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RESEARCH ARTICLE

Cross-city insights on sustainable consumption: consistency and disparities in willingness to buy and pay for green air conditioners

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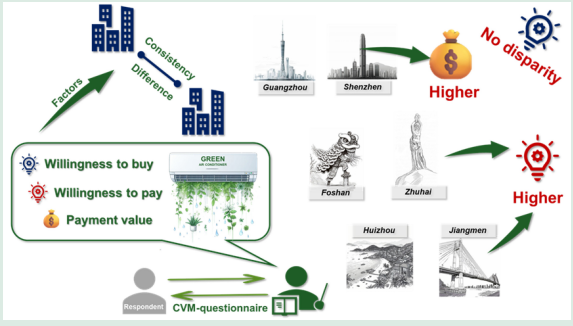
HIGHLIGHTS

- It first investigates residents' WTB and WTP for green air conditioners.
- Income, education, knowledge level, and confidence level are key factors.
- Male, high-income, and high-education residents are more willing to pay.
- WTB is consistent across cities, while WTP and its payment value vary widely.
- Jiangmen, Zhuhai have higher WTP, while Shenzhen has the highest payment.



ABSTRACT: The intensification of climate change action has made air conditioners a key target for emission reductions. This study examines the factors influencing residents' willingness to buy (WTB) and willingness to pay (WTP) for green air conditioners across six cities in the Pearl River Delta (PRD) region, aiming to understand consumer behavior and inform targeted market strategies. Using a novel Contingent Valuation Method (CVM), this study surveyed 1732 residents through online and face-to-face interviews. Binary logistic and ordered logistic regression analyses identified key factors affecting WTB and WTP, including gender, income, education, knowledge of green air conditioners, and confidence in their emission reduction potential. However, the study reveals significant regional disparities in WTP and payment amounts through the Kruskal–Wallis H and Mann–Whitney U tests. The results also highlight Shenzhen has significant difference and highest payment value than other cities. These findings provide valuable insights into regional disparities and common factors in green consumption, offering guidance for market strategies and policy development aimed at promoting green

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air conditioners.

KEYWORDS: Contingent valuation method, Green air conditioners, WTB and WTP, Influence factors, Consistency and difference

1 Introduction

The IPCC (2021) has identified anthropogenic greenhouse gases emissions as the primary driver of global climate change, reaching 59.6 Gt CO_2-eq in 2019 with 34% originating from the energy sector (IPCC, 2022). As global economic growth and urbanization accelerate, energy consumption has surged, particularly from household appliances (Wang et al., 2017). Meanwhile, the average carbon emissions generated per air conditioner per household in 2012 was 950.69 kg CO_2-eq (Song and Li, 2015). Furthermore, residential air conditioner loads contribute to 30%–40% of summer electricity consumption and make a strong impact on the city's peak demand (Zhang et al., 2020b). Notably, in China's urban households, air conditioner ownership reached 149.6 units per 100 households in 2020, with the Pearl River Delta (PRD) region surpassing this national average at 239.5 units per 100 households. Since the region's subtropical monsoon climate, demand for air conditioner has surged, along with energy consumption and carbon emissions, underscoring the imperative for a transition from production-side to consumption-side management.

Nowadays, with the intensification of global climate change and the increasing energy crisis (Li and Yuan, 2024), the development and application of green technologies have become an unavoidable topic (Zhu and Rao, 2024). Among various green technologies, green appliances have emerged as a significant innovation within the segment of energy saving and emission reduction. Unlike well-defined terms such as "green products" or "green consumption", there is no unified standard for defining "green appliances". Authoritative viewpoints emphasize that green appliances should possess features that are both beneficial to consumer health and environmentally friendly. Unlike traditional appliances, green appliances not only minimize energy consumption (Wang et al., 2020) but also prioritize environmental sustainability throughout their entire lifecycle. Green air conditioner, for instance, achieves energy efficiency by adopting advanced environmentally friendly technologies and materials, such as eco-friendly refrigerants, smart control systems, and renewable energy technologies. These innovations position green air conditioner as an effective tool for reducing greenhouse gas emissions. Given the increasing frequency of extreme heat events in urban centers, this adoption serves as a dual-purpose solution.

In this study, green air conditioner is defined as an air conditioner system that meets both traditional basic usage requirements and features health and environmental characteristics. Health features refer to functions or attributes that benefit consumer health, such as air sterilization. Environmental protection features encompass measures taken at every stage, from production to disposal and recycling, such as cleaner production (production stage), reduction of energy consumption (use stage), recycling (disposal stage), and etc. However, the widespread adoption of green air conditioner depends not only on technological advancements but also on consumer acceptance and willingness to pay. Factors like pricing, marketing strategies, and variations in consumer perceptions of the value of green products directly impact the market penetration of green air conditioner. Therefore, understanding the factors that drive urban residents' WTB and WTP is crucial for developing effective market strategies and policies.

Residents' WTP is critical to the promotion of green air conditioners. Enhancing WTP through targeted pricing strategies, financial incentives, and environmental awareness campaigns can expedite the market acceptance of green products, contributing to both environmental and economic sustainability. Since the economic value of the environmental benefits of green air conditioner is non-market oriented, it is ineffective to use traditional market valuation methods to accurately assess the issue (Ke et al., 2022). Nowadays, researchers typically use stated preference methods to estimate non-use values. Contingent Valuation Method (CVM) is a typical stated preference valuation method. It uses the principle of utility maximization through hypothetical questions that can reveal the likelihood of behavior, and directly investigates the respondent's willingness through questionnaires survey in a hypothetical market environment from respondent's subjective willingness (Carson and Hanemann, 2005). To reduce the bias relating to different CVM elicitation techniques (such as range bias, midpoint bias, yea-saying bias, and starting point bias) (Ke et al., 2022), this study innovatively combines two elicitation techniques: the

payment card format (PC) and the double-bounded dichotomous choice (DBDC). The PC simplifies respondent choices, reducing non-response rates, while the DBDC adapts follow-up questions to directly capture true WTP values, mitigating strategic and starting-point biases. By combining these methods, respondents find it easier to provide answers, leading to reduced biases and a more accurate reflection of their true preferences.

Recent studies have emphasized the effect of energy labels on consumer purchase intentions for energy-saving household appliances (Shen and Saijo, 2009; Wang et al., 2019; Zha et al., 2020; Zhang and Song, 2023). Generally, observed that energy-efficient appliances command a higher price point compared to their conventional counterparts. The energy efficiency labeling policy predominantly fosters green consumption among those who opt for mid-to-high-priced products. This inclination toward higher-priced, energy-saving products results in a reduced willingness to purchase among cost-sensitive consumers, thereby giving rise to what can be termed as the energy efficiency paradox (Fraas et al., 2019; Wang et al., 2021; Li et al., 2024b).

However, the paradox necessitates a deeper exploration of the underlying consumer behaviors, particularly in terms of their WTB and WTP. A comprehensive review of the literature reveals that while there is a discernible trend toward energy conservation, the actual purchase intentions and payment premiums for energy-efficient appliances vary significantly across different demographics and regions. This variation underscores the need for a nuanced understanding of the factors that drive consumer decisions in the context of energy-efficient products. Empirical studies, such as the impact of purchasing energy-efficient appliances on energy savings by residents of a tropical metropolis (Liddle et al., 2020), revealing that actual energy savings amounted to 7.8% of total energy consumption. The purchase intention and actual behavior of rural residents in Chongqing, China (He et al., 2023), toward energy-efficient refrigeration appliances. The purchasing patterns of solar water heaters among urban residents in China (Zhang and Zhu, 2023).

However, few attentions have been paid to the WTP and WTP value (price premium) of energy-efficient appliances, and it is even rarer to examine for regional and multi-city perspectives. Consumers' WTP for eco-friendly refrigerators (Ward et al., 2011), revealing a willingness to pay an extra $48.52 to $70.95. The WTP of higher-class energy-saving appliances in urban consumers in Jilin, China (Wang et al., 2020). The determinants of the price premium WTP for energy-efficient appliances (Zhang et al., 2020a), considering product attributes, consumer characteristics, and the impact of regulatory measures and public awareness campaigns.

As aforementioned, the promotion of green air conditioners is vital for achieving carbon neutrality and aligns with consumers' preferences for a healthy living environment. It also plays a synergistic role in driving down pollution and carbon emissions, contributing to the "Beautiful China" initiative and the "dual carbon" goals. To fill the research gap, it focuses on the PRD region and, through a questionnaire survey, examines the consistency and differences in the WTB and WTP for green air conditioners among residents from different socio-economic backgrounds, as well as the key factors influencing these intentions. The results will provide theoretical and practical guidance from an environmental economic perspective for the market promotion of green air conditioners.

2 Methodology

2.1 Research boundaries and framework

Pearl River Delta (PRD) region, an area of 54766 km^2, is located in the central-south of Guangdong, China, and consists of nine cities (Guangzhou, Shenzhen, Foshan, Zhuhai, Zhongshan, Huizhou, Dongguan, Jiangmen, and Zhaoqing). In 2021, the population of PRD region was 78.61 million and its GDP reached 9.87 trillion Yuan. Given the diversity in economic development, urbanization, and socio-economic characteristics across the PRD, this study selected six representative cities for in-depth analysis: Guangzhou and Shenzhen (first-tier cities), Foshan and Zhuhai (emerging industrial and technological cities), and Huizhou and Jiangmen (regional central cities).

This study aims to quantify residents' preference for green air conditioners and reveal key factors through a large-scale questionnaire survey in selected cities in the PRD region, and to form a strategic basis for the popularization of green air conditioners. The research boundaries and framework are shown in Fig. 1, which includes the following steps:

Step 1: Guangzhou, Foshan, Shenzhen, Huizhou, Jiangmen, and Zhuhai as the research locales. The questionnaire was well structured, employing the innovative CVM elicitation technology to mitigate bias, with cities selected based on their economic development level. Data were collected through face-to-face interviews (30.7%) and online survey (69.3%).

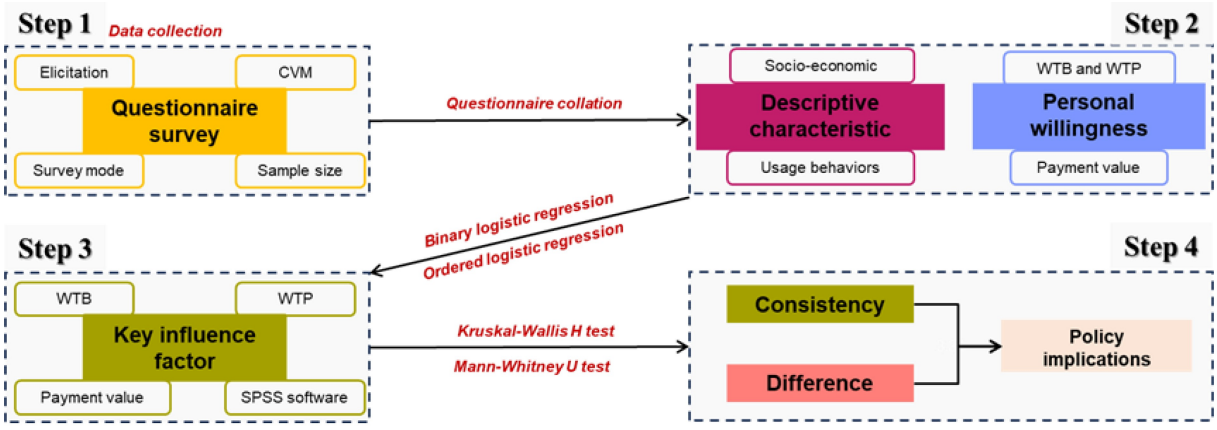

Fig. 1 Research framework.

Research process was divided into two stages: pre-survey and formal research.

Step 2: Based on the questionnaire survey, the questionnaires will be organized and counted to understand the respondents' socio-economic characteristics, as well as their preference, knowledge, and personal willingness for green air conditioners.

Step 3: Applying SPSS software, binary logistic regression analysis and ordered logistic regression were used to clarify the key influencing factors of residents' WTB and WTP for green air conditioners.

Step 4: Based on the results of step 3, the Mann–Whitney U test was adopted to compare the mean ranks of WTB, WTP, and payment amount across different cities, and to analyze the consistency and difference of residents' preference in different socio-economic contexts. Finally, it discusses the implications and recommendations for the promotion of green air conditioners in different cities based on the results.

2.2 Questionnaire design and survey method

This study conducted a pre-survey using trained interviewers through face-to-face interviews and open-ended elicitation technology to determine the objective bid median and revised the questionnaire. The formal survey was conducted using a combination of face-to-face interviews (Guangzhou, Shenzhen, Zhuhai, Jiangmen, Huizhou, Foshan) and an online survey (Tencent Questionnaire). The questionnaire is divided into three sections in this study: 1) personal information (6 questions); 2) usage behavior characteristics and attention and attitude toward green air conditioners (7 questions); 3) WTB and WTP (5 questions). The detailed information of the questionnaire is in Supplementary. A, and the explanation of variables is presented in Table 1. The research boundaries and questionnaire detail were shown in Supplementary. B.

Despite the usefulness of the CVM valuation tool and the mutually exclusive relationship between willingness to pay and willingness to accept. The reliability of the CVM can be improved by using WTP as a measure of welfare, accounting for the substitution effect and the reference point effect of green air conditioners (Knetsch et al., 2012). A combination of two elicitation technologies, PC and DBDC, was used to reflect respondent's true reactions directly, and the details of the elicitation technical process in the formal survey of this study are shown in Fig. 2.

Considering that some respondents had reservations about purchasing green air conditioners, the questionnaire went on to probe their WTP, aiming to gain insights into their price sensitivity and level of support for environmental measures. This reflects that while respondents may be satisfied with their current products and are not in a hurry to replace them, they are willing to pay a certain payment value for improved sustainability of the environment. This finding reveals that consumers still have a positive attitude toward environmental values even when they are not considering immediate purchase of new products. The interviewer will directly ask whether they are willing to pay extra for green air conditioners. When the respondent answers "YES", they will provide the Bid_0 value of the payment card format to the respondent for one choice. After the respondent answers, they will conduct a second question and answer "YES" or "NO" to finally confirm the willingness to pay amount. If the respondent chooses "NO" on the response, unlike DBDC, the procedure will end.

2.3 Data processing methods

In this study, the questionnaire comprised 18 items,

Table 1 Explanatory item summaries

Variables	Explanation	Measure scale	Item
Region	Permanent residence of the respondent	Nominal	1 = "Guangzhou"; 2 = "Foshan"; 3 = "Jiangmen"; 4 = "Zhuhai"; 5 = "Shenzhen"; 6 = "Huizhou".
Gender	Sex of respondents	Nominal	1 = "Male"; 2 = "Female."
Age	Age of respondents	Scale	—
Family size	Respondents' family size	Scale	—
Income level	Monthly income of respondents	Ordinal	1 = "Under 2000"; 2 = "2000 to 4000"; 3 = "4000 to 6000"; 4 = "6000 to 8000"; 5 = "8000 to 10000"; 6 = "10000 to 20000"; 7 = "20000 or above".
Educational level	Educational level of respondents	Ordinal	1 = "Under middle school"; 2 = "High school/ Technical secondary school"; 3 = "Junior college"; 4 = "College"; 5 = "Master or above".
Ownership	Household air conditioner ownership	Scale	—
Serviced-life	Years of use of air conditioners	Scale	—
Use frequency (cooling)	Frequency of use (air conditioner cooling)	Scale	—
Use frequency (heating)	Frequency of use (air conditioner heating)	Scale	—
Knowledge	Level of knowledge about green air conditioner	Ordinal	1 = "Extremely disagree"; 2 = "Disagree"; 3 = "Neutral"; 4 = "Agree"; 5 = "Extremely agree".
Confident	Level of confidence in the emission reduction potential of green air conditioner	Ordinal	1 = "Extremely disagree"; 2 = "Disagree"; 3 = "Neutral"; 4 = "Agree"; 5 = "Extremely agree".
WTB	Willingness to buy	Nominal	1 = "Unwilling"; 2 = "Willing".
WTP	Willingness to pay	Nominal	1 = "Unwilling"; 2 = "Willing".
WTP value (Yuan)	Payment value	Ordinal	—

Notes: Regression analyses were conducted using indicator lights to compare categorical covariates, with the reference category being the first category.

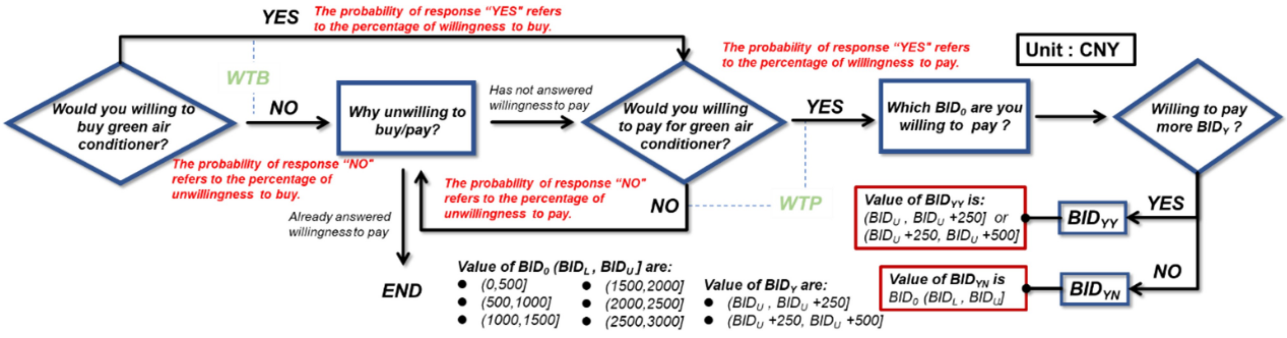

Fig. 2 Detail of elicitation process.

targeting pivotal aspects inclusive of socio-economic characteristics. Some experts indicated that for populations exceeding 5000 individuals, approximately 400 samples would be sufficient (Leedy and Ormrod, 2020). Smaller sample sizes may introduce potential sampling errors into the research findings. To guarantee the credibility of the data, the representativeness of all survey items ought to be at least ten times the sample size (Pohlmann, 2004). Theoretically, this necessitates a minimum of 180 samples to facilitate effective statistical analysis. The actual sample size obtained in this study, amounting to 1732 (Total sample size is 1874), significantly surpasses this benchmark, thereby guaranteeing the adequacy of data and the representativeness of the research outcomes. This excess in sample size endows the study with enhanced statistical power to discern subtle effects and trends, consequently fortifying the credibility and validity of the research conclusions.

According to the data types of WTB, WTP, and payment value, different regression methods were used. Binary logistic regression analysis was employed to explain the factors characterizing residents' WTB and WTP for green air conditioners, and ordered logistic regression analysis was used to explore the key factors of residents' payment value. Due to the large sample

size, it is easy to cause the test to fail, so the payment amount was dummy variable coded and simplified into four levels of rank, respectively 0–1000 (Yuan), 1000–2000 (Yuan), 2000–3000 (Yuan), and 3000 and above levels (Yuan).

Binary logistic regression (Eq. (1)) and ordered logistic regression (Eq. (2)) were employed to identify the factors influencing residents' WTB, WTP and its value for green air conditioners. These methods are particularly suitable for analyzing categorical dependent variables. The logistic regression model is given as:

$$logit(P) = \ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \ , \quad (1)$$

where P refers to probability of the outcome (e.g., WTB = 1); β_0 refers to intercept term; $\beta_1, \beta_2, \ldots, \beta_k$ refers to coefficients of predictor variables $X_1, X_2, \ldots, X_k$; X_k refers to independent variables (socio-economic characteristics, environmental awareness, and etc.).

$$logit(P(Y \leqslant j)) = \ln\left(\frac{P(Y \leqslant j)}{1-P(Y \leqslant j)}\right) = \alpha_j - (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k), \quad (2)$$

where $P(Y \leqslant j)$ refers to cumulative probability of the outcome being in category j or lower; α_j refers to threshold parameter for category j.

To identify the factors influencing consumers' WTB, WTP, and payment values for green air conditioners, a bivariate analysis approach and Spearman's rank correlation coefficient will be adopted to estimate the relationship between two variables and determine the strength and direction of the linear correlation between them. Spearman's rank correlation coefficient, denoted as r, is a non-parametric measure used to evaluates the intensity and direction of the correlation between two ordinal variables. The coefficient is calculated as follows (Eq. (3)):

$$r = 1 - [6\sum_{i=1}^{n} d_i^2 / n(n^2-1)] \ , \quad (3)$$

where d_i refers to the difference between the ranks of the relevant variables, n is the observed number of values.

To identify the consistency and differences in the WTB, WTP, and payment amounts for green air conditioner among residents of different cities, this study was analyzed using Kruskal–Wallis test and the Mann–Whitney U test. The Kruskal–Wallis test which is a non-parametric method for comparing differences in medians of three or more independent samples is a non-parametric alternative to one-way ANOVA. The Mann–Whitney U test was used to compare the median difference between two independent samples.

Given that the data involve multiple cities, which may exhibit different distribution characteristics, the Kruskal–Wallis test can effectively compare whether there are significant differences in the medians of WTB, WTP, and payment amounts among the residents of different cities The H index is calculated as follows (Eq. (4)):

$$H = [12/N(N+1)] \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1) \ , \quad (4)$$

where N represents the total number of all samples, while k denotes the group count. R_i is the sum of the ranks of group i^{th}, and n_i is the samples number in the group i^{th}. By comparing the H value with the critical chi-square value and interpreting the obtained P value, a larger H indicates more significant differences between the samples.

If the Kruskal–Wallis test indicates significant differences, it will further explore the differences in WTB, WTP, and payment amounts between two specific cities. The Mann–Whitney U test (Eqs. (5) and (6)) can provide a more precise analysis for this purpose.

$$U_1 = n_1 n_2 + [n_1 + (n_1+1)/2] - R_1 \ , \quad (5)$$

$$U_2 = n_1 n_2 + [n_1 + (n_1+1)/2] - R_2 \ . \quad (6)$$

Furthermore, n_1 and n_2 represent the sizes of sample 1 and sample 2, respectively, and R_1 and R_2 denote the sum of the ranks of sample 1 and sample 2, respectively. Based on the comparison of the U values, statistical inferences are made to determine whether there is a significant difference between the two data sets.

To account for urban socio-economic disparities, the statistical models applied in this study incorporated controls for income, education level, and household size across the six cities. This adjustment ensures that variations in willingness to buy (WTB), willingness to pay (WTP), and payment values can be more accurately attributed to environmental awareness and other influencing factors, while mitigating the confounding effects of socio-economic status.

3 Results

3.1 Descriptive characteristics

As illustrated in Fig. 3, the survey garnered 1732 valid questionnaires, with 810 male (46.8%) and 922 female

(53.2%) respondents. The average family size was 3.67 persons, with average income was 7548.5 Yuan per month, and the average age of respondent was 35.6 years. The average educational level of respondents was 3.51, where a score of 3 indicates "Junior College" and 4 represents "College".

3.2 Personal behaviors and awareness

Regarding personal usage behaviors, Figure 3 shows the average household air conditioner ownership was 2.92 units, with an average service life of 3.73 years. The cooling time averaged 6.63 h/d, while the heating

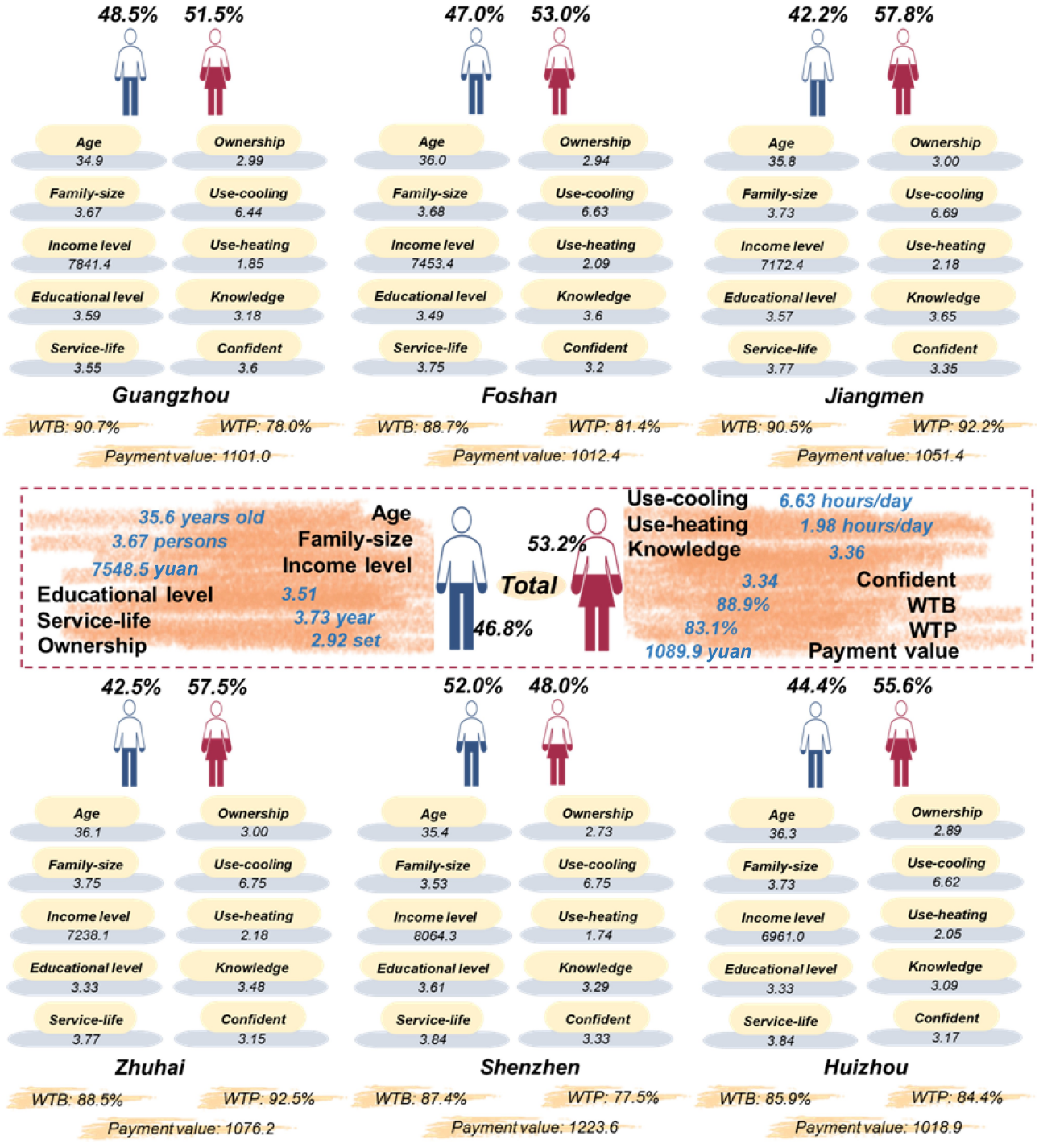

Fig. 3 Details of the city-specific findings.

time averaged 1.98 h/d. The respondents' level of knowledge about green air conditioners was rated as moderate, with an average score of 3.36 (where 3 signifies "Neutral"). There were some obstacles to the promotion of relevant information and policies on green air conditioners, which may be attributed to the green concept not yet being deeply rooted in people's hearts and a lack of publicity. The respondents' confidence in the emission reduction potential of green air conditioners was also rated as moderate, with an average score of 3.34 (where 3 denotes "Neutral").

"Energy efficiency class" (4.33), "Operating noise/bactericidal function" (4.10), and "Price" (3.94) are the three factors that the public is more concerned about in Fig. 4(A), while "Appearance" (3.35) is relatively low consideration factor. This confirms that the public is mainly concerned about their own experience (low noise, saving electricity). As aforementioned, the development and promotion of green air conditioners should be gradual, and gradually increase residents' confidence in green air conditioners based on increasing publicity and gradually popularizing green concepts.

The personal awareness of respondents in what characteristics should residents have for green air conditioner was shown in Fig. 4(B). Regarding residents' perceptions of what characteristics green air conditioners should have, "Low energy consumption" (85.5%), "Purify the air and improve the air quality" (80.5%), "Low operating noise" (73.4%), "Use of materials that cause less pollution to the environment" (70.6%), "Use new energy" (68.1%), "Less environmental pollution after disposal" (62.3%), and "Intelligent" (54.2%) are the main characteristics. Resident have less recognition in "Novel and beautiful fashionable appearance" (37.1%) and "No or low fluorine refrigerant" (10.7%). This shows that the public is most concerned about their own experience (low noise, power saving, and improving indoor air quality air conditioners), followed by considering environmental protection (harmless, low carbon). There is a certain proportion of attention to the environmental protection of materials and disposal after disposal, reflecting that residents have a certain environmental awareness. However, the lower level of awareness of refrigerants reflects the lack of awareness among residents of the environmentally harmful effects of air conditioner refrigerants, which would be a direction to improve residents' environmental awareness.

3.3 Personal WTB and WTP

The analysis results show that 88.9% of residents are willing to buy green air conditioners in Fig. 3, and the purchase intention varies from 85.9% to 90.7% among different cities. Guangzhou residents have the highest

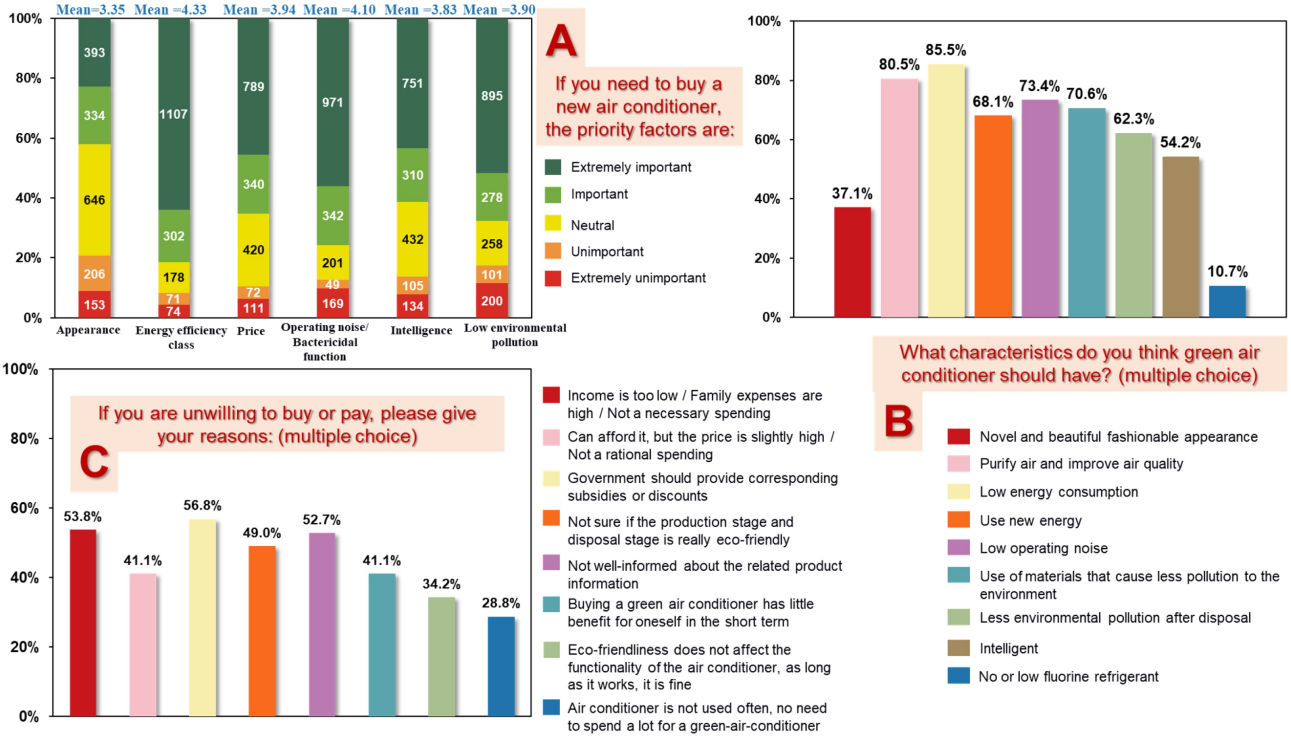

Fig. 4 Priority factors of purchase behavior (A), feature preference (B), reasons for unwillingness to pay (C).

purchase intention (90.7%), while Huizhou has the lowest purchase intention (85.9%). However, when asked about actual payment, only 83.1% (77.5%–92.5%) of residents are willing to pay additional fees for green air conditioners. The average payment value is 1089.9 Yuan. The extra average payment amount of Guangzhou (1101.0 Yuan), Shenzhen (1223.6 Yuan), and Zhuhai (1076.2 Yuan) are significantly higher than those of Foshan (1012.4 Yuan), Huizhou (1018.9 Yuan), and Jiangmen (1051.4 Yuan). Among them, only 292 respondents (16.9%) are unwilling to pay extra for green air conditioners.

As shown in Fig. 4(C), "Government should provide corresponding subsidies or discounts" (56.8%), "Income is too low/ Family expenses are high/ Not a necessary spending" (53.8%), "Not well-informed about the related product information" (52.7%), and "Not sure if the production stage and disposal stage is really eco-friendly" (49.0%) are the primary reasons affecting residents' reluctance to pay. This indicates that a relative lack of information, except for economic reasons, is an important reason for residents' refusal to purchase green air conditioners. Therefore, vigorously promoting and popularizing information about green air conditioners will have a good effect on improving residents' WTP.

3.4 Key influence factors

3.4.1 WTB

The bivariate analysis presented in Fig. 5 illustrates the relationship between various socio-economic factors and WTB for green air conditioners. The results show that almost all cities have the same phenomenon: income level, education level, awareness of green air conditioners, and confidence in their emission reduction potential are significantly correlated with WTB, but the strength is not strong. On the whole, family size and actual service life of air conditioners are negatively weakly correlated with WTB. Figure 5 also gives the statistics of the Hosmer and Lemeshow test for all cities, which are all significant at over 0.05 and meet the null hypothesis, and the equation fitting effect is ideal. Income level, education level, and knowledge level of green air conditioners are the crucial factors influencing the WTB of residents among most cities. Incorporating urban socio-economic disparities into the analysis revealed a notable trend: cities with higher household incomes and educational attainment showed consistently higher levels of WTB, suggesting a link between socio-economic resilience and environmental purchasing behaviors. These findings highlight how urban economic development directly influences the willingness to adopt sustainable technologies, further linking consumer behavior to broader urban climate vulnerability. On the whole, gender, income, education level, actual serviced life of air conditioners, knowledge of green air conditioners and confidence in their emission reduction potential, and usage time (cooling/heating) are correlated with WTB at a significance level of 1%.

3.4.2 WTP

Similarly, the bivariate analysis concerning the WTP for green air conditioners, as shown in the same figure, indicates that educational level, knowledge level of green air conditioners, confidence in their emission reduction potential, and usage time for cooling are significantly correlated with WTP in all cities, though the correlations are not pronounced. With the exception of age and actual service life of air conditioners, all other variables demonstrate a positive but weak correlation with WTP. To delve deeper into the determinants of WTP, binary logistic regression was utilized. The comprehensive results of this analysis are provided in Supplementary. C. The Hosmer and Lemeshow test statistics for all cities, as shown in Fig. 5, confirm a p-value greater than 0.05, aligning with the null hypothesis and indicating an ideal fit for the regression model. The findings from most cities highlight that educational level and knowledge level of green air conditioners significantly influence WTP. On the whole, with the exception of age, ownership, and usage time for heating, all variables are correlated with WTP at a 1% significance level.

3.4.3 WTP value

The left bubble chart in Fig. 6 shows the bivariate analysis of the variables and the payment amount for green air conditioners. The results show that in most cities, residents' education level, knowledge of green-air-conditioners and confidence in their emission reduction potential are significantly correlated with the payment amount, but the strength is not strong. On the whole, except for age, practice serviced life of air conditioners, and usage time (cooling/heating), all variables are correlated with the payment amount.

This study adopts ordered logistic regression to analyze the payment amount for green air conditioners. The detailed analysis results are presented in Supplementary. C. Figure 6 gives the statistics of the parallelism test and the pseudo-R-square for all cities, and the significance is over 0.05, indicating that the null hypothesis can not be rejected and the equation fits satisfactorily. According to the Odds ratio (OR) values of the continuous variables, the OR values of males in

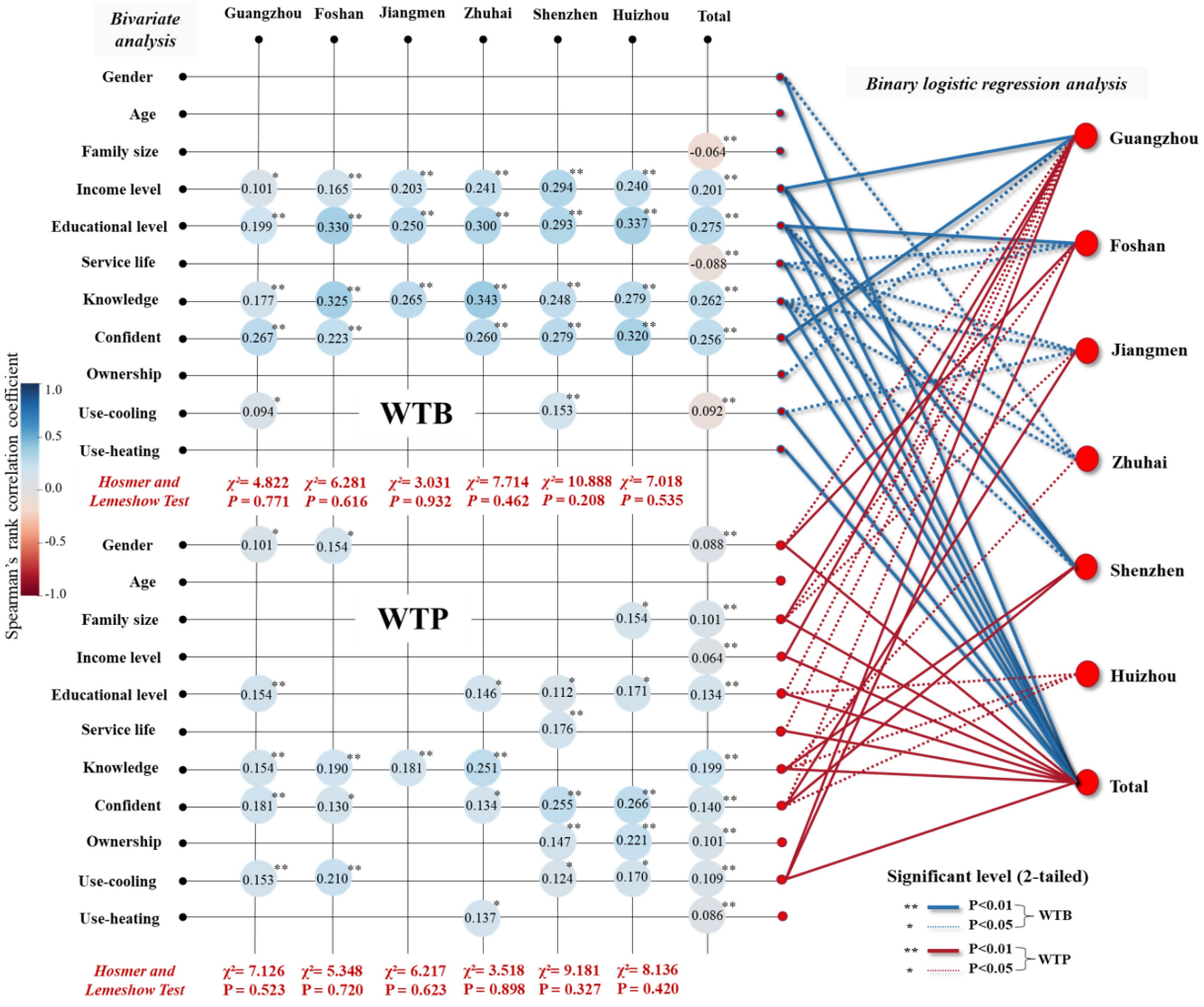

Fig. 5 Influence factors of WTB and WTP (Tables S1–S21 for details).

each city are greater than 1 (1.101–2.259), and the overall OR value is 1.429, indicating that males' payment amount is higher than females', and the odds of increasing the payment amount by at least one level are 2.105 times higher for males than for females. The OR values of the other continuous variables are mainly concentrated in 0.9–1.1, whether from the perspective of a single city or the whole, which indicates that the other continuous variables have little impact on increasing the payment amount by one level.

According to the ordered categorical variables (Tables S1–S3), the OR values of each level of Guangzhou residents' knowledge of green air conditioners (the group that strongly agrees as the control group) are greater than 1, and the average possibility of increasing the payment amount by at least one level, the odds of increasing the payment amount by at least one level are 1.231–2.675 times higher for each level than for the group that strongly agrees. And Foshan and Jiangmen residents' confidence in the emission reduction potential of green air conditioners (the group that strongly agrees as the control group) are 1.287–3.225 times and 1.157–2.604 times that of the group that strongly agrees, respectively. Variations in the educational level has no positive effect on the possibility to increase the payment amount.

4 Discussion

4.1 Consistency and difference analysis

To further explore the consistency and difference of the key influencing factors of residents' WTB, WTP, and payment amount for green air conditioners in different cities, the Mann–Whitney U test was used in this study to compare the mean rank of different urban variables, and the ordered logistic regression to analyze the effects

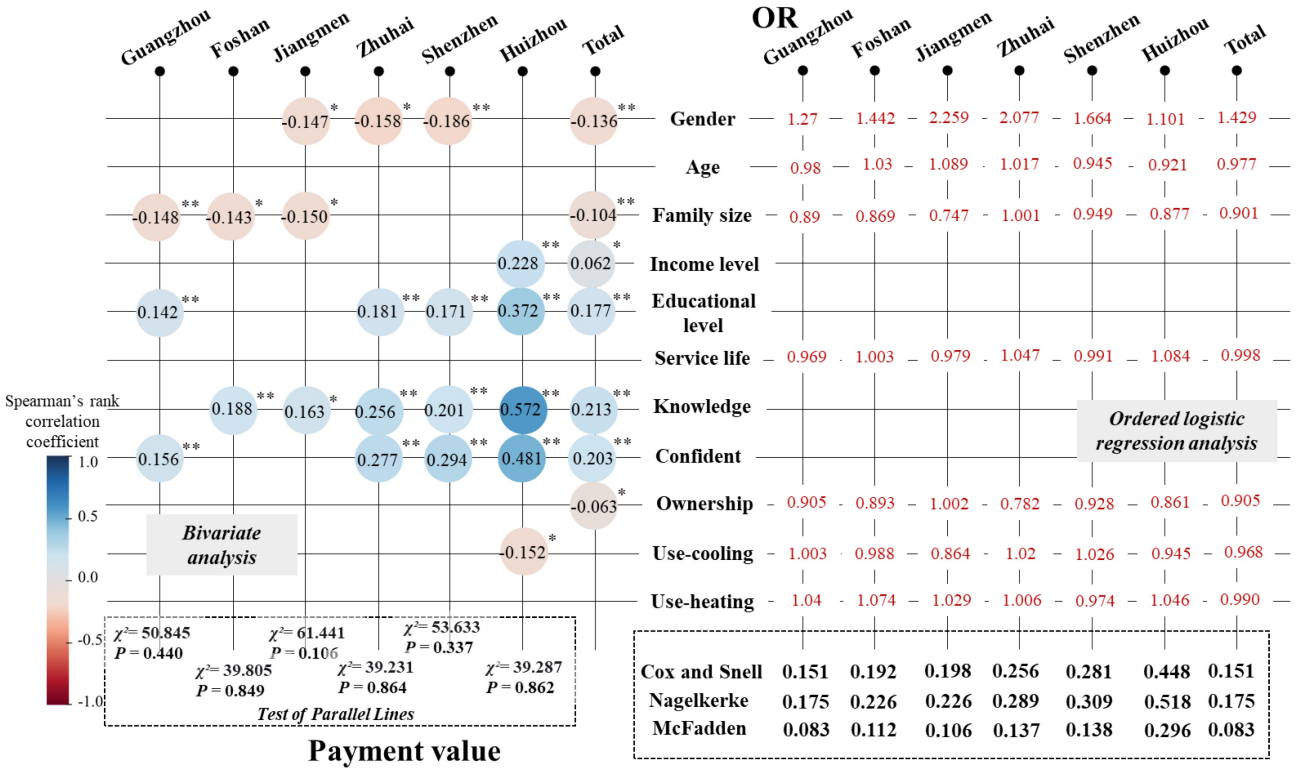

Fig. 6 Influence factors of payment value (Tables S1–S21 for details).

of the variables on the ordinal outcomes. The detailed analysis results are shown in Supplementary. C and Tables S1–S3 (variable: region). The results indicated that mean rankings were significantly different and the effects of some variables among different cities, indicating that the socio-economic background of different cities has an impact on residents' preference for green air conditioners.

For the WTB in Table S22, the mean ranks of WTB are not significantly different among different cities through Kruskal–Wallis H test (P = 0.704 > 0.05). However, there are some effects on the WTB show some variations among different cities. Table S1 shows that, although none of the cities have significant P values, the P values show a clear bipolar trend when Foshan is used as the reference group. Guangzhou = 0.972, Shenzhen = 0.777, Jiangmen = 0.579, Zhuhai = 0.175, Huizhou = 0.083. This indicates that the residents of Guangzhou and Shenzhen have similar WTB to the residents of Foshan, while the residents of Zhuhai and Huizhou have dissimilar WTB to the residents of Foshan.

While WTP (P = 0.000 < 0.05), and payment amount (P = 0.000 < 0.05) has significantly different among different cities through Kruskal–Wallis H test. For the WTP, the mean ranks of WTP are significantly different (Table S23) between Guangzhou and Jiangmen, Guangzhou and Zhuhai, Foshan and Jiangmen, Foshan and Zhuhai, Jiangmen and Shenzhen, Zhuhai and Shenzhen, and Jiangmen and Huizhou, indicating that these pairs of cities have different levels of WTP for green air conditioners. Findings of the Mann–Whitney U test (Fig. 7) reveal that the mean ranks of WTP are higher in Guangzhou, Foshan, Shenzhen, and Zhuhai than in Jiangmen and Huizhou, indicating that the former group of cities have higher WTP for green air conditioners than the latter group of cities. The effects of the region variable on the WTP also show significant differences among different cities. Table S2 shows that the region variable has a strong and significant impact on the WTP at the 1% significance level. When Foshan is used as the reference group, Huizhou (B = 0.607, P = 0.032 < 0.05), Jiangmen (B = 0.986, P = 0.002 < 0.01), and Zhuhai (B = 1.169, P = 0.000 < 0.01) have significant differences. Guangzhou and Shenzhen do not have significant differences from Foshan, but show negative correlations, indicating that Foshan has a higher WTP (but not significant) than Guangzhou and Shenzhen.

For the payment amount, the mean ranks of payment amount are significantly different (Table S23) between Guangzhou and Shenzhen, Foshan and Shenzhen, Jiangmen and Shenzhen, Zhuhai and Shenzhen, and

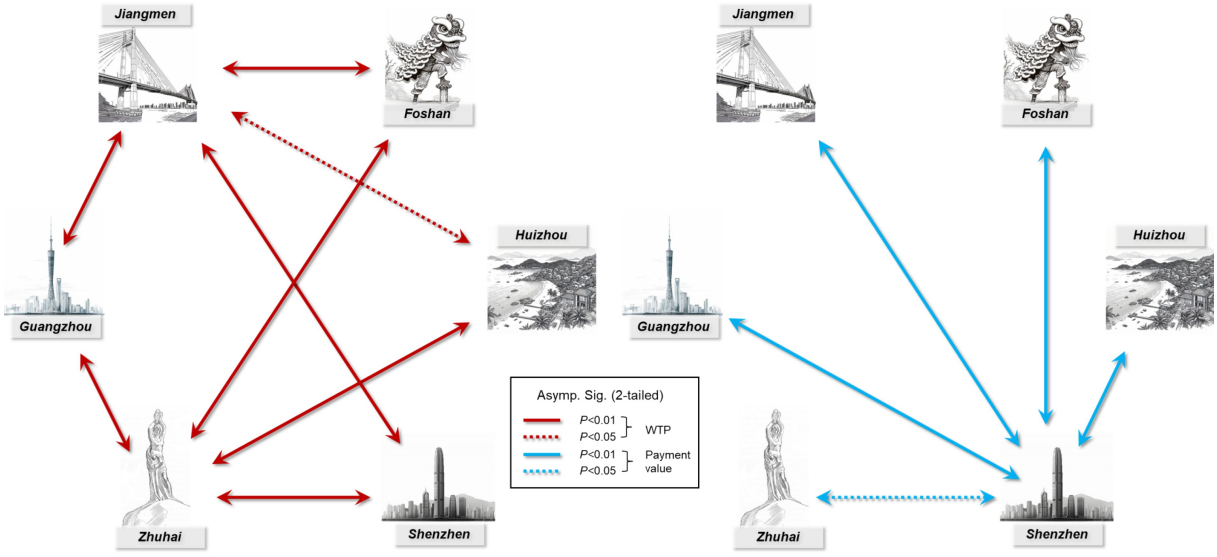

Fig. 7 Inter-city difference (Mann–Whitney U test (Table S24).

Shenzhen and Huizhou, indicating that these pairs of cities have different levels of payment amount for green air conditioners. Findings of the Mann–Whitney U test (Fig. 7) reveal that the mean ranks of payment amount are higher in Shenzhen than in Guangzhou, Foshan, Jiangmen, Zhuhai, and Huizhou, indicating that Shenzhen has the highest payment amount for green air conditioners among all cities. These findings suggest that cities with stronger economic capacities not only show a higher willingness to adopt green air conditioners but also have greater potential to enhance urban climate resilience through such technologies. In regions like Guangzhou and Shenzhen, where WTP is higher, the adoption of green air conditioners could play a critical role in reducing the urban heat island effect and ensuring energy stability during extreme heat events. On the other hand, the lower WTP in cities like Huizhou and Jiangmen highlights a potential gap in resilience, where targeted interventions, such as subsidies, may be necessary to improve the adoption of green technologies and thus enhance the overall climate resilience of these more vulnerable areas.

The effects of the region variable on the payment amount also show significant differences among different cities. Table S3 shows that, when Zhuhai is used as the reference group, Shenzhen has an OR value of 1.168, indicating that the payment amount of Shenzhen residents is higher than that of Zhuhai residents, and the odds of increasing the payment amount by at least one level are 1.168 times higher for Shenzhen residents than for Zhuhai residents. Similarly, Foshan (OR = 0.706), Guangzhou (OR = 0.736), Huizhou (OR = 0.834), and Jiangmen (OR = 0.824) have lower odds of increasing the payment amount by at least one level than Zhuhai.

However, while differences in WTP and payment amounts were evident, there were notable consistencies in some key influencing factors across all cities. For instance, factors such as education level, knowledge of green air conditioners, and confidence in their emission reduction potential had a consistently positive impact on WTP. These findings suggest that, despite socio-economic disparities among cities, residents who are more educated and environmentally aware tend to exhibit a greater willingness to support green technologies.

From a climate adaptation perspective, this consistency in key influencing factors suggests that enhancing environmental education and awareness could be an effective strategy to boost green technology adoption across diverse urban settings. However, the observed regional disparities in WTP and payment amounts highlight the socio-economic vulnerability of lower-income cities, where residents may struggle to afford green technologies despite their environmental benefits. This underscores the need for targeted policy interventions to address these urban inequities.

4.2 Improving the residents' WTB and WTP

This study examined the influencing factors and differences of residents' WTB and WTP for green air conditioners in the PRD region. Through sentiment analysis that environmental health information (save electricity, energy efficient sterilization, ECO, quiet, temperature) is the most critical factor in affecting the purchasing behavior of green appliances (Li and Yuan, 2024), which is consistent with the results of this study.

In Jilin, China, women with full-time housework, environmentally conscious young people, people with master's degree or higher, and workers with high recognition in government departments had higher WTP for higher-class energy-efficient appliances (Wang et al., 2020). This observation is consistent with the results of this study. There are also some empirical studies on WTB and WTP on electric motorcycles (Zhu et al., 2019) and electric vehicles (Zhang et al., 2023) in Macao consumers, and indicated that both their respondents' income levels significantly contribute to WTB and WTP, as well as knowledge of electric motorcycles and education level, which is similar to the results of this study. Moreover, from an urban resilience standpoint, increasing the affordability of green air conditioners can significantly enhance the climate adaptation capacities of economically vulnerable cities. Providing financial subsidies or introducing regional carbon credit schemes can bridge the gap between high-income and lower-income cities, enabling broader access to energy-efficient technologies and reducing urban climate vulnerability. However, unlike the research (Duan et al., 2023), which found that among 55 Chinese cities, the higher the city class, the higher the consumers' WTP for high-grade energy-efficient appliances, and that the WTP was higher among young people, those with higher incomes, those without children, and those with higher monthly electricity bills. This study suggests that an individual's socio-economic status determines WTP more than the level of urban development.

4.3 Key factors and WTP values

The intricate interplay of socio-economic factors exerts a profound influence on residents' WTP for green air conditioners. This study corroborates the findings (Yadav and Pathak, 2016), emphasizing the pivotal role of personal concern for the environment in purchasing green products. However, our research advances the discourse by quantifying these concerns' tangible impact on actual WTP values.

➢ Income and education levels: This study underscores the significance of income and education levels as primary determinants of WTP. Higher income levels are associated with increased financial flexibility, thereby enhancing the propensity to invest in environmentally friendly technologies. Concurrently, education serves as a conduit for heightened environmental awareness, translating into a greater valuation of green products' benefits.

➢ Environmental concern: The moderate correlation between knowledge of green air conditioners and payment amounts indicates that while environmental concern is a critical driver, it does not invariably lead to a higher financial commitment. This discrepancy may stem from a nuanced understanding of green products' long-term economic and ecological dividends. It suggests that residents, despite recognizing the importance of sustainable living, may not fully grasp the cost-saving implications of energy-efficient appliances over their lifecycle.

➢ Gender dynamics: Intriguingly, the study reveals gender dynamics at play, with males demonstrating a higher likelihood of paying more for green air conditioners than females. This finding invites further exploration into the socio-cultural factors that may influence such disparities in environmental investment behaviors.

➢ Regional variations: The study also illuminates the regional variations in WTP, underscoring the influence of local socio-economic contexts. Cities with higher economic development levels exhibit a greater WTP, reflecting the interconnection between economic prosperity and environmental prioritization.

In summary, this study expands the knowledge of the factors influencing WTP for green air conditioners, highlighting the need for nuanced approaches to foster sustainable consumer behaviors. It offers a pathway for future in-depth study of the psychological and cultural underpinnings of environmental economics.

4.4 Policy implications

For instance, Shenzhen's policy framework, as evidenced by the "Shenzhen Carbon Peak Implementation Plan", the "Shenzhen's Climate Change Response 14th Five-Year Plan", and the "The work plan for the construction of Shenzhen carbon inclusive system" is notably sophisticated and comprehensive. While other cities have also developed policies to encourage green consumption and low-carbon living, these tend to lack the depth and enforcement seen in Shenzhen, particularly in terms of policy advancement, comprehensiveness, and transparency. Often, these policies are missing specific, actionable steps to incentivize the adoption of green appliances, such as detailed incentives for household appliance trade-ins and carbon credits. Furthermore, the lack of cooperative interaction between policies leads to an underutilization of regional uniformity and differentiation in promoting sustainable consumption practices and low-carbon lifestyles. To increase the market penetration of green air conditioners and reduce carbon emissions at the consumer level, this study proposes the following policy recommendations:

1) Market strategy diversification and regional cooperative interaction. Governments and enterprises should adopt differentiated market strategies personalized to the diverse characteristics and preferences of urban residents. High-end and environmentally friendly product positioning and pricing strategies should be targeted at male, high-income, and highly educated residents, while economically disadvantaged cities like Huizhou and Jiangmen would benefit from more affordable product options. Additionally, fostering collaboration across cities—through sharing market information and resources—can create synergistic effects that enlarge the promotion of green air conditioners, enhancing regional purchasing power and contributing to the broader goal of sustainable urban consumption. This regional cooperative interaction can also help cities collectively respond to climate challenges by promoting technologies that contribute to urban climate resilience.

2) Governments and enterprises should enhance the publicity and promotion (Zhang et al., 2022) of green air conditioners, especially highlighting their role in addressing climate change and improving urban climate resilience. This would raise residents' environmental awareness and knowledge (Cai et al., 2021). Actively introducing NGOs as partners can further enlarge these efforts. NGOs play a unique role in raising public awareness, education, and environmental advocacy (Shen et al., 2023). By collaborating with NGOs (Valera et al., 2023) and leveraging their networks and credibility, governments can expand the promotion of green air conditioners through various media platforms (Wei et al., 2019; Amirudin et al., 2023), focusing on their energy-saving features, environmental benefits, emission reduction potential, and economic advantages. This approach will stimulate consumer interest and confidence in purchasing green air conditioners.

3) Economic incentives and subsidies. The adoption of green air conditioners should be promoted through economic incentives and subsidies aligned with national carbon reduction targets (Sun, 2024). In addition to region-specific market strategies, targeted subsidies should be provided to economically disadvantaged and climate-vulnerable cities. These subsidies will enhance the economic resilience of low-income residents in these regions and help them better adapt to climate challenges. A practical initiative under this framework could include "old-for-new" programs, which incentivize consumers to replace older, less energy-efficient appliances with green technologies. This approach not only reduces initial purchase costs for consumers but also fosters resource recycling and sustainable consumption. By incentivizing consumers and encouraging manufacturers to engage in carbon offsetting practices, these measures reward eco-conscious consumer behavior (Tong et al., 2024). Furthermore, the introduction of subsidies for green technologies like air conditioners in climate-vulnerable urban areas will not only help mitigate the urban heat island effect but also improve energy stability, particularly in densely populated areas during periods of increased energy demand.

4) Expansion of carbon inclusion initiatives (Ke et al., 2024). The carbon inclusion initiative should be expanded to incorporate a broader range of carbon reduction activities, accessible through user-friendly digital platforms (Li et al., 2024a). The initiative should aim to integrate carbon reduction into daily consumer behaviors, while simultaneously linking these actions to broader urban climate resilience strategies. By fostering a culture of carbon consciousness and promoting green technologies, this program could serve as a mechanism for widespread engagement in environmental stewardship.

The study's revelations offer a treasure trove of insights for future research on market dynamics and consumer behavior concerning green air conditioners. It serves as a compass for manufacturers and marketers, guiding the strategic direction for production and sales. Additionally, promoting green air conditioners contributes directly to urban climate resilience by reducing energy demands during peak periods and mitigating heat island effects in densely populated areas. Ensuring that vulnerable cities have access to these technologies through targeted subsidies will be crucial to fostering equitable climate adaptation across urban regions. Moreover, the findings bolster policy development, advocating for informed and effective strategies to foster the adoption of green technologies. In essence, this research not only charts the current landscape of consumer attitudes toward green air conditioners but also lights the path for sustainable practices in urban development.

5 Conclusions

This study examines the factors influencing and differences in the willingness to buy (WTB), willingness to pay (WTP), and its value for green air conditioners by urban residents at different levels of economic development, by using a novel elicitation technique to guide residents to express their true demand and preference for green air conditioners, and effectively avoiding bias that exist in general questionnaire surveys. This study provides a valuable

reference for future in-depth research on the market potential and consumer behavior of green air conditioners, a useful guidance for the production and sales of green air conditioners, and a strong support for the policy development and execution of green air conditioners.

Through a questionnaire survey conducted across six cities within the Pearl River Delta region, a total of 1732 valid sample were collected. The analysis utilized binary logistic regression and ordered logistic regression to pinpoint key variables affecting residents' WTB, WTP, and payment amount for green air conditioners, and uses Kruskal–Wallis H test and Mann–Whitney U test to compare the consistency and difference of residents' WTB, WTP, and payment amount for green air conditioners in different cities.

This study draws the following main conclusions: The key variables affecting residents' WTB, WTP, and payment amount for green air conditioners, income level, education level, knowledge of green air conditioners, and confidence in their emission reduction potential. Among them, gender, income level and education level have the same influence direction on WTB, WTP, and payment amount, that is, male, high-income and high-education residents are more inclined to buy and pay for green air conditioners. Knowledge of green air conditioners, and confidence in their emission reduction potential have the same influence direction on WTB and WTP, that is, the higher the knowledge and confidence of residents, the more inclined they are to buy and pay for green air conditioners, but the influence direction on payment amount is inconsistent, that is, the higher the knowledge of residents, the higher the payment amount, and the higher the confidence of residents, the lower the payment amount.

Residents of Guangzhou and Shenzhen (first-tier cities) exhibit higher payment amounts but relatively lower WTP compared to those of Huizhou and Jiangmen (regional center cities). This could be attributed to differing perceptions of green air conditioners' value rather than economic constraints. In Guangzhou and Shenzhen, the higher levels of economic development, advanced environmental awareness, and greater disposable income may lead residents to prioritize quality and functionality over environmental benefits alone. Meanwhile, Huizhou and Jiangmen residents, despite having lower overall economic capacity, may demonstrate higher WTP due to increased sensitivity to government incentives and environmental messaging. Shenzhen, in particular, shows distinct advantages in payment amounts, likely due to its technological innovation, strong green development policies, and concentration of high-income, educated professionals. These variations highlight the uneven implementation and impact of policies promoting green consumption and low-carbon lifestyles across cities with diverse socio-economic and cultural backgrounds.

CRediT Authorship Contribution Statement

Jiachao Ke: Conceptualization, Software, Investigation, Data Curation, Writing– original draft. **Shujie Zhao:** Conceptualization, Software, Investigation. **Yaozhong Guo:** Software, Investigation. **Qingbin Song:** Methodology, Validation, Supervision, Writing – Review & Editing. **Ni Sheng:** Supervision, Writing – Review & Editing., **Jinhui Li:** Writing – Review & Editing.

Conflict of Interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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