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The Impact of Adjustments to Time-of-Use Tariff Policies on the Usage Behaviour of New Energy Vehicle Charging Infrastructure

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Abstract

Driven by the strategy for green and low-carbon transition, the development of charging infrastructure for new energy vehicles faces the coupled challenge of fluctuating demand and the optimisation of resource allocation. This paper utilises the time-of-use tariff policy adjustment implemented by the Jibei Power Grid on 1 January 2026 as a natural experiment. Questionnaire surveys were conducted at two time points—before and after the policy announcement—and Structural Equation Modelling (SEM) was employed to empirically analyse the mechanisms through which the policy adjustment influences the charging behaviour of new energy vehicle users. Based on the Technology Acceptance Model (TAM) and demand response theory, the study constructs a conceptual model comprising five latent variables: perceived ease of use, perceived usefulness, policy awareness, subjective norms, and willingness to adjust charging behaviour. A total of 669 valid questionnaires were collected from the two rounds of surveys. Data tests indicated that the data met the normality assumption, with no severe common method bias. Harman's single-factor variance explained was 29.8%, and all VIF values in the multicollinearity diagnostics were less than 3; furthermore, the model used in this study outperformed competing models. The study found that: (1) The policy adjustment significantly enhanced users' perceived sensitivity to electricity price signals, with the mean willingness to adjust charging behaviour rising from 3.18 to 4.09, an increase of 28.6%; (2) Policy awareness is the most critical factor influencing the willingness to adjust, with a path coefficient of 0.428 ($p < 0.001$), and it plays a significant mediating role between perceived usefulness and the willingness to adjust, accounting for 34.9% of the indirect effect; (3) Perceived usefulness (0.347) and subjective norms (0.186) have a significant positive impact on the willingness to adjust, whilst perceived ease of use exhibits a slight negative impact (-0.124); (4) Multi-group analysis indicates that the path coefficients for perceived usefulness and policy awareness significantly increased following the policy announcement; (5) There is a marked disparity between users' willingness to adjust and the availability of charging facilities during specific time slots: during the winter off-peak period (12:00–15:00), the availability of charging points in office areas was only 31.8%, whilst during the summer peak period (18:00–21:00), the congestion rate of residential charging points reached 67.2%. This paper provides theoretical grounds and empirical support for the refined design of time-of-use pricing policies and the coordinated optimisation of new energy vehicle charging infrastructure.

Keywords

Time-of-use pricing, New Energy Vehicles, Charging facilities, Structural equation modelling, Resource allocation.

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1. INTRODUCTION

The vigorous pursuit of the 'dual carbon' goals is profoundly reshaping China's energy structure and transport landscape[1]. According to data from the China Association of Automobile Manufacturers, by 2025, the number of new energy vehicles in China had exceeded 35 million, with a penetration rate of over 45 per cent. The rapid growth of new energy vehicles has injected strong momentum into the green transition of the transport sector[2], but it has also placed unprecedented pressure on the operation of the power system and the construction of charging infrastructure. The highly uneven distribution of charging demand across time and space, coupled with a mismatch in the allocation of charging facilities, has become a core bottleneck constraining the sustainable development of new energy vehicles.

The time-of-use pricing mechanism[3] is the core tool for using price levers to guide user demand response[4]. By setting differentiated electricity price levels for different time periods, it incentivises users to shift their electricity consumption from peak to off-peak hours, thereby achieving peak shaving and valley filling, promoting the integration of renewable energy, and ensuring the safe and stable operation of the power system[5]. In 2021, the National Development and Reform Commission issued the 'Notice on Further Improving the Time-of-Use Tariff Mechanism' (NDRC Price [2021] No. 1093), requiring local authorities to scientifically delineate peak and off-peak periods, reasonably widen the price differential between them, and establish a peak-hour tariff mechanism.

Against this backdrop, on 26 November 2025, the Hebei Provincial Development and Reform Commission issued the 'Notice on Optimising and Adjusting the Time-of-Use Tariff Policy for Industrial, Commercial and Other Users in the Northern Hebei Power Grid' (Ji Fa Gai Neng Jia [2025] No. 1275), which came into effect on 1 January 2026. Building upon the guiding principles of national policy and taking into account the operational characteristics of the North Hebei Power Grid, this adjustment systematically optimises the time-of-use classifications and floating ratios. Its core elements include: a more refined classification of time periods, dividing the year into four categories—summer (June, July, August), winter (January, November, December), February (separately), spring and autumn (March, April, May, September and October), with five distinct time bands established for each: peak, high, standard, low and deep low (applicable to winter and February). The fluctuation ranges have been significantly expanded: high and low-peak electricity prices may fluctuate by up to 70% above or below the standard-peak price; peak-peak prices may rise by 20% above the high-peak price; and deep-low prices may fluctuate by 20% above or below the low-peak price. This represents the largest adjustment to peak-off-peak price differentials in the history of the North Hebei Power Grid. The scope of implementation is clearly defined: all types of commercial and industrial users purchasing electricity through agents within the North Hebei Power Grid's supply service area are subject to time-of-use pricing; commercial and industrial users with voltages below 1 kV are temporarily exempt from the super-peak and deep-off-peak tariffs; users such as government agencies and hospitals may voluntarily opt to participate [6].

The effectiveness of time-of-use pricing policies depends not only on the scientific soundness of the design itself, but also on the actual level of response from the consumer side[7]. As an important emerging group of electricity consumers[8], the charging behaviour of new energy vehicle users has a significant impact on the grid load curve. If users can proactively shift their charging behaviour from peak/high-demand periods to off-peak/low-demand periods in response to price signals, they will not only reduce their own electricity costs but also make a significant contribution to peak shaving and valley filling for the grid, as well as promoting the integration of renewable energy. However, do users truly understand the complex time-of-use classifications? Do they perceive such adjustments as having practical value? What factors influence their willingness to adjust their behaviour? The answers to these questions hold

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significant practical implications for policy optimisation and the allocation of charging infrastructure resources.

Accordingly, this study utilises the adjustment of the time-of-use tariff policy in the Jibei power grid as a natural experiment. Surveys were conducted before and after the policy announcement, and structural equation modelling was employed to investigate the mechanism through which policy adjustments influence the willingness of new energy vehicle users to adjust their charging behaviour[9]. Specifically, the study addresses the following core questions: regarding the effects of policy adjustments, the trends in changes to users' perception of price signals and their willingness to adjust charging behaviour before and after the announcement of the time-of-use tariff policy[10]; Regarding the mechanisms of influence: how perceived ease of use, perceived usefulness, policy awareness and subjective norms affect the willingness to adjust charging behaviour[11], with a particular focus on the most prominent factor and the mediating role played by policy awareness[12]; Regarding temporal differences: the significant variations in the strength of each influence pathway before and after the policy announcement, as well as the impact of information shock events on users' psychological decision-making processes[13]; Regarding supply-demand coupling: the gap between users' willingness to adjust charging behaviour and the availability of charging facilities during specific time slots[14], and the constraints this gap imposes on policy effectiveness.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

(1)A Study of Time-of-Use Tariffs and Electric Vehicle Charging Behaviour

Time-of-Use (TOU) pricing is a time-differentiated electricity pricing mechanism[15] that sets different electricity rates for different time periods to encourage users to alter their electricity consumption behaviour, thereby achieving peak-shaving and valley-filling of electricity demand. Extensive research both domestically and internationally indicates that time-of-use pricing can effectively influence the electricity consumption behaviour of users. At the industrial user level, time-of-use pricing has significantly reduced electricity demand during peak periods; at the residential user level, it has also demonstrated a guiding effect on shiftable loads such as air conditioning and water heaters[16].

Focusing on the field of electric vehicle charging behaviour, existing research has primarily been conducted along two dimensions. The first is the optimisation of scheduling: researchers have developed ordered charging strategies for electric vehicles based on time-of-use pricing, establishing multi-objective non-linear programming models with constraints such as charging power, user demand and battery status, and using algorithms to derive optimal charging schedules[17]. Secondly, the user response dimension: researchers have examined the guiding effect of price elasticity on vehicle owners' charging behaviour, positing that charging habits can be altered through the appropriate setting of electricity prices[18]. Questionnaire surveys and empirical analyses indicate that the greater the peak-to-off-peak price differential, the higher the proportion of users who proactively adjust their charging behaviour; simultaneously, factors such as charging convenience and information transparency also significantly influence the degree of user response.

However, existing research suffers from two main limitations. Firstly, most studies are based on the rational economic agent hypothesis, assuming that users will automatically make optimal decisions driven by price signals, whilst overlooking the moderating effects of users' cognitive constraints, information-gathering capabilities and psychological factors on decision-making. Secondly, most studies utilise cross-sectional data, making it difficult to capture the dynamic changes in users' psychological states and behavioural intentions before and after policy adjustments. Addressing these two limitations, this study introduces theoretical

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perspectives from behavioural economics and psychology and employs a quasi-experimental design to address the shortcomings of existing research.

(2)A Structural Equation Modelling Study on the Willingness to Use Charging Facilities

Structural Equation Modelling (SEM) is a multivariate statistical method capable of simultaneously handling multiple dependent and latent variables and testing complex causal relationships; it is finding increasingly widespread application in the field of charging behaviour research.

Yang Yan et al. [19], based on a sample of 405 respondents, employed structural equation modelling to investigate the factors associated with the charging behaviour of users of new energy ride-hailing vehicles. They found that factors such as mileage, personal attributes, vehicle attributes and queueing time thresholds influence charging decisions through different pathways. This study revealed the driving factors behind the charging behaviour of this specific user group—ride-hailing vehicle users—and provided guidance for the planning of charging infrastructure.

Xiong Renjiang et al.[20] constructed an integrated model using the Theory of Planned Behaviour (TPB) and the Technology Acceptance Model (TAM), incorporating a charging station satisfaction indicator, and utilised structural equation modelling to analyse the latent variables influencing residents' intention to use electric vehicles. The study found that charging station satisfaction exerts both direct and indirect effects, with the overall effects of the variables exhibiting the following characteristics: Perceived behavioural control (0.464) > charging station satisfaction (0.432) > attitude (0.386) > perceived usefulness (0.219) > subjective norm (0.195) > perceived ease of use (-0.088). These results provide important quantitative evidence for understanding residents' charging intentions, with the negative effect of perceived ease of use warranting particular attention.

Furthermore, research on public charging station user willingness to use, based on the extended TAM model, analysed the influencing mechanisms of charging facility usage behaviour from dimensions such as perceived usefulness, perceived ease of use, perceived risk and social influence. These studies provide direct methodological references for the construction of the theoretical model and questionnaire design in this study.

(3)Theoretical basis

The Technology Acceptance Model, proposed by Davis, is one of the most influential theoretical models for explaining and predicting users' acceptance of information technology. TAM posits that users' willingness to accept and use a technological system is primarily determined by two core belief variables: Perceived Usefulness (PU), which refers to the extent to which users believe that using a particular technological system can improve their work performance or yield tangible benefits; and Perceived Ease of Use (PEOU), which refers to the ease with which users believe they can use a particular technological system.

In the context of charging behaviour research, the technological system can be understood as a 'charging strategy' under a time-of-use pricing mechanism. Perceived usefulness reflects users' cognitive evaluation that implementing a time-of-use charging strategy can reduce charging costs and improve charging efficiency; perceived ease of use reflects users' perception of the convenience of understanding and implementing such a strategy. TAM provides a fundamental theoretical framework for explaining why users are willing or unwilling to adjust their charging behaviour.

Demand Response (DR) refers to the behaviour whereby electricity users proactively alter their electricity consumption patterns in response to price signals or incentive mechanisms to meet the operational requirements of the power system. Time-of-use pricing is a typical form of price-based demand response. Demand response theory emphasises that users' sensitivity to price signals and their willingness to adjust their behaviour are influenced by the following factors: the magnitude of price differentials, the transparency and accessibility of information, users' level of understanding of the power system, as well as social norms and environmental awareness.

In this study, Demand Response theory provides a theoretical foundation for understanding the roles of policy awareness and subjective norms. Policy awareness directly influences the extent to which users receive and understand price signals, serving as a prerequisite for Demand Response; subjective norms, in turn, reinforce or weaken users' willingness to respond through social influence mechanisms.

The Theory of Planned Behaviour, proposed by Ajzen, posits that behavioural intentions are influenced by three factors: attitude, subjective norms, and perceived behavioural control. In this study, subjective norms are one of the core variables. Among users of new energy vehicles, the convergence effect and social diffusion effect regarding charging behaviour are particularly pronounced. When users perceive that charging during off-peak hours has become the new norm among their colleagues, neighbours, or community, their own willingness to adjust their behaviour also increases.

(4) Research Framework and Conceptual Model

By integrating the theoretical foundations outlined above, this study constructs the conceptual model shown in Figure 1. The model comprises four exogenous latent variables and one endogenous latent variable: the exogenous latent variables are perceived ease of use (PEOU), perceived usefulness (PU), policy awareness (PA) and subjective norms (SN); the endogenous latent variable is willingness to adjust charging behaviour (CAI).

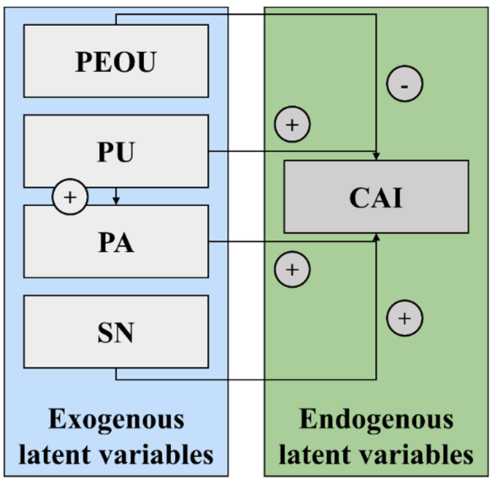

Figure 1. Conceptual model

The model posits that PEOU, PU, PA and SN influence CAI through pathways of varying directions and strengths; simultaneously, policy awareness mediates the relationship between perceived usefulness and willingness to adjust charging behaviour. The policy adjustment time point serves as a grouping variable to examine differences in pathway coefficients before and after the policy's announcement.

3. RESEARCH HYPOTHESES AND MODEL DEVELOPMENT

(1)Formulation of the research hypothesis

Perceived usability refers to the ease with which users perceive the process of understanding and implementing time-of-use charging strategies. When time-of-use periods are complex and

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calculations are cumbersome, users may abandon proactive adjustments to their charging behaviour due to excessive cognitive load. The Jibei Power Grid's latest adjustment divides the year into four categories of time periods: summer (June–August), winter (January, November and December), February (separate), spring and autumn (March–May, September–October)—with the time-of-day divisions and tariff tiers varying across seasons. Winter features a deep-off-peak period (12:00–15:00), whilst summer has a peak period (18:00–21:00); spring and autumn have only three tiers: off-peak, standard and peak. Users need to expend considerable cognitive effort to remember when it is most cost-effective to charge.Existing research indicates that, in the field of charging services, perceived ease of use has an indirect negative effect. In other words, when users perceive policies to be overly complex, they may develop cognitive avoidance and become reluctant to actively adjust their charging behaviour. Based on this, we propose H1: Perceived ease of use negatively influences users' willingness to adjust their charging behaviour.

Perceived utility refers to the extent to which users believe that adopting a time-of-use charging strategy will yield tangible benefits. When users recognise that charging during off-peak or super-off-peak periods can significantly reduce charging costs, their willingness to adjust their behaviour increases accordingly. In this adjustment, the peak-to-off-peak price differential reaches as high as 70%, meaning that off-peak electricity prices are 70% lower than the standard rate, peak prices are 70% higher, and super-off-peak prices are a further 20% lower than off-peak rates. This implies that the ratio of super-off-peak prices to peak prices can reach 0.14, meaning that super-off-peak prices are approximately 14% of peak prices, representing a significant economic incentive. Furthermore, perceived utility encompasses not only personal economic benefits but also contributions to society. When users perceive their behaviour to have positive social value, their willingness to adjust their behaviour also increases. Based on this, we propose H2: Perceived utility has a positive influence on users' willingness to adjust their charging behaviour.

Policy awareness refers to the extent to which users understand the content of time-of-use electricity pricing policies, the time bands, and price fluctuations. Information asymmetry is a key factor constraining the efficiency of price signal transmission. Even if the policy design is perfectly sound, behavioural adjustments cannot be expected if users lack awareness of it. The policy adjustment by the Jibei Power Grid was announced on 26 November 2025 and came into effect on 1 January 2026, with a policy awareness campaign period of approximately 35 days in between; this provided a natural setting for examining the mediating effect of policy awareness. Policy awareness plays a dual role in this study: on the one hand, it directly drives users' willingness to adjust their behaviour; when users clearly know when charging is cheapest and when it is most expensive, they are more likely to make rational charging decisions; on the other hand, it may act as a mediating variable, transmitting the influence of perceived usefulness on the willingness to adjust behaviour; only when users are first aware of the policy content can they translate perceived usefulness into actual willingness to adjust. Accordingly, we propose: H3a: Policy awareness positively influences users' willingness to adjust their charging behaviour. H3b: Policy awareness mediates the relationship between perceived usefulness and willingness to adjust charging behaviour.

Subjective norms refer to the pressure users feel regarding behavioural expectations from social groups, namely whether others are behaving in the same way. According to the Theory of Planned Behaviour, subjective norms are a key antecedent of behavioural intention. Among users of new energy vehicles, the convergence effect and social diffusion effect regarding charging behaviour are particularly pronounced. When users perceive that charging during off-peak hours has become the new norm amongst their colleagues, neighbours or community, their own willingness to adjust their behaviour also increases. Furthermore, discussions and sharing within new energy vehicle owner communities and on social media also reinforce the

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influence of subjective norms. Based on this, Hypothesis 4 is proposed: Subjective norms have a positive influence on users' willingness to adjust their charging behaviour.

The announcement of the time-of-use electricity pricing policy constitutes an information shock in itself. Prior to the announcement, users lacked understanding of the policy's content; their charging behaviour was primarily based on the existing tariff structure and established habits, with only vague expectations regarding future policy adjustments. Following the announcement, users learn the specific details of the policy through various channels—including official notifications, news reports, social media and push notifications from charging apps—leading to systematic changes in their sensitivity to price signals and their expectations regarding behavioural adjustments. Specifically, following the policy announcement, users' awareness of the policy will increase significantly, and their perceived usefulness will also be enhanced due to the clarity of the policy information; consequently, the driving effect of these variables on the willingness to adjust behaviour may be more pronounced than before the policy was announced. Based on this, it is proposed that, following the policy announcement, the path coefficients of each latent variable on the willingness to adjust charging behaviour are significantly higher than before the policy was announced.

(2) Theoretical model

Table 1. Operational definitions of each latent variable

Latent variable	Operational definition	Number of items
PEOU	The perceived ease with which users understand and implement time-of-use charging strategies	4
PU	The actual benefits users believe can be gained from implementing a time-of-use charging strategy	5
PA	Users' understanding of the specific details of the time-of-use electricity pricing policy	5
SN	Pressure perceived by users regarding expectations of charging behaviour from significant others or social groups	3
CAI	The extent to which users are willing to proactively adjust their charging times and opt to charge during off-peak or super-off-peak periods following policy changes	4

The model comprises two parts: the measurement model and the structural model. The measurement model specifies that each latent variable is measured by a number of observed variables, reflecting the factor relationships between the latent variables and the observed variables. The structural model depicts the causal pathways between the latent variables, including four direct pathways as well as mediating pathway.

4. STUDY DESIGN AND DATA COLLECTION

(1)Questionnaire design

The questionnaire consists of three sections: the first section covers basic user information, the second section measures latent variables, and the third section assesses perceptions of charging facilities.

Basic user information includes gender, age, occupation, monthly income, type of new energy vehicle, primary charging method, charging voltage level, average daily mileage, number of times charged per week, and length of time the new energy vehicle has been in use.Latent

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variables are measured using a 5-point Likert scale, where 1 = “Strongly disagree”, 2 = “Disagree”, 3 = “Neutral”, 4 = “Agree”, and 5 = “Strongly agree”.

Table 2. Questionnaire Variable Settings

Variable	No.	Title
PEOU	1	I have no difficulty understanding the rules governing the different time bands in time-of-use pricing (including the differences between summer, winter, February, and spring and autumn).
	2	I can accurately identify the specific times of the peaks, peaks, plateaus, troughs and troughs.
	3	Channels for obtaining information on time-of-use electricity pricing policies are convenient and accessible.
	4	I’m not particularly confused about how to make the most of off-peak charging periods.
PU	1	Charging during off-peak hours can significantly reduce my charging costs.
	2	Charging during the midday off-peak hours in winter (12:00–15:00) is very appealing to me.
	3	Making sensible use of time-of-use pricing offers clear financial benefits for me.
	4	I believe that the time-of-use pricing mechanism helps to promote the uptake of renewable energy and has social value.
	5	Overall, the benefits of implementing a time-of-use pricing scheme outweigh the drawbacks.
PA	1	I am fully aware that, following this adjustment, the summer peak period is from 18:00 to 21:00.
	2	I am fully aware that during the winter months and in February, there is an off-peak period (12:00–15:00), during which electricity prices are 20% lower than the standard off-peak rate.
	3	I am aware of the fluctuation range (±70%) for peak and off-peak electricity prices.
	4	I have followed the official notices or news reports regarding adjustments to the time-of-use electricity pricing policy in the Jibei Power Grid.
	5	I can state the specific percentage changes for peak and off-peak electricity prices in this adjustment.
SN	1	Most of the electric vehicle owners I know are keeping a close eye on changes in charging prices.
	2	Most of the electric vehicle owners I know choose to charge their cars during off-peak or super-off-peak hours.
	3	My family and friends encourage me to recharge during difficult times.
CAI	1	Following the policy changes, I will proactively adjust my charging times to reduce charging costs.
	2	I will try to schedule charging during off-peak or very low-demand periods.
	3	Even if it means sacrificing some convenience (such as staying up late or getting up early to plug in my devices), I am still willing to comply with the time-of-use pricing policy.
	4	I would recommend charging during off-peak or super-off-peak hours to other owners of new energy vehicles.
CF	1	I am satisfied with the overall density of the current charging infrastructure.
	2	The charging points in my estate are available during off-peak hours at night (e.g. 1:00–6:00 in winter).
	3	The charging points near my office/workplace are convenient to use during the midday off-peak period (12:00–15:00).
	4	During the summer peak hours (18:00–21:00), there are often long queues at the estate’s charging points.
	5	The waiting time at charging points is a factor that influences my decision on when to charge.

(2) Data Collection Solution

This study employs a pre-post comparison design within a quasi-experimental framework. The questionnaire was administered on two occasions: the first survey was conducted prior to the official release of the policy. At this stage, users were not yet aware of the policy changes; the questionnaire primarily measured their current charging habits, perceptions of the existing electricity pricing structure, and their experience of using charging facilities. The purpose of this survey was to establish a baseline prior to the policy intervention. The second round of questionnaires was conducted after the policy was announced but before its formal implementation. By this stage, users had become aware of the policy details through various channels. In addition to measuring the same latent variables as the first round, this questionnaire focused on assessing policy awareness and the willingness to adjust behaviour. The purpose of this survey was to evaluate changes in psychological attitudes and behavioural intentions following the policy information shock.

The survey targets new energy vehicle users in Tangshan City within the service area of the North Hebei Power Grid. Questionnaires were distributed via a combination of online and offline channels. Online channels included WeChat groups for new energy vehicle owners and promotions via Douyin/WeChat communities; offline channels included on-site QR code scanning at public charging stations, new energy vehicle dealerships, and community noticeboards.

According to the empirical rule for sample size in structural equation modelling, the sample size should be at least 10–20 times the number of observed variables. As this study has 21 observed variables, the minimum sample size is 210–420 responses. Taking into account the two-round comparative analysis and potential invalid questionnaires, the plan is to collect no fewer than 300 valid questionnaires per round, totalling no fewer than 600 across both rounds.

(3)Data analysis methods

SPSS 26.0 was used to perform descriptive statistical analysis, reliability and validity tests (Cronbach's α), correlation analysis and independent samples t-tests. AMOS 26.0 was used for structural equation modelling. The analytical procedures included reliability testing to calculate Cronbach's α coefficients and composite reliability (CR) for each latent variable, with requirements that $\alpha > 0.7$ and $CR > 0.7$. Validity tests involved calculating the average variance extracted (AVE) for each latent variable, with a requirement that $AVE > 0.5$; the Fornell-Larcker criterion was used to test discriminant validity, requiring that the square root of the AVE for each latent variable be greater than its correlation coefficient with other latent variables. Measurement model validation utilised confirmatory factor analysis (CFA) to assess the model fit, with key fit indices including χ^2/df (<3), RMSEA (<0.08), CFI (>0.9), TLI (>0.9) and SRMR (<0.08). Structural model analysis and hypothesis testing were conducted to examine the significance and direction of path coefficients. Multi-group analysis used the period before and after policy implementation as grouping variables to test the significance of differences in path coefficients. The mediating effect of policy awareness was tested using the Bootstrap method, with confidence intervals for the indirect effect calculated. Additionally, tests for normality, common method bias, multicollinearity, comparison of competing models, and robustness were performed.

5. DATA ANALYSIS AND EMPIRICAL FINDINGS

(1) Sample characteristics and descriptive statistics

The first round of the survey (prior to the policy announcement) yielded a total of 356 completed questionnaires. After excluding invalid responses—such as those with repetitive answers or missing key information—328 valid samples were obtained, representing a valid response rate of 92.1%. The second round of the survey (conducted after the policy was

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announced) yielded a total of 372 questionnaires, resulting in 341 valid samples, with a valid response rate of 91.7%. The combined total of valid samples from both rounds was 669. The distribution of the samples across both rounds was largely consistent in terms of gender, age and vehicle type, indicating that the samples are reasonably comparable. The composition of the pooled samples is shown in Figure 2.

The means, standard deviations and results of the tests for differences in the latent variables before and after the policy announcement are shown in Table 2. Note: The figures in the table represent mean values; Cohen's d is an effect size, where 0.2 indicates a small effect, 0.5 a medium effect, and 0.8 a large effect.

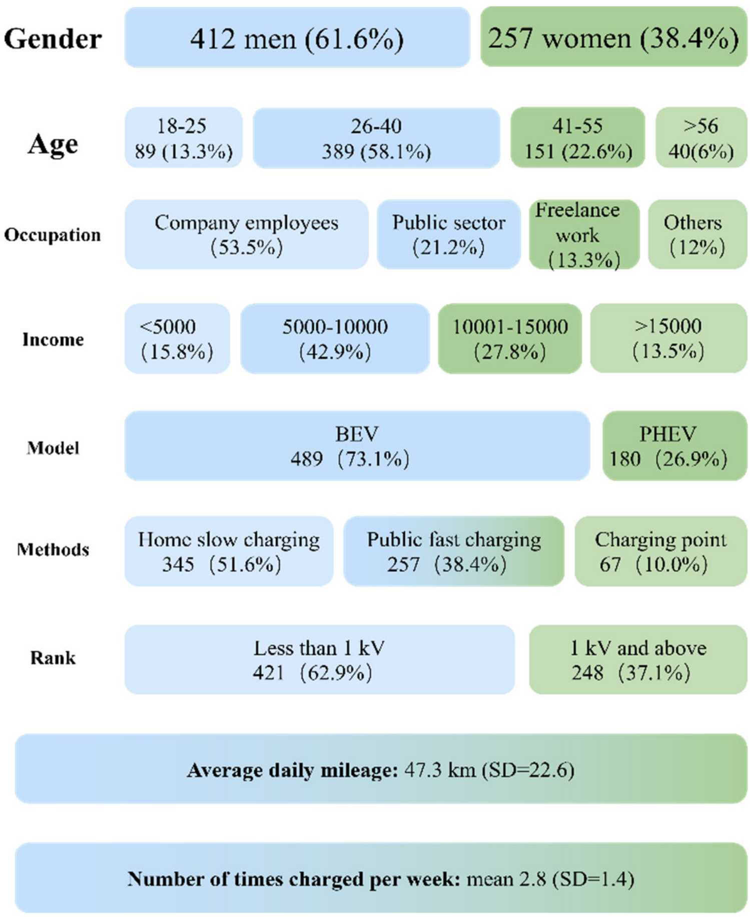

Figure 2. Descriptive statistics for the combined sample

Table 2. Comparison of mean values of latent variables before and after the policy announcement

Latent variable	F	B	difference in means	t	p	Cohen's d
PEOU	2.870.76	3.12 0.81	+0.25	4.23	<0.001	0.32
PU	3.560.69	4.18 0.72	+0.62	8.56	<0.001	0.88
PA	2.410.84	4.05 0.79	+1.64	15.32	<0.001	2.01
SN	2.930.78	3.41 0.85	+0.48	5.91	<0.001	0.59
CAI	3.180.82	4.09 0.74	+0.91	10.47	<0.001	1.17

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The results show that following the policy announcement, the mean values of all latent variables rose significantly. Among these, the increase in policy awareness was the most pronounced (+1.64, Cohen's d = 2.01, very large effect), indicating that the policy announcement and subsequent publicity rapidly improved users' understanding of the policy content. The increase in willingness to adjust charging behaviour was also substantial (+0.91, large effect), suggesting that users expect to respond positively to the policy adjustments. Perceived usefulness also increased substantially (+0.62, large effect), reflecting users' high level of acceptance of new mechanisms such as off-peak electricity tariffs.

It is particularly noteworthy that, among the five items measuring policy awareness, the mean scores for 'Awareness of Off-Peak Periods' (PA2) and 'Awareness of Peak Periods' (PA1) showed the most significant increases—rising from 2.12 to 4.31 and from 2.35 to 4.22 respectively. This indicates that users paid the most attention to and retained the best memory of the two most distinctive elements of this adjustment.

(2) Reliability and Validity Testing

The internal consistency reliability of the measurement scale was assessed using Cronbach's α and composite reliability (CR). The results are shown in Table 3.

Table 3. Results of the reliability test

Latent variable	Number of items	Cronbach's α	CR
PEOU	4	0.846	0.851
PU	5	0.890	0.895
PA	5	0.902	0.907
SN	3	0.813	0.821
CAI	4	0.877	0.883

The Cronbach's α coefficients for each latent variable ranged from 0.813 to 0.902, all exceeding the accepted threshold of 0.7; the composite reliability (CR) ranged from 0.821 to 0.907, all exceeding 0.7. This indicates that the scale possesses good internal consistency.

Validity was tested using the Average Variance Extract (AVE). The results are shown in Table 4.

Table 4. Results of convergent validity tests

Latent variable	AVE
PEOU	0.587
PU	0.623
PA	0.673
SN	0.602
CAI	0.648

The AVEs for each latent variable ranged from 0.587 to 0.673, all exceeding the recommended threshold of 0.5, indicating that the measurement model possesses good convergent validity.

Discriminant validity was assessed using the Fornell–Larcker criterion, which stipulates that the square root of the AVE for each latent variable should be greater than the correlation

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coefficient between that latent variable and any other latent variable. The results are shown in Figure 3.

	PEOU	PU	PA	SN	CAI
PEOU	0.766				
PU	0.214	0.789			
PA	0.178	0.458	0.820		
SN	0.302	0.367	0.402	0.776	
CAI	0.085	0.512	0.589	0.413	0.805

Figure 3. Results of the discriminant validity test

Note: The bolded values on the diagonal represent the square roots of the AVE, whilst the values in the lower triangle represent Pearson's correlation coefficients.

The square roots of the AVE for each latent variable are greater than the off-diagonal correlation coefficients in their respective rows and columns, indicating that the measurement model possesses good discriminant validity.

(3)Verification of measurement models

The measurement model was validated using confirmatory factor analysis (CFA) to assess its goodness of fit. The CFA results based on the combined sample (N = 669) are shown in Table 5.

Table 5. Measurement of model fit metrics

Fitting criteria	Measured values	Recommendation criteria	Judgement
χ^2/df	2.86	<3	Passed
RMSEA	0.058	<0.08	Passed
CFI	0.934	>0.9	Passed
TLI	0.921	>0.9	Passed
SRMR	0.046	<0.08	Passed

All fit indices met or exceeded the recommended standards, indicating that the measurement model fits well and that the observed variables effectively measure their corresponding latent variables.

The standardised factor loadings for each observed variable ranged from 0.62 to 0.89 and were all significant at the $p < 0.001$ level, suggesting that the observed variables have a strong explanatory power for the latent variables. Among these, the items with the highest loadings were PA2 ("I am fully aware that off-peak and super-off-peak periods are in place during winter and in February", loading 0.89) and CAI2 ("I will endeavour to schedule my charging activities

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during off-peak or super-off-peak periods" , loading 0.86), reflecting the strong level of user attention to and willingness to respond to super-off-peak policies.

(4)Structural Models and Hypothesis Testing

Once the measurement model has been validated, a structural model is constructed to examine the path relationships between the latent variables. The fit indices for the structural model are shown in Table 6.

Table 6. Structural model fit statistics

Fitting criteria	Measured values	Recommendation criteria	Judgement
χ^2/df	2.93	<3	Passed
RMSEA	0.061	<0.08	Passed
CFI	0.928	>0.9	Passed
TLI	0.915	>0.9	Passed

The model fits well, allowing for path analysis and hypothesis testing. The results of the structural equation modelling path analysis based on the combined sample are shown in Table 7.

Table 7. Path coefficients in structural models and hypothesis testing

Assum	Path	coefficient	SE	CR	p	Clusion
H1	PEOU → CAI	-0.124	0.042	-2.95	0.003	Support
H2	PU → CAI	0.347	0.045	7.71	<0.001	Support
H3a	PA → CAI	0.428	0.041	10.44	<0.001	Support
H4	SN → CAI	0.186	0.038	4.89	<0.001	Support

For H1 (perceived ease of use → willingness to adjust), the path coefficient is −0.124 ($p = 0.003$), indicating a negative direction consistent with the hypothesis. This suggests that for every one standard deviation increase in users' perception of policy complexity, their willingness to adjust their charging behaviour decreases by 0.124 standard deviations. Although the effect size is small, it is statistically significant, indicating that policy design should prioritise user-friendliness.

For H2 (Perceived Usefulness → Willingness to Adjust), the path coefficient is 0.347 ($p < 0.001$), indicating a positive and significant relationship. The stronger users' perception of the economic and social value of the time-of-use pricing strategy, the higher their willingness to adjust. This is the second strongest influencing factor.

For H3a (Policy Awareness → Willingness to Adjust), the path coefficient is 0.428 ($p < 0.001$), the highest coefficient among all paths. Users' understanding of the specific details of the policy (time periods, floating rates) is the most critical factor driving behavioural adjustment. This finding emphasises the central role of policy promotion and information dissemination.

For H4 (Subjective Norm → Willingness to Adjust): the path coefficient is 0.186 ($p < 0.001$), indicating a significant positive relationship. The charging behaviour choices of those around an individual exert a positive social influence on their willingness to adjust, although the strength of this influence is lower than that of perceived usefulness and policy awareness.

The structural model explains 0.463 of the variance (R^2) in the endogenous latent variable CAI, meaning that the four exogenous latent variables collectively account for 46.3% of the

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variation in the intention to adjust charging behaviour, demonstrating a moderately high level of explanatory power.

(5)Multi-group analysis before and after the policy was announced

To examine H5 (the difference in path coefficients before and after the policy was announced), a multi-group structural equation model was employed. First, a measurement invariance test was conducted; the results indicated that both configural and metric invariance were established, allowing for a comparison of path coefficients. The results of the multi-group analysis are presented in Tables 8.

Tables 8. Comparison of path coefficients before and after the policy was announced

Path	F	B	Coefficient difference	Wald χ^2	p
PEOU → CAI	-0.098*	-0.146**	0.048	1.24	0.265
PU → CAI	0.251***	0.412***	0.161	4.87	0.027
PA → CAI	0.311***	0.509***	0.198	6.32	0.012
SN → CAI	0.143*	0.217**	0.074	2.01	0.156

Note: p<0.05, p<0.01, p<0.001.

Following the policy announcement, the influence of perceived usefulness on the willingness to adjust significantly increased. This is because, after the policy was announced, users obtained specific information, and their perception of usefulness shifted from abstract to concrete, thereby driving behavioural willingness more strongly. Following the policy announcement, the influence of policy awareness on the willingness to adjust significantly increased. Prior to the policy announcement, users had little understanding of the policy, and variations in awareness stemmed primarily from vague impressions of the existing electricity pricing mechanism; following the announcement, awareness increased substantially and the information became clear, correspondingly amplifying its effect on behaviour. Although the path coefficients for perceived ease of use and subjective norms changed between the two periods, they did not reach statistical significance ($p > 0.05$). The H5 hypothesis is partially supported: the driving effects of perceived usefulness and policy awareness significantly strengthened following the policy announcement, reflecting the profound reshaping of users' psychological and behavioural patterns by the information shock event.

(6)Testing for mediation effects

Using the Bootstrap method, with 5,000 bootstrap samples and a 95% confidence interval, we tested the mediating effect of policy awareness on the relationship between perceived usefulness and willingness to adjust charging behaviour (H3b). The results are shown in Table 9.

Table 9. Testing the mediating effect of policy awareness

Effect type	Effect size	Standard error	95% confidence interval	Rate
Direct effect PU→CAI	0.347	0.045	[0.259, 0.435]	65.1%
Indirect effects PU→PA→CAI	0.186	0.032	[0.132, 0.247]	34.9%
Overall effect	0.533	0.051	[0.433, 0.633]	100%

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The 95% confidence interval for the indirect effect is [0.132, 0.247], which does not include zero, indicating that the mediating effect is significant. Policy awareness plays a partial mediating role between perceived usefulness and willingness to adjust charging behaviour, with the mediating effect accounting for 34.9% of the total effect. This result highlights the importance of policy communication: users' perception of policy utility is partially translated into willingness to adjust behaviour via the mediating pathway of 'awareness'. In other words, even if users consider time-of-use pricing to be useful, if they are unaware of the specific details (time slots, fluctuation rates), this perception of utility is unlikely to translate into actual action.

(7)Perception of Charging Infrastructure and Willingness–Ability Gap

Table 10 shows users' assessments of the availability of charging facilities during different time slots in the second round of the survey, which was conducted after the policy was announced.

Table 10. Evaluation of the availability of charging facilities by time slot

Title	Percentage agreeing/ somewhat agreeing	Average (out of 5)
CF2	46.3%	3.12
CF3	31.8%	2.68
CF4	67.2%	3.94
CF5	58.7%	3.76

Although the average willingness to adjust charging behaviour stands at 4.09, indicating that the vast majority of users are willing to proactively shift their charging times to off-peak or deep off-peak periods, there are significant shortcomings in the actual availability of charging facilities:

The winter off-peak period (12:00–15:00) falls during the midday hours; for office workers, the availability of charging points near their workplace is crucial. However, only 31.8% of users consider them convenient to use, meaning that nearly seven in ten users face issues with charging points being unavailable or inconvenient during the midday off-peak period.

Summer peak periods (18:00–21:00) coincide heavily with residents' charging needs after work. 67.2% of users report that charging points in their residential estates are frequently congested with queues, which is precisely the high-load period that policy aims to encourage users to shift away from. If users cannot charge smoothly during peak periods, they may be forced to charge at later times or abandon orderly charging altogether.

Availability during night-time off-peak hours (e.g. 01:00–06:00 in winter) is relatively good (46.3%), but more than half of users still believe that charging points in their residential complexes are not free during this period, reflecting issues such as charging points being occupied without charging or insufficient capacity.

This finding reveals the essence of the coupling between demand fluctuations and resource allocation optimisation: whilst policies encourage users to shift their charging behaviour to off-peak or deep-off-peak periods, if the supply of charging infrastructure during these periods is insufficient, users' intentions cannot be translated into actual behaviour. There is a clear gap between users' willingness to adjust their behaviour and the availability of charging infrastructure.

6. DISCUSSION

(1)A theoretical explanation of the effects of policy adjustments

One of the key findings of this study is that policy awareness has the most significant impact on the willingness to adjust charging behaviour, with a path coefficient of 0.428 and a total effect of 0.533. This result can be explained by the theories of bounded rationality and information transmission in information economics.

Traditional economics assumes that rational economic agents make optimal decisions under conditions of perfect information; however, in reality, users' decisions are limited-rationality choices subject to cognitive constraints. The effectiveness of time-of-use pricing policies relies heavily on the efficiency of information dissemination, and users' level of awareness regarding policy content directly determines the quality of price signal transmission. In the policy adjustment of the North Hebei Power Grid, there was a time window of approximately 35 days between the policy announcement and its formal implementation, which was precisely the critical period for information diffusion and the formation of public awareness. The research findings indicate that effective publicity during this period, delivered through channels such as official notifications and media reports, significantly enhanced users' level of awareness, thereby driving a shift in their behavioural intentions.

It is worth noting that the mediating effect of policy awareness accounts for 34.9% of the total effect; this implies that more than one-third of the influence of perceived usefulness on the willingness to adjust is realised through a pathway where cognition precedes action. The theoretical significance of this finding lies in the fact that, in the context of policy intervention, cognitive variables are not only independent antecedent variables but also serve as a pivotal link in conveying perceived value. This suggests that future research should consider policy awareness as a key mediating variable when constructing user behaviour models.

The path coefficient for perceived usefulness (0.347) is also statistically significant and has practical implications. This validates the principle of price elasticity in economics: when the peak-off-peak price differential expands to 70% and off-peak electricity prices are further reduced by 20%, the strength of the economic incentive is sufficient to alter users' rational choices. However, it is worth noting that the influence of perceived usefulness was already present prior to the policy announcement (0.251), indicating that users already possessed a basic understanding of and positive evaluation of the peak-off-peak pricing mechanism itself; following the policy announcement, this influence further strengthened (0.412), reflecting that the introduction of the deep-off-peak period and the resetting of the peak period in this adjustment provided users with clearer and more attractive price signals.

Although the negative impact of perceived ease of use (-0.124) is not significant in magnitude, its direction offers important policy implications. The Jibei Power Grid's adjustment divides the year into four categories of time periods, with the division varying across seasons. In summer, there is a peak period (18:00–21:00) but no deep off-peak period; in winter, there is a deep off-peak period (12:00–15:00) and a peak period (17:00–19:00); in February, there is a deep off-peak period but no peak period (the peak period runs from 16:00 to 22:00); whilst in spring and autumn, there are only three tiers: off-peak, standard and peak. Users need to expend considerable cognitive resources to remember when it is most cost-effective to charge. Research has found that when users perceive policies to be overly complex, their willingness to adjust their behaviour actually decreases. This suggests a tension between the precision of policy design and the ease of user comprehension, which needs to be balanced in subsequent adjustments.

The path coefficient for subjective norms is 0.186 ($p<0.001$); although lower than that for perceived usefulness and policy awareness, it remains statistically significant. This finding is

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consistent with the Theory of Planned Behaviour, indicating the presence of a peer effect on charging behaviour within the new energy vehicle user group. Within car owner communities, on social media and in everyday social interactions, when users observe an increasing number of people charging during off-peak or deep-off-peak periods, they experience a herd mentality and social pressure, thereby strengthening their own willingness to adjust their behaviour.

(2)A dialogue with existing research

This study engages in a valuable dialogue with the existing literature. Compared with technical studies focusing on the optimisation of power system dispatch, this study adopts a behavioural perspective to reveal the psychological mechanisms through which policy adjustments influence charging behaviour. Unlike the findings of Xiong Renjiang et al., who identified the 'perceived behavioural control effect' as the strongest, this study found that policy awareness played the most significant driving role in the context of policy adjustments (0.428 vs. 0.464); although the numerical values are similar, the variables differ. This discrepancy stems from differences in the research contexts: this study focuses on the 'information shock window' before and after policy adjustments, where the variance in policy awareness is greater, naturally making its impact more pronounced; whereas Xiong Renjiang et al.'s study was conducted under normal conditions, where perceived behavioural control—that is, users' assessment of their own ability to execute charging behaviour—may be more significant.

Regarding the direction of the effect of perceived ease of use, this study aligns with that of Xiong Renjiang et al., both identifying a negative effect (−0.124 vs. −0.088), thereby validating the cross-contextual stability of the principle that 'cognitive load inhibits behavioural intention'. This suggests that in the field of charging services, the 'user-friendliness' of policy design and interface interaction does indeed influence users' willingness to use the service.

This study is also unique in its methodological approach. Most existing SEM studies employ cross-sectional designs, making it difficult to capture the temporal effects of policy interventions. This study adopted a quasi-experimental design comparing pre- and post-policy periods. Through multi-group SEM analysis, it revealed structural changes in path coefficients before and after policy implementation: the path coefficient for perceived usefulness increased significantly from 0.251 to 0.412, whilst that for policy awareness rose significantly from 0.311 to 0.509, providing stronger evidence to support causal inferences.

7. CONCLUSION

This study utilises the adjustment to the time-of-use electricity pricing policy implemented in the North Hebei Power Grid on 1 January 2026 as a natural experiment. Questionnaire surveys were conducted both before and after the policy announcement, and structural equation modelling was employed to empirically analyse the mechanism through which the policy adjustment influences the charging behaviour of new energy vehicle users. The following main conclusions were drawn:

(1) Adjustments to the time-of-use electricity pricing policy have significantly increased users' perceived usefulness and awareness of the policy, thereby driving a greater willingness to adjust charging behaviour. Following the policy announcement, the mean willingness to adjust charging behaviour rose from 3.18 to 4.09, an increase of 28.6%; policy awareness jumped from 2.41 to 4.05, an increase of 68.0%; and perceived usefulness rose from 3.56 to 4.18, an increase of 17.4%. Effect size analysis indicates that the change in policy awareness represents a very large effect (Cohen's d = 2.01), suggesting that the policy's promotional impact was significant.

(2)Policy awareness is the most critical factor influencing the willingness to adjust charging behaviour, with a path coefficient of 0.428, and it plays a significant mediating role between perceived usefulness and willingness to adjust, accounting for 34.9% of the indirect effect. This indicates that the effectiveness of policy communication is a key prerequisite for successful policy implementation, as users can only translate their perception of usefulness into a willingness to adjust their behaviour once they are aware of the specific details of the policy.

(3)Perceived usefulness (0.347) and subjective norms (0.186) have a significant positive influence on the willingness to adjust behaviour, whilst perceived ease of use (-0.124) exhibits a slight negative influence. This result suggests that policy design must strike a balance between refinement—i.e. precisely guiding load management—and user-friendliness—i.e. reducing the cognitive burden.

(4)Following the policy's release, the driving effects of perceived usefulness and policy awareness on the willingness to adjust behaviour significantly increased. Multigroup analysis revealed that the path coefficient for perceived usefulness rose from 0.251 to 0.412 ($p=0.027$), whilst that for policy awareness increased from 0.311 to 0.509 ($p=0.012$), reflecting the profound reshaping of users' psychological and behavioural patterns following the information shock event.

(5)There is a clear 'willingness–ability' gap between users' willingness to adjust their charging behaviour and the availability of charging facilities during specific time periods. During winter off-peak hours (12:00–15:00), the availability of charging points in office areas was only 31.8%, whilst during summer peak hours (18:00–21:00), the congestion rate of residential charging points reached 67.2%. This indicates that the optimisation of charging infrastructure resource allocation requires a two-way coupling with demand-side response.

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