

Clean Energy Transformation Investigation and Carbon Emission Analysis in Existing Urban Settlements in China

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Research

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Abstract

Carbon peak and carbon neutrality have been incorporated into the ecological civilization construction and social development strategy in China. At the same time, the implementation of clean energy transformation in urban settlements only relies on the mandatory provisions in the transformation design standards for a long time, and the transformation effect is inconsistent with the actual transformation demands of residents, which is contrary to the original intention of improving the living environment. A clean energy transformation investigation was conducted in the existing urban settlements in China from July to August 2020 in order to study the influencing factors and demands of residents' transformation intention in the clean energy transformation. The influencing factors and demand of urban residents' clean energy transformation intention were analyzed according to different climate zones, multivariate logistic regression and binary logistic regression. Taking Shandong Province as a case, a specific analysis of residential energy consumption data in cold climate zones is carried out, and the peak of residential carbon dioxide is predicted under the condition of different annual replacement rates of clean energy power generation. The results show that the residents' intention index of clean energy transformation is the highest in hot summer and cold winter area. The low motivation of clean energy transformation intention mainly comes from low annual income and high cost of living energy consumption considering the influencing factors of urban residents' clean energy transformation intention. In contrast, the high motivation of clean energy transformation intention is mainly from the not popular user of clean energy. For the demand of clean energy transformation, residents in cold regions have clear demand for energy-saving transformation of external walls and air conditioning, etc. residents consumption can be achieved the carbon peak by 2030 only when the annual growth rate of clean electricity reaches more than 5%.

Introduction

China's carbon neutrality time is 2060 through a policy announcement.. Low carbon transformation technology is a necessary path to achieve carbon neutrality in the field of building energy consumption. In 2018, the total energy consumption for building operation in China is 1 billion tons of standard coal, accounting for 21.7% of the total national energy consumption. The total carbon emission of construction is 2.11 billion Ton, accounting for 21.9% of the total energy carbon emission in China (China Building Energy Consumption Research Report, 2018-2020). The building energy efficiency in China will become a key factor affecting energy security, optimizing energy structure, improving energy efficiency, and implementing the strategy of resources and sustainable development (Li Deying, 2018). China attaches great importance to the development of buildings and the improvement of living environment. However, for a long time, the implementation of building energy conservation only relies on the mandatory provisions in the design standards of building energy conservation, and the transformation effect is inconsistent with the actual transformation demands of residents, which is contrary to the original intention of improving the living environment.

In recent years, different scholars have studied the low-carbon transformation technology of buildings from different ways. The indicator system on the ageing degree of the community has been constructed based on a questionnaire survey and is based on the aging of the population. It is suitable for the current status and needs assessment of the ageing of existing urban settlements (Huang Wenwei. et al. 2020). Energy-saving renovation of building envelope in cold areas and hot summer and cold winter areas were respectively provided suggestions (Zheng Qian. et al, 2020, Ding Xinzhi. et al, 2019. Zhang Rui et al. 2018 provided reference suggestions for building energy-saving transformation in hot summer and cold winter and hot summer and warm winter areas from the perspective of maximizing transformation decision-making benefits. Zhang chunhuan, 2019 from the perspective of performance improvement, also selected the existing residential building envelope system as the research object, combined with BIM Technology to study the energy consumption performance improvement. Yu Shiyan, 2017 studied the existing urban residential transformation in Zhengzhou from four different levels, and provided some feasible green transformation strategies. Ke Xiong et al. 2017 studied how to carry out building energy-saving transformation while ensuring thermal comfort. Karlijn, 2019 studied the drivers of energy saving behavior of European residents through an online survey, and then put forward the optimization scheme of residential energy saving transformation. Gianluca, 2017 also proposed effective and targeted policies that promote energy responsible lifestyles by studying the daily behaviors of British residents. Stefan. et al. 2016 compared heat savings and heat supply options from a private-economic perspective to calculate potentials and costs of heat saving measures of Ringk ø Bing skjern. Agustin, 2018 has provided renovation measures to improve the thermal performance of European buildings.

The survey has the following three objectives to achieve:

1. The basic situation of energy consumption in urban residential buildings will be investigated.
2. The demand and influencing factors of clean energy transformation will be investigated and analyzed.
3. The development trend of carbon emissions from urban building life energy consumption will be predicted and analyzed based on low-carbon scenarios.

The results of the questionnaire survey showed that the energy-saving renovation suggestions in existing urban settlements have been obtained that meet the residents' renovation intentions and needs. At the same time, it provides suggestions to promulgate more accurate and appropriate energy-saving policies in China. The cross-sectional study method was used to determine the minimum sample size by using the sample size estimation formula of sampling rate (Xu biao, 2011). Logistic regression was used to analyze the data. Logistic regression, also known as logistic regression analysis, is a generalized linear regression analysis model, which is often used in data mining, prediction and other fields, and the effect of regression analysis is good. In this paper, firstly, the multiple disordered logistic regression is used to analyze the significance of the influencing factors of residents' transformation intention. Secondly, according to different climate zones, the binary logistic regression is used to get the residents' demand for clean energy transformation. In this part, cold regions and severe cold regions are taken as examples, Finally, the development trend of carbon emission of urban building energy consumption is analyzed

based on the prediction of different clean energy power growth rates. The research and analysis path is shown in Fig. 1.

Research Methods

2.1 Survey design

The questionnaire survey was conducted in different climatic regions above county level. The research objects are urban residents of all ages and occupations. The sample is determined by random sampling, therefore the minimum sample size is determined by the sample size estimation formula of the selection rate (Wu Minglong, 2010). Namely:

$$n = \frac{t^2}{r^2} * p * (1 - p) \quad (1)$$

where,

n : minimum sample size; r : the error rate; The difference between the sample rate p and the overall rate p was not more than 2%, $r = 0.02$. p : sample rate; Based on the scale of pre survey, $p = 0.04$; t : t -value is the statistical value of t -test, also known as student's t test; Look up the t -value table,

$t = \mu_{\alpha/2} = 1.96, (\alpha = 0.05)$ Considering the response situation and invalid questionnaire, 10% more sample size should be added to the minimum sample size, final sample size should be no less than 406. The questionnaire mainly includes two parts. The first part includes five questions: annual income, housing construction year, clean energy use degree and living energy consumption cost satisfaction. The options in this part adopt orderly multi classification, and each question is set with 1-3 levels; The second part is to study transformation demand of four specific ways of building transformation, namely, the transformation needs of external walls, external windows, heating and cooling, this part of the question is set to 0-1 classification.

2.2 Data analysis method

The questionnaire data of this study were derived from the questionnaire and analyzed by SPSS statistics. All percentages in this paper are valid percentages without missing values. In this paper, multiple logistic regression model is used to analyze the significance of the factors affecting the degree of urban residents' transformation intention. Likelihood ratio test and pseudo R^2 test were used to test the model. Binary logistic regression analysis was used to analyze the four types of specific building renovation intention and overall renovation intention, and Hosmer test was used to test the model. In this paper, 5% significance level and two-sided test were used for all statistical analysis, and the significance p value less than 0.05 was the judgment basis of significance.

2.3 Carbon dioxide emission estimation method

The carbon emission of residential energy consumption is calculated based on the carbon emission coefficient method recommended by IPCC

$$T(\text{CO}_2) = \sum HEC_j * CDE_j \quad (2)$$

where,

$T(\text{CO}_2)$: the carbon dioxide emission of energy consumption ; HEC_j : the j-th energy consumption; CDE_j : the carbon dioxide emission coefficient of the j-th energy.

The data of household energy consumption comes from the energy balance (physical quantity) of Shandong Province in China energy statistical yearbook from 1996 to 2019, and the carbon emission coefficient is calculated by the carbon emission calculation formula recommended by IPCC.

Results

3.1 Family and energy consumption characteristics

425 valid questionnaires were collected and sorted out to meet the above minimum sample size requirements. The questionnaire and option settings are shown in Table 1. Statistics of the results of the effective questionnaire, the first part of the residents option distribution map. As shown in Fig. 2, the number of families with annual income of RMB100000-300000 is the largest, accounting for 51.53%, and the number of families with annual income of RMB300000 or more accounts for 16.47%. The highest proportion of residential buildings was 40.94% from 2000 to 2010, followed by 34.12% after 2010. The households with P < 10% of clean energy use accounted for the most, accounting for 49%. The households with P > 30% of clean energy use accounted for less than 20%, while the residents with less than moderate satisfaction of living energy consumption cost accounted for 95%. The average values of the provincial index of household annual income, household clean energy use degree, satisfaction degree of living energy consumption cost and residential construction year are shown in Fig. 3-6. It can be seen that the household annual income index, household clean energy use degree index and residential construction generation index are higher in the East, indicating that the annual income of households in the east coast is higher, In the East, the household clean energy utilization is relatively high, and the housing in the East is relatively new.

According to the division of urban residents' clean energy transformation intention, the residents' income in the range of RMB100000-300000 have the highest intention of building energy-saving transformation, the construction years in 2000-2010 have the highest intention, the transformation intention with lower clean energy use level has the highest degree, and the transformation intention with appropriate living energy consumption cost has the highest degree.

Table1. Questionnaire items and options

Part I: Basic information of residents' life and residents' intention of clean energy transformation			
Grade or Range options	1	2	3
Questionnaire items			
T: Transformation intention of residential clean energy	T=Slight intention	T=Moderate intention	T=Strong intention
H: Housing completion time	H=Before 2000	H=2000-2010	H=After 2010
P: Proportion of household clean energy use	$P \leq 10\%$	$10\% < P \leq 30\%$	$30\% < P$
S: Satisfaction level of living energy consumption cost	S=Less satisfied	S=Moderately satisfied	S=Highly satisfied
A: Annual household income	$A < 10^5$ RMB	$10^5 \leq A < 3 \times 10^5$ RMB	3×10^5 RMB $\leq A$
Part II: Residents' demand for clean energy transformation			
Grade or Range options	0	1	
Questionnaire items			
Is the external wall necessary to be transformed	No	Yes	
Is the external window necessary to be transformed	No	Yes	
Is the heating system necessary to be transformed	No	Yes	
Is the cooling system necessary to be transformed	No	Yes	

3.2 Regions characters

According to the Fig.7, the average value of the national transformation intention index is 1.71. Residents' transformation intention in hot summer and cold winter areas exceeds the national level. Almost all heating and cooling in urban areas with hot summer and cold winter adopt air conditioning, and the large annual living energy consumption cost is the general feedback problem of residents in this area.

The average value of transformation intention index by province is shown in Fig. 8. In general, the provinces with relatively low intention of clean energy transformation are those with large area of clean energy transformation, especially Inner Mongolia Autonomous Region; On the contrary, provinces with relatively high intention of clean energy transformation have smaller area of clean energy transformation. However, there are some provinces with large area of clean energy transformation, but residents' intention of transformation is still on the high side, such as Heilongjiang, Jilin and so on. After 2010, by the end of

2020, the phenomenon of "power rationing" will appear again in many places in southern China. Zhejiang, Hunan and other places have also introduced different policies to limit power consumption. The residents in the above provinces generally have a high intention of transformation. From the demand side and supply side to analyze. From the demand side, first of all, with the gradual stabilization of the epidemic, the accelerated recovery of industrial production (especially heavy industrial production) has brought relatively large short-term power demand. Secondly, the early cold winter leads to the rise of residential power load. From the supply side point of view, renewable energy power instead of thermal power has higher requirements on the system stability of power grid. The proportion of renewable energy in the power structure has increased, which brings challenges to the stable and safe operation of power grid due to its unstable characteristics. This year, the precipitation in southern China in autumn and winter is reduced, and winter is the time when wind power and photovoltaic power generation are low.

To sum up, clean energy transformation is undoubtedly the inevitable trend of low-carbon transformation, and the key to promote the transformation is to make rational use of the advantages of clean energy in different climate zones to carry out energy-saving transformation of existing buildings to effectively meet the needs of residents and carbon emission goals.

3.3 Clean energy transformation intention

Based on the questionnaire data, this paper takes the degree of clean energy transformation intention as the dependent variable, and takes the annual income, the degree of clean energy utilization, and the satisfaction of living energy consumption cost as the influencing factors to carry out multiple disordered logistic regression. The fitting results of likelihood ratio test $p = 0.000 < 0.05$, the fitting effect is good, with 5% significance level and two-sided test, the significance p value is less than 0.05 as the judgment basis, the operation results are shown in Table 2.

From the operation results, compared with the people who think that there is no need to reform, the people with low intention to reform and annual income of 100000-300000 yuan are more likely to think that there is no need to reform than the people with annual income of more than 300000 yuan; The people with low transformation intention and low satisfaction of living energy consumption cost have higher transformation intention than those with high satisfaction of living energy consumption cost. Compared with the people who think that there is no need to reform, the low level of clean energy use is a significant influencing factor for the high intention of reform. The results show that: with the development of economy, the demand of clean energy consumption for a better life of residents in existing settlements does not match with the speed of low-carbon transformation and development of urban existing settlements, which requires high-quality and efficient development of low-carbon energy. On the whole, the motivation of the people with low transformation intention tends to come from low annual income and high energy consumption; However, the motivation of the people with higher transformation intention tends to come from the low level of clean energy use, and there is no obvious regression relationship between the impact of residential building completion time and the degree of transformation intention. It

can be seen that the current demand for building energy-saving transformation is not only for the residents of old settlements, but also for the residents of urban settlements with relatively new age.

Table 2. Influencing factors of clean energy transformation intention in existing urban settlements

Transformation intention of residential clean energy ^a		<i>p</i>	<i>Exp(B)</i>	Transformation intention of residential clean energy ^a		<i>p</i>	<i>Exp(B)</i>
T=Moderate intention	intercept	0.018		T=Strong intention	intercept	0.007	
	$A \times 10^5$ RMB	0.209	0.649		$A \times 10^5$ RMB	0.987	0.993
	$10^5 \leq A \leq 3 \times 10^5$ RMB	0.042	0.515		$10^5 \leq A \leq 3 \times 10^5$ RMB	0.991	1.004
	3×10^5 RMB $\leq A$.	.		3×10^5 RMB $\leq A$.	.
	H=Before 2000	0.687	1.133		H=Before 2000	0.920	1.038
	H=2000-2010	0.412	1.248		H=2000-2010	0.130	1.639
	H=After 2010	.	.		H=After 2010	.	.
	P \leq 10%	0.542	1.215		P \leq 10%	0.001	3.092
	10% \leq P \leq 30%	0.060	1.810		10% \leq P \leq 30%	.	31.550
	30% \leq P	.	.		30% \leq P	.	.
	S=Less satisfied	0.017	6.413		S=Less satisfied	0.093	2.522
	S=Moderately satisfied	0.055	4.380		S=Moderately satisfied	0.798	1.150
S=Highly satisfied	.	.	S=Highly satisfied	.	.		

a: 'T=Slight intention' as reference condition

Discussion

4.1 Clean energy transformation demand

According to the questionnaire, whether the immediate transformation is needed as the dependent variable, whether the wall, window, heating and cooling need to be transformed as independent variables, this paper takes cold and cold areas as examples, and the models are respectively connected. The model is effective after the Hosmer test. From the view of Fig.9, the residents' transformation needs of the

outside window and heating in the cold area, and the external window needs to be reformed is 6.449 times that the transformation is not required. The demand for the renovation of the residents who think that the heating needs to be reformed is 5.025 times that the transformation is not required.

Since the clean heating was started in 2016, the effect of different heating methods can be evaluated from different angles. From the perspective of heating energy, the problem of coal to gas is particularly prominent in the reform practice, and the gas supply is difficult to guarantee. In 2017-2018 heating season, the shortage of natural gas in the whole country has caused serious problems in heating safety. From the view of heating cost, the cost of cogeneration is the lowest, only 1 / 5 of the construction cost of large-scale natural gas boiler room; From the objective of improving the haze phenomenon in winter in northern China, the waste heat from power plants and industry will not be discharged by new pollutants, which has obvious advantages in reducing emission. From the perspective of the people's intention of this paper, heating problem is still a significant factor that causes residents to think that the housing needs immediate renovation in the cold area. The questionnaire feedback shows that heating not only has the phenomenon of insufficient heating, but also the phenomenon of excessive heating and high indoor temperature, and the residents think that the heating cost is high. Considering that the heating requirements in the cold area are higher than those in other areas, combined with the above analysis, the heating clean transformation should meet the established energy saving and emission reduction targets, ensure the safety and quality of heating, and make it economical and reasonable. The best way to combine heat and power production is at present.

From the perspective of Fig. 10, the residents' transformation needs in cold areas are external wall transformation and refrigeration transformation, and it is considered that the refrigeration needs to be reconstructed 5.579 times that is not needed, and the demand for residents' transformation is clear.

In the building energy consumption, air conditioning energy consumption accounts for a large proportion, so it is particularly important to analyze the energy saving of air conditioning. Air conditioning performance is an important factor affecting air conditioning energy saving, but air conditioning energy saving is not only related to the performance of air conditioning itself, but also depends on the behavior of users to a large extent. The energy consumption of residential air conditioning in China is far lower than that of the United States. Through a detailed investigation of typical residential buildings in China and the United States, it is found that this huge energy consumption is mainly caused by air conditioning of "half hour and half an air". Further investigation found that the gap of dozens of times is not related to the economic income of each family, but negatively related to age. The reason is that the difference of life style leads to the difference of use mode and energy consumption.

4.2 Carbon emissions

According to Fig.11-12, as the main energy supply mode of urban residents, the carbon emission level and peak time of urban energy consumption are predicted under the annual growth rate of different clean energy generation based on the existing settlements in Shandong Province, while maintaining the energy consumption intensity of various types of energy per capita is unchanged. As can be seen from Figure 1, when $i=0.5\%$, the domestic energy consumption carbon dioxide emission of the whole province will continue to rise before 2040. When $i = 0.6\%$, the carbon dioxide of the residents in the province can reach the peak in 2035, but the goal of achieving the peak by 2030 can still not be achieved. If $i = 1\%$, the peak of the energy consumption carbon emission of the residents in the province can be achieved by 2025. However, with the increasing urbanization rate, compared with the peak of the energy consumption of residents in the province, the scenario of $i=1\%$ can not achieve the peak of urban life energy consumption carbon emission before 2030. When $i = 1.5\%$, the peak of urban household energy consumption carbon emission can be achieved by 2030, and the peak of household energy consumption carbon emission can be achieved by 2025 when $i = 2\%$.

Conclusion

In summary, for cold areas, 1. The key point of heating transformation is to improve the efficiency of heating station and exchange station. 2. The renovation of the exterior wall and exterior window of residential building envelope structure needs to be modified based on the residents' intention of reconstruction. The key point of the renovation is the selection and research of the enclosure materials. 3. The energy saving transformation of air-conditioner system is an urgent problem in cold area. The transformation needs to start from two key points: system design and equipment energy consumption. At the same time, the above three building energy-saving transformation work can not be carried out in isolation, and the comprehensive and systematic solution to the problem of building energy saving transformation is needed. For different regions, the demand for transformation is different. The residents questionnaire survey provides strong feedback on the achievements of energy-saving transformation of buildings in China, and guides the key points of the next step of reconstruction, the questionnaire work should be timely and detailed.

From the results of this study, the influence factors of different intention to transform are different, and the demands of people transformation in different climate zones are different. In the future, the energy-saving transformation of buildings should be based on full investigation, and the circulation system of bottom feedback top design should be formed. The top design is the direction of building energy saving transformation, and the feedback from the bottom is the driving force to promote the transformation of building energy conservation. The top design should meet the energy saving goal of our country building, and also meet the needs of residents' actual transformation. The realization of the bottom layer is the standard to check the rationality and feasibility of the top-level design. A reasonable energy-saving transformation path of building and better promote the work of carbon emission reduction can be formed only by combining top design with bottom feedback, through several rounds from top to bottom.

Based on the results of the demand of clean energy transformation in settlements studied in this paper, the project team will further study on the next research of clean energy alternative strategy. The overall research technical route is shown in Fig.13, where the red part is the content of this paper.

Declarations

Author Contributions Conceptualization, Wei Chen; methodology, Qiong Li; investigation, Li Zhao; 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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Conflicts of Interest The authors declare no conflict of interest. The funders had no role in (i) the design of the study, (ii) the collection, analyses, or interpretation of the data, (iii) the writing of the manuscript, or (iv) the decision to publish the results.

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Figures

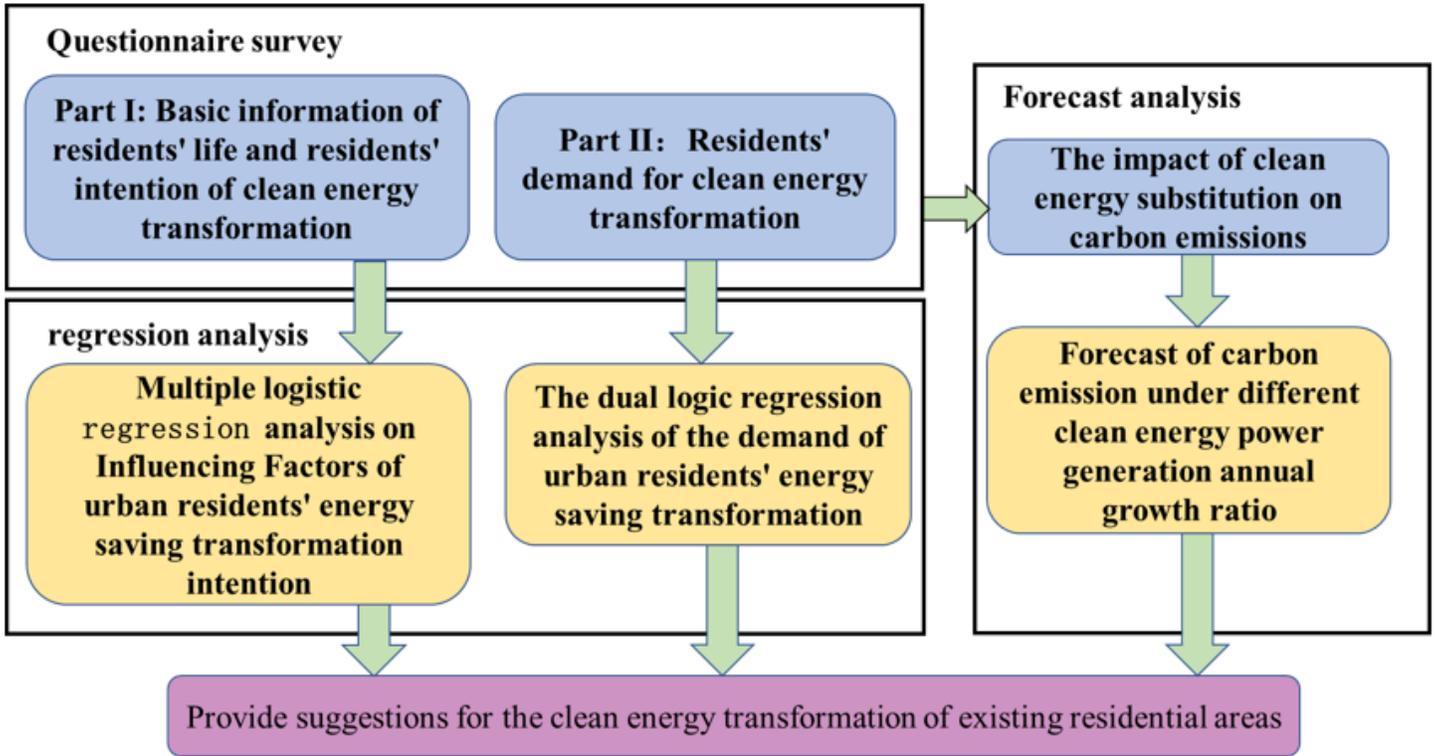


Figure 1

Research and analysis path

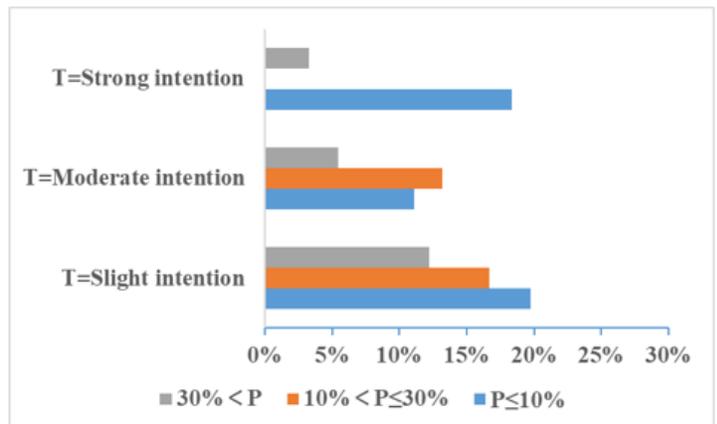
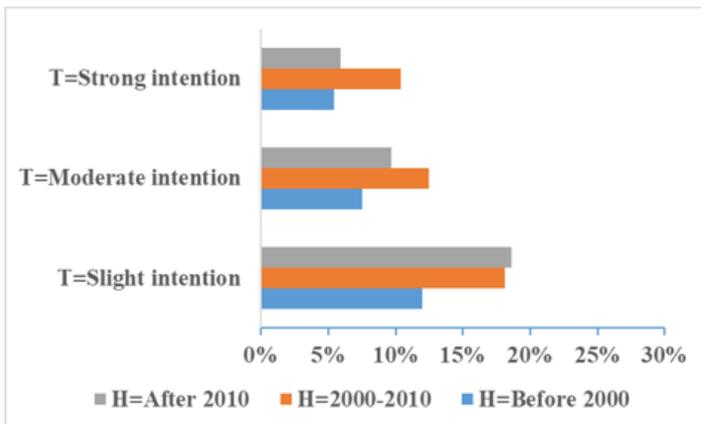
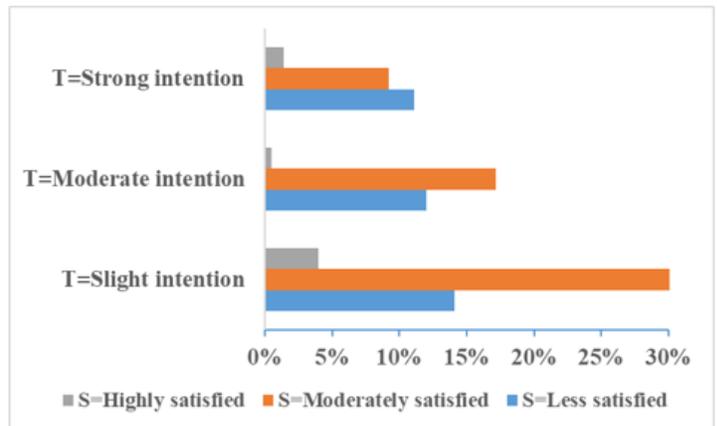
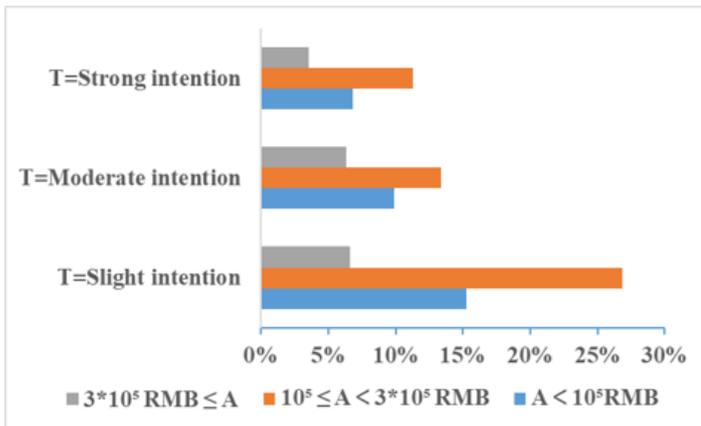


Figure 2

Opinions on transformation intention of residential clean energy

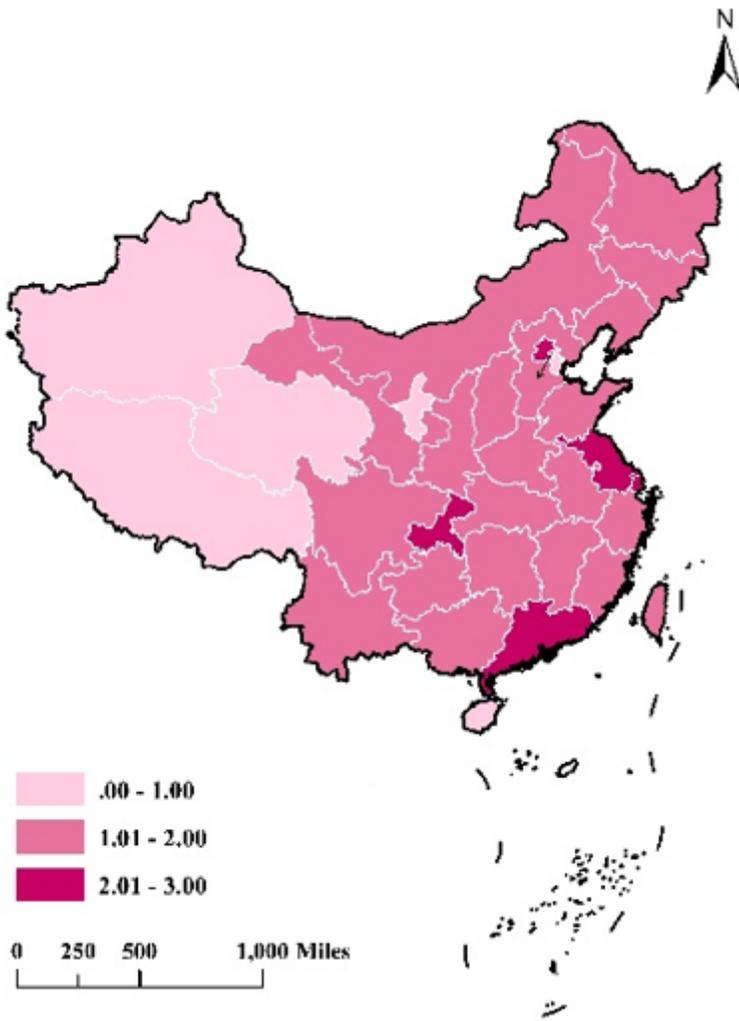


Figure 3

Annual household income index

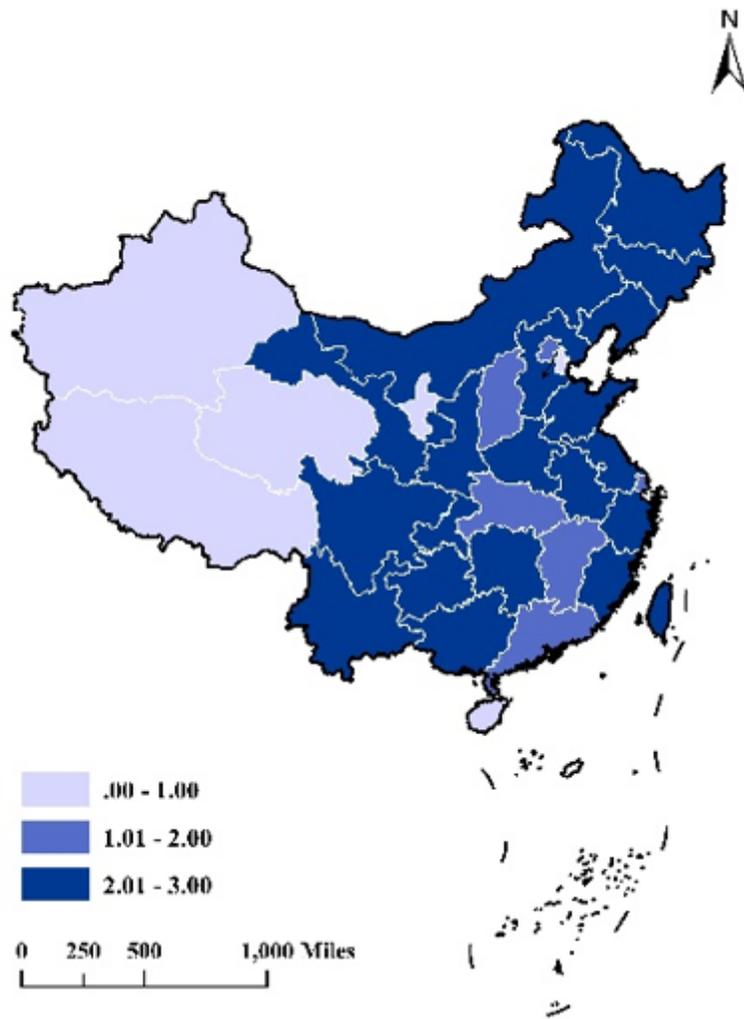


Figure 4

Opinions on transformation intention of residential clean energy

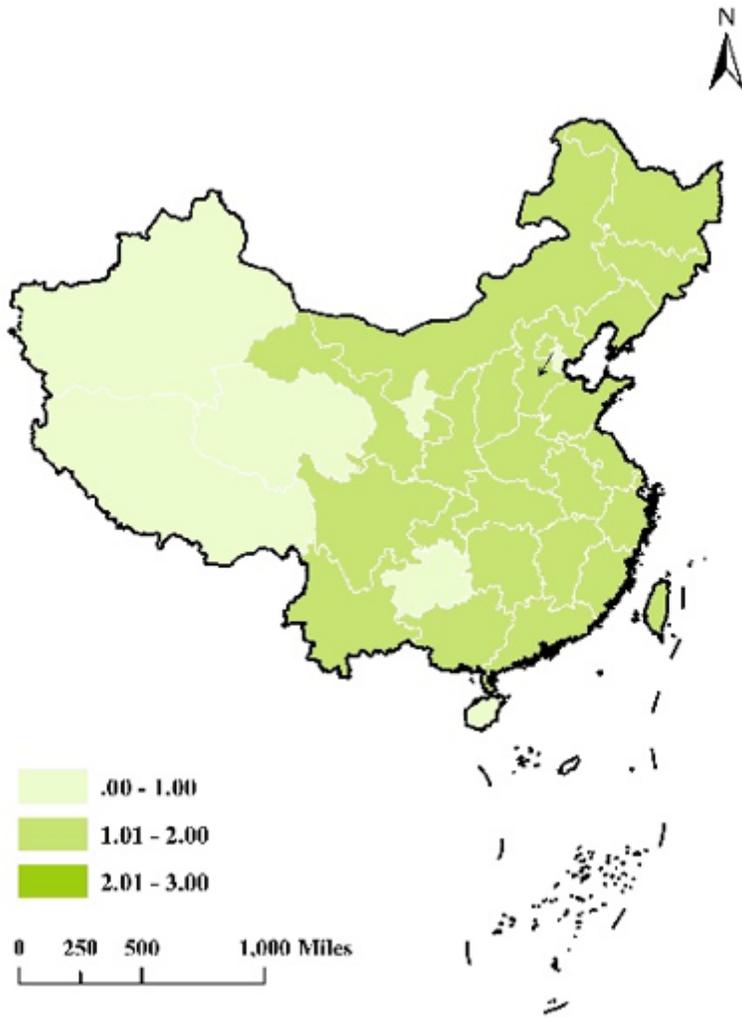


Figure 5

Proportion of household clean energy use index

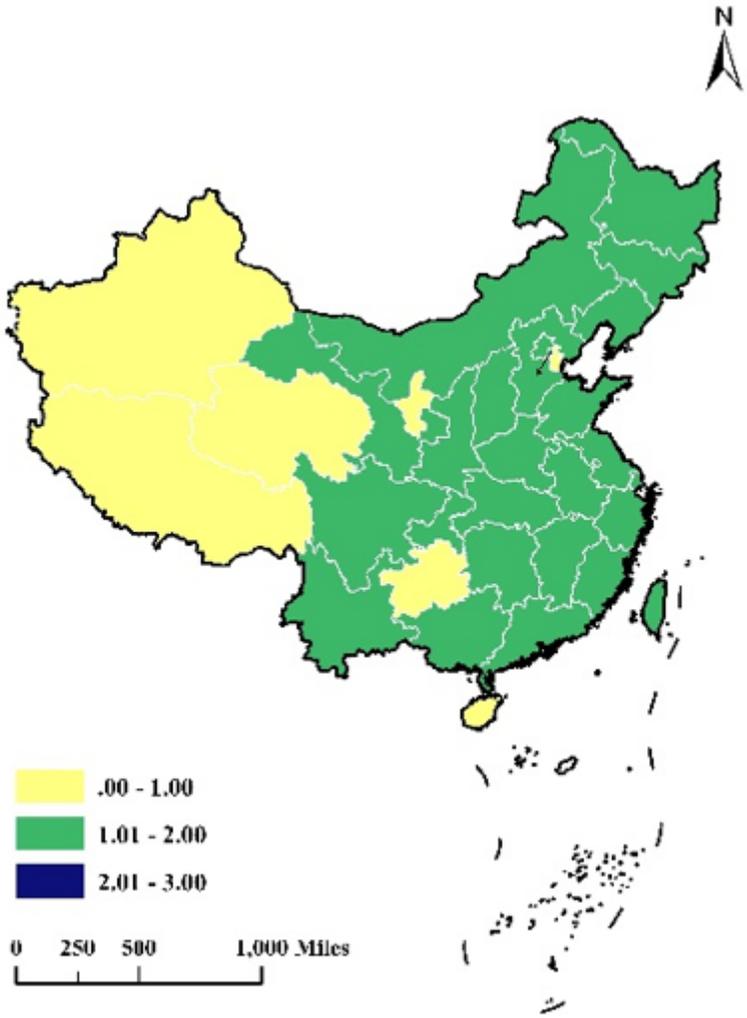


Figure 6

Satisfaction level of living energy consumption cost index

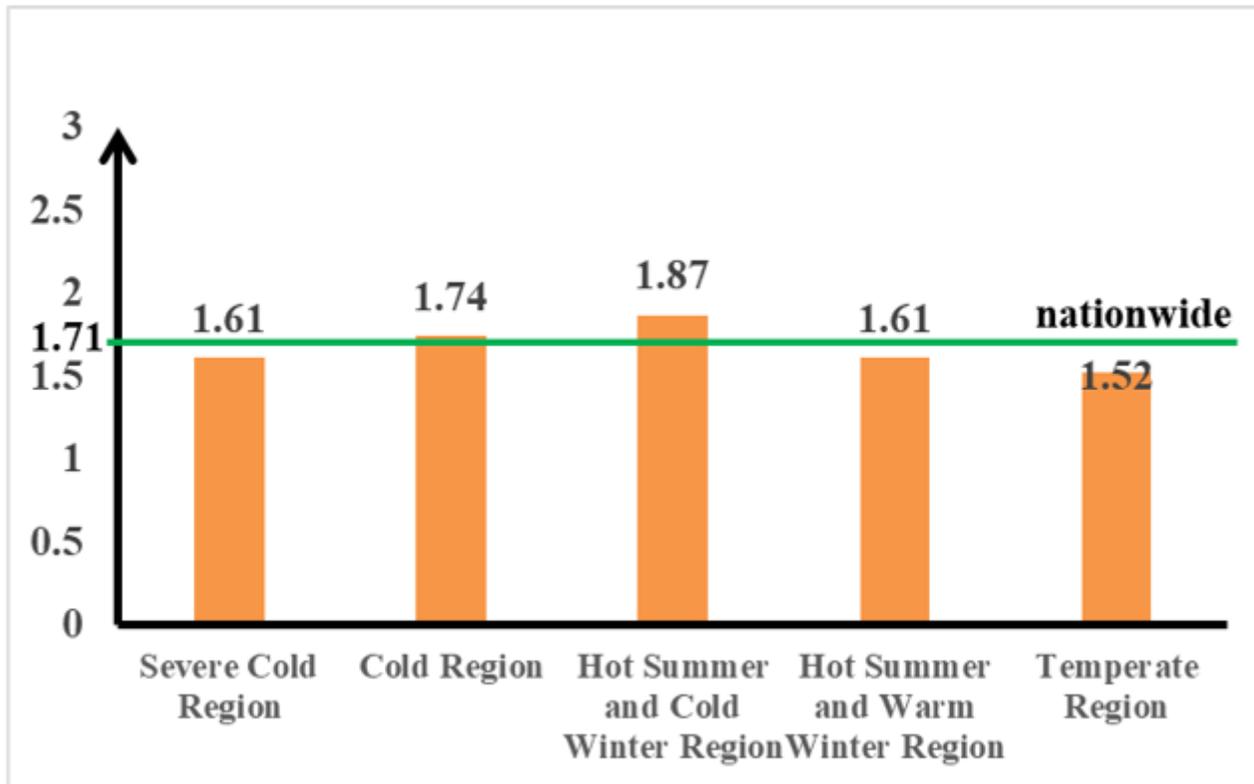


Figure 7

Transformation intention index of different climatic regions

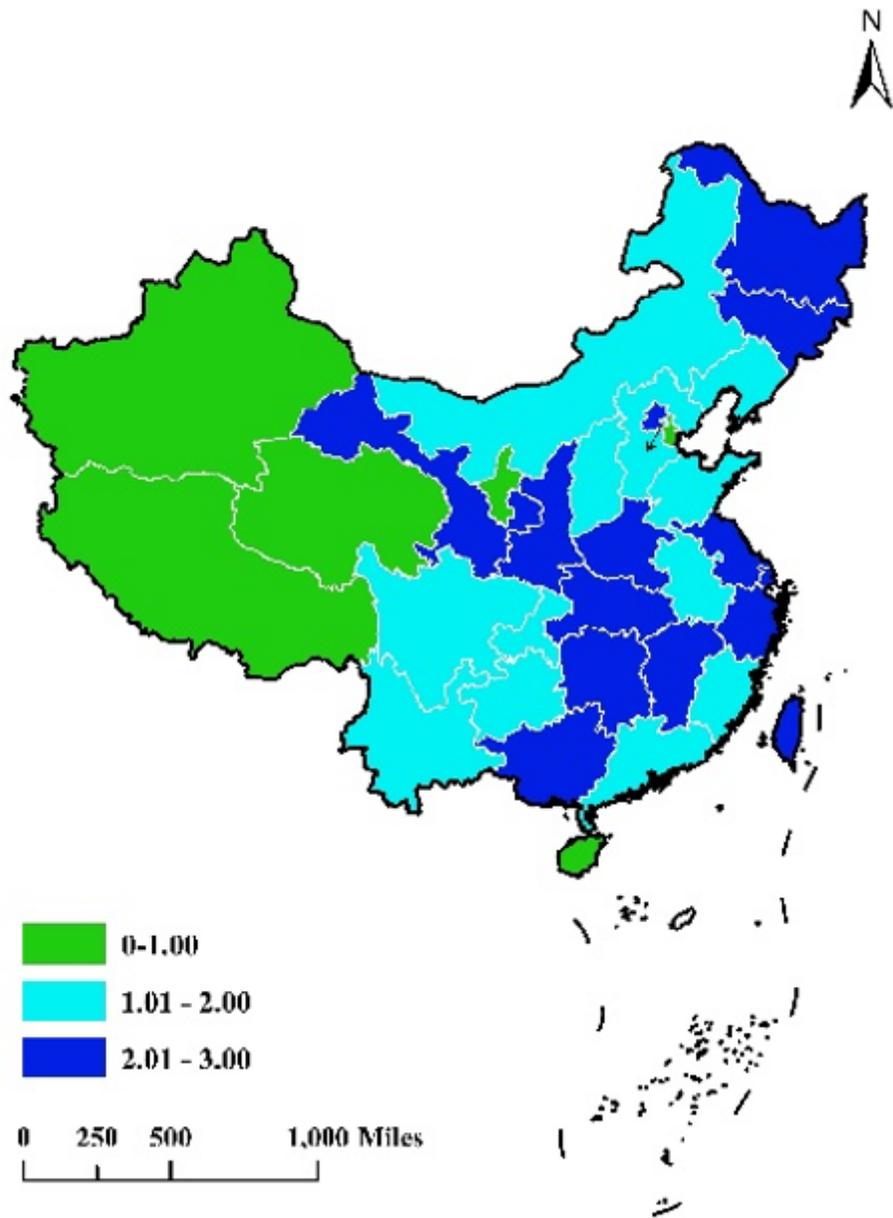


Figure 8

Transformation intention index of different provinces

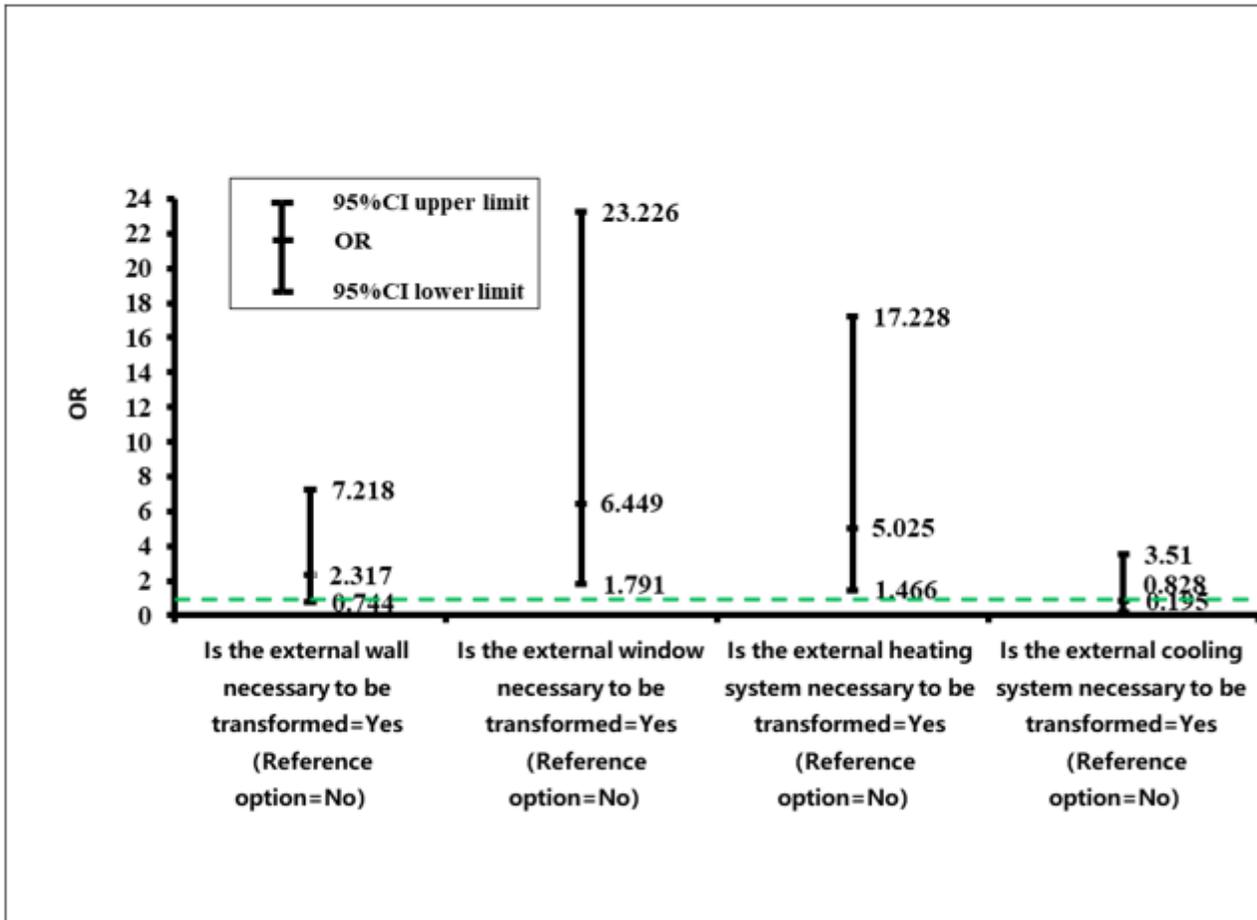


Figure 9

Demand of residents in severe cold region for clean energy transformation

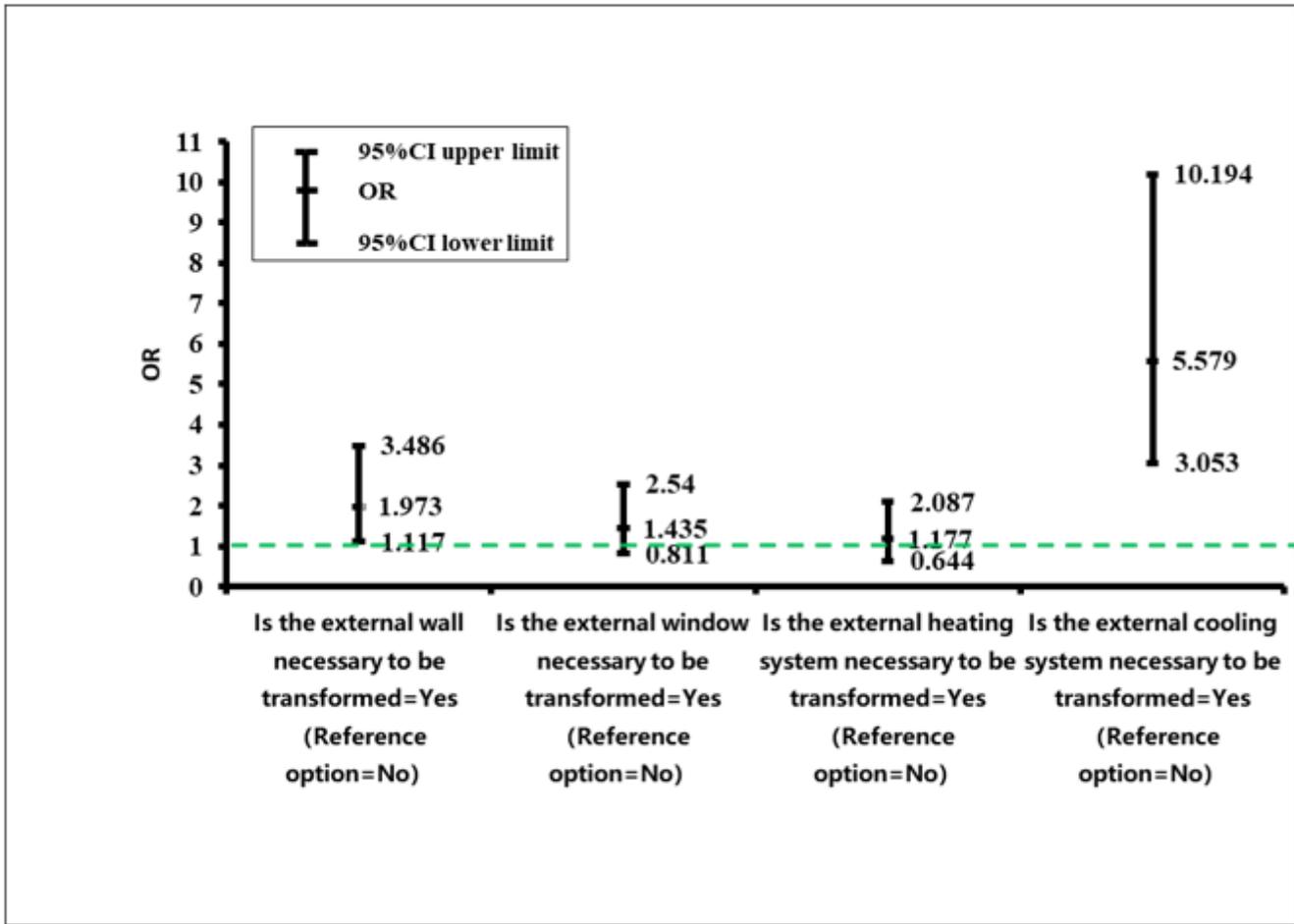


Figure 10

Demand of residents in cold region for clean energy transformation

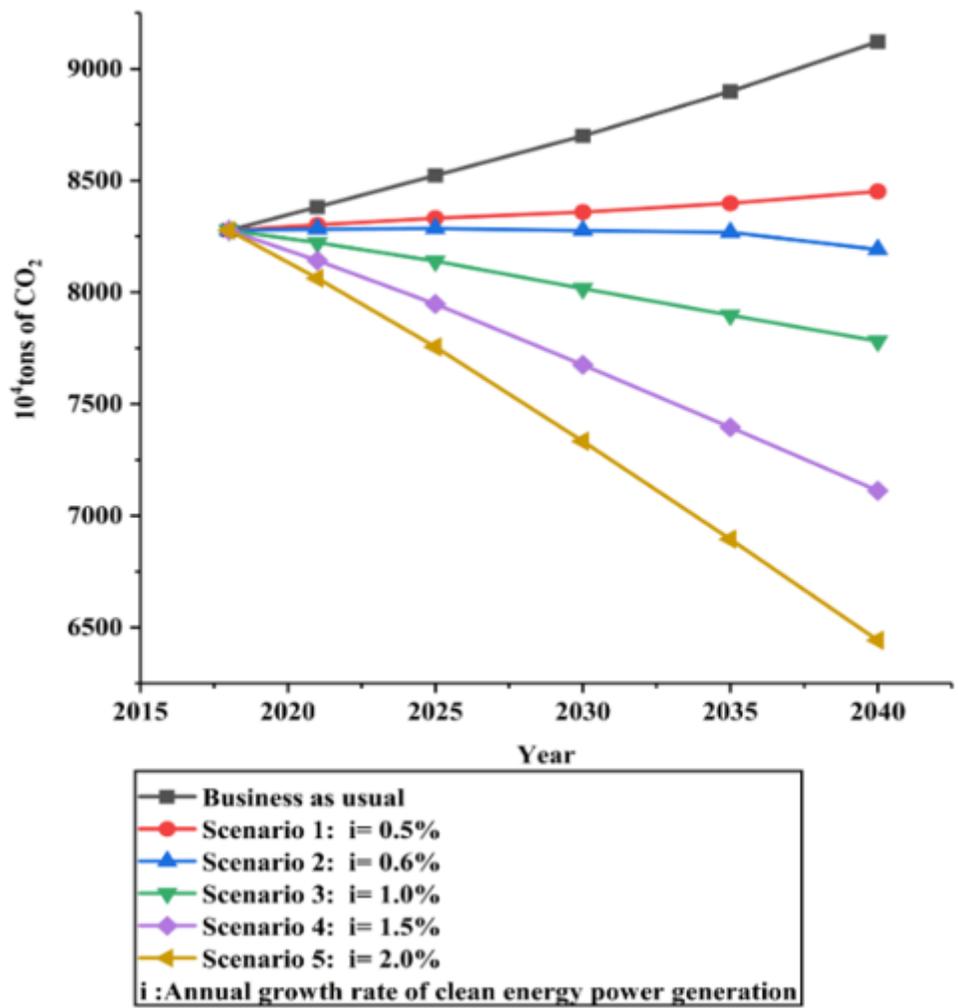


Figure 11

Prediction of carbon emissions from residents' life in Shandong Province

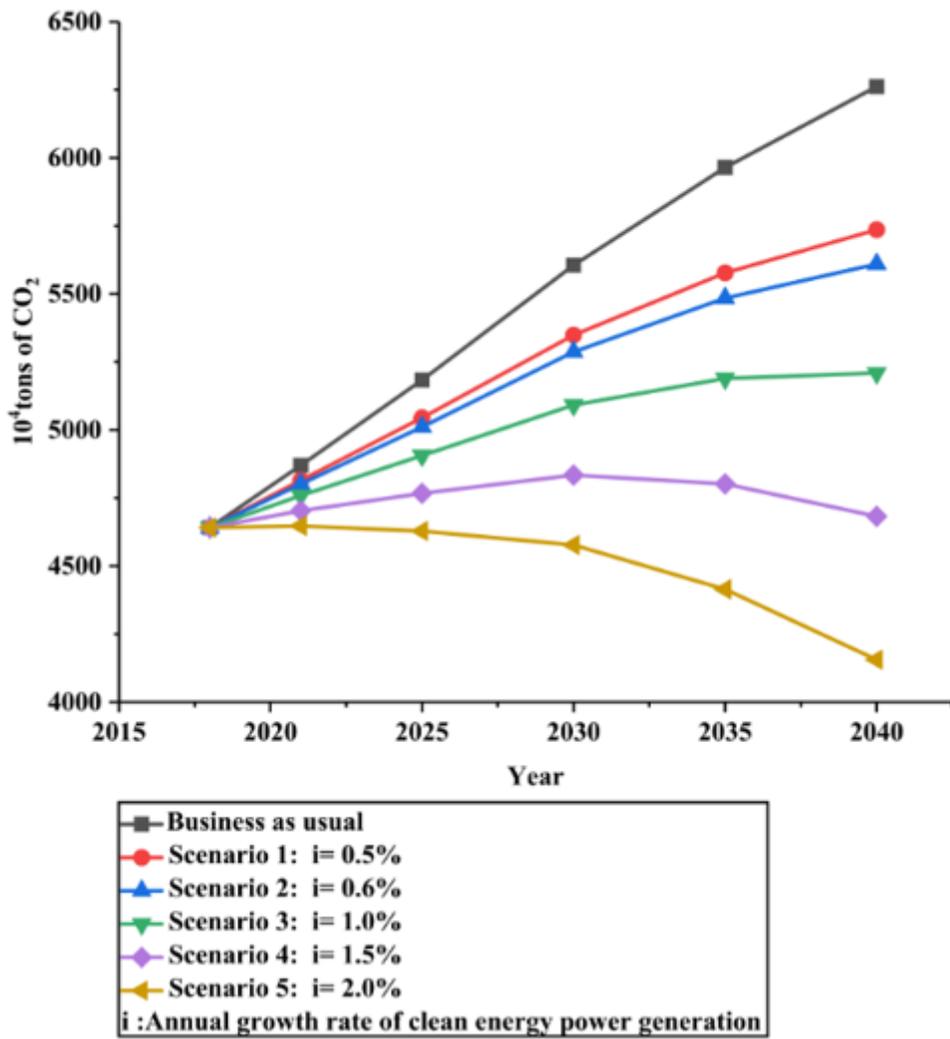


Figure 12

Prediction of carbon emissions from urban residents' life in Shandong Province

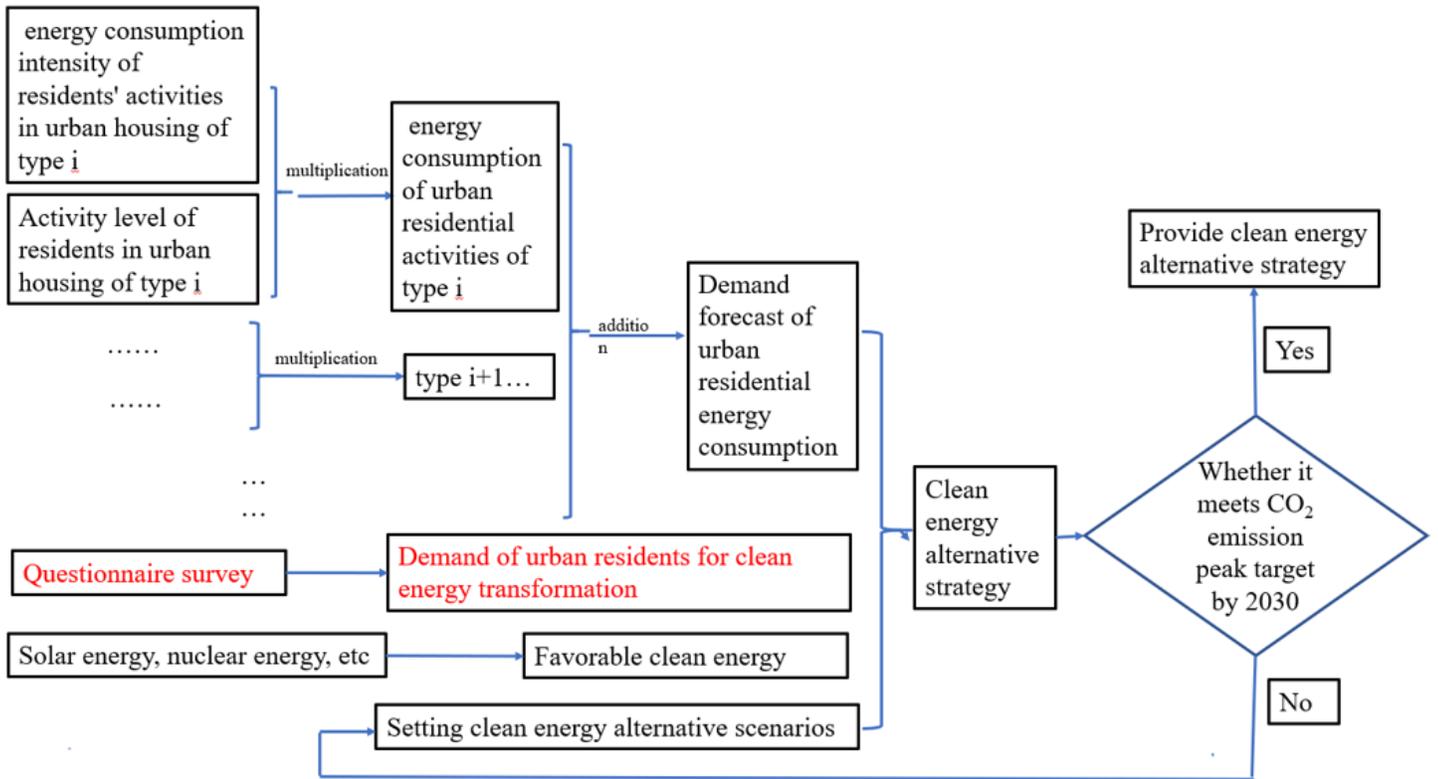


Figure 13

Research ideas of clean energy alternative strategy