Journal of Cleaner Production 427 (2023) 139216

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Residents' willingness to pay for renewable electricity can bridge the gap in financing for renewable electricity development in China

Yun Sun [a,1], Dingxin Chen [b,1], Cenchao Wang [a], Bai-Chen Xie [c], Mei Shan [a], Yuan Wang [a,*]

[a] School of Environmental Science and Engineering, Tianjin University, Tianjin, 300072, China
[b] State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin, 300350, China
[c] College of Management and Economics, Tianjin University, Tianjin, 300072, China

ARTICLE INFO

Handling Editor: Giovanni Baiocchi

Keywords:
Contingent valuation method
Geographically weighted regression model
Renewable electricity
Willingness to pay
Spatial heterogeneity

ABSTRACT

The current state in China is characterised by an increased demand for renewable electricity due to energy shortage and emission reduction targets. This study utilises the contingent valuation method (CVM) to investigate provincial residents' willingness to pay (WTP) for renewable electricity and employs the geographically weighted regression (GWR) model to analyse the spatial heterogeneity of influencing factors. The average WTP for renewable electricity among Chinese residents is 0.85 yuan/kWh, surpassing the current electricity price of 0.5 yuan/kWh. Reducing air pollution and the occurrence of haze is prioritised by residents (66.89%), followed by saving fossil energy and avoiding energy crises (10.09%), and reducing carbon emission and mitigating climate change (22.04%). Chinese residents pay more attention to the immediate impacts of renewable electricity on personal well-being and quality of life. Factors such as economic status, education background, air quality, health concerns, and environmental crisis awareness significantly influence WTP, with spatial disparities further compounding these effects. Sensitivity to economic level and air quality was observed in the southeast, while the southwest showed sensitivity to air quality, and the northwest exhibited sensitivity to environmental awareness. These findings suggest that residents' adoption of renewable electricity could partially alleviate China's funding gap in this sector. Recognising the factors that shape WTP provides a strategic pathway to enhance residents' financial support for renewable electricity initiatives.

1. Introduction

Presently, atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases have surged to unprecedented levels (United Nations, 2021). China, as the foremost consumer of energy and emitter of CO_2 since 2009 (Wang et al., 2017), has set forth plans to reach its carbon peak by 2030 and attain carbon neutrality before 2060 (China Gansu News, 2021). Concurrently, China is facing an electricity crisis, evident from power rationing and production cuts implemented in at least five provinces during the autumn and winter of 2021, and the main reason is the shortage of coal (People's information, 2021). Globally, the United Nations' 2015 Agenda for Sustainable Development encompasses 17 Sustainable Development Goals (SDGs), including SDG 13, which emphasises the need for urgent action to combat climate change and its consequences, and SDG 7, which aims to ensure access to affordable, reliable, and sustainable energy sources (United Nations, 2015). These goals provide a strategic direction for China to curtail its carbon emissions and address its energy crisis. Notably, China's electricity sector exhibits the highest carbon emission rate among all economic sectors and consumes a substantial amount of fossil fuel annually (Wang et al., 2017). Consequently, the crucial strategy involves the rapid phasing out of coal usage in China's energy system, emphasising the promotion and utilisation of renewable electricity (Cui et al., 2019, 2021).

Renewable electricity not only contributes to mitigating climate change and reducing pollutant emissions but also diminishes China's excessive dependence on fossil fuels. In previous years, electricity price subsidies played a pivotal role in driving the development of renewable electricity in China. However, since 2019, the central government has discontinued subsidies for wind and photovoltaic power generation (China Gansu News, 2021). Under the new policy implemented in 2021, renewable electricity projects can determine their electricity prices

* Corresponding author.
E-mail address: wyuan@tju.edu.cn (Y. Wang).
[1] Yun Sun and Dingxin Chen contributed equally to this work.

https://doi.org/10.1016/j.jclepro.2023.139216
Received 9 August 2023; Received in revised form 21 September 2023; Accepted 6 October 2023
Available online 7 October 2023
0959-6526/© 2023 Elsevier Ltd. All rights reserved.

through participation in market transactions, potentially exceeding the local benchmark price for coal-fired power generation. Thus, in the absence of central subsidies, the market may serve as a feasible mechanism to offset the premium of renewable electricity over the benchmark price of coal-fired power.

Moreover, as environmental pollution worsens and the impacts of climate change escalate, an increasing number of individuals acknowledge the significance of environmental protection and are willing to pay a premium for clean energy and an improved living environment. Currently, the concept of willingness to pay (WTP) is widely employed to assess the value of public goods, including environmental quality (Gomes et al., 2023; Xie and Zhao, 2018). Numerous studies have focused on understanding the pro-environmental intentions and behaviours of the general public concerning air quality, exploring the relationship between economic costs, political trust, education level, health status, and WTP for improved air quality, with environmental awareness serving as a moderating factor (Hu and Liao, 2023; Liang, 2023; Liu et al., 2018; Malik et al., 2022; Sun et al., 2016). Given the urgency of carbon reduction and the widespread adoption of carbon neutrality targets by various countries, consumer preferences for emission reductions have been investigated across diverse domains such as vehicle transportation (Hulshof and Mulder, 2020; Ma et al., 2021), households (Benjamin et al., 2022; Williams and Rolfe, 2017), and carbon-labelled products (Sun et al., 2023; Zhao et al., 2018, 2020). The energy crisis has long been a primary global concern, prompting studies on community preferences and attitudes towards harnessing renewable energy. Notably, a contrast has been revealed between households' general acceptance of supporting renewable energy technologies and their actual WTP (Andor et al., 2017), and the price premium for renewable heating compared to firepower heating for residential heating has been assessed (Kim et al., 2019). Various studies have also explored WTP about specific plans or goods, such as decarbonisation policies (Alberini et al., 2018; Raffaelli et al., 2022), energy supply system plans (Andor et al., 2017; Kim et al., 2019), renewable electricity products (Cheng et al., 2017; Entele et al., 2018; Harajli and Chalak, 2019; Zhu et al., 2022), and new energy vehicles (Ma et al., 2020; Tan and Lin, 2020). These investigations primarily focus on environmental benefits related to pollution reduction, carbon emission reduction, and energy sustainability, aligning with our research on WTP for renewable electricity, which predominantly centres around these three environmental aspects.

Estimating residents' willingness to pay (WTP) for renewable or green electricity in different regions has been a subject of existing research. Previous studies have explored the WTP of French residents (Faulques et al., 2022), residential consumers in Poland (Kowalska-Pyzalska, 2019), the public in Korea (Lee et al., 2018), and Turkish citizens (Muhammad et al., 2021) for renewable electricity on a global scale. Similarly, in China, the WTP of residents in various cities and provinces for renewable electricity has been investigated. For instance, Zhang and Wu (2012) examined the market segmentation and estimated the WTP of Chinese residents in Jiangsu province, ranging from 7.91 to 10.30 yuan. Wu et al. (2018) assessed household WTP for green power in Shanghai and its influencing factors. Xie and Zhao (2018) employed the contingent valuation method to investigate the WTP of residents in Tianjin, China, for green electricity. The average WTP for research and development of solar energy in Beijing is about 5.85 yuan per household per month (Jin et al., 2019). The annual WTP for green heating in one rural area of Henan Province is about 1071 yuan per household (Guo et al., 2023). However, existing research on WTP for renewable electricity in China is predominantly focused on developed cities or specific provinces, lacking a nationwide study. Furthermore, the survey methods, investigation years, statistical calibres and hypothetical scenarios employed in questionnaires may lead to different WTP estimations (Burghart et al., 2007).

Consequently, a significant gap exists in the current body of knowledge, as previous research has primarily concentrated on individual cities or provinces within China. Given the vast territory of China, encompassing numerous provinces, municipalities, autonomous regions, and special administrative regions, the inconsistent estimation methods of WTP across different study areas hinder the formulation of a comprehensive national renewable electricity policy. Therefore, it is crucial to adopt a unified survey method to estimate Chinese residents' WTP for renewable electricity with the consideration of regional differences.

To address this gap, this study employs the contingent valuation method (CVM) to examine the provincial WTP for renewable electricity in China and identify the primary influencing factors for residents' WTP. Then, we discuss the spatial heterogeneity of influence factors of WTP. The subsequent sections of this paper are organised as follows: Section 2 introduces the methodology employed in this study, including the questionnaire design and descriptions of the contingent valuation method (CVM) and geographically weighted regression model (GWR). Section 3 discusses and analyses the spatial distribution of residents' WTP for renewable electricity in China, examines its influencing factors, and explores spatial heterogeneity. Finally, Section 4 presents the conclusions of this research and provides policy implications.

2. Methods

2.1. Questionnaire design

Prior to initiating the survey, a questionnaire was meticulously crafted to align with the research objectives and draw upon insights from previous similar studies (Table 1). Notably, the estimated value of WTP varies significantly across different regions due to disparities in economic development levels, environmental awareness, cultural backgrounds, social customs, and other pertinent factors. Previous investigations have unearthed several influential factors affecting respondents' WTP for environmentally-valued products. These factors encompass age (Faulques et al., 2022; Zografakis et al., 2010), educational background (Bigerna and Polinori, 2014; Hu and Liao, 2023), gender (Sun et al., 2016), household income (Abdullah et al., 2021; Guo et al., 2023; Zhang and Wu, 2012), family size (Lee and Heo, 2016), homeownership, alongside other social and economic conditions. Additionally, factors like payment methods (Sonnenschein and Mundaca, 2019), electricity consumption (Guo et al., 2014), risk attitudes (Jin et al., 2019), history of respiratory diseases (Xie and Zhao, 2018), sensitivity to environmental pollution (Gomes et al., 2023; Sun et al., 2023; Wu et al., 2018), attitudinal beliefs regarding energy issues (Jin et al., 2019), awareness of renewable energy and environmental concerns (Kowalska-Pyzalska, 2018), and trust in the government (Benjamin et al., 2022; Xie and Zhao, 2018; Zhu et al., 2022) exert notable impacts on the WTP.

Therefore, considering the influence of the aforementioned factors on the WTP, the questionnaire was developed by incorporating them based on insights from existing studies. Furthermore, a pre-survey was conducted to mitigate potential biases and enhance the questionnaire's quality prior to the formal survey. The structure of the questionnaire design is visually presented in Fig. 1.

The questionnaire is mainly composed of three parts:

The first part is a survey of personal information, which contains two categories. The demographic variables include the respondent's age, gender, province, educational background, occupation, electricity consumption, etc. The economic factors include residents' household income and household electricity consumption.

The second part mainly investigates the respondents' environmental awareness, including their opinions of renewable electricity and understanding of related policies, and respondents' trust and belief towards the government.

In the third part, respondents were asked about their greatest expectations for renewable electricity (choosing one from reducing air pollution & the occurrence of haze, saving fossil energy & avoiding

Table 1
Studies on influencing factors of WTP.

Influencing factor	Reference	Region
Age	Bigerna and Polinori (2014)	Italy
	Zografakis et al. (2010)	Crete
	Faulques et al. (2022)	France
Educational attainment	Bigerna and Polinori (2014)	Italy
	Jin et al. (2019)	Beijing, China
	Benjamin et al., (2022)	Canada
	Hu and Liao (2023)	China
Gender	Bigerna and Polinori (2014)	Italy
	Sun et al. (2016)	China
Household income	Abdullah et al. (2021)	Malaysia
	Guo et al. (2023)	Henan, China
	Jin et al. (2019)	Beijing, China
	Sun et al. (2016)	China
	Zhang and Wu (2012)	Jiangsu, China
Family size	Bigerna and Polinori (2014)	Italy
	Lee and Heo (2016)	South Korea
Payment methods	Sonnenschein and Mundaca (2019)	Sweden
Electricity consumption	Guo et al. (2014)	Beijing, China
Risk attitudes	Jin et al. (2019)	Beijing, China
History of respiratory disease	Xie and Zhao (2018)	Tianjin, China
Sensitivity to environmental pollution	Wu et al. (2018)	Shanghai, China
	Sun et al. (2023)	Shaanxi, China
	Gomes et al. (2023)	Portugal
Attitudinal beliefs about energy problems	Jin et al. (2019)	Beijing, China
Awareness of renewable energy and environmental issues	Abdullah et al. (2021)	Malaysia
	Kowalska-Pyzalska (2018)	Poland
	Lee and Heo (2016)	South Korea
	Sun et al. (2016)	China
Belief towards the government	Zhu et al. (2022)	China
	Xie and Zhao (2018)	Tianjin, China
	Benjamin et al., (2022)	Canada

energy crises and reducing carbon emission & mitigating climate change) and related questions. The questions of whether the respondents would be willing to pay a certain amount of extra money for renewable electricity, as well as the specific value of their WTP, are contained.

2.2. Questionnaire distribution and data collection

This study employed the online questionnaire method using the "Questionnaire Star" online platform, which is a free online platform widely used in China. The online pre-survey took place from January to February 2019, during which the initial questionnaire was developed based on the pre-survey results and the valuable input provided by experienced teachers in questionnaire design.

The formal survey was conducted from February to August 2019 online. To ensure a representative sample, the questionnaires were distributed according to a specific age ratio, aiming to cover respondents from 18 to 80 years old. For elderly individuals who did not use mobile phones or were unable to fill out the questionnaire themselves, volunteer students assisted them in completing the questionnaires in person.

In total, 5273 questionnaires were collected during the survey period. Among these, 4528 questionnaires were considered valid, resulting in an effective response rate of 85.87%. The high response rate indicates a robust sample size for data analysis and enhances the reliability of the study's findings.

2.3. Contingent valuation method (CVM) and WTP estimation

The study on WTP can be conducted by direct investigation, including the expert evaluation and consumer survey. The consumer survey method is more widely used since it is more conducive to obtaining accurate data. Methods to obtain WTP data include choice experiment (CE) and conditional value assessment (CVM). At present, CVM has become the most widely used method for the value assessment of environmental public goods due to its flexibility and wide applicability (Oerlemans et al., 2016). The CVM is a typical value assessment method of declarative preference. This method can be used to measure the value of non-market goods and then to evaluate the value of the public goods based on the answers.

The mode of questioning respondents is an essential component of CVM, including bidding game, open-ended (OE), payment card (PC), and dichotomous choice (DC) (Oerlemans et al., 2016), etc. The PC mode is used in this study, which is an improvement based on the OE mode and provides respondents with a number of bid values for reference to choose from. Generally, the respondent will be given certain restrictive background materials or certain scenario settings so that they can choose the option in a specific circumstance. This method is relatively simple and avoids the difficulty of open answers, but there may be some hypothetical market bias. In fact, people's subjective willingness will change over time and place, and the choice of PC will inevitably produce starting point deviation, range deviation and so on. In this study, this effect was reduced by pre-investigation and by adding open-answer options.

The estimated WTP for renewable electricity in 31 provinces of China can be obtained through the following equation:

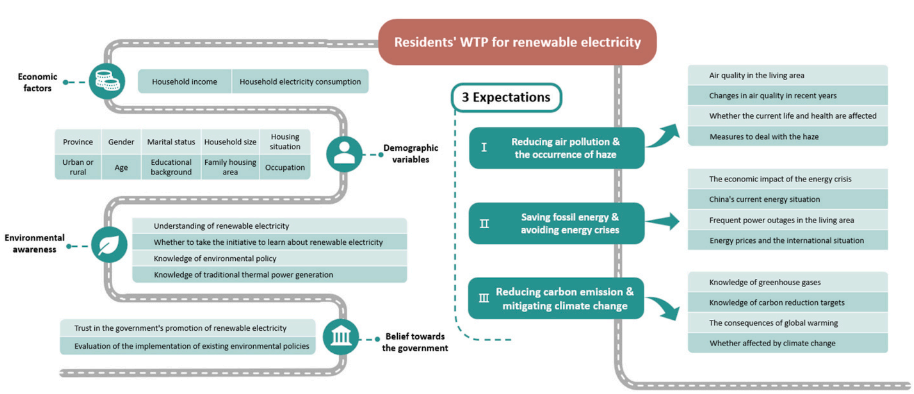

Fig. 1. The framework of questionnaire design.

$$E_m(WTP) = \sum_{i=1}^{n}\left(\frac{N_{mi}}{A_m} \times M_{mi}\right) \quad (1)$$

Where $E_m(WTP)$ is the estimated residents' WTP for renewable electricity in province m of China; A_m is the questionnaire collection number of province m; N_{mi} is the number of residents who choose the option i in province m; and M_{mi} is the median of WTP range of option i in province m, n is the number of options for question asking WTP in the questionnaire.

2.4. Geographically weighted regression model

The geographically weighted regression model (GWR) is a method for incorporating spatial correlation into regression analysis first proposed by Fotheringham (Geary, 1954). It improves the traditional regression model, such as least squares (OLS) and uses the information of neighbouring units to the parameters of the local regression to ensure that the variable coefficients of the regression model can follow the change of the spatial geographic location, that is, to realise the regression of the geographic spatial variable coefficient. The expression of the model is as follows:

$$y_i = \beta_0(\mu_i, v_i) + \sum_k \beta_k(\mu_i, v_i)x_{ik} + \varepsilon_i \quad (2)$$

Where y_i represents the dependent variable matrix of order n × 1 of province i; x_{ik} represents the explanatory variable matrix of order n × k of province i; (μ_i, v_i) represents the spatial geographic coordinates of province i; $\beta_k(\mu_i, v_i)$ is the regression coefficient of the centroid (μ_i, v_i) of the research object unit i area; ε_i stands for the random error term.

In the GWR model, the regression coefficient $\beta_k(\mu_i, v_i)$ of the research object i province can change with the change of the spatial weight matrix $W(\mu_i, v_i)$. The distance $W(\mu_i, v_i)$ of the research object i province can be determined according to the distance of other unit intervals. The weighted least square method can be used to estimate the parameter $\beta_k(\mu_i, v_i)$, and its expression form is:

$$\beta_k(\mu_i, v_i) = \left[X^T W(\mu_i, v_i)X\right]^{-1} X^T W(\mu_i, v_i)y \quad (3)$$

Where $\beta_k(\mu_i, v_i)$ is the estimated parameter of the GWR model; X is the matrix of explanatory variables; y is the matrix of dependent variables; X^T is the transposed matrix of the matrix X; for the parameter estimation of the research unit, this article uses the Gauss function method as the weighting function for geographically weighted regression calculation.

In this study, GDP per capita, air quality index, and environmental awareness are used as three dominant factors to estimate the spatial heterogeneity analysis of residents' WTP by the GWR model. The regression function is:

$$LnI_i = \beta_0(\mu_i, v_i) + \beta_1(\mu_i, v_i)ln\ GDP_i + \beta_2(\mu_i, v_i)ln\ AQI_i + \beta_3(\mu_i, v_i)ln\ EA_i + \varepsilon_i \quad (4)$$

Where (μ_i, v_i) is the spatial coordinates of i province. $\beta_k(k = 1, 2, 3)$ is the coefficient of the regression function. I_i is residents' WTP of renewable electricity in the i province, GDP is the gross domestic product per capital, and AQI is the air quality index. EA is environmental awareness, which is represented by the quantified results of the residents' environmental awareness part in the questionnaire. ε_i is the residual.

3. Results and discussions

3.1. Descriptive statistics

Table 2 presents the key characteristics of the respondents. The target group primarily consists of residents aged 18 and above, as minors typically have limited financial capacity. The data reveals that 65.88% of the respondents are from urban areas, aligning with the current

Table 2
Descriptive statistics.

Statistical variable	Survey frequency and distributions
Expectations	
Reducing air pollution and the occurrence of haze	3073 (67.87%)
Saving fossil energy and avoiding energy crises	457 (10.09%)
Reducing carbon emission and mitigating climate change	998 (22.04%)
Region	
Urban	2983 (65.88%)
Rural	1545 (34.12%)
Gender	
Man	2272 (50.18%)
Woman	2256 (49.82%)
Age	
Under 18	10 (0.23%)
18–25	1331 (29.39%)
26–35	1004 (22.17%)
36–45	816 (18.02%)
46–55	787 (17.38%)
56–65	474 (10.47%)
Above 65	106 (2.34%)
Marital status	
Married	2605 (57.53%)
Unmarried	1923 (42.47%)
Education level	
Primary school	320 (7.08%)
Junior high school	1130 (24.95%)
High school/technical secondary school	1332 (29.41%)
Undergraduate/College	1407 (31.07%)
Postgraduate and above	339 (7.49%)
Household size	
1	58 (1.29%)
2	282 (6.22%)
3	1825 (40.31%)
4	1276 (28.18%)
5	673 (14.86%)
5 or more	414 (9.14%)
Housing area	
50 or less	192 (4.25%)
51–100	1670 (36.88%)
101–150	2010 (44.38%)
151–200	393 (8.68%)
200 or more	263 (5.81%)
Housing situation	
Rent	444 (9.81%)
Own	3513 (77.59%)
Others	571 (12.6%)
Occupation	
Heads of Party and Mass Organizations of State Organs, Enterprises, and Institutions	375 (8.29%)
Professional technicians (teachers, doctors, engineers, etc.)	990 (21.86%)
Clerks and related personnel	327 (7.22%)
Commercial, waiter staff	410 (9.05%)
Agriculture, forestry, animal husbandry, fish, and water conservancy production personnel	164 (3.63%)
Industrial worker	211 (4.66%)
Soldier	19 (0.43%)
Unemployment	136 (3%)
Retirees	288 (6.36%)
Student	1105 (24.41%)
Others	503 (11.1%)
Monthly electricity consumption	
Within 150 KWH	1888 (41.69%)
150° ~300 KWH	1486 (32.82%)
300° ~400 KWH	245 (5.42%)
450° ~500 KWH	72 (1.58%)
Not sure	837 (18.49%)
Household income	
Below RMB 5000 per month	1444 (31.88%)
RMB 5000 – RMB 8000 per month	1296 (28.63%)
RMB 8000 – RMB 12000 per month	915 (20.2%)
RMB 12000 – RMB 20000 per month	533 (11.78%)
Above RMB 20000 per month	340 (7.51%)

population distribution in China. The gender distribution is balanced, and there is also a well-distributed age range among the respondents. Based on the survey results, the respondents' highest expectation for renewable electricity is "reducing air pollution and the occurrence of haze" (67.87%). This finding suggests that residents place significant emphasis on the immediate impact of renewable electricity, particularly its potential to improve their health and quality of life. The second-highest expectation is "saving fossil energy and avoiding energy crises" (10.09%), followed by " reducing carbon emission and mitigating climate change " (22.04%). This indicates that respondents prioritise the short-term benefits and practical implications of renewable electricity rather than its long-term environmental impact.

These findings highlight the residents' concerns regarding the tangible and immediate effects of renewable electricity, suggesting a strong emphasis on personal well-being and the local environment.

3.2. Residents' WTP for renewable electricity in China

3.2.1. Spatial distribution of residents' WTP for renewable electricity

The average resident's renewable electricity WTP is 0.85 yuan/kWh (the current electricity price is 0.5 yuan/kWh (National Energy Information Platform, 2020)) in China. According to the findings presented in Fig. 2a, individuals in China who exhibit the most significant concern for air quality have an average WTP of 0.85 yuan/kWh for renewable electricity, while the current electricity price stands at 0.5 yuan/kWh. However, the acceptable price for renewable electricity varies across provinces, which spans from 0.64 to 1.05 yuan/kWh in most provinces. Shanghai demonstrates the highest WTP (1.1 yuan/kWh), closely followed by Guangdong, while Ningxia exhibits the lowest WTP (0.6 yuan/kWh), trailed by Qinghai and Jiangxi. Strikingly, the WTP of developed regions such as Shanghai and Guangdong exceed twice the current price, whereas the WTP of Qinghai and Ningxia provinces shows a mere 20 percent increment. Several factors may account for these outcomes. Firstly, the disparity in economic development implies that individuals residing in economically prosperous provinces or regions display a heightened awareness of the need for environmental protection. Secondly, the varying degrees of air pollution across regions suggest that individuals residing in areas with better air quality exhibit a greater interest in the development of renewable electricity due to their heightened sensitivity to air quality fluctuations.

In contrast, consumers who prioritise energy conservation and carbon reduction display a relatively narrower range of WTP, particularly in central provinces, with respondents from certain western provinces not selecting these two expectations. Fig. 2b highlights individuals who primarily prioritise energy conservation, with an average WTP of 0.79 yuan/kWh. Notably, residents of developed provinces also exhibit the highest WTP. Moreover, residents in select northern and southwestern provinces demonstrate a willingness to pay significantly higher amounts for renewable electricity. This might be attributed to proactive efforts by local governments in these regions to promote new energy sources, allocate funds for their production and related infrastructure, and raise public awareness about their utilisation.

In Fig. 2c, which depicts the WTP levels of residents primarily concerned about carbon reduction, the average WTP stands at 0.82 yuan/kWh. The gap in residents' WTP between provinces diminishes, ranging from 0.7 yuan/kWh in Xinjiang to 1.0 yuan/kWh in Shanghai. Coastal city dwellers generally exhibit higher WTP compared to their inland counterparts, likely due to heightened concerns about climate change and rising sea levels resulting from increased greenhouse gas emissions. Concurrently, China's coastal cities boast higher levels of development compared to inland cities, leading to higher income and educational levels among coastal residents, which may further contribute to their increased willingness to pay. Overall, residents' WTP in most provinces exceeds the current electricity prices by 50 percent, which creates the possibility of renewable electricity prices surpassing the local benchmark for coal-fired power generation.

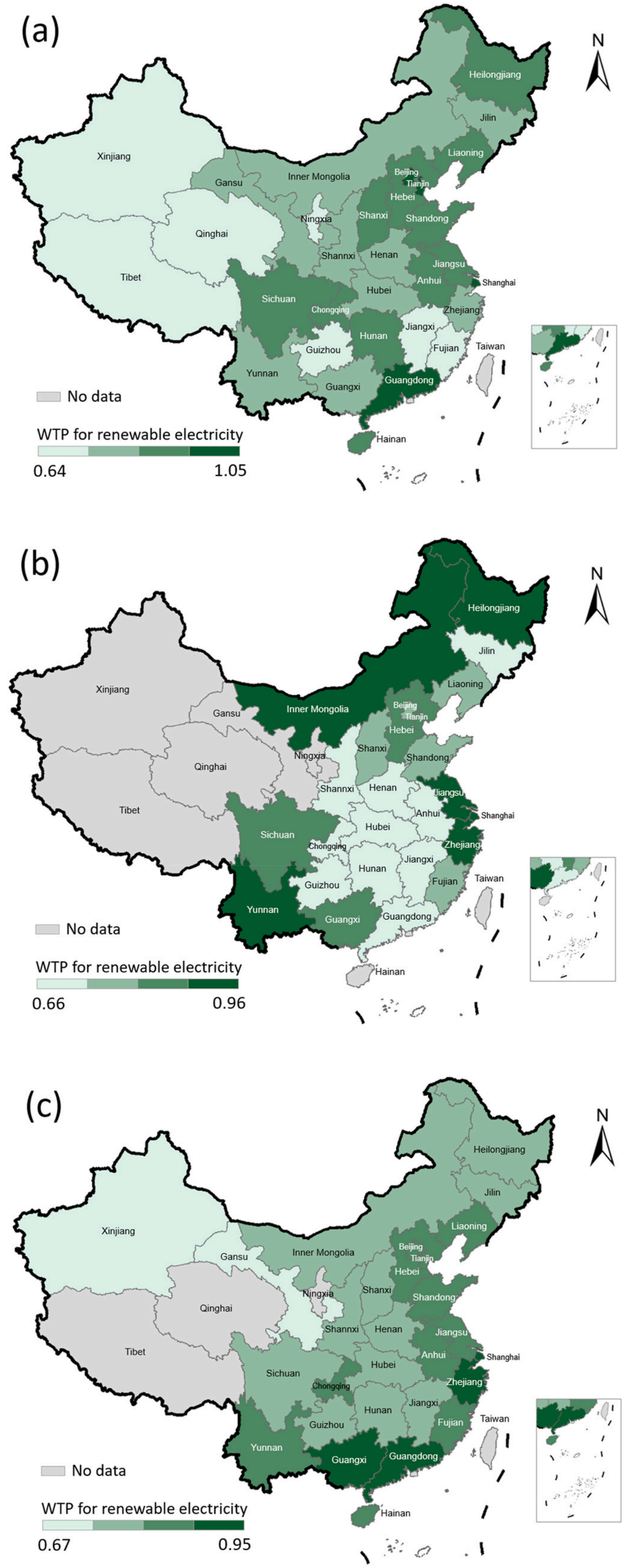

Fig. 2. Residents' WTP for renewable electricity in China (a) Expectation 1, reducing air pollution and the occurrence of haze; (b) Expectation 2, saving fossil energy and avoiding energy crises; (c) Expectation 3, reducing carbon emission and mitigating climate change.

3.3. Analysis of the influencing factors of the WTP

The analysis of Table 3 reveals that various factors, including economic indicators, educational background, air quality, and health concerns, have a significant impact on individuals' WTP. Among these factors, family monthly income emerges as the most influential, followed by educational attainment. These findings align with the results obtained by Kowalska-Pyzalska (2018), which demonstrated a positive correlation between WTP and both income and education levels. Furthermore, residents with higher household electricity consumption exhibit a greater WTP. Notably, this study also takes into account factors related to air pollution and health concerns, as well as awareness of energy conservation and carbon emission reduction. The impact of these factors on WTP is noteworthy. Specifically, the perceived effects of air pollution on current life and health, air quality in the residential area, and various measures taken to mitigate the impact of air pollution significantly influence WTP. This finding aligns with our initial expectations, indicating that individuals who prioritise air quality and health concerns are more likely to have a higher WTP.

Additionally, a portion of the respondents (10.09%) display significant concerns regarding energy conservation. Their awareness of the economic implications of an energy crisis and their views on the scarcity of fossil fuels play a crucial role in determining their WTP. Individuals with a greater understanding of the energy shortage crisis are more willing to pay higher prices for renewable electricity. Moreover, 22.04% of the respondents prioritise carbon emission reduction and climate change mitigation. Residents possessing basic knowledge of greenhouse gases exhibit a relatively high WTP. Their awareness of the negative consequences of global warming also influences their WTP.

Age and marital status also play a role in determining WTP. As age increases, residents' WTP for renewable electricity decreases, and unmarried individuals exhibit higher WTP compared to married individuals. Moreover, the province of residence influences residents' WTP. As depicted in Fig. 2, urban residents generally display higher WTP than rural residents. Lastly, individuals' trust in the government significantly affects the increasing WTP of residents. Xie and Zhao (2018) also found that understanding of renewable energy and belief in the government strongly influenced respondents' attitudes towards renewable electricity.

3.4. Spatial heterogeneity analysis of influencing factors

The paper utilises ArcGIS software to visually analyse the regression coefficients of each influencing factor in the Geographically Weighted Regression (GWR) model analysis of Willingness to Pay (WTP) for renewable electricity. On this basis, we examine the regional spatial differences in the impact of each influencing factor. The main expectation of residents (68%) is to reduce air pollution by promoting the use of renewable electricity. So, three non-collinear influencing factors, namely GDP per capita, air quality index (AQI), and environmental awareness, are selected as independent variables, while WTP for renewable electricity is designated as the dependent variable. GDP per capita represents the economic level, AQI serves as an indicator of air quality, and environmental awareness is a quantified measure derived from the survey on residents' environmental consciousness.

Fig. 3 displays the results of the analysis, with the absolute values of standard residuals all falling below 2.5. This suggests that the analysis outcomes are reliable and can be interpreted with confidence.

According to Fig. 4, the Air Quality Index (AQI) emerges as the influencing factor with the most extensive influence range and the largest regression coefficient in the analysis. Fig. 4b indicates a positive correlation between AQI and the Willingness to Pay (WTP) for renewable electricity, with a regression coefficient ranging from 0 to 0.64. This implies that as air pollution worsens, the WTP for renewable electricity increases. Interestingly, although air quality is generally lower in northern China compared to the southern regions, residents in the south

Table 3
The correlation between WTP and influence factors.

Influence factor	Expectation 1	Expectation 2	Expectation 3
Environmental awareness			
Understanding of renewable electricity	.056[a]		
Whether to take the initiative to learn about Renewable electricity	.001		
Knowledge of environmental policy	.006		
Economic factors			
Household electricity consumption	.078[a]		
Family monthly income	.168[a]		
Belief towards the government			
Trust in the government's promotion of renewable electricity	.061[a]		
Evaluation of the implementation of existing environmental policies	.046[b]		
Air quality & concern for health			
Air quality in the living area	−.068[a]	–	–
Changes in air quality in recent years	.001	–	–
Whether the current life and health are affected	−.101[a]	–	–
Have bought masks	0.028	–	–
Used an air purifier	.101[a]	–	–
Purchase housing in a high-air-quality area	.045[b]	–	–
Avoid going out in heavily polluted weather	.067[a]	–	–
Prefer the food that may reduce the impact of haze	.055[a]	–	–
Energy saving			
Cognition of the availability of fossil fuel	–	.091[b]	–
Cognition of the proportion of thermal power energy	–	.028	–
Cognition of the impact of energy crisis on economy	–	.147[a]	–
Cognition of China's oil import and export proportion	–	.046	–
Knowledge about the scarcest fossil fuel in China	–	.101[a]	–
Frequency of power failure in the region	–	.024	–
Reducing carbon emission			
Knowledge of greenhouse gases	–	–	.138[a]
Opinions about the relationship between greenhouse gas and global warming	–	–	.037
Knowledge of China's carbon reduction targets	–	–	.070[a]
Knowledge of the influences of global warming	–	–	.092[a]
Demographic variables			
City	.054[a]		
Urban or rural	.070[a]		
Gender	.025		
Age	−.065[a]		
Marital status	.055[a]		
Education background	.111[a]		
Household size	−.030		
Family housing area	.049[a]		
Housing situation	−.066[a]		
Occupation	.018		

[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

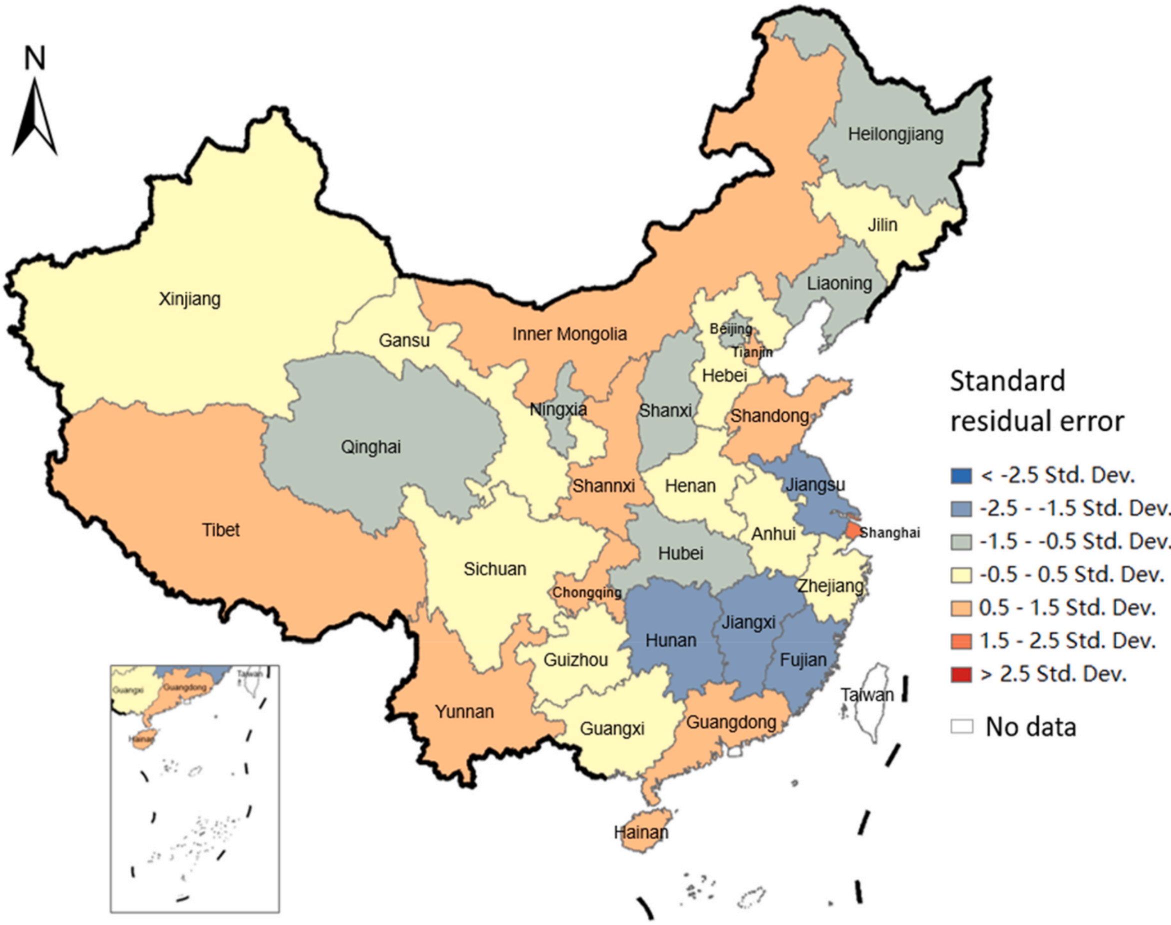

Fig. 3. Standard residual error of GWR Model regression analysis.

appear to be more sensitive to air quality. This could be attributed to the fact that residents in northern China have become accustomed to long-term exposure to air pollution and have adopted self-protective measures. Additionally, the government's ongoing efforts to control air pollution may not have yet achieved the desired outcomes, leading to relatively low expectations among residents in northern China regarding the ability of renewable electricity to improve air quality.

Fig. 4a reflects that the influence of GDP per capita is positively correlated with WTP for renewable electricity (regression coefficient 0–0.47). The high-value provinces are mainly distributed in the southeast of China, especially Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu, etc., while the low-value provinces are mainly distributed in the northwest region. It can be seen that economic factors are an important factor driving residents of the developed provinces in the southeast to pay for renewable electricity. Compared with AQI and GDP per capita, environmental awareness (Fig. 4c) has a slightly smaller impact (regression coefficient 0–0.11). Environmental awareness is the main factor affecting WTP for renewable electricity in northwest China, especially in Xinjiang and Inner Mongolia. The environmental awareness effect on WTP in economically underdeveloped areas is much higher than that in economically developed areas, which indicates that economically underdeveloped area has significant potential to improve WTP with the development of education (Tianyu and Meng, 2020).

The Geographically Weighted Regression (GWR) model analysis reveals regional variations in the Willingness to Pay (WTP) of Chinese residents, with distinct sensitivities observed across different factors. In the southeast, the WTP is responsive to both GDP per capita and the Air Quality Index (AQI), while in the southwest, it is primarily influenced by AQI. Conversely, in the Northwest, environmental awareness plays a significant role. However, minimal divergence in WTP sensitivity to these factors is observed in north and northeast China. Consequently, tailored promotion policies are warranted to facilitate renewable electricity adoption across diverse regions. Notably, northern China experiences severe air pollution; nevertheless, residents' WTP for renewable electricity exhibits low sensitivity to air quality, conceivably due to long-standing exposure prompting defensive measures and limited familiarity with renewable energy's air quality-enhancing potential. Thus, reinforcing public awareness campaigns concerning renewable electricity holds promise for augmenting WTP. Additionally, pre-emptive demonstration and implementation efforts in other regions can foster trust in policies and bolster residents' WTP. Moreover, the northwest region manifests heightened sensitivity of WTP to environmental awareness, underscoring the efficacy of enhancing eco-consciousness among residents as a means to promote renewable electricity in that locale.

4. Conclusions and policy implications

This study employs the Contingent Valuation Method (CVM) to estimate the willingness to pay (WTP) for renewable electricity among provincial residents in China. The average WTP for renewable electricity among Chinese residents is 0.85 yuan/kWh, surpassing the current electricity price of 0.5 yuan/kWh. Furthermore, we analyse the influencing factors of WTP and explore spatial heterogeneity using the Geographically Weighted Regression (GWR) model.

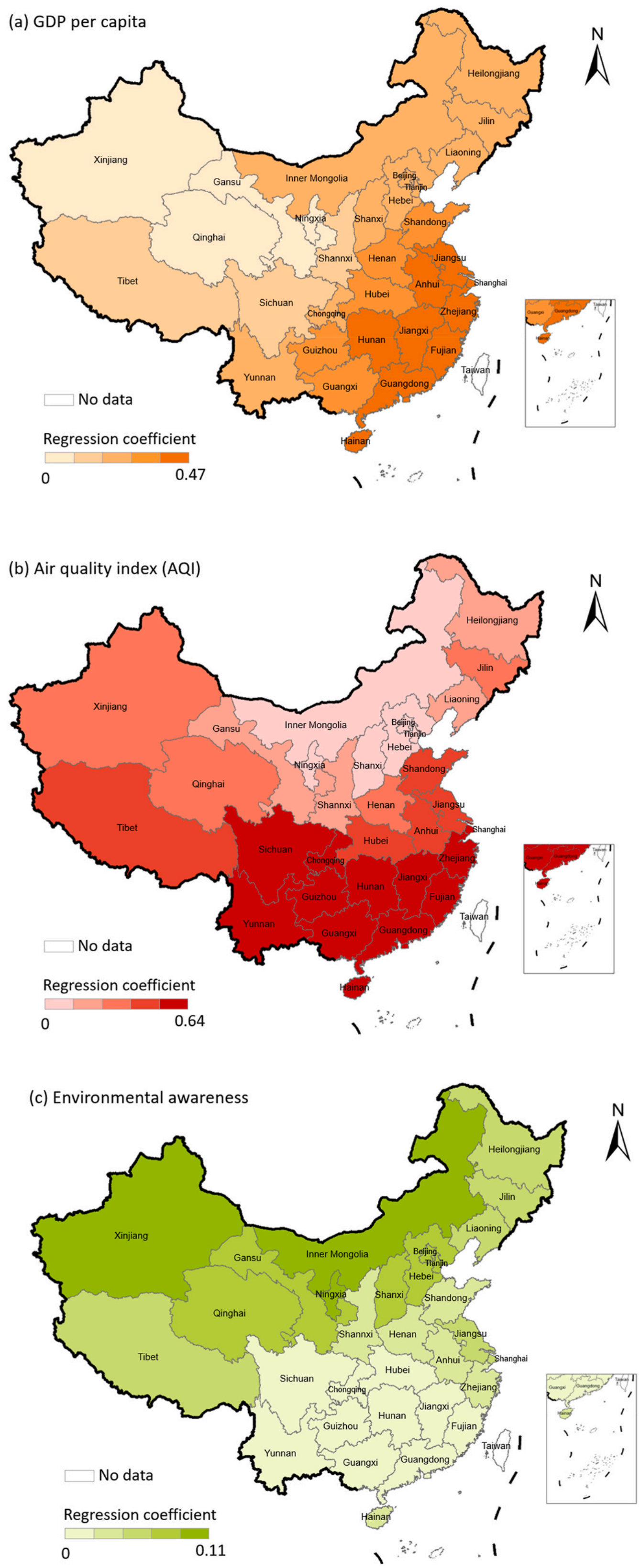

Fig. 4. The spatial distribution of regression coefficients of (a) GDP per capita, (b) Air Quality Index (AQI), and (c) Environmental awareness in the GWR model.

4.1. Residents financially support the renewable electricity development by purchasing renewable electricity

International Renewable Energy Agency (IRENA) recently released *Renewable Power Generation Costs in 2022*, which noted rising materials and equipment costs for renewable energy. The government can incentivise residents to purchase renewable electricity to compensate for the funding gap in renewable electricity development. According to the results of the questionnaire, 80% of residents are willing to pay extra for renewable electricity, and the average resident's renewable electricity WTP is 0.85 yuan/kWh, more than 70% of the current electricity price (0.5 yuan/kWh). This is expected to provide about 390 million yuan in economic support for renewable power development. Notably, the WTP of residents in economically underdeveloped areas in China (e.g., northwest provinces) is highly sensitive to residents' environmental awareness. These provinces have the significant potential for improvement of WTP through educational development. However, in the current situation, there is still a need to provide these provinces with substantial government subsidies to help them complete the construction and renovation of green power plants.

4.2. Chinese residents pay more attention to the effect of renewable electricity on reducing air pollution

According to the survey results, residents have the highest expectations for reducing air pollution and the occurrence of haze by promoting the use of renewable electricity, and their WTP is the highest (0.86 yuan/kWh). However, the factors influencing their WTP vary widely by region. The sensitivity of residents' WTP in areas with severe air pollution, such as northern China, is lower compared to regions with milder pollution levels. This can be attributed to residents in the north of China having already adopted self-protective measures against air pollution, such as purchasing masks and using air purifiers, and therefore being less willing to pay extra. Additionally, residents in the north may have lower expectations for renewable electricity's ability to improve air quality. Strengthening public awareness campaigns on renewable electricity and implementing demonstration projects in other regions can enhance residents' trust in policies and subsequently improve their willingness to pay.

4.3. Contributions and innovations

The primary financing for renewable power development in China comes from government subsidies or investment by enterprises. However, it ignores that residents can supplement their funding by paying extra for renewable electricity. We assess the likelihood of Chinese residents providing economic support for renewable electricity development in the future.

Our research fills essential gaps in the existing literature in several ways. The previous research has predominantly focused on WTP for renewable electricity within specific cities or provinces in China, resulting in poor comparability due to variations in questionnaire design and data collection methods. Therefore, there is a lack of research on renewable power development policies applicable to nationally coordinated plans and regionalisation. This study makes three primary contributions: firstly, we conducted a nationwide survey and collected 5273 questionnaires with an effective response rate of 85.87%. From this, we estimated the willingness of residents in 31 provinces to pay for renewable electricity. Secondly, it estimated the WTP for three environment-related expectations, including reducing air pollution and the occurrence of haze, saving fossil energy and avoiding energy crises, and reducing carbon emission and mitigating climate change. Thirdly, it incorporates crucial factors overlooked in previous studies, such as consumer behaviour and spending on air pollution protection, as well as examines the spatial heterogeneity of influencing factors.

4.4. Limitations and research prospects

To enhance the quality of survey results and mitigate biases introduced by external factors, a pre-survey was conducted. The questionnaire design ensured the confidentiality of personal information and was aimed solely at scientific research purposes. Stratifying the survey by region and age helped reduce bias. However, there remains an imbalance in the number of questionnaires collected across different regions, with smaller sample sizes in Qinghai, Tibet, and Ningxia. Furthermore, uncertainties and accidental deviations persist in the estimation of WTP. Hence, further studies focusing on this topic are necessary to validate the findings presented in this paper.

CRediT authorship contribution statement

Yun Sun: Conceptualization, Methodology, Investigation, Data curation, Writing – original draft. **Dingxin Chen:** Investigation, Data curation, Writing – original draft, Writing – review & editing. **Cenchao Wang:** Investigation, Data curation, Writing – review & editing. **Bai-Chen Xie:** Investigation, Methodology, Writing – review & editing. **Mei Shan:** Investigation, Data curation. **Yuan Wang:** Conceptualization, Methodology, Writing – review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work is financially supported by the National Natural Science Foundation of China (42371298, 71834004).

References

Abdullah, W.M.Z.B.W., Zainudin, W.N.R.A.B., Ishak, W.W.B.M., Sulong, F.B., Zia Ul Haq, H.M., 2021. Public participation of renewable energy (PPRED) model in Malaysia: an instrument development. Int. J. Renew. Energy Dev. -Ijred 10 (1), 119–137.
Alberini, A., Scasny, M., Bigano, A., 2018. Policy- v. individual heterogeneity in the benefits of climate change mitigation: evidence from a stated-preference survey. Energy Pol. 121, 565–575.
Andor, M.A., Frondel, M., Vance, C., 2017. Germany's energiewende: a tale of increasing costs and decreasing willingness-to-pay. Energy J. 38, 211–228.
Benjamin, E.O., Hall, D., Sauer, J., Buchenrieder, G., 2022. Are carbon pricing policies on a path to failure in resource-dependent economies? A willingness-to-pay case study of Canada. Energy Pol. 162, 112805.
Bigerna, S., Polinori, P., 2014. Italian households' willingness to pay for green electricity. Renewable Sustainable Energy Rev. 34, 110–121.
Burghart, D.R., Cameron, T.A., Gerdes, G.R., 2007. Valuing publicly sponsored research projects: risks, scenario adjustments, and inattention. J. Risk Uncertain. 35 (1), 77–105.
Cheng, Y.S., Cao, K.H., Woo, C.K., Yatchew, A., 2017. Residential willingness to pay for deep decarbonization of electricity supply: contingent valuation evidence from Hong Kong. Energy Pol. 109, 218–227.
China Gansu News, 2021. Report on the Work of the Government in 2021. https://baijiahao.baidu.com/s?id=1694172309645008929&wfr=spider&for=pc. 2021.
Cui, R.Y., Hultman, N., Cui, D., McJeon, H., Yu, S., Edwards, M.R., Sen, A., Song, K., Bowman, C., Clarke, L., Kang, J., Lou, J., Yang, F., Yuan, J., Zhang, W., Zhu, M., 2021. A plant-by-plant strategy for high-ambition coal power phaseout in China. Nat. Commun. 12 (1), 1468.
Cui, R.Y., Hultman, N., Edwards, M.R., He, L., Sen, A., Surana, K., McJeon, H., Iyer, G., Patel, P., Yu, S., Nace, T., Shearer, C., 2019. Quantifying operational lifetimes for coal power plants under the Paris goals. Nat. Commun. 10 (1), 4759.
Entele, B.R., Emodi, N.V., Murthy, G.P., Dioha, M.O., Ieee, 2018. Consumer Preference for Green Electricity Service Connection for Rural Residential Households in Ethiopia.
Faulques, M., Bonnet, J., Bourdin, S., Juge, M., Pigeon, J., Richard, C., 2022. Generational effect and territorial distributive justice, the two main drivers for willingness to pay for renewable energies. Energy Pol. 168, 113094.
Geary, R.C., 1954. The contiguity ratio and statistical mapping. Inc. Statistician 5 (3).
Gomes, S., Lopes, J.M., Nogueira, S., 2023. Willingness to pay more for green products: a critical challenge for. Gen Z. J. Clean. Prod. 390, 136092.
Guo, X., Jiao, W., Wang, K., Wang, H., Chen, J., Yan, Y., Huang, Y., 2023. Attitudes and willingness to pay for clean heating by typical households: a case study of rural areas in Yongcheng City, Henan Province, China. Environ. Sci. Pollut. Control Ser. 30 (6), 15842–15860.
Guo, X., Liu, H., Mao, X., Jin, J., Chen, D., Cheng, S., 2014. Willingness to pay for renewable electricity: a contingent valuation study in Beijing, China. Energy Pol. 68, 340–347.
Harajli, H., Chalak, A., 2019. Willingness to pay for energy efficient appliances: the case of Lebanese consumers. Sustainability 11 (20).
Hu, L., Liao, W., 2023. Is there a stronger willingness to pay for air quality improvement with high education: new evidence from a survey in China. Environ. Sci. Pollut. Control Ser. 30 (11), 28990–29014.
Hulshof, D., Mulder, M., 2020. Willingness to pay for $$\hbox {CO}_2$$ emission reductions in passenger car transport. Environ. Resour. Econ. 75 (4), 899–929.
Jin, J., Wan, X., Lin, Y., Kuang, F., Ning, J., 2019. Public willingness to pay for the research and development of solar energy in Beijing, China. Energy Pol. 134, 110962.
Kim, H.-H., Lim, S.-Y., Yoo, S.-H., 2019. Residential consumers' willingness to pay price premium for renewable heat in South Korea. Sustainability 11 (5).
Kowalska-Pyzalska, A., 2018. An empirical analysis of green electricity adoption among residential consumers in Poland. Sustainability 10 (7).
Kowalska-Pyzalska, A., 2019. Do consumers want to pay for green electricity? A case study from Poland. Sustainability 11 (5).
Lee, C.Y., Heo, H., 2016. Estimating willingness to pay for renewable energy in South Korea using the contingent valuation method. Energy Pol. 94 (jul), 150–156.
Lee, M.-K., Kim, J.-H., Yoo, S.-H., 2018. Public willingness to pay for increasing photovoltaic power generation: the case of Korea. Sustainability 10 (4).
Liang, C., 2023. The impact of air pollution on urban land price and willingness to pay for clean air-Evidence from micro level land transactions in China. J. Clean. Prod., 137790
Liu, R., Liu, X., Pan, B., Zhu, H., Yuan, Z., Lu, Y., 2018. Willingness to Pay for Improved Air Quality and Influencing Factors Among Manufacturing Workers in Nanchang, China, Sustainability.
Ma, W., Opp, C., Yang, D., 2020. Past, present, and future of virtual water and water footprint. Water 12 (11), 3068.
Ma, W., Zhang, Y., Cui, J., 2021. Chinese future frequent flyers' willingness to pay for carbon emissions reduction. Transport. Res. Transport Environ. 97, 102935.
Malik, S., Arshad, M.Z., Amjad, Z., Bokhari, A., 2022. An empirical estimation of determining factors influencing public willingness to pay for better air quality. J. Clean. Prod. 372, 133574.
Muhammad, I., Shabbir, M.S., Saleem, S., Bilal, K., Ulucak, R., 2021. Nexus between willingness to pay for renewable energy sources: evidence from Turkey. Environ. Sci. Pollut. Control Ser. 28 (3), 2972–2986.
National Energy Information Platform, 2020. A Picture to Read the Level of Electricity Price in China. https://baijiahao.baidu.com/s?id=1667188636492543981&wfr=spider&for=pc. (Accessed 15 June 2021).
Oerlemans, L.A.G., Chan, K.Y., Volschenk, J., 2016. Willingness to pay for green electricity: a review of the contingent valuation literature and its sources of error. Renewable Sustainable Energy Rev. 66 (DEC), 875–885.
People's information, 2021. New Regulations on Blackout in Northeast China 2021. https://baijiahao.baidu.com/s?id=1712123488162467504&wfr=spider&for=pc. (Accessed 10 October 2021).
Raffaelli, R., Franch, M., Menapace, L., Cerroni, S., 2022. Are tourists willing to pay for decarbonizing tourism? Two applications of indirect questioning in discrete choice experiments. J. Environ. Plann. Manag. 65 (7), 1240–1260.
Sonnenschein, J., Mundaca, L., 2019. Is one carbon price enough? Assessing the effects of payment vehicle choice on willingness to pay in Sweden. Energy Res. Social Sci. 52, 30–40.
Sun, C., Yuan, X., Yao, X., 2016. Social acceptance towards the air pollution in China: evidence from public's willingness to pay for smog mitigation. Energy Pol. 92, 313–324.
Sun, M., Gao, X., Jing, X., Cheng, F., 2023. The influence of internal and external factors on the purchase intention of carbon-labeled products. J. Clean. Prod. 419, 138272.
Tan, R., Lin, B., 2020. Are people willing to support the construction of charging facilities in China? Energy Pol. 143.
Tianyu, J., Meng, L., 2020. Does education increase pro-environmental willingness to pay? Evidence from Chinese household survey. J. Clean. Prod. 275, 122713.
United Nations, 2015. 17 Goals to Transform Our World. https://www.un.org/sustainabledevelopment/.
United Nations, 2021. Goal 13: Take Urgent Action to Combat Climate Change and its Impacts. https://www.un.org/sustainabledevelopment/climate-change/. (Accessed 9 June 2021).
Wang, Y., Lai, N., Mao, G., Zuo, J., Crittenden, J., Jin, Y., Moreno-Cruz, J., 2017. Air pollutant emissions from economic sectors in China: a linkage analysis. Ecol. Indicat. 77, 250–260.
Williams, G., Rolfe, J., 2017. Willingness to pay for emissions reduction: application of choice modeling under uncertainty and different management options. Energy Econ. 62, 302–311.
Wu, L., Zhou, Y., Xu, C., 2018. Research on household's willingness to pay for green power in Shanghai. China Population Res.Environ. 28 (2), 86–93.

Xie, B.-C., Zhao, W., 2018. Willingness to pay for green electricity in Tianjin, China: based on the contingent valuation method. Energy Pol. 114, 98–107.

Zhang, L., Wu, Y., 2012. Market segmentation and willingness to pay for green electricity among urban residents in China: the case of Jiangsu Province. Energy Pol. 51, 514–523.

Zhao, R., Geng, Y., Liu, Y., Tao, X., Xue, B., 2018. Consumers' perception, purchase intention, and willingness to pay for carbon-labeled products: a case study of Chengdu in China. J. Clean. Prod. 171, 1664–1671.

Zhao, R., Yang, M., Liu, J., Yang, L., Bao, Z., Ren, X., 2020. University students' purchase intention and willingness to pay for carbon-labeled food products: a purchase decision-making experiment. Int. J. Environ. Res. Publ. Health 17 (19), 7026.

Zhu, R., Chen, Y., Lin, B., 2022. How "informing consumers" impacts willingness to pay for renewable energy electricity in China. J. Global Inf. Manag. 30 (1), 1–23.

Zografakis, N., Sifaki, E., Pagalou, M., Nikitaki, G., Psarakis, V., Tsagarakis, K.P., 2010. Assessment of public acceptance and willingness to pay for renewable energy sources in Crete. Renew. Sustain. Energy Rev. 14 (3), 1088–1095.