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Flexibility justice: Exploring the relationship between electrical vehicle charging behaviors, demand flexibility and psychological factors

Wei-An Chen [a], Chien-Fei Chen [b,*], Stephanie Tomasik [c], Evangelos Pournaras [d], Mingzhe Liu [e]

[a] Department of Multidisciplinary Engineering, Texas A&M University, College Station, TX, USA
[b] Department of Sociology, Anthropology and Criminal Justice, Clemson University, Clemson, USA
[c] Department of Electrical Engineering, University of Tennessee, Knoxville, USA
[d] School of Computing, University of Leeds, Leeds, UK
[e] J. Mike Walker'66 Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA

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ABSTRACT

The adoption of electric vehicles (EVs) is transforming the landscape of energy consumption. While the technical and economic dimensions of EV adoption are increasingly well understood, the aspect of justice in demand flexibility remains underexplored. This study examines the complex relationship between flexibility in EV charging behaviors and the influence of socio-psychological and justice factors. We explore a range of demographic and social-psychological variables including charging anxiety, environmental concerns, perceived cost-saving perception, perceived privacy, and trust in utility providers. Our results reveal that these variables positively influence the changes in charging habits, including time-shifting and load-reduction. This study also uncovers disparities in charging behavior adjustments across various demographics groups. For instance, White respondents are more likely to charge their EVs during off-peak hours than their non-White counterparts and homeowners show a greater intention to reduce EV charging load during peak hours compared to renters. Additionally, high-income individuals exhibit a stronger willingness to shift charging times to off-peak, with White respondents within the high-income group being the most likely to reduce the amount of charging load during peak hours. Conversely, low-income White respondents are less inclined to make such adjustments. These disparities are likely tied to socioeconomic status, as more vulnerable groups often face greater constraints in adjusting their schedules. Therefore, it is imperative that policies prioritize flexibility justice by addressing the specific needs and behaviors of vulnerable groups, aiming to mitigate the additional burdens resulting from their limited flexibility.

1. Introduction

Recent research has made significant strides in understanding the technical and economic aspects of electric vehicle (EV) adoption [1,2]. However, there remains a notable gap in the literature regarding justice issues within demand flexibility. This gap is especially evident when considering EV charging behaviors and the challenges of equitable access. Demand flexibility, a vital element of a dynamic and responsive energy system, involves the capacity to modify energy consumption patterns [3,62,64]. This can mean changes in the timing, location, or intensity of energy use, including the shift from traditional fuels to electricity [4]. The factors influencing this flexibility are varied, encompassing accessibility [5], ingrained social practices [6], and broader energy-related concerns [7]. The current transportation system, heavily dependent on private vehicles, often intensifies social and economic inequalities [8]. Given this context, exploring the justice dimensions of demand flexibility is crucial. Moreover, marginalized and underserved communities often contend with higher energy expenses, restricted access to clean energy, substandard living conditions, and uneven infrastructure [9]. Through reducing electricity usage during peak times, these communities can help achieve a fairer distribution of energy resources, alleviating strain on disadvantaged groups and reducing energy costs for all [10,57]. However, despite its importance, the justice aspect of demand flexibility has been relatively neglected in discussions on energy systems, especially within the new technologies such as EVs. Addressing this oversight is crucial for policymakers and

* Corresponding author.
E-mail addresses: weian.chen@tamu.edu (W.-A. Chen), chienfc@clemson.edu (C.-F. Chen), zrd392@vols.utk.edu (S. Tomasik), e.pournaras@leeds.ac.uk (E. Pournaras), mingzhe37@tamu.edu (M. Liu).

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society, as variations in flexibility can significantly impact the equitable distribution of energy resources, raising concerns of energy justice. This calls for a deeper understanding of the implications when certain groups lack the flexibility to adjust their energy use.

While previous research has widely investigated aspects of EV adoption, including technological advancements [11,12,63], consumer preferences [13,14], policy incentives [15,16], and environmental impacts [17], the justice dimension in EV adoption has been comparatively overlooked. As the shift to EVs accelerates, understanding the factors that drive EV charging infrastructure and service demand becomes increasingly vital. Examining psychological dimensions such as attitudes, perceptions, and decision-making processes is foundational because these factors significantly affect when, where, and how often EV charging occurs, impacting the overall demand flexibility of the electricity grid [4,18].

This study aims to fill existing research gaps by exploring the complex relationship between sociological factors and EV charging behaviors. We aim to shed light on the challenges and opportunities of enhancing demand flexibility, focusing on justice to understand the behaviors of time-shifting and load-reduction. We investigate how disparities in EV charging behaviors concerning demand flexibility may differ among various income groups, ethnicities, and homeownership statuses, providing a holistic understanding of the demographic and social-psychological factors that shape demand flexibility in the context of EV adoption. This study contributes to a more equitable and socially just energy transition.

2. Literature review

2.1. Development and the importance of demand response and flexibility

Extensive research has delved into demand response (DR) and demand flexibility in energy consumption and management. Demand response [19] is a strategy aimed at modifying electricity consumption patterns in response to external signals, such as price fluctuations or grid conditions, to achieve a more efficient and sustainable use of energy resources [20,21,58,64]. It involves incentivizing consumers to adjust their energy consumption during peak demand periods or when renewable energy generation is at its highest. Demand flexibility, on the other hand, refers to the ability of consumers to adapt their energy usage patterns voluntarily, allowing for greater control over when and how they consume electricity [22,61,62,64].

Several previous studies have explored a range of factors that influence demand flexibility and demand response, including occupant behaviors [23,24,60], power grid dynamics [25,26,58,62], socio-demographic factors [21], and spatial-temporal assessments [27,59]. The importance of analyzing energy consumption patterns within the demand response framework is highlighted, focusing on the role of incentives, involved home appliances, technological advancements, and personal circumstances in influencing consumer choices regarding energy usage [5,28,60]. In particular, researchers have developed various modeling techniques and evaluation metrics to better understand and quantify demand flexibility [13,29,59,61]. For instance, Luo et al. [7] systematically reviewed residential building demand flexibility, including definitions, flexible loads, and quantification methods, emphasizing the distinction between demand, operation, and energy flexibility. Agbonaye et al. [27] developed a methodology to assess flexibility opportunities for spatial and temporal congestion management, ancillary services, and wind energy dispatch-down, incorporating a fairness framework and socio-demographic considerations. Munankarmi et al. [30] proposed a model linking energy efficiency measures like building envelope upgrades and smart appliances to demand flexibility via home energy management systems (HEMS), highlighting the potential energy savings, especially in homes with higher envelope efficiency. Stavrakas et al. [31] introduced a dynamic demand-side management model to overcome the limitations of existing models, focusing on the building sector.

The significance of demand response and flexibility in the contemporary energy landscape cannot be overstressed. As the world transitions toward cleaner and more sustainable energy sources, these concepts play a pivotal role in optimizing energy consumption, enhancing grid stability, and reducing carbon emissions [14,64]. Demand response and flexibility empower consumers to actively participate in shaping their energy usage patterns, contributing to a more efficient and resilient power grid [32,58,62]. Moreover, they facilitate the integration of renewable energy sources, which are inherently variable, by allowing consumers to align their electricity consumption with periods of abundant renewable generation. These strategies benefit individual households and businesses by potentially reducing energy costs and serve as a crucial tool for grid operators and policymakers to address energy challenges in a rapidly evolving landscape. The adoption of EVs has introduced new dynamics and challenges in the energy landscape [7,28,33,63], further reshaping the energy sector. These developments are transforming how energy is consumed and managed, offering new opportunities and complexities that require careful consideration. As we navigate these transformative changes, the continued research, development, and adoption of demand response and flexibility solutions remain paramount in ensuring a sustainable and reliable energy future [4,34,64].

2.2. EV demand flexibility

Demand flexibility within EV charging is paramount in comprehending the broader context of EVs' electricity consumption [63]. As the world rapidly transitions toward sustainable transportation solutions, the EV adoption surge presents unprecedented opportunities and challenges for our electric grid. Understanding how EV owners engage in charging behaviors such as time-shifting and load-reduction becomes crucial in harnessing the full potential of EVs as dynamic assets within the energy ecosystem [63]. Numerous previous studies have explored various aspects of EV charging behaviors and demand flexibility [35–37,63]. Quirós- Tortós et al. [38] conducted a comprehensive statistical analysis of the charging behavior of 221 residential EV users in the UK. The study revealed distinct patterns in charging behavior on weekdays and weekends. Specifically, their findings indicate that approximately 70 % of EVs connect once a day, consistently observed on both weekdays and weekends. The start charging time varies between weekdays and weekends, reflecting the UK residential load curve. Notably, over 70 % of EVs initiate their first connection when the state of charge (SOC) is between 25 % and 75 %. Moreover, about 65 % of EVs complete their first connection with a fully charged battery, and second connections typically occur with a higher SOC. These findings were then utilized to create stochastic, realistic, and detailed EV profiles, which are instrumental for conducting impact and smart grid-related studies.

A previous study [14] explored EV owners' motivations for adopting smart charging technologies in Norway's growing electric vehicle market. The research identifies four key drivers: safety concerns, technological curiosity, practical and economic benefits, and improvements in physical comfort. These motivations are essential to understanding how smart charging contributes to demand flexibility and grid optimization, making the findings relevant for policymakers and stakeholders in the energy transition. Sadeghianpourhamami et al. [24] previously investigated EV owners' charging habits and time patterns, shedding light on flexibility exploitation. Their notable contributions encompassed clustering EV charging behavior, assessing session characteristics influenced by weekdays and seasons, and proposing quantitative measures for flexibility evaluation. Nevertheless, it is imperative to acknowledge the conspicuous gap in the existing literature concerning demand flexibility, social factors, and demographic disparities, including race/ethnicity and income.

Table 1
Descriptive statistics of the demographics.

Demographics	Frequency (%)		Demographics	Frequency (%)	
	Within Sample	National		Within Sample	National
Income			Homeownership		
LIH (<$50,000/year)	37.5 %	36.5 %	Homeowners	55.9 %	65.4 %
MIH ($50,001–$99,999/year)	29.1 %	29.5 %	Renters	44.1 %	34.6 %
HIH (>$100,000/year)	33.4 %	34.0 %	EV Ownership		
			EV Owners	16.7 %	N/A
Race			Non- EV Owners	83.3 %	N/A
White	60.4 %	60.9 %	Age		
Non-white	39.6 %	39.1 %	Young Adult (18–37)	36.4 %	32.5 %
Gender			Middle Age (38–61)	38.1 %	38.9 %
Male	40.4 %	49.6 %	Elderly (62+)	25.5 %	28.6 %
Female	59.6 %	50.4 %			

2.3. Justice in EV flexibility and social-psychological factors

In the evolving landscape of energy systems and sustainability, justice has emerged as a critical and nuanced dimension, with a growing emphasis on energy systems, demand response, and occupants' behaviors [9,39,40,60], particularly concerning smart energy systems [3,61,64] and EVs. Ingvild Firman Fjellså et al. [41] explored the justice aspects of household electricity consumption in future smart energy systems. Their results revealed that individuals with low energy flexibility generally exhibit limited adaptability due to a lack of awareness of their own capacity for flexibility and a shortage of options to engage in flexible behaviors. For instance, individuals may struggle to adjust their energy usage patterns in response to fluctuating electricity prices or grid conditions, resulting in higher energy bills and potential discomfort due to inadequate heating or cooling. This inequality calls for energy justice initiatives to distribute the burden of flexible work more equitably. Further, the low availability of public charging stations, especially for renters, is a barrier for low-income households. Increasing access to public charging infrastructure may incentivize the adoption of low-cost, low-maintenance EVs for low-income households [42]. Moreover, concerns about the equitable distribution of EV charging infrastructure, especially in disadvantaged communities, are raised. Disparities in charging access underscore concerns regarding the exclusive or privileged characteristics of EV adoption. Critics argue that the current approach to transportation electrification may exacerbate existing inequalities, favoring higher-income individuals and specific communities [43,44]. The studies above indicate that addressing transportation equity and justice is crucial for ensuring EVs' inclusive and widespread adoption.

In examining the influence of psychological factors on EV adoption, it is evident that most studies have primarily focused on exploring the connections between anxiety, cost concerns, and EV charging behaviors. These investigations have certainly contributed valuable insights into the drivers and barriers associated with EV adoption, shedding light on the role of individual anxieties [36,42,43,63] and financial considerations [8,37,42] in shaping consumer choices. While anxiety and cost concerns are undeniably important facets of the psychological landscape surrounding EV adoption, they represent only a fraction of the intricate web of cognitive and emotional processes that influence decision-making.

It is essential to note that other vital aspects warrant attention in this context. Privacy and trust in the context of demand response, although not extensively studied concerning EV adoption, are significant factors that might influence consumer behavior and choices. Additionally, considering the broader socioeconomic factors and psychological considerations can provide a more comprehensive understanding of EV adoption and charging behaviors. While previous research has explored aspects of equity and justice in EV adoption, there remains a dearth of investigation into these dimensions, which presents an opportunity for future research to delve deeper into the nuanced interplay between psychological, economic, and social factors in shaping the EV landscape.

3. Purpose of the study

This study focuses on psychological factors like anxiety, privacy, environmental, and cost concerns. We undertake a comprehensive exploration of the intricate psychological domain influencing the adoption and usage patterns of EVs while also delving into the concept of justice in demand flexibility. This study is distinctive in incorporating socioeconomic factors and psychological considerations, providing an overall understanding of the multifaceted aspects of EV adoption and charging behaviors. Ultimately, we aim to enhance the understanding of equitable and just pathways during the energy transition. This study attempts to answer the following research questions:

1) Do EV ownership and the intention to purchase an EV significantly differ across demographics, such as various income groups and homeownership status?
2) Is there a significant relationship between EV charging behaviors and psychological factors, including charging anxiety, environmental concern, cost-saving perception, perceived privacy, and trust in utilities?
3) What disparities exist in psychological factors across demographics, including income levels, race, and home ownership?
4) Compared to higher income households, are LIHs less flexible in adjusting their charging behaviors, potentially causing the issues of injustice?

4. Methodology

4.1. Survey procedures

This study conducted an online survey ($n = 1196$) among residents in California in 2021, utilizing an internet-based questionnaire distributed through Qualtrics Paid Panel Service, a widely recognized online data collection platform for researchers. Our comprehensive survey covered a diverse spectrum of essential domains, with a primary emphasis on gaining insights into individuals' inclinations regarding adopting home energy management systems (HEMS) and their interest in purchasing EVs. Within the context of EVs, our investigation evaluated various facets of charging behaviors, including practices related to time-shifting and load-reduction, and closely examined their intricate relationships with an array of psychological factors, environmental concerns, and trust in utilities, etc., which are elucidated in detail in the forthcoming section of this study.

Furthermore, our inquiry extended to those who may become prospective EV owners, as we asked, “If you do not currently own an EV, how interested are you in purchasing one in the near future?” This effort allowed us to assess and analyze the intentions of potential EV purchasers and gain insights into occupants' charging behaviors across different demographics, including income levels, racial backgrounds, and homeownership status. Through this multifaceted examination, our research aims to illuminate the variations in charging behaviors among diverse individuals and emphasize the pressing issues of equity and flexibility justice within the broader context of EV adoption. By doing so, we hope to contribute valuable insights that can inform policy decisions and promote sustainable transportation practices.

4.2. Participants' demographics

The study surveyed 1196 respondents, revealing a balanced gender distribution, with 59.6 % identifying as women and 40.4 % identifying as men. The income distribution among respondents portrayed a multifaceted socioeconomic landscape. As shown in Table 1, the sample closely reflects the national composition across various demographics, while with slight differences. Although it generally represents the national demographics well, there are instances of over- or under-representation, notably in homeownership and age groups.

Although commonly used definitions, such as those from the U.S. Department of Housing and Urban Development, classify low-income households as those earning less than 80 % of the area median income, this study categorizes income levels based on relative differences within the sample rather than absolute thresholds. Accordingly, respondents were grouped into three distinct income brackets: Low-Income Households (LIH) at 37.5 % ($n = 449$), defined as those with an annual household income of $50,000 or less; Middle-Income Households (MIH) at 29.1 % ($n = 348$), defined as those with an annual income between $50,001 and $99,999; and High-Income Households (HIH) at 33.4 % ($n = 399$), defined as those with an annual household income of $100,000 or more. There was a diverse composition of homeowners and renters. A majority, 55.9 % of the sample, were homeowners, while renters constituted 44.1 %. Within the renter demographic, 61.5 % were categorized as LIH, 26.2 % were categorized as MIH, and 12.3 % were categorized as HIH. Conversely, in the homeowner demographic, 18.7 % were LIH, 31.4 % were MIH, and 49.9 % were HIH. The racial demographics in our sample closely mirror the national composition, with 60.4 % identifying as White and 39.6 % as Non-White. This aligns closely with the national proportion of 60.9 % White and 39.1 % Non-White. Regarding age, the majority (38.1 %) were middle-aged, ranging from 38 to 61 years old. Young adult participants (18–37 years old) accounted for 36.4 % of the group; another 25.5 % were older individuals aged 62 or above. This varied distribution suggests a representative cross-section of economic backgrounds that helps analyze different demand flexibility routines.

4.3. Procedure of measurement key variables

Two critical variables related to EV charging behaviors, including "time-shifting" and "load-reduction," as well as six variables from the perspective of psychological factors, including "charging anxiety," "environmental concern," "EV buying intention," "cost-saving perception," "perceived privacy," and "trust in utilities," are considered in this study to explore the impact of psychological factors on charging behaviors.

The selection of the six psychological variables is grounded in theoretical frameworks that are relevant to our research objectives, existing literature and the specific context of our survey. Each variable draws from established research indicating its significance in shaping attitudes and behaviors. "Charging anxiety," rooted in the Unified Theory of Acceptance and Use of Technology [45], reflects how anxiety impacts the adoption of new technologies like EVs. "Environmental concern", based on the New Ecological Paradigm and often associated with the Value-Belief-Norm theory, measures individuals' awareness of environmental issues and willingness to take action. "EV buying intention", also from the Theory of Planned Behavior [46], assesses the likelihood of purchasing an EV influenced by attitudes and subjective norms. "Cost-saving perception," grounded in economic theory [47], evaluates beliefs about financial savings from owning an EV. "Perceived privacy" considers privacy calculus theory [48], weighing benefits and risks of disclosing personal information in utility services and smart technology. Finally, "trust in utilities," based on social exchange theory [49], examines the role of trust in consumer-provider relationships and its impact on technology adoption. These variables collectively enable a comprehensive analysis of consumer attitudes and behaviors in our study. The definition of each variable is elaborated below.

Table 2
Factor analysis results of key variables.

Variables	Mean	S.D	Factor Loading
Charging anxiety: (Do you feel anxious about your EV issues regarding the following situation?)			
Cronbach's α = 0.85; Composite Mean = 3.21			
EV is not fully charged	3.19	1.1	0.90
EV getting stuck in the middle of a trip	3.42	1.14	0.88
Need for the EV to be fully charged	3.02	1.11	0.87
Environmental concern: (The agreement with the following views on the environmental impacts of energy use)			
Cronbach's α = 0.92; Composite Mean = 3.94			
Overall impacts on the environment	3.95	1.03	0.93
Carbon emissions	3.91	1.04	0.94
Climate change	3.94	1.09	0.92
Perceived privacy (The opinions on the following statements relating to EV usage and privacy)			
Cronbach's α = 0.92; Composite Mean = 3.22			
EV's electricity usage data is private and sensitive	3.25	1.17	0.89
Concern of utility companies can infer mobility and lifestyle information from EV's electricity usage data	3.22	1.14	0.91
EV's status of battery charging as private and sensitive	3.17	1.15	0.90
Concern of utility company can infer mobility and lifestyle information from the status of my EV battery charging data	3.22	1.16	0.91
Trust in utilities (The agreement with the following statements related to the perception of the utility company)			
Cronbach's α = 0.88; Composite Mean = 3.13			
Provide good services in protecting customers' privacy	3.33	0.94	0.86
Keep customers' best interests in mind	3.00	1.06	0.92
Keep their promises	3.06	1.04	0.91

4.3.1. Time-shifting

Time-shifting involves adjusting electricity consumption by shifting the timing of EV charging to periods occurring after peak hours, typically between 5 pm and 8 pm. We collected respondents' opinions based on the question: "I am willing not to charge my EV during peak hours, instead, charge it __ hour(s) later." The aim of this strategy is to ease the burden on the grid during peak demand periods and promote adoption of sustainable energy practices. By adjusting EV charging to off-peak hours, individuals can contribute to a more balanced and efficient distribution of electrical energy, potentially leading to cost savings and environmental advantages.

4.3.2. Load-reduction

Load-reduction stands as a pivotal strategy in electricity consumption management. It entails adjusting electrical usage by minimizing the extent of EV charging during peak hours. By reducing the demand for electricity during these high-demand intervals, load-reduction serves to mitigate strain on the grid, ensuring a more steadfast and efficient distribution of electrical power. This not only enhances grid reliability but also holds the potential for cost savings and diminished environmental impact, rendering it a valuable approach for both individuals and utilities aiming to optimize energy utilization. This variable was assessed using the following question: "I am willing to charge my EV less than

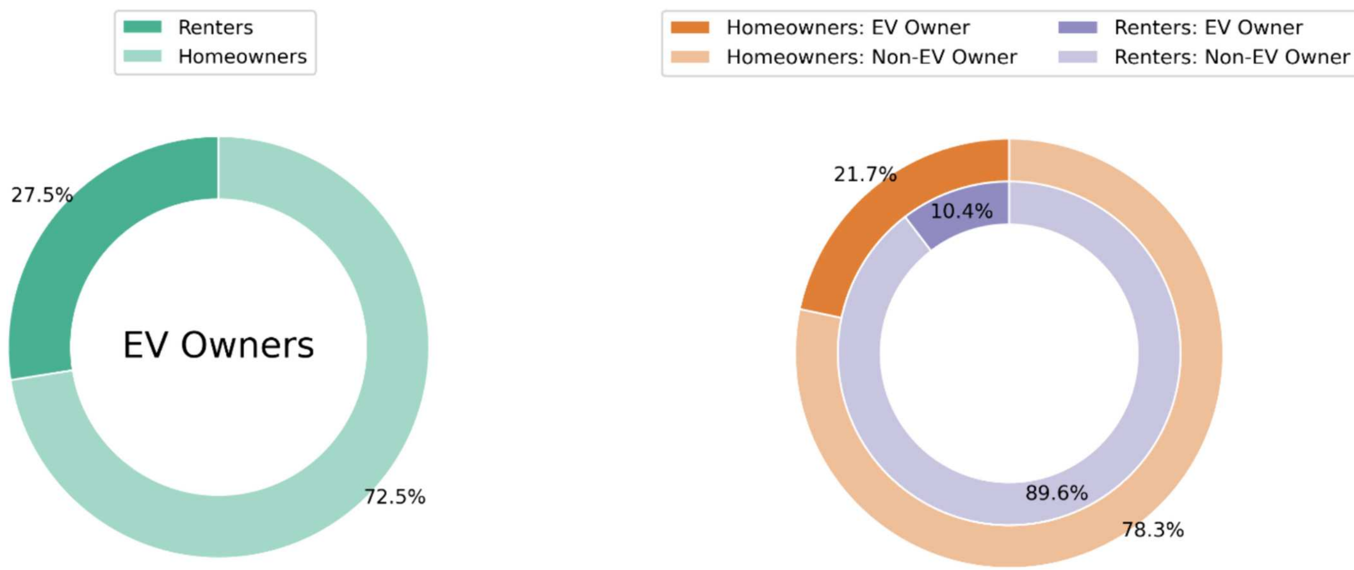

Fig. 1. Proportion of the current EV ownership across homeowners and renters.

fully (100%) during peak hours, opting instead to charge it at __%."

Charging anxiety is a prevalent concern among EV owners, encompassing a range of feelings and worries related to the state of their vehicle's charge. This study assessed the level of charging anxiety based on individuals' agreement and disagreement with the statements, including 1) I feel anxious if my EV is not fully charged all the time; 2) I always feel anxious at the thought of my car running out of electricity and getting stuck in the middle of a trip; 3) My need for the EV to be fully charged would be higher than ordinary people. These three variables were further averaged to represent the "charging anxiety" indicator based on the factor analysis results, as shown in Table 2.

Environmental concern is a multifaceted perspective that reflects an individual's apprehensions about the consequences of energy use. This indicator was measured by the level of respondents' agreement or disagreement with the following statements. Firstly, it encompasses a broader awareness of the overall impacts by the statement "I am concerned about the overall impacts on the environment due to energy use;" secondly, this concern extends to specific worries about carbon emissions resulting from energy use, with individuals recognizing the role of carbon emissions in contributing to environmental challenges by the statement of "I am concerned about carbon emissions due to energy use." Lastly, a key component of environmental concern is the apprehension about the contribution of energy use to climate change was assessed by the statement of "I am concerned about climate change due to energy use." We averaged the score of the three variables based on the results of the factor analysis. These considerations collectively shape a comprehensive perspective on the environmental impacts of energy consumption.

4.3.3. EV buying intention

This study employed the "EV buying intention" variable as a pivotal element to investigate potential EV owners. To gauge this intention, participants were asked: "If you don't have an EV now, how interested are you in buying an EV in the near future?" This question was a reliable indicator of individuals' readiness and inclination to adopt EVs as a transportation option. By exploring respondents' responses to this query, the study sought to discern the level of enthusiasm and willingness among non-EV owners to embrace EV technology in the foreseeable future. "EV buying intention" emerged as a valuable parameter, shedding light on the potential market demand and the factors that influence the adoption of EVs within the study population.

Cost-saving perception is a variable that encompasses people's belief that reducing electricity consumption during peak hours can lead to lower electricity costs during those high-demand periods. In this study, this variable is defined to reflect the understanding that strategic adjustments in energy usage can lead to tangible financial benefits. This is assessed by asking participants' varying levels of agreement with the statement: "Reducing electricity consumption during peak hours can help decrease electricity costs during peak hours."

4.3.4. Perceived privacy

This study incorporated the concept of perceived privacy as one of the dimensions in its research framework. To assess this perception, participants were presented with questions that delved into their views on the privacy and sensitivity of their EV data. This indicator was measured based on factor analysis. It averaged the score of the three questions regarding their agreement and disagreement, including statements such as "I consider my EV's electricity usage data as private and sensitive," "I am concerned that my utility company can infer mobility and lifestyle information from my EV's electricity usage data," and "I consider my EV's status of battery charging as private and sensitive." These inquiries were designed to probe how individuals regard their EV-related data as private and sensitive information. By examining participants' responses to these statements, the study aimed to gain insights into the level of privacy concerns surrounding EV data and the potential implications for data sharing and EV-related decision-making among EV owners.

4.3.5. Trust in utilities

To measure individuals' trust in utilities, participants were presented with a set of statements regarding utility company performance, including "my utility company always provides good services in protecting customers' privacy," "my utility company always keeps customers' best interests in mind," and "my utility company always keeps their promises." Participants were asked to express their level of agreement or disagreement with these statements, thereby allowing the study to measure the extent to which individuals trust their utility companies in matters related to privacy protection, customer interests, and reliability in fulfilling promises. The assessment of "Trust in utilities" aimed to provide insights into the perception of utility companies' performance and their ability to build and maintain trust among their customers.

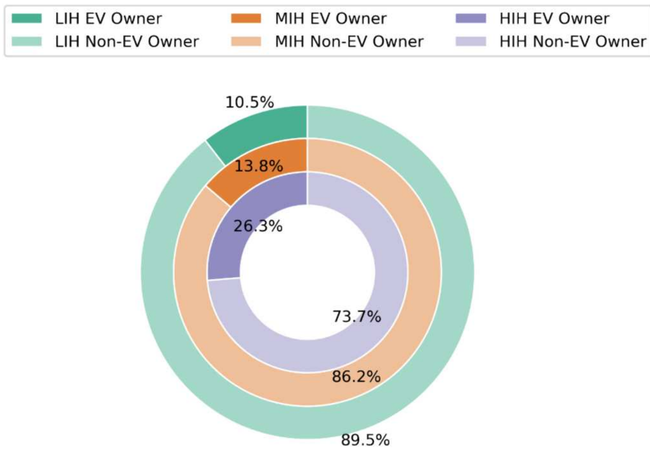

Fig. 2. Proportion of the current EV ownership across income levels.

5. Results and discussion

5.1.1. *EV ownership*

Fig. 1 provides a visual summary of EV ownership among different housing demographics based on survey data. Among our sample, 16.7 % of survey respondents own EVs, with a notable majority (72.5 %) of these EV owners being homeowners while renters account for merely 27.5 % of EV owners. The Chi-square test result (χ^2 (1, 1196) = 26.73; $p < .001$) confirms this distinction, indicating a greater propensity of EV ownership among homeowners within the surveyed population. (See Fig. 2.)

Income brackets also significantly shape EV ownership trends. Among the LIH respondents, 10.5 % were EV owners, while MIH and HIH exhibited relatively higher ownership rates at 13.8 % and 26.3 %, respectively. This discrepancy indicates a discernible correlation between income levels and EV ownership, where higher income brackets displayed a more significant propensity for EV ownership compared to lower income categories, as evidenced by the statistical significance based on a Chi-square test (χ^2 (2, 1196) = 41.13; $p < .001$). These findings indicate the connections between EV ownership, housing status, and income levels. Understanding these associations is crucial in developing targeted policies and incentives that address socioeconomic barriers and foster a more inclusive path toward widespread EV adoption.

5.1.2. *Potential EV ownership*

Fig. 3 illustrates the percentage of survey participants from different income groups regarding their intentions for future EV purchases and reveals insights into prospective adoption patterns. Among the surveyed population, a Chi-square analysis unveiled distinct differences in the intent to purchase an EV across income categories (χ^2 (2, 1189) = 12.75, $p = .002$). Specifically, the result indicates that LIH participants have a significantly lower intention to purchase an EV within the next three years compared to their MIH and HIH counterparts. For instance, only 12.3 % of LIH respondents plan to buy an EV within one year and 29.3 % in 1–3 years, as opposed to 18 % and 34.6 % of MIH and 13 % and 35.8 % of HIH, respectively. This disparity suggests a difference in the readiness or willingness of lower-income individuals to invest in EVs within a shorter timeframe, highlighting potential limitations in their capacity to engage in demand flexibility, particularly in terms of integrating EVs into their energy consumption patterns in a manageable way.

The results also indicate that as the timeline for intended purchases extends, the percentages tend to converge among the income groups, except those not interested. Within the entire sample, a higher percentage of LIH respondents (27.3 %) express no interest in purchasing EVs compared to MIH (23.3 %) and HIH (19 %). These findings underscore the critical role of income disparities in shaping the timeline and likelihood of EV adoption among different economic strata and highlight the importance of developing targeted policies and interventions to bridge these gaps.

5.2. *Relationship between EV charging behaviors and psychological factors*

To answer our research questions, a series of Ordinary Least Squares (OLS) regression models were used to investigate the relationship between EV charging behaviors, including time-shifting and load-reduction, as well as the psychological factors for the entire sample. In this study, our decision to utilize the OLS model is based on several key factors: the common practice of treating ordinal variables as continuous

Table 3
Results of OLS regression models.

Independent variables	Dependent variable: Time-shifting		
	Standardized Coeff. (Beta)	*Std. Error*	*F*
Charging anxiety	−0.077 *	0.055	
Environmental concern	0.102 ***	0.054	
Cost-saving perception	0.125 ***	0.057	*F* (6,1192) = 17.535 ***
Perceived privacy	−0.009**	0.052	
Trust in utilities	−0.009	0.055	

Note: All models are controlled for the effects of gender, ethnicity, and income.
* p < .05,
** p < .01,
*** p < .001.

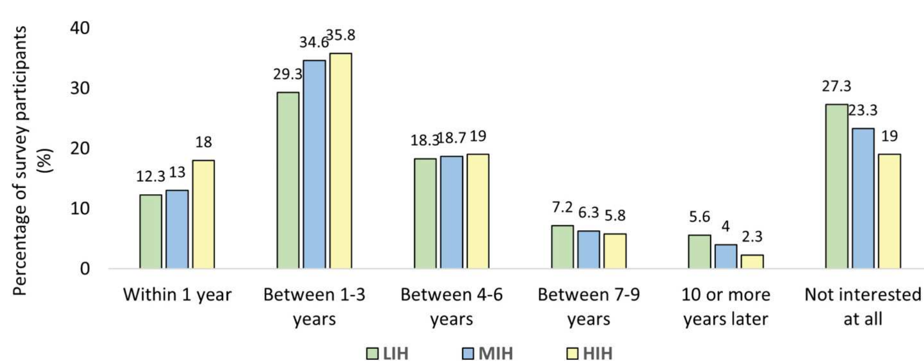

Fig. 3. Proportion of the potential EV owners across different income levels.

Table 4
Results of OLS regression models.

Independent variables	Dependent variable: Load-reduction		
	Standardized Coeff. (Beta)	*Std. Error*	*F*
Charging anxiety	0.201 ***	0.113	
Environmental concern	0.005*	0.110	
Cost-saving perception	−0.005**	0.117	F (6,1192) = 33.774 ***
Perceived privacy	−0.015	0.106	
Trust in utilities	0.108 ***	0.113	

Note: All models are controlled for the effects of gender, ethnicity, and income.
* p < .05,
** p < .01,
*** p < .001.

when the number of categories equals or exceeds five, the validation of Likert scales with balanced intervals as approximately continuous, and the empirical evidence supporting the reliability of OLS regression for ordinal data [50,51].

Table 3 presents the results from an OLS regression analysis, examining the relationship between several psychological factors as independent variables and the dependent variable of time-shifting. The independent variables include charging anxiety, environmental concern, cost-saving perception, perceived privacy, trust in utilities, and intention to buy EVs. Charging anxiety has a small but significant negative effect on time-shifting ($B = -0.077$; $p < .05$), indicating that individuals with a higher degree of charging anxiety are less likely to shift their charging time. On the other hand, environmental concern ($B = 0.102$; $p < .001$) and cost-saving perception ($B = 0.125$; $p < .001$) show significant positive effects. Surprisingly, perceived privacy and trust in utilities do not appear to significantly influence the tendency to shift EV charging to different times. This result could indicate a complex relationship between consumers' privacy concerns, trust in energy providers, and actual energy consumption behaviors. This lack of significant association suggests that while privacy and trust may be essential factors in consumer behavior, they may not directly affect decisions to use electricity at off-peak hours. These findings could reflect a scenario where the benefits of cost-saving and environmental impact are more tangible and immediate to consumers, overshadowing more abstract concerns about data privacy and trust in utilities. This could imply that efforts to encourage time-shifting might focus more effectively on highlighting the economic and ecological benefits rather than addressing privacy and trust issues.

The overall model is statistically significant, F (6,1192) = 17.535, $p < .001$, implying that the model is a good fit for the data and that the independent variables collectively have significant predictive power on time-shifting behavior.

The regression analysis summarized in Table 4 focuses on the dependent variable of load-reduction, typically associated with efforts to decrease EV charging load during peak demand periods. Our analysis

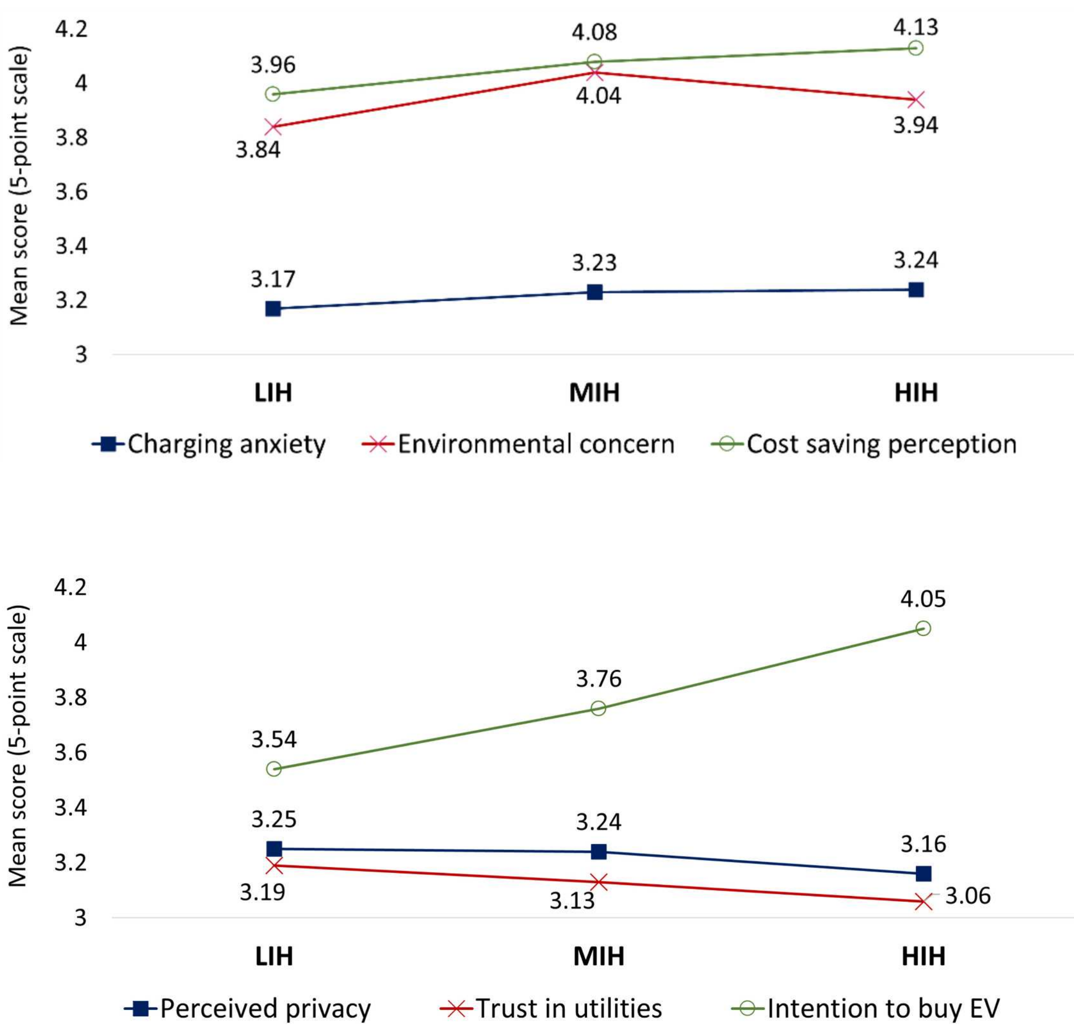

Fig. 4. Disparities of the psychological perception across income groups.

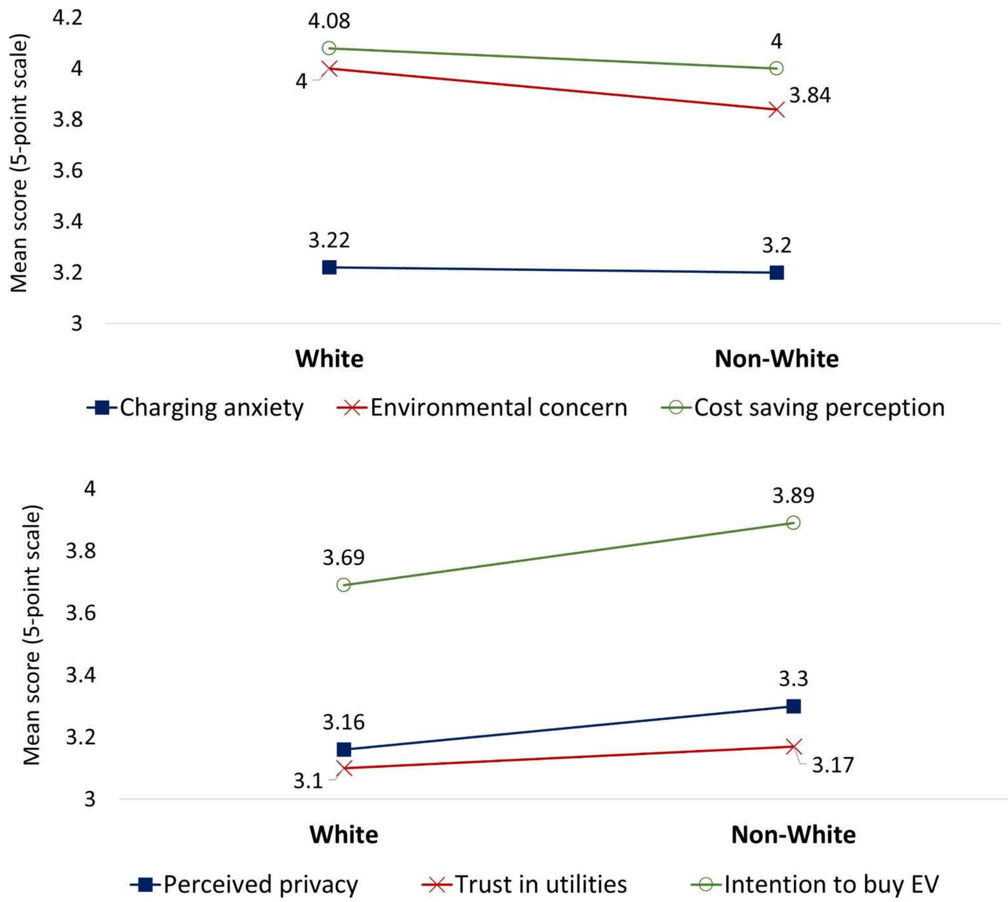

Fig. 5. Disparities of the psychological perception across race.

revealed a noteworthy finding that charging anxiety has a significantly positive relationship with load-reduction ($B = 0.201$; $p < .001$). This result suggests that individuals who perceive higher levels of charging anxiety are more inclined to charge their battery with heavier loads during peak hours, potentially due to a heightened sense of urgency or concern about ensuring an adequate charge. Additionally, such individuals might prioritize the need for a full battery charge, even at the expense of convenience or energy management strategies aimed at load-reduction during peak demand periods. Unlike the results of time-shifting, it is surprising that environmental concern and cost-saving perception do not significantly influence load-reduction, with coefficients close to zero. This result suggests that the motivations to reduce load are not strongly linked to these factors, at least not in the direct manner this model captures. In contrast, trust in utilities shows a moderately positive effect on load-reduction ($B = 0.108$; $p < .001$), which could imply that greater trust in utility providers leads to more engagement in load-reducing behaviors, perhaps due to a belief in the benefits or efficacy of such actions as communicated by the providers. Comprehensively, these results underscore the impact of psychological factors on EV charging behaviors and highlight the importance of addressing these concerns in the design and implementation of charging infrastructure and policies.

The overall *F*-statistic of the model is highly significant, suggesting that when taken together, these variables provide a reliable prediction of load-reduction behaviors. It is important to note that all models are controlled for the effects of gender, ethnicity, and income, indicating that these demographic factors do not confound the results.

5.3. Disparities in psychological factors across demographics

This study investigated the disparities in psychological factors across demographics, including income levels, race, and home ownership status. It clarified how they impact EV charging behaviors through the One-way ANOVA model.

First, we investigated the relationship between various psychological factors and income levels. Referring to Fig. 4, for charging anxiety, the data indicates a marginal increase across the income spectrum, with LIH reporting an average score of 3.17, MIH at 3.23, and HIH at 3.24. However, this trend does not show a statistically significant difference in charging anxiety across income levels, $F(2,1197) = 0.492$, $p = .612$. In contrast, there is a significant relationship between environmental concern and income, $F(2,1197) = 3.99$, $p < .05$. Environmental concern shows a notable variance. LIHs score 3.84 on average, which then slightly increases for MIHs to 4.04, and slightly decreases for HIHs to 3.94. Regarding cost-saving perception, there is a clear ascending trend with increasing income. LIHs exhibit a perception level of 3.96, MIHs show a higher level at 4.08, and HIHs demonstrate the highest level of perception of cost-savings at 4.13. This trend is statistically significant, $F(2,1197) = 4.037$, $p < .05$, indicating that individuals with higher income are more likely to agree that reducing electricity consumption during peak hours can help reduce electricity costs in peak hours.

Regarding privacy concerns, the average scores show a slight decrease from LIH ($M = 3.25$) to MIH ($M = 3.24$) and further to HIH ($M = 3.16$). However, the relationship between perceived privacy and income is not statistically significant, indicating that privacy concerns do not vary substantially across income groups in the context of EV charging behaviors. Regarding trust in utilities, scores marginally decrease from LIH ($M = 3.19$) to MIH ($M = 3.13$) and then to HIH ($M =$

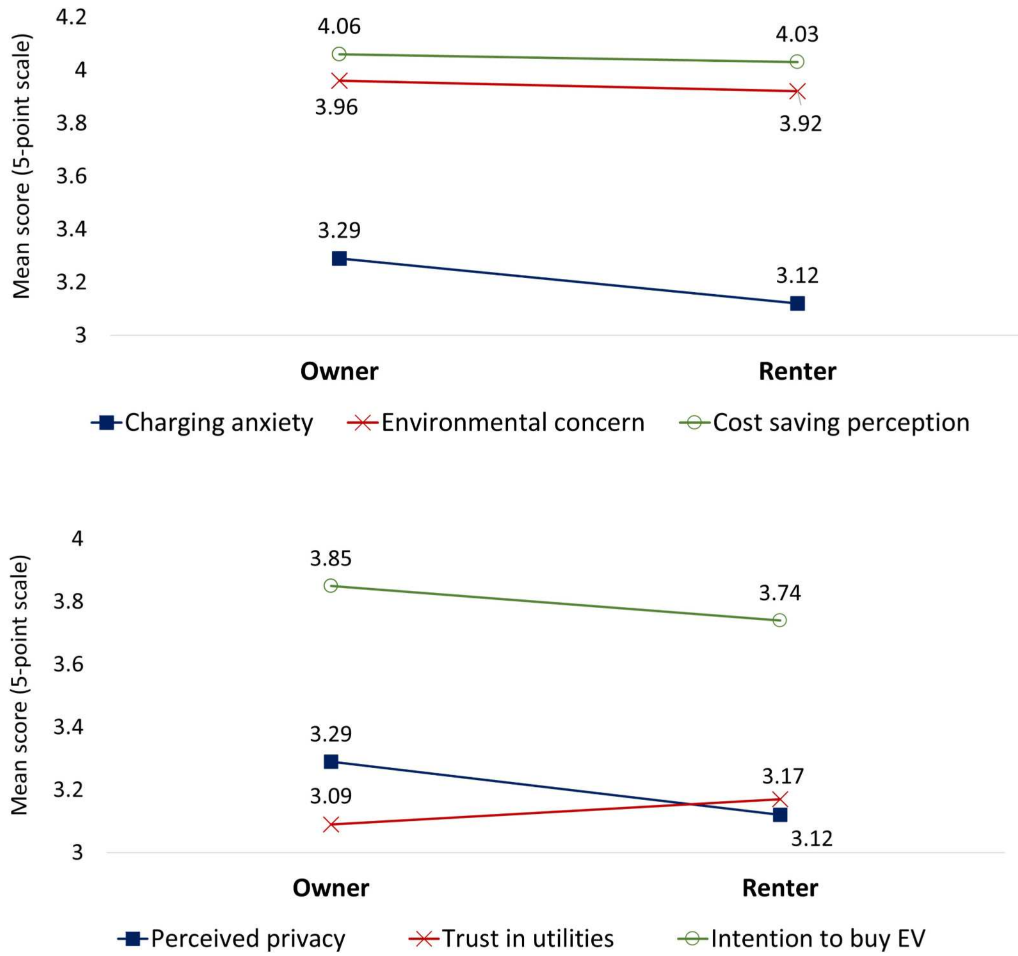

Fig. 6. Disparities of the psychological perception across homeownership status.

3.06). Like perceived privacy, trust in utilities is not significantly related to income. Intention to buy EV demonstrates a clear upward trend and a highly significant relationship with income, F (2,1190) = 8.659, $p <$ .001. LIHs have the lowest average score of interest ($M = 3.54$), which increases notably for MIHs (M = 3.76) and peaks for HIHs ($M = 4.05$). This result indicated a strong correlation between higher income levels and increased interest in purchasing EVs.

These results highlight that while charging anxiety, privacy, and trust in utilities do not show significant differences across income levels concerning EV interest, and there is a significant positive correlation between income level and interest in purchasing EVs. This finding suggests that financial capacity may be more critical in determining interest in EV acquisition than privacy or trust concerns.

Secondly, we investigated the relationship between those psychological factors and race (Fig. 5). For charging anxiety, both White and Non-White respondents reported similar levels, with White respondents averaging a score of 3.22 and Non-White respondents slightly lower at 3.20. There is not statistically significant difference between charging anxiety and race, F (1,1198) = 0.039, $p = .844$, implying that charging anxiety does not vary notably between these racial groups. Regarding the reported environmental concern, our results show a significant relationship with race, F (1,1198) = 7.122, $p < .01$. White respondents show an average score of 4.00, which decreases to 3.84 for Non-White respondents. Regarding cost-saving perception, the scores are relatively high for both groups but do not differ statistically significantly between them, F (1,1198) = 2.447, $p = .118$; White respondents have an average score of 4.08, while Non-White respondents have a score of 4.0.

For perceived privacy, White individuals reported a lower concern level, with an average score of 3.16, whereas Non-White individuals showed a higher level of concern, with an average score of 3.3. The difference between the groups is statistically significant, F (1,1198) = 4.994, $p < .05$, indicating that privacy concerns are more pronounced among Non-White individuals. Regarding trust in utilities, the average scores indicate that White individuals have slightly less trust, with a score of 3.1, compared to Non-White individuals who scored 3.17 on average. However, this difference is not statistically significant, F (1,1198) = 1.523, $p = .217$, suggesting that trust in utilities is relatively consistent across these demographic groups. When investigating the intention to buy EVs, White individuals have a lower average score of 3.69 compared to Non-White individuals, who show a higher interest with a score of 3.89. However, the relationship between intention to buy EVs and race is not statistically significant, F (1,1191) = 3.532, $p = .06$, indicating a trend where Non-White individuals may have a slightly higher inclination to purchase EVs, although this result does not reach the conventional threshold for statistical significance.

Thirdly, the relationship between psychological factors and home ownership status was investigated. As shown in Fig. 6, owners reported higher levels of charging anxiety, with an average score of 3.29, while renters showed a lower average score of 3.12. This difference is statistically significant, F (1,1182) = 8.278, $p < .01$. This result suggested that homeowners may experience more anxiety related to EV charging compared to renters. For environmental concerns, the average scores between owners and renters are 3.96 and 3.92, respectively. The ANOVA model shows that the difference between homeowners and renters in environmental concern is not statistically significant, F (1,1182) = 0.468, $p = .494$, implying similar levels of environmental awareness regardless of home ownership status. In terms of cost-saving perception, both owners and renters display nearly identical responses,

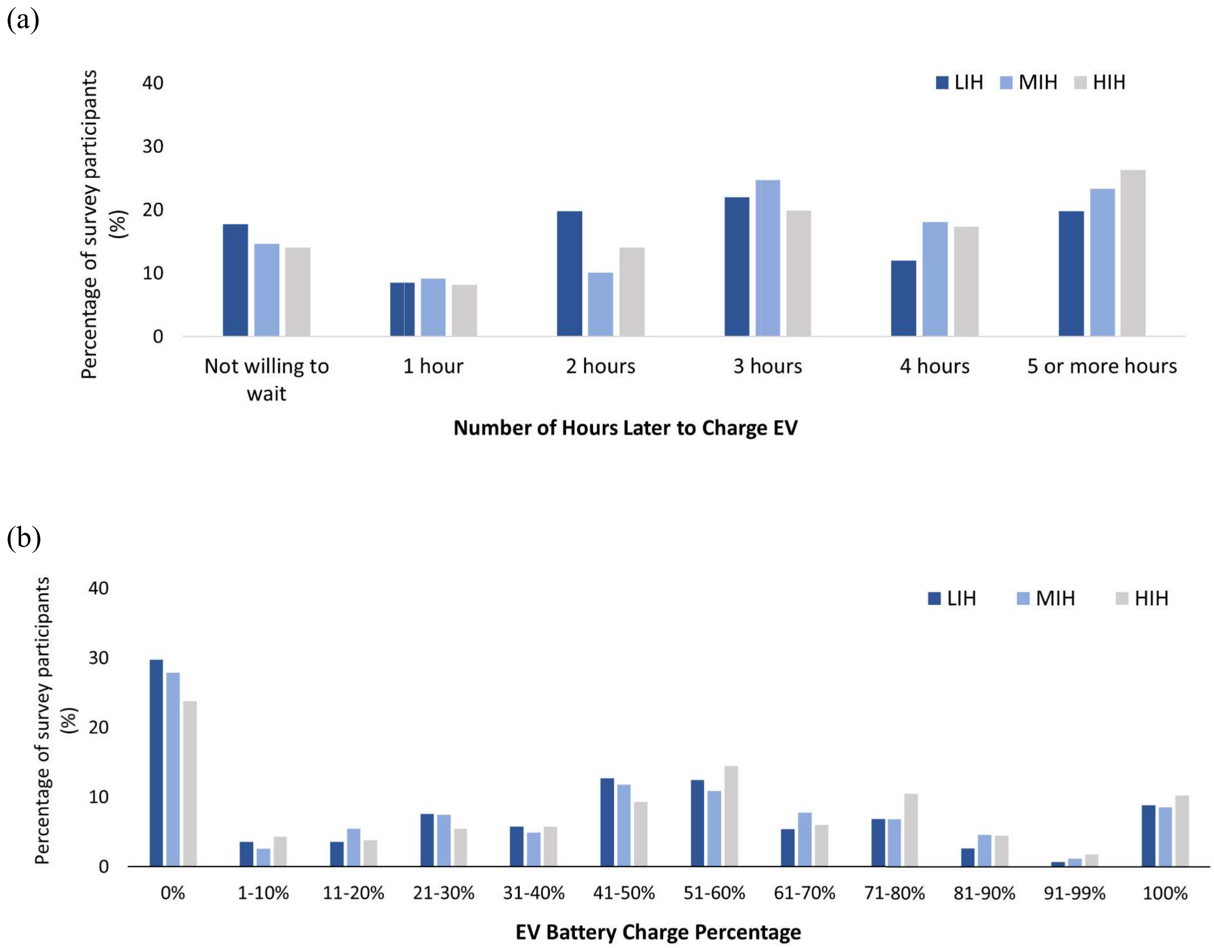

Fig. 7. Disparities of the EV demand flexibility across income levels in (a) time-shifting and (b) load-reduction.

with no significant difference in their scores, F (1,1182) = 0.221, p = .638.

Regarding perceived privacy, homeowners express greater privacy concerns, with an average score of 3.29, compared to renters, who score an average of 3.12. This difference is statistically significant, F (1,1182) = 8.654, $p < .01$. Regarding trust in utilities, owners have a slightly lower trust level with a score of 3.09, whereas renters show a marginally higher score of 3.17. However, this difference is not statistically significant, F (1,1182) = 2.071, p = .15. Regarding the interest in purchasing EVs, owners have an average score of 3.85, while renters have a slightly lower score of 3.74. The ANOVA model shows that the difference in interest levels between owners and renters is not statistically significant, F (1,1175) = 0.594, p = .441.

These results highlight that while home ownership may affect charging anxiety and privacy concerns regarding EVs, it does not significantly impact environmental concerns, cost-saving perception, trust in utilities, or the intention to buy EVs.

5.4. EV charging behaviors: Time-shifting & load-reduction

5.4.1. Disparities across demographics - income, homeownership, and race/ethnicity

Income demographic disparities significantly impact the willingness to engage in EV charging time-shifting, as shown in Fig. 7. The data in our survey indicates that a higher percentage of LIH respondents not willing to wait for charging (17.8 %) compared to MIH (14.7 %) and HIH (14.3 %) demographics. Conversely, as the charging time delay increases, there is a noticeable shift in willingness. The HIH category has a higher percentage for those willing to wait for extended periods, especially in the "5 or more hours" category, with 25.8 % of HIH, 23.3 % of MIH, and 19.8 % of LIH. The Chi-square test indicates these disparities, revealing a statistically significant relationship between income levels and EV charging flexibility of time-shifting (χ^2 (10, 1196) = 25.89; $p <$ .01).

Income demographic disparities also existed in EV charging reduction, as shown in Fig. 7. The distribution of load-reduction flexibility across the three income categories displays variations. The HIH category has a higher percentage for those willing to wait for extended periods, especially in the "5 or more hours" category, with 25.8 % of HIH, 23.3 % of MIH, and 19.8 % of LIH. However, the Chi-square test results suggest a lack of statistically significant correlation between income level and the extent of load-reduction in EV charging, with χ^2 (22, 1196) = 24.05; p = .344. This finding indicates that while disparities exist in load-reduction across income demographics, there might not be a direct and significant relationship.

Homeownership status appears to impact EV charging behavior, with homeowners showing a higher willingness to wait to charge their EV during peak hours than renters as time delay increases (Fig. 8 (a)). In the "5 or more hours" bracket, there were 24.5 % of homeowners compared to 20.7 % of renters, while in the "Not willing to wait" bracket, there were 14.8 % of homeowners and 16.9 % of renters. However, the Chi-square test results suggest no statistically significant link between homeownership and the flexibility in time-shifting EV charging willingness (χ^2 (5, 1196) = 5.94; p = .312).

Analysis of homeownership disparities concerning load-reduction in EV total charging percentages between renters and homeowners also

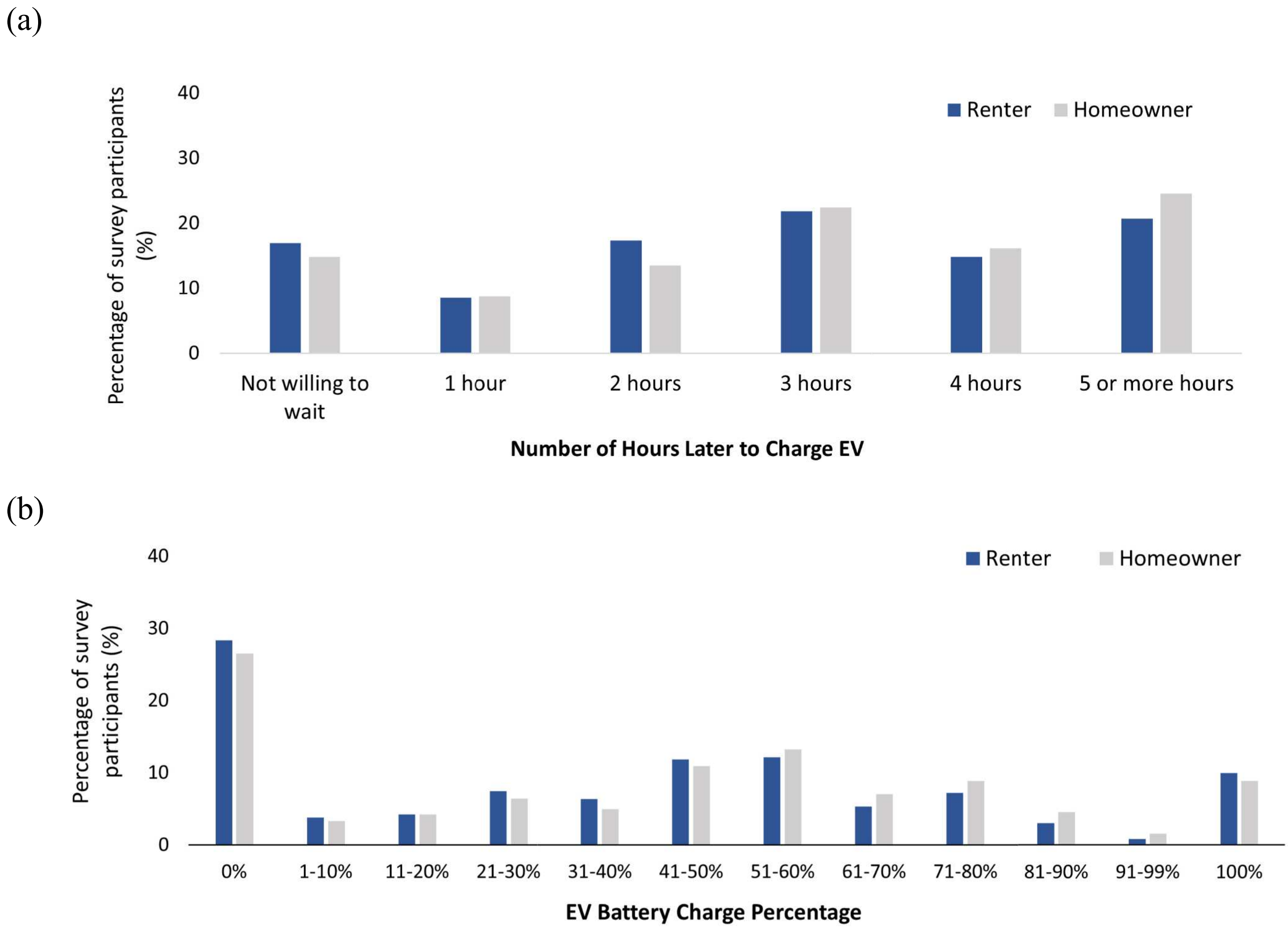

Fig. 8. Disparities of the EV demand flexibility across homeownership status in (a) time-shifting and (b) load-reduction.

resulted in an insignificant Chi-square result (χ^2 (11, 1196) = 7.99; p = .714). This suggests that while observable differences exist, homeownership status alone might not directly influence the degree of charging load-reduction, prompting further exploration. Fig. 8 (b) illustrates varying distributions across charging reduction brackets across different homeownership status. The analysis regarding homeownership and charging behaviors indicates a need for deeper investigation into the specific factors influencing the flexibility of EV charging behaviors.

Time-shifting and load-reduction behaviors for EV charging were analyzed to discern correlations within the LIH renter and non-LIH renter subgroups to deepen the research on the homeownership variable. Regarding time-shifting behaviors, Fig. 9 (a) reveals marked differences between percentage of LIH renters and non-LIH renters across various charging time brackets. Within the larger time-shifted EV charging brackets there is consistently a smaller percentage of LIH renters than non-LIH renters while conversely in the shorter delay or no delay at all, there is a larger percentage of LIH renters than non-LIH renters. For instance, the "Not willing to wait" bracket is composed of 18.8 % of LIH renters and 14.6 % of non-LIH renters while the "5 or more hours" bracket has 19.4 % of LIH renters but 24.1 % of non-LIH renters. The trend emerges resulting in the statistically significant Chi-square result (χ^2 (5, 1196) = 18.22; p < .01). Conversely, when examining load-reduction behaviors for EV charging (Fig. 9 (b)), it was found that 30.3 % of LIH renters reported they would not charge their EV at all during peak hours, compared to 26.2 % of non-LIH renters. Similarly, 9.9 % of LIH renters and 9.1 % of non-LIH renters expressed they would charge their EV to 100 % battery level during peak hours. These slight disparities are reflected in the Chi-square test results, which revealed no statistically significant correlation (χ^2 (11, 1196) = 7.76; p = .735). These findings suggest that when analyzing the subcategory of homeownership among LIH renters and non-LIH renters, time-shifting behaviors hold greater significance compared to load-reduction.

The analysis of EV charging flexibility during peak hours among White and Non-white respondents demonstrates disparities in both time-shifting behaviors and load-reduction strategies. Regarding time-shifting abilities, Fig. 10 (a) shows a difference between groups across various time brackets. White respondents report a greater willingness to delay EV charging at the time increases compared to Non-white respondents. Specifically, the "Not willing to wait" bracket is composed of 16.9 % of Non-White respondents and 15.0 % of White respondents while in the "5 or more" bracket is 15.8 % of Non-White respondents and 27.4 % of White respondents. These observations are supported by the statistically substantial Chi-square test result (χ^2 (5, 1196) = 26.97; p < .001).

Similarly, in load-reduction behavior (Fig. 10 (b)), White respondents (28.8 %) demonstrated a higher percentage of individuals able to forego charging their EV entirely than Non-white respondents (24.9 %). The differences between groups, however, are less significant within the load-reduction than time-shifting analysis. Despite these observed disparities in load-reduction behavior, the Chi-square test results do not indicate statistically significant correlations (χ^2 (11, 1196) = 11.87; p = .373). Overall, when considering racial demographics for EV charging behaviors, time-shifting is the statistically significant variable to examine.

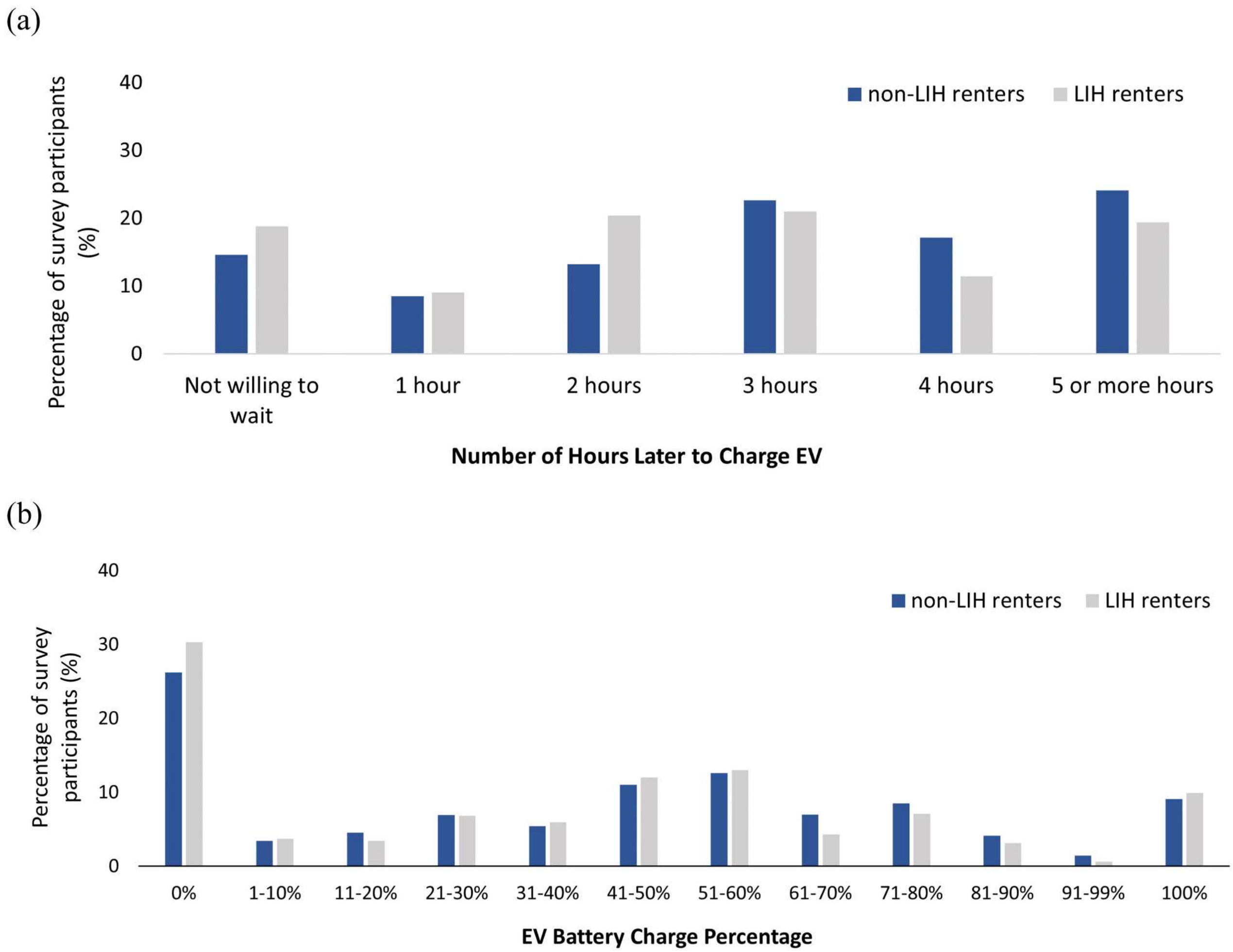

Fig. 9. Disparities of the EV demand flexibility across LIH renters in (a) time-shifting and (b) load-reduction.

5.4.2. *Interaction of social-psychological factors and demographics*

The interaction between social-psychological factors and demographics significantly shapes attitudes toward willingness regarding EV charging behaviors. Previous analyses have highlighted disparities across various demographic groups—such as income levels, homeownership status, and racial backgrounds—in managing EV charging during peak hours. This section involves further analysis using two-way ANOVA to explore the interaction between demographics and the psychological factor of charging anxiety. Since charging anxiety is significantly related to both time-shifting and load-reduction charging behaviors, it is selected for further analysis to investigate their interaction with income levels and homeownership status. Understanding how these demographics intersect with underlying social-psychological factors offers insight into the factors influencing individuals' flexibility to adopt charging behaviors to reduce load during critical periods. Examining this intersection informs targeted strategies addressing demographic disparities and the complex behavioral and psychological factors influencing flexible EV charging practices.

5.4.2.1. Charging anxiety and income. The intersection of EV charging anxiety and income levels significantly influences attitudes toward time-shifting and load-reduction strategies in EV charging practices. Referring to section 4.3 of the key variables' measurement, we averaged the score calculated based on the three questions related to respondents' agreement on charging anxiety. The resulting scores were then stratified into three levels: low charging anxiety (1.0–2.0), medium charging anxiety (2.33–3.67), and high charging anxiety (4.0–5.0). This classification allows for a more detailed understanding of the diverse charging anxiety levels exhibited by the survey respondents as it is examined for interaction with demand response behaviors.

For time-shifting behaviors (Fig. 11(a)), the hours during which people are willing to charge their EV after peak hours are represented by the numbers in the central pie chart. Within the three levels of charging anxiety, LIHs consistently show the lowest mean of 3.48 h for low charging anxiety, 3.69 h for medium charging anxiety, and 3.55 h for high charging anxiety, among three income groups. These results indicated that LIH respondents have less flexibility to shift EV charging off-peak hours. Notably, within the high-income group, those with high charging anxiety have the lowest mean of 3.68 compared to other levels of anxiety, indicating that high-income individuals with high charging anxiety are the least willing to charge their EVs during off-peak hours within the HIH group. The ANOVA test result shows significant differences across income levels and charging anxiety in time-shifting behaviors (F (8, 1195) = 3.10; $p < .01$).

Examining load-reduction attitudes also reveals disparities (Fig. 11 (b)). The numbers shown in the central pie chart represent the percentage of battery load that people are willing to charge during the peak hours. Among those with low charging anxiety, individuals in the HIH category exhibit a notably higher demand for their EV batteries to be entire (25 %) compared to LIH (21 %) and MIH (16 %) groups. These results show that when charging anxieties are low, MIH and LIH respondents are more willing to charge their EV less during peak hours than HIH individuals. Conversely, individuals with high charging anxiety across all income levels display higher means. HIH respondents exhibit the highest charging percentage of 39 %, indicating that HIH

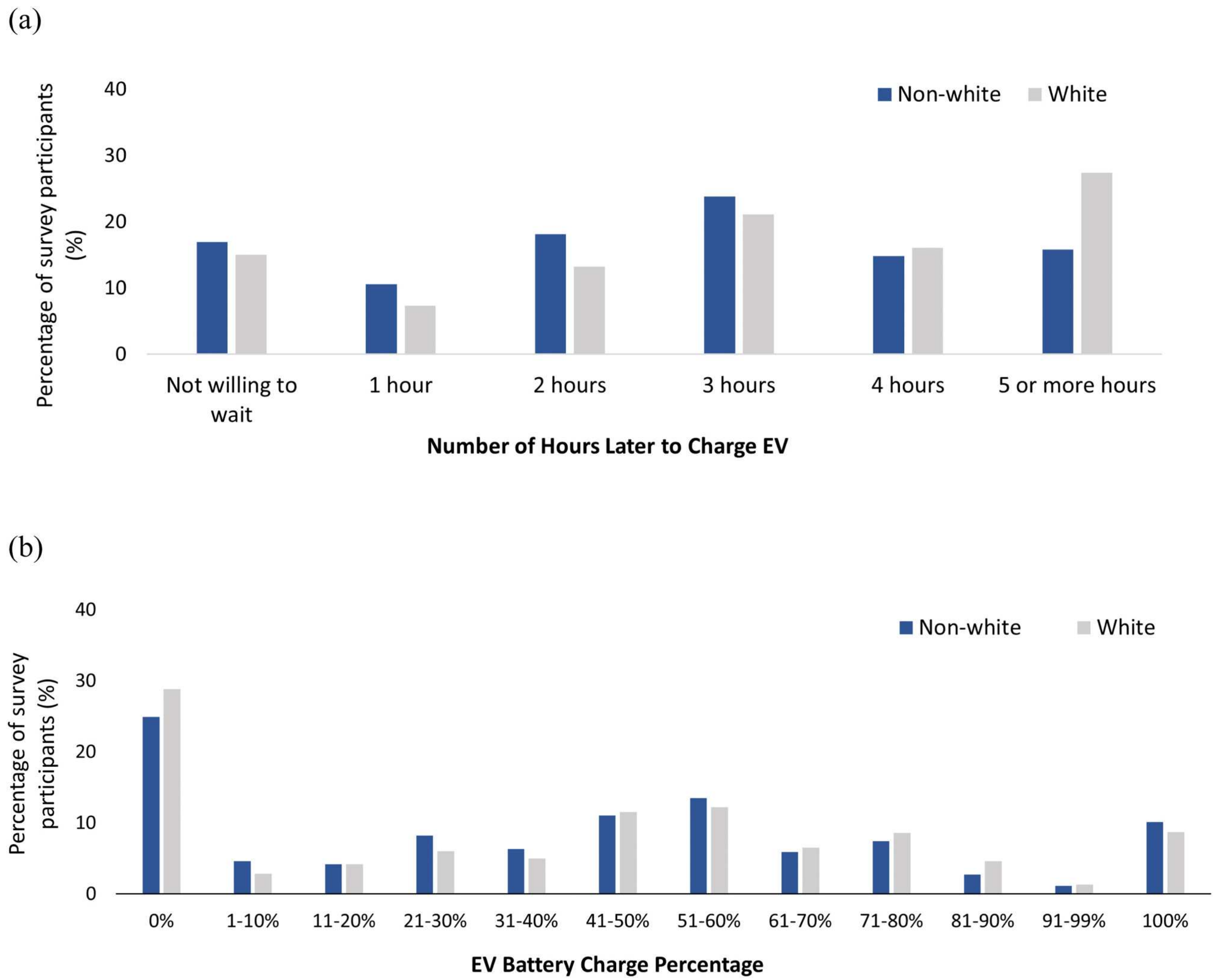

Fig. 10. Disparities of the EV demand flexibility across racial backgrounds in (a) time-shifting and (b) load-reduction.

with high charging anxiety will still charge their EV more during peak hours. The ANOVA result suggests a significant relationship between income levels and charging anxiety in load-reduction behaviors (F (8, 1195) = 10.38; $p < .001$).

5.4.2.2. Charging anxiety and homeownership. Influence from EV charging anxiety and homeownership affects attitudes toward time-shifting in EV charging practices is statistically significant (F (5, 1195) = 2.74; $p < .05$). In Fig. 12 (a), the hours during which people are willing to charge their EV after peak hours are represented by the numbers in the central pie chart. When observing time-shifting perceived willingness within the low charging anxiety group, homeowners showed a slightly lower mean of 4.01 h compared to renters (4.06 h), with no significant difference. Within the high charging anxiety group, however, renters (3.77 h) have a slightly higher mean score than homeowners (3.69 h). These results indicated that regardless of homeownership, those with lower charging anxiety are more willing to charge their EV off-peak than those with high charging anxiety.

For load-reduction attitudes, the influence of charging anxiety and homeownership is statistically significant (F (5, 1195) = 13.53; $p < .001$), demonstrating a substantial effect on load-reduction behavior. As shown in Fig. 12 (b), the numbers depicted in the central pie chart indicate the proportion of battery load individuals are willing to charge during peak hours. Specifically, renters report an intent to charge their EV 23 % when examining the low charging anxiety group. In comparison, homeowners only report a charge percentage of 20 %, indicating that of the low anxiety group, homeowners have a more significant propensity to charge their EV less during peak hours. On the other end of the spectrum, within the high charging anxiety group, renters and homeowners will charge their EVs 34 % and 35 %, respectively.

6. Discussion and policy recommendations

The nexus of demand response, flexibility, justice, and social-psychological considerations are critical in pursuing a sustainable and equitable energy future. Our exploration is discussed and underscored through several key insights:

1. Demand response, pivotal in decarbonization efforts, must be viewed through the lens of flexibility justice to ensure accessibility for all, particularly vulnerable populations. Previous studies have primarily focused on household appliances such as AC units [52], refrigerators, and laundry [6,26,60], with only a few incorporating EVs into consideration. Moreover, financial constraints and inadequate infrastructure in underserved areas [53,54] may limit technology access, preventing vulnerable groups from effectively using advanced products like EVs due to a lack of familiarity and knowledge. With the increasing rates of EV adoption, our study emphasizes the imperative of addressing justice concerns in EV demand

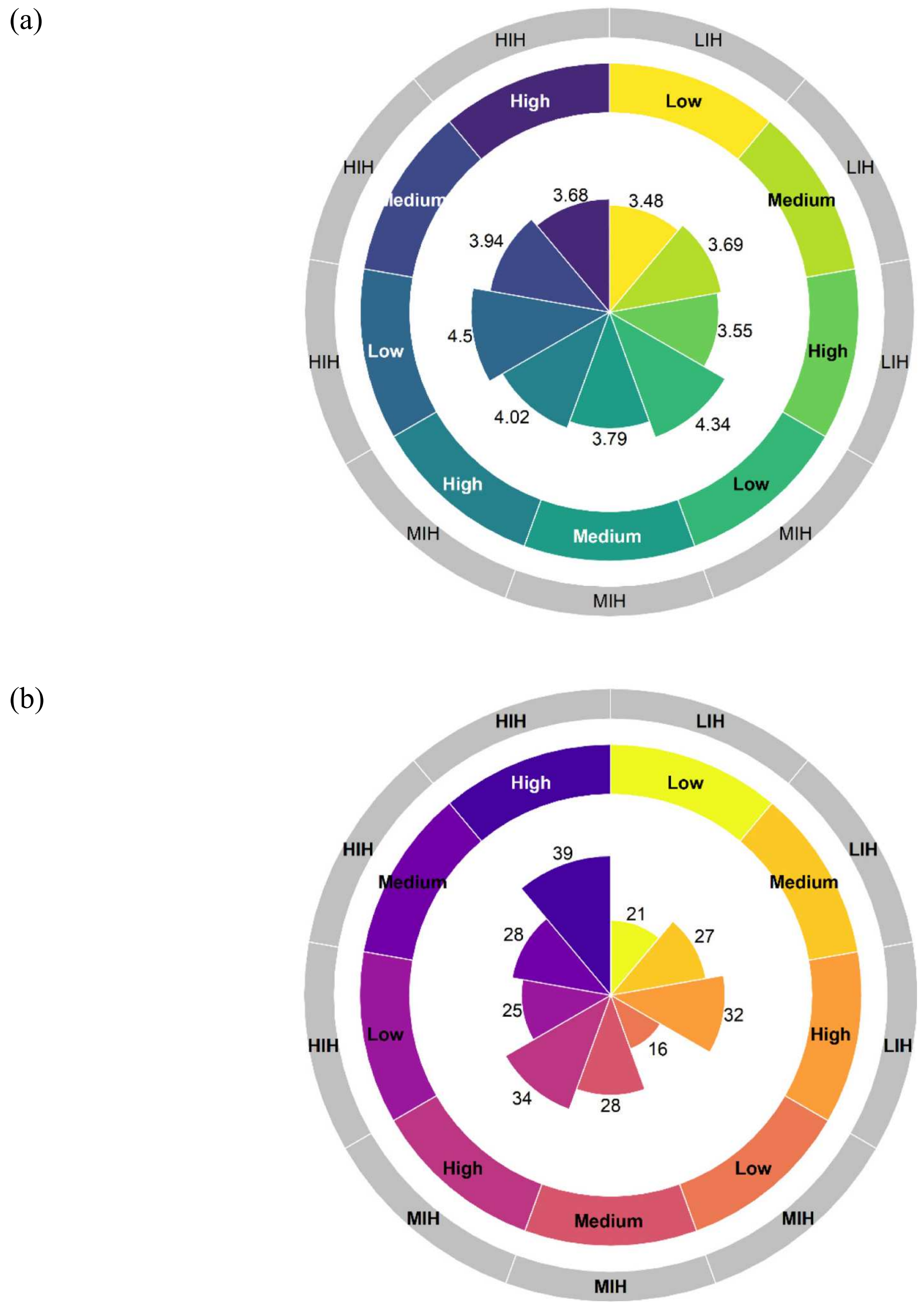

Fig. 11. Disparities in psychological perception based on charging anxiety and income level in (a) time-shifting: Time (hr) willing to charge after peak hours and (b) load-reduction: EV charge percentage during peak hours.

flexibility. Notably, our findings in section 5.4.1 shed light on the inequity faced by LIHs, indicating a higher proportion unwilling to wait for charging (42.6 %) compared to MIHs (27.1 %) and HIHs (30.3 %). These disparities may stem from the inflexible schedules often faced by LIHs.

2. The differences in predictors for time-shifting and load reduction, as seen in Tables 3 and 4, can be explained by the distinct nature of these behaviors. Time-shifting involves adjusting the timing of EV charging to after peak hours, focusing on convenience, cost savings, and environmental benefits from using off-peak energy. This behavior primarily requires a change in when electricity is used, not how much. In contrast, load reduction requires reducing the total amount of energy consumed during peak hours, reflecting a stronger commitment to minimizing grid strain and environmental impact. This approach might be influenced by factors like willingness to compromise on charging levels and a focus on sustainability. Understanding these differences is important for developing strategies to encourage both types of energy management behaviors.
3. Psychological factors play a significant role in demand flexibility, shaping individuals' willingness to adjust charging behaviors, particularly regarding charging anxiety. Surprisingly, this study did not find privacy concerns to be a critical factor influencing charging behaviors. Instead, our findings indicate that individuals may prioritize factors such as cost savings, environmental considerations, and trust in utilities over privacy concerns when making decisions related to EV charging. These insights provide valuable guidance for policymakers, energy providers, and researchers aiming to promote demand flexibility and its benefits in a rapidly evolving energy landscape. Therefore, efforts should be directed toward enhancing public awareness and education about these key factors. By

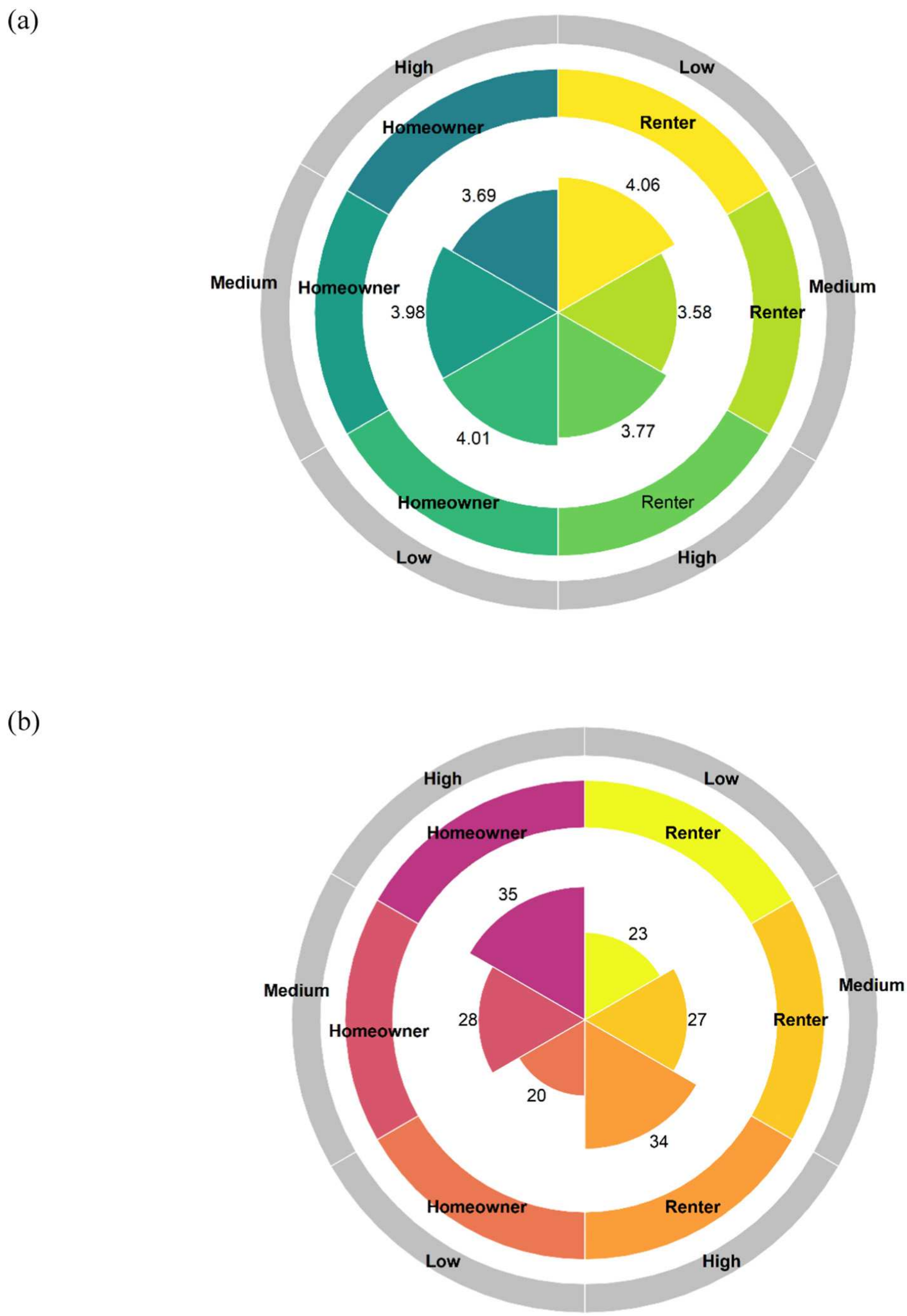

Fig. 12. Disparities in psychological perception based on charging anxiety and homeownership in (a) time-shifting: Time (hr) willing to charge after peak hours and (b) load-reduction: EV charge percentage during peak hours.

understanding and addressing the priorities that influence user behavior, targeted interventions and tailored strategies can be developed to align with the diverse motivations of EV users.

4. The study clarifies disparities in the intention to purchase EVs and the impacts of psychological factors across various demographics, including income levels, races, and homeownerships. We found that income level significantly influences the intention to purchase EVs, with higher-income individuals showing more interest. However, it is worth noting that a previous study estimated substantial savings from EV adoption, especially benefiting lower-income households, with potential cost savings approaching 7 % of income by 2030 [8]. Therefore, policies for promoting EV adoption among lower-income households are crucial, necessitating incentives to eliminate barriers and increase willingness to purchase EVs. Additionally, White respondents report greater environmental concern, while Non-White respondents indicate higher privacy concerns. Homeownership also impacts charging anxiety and privacy concerns, with homeowners experiencing more anxiety and privacy concerns. These insights contribute valuable knowledge about how demographics influence psychological factors related to EV adoption.
5. There are disparities between homeowners and renters in the charging behavior of time-shifting. It is speculated that renters may have fewer charging infrastructure options available at their residences than homeowners. Rall [55] indicated that recent decision of American building codes leaves renters paying extra for EVs. Owners of single-family homes can adapt to the EV transition while apartment owners and renters will be left paying higher prices for less convenient charging. This limited availability could lead renters to

prioritize charging efficiency by maximizing their charging time during off-peak periods when charging facilities are accessible. On the other hand, homeowners, who typically have more control over their charging infrastructure, may be more flexible in choosing when to charge their EVs. Meanwhile, our findings align with this situation that highlights the needs and inconvenience of renters for adopting EVs. We recommend that policymakers address disparities in EV charging behavior between renters and homeowners by increasing charging infrastructure access through subsidies and standardized requirements, offering financial incentives for off-peak charging, educating renters about the benefits of time-shifting, and encouraging community charging solutions. Additionally, offering financial incentives for EV adoption among renters, along with safeguarding tenant rights to install home charging stations, can contribute to fostering greater fairness and accessibility to these vehicles.

7. Conclusions

This study reveals the significant influence of socioeconomic and demographic factors on the equitable distribution of benefits and burdens associated with EV adoption and charging behaviors. Investigating how these justice issues intersect with demand flexibility is paramount, bringing awareness to potential inequities within the evolving electric mobility field. The disparities observed in our research may be attributed to the socioeconomic status of individuals, particularly those in vulnerable groups who often face constraints that limit their flexibility in adjusting their schedules and charging behaviors. These constraints can be related to factors such as income levels, homeownership status, and historical inequities such as racial background. Policies and practices in EV adoption should emphasize justice by addressing vulnerable groups' unique needs and behavioral patterns, recognizing the challenges they face, and actively working to alleviate additional energy burdens resulting from their lack of flexibility. For instance, utilities have implemented incentive plans to encourage people to adjust their energy use away from peak hours in exchange for lower energy prices [56]. However, vulnerable populations may not always have the flexibility or resources to shift their energy consumption patterns effectively due to limited income, housing situations, or constraints related to their work schedules and daily routines. Consequently, these individuals may face challenges in taking full advantage of such incentive programs, exacerbating energy-related disparities causing additional energy burdens.

The present research has limitations that may offer valuable insights for future investigation. First, despite our meticulous efforts to align our sample with the demographic makeup, it is imperative to recognize that our sample may not encompass the full spectrum of the broader population. Nevertheless, it is worth noting that our statistical analysis has unveiled noteworthy relationships among the groups within our sample size. These findings indicate that within the confines of our study and the accessible participants, significant patterns and associations have emerged. Secondly, regarding the classification of income levels, this study categorizes income levels based on relative differences within the sample rather than absolute thresholds. This approach might limit the generalizability of our results to the broader population, as it may overlook the unique challenges faced by households at the very bottom of the income spectrum. We also recognize that using relative income classifications might affect the interpretation of income disparities within our sample. Thirdly, while this study focused on examining the influence of psychological factors on EV charging behaviors across diverse demographics, other potential factors remain worthy of investigation. Consequently, we intend to undertake a more comprehensive and in-depth study to delve deeper into the underlying reasons behind these outcomes. This endeavor seeks to provide further insights into the disparities in charging behaviors to meet the needs of diverse groups, especially vulnerable populations.

Ultimately, this study highlights the intricate challenges involved in building a sustainable EV infrastructure that is both fair and accessible to all. It necessitates a comprehensive understanding of the intricate interplay between technical, psychological, and socioeconomic factors. Bridging the gap between these dimensions is crucial in shaping policies and strategies that ensure fairness and accessibility for all, regardless of their socioeconomic circumstances. The findings of this research aim to contribute to the ongoing discourse surrounding EV adoption and demand flexibility, advocating for equitable access to the benefits and opportunities they offer, fostering a more inclusive and sustainable energy future.

CRediT authorship contribution statement

Wei-An Chen: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Chien-Fei Chen:** Supervision, Investigation, Conceptuatlization and Survey Design, Writing - review & editing, Funding acquisition and Data curation. **Stephanie Tomasik:** Writing – original draft, Visualization, Formal analysis, Data curation. **Evangelos Pournaras:** Supervision, Investigation, Conceptualization. **Mingzhe Liu:** Writing – original draft, Visualization, Investigation.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. This manuscript has not been published and is not under consideration for publication elsewhere. All authors have read the manuscript and have approved this submission. The authors report no conflicts of interest. The authors also confirm that any necessary permissions have been obtained.

Data availability

The data that has been used is confidential.

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