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CLUSTER ANALYSIS OF CONSUMER CHARACTERISTICS INFLUENCING WILLINGNESS TO PAY FOR GREEN BUILDINGS AND ASSOCIATED ENERGY-EFFICIENT PURCHASES IN TAIWAN

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Abstract

Given the built environment's central role in driving sustainability, understanding consumer cluster characteristics that shape willingness to pay (WTP) for environmentally friendly built environment technologies is essential for informing effective urban sustainability strategies. This study applies principal component analysis (PCA) to identify the sociodemographic, psychographic and cognitive characteristics of different consumer clusters in Taiwan, and their influence on WTP for green buildings and associated energy-efficient purchases. Data from a comprehensive survey examining variables such as age, gender, income, education, household composition, and environmental knowledge and attitudes were analyzed. Principal component analysis was applied to reduce data dimensionality, followed by k-means clustering to identify distinct consumer clusters. Four clusters with unique characteristics were observed. The cluster with the lowest WTP was composed of low-income, less-educated individuals with low environmental knowledge and the oldest average age. The cluster exhibiting the highest WTP mostly consisted of highly educated, high-income females with high environmental awareness and attitude. The second-ranking WTP was observed in a cluster primarily composed of moderately educated individuals with moderate incomes, high environmental awareness and attitude scores, and living in households with very few or no children or seniors. A family-oriented cluster was also identified, characterized by moderate income, moderate education levels, and large households including children and seniors, ranking third in WTP. Recognizing these distinct cluster characteristics allows for the development of targeted interventions that address specific barriers and motivators within each consumer cluster, thus facilitating the adoption and integration of energy-efficient and sustainable built environment technologies in Taiwan.

Keywords: principal component analysis; k-means clustering; consumer characteristics; willingness-to-pay; green buildings.

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1. Introduction

The building sector and built environment in general contribute significantly towards global energy consumption and greenhouse gas emissions [1, 2]. Residential buildings specifically account for 39% of total electricity consumption in the United States and up to 68% of total building energy use in Europe [3, 4], most of which is driven by household electrical appliances and plug loads [3]. As climate change and energy efficiency concerns rise globally, sustainable buildings and appliances have gained increasing importance. In this context, understanding consumers' willingness to pay (WTP) for sustainable products such as green buildings, energy-efficient appliances (EEAs), and renewable electricity is essential for advancing sustainability goals within the built environment. While prior research has examined factors influencing WTP across different countries and sectors, there remains

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a need to uncover the underlying unique characteristics that shape these preferences within different consumer clusters.

Numerous studies across different contexts have explored the complex and multidimensional factors shaping WTP for green buildings. Li et al. [5] examined urban residents in five Chinese cities and identified gender, income, and education as key factors. Individuals with higher education levels tended to rely more on product understanding than on external pricing cues, and government subsidies significantly raised WTP for certified green housing. Psychological and social factors such as peer pressure and perceived risks also played a substantial role. Ofek and Portnov [6] found that informed homebuyers in Israel were more willing to pay a green premium (9.25%) compared to less informed buyers (7.74%). Huang [7] established that that consumer perception and attitude directly and indirectly affect WTP in Taiwan, driven largely by educational and promotional efforts. Chau et al. [8] revealed that energy conservation was a top priority for both green and conventional homeowners in Hong Kong. Golbazo et al. [9] surveyed university students in green dormitories, noting high satisfaction with comfort and study environments but a limited intention to choose green housing in the future. However, students with more environmental knowledge displayed higher WTP, underscoring the role of education. In Sweden, Zalejska-Jonsson [10] found that consumers were willing to pay more for buildings with very low energy use, with a 5% premium considered rational.

The body of research on EEAs reveals similar complexities. Park and Woo [11] established that consumer demand for EEAs in South Korea is sensitive to energy prices and that rebate structures must be responsive to market changes. In China, Wang et al. [12] observed that consumers were willing to pay 12.31% more for level-2 and 33.43% more for level-1 energy-efficient appliances, driven by income, education, and environmental awareness. Honga et al. [13] found that consumers were willing to pay more for top-efficiency models, with energy efficiency as the dominant decision factor. Li et al. [14] echoed these results, noting that environmental concern, knowledge, and perceived behavioral control were more influential in shaping WTP than subjective norms. These studies highlight that while economic factors like price and rebate schemes matter, trust, internal motivations, and contextual awareness are equally critical.

Consumers' WTP for renewable electricity has also been extensively studied, revealing wide variations influenced by factors such as valuation methodologies, energy types, socio-demographic characteristics, and cultural factors. Ayodele et al. [15] found that people were willing to pay 5-10% more for renewable electricity in Nigeria, influenced by income, education, age, and awareness. Roe et al. [16] found that U.S. consumers were willing to pay premiums for electricity sourced from renewables that reduce air pollution, while Bollino et al. [17] identified age, gender, education and inaccurate knowledge about renewable energy as some of the factors influencing WTP. Guo et al. [18] also found that the main factors affecting the WTP for renewable electricity in China included knowledge, attitude, income and nature of the payment vehicle, with higher WTP observed for a mandatory payment vehicle.

Although some factors influencing willingness to pay (WTP) show consistent patterns across different countries, it remains essential to investigate the unique characteristics of specific populations. Building on the extensive literature, this study focuses on the context of consumers in Taiwan. Consumers are grouped according to key socio-demographic, psychographic, and cognitive factors, using principal component analysis (PCA) based clustering. By identifying these consumer clusters, the study aims to uncover the underlying characteristics that influence WTP more for sustainable built environment technologies. This is essential for different built environment stakeholders to develop targeted incentives, communication strategies, and product offerings that align with the diverse moti-

vations and constraints of different groups of Taiwanese consumers. Ultimately, this can contribute to enhancing the adoption of green buildings and associated energy-efficient purchases, thus advancing Taiwan's sustainability goals in the built environment.

2. Research methodology

In this study, a structured web-based survey was designed and distributed across Taiwan to collect data on consumer characteristics and their willingness to pay a 10% premium for green buildings, energy-efficient air conditioners, energy efficient washing machines, and renewable electricity. The selection of these items was motivated by the growing global and national emphasis on reducing energy consumption and emissions in the built environment. These products have a significant environmental impact and they can also reflect varying levels of consumer commitment to sustainability within the built environment. A 10% premium was selected across all products since it is a noticeable but not prohibitive price increase commonly used to test consumer WTP in many studies [19, 20].

The structured web-based survey included questions on demographic factors (gender, age, educational level, income, and household size, number of children in household, number of seniors in household), cognitive factors (objective environmental knowledge and self-assessed environmental knowledge), and psychographic factors known to influence pro-environmental behavior (environmental awareness and environmental attitude), as listed in Table 1. These factors were selected based on their frequent adoption in WTP studies related to sustainability in the built environment. Socio-demographic factors were included to explore how personal background influences environmental decisions. Cognitive factors were considered to capture the role of information on and understanding

Table 1. Summary of factors investigated in the study

	Factor	Abbreviation	Scale
Socio-demographic	Gender	Gender	Male/Female
	Age	Age	18 to 29; 30 to 44; 45 to 59; > 59
	Education level	Edu	Below university; Bachelor's; Masters; Doctorate
	Income	Inc	< NT$50,000; NT$50,001 - 100,000; NT$100,001 - 200,000; > NT$200,000
	Household size	H_Size	1; 2; 3; 4; > 4
	Number of children in household	Child	0; 1; 2; 3; > 3
	Number of seniors in household	Senior	0; 1; 2; 3; > 3
Cognitive	Environmental knowledge	K	1 to 5
	Self-assessed environmental knowledge	K_Self	1 to 5
Psychographic	Environmental awareness	EA	1 to 5
	Environmental attitude	AT	1 to 5
	Willingness to pay	WTP	1 to 5

of environmental sustainability concepts in shaping consumer decision-making, while psychographic factors were incorporated to reveal internal motivations, values, and attitudes. The survey questionnaire is shown in Appendix A. It was distributed through social media platforms and the data obtained was processed to eliminate any incomplete responses. Principal component analysis was then performed to reduce dimensionality of the data. The resulting principal components were subsequently used as input for k-means clustering to identify different consumer clusters. The elbow method was used to determine the optimal number of clusters. After clustering, each group was profiled by examining the socio-demographic, cognitive, and psychographic characteristics associated with its members. This allowed for the identification of distinct consumer cluster characteristics. The study flowchart is illustrated in Fig. 1.

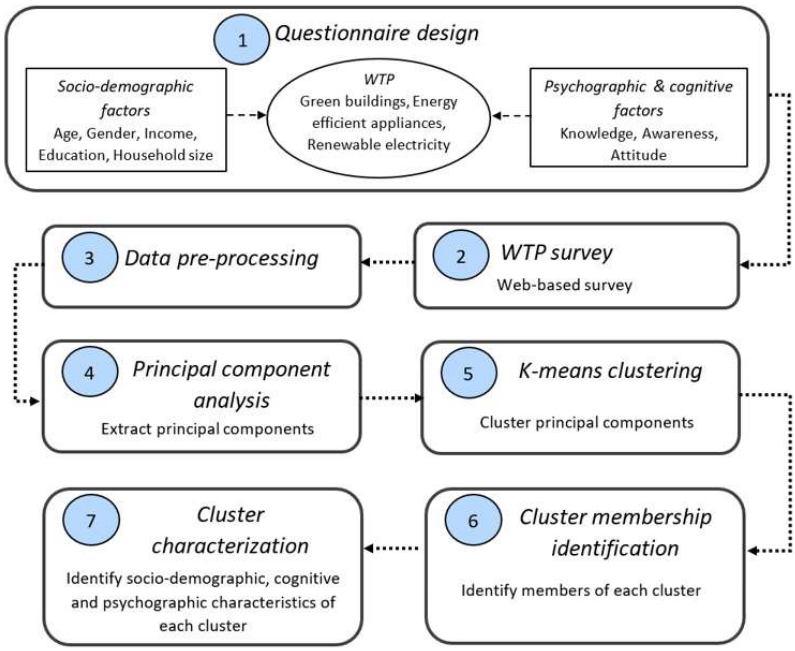


Figure 1. Study flowchart

3. Results and discussion

3.1. Cluster analysis results

A total of 554 responses were collected and 240 valid responses (43.3%) were retained for analysis, after filtering out incomplete responses and those with unrealistic time taken to complete the survey. The socio-demographic breakdown of the responses is shown in Fig. 2. The majority of respondents were male (60% male and 40% female). The average age of respondents was 37.22 years, with a standard deviation of 9.27 years, and 65% of the respondents had attained at least a bachelor's degree. Most of the respondents had incomes within the < NT$50000 level (34%) and the NT$50000 - NT$100000 level (41%). The average household size was 3.10 people, with a standard deviation of 1.20. Most households had no children, with a mean score of 0.23 and a standard deviation of 0.54. There was a higher prevalence of seniors above 65 years old, with a mean score of 0.63 and a standard deviation of 0.63, indicating a significant proportion of households with elderly members. The distribution of household sizes was spread out between 1 to > 4, with 33% living in a 3-person household.

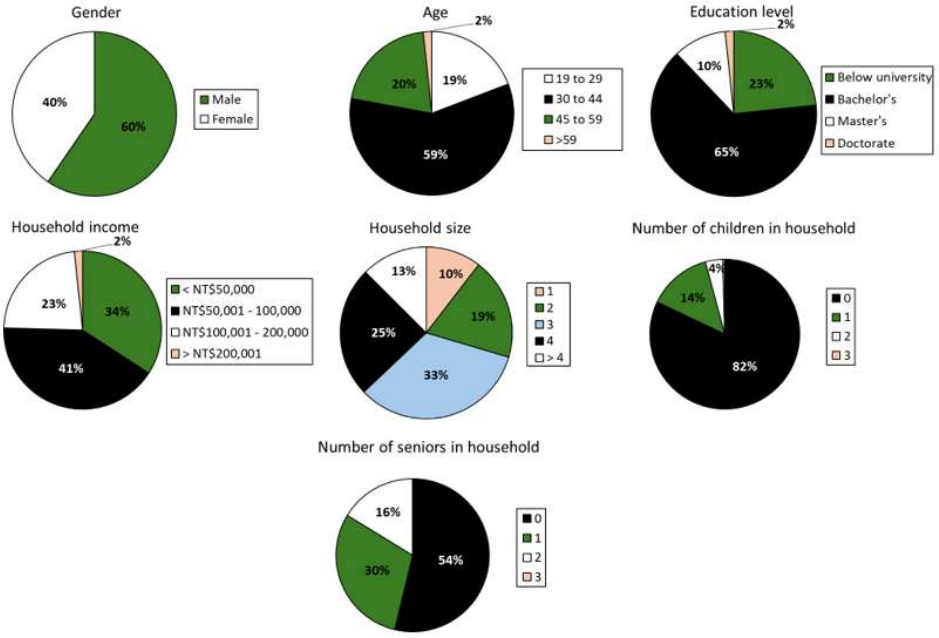
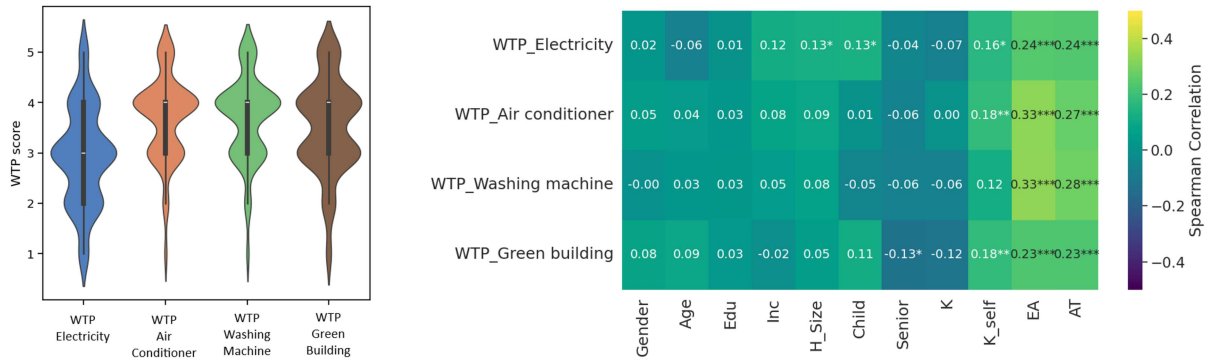


Figure 2. Demographic characteristics of the respondents



(a) WTP scores

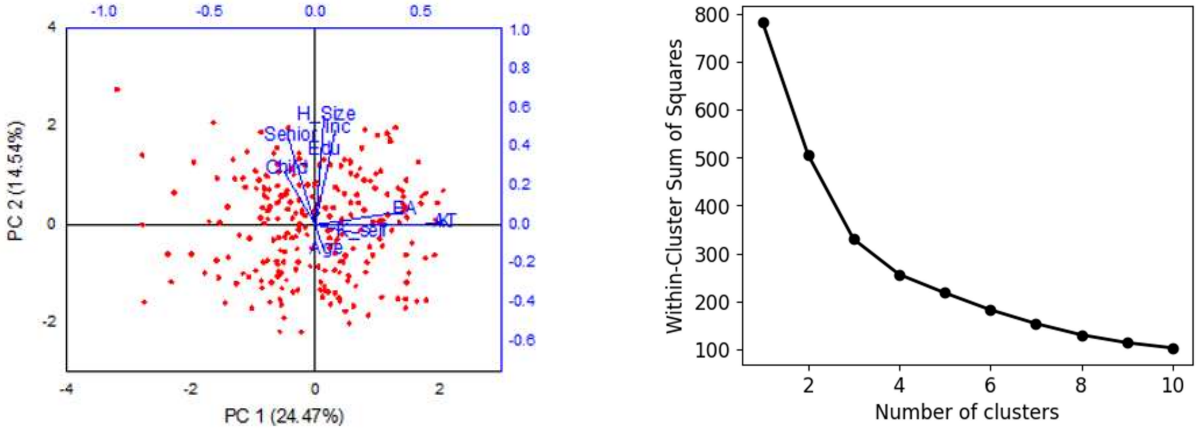
(b) Correlation coefficients

Figure 3. WTP scores and correlation coefficients

Fig. 3 presents the WTP results for all the survey participants. The respondents' willingness to pay a 10% premium for green buildings, energy-efficient air conditioner, energy-efficient washing machine, and renewable electricity is shown in Fig. 3(a). The WTP for renewable electricity was the lowest among the four items investigated, with a mean score of 2.95 and a standard deviation of 0.91. The distribution was relatively symmetrical, with the mean and median scores being close. The mean WTP score for an energy efficient air conditioner was 3.70, with a standard deviation of 0.90. The WTP for washing machines was similar to that of the air conditioner, with a mean score of 3.70, and a standard deviation of 0.90. The WTP for green buildings was slightly less than the energy efficient appliances, with a mean score of 3.52 and a standard deviation of 0.90. When the entire sample was analyzed before clustering, the spearman's correlation coefficients in Fig. 3(b) indicate that psychographic factors, particularly environmental awareness and attitudes, have the strongest and most consistent positive correlations with willingness to pay a 10% premium for all four items. Self-evaluated knowledge also positively influences WTP, while objective knowledge does not. Socio-

demographic factors have minimal impact, with only household size and presence of seniors showing weak correlations.

All variables were standardized to z scores and principal component analysis was conducted. The PCA biplot in Fig. 4(a) illustrates the contribution of the socio-demographic, cognitive, and psychographic factors to variations in WTP. The two principal components together explain 39.01% of variation, 24.47% by PC1 and 14.54% by PC2. PC1 represents a dimension of cognitive and psychographic factors, as indicated by the strong positive loadings of variables such as environmental knowledge (K), self-assessed knowledge (K_self), environmental awareness (EA), and environmental attitude (AT). These variables cluster together and point strongly in the same direction, suggesting that participants with high PC1 scores are more knowledgeable, aware, and hold more favorable attitudes toward sustainability-related issues. On the other hand, PC2 reflects a socio-demographic dimension. Variables such as income (Inc), education (Edu), and household size (H_Size) have strong positive loadings on PC2. The elbow plot in Fig. 4(b) was used to determine the appropriate number of PCA clusters, with the elbow visible at 4 clusters. K-means clustering of the principal components was performed, achieving a silhouette score of 0.35. While this value suggests that the clusters are not perfectly separated, it still reflects a reasonable level of cohesion and separation among the clusters. The four distinct clusters are shown in Fig. 4(c).



(a) PCA loadings

(b) Elbow plot

(c) K-means clusters of principal components

Figure 4. PCA clustering results

Table 2 shows the characteristics of each cluster. Cluster 1 is predominantly male (79.1%), with the oldest mean age (39.67), although the age difference between the four clusters is quite small. This cluster has the lowest income, with almost all individuals earning less than NT$50,000. It also has the lowest education levels and most individuals have not attained a university degree. They live in smaller households with few children and seniors. Cluster 1 has the lowest scores in environmental knowledge, self-assessed knowledge. This cluster appears to be constrained by both educational and financial resources, thus their WTP a 10% premium is the lowest among the 4 clusters.

Table 2. Cluster characteristics

Factor	Indicator	Cluster 1 N = 43	Cluster 2 N = 68	Cluster 3 N = 69	Cluster 4 N = 60
Gender	Male	34	45	39	25
	Female	9	23	30	35
Age	Mean (SD)	39.67 (10.65)	37.15 (10.20)	36.39 (8.18)	36.48 (8.14)
Inc	Mean (SD)	1.12 (0.32)	1.82 (0.73)	1.93 (0.69)	2.60 (0.62)
	< NT$50000	38	24	19	1
	NT$50001 to NT$100000	5	33	36	25
	NT$100001 to NT$200000	0	10	14	31
	> NT$200001	0	1	0	3
Edu	Mean (SD)	1.44 (0.50)	1.71 (0.57)	1.99 (0.45)	2.37 (0.61)
	Below university	24	24	8	0
	Bachelor's	19	40	54	42
	Master's	0	4	7	14
	Doctorate	0	0	0	4
H_Size	Mean (SD)	2.33 (0.92)	2.57 (1.16)	3.71 (0.97)	3.53 (0.93)
Child	Mean (SD)	0.12 (0.32)	0.03 (0.17)	0.54 (0.78)	0.17 (0.38)
Senior	Mean (SD)	0.37 (0.58)	0.19 (0.47)	1.20 (0.76)	0.63 (0.69)
K	Mean (SD)	2.26 (1.14)	3.35 (0.97)	2.81 (1.19)	3.55 (1.11)
K_self	Mean (SD)	2.53 (0.59)	3.10 (0.72)	2.59 (0.69)	3.20 (0.73)
EA	Mean (SD)	3.54 (0.26)	3.80 (0.34)	3.49 (0.29)	3.92 (0.29)
AT	Mean (SD)	4.10 (0.41)	4.43 (0.40)	3.99 (0.44)	4.57 (0.35)
WTP					
Green building	Mean (SD)	3.33 (0.92)	3.57 (0.95)	3.42 (0.86)	3.72 (0.96)
Electricity	Mean (SD)	2.63 (0.90)	2.94 (0.93)	2.90 (0.96)	3.25 (1.02)
Air conditioner	Mean (SD)	3.40 (0.88)	3.72 (0.77)	3.59 (0.81)	4.02 (0.75)
Washing machine	Mean (SD)	3.47 (0.91)	3.72 (0.79)	3.52 (0.82)	4.03 (0.74)

Cluster 2 also comprises of 66.2% male and 33.8% female respondents, which is closer to the 60% to 40% overall gender ratio of the sample. This cluster has a slightly younger mean age (37.15) than Cluster 1, and a more balanced income distribution, with a substantial proportion falling into the NT$50,001-NT$100,000 range. Cluster 2 is more educated than Cluster 1, with most individuals

holding a bachelor's degree. They also live in households with very few children or seniors. This cluster has the second highest scores in environmental knowledge (K = 3.35) and awareness (EA = 3.80) and attitude (AT = 4.43). As a result, it has the second highest WTP scores and appears more willing to pay more for green buildings, renewable electricity and energy efficient appliances than Clusters 1 and 3.

Cluster 3 has the youngest average age (36.39), and a gender distribution of 56.5% male, 43.5% female, which is also close to the overall gender distribution ratio. This cluster has the largest mean household sizes (3.71), number of children in household (0.54) and number of seniors in household (1.20), indicating a more family-oriented demographic. Although their income and education levels are relatively similar to Cluster 2 with most individuals having attained a bachelor's degree, their knowledge, environmental awareness, and attitude are lower (K = 2.81, EA = 3.49, AT = 3.99). Consequently, their WTP a 10% premium is higher than Cluster 1 but lower than Cluster 2 and Cluster 4. This cluster appears to be more influenced by household considerations.

Cluster 4 consists of significantly more females than males (58.3% female, 41.7% male), despite the higher overall number of males in the sample. This cluster has the highest income, with most individuals earning between NT$100001 to NT$200000. They also have the second-largest average household size, and the highest education levels with every individual having attained a bachelor's degree or above. A notable number of individuals have also attained postgraduate degrees (14 with master's and 4 with doctorates). This cluster has the highest scores in environmental knowledge (K = 3.55), self-assessed knowledge (K_self = 3.20), awareness (EA = 3.92), and attitude (AT = 4.57). Their WTP was the highest across all products examined. Cluster 4 represents an environmentally conscious and financially well-off demographic, willing to spend more on environmentally friendly purchases.

Based on these distinct characteristics, policy makers and green product marketers can develop specific strategies to enhance WTP in each cluster. Cluster 1 may benefit from financial incentives such as subsidies and educational programs to increase environmental awareness, while Cluster 2 could be motivated by promotional offers on green products to reduce costs and reinforce their environmental values. For Cluster 3, family-oriented incentives like household energy-saving rebates may be effective, whereas Cluster 4 could be encouraged through premium green financing options and access to high-end sustainable products.

3.2. Comparison between correlation analysis and cluster analysis

The clustering results offer a deeper and more practical understanding of willingness to pay (WTP) a 10% premium for green buildings, and associated energy-efficient purchases in Taiwan. While correlation analysis also shows that psychographic factors such as environmental awareness, attitude, and self-assessed knowledge positively correlate with WTP, it treats the sample as a single group thus missing the variability among individual groups. Correlation analysis indicates that socio-demographic characteristics have minimal overall influence overall, with a few weak correlations between WTP and household size and presence of seniors. In contrast, clustering identifies distinct subgroups with unique combinations of traits that influence their WTP differently. For example, Cluster 4, with the highest education, income, and environmental knowledge, also has the highest WTP, while Cluster 1 with the lowest education, income, and environmental knowledge, has the lowest WTP. Clustering also reveals that household size and composition do influence WTP as observed in Cluster 3, which has larger average household sizes and lower WTP than similarly educated Cluster 2, a relationship not captured by correlation analysis. This underscores the advantages of cluster analysis over simple correlation analysis.

3.3. Limitations of the study

This study relies on data reported by survey participants, which may not be accurate since willingness to pay does not always translate to actual purchases. The results are also specific to Taiwan, which has a high-density built environment, provides energy efficiency incentives, and has developed proactive government policies aimed at promoting sustainable building practices and green building standards. The findings may not be applicable in other countries with varying levels of government support, and different urban densities, cultural motivations or economic conditions. Additionally, the sample may not be fully representative of Taiwan's population, which limits the generalizability of the findings. The study also shows relationships between consumer characteristics and willingness to pay, but it doesn't prove actual causality. Additional factors such as government policies were not considered, which could also influence consumers' choices. Future research integrating different methods, factors, and more diverse samples can build on these findings.

4. Conclusions

This study applied principal component analysis and k-means clustering to identify distinct socio-demographic, cognitive and psychographic characteristics influencing willingness to pay a 10% premium for green buildings, renewable electricity, and energy-efficient appliances among different clusters of respondents in Taiwan. Four clusters were identified, each with unique characteristics.

- Cluster 1 consisted mainly of older, lower-income males with the least education, smallest household sizes, and lowest environmental knowledge, resulting in the lowest WTP.

- Cluster 2 was moderately educated, with moderate income, small household size with few or no children, higher environmental knowledge, awareness, and attitude, and the second-highest WTP.

- Cluster 3 included family-oriented participants living in larger households with more children and an average of at least one senior in the household. This cluster had the second-lowest WTP.

- Cluster 4 was primarily comprised of females. It was the most educated and affluent, with the highest environmental knowledge and attitudes, leading to the highest WTP among all clusters.

These findings reveal the varying influence of socio-demographic, psychographic, and cognitive factors on WTP among different consumer clusters in Taiwan. They also highlight the novelty of combining PCA-clustered consumer segmentation with WTP analysis, which enables a more refined understanding of how different consumer profiles relate to sustainability preferences. The results can be used to identify specific targeted interventions to facilitate or accelerate the adoption of sustainable technologies within the built environment in Taiwan.

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Appendix A. Survey questionnaire

Demographic factors

1. Gender
   ☐ Male ☐ Female

2. How old are you?

3. What is your latest completed education level?
   ☐ Below university degree ☐ Bachelor's ☐ Master's ☐ Doctorate

4. What is the amount of your individual total monthly income?
   ☐ No income

□ < NT$50,000
□ NT$50,001 - 100,000
□ NT$100,001 - 200,000
□ > NT$200,001

5. Please write down the exact number of people living with you including yourself (friends, roommates, family members, etc.)

Environmental knowledge

1. What is sustainability?
   □ Using resources that have been around for thousands of years
   □ Recycling everything in the workplace
   □ Only using items made from natural products such as wood
   □ Preventing environmental damage that may impact on future generations
   □ Not using fossil fuels for everything
   □ I don't know

2. What is the BEST description of a sustainable city?
   □ Lots of playgrounds
   □ Designed for social, economic, environmental balance
   □ Livable wages
   □ Lots of green roofs
   □ Lots of electric vehicles
   □ I don't know

3. Which of the following creates the most greenhouse gas emissions?
   □ Beef □ Pork □ Potato □ Cabbage □ Chicken □ I don't know

4. Which of the following gases is not a greenhouse gas?
   □ Water Vapor □ Methane □ Nitrogen □ Carbon Dioxide □ Sulphur Dioxide
   □ I don't know

5. How does the greenhouse effect work?
   □ Greenhouse gases reflect the sun's energy, causing it to warm the Earth
   □ Greenhouse gases allow transmission of the sun's energy into the earth, but slow or prevent heat from escaping into space
   □ Greenhouse gases directly warm oceans and cause dramatic weather
   □ Oceans absorb greenhouse gases, which cause the Earth's temperature to rise
   □ Greenhouse gases absorb ocean's energy and reflect the heat into the atmosphere
   □ I don't know

Environmental awareness (1 = Strongly Disagree to 5 = Strongly Agree)

□ I consciously conserve water usage in my daily routines, such as taking shorter showers, turning off the faucet while brushing teeth, and watering plants sparingly.
□ I always sort recyclable items and place them in their respective bins, avoiding disposal in regular trash.
□ I prioritize purchasing products that are made from recycled materials or have environmentally

friendly packaging.
☐ I strive to reduce energy consumption in my home by using energy-efficient appliances and lights, and by turning off devices when they're not in use.
☐ I make an effort to understand and reduce my carbon footprint, considering aspects such as food consumption, travel, and home energy use.
☐ I often dispose of recyclable items directly in regular trash rather than sorting them into their respective bins.

Environmental attitude (1 = Strongly Disagree to 5 = Strongly Agree)

☐ Individuals have a personal responsibility to contribute to the conservation of the environment.
☐ The impact of climate change is severe and poses a significant threat to future generations.
☐ Governments should prioritize investments in renewable energy sources over traditional fossil fuels.
☐ Consumer decisions, such as purchasing eco-friendly products and reducing waste, can significantly influence the state of the environment.
☐ Strict environmental regulations are necessary to protect our natural resources and should be enforced more rigorously.

Willingness to pay (1 = Strongly Disagree to 5 = Strongly Agree)

☐ I am willing to pay for 10% premium for renewable electricity.
☐ I am willing to pay for 10% premium to purchase energy-efficient air conditioner.
☐ I am willing to pay for 10% premium to purchase energy efficient washing machine.
☐ I am willing to pay for 10% premium to purchase green building.