Rosa, "Effects of population and affluence on CO₂ emissions," *Proceedings of the National Academy of Sciences*, vol. 94, no. 1, pp. 175–179, 1997.
- [35] R. York, E. A. Rosa, and T. Dietz, "STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts," *Ecological Economics*, vol. 46, no. 3, pp. 351–365, 2003.
- [36] Z. Nasrollahi, M.-S. Hashemi, S. Bameri, and V. Mohamad Taghvaei, "Environmental pollution, economic growth, population, industrialization, and technology in weak and strong sustainability: using STIRPAT model," *Environment, Development and Sustainability*, vol. 22, no. 2, pp. 1105–1122, 2020.
- [37] B. Li, X. Liu, and Z. Li, "Using the STIRPAT model to explore the factors driving regional CO₂ emissions: a case of Tianjin, China," *Natural Hazards*, vol. 76, no. 3, pp. 1667–1685, 2015.
- [38] C. Wang, F. Wang, X. Zhang et al., "Examining the driving factors of energy related carbon emissions using the extended STIRPAT model based on IPAT identity in Xinjiang," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 51–61, 2017.
- [39] M. Wang, Y. Che, K. Yang, M. Wang, L. Xiong, and Y. Huang, "A local-scale-low-carbon plan based on the STIRPAT model and the scenario method: the case of Minhang District, Shanghai, China," *Energy Policy*, vol. 39, no. 11, pp. 6981–6990, 2011.
- [40] B. Liddle and S. Lung, "Age-structure, urbanization, and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts," *Population and Environment*, vol. 31, no. 5, pp. 317–343, 2010.
- [41] B. Liddle, "Urban density and climate change: a STIRPAT analysis using city-level data," *Journal of Transport Geography*, vol. 28, pp. 22–29, 2013.
- [42] S. G. Zheng, G. H. Huang, X. Zhou, and X. H. Zhu, "Climate-change impacts on electricity demands at a metropolitan scale: a case study of Guangzhou, China," *Applied Energy*, vol. 261, Article ID 114295, 2020.
- [43] J. L. Fan, B. Zeng, J. W. Hu, X. Zhang, and H. Wang, "The impact of climate change on residential energy consumption in urban and rural divided southern and northern China," *Environmental Geochemistry and Health*, vol. 42, no. 3, pp. 969–985, 2020.
- [44] J.-L. Fan, Y.-J. Zhang, and B. Wang, "The impact of urbanization on residential energy consumption in China: an aggregated and disaggregated analysis," *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 220–233, 2017.
- [45] H. Nie and R. Kemp, "Index decomposition analysis of residential energy consumption in China: 2002–2010," *Applied Energy*, vol. 121, pp. 10–19, 2014.
- [46] Y.-J. Zhang and H.-R. Peng, "Exploring the direct rebound effect of residential electricity consumption: an empirical study in China," *Applied Energy*, vol. 196, pp. 132–141, 2017.
- [47] M. J. Herrerias, C. Aller, and J. Ordóñez, "Residential energy consumption: a convergence analysis across Chinese regions," *Energy Economics*, vol. 62, pp. 371–381, 2017.
- [48] Y. Lu, P. Cui, and D. Li, "Which activities contribute most to building energy consumption in China? A hybrid LMDI decomposition analysis from year 2007 to 2015," *Energy and Buildings*, vol. 165, pp. 259–269, 2018.
- [49] X. Zhao, N. Li, and C. Ma, "Residential energy consumption in urban China: a decomposition analysis," *Energy Policy*, vol. 41, pp. 644–653, 2012.
- [50] P. Berrill, K. T. Gillingham, and E. G. Hertwich, "Drivers of change in US residential energy consumption and greenhouse gas emissions, 1990–2015," *Environmental Research Letters*, vol. 16, no. 3, Article ID 034045, 2021.
- [51] M. Zhang, Y. Song, P. Li, and H. Li, "Study on affecting factors of residential energy consumption in urban and rural Jiangsu," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 330–337, 2016.
- [52] J. P. Levy and F. Belaid, "The determinants of domestic energy consumption in France: energy modes, habitat, households and life cycles," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 2104–2114, 2018.
- [53] S. Karatasou and M. Santamouris, "Socio-economic status and residential energy consumption: a latent variable approach," *Energy and Buildings*, vol. 198, pp. 100–105, 2019.
- [54] Q. Li, J. Hu, and B. Yu, "Spatiotemporal patterns and influencing mechanism of urban residential energy consumption in China," *Energies*, vol. 14, no. 13, 3864 pages, 2021.
- [55] Z. Liu and T. Zhao, "Contribution of price/expenditure factors of residential energy consumption in China from 1993 to 2011: a decomposition analysis," *Energy Conversion and Management*, vol. 98, pp. 401–410, 2015.
- [56] N. C. Iraganaboina and N. Eluru, "An examination of factors affecting residential energy consumption using a multiple discrete continuous approach," *Energy and Buildings*, vol. 240, Article ID 110934, 2021.
- [57] Z. Wang, F. Yin, Y. Zhang, and X. Zhang, "An empirical research on the influencing factors of regional CO₂ emissions: evidence from Beijing city, China," *Applied Energy*, vol. 100, pp. 277–284, 2012.
- [58] Y. Yang, J. Liu, Y. Lin, and Q. Li, "The impact of urbanization on China's residential energy consumption," *Structural Change and Economic Dynamics*, vol. 49, pp. 170–182, 2019.
- [59] M. Y. Zhang, Y. L. Chen, W. Y. Hu, N. X. Deng, and W. J. He, "Exploring the impact of temperature change on residential electricity consumption in China: the 'crowding-out' effect of income growth," *Energy and Buildings*, vol. 245, Article ID 111040, 2021.
- [60] M. K. Anser, M. Alharthi, B. Aziz, and S. Wasim, "Impact of urbanization, economic growth, and population size on residential carbon emissions in the SAARC countries," *Clean Technologies and Environmental Policy*, vol. 22, no. 4, pp. 923–936, 2020.
- [61] A. A. Alola and H. Yildirim, "The renewable energy consumption by sectors and household income growth in the United States," *International Journal of Green Energy*, vol. 16, no. 15, pp. 1414–1421, 2019.
- [62] S. Wang, X. Sun, and U. Lall, "A hierarchical Bayesian regression model for predicting summer residential electricity demand across the USA," *Energy*, vol. 140, pp. 601–611, 2017.

- [63] C. A. Craig and S. Feng, "Exploring utility organization electricity generation, residential electricity consumption, and energy efficiency: a climatic approach," *Applied Energy*, vol. 185, pp. 779–790, 2017.
- [64] S. Zhu, L. Guo, Y. Cui et al., "Quality suitability modeling of volatile oil in Chinese Materia Medica - based on maximum entropy and independent weight coefficient method: case studies of *Atractylodes lancea*, *Angelica sinensis*, *Curcuma longa* and *Atractylodes macrocephala*," *Industrial Crops and Products*, vol. 142, Article ID 111807, 2019.
- [65] A. Turkmen and O. Ozturk, "Rank-based ridge estimation in multiple linear regression," *Journal of Nonparametric Statistics*, vol. 26, no. 4, pp. 737–754, 2014.
- [66] R. Salmeron, C. B. Garcia, and J. Garcia, "Variance inflation factor and condition number in multiple linear regression," *Journal of Statistical Computation and Simulation*, vol. 88, no. 12, pp. 2365–2384, 2018.
- [67] P. Kumar Narayan and R. Smyth, "Are shocks to energy consumption permanent or temporary? Evidence from 182 countries," *Energy Policy*, vol. 35, no. 1, pp. 333–341, 2007.
- [68] S. Niu, X. Zhang, C. Zhao, Y. Ding, Y. Niu, and T. H. Christensen, "Household energy use and emission reduction effects of energy conversion in Lanzhou city, China," *Renewable Energy*, vol. 36, no. 5, pp. 1431–1436, 2011.
- [69] F. Lun, J. G. Canadell, Z.-Q. Xu et al., "Residential energy consumption and associated carbon emission in forest rural area in China: a case study in Weichang County," *Journal of Mountain Science*, vol. 11, no. 3, pp. 792–804, 2014.
- [70] ASHRAE, *Ashrae Handbook Atlanta*, G. A.: ASHRAE, ASHRAE, Georgia, GA, USA, 2019.
- [71] S. A. Raza, N. Shah, and K. A. Khan, "Residential energy environmental Kuznets curve in emerging economies: the role of economic growth, renewable energy consumption, and financial development," *Environmental Science and Pollution Research*, vol. 27, no. 5, pp. 5620–5629, 2020.
- [72] Z. Tian, Y. Lei, and X. Gu, "Building energy impacts of simple green roofs in the hot summer and cold winter climate zone: suzhou as a study case," *Procedia Engineering*, vol. 205, pp. 2918–2924, 2017.
- [73] X. Xu, F. Luo, W. Wang, T. Hong, and X. Fu, "Performance-based evaluation of courtyard design in China's cold-winterhot-summer climate regions," *Sustainability*, vol. 10, no. 11, 3950 pages, 2018.
- [74] X. Feng, P. Zhang, and S. Ji, "Energy efficient retrofit technology of existing village and town residential houses in southern region," *Green Building Technologies and Materials*, vol. 224, p. 205, 2011.
- [75] S. N. Smith and S. F. Mueller, "Modeling natural emissions in the Community Multiscale Air Quality (CMAQ) Model-I: building an emissions data base," *Atmospheric Chemistry and Physics*, vol. 10, no. 10, pp. 4931–4952, 2010.
- [76] P. U. Onu, X. Quan, L. Xu, J. Orji, and E. Onu, "Evaluation of sustainable acid rain control options utilizing a fuzzy TOPSIS multi-criteria decision analysis model frame work," *Journal of Cleaner Production*, vol. 141, pp. 612–625, 2017.
- [77] J. Islas, F. Manzini, and M. Martinez, "Renewable energies in electricity generation for reduction of greenhouse gases in Mexico 2025," *AMBIO: A Journal of the Human Environment*, vol. 31, no. 1, pp. 35–39, 2002.
- [78] D. Xiang and C. Lawley, "The impact of British Columbia's carbon tax on residential natural gas consumption," *Energy Economics*, vol. 80, pp. 206–218, 2019.
- [79] S. H. Cho, M. Soh, K. Park, and H. J. Kim, "Impact of the Rise of Solo Living and an Ageing Population on Residential Energy Consumption in South Korea," *Energy & Environment*, vol. 33, 2021.
- [80] G. K. F. Tso and J. J. Guan, "A multilevel regression approach to understand effects of environment indicators and household features on residential energy consumption," *Energy*, vol. 66, pp. 722–731, 2014.
- [81] P. Esmailimoakher, T. Urmee, T. Pryor, and G. Baverstock, "Identifying the determinants of residential electricity consumption for social housing in Perth, Western Australia," *Energy and Buildings*, vol. 133, pp. 403–413, 2016.
- [82] P. X. Li and W. Sun, "Temporal evolution and influencing factors of energy consumption and related carbon emissions from the perspective of industrialization and urbanization in shanghai, China," *Sustainability*, vol. 10, no. 9, 3054 pages, 2018.
- [83] Q. Chen, H. R. Yang, W. G. Wang, and T. B. Liu, "Beyond the city: effects of urbanization on rural residential energy intensity and CO₂ emissions," *Sustainability*, vol. 11, no. 8, 2421 pages, 2019.
- [84] Q. Wang, J. Lin, K. Zhou, J. Fan, and M. P. Kwan, "Does urbanization lead to less residential energy consumption? A comparative study of 136 countries," *Energy*, vol. 202, Article ID 117765, 2020.
- [85] G. Chhipi-Shrestha, M. Kaur, K. Hewage, and R. Sadiq, "Optimizing residential density based on water-energy-carbon nexus using UTilities Additives (UTA) method," *Clean Technologies and Environmental Policy*, vol. 20, no. 4, pp. 855–870, 2018.
- [86] A. Thonipara, P. Runst, C. Ochsner, and K. Bizer, "Energy efficiency of residential buildings in the European Union – an exploratory analysis of cross-country consumption patterns," *Energy Policy*, vol. 129, pp. 1156–1167, 2019.
- [87] J. Gao, X. Zhong, W. Cai et al., "Dilution effect of the building area on energy intensity in urban residential buildings," *Nature Communications*, vol. 10, no. 1, 4944 pages, 2019.
- [88] J. Li, L. Yang, and H. Long, "Climatic impacts on energy consumption: intensive and extensive margins," *Energy Economics*, vol. 71, pp. 332–343, 2018.
- [89] S. Jing, B. Li, M. Tan, and H. Liu, "Impact of relative humidity on thermal comfort in a warm environment," *Indoor and Built Environment*, vol. 22, no. 4, pp. 598–607, 2013.
- [90] H. Yan, Q. Liu, W. Zhao et al., "The coupled effect of temperature, humidity, and air movement on human thermal response in hot-humid and hot-arid climates in summer in China," *Building and Environment*, vol. 177, Article ID 106898, 2020.
- [91] W. Liu, Q. Dai, J. Bao et al., "Influenza activity prediction using meteorological factors in a warm temperate to subtropical transitional zone, Eastern China," *Epidemiology and Infection*, vol. 147, e325 pages, 2019.
- [92] P. Zong, Y. Zhu, H. Wang, and D. Liu, "WRF-chem simulation of winter visibility in Jiangsu, China, and the application of a neural network algorithm," *Atmosphere*, vol. 11, no. 5, 520 pages, 2020.
- [93] X. L. Kong, X. L. Zi, L. Yun, and X. S. Zhang, "An experimental research on wall radiant cooling and wall-attached-jet air-conditioning system," *Applied Mechanics and Materials*, vol. 501–504, pp. 2244–2251, 2014.