Capturing the Influence of Travel Behavior Factors on Energy Consumption - An Empirical Study

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Abstract. The transportation sector is a major contributor to global energy consumption and is responsible for significant carbon emissions. Understanding the behavioral factors that influence travelers' energy choices is crucial. This study, through an examination of individual cognitive traits, explores the rationale behind energy consumption choices and their alignment with environmental objectives, providing a novel perspective on sustainable development. To investigate these dynamic relationships, a questionnaire was designed to collect data, and a multiple linear regression model was employed for statistical analysis to reveal the impact of personal preferences and habits on travelers' energy choices. The results indicate that individuals are aware of the relationship between higher carbon-emitting energy sources and lower costs, influencing their willingness to incur higher costs to transition to environmentally friendly energy sources. This willingness is also influenced by external factors such as peer recommendations, mode of transportation choices, and planning habits related to energy usage. Furthermore, the study provides policy recommendations for government interventions based on statistically significant variables to encourage cleaner energy usage behaviors. Future research in behavioral science can explore more effective intervention methods through the dissemination of energy-related information. This research contributes to the field of behavioral studies, particularly in the context of sustainable development within the transportation sector.

Keywords: Travel choices, energy consumption, clean energy, interventions, travel habits, travel preferences.

1. Introduction

The transportation sector's significance as a major contributor to energy consumption is underscored by recent data from the International Energy Agency (IEA) for the year 2022. Global transportation emissions surpassed 8.4 billion tons, 23% of total carbon emissions [1]. Transport of China contributed 10.4% to the total emissions in 2022 [1]. Reducing carbon emissions in the transportation sector is one of the ways to achieve carbon neutrality. Promoting the use of new energy vehicles can contribute to sustainable mobility and environmental conservation [2]. The rise of power batteries and NEVs is transforming the energy landscape, with China leading the way, accounting for 63% of global NEV sales in 2022 [3]. These developments signify a significant leap towards sustainable transportation and hold promise in the fight against climate change.

In order to achieve the critical objectives of constraining global temperature increases and preventing uncontrolled climate change, it is imperative to make substantial reductions in greenhouse gas emissions. These emissions primarily originate from the combustion of fossil fuels within the transportation sector. As emphasized by Sperling and Gordon, addressing the challenges associated with attaining sustainability in the transportation sector necessitates a comprehensive approach that encompasses both vehicle choices and the transformation of energy sources [4]. The transition towards a sustainable paradigm in transportation entails the consideration of a multitude of factors, as proposed by Banister [5]. This encompasses a holistic evaluation of various facets, including transportation modes, energy preferences, and urban planning, among others. The central challenge lies in redirecting travelers' consumption patterns away from traditional gasoline vehicles towards electric vehicles (EVs). This transition is not solely a technological shift but also involves intricate behavioral aspects.

Recognizing the behavioral determinants that influence travelers' energy choices is of paramount significance. Delving into the rationale underpinning energy consumption decisions and their alignment with environmental goals, taking into account individual cognitive traits, offers a novel approach to sustainable development, as posited by Huebner et al. [6]. Individual decisions regarding energy choices may be subject to psychological influences, as Stern has articulated. Environmental behaviors are shaped by intricate psychological mechanisms [7]. Another facet considered in this study pertains to travelers' attitudes and external information. Gifford has postulated that individual decisions on energy choices may be influenced by their perceptions and attitudes towards the environment [8]. Understanding and influencing traveler behavior can promote eco-friendly transportation choices, reducing reliance on gasoline vehicles and encouraging clean energy adoption. Targeted interventions can enhance resource efficiency and drive sustainable transportation.

In this context, this research aims to capture the multifaceted influence of travel behavior factors on energy consumption. Deciphering the intricate web of choices made by travelers contribute to identifying the levers that can nudge these choices towards cleaner, more sustainable options. Through rigorous empirical analysis, this study provides insights and actionable recommendations that will contribute to the realization of a greener, more sustainable future.

2. Methodology

2.1. Experiment Design

This study focused its attention on individual decision-makers, specifically targeting travelers and daily commuters as the subjects of inquiry. These individuals possess the requisite travel experiences and needs to develop their distinct travel habits and preferences. To address latent biases stemming from the limited sample size (500), an online questionnaire was published on the Wenjuanxing platform (China). The objective of this survey was delving into the stated and revealed preferences from travelers with various characteristics.

The survey incorporated four distinct sections. The first part (A) aimed to elicit information on individual travel patterns, encompassing parameters such as commute duration, travel frequency, and the extent of detail in energy planning. This section comprised a total of ten questions. Part B employed a Likert scale format to present 20 questions, seeking to delve into the underlying factors that influence energy-related decisions (independent variables). These factors encompassed habits related to accessing energy information, levels of effort invested in energy planning, preferences regarding travel modes, and the assessment of energy options. Respondents were required to score each statement on a scale of 1 to 5, corresponding to the options of 'Strongly Disagree', 'Disagree', 'Neither Agree nor Disagree', 'Agree', and 'Strongly Agree'. Part C gathering revealed preferences data and offered two distinct travel energy scenarios. Participants were presented with information regarding three energy alternatives, including their associated prices and carbon emissions per mile (Table 1 and Table 2). Part D was dedicated to gathering socio-demographic factors from respondents and consisted of 11 questions related to gender, age, educational background, financial conditions, and employment status.

In summary, a multifaceted approach was developed to thoroughly investigate the underlying factors that influence decisions related to energy choices. This methodological framework seamlessly integrated both stated and revealed preferences, harnessing the capabilities of an online platform to adeptly accumulate information on travel decision-makers by country-ranged sampling.

Table 1. Transportation Energy Sources with Cost and Carbon Emissions (Version 1)

	Electricity	Gasoline 1	Gasoline 2
Carbon Emission/ mile	0 kg CO_2	1 kg CO_2	4 kg CO_2
Cost	$7	$4	$1

Table 2. Transportation Energy Sources with Cost and Carbon Emissions (Version 2)

	Electricity	Gasoline 2	Gasoline 1
Carbon Emission/ mile	0 kg CO_2	2 kg CO_2	3 kg CO_2
Cost	$5	$3	$2

2.2. Modeling

Multiple linear regression is a statistical analysis method used to examine the relationship between multiple independent variables and a continuous dependent variable. It allows for the simultaneous consideration of the impact of multiple independent variables on the dependent variable, aiding in a more comprehensive understanding of the complex relationships among these variables. By introducing multiple independent variables, multiple linear regression can assist in controlling potential confounding variables, leading to a more accurate assessment of the relationship between independent and dependent variables. In this study, multiple linear regression was employed to explore the influence of situational information, individual preferences, and travel habits on travel energy choices (Table 3), with socio-demographic factors treated as covariates to control for their impact on energy consumption decision (dependent variable).

Table 3. Regression Variables

Category	Factor	Variable Name
Scenario Information	Carbon Emission	Carbon Emission/ mile
Travel Preferences	Clean-Energy Preference	prfrc_clean
	Carbon-Footprint Reduction Effort	prfrc_efforts
	Energy-Information Preference	prfrc_info
Travel Habits	Transportation Choices	Trav_mode
	Information Source	Enrg_info
	Transport Energy	Enrg_Trspt

3. Results and Discussion

3.1. Socio-demographic

The surveyed population displays an equitable dispersion (Fig. 1), with the average age falling to the 41-50 age bracket. Females make up 48% of the sample, while males constitute the remaining 52%, ensuring a balanced demographic representation and mitigating potential selection bias.

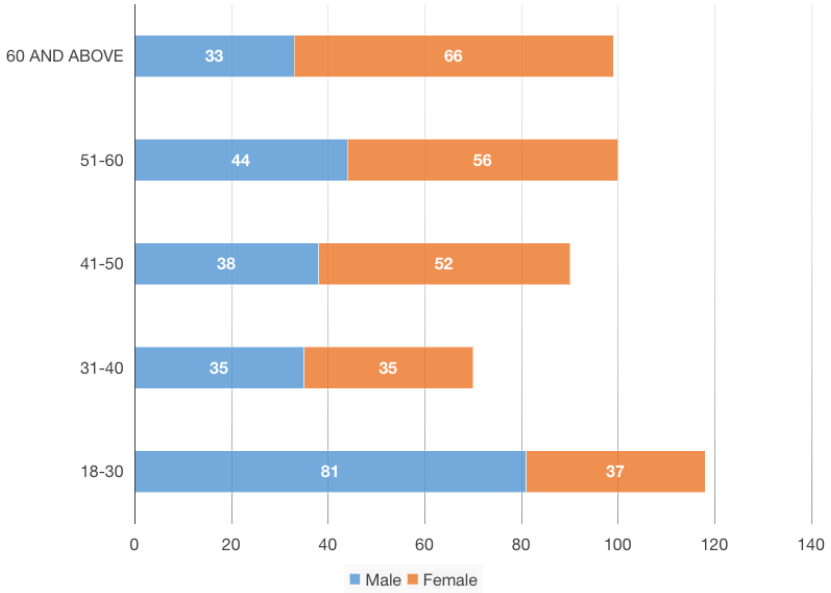


Figure 1. Age and Gender (Picture credit: Original)

In terms of educational attainment (Fig. 2), it is noteworthy that 25% of the respondents held doctoral degrees, while 22% did not possess formal educational certifications. The remaining educational categories exhibited fairly equal representation. This rich diversity in educational backgrounds within the sample, coupled with a well-distributed representation across various education levels, not only enhances the overall representativeness of the sample but also mitigates potential biases. This suggests that the research findings can be more broadly applicable and generalize effectively across diverse demographic segments.

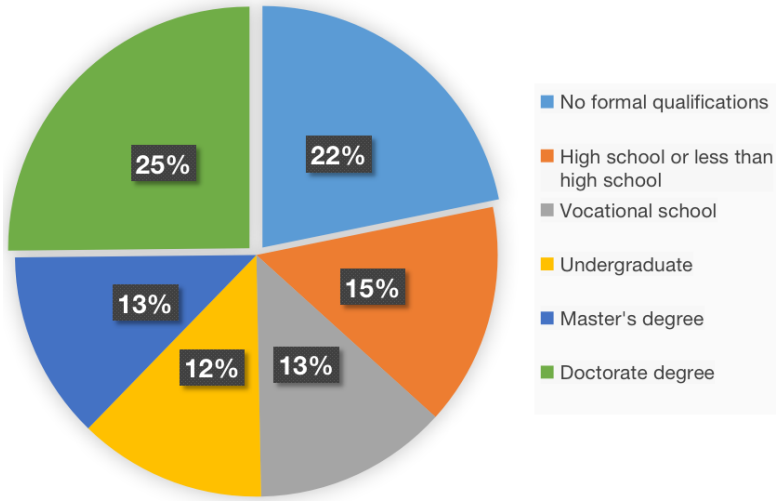


Figure 2. Education (Picture credit: Original)

Within the cohort of respondents (Fig. 3), individuals either holds part-time or full-time employment account for 49%, as indicated by the semicircle with red margin. The prevailing professions among these employed respondents include service personnel (18%), freelancers (18%), and company employees (17%). The adequate proportion of employed individuals within the sample presents a valuable opportunity to delve into the intricacies of travel decision-making, particularly among those with daily commuting obligations. Careful attention has been devoted to maintaining a balanced distribution of professions, assuring the sample's representativeness across various occupational categories.

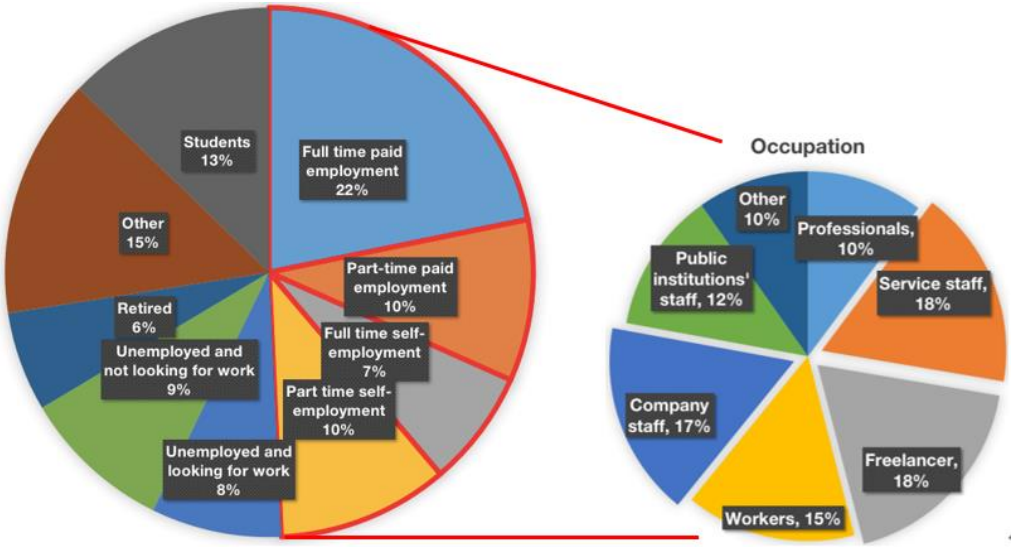


Figure 3. Employment Status (Picture credit: Original)

When examining income levels among the respondents (Fig. 4), it becomes evident that there exists a diverse and well-distributed range of incomes. This distribution implies low risk of bias regarding spending power within the sample. Consequently, it helps to mitigate concerns about varying cost-sensitivity among respondents.

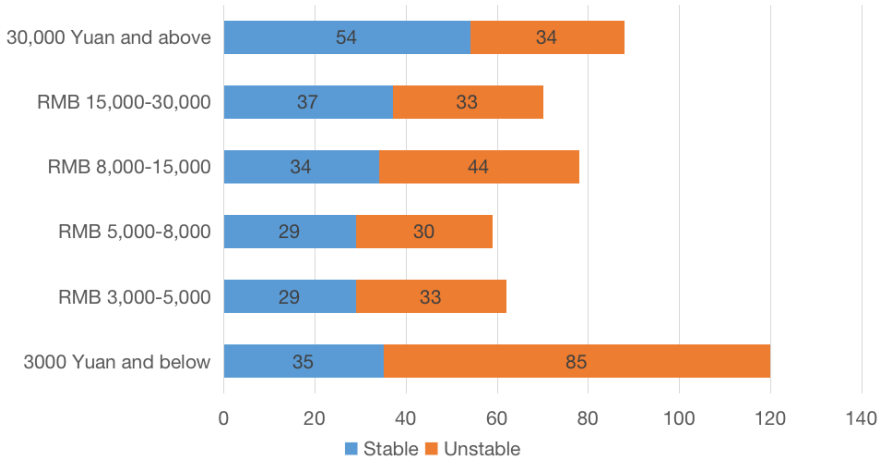


Figure 4. Monthly Income Distribution (Picture credit: Original)

The sample of this questionnaire exhibits an even distribution of socio-demographic factors. While these factors may have potential impacts on travel energy usage, they are not the primary focus of this study. Therefore, they are included in the regression model as covariates to control for their influence on the dependent variable (energy choice).

3.2. Personal Habits

Analysis of Variance (ANOVA) was used to investigate the differences in stated habits with respect to C1 and C2 (dependent variables), representing the choices of three different transportation energy sources in the first and the second scenarios (versions). Results with statistical significance are presented, indicating that respondents in different option groups exhibited variations in energy selection.

The single-choice query presented as, 'How do you typically make transportation selections?' with available options: prioritizing environmental friendliness [1], selecting the most economical option [2], choosing the most convenient mode [3]. As detailed in Table 4, varying transportation choice patterns exhibited substantial distinctions at the 0.01 significance level concerning energy consumption decisions. A reasonable deduction is that habits pertaining to the prioritization of distinct energy source characteristics substantially shape energy utilization behaviors.

Table 4. ANOVA Result on Transportation Choices Habits Responses

	Q2 (mean value ± SD)			F	p
	1.0	2.0	3.0		
C1	1.94±0.86	2. 19±0.77	2.52±0.65	6. 179	0.003**
C2	2.00±0.75	2. 10±0.79	2.50±0.76	5.204	0.007**

Note: * p <0.05, ** p <0.01

The single-choice question gauging information source habits was presented as: 'How do you typically access information regarding transportation energy?' featuring choices, smartphone applications, newspapers, television news, gas station price listings, and inquiring with others [1-5]. Table 5 underscores that disparate information source habits showed notable disparities at the 0.05 significance level in the context of choices for the first and second scenarios. Consequently, respondents with diverse habits in utilizing information sources exhibited markedly distinct behaviors in energy source acquisition.

Table 5. ANOVA Result on Information Sources Responses

	Q6 (mean value ± SD)					F	p
	1.0	2.0	3.0	4.0	5.0		
C1	2.09±0.73	2.05±0.74	2.15±0.80	1.79±0.89	1.89±0.83	2.363	0.034*
C2	1.96±0.82	2.10±0.83	1.85±0.69	2.21±0.80	2.28±0.83	2.190	0.049*

Note: * p <0.05, ** p <0.01

Concerning the single-choice inquiry, 'Do you usually formulate a plan for energy usage?' offering selections: comprehensive planning [1], basic planning [2], infrequent planning [3], and dependence on prevailing disposable income [4]. Table 6 reveals that distinctive energy planning routines manifested considerable variations at the 0.01 significance level for the initial and secondary energy source preferences. This implies that respondents with dissimilar practices in terms of the frequency and precision of energy usage planning demonstrated markedly dissimilar energy planning tendencies.

Table 6. ANOVA Result on Energy-Planning Responses

	Q 7 (mean value ± SD)					
	1.0	2.0	3.0	4.0	F	p
C 1	1.98±0.86	2.12±0.80	2.06±0.77	2.38±0.75	7. 163	0.008**
C 2	2.00±0.75	2.16±0.68	2.24±0.75	2.53±0.61	17.345	0.000**

Note: * p <0.05, ** p <0.01

3.3. Travel Energy Preferences

The questionnaire employed three statements to investigate preferences regarding acquiring energy information: A6: I always check the price of energy and adjust consumption accordingly; A7: I usually evaluate the carbon emission of available types of energy before making decisions; A8: I am very happy to follow the public welfare promotion on clean energy. All three of these statements signify a willingness to alter energy usage based on the information received. In this context, Likert Scale format was used, where respondents chose from the options 'Strongly Disagree', 'Disagree', 'Neither agree nor disagree', 'Agree', or 'Strongly Agree'., corresponding to 1, 2, 3, 4, and 5 respectively. As shown in the Fig. 5, respondents were categorized into two groups based on the questionnaire responses. Class 1, characterized by a tendency to agree with the three statements, stated a willingness to adjust energy sources after receiving new information, accounting for 52.5% of the surveyed population. Class 2, constituting the remaining 47.5%, is characterized by 'Disagree,' indicating that they do not adjust their energy usage based on unfavorable information about energy.

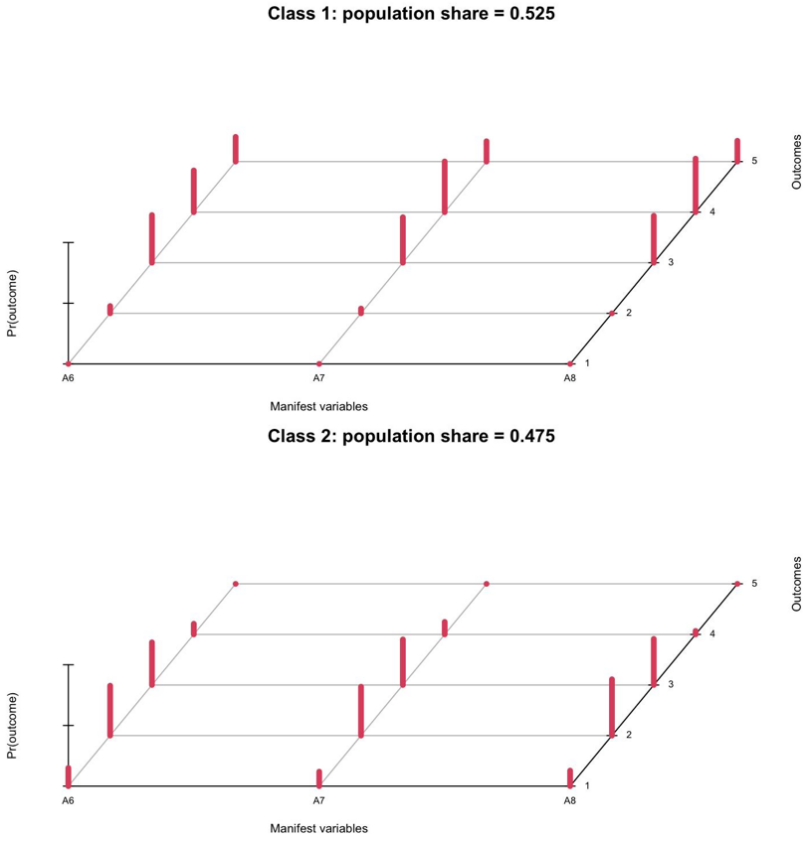


Figure 5. Clusters of Energy Information Preference (Picture credit: Original)

The part that investigated factors related to efforts in reducing one's carbon footprint, incorporated four statements: A9– 'Consistently opting for the cleanest energy source', A10– 'Regularly calculating the carbon footprint of travel', A11– 'Meticulously considering all energy information (price and carbon emissions) before selecting an energy source', and A12– 'Expressing dissatisfaction with unnecessary energy consumption during travel'. These statements collectively indicate a commitment to environmentally friendly and efficient energy usage through improved planning. Efforts in this context manifest across two dimensions: selecting the most suitable option and averting uncertainties. Respondents employed the Likert Scale format to respond to these four questions, choosing from 1 to 5 to convey their personal inclinations. As depicted in the Fig. 6, the sample was categorized into two distinct classes based on responses. Class 1, constituting 52.6% of the participants, is characterized by a clear 'Disagree' stance, indicating a lesser inclination to exert efforts in planning. On the other hand, Class 2, representing 42.1%, exhibits an 'Agree' disposition, signifying a greater propensity for planning efforts. Given that the [3]: 'Neither agree nor disagree' option does not convey a definitive stance, it can be effectively discounted. This implies that Class 2 respondents are more willing to invest additional effort in planning, while Class 1 demonstrates the opposite inclination.

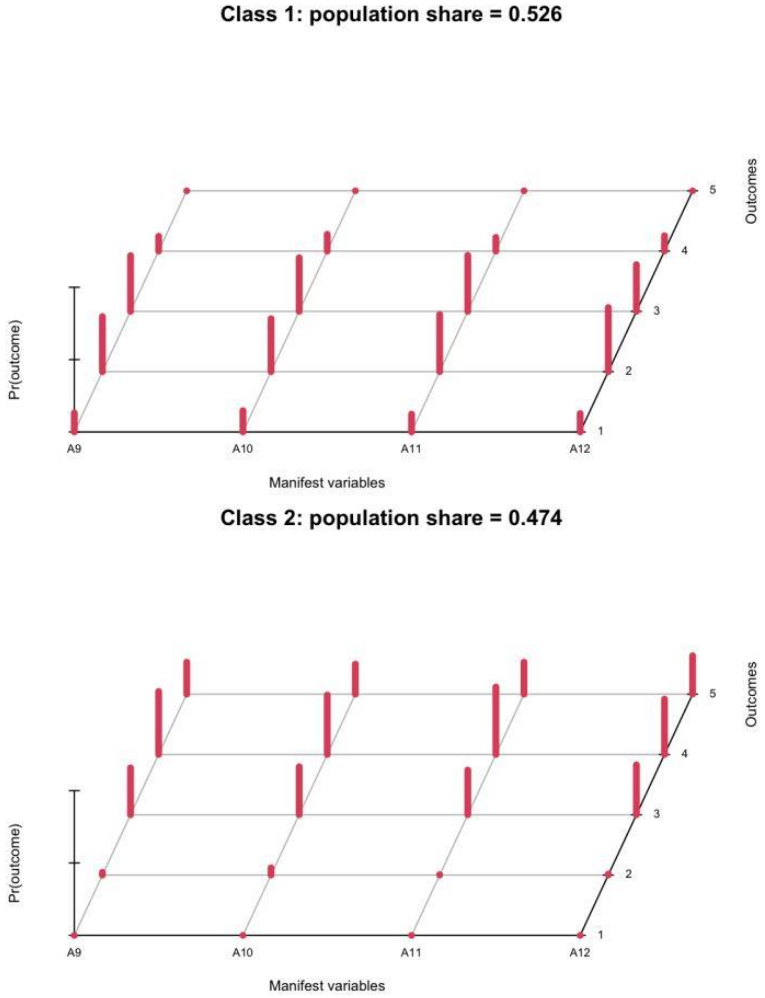


Figure 6. Clusters of Carbon-Footprint Reduction Efforts (Picture credit: Original)

Regarding preferences for clean energy, the survey incorporated three statements: A18– 'Having a preference for energy sources that minimize my carbon footprint', A19 – 'Favoring eco-friendly modes of transportation, such as electric cars and bicycles', and A20– 'Experiencing guilt over emitting exhaust fumes'. The same Likert Scale format and response options were applied to all three statements. These statements signify a preference for adopting clean energy practices. As illustrated

in Fig. 7, responses in Class 1 (57.9%) are predominantly distributed across [2] and [3], showing hesitating to utilize clean energy or neutral stances, while Class 2 (42.1%) exhibits the opposite trend.

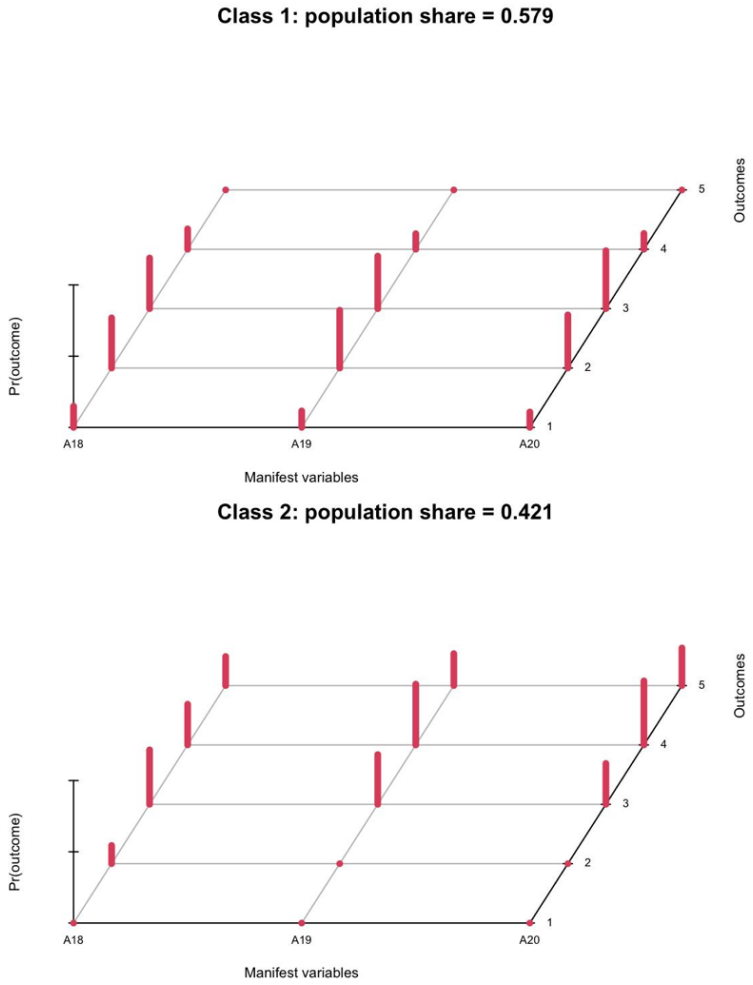


Figure 7. Clusters of Clean-Energy Preference Data (Picture credit: Original)

3.4. Modeling

3.4.1. Modeling results

The results of the model (see Table 7) indicate that certain factors, namely Carbon Emission per mile (Carbon Emission/mile), preference for information sources (prfrc_infol2:1), habits on transportation choice (Trav_mode2:1, Trav_mode3:1), Information Source (Enrg_info1:5, Enrg_info2:5, Enrg_info3:5, Enrg_info4:5), and Efforts on Energy-Planning (Enrg_plan4:1), have statistical significance, with p-values less than 0.05. Upon examining the coefficients, it is evident that these factors are inversely related to cost.

Table 7. Multifactor Linear Model Result with Dependent Variables (DV) and Covariates (CV)

Category	Variable Name	Variable Type	coef	p-value ($p < 0.05$)
Scenario Information	Carbon Emission/ mile	IV	-0.380	0.027
		CV	-0.383	0.027
Personal Preference	Prfrc_clean2:1	IV	-0.171	0.448
		CV	-0.193	0.395
	prfrc_efforts2:1	IV	0.314	0.184
		CV	0.273	0.253
	prfrc_info2:1	IV	-0.504	0.026
		CV	-0.486	0.034
Travel Habits	Trav_modee2:1	IV	-0.533	0.014
		CV	-0.552	0.012
	Trav_mode3:1	IV	-0.491	0.026
		CV	-0.492	0.031
	Enrg_info1:5	IV	-0.713	0.020
		CV	-0.751	0.021
	Enrg_info2:5	IV	-0.650	0.044
		CV	-0.702	0.040
	Enrg_info3:5	IV	-0.655	0.036
		CV	-0.713	0.027
	Enrg_info4:5	IV	-0.846	0.009
		CV	-0.902	0.008
	Enrg_info6:5	IV	-0.984	0.001
		CV	-1.092	0.001
	Enrg_Trspt2:1	IV	-0.057	0.749
		CV	-0.114	0.530
	Enrg_plan2:1	IV	-0.120	0.627
		CV	-0.206	0.428
	Enrg_plan3:1	IV	-0.360	0.165
		CV	-0.443	0.101
	Enrg_plan4:1	IV	-0.517	0.030
		CV	-0.594	0.018

To elaborate further, while all other factors remained constant, for every unit increase in Carbon Emissions, respondents exhibited a willingness to pay \$0.380 less. When the Energy-Information Preference transitioned from level 1 to level 2, signifying a readiness among consumers to seek energy-related information, they opted to pay \$0.504 less. A shift in Transportation Choice Habits from prioritizing environmental friendliness to selecting the most economical option resulted in a preference for a more cost-effective energy source (-\$0.533) [1, 2]. When Transportation Choice Habits transitioned from prioritizing environmental friendliness to prioritizing convenience, travelers gravitated toward a lower-cost alternative (-\$0.491) [1, 3]. As the Information Source shifted from Seeking advice from others to smartphone applications, newspapers, television news, and gas station price listings, the willingness on payment diminished by \$0.713, \$0.650, \$0.655, \$0.846, and \$0.984, respectively [1-5]. In terms of Energy-Planning (Enrg_plan4:1), shifting from a comprehensive plan to depending on prevailing disposable income resulted in a \$0.517 reduced willingness to pay for energy in comparison to individuals who consistently upheld high standards of energy planning accuracy [1, 4].

Moreover, independent variables with statistical significance exhibit more salient patterns in the model with covariates. Furthermore, Preference for clean energy (prfrc_clean2:1), preference for energy-planning (prfrc_efforts2:1), and Habits on transport energy (Enrg_trspt2:1) do not influence the willingness to pay for travel energy. In other words, these factors do not have significant relationship with the respondents' choice on energy choices.

The assessment of model goodness-of-fit encompasses the evaluation of several key indicators, including R-Square, Residual Standard Error (RSE), and Akaike Information Criterion (AIC). The

R-Square represents the proportion of variance elucidated by the model. For the model restricted to independent variables, the R-Square equals 0.1191. Remarkably, this figure closely mirrors the R-Square calculated for the model that incorporates both independent variables and covariates, amounting to 0.1151. This convergence underscores the absence of a significant advantage in terms of variance explanation between the two models. The RSE serves as a measure of the model's fitting error concerning the dataset. Specifically, the RSE value stands at 1.773, with 457 degrees of freedom for the model comprising solely independent variables. In contrast, the RSE value slightly increases to 1.777, with 446 degrees of freedom, for the model that integrates independent variables and covariates. These closely aligned values denote a resemblance in fitting errors between the two models. The AIC is employed to gauge the goodness of fit for two competing models while accounting for model complexity. In this context, the AIC value for the model featuring only independent variables amounts to 1916.543. This figure is notably lower than the AIC value recorded for the model encompassing both independent variables and covariates, which stands at 1929.08. Consequently, the model relying solely on independent variables exhibits a marginally superior performance in terms of AIC. To summarize, both models demonstrate akin performance in accommodating the dataset, with the inclusion of social factors as covariates yielding no substantial impact.

3.4.2. Discussion

The modeling findings reveal that individuals exhibit awareness of the inverse relationship between higher carbon-emitting energy sources and lower costs, thereby demonstrating an increased willingness to pay for energy when considering the adoption of environmentally friendly energy sources. This willingness is influenced by several factors, including recommendations from peers, transportation preferences, and energy usage planning habits. As highlighted in the comprehensive review conducted by Abrahamse et al., interventions targeted at household energy consumption encompass a wide array of strategies, encompassing information dissemination, social comparisons, and economic incentives [9]. The research outcomes associated with these interventions underscore their pivotal role in shaping individuals' energy choices.

Drawing from the model-derived results, the proposed interventions also encompass policy incentives, energy information dissemination, and public infrastructure development. These interventions aim to promote the development and widespread adoption of clean energy sources, while concurrently reducing reliance on conventional fossil fuels.

Customized government incentives should be implemented to optimize the allocation of public resources efficiently. This can be realized through mechanisms such as subsidies, tax exemptions, or reductions. As emphasized by Dwivedi, governmental authorities play a crucial role in driving the adoption of new energy sources [10]. Tax incentives and subsidy programs can effectively mitigate the costs associated with new energy technologies, thereby incentivizing individuals and businesses to embrace these innovative solutions. The implementation of these policies not only bolsters the competitiveness of new energy but also alleviates the financial burdens associated with energy transition, thereby propelling the development of clean energy solutions. The suggested incentives should be meticulously tailored to stimulate residents towards adopting a proactive approach to their energy planning. By rendering clean energy options more financially appealing, residents can be encouraged to develop a proclivity for clean energy sources.

Infrastructure development emerges as a critical catalyst in propelling clean energy adoption. As evidenced in the study conducted by Dill and Carr, the establishment of bicycle commuting facilities in major urban centers can substantially improve both preferences and habits associated with bicycle commuting, thereby offering a tangible illustration of promoting clean energy-powered travel [11]. To harmonize with residents' travel inclinations, it becomes imperative to fine-tune the prevalence and practicality of electric vehicle (EV) charging stations. This calibration ensures heightened accessibility and convenience for the community, ultimately incentivizing residents to transition towards cleaner modes of transportation. Augmenting the practicability of clean energy-driven

transportation endeavors to guide residents towards embracing sustainable and eco-friendly travel behaviors.

Public education and awareness campaigns should be systematically employed to impart knowledge to residents concerning energy-related matters, with particular emphasis on carbon emissions and clean energy alternatives. A nuanced understanding of residents' information sources and their awareness levels pertaining to energy-related issues is of paramount significance. Leveraging public platforms, these campaigns can serve as conduits for disseminating energy-related education and cultivating environmental consciousness. By elevating awareness levels and fostering informed perspectives among the public, these campaigns aspire to exert influence over residents' behavioral patterns and choices, nudging them towards cleaner and more sustainable energy alternatives.

In summation, the recommended interventions are meticulously designed to optimize public resource allocation efficiency, mold traveler behavior, and engender a propitious milieu for the development and adoption of clean energy sources. Tailored government incentives, infrastructural enhancements, and educational campaigns collectively constitute a formidable synergy that aims to mitigate dependence on traditional fossil fuels, while concurrently encouraging the utilization of clean and sustainable energy solutions.

4. Conclusion

Transportation's energy use is a global concern due to its impact on pollution, climate change, and resource sustainability. Understanding how personal travel habits influence energy choices is vital. This research, through surveys and data analysis, reveals key personal factors affecting transportation energy selection. Established habits significantly influence preferences due to their comfort and convenience, making them crucial for transitioning to cleaner energy. The source of energy-related information plays a pivotal role, with sources highlighting clean energy benefits shaping choices. Thoughtful energy consumption planning is also crucial in selecting energy sources. Individuals who strategically manage energy usage tend to embrace clean energy to reduce emissions and save costs. Clean energy awareness is significant, motivating people to accept higher costs for its environmental benefits. To promote environmental preservation and carbon reduction, governments should offer incentives, improve energy infrastructure, and enhance public education. In summary, this study provides insights and recommendations for emission reduction and sustainable transportation based on individual factors. To advance environmental preservation and carbon mitigation objectives, it is incumbent upon government authorities to tailor incentive mechanisms, bolster nascent energy infrastructure, and harness efficacious public educational platforms. In summation, this study proffers empirical insights and pragmatic recommendations germane to emission reduction and the sustainable evolution of the transportation sector, refracted through the lens of individual determinants.

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