

# Management of Household Energy Saving and Its Green Alternatives: Information of Chinese Energy Consumption Patterns

Qiao Qiao, Xiamen University, China

Boqiang Lin, Xiamen University, China\*

 <https://orcid.org/0000-0002-1308-400X>

## ABSTRACT

Given the significant growth potential in households' energy consumption in China, studying household consumption behavior becomes even more valuable. This study explores factors influencing the shift in households' energy-saving preferences from habitual energy-saving behavior to consumption-oriented energy-saving behavior, as well as to analyze the potential for using other green alternatives to traditional energy in energy consumption. Empirical results reveal an inverted U-shaped relationship between household income and energy consumption, occurring when energy-saving awareness (ESA) exceeds a critical threshold. Below this threshold, household income is positively correlated with energy consumption. Further analysis indicated that once income exceeds the turning point, households' higher ESA leads to reduced energy consumption, indicating potential for green alternatives in higher-income households. Overall, the study highlights how awareness and income interact to shape energy-saving choices, emphasizing the potential for sustainable energy options in affluent households.

## KEYWORDS

Energy-Saving Behavior, Engel Curve, Green Alternatives of Conventional Electricity, Habitual Energy Saving Behavior, Residential Electricity Consumption

## 1. INTRODUCTION

In China, the power sector contributes to over 40% of total carbon emissions (He et al., 2022). With the Chinese government proposing a carbon-neutral timeline by 2060 (Jia et al., 2022), regulating electricity emissions has become a pressing concern (Qiao and Lin, 2023; Zhang and Gao, 2016). The power sector faces significant pressure to reduce emissions, with particular emphasis on the reduction of emissions from industries, especially those that are energy-intensive (Jia et al., 2023; Otsuka, 2023). Some scholars have explored the path to emission reduction in the power industry from the perspective of commercial electricity consumption. However, there is a limited number of studies examining the

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\*Corresponding Author

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carbon emission reduction effects of household energy consumption (Xin-gang and Pei-ling, 2020). This is primarily due to the difficulty in regulating carbon emissions from household electricity use, and the challenge in accurately calculating the carbon potential of households. Moreover, there is currently a scarcity of comprehensive data on household energy consumption behavior in China, posing significant obstacles to the research on household carbon emission reduction (Wang and Lin, 2021a).

In recent years, the proportion of residential electricity consumption in China has consistently risen (Mack and Tampe-Mai, 2016). Consequently, there has been a renewed focus on household energy consumption through data obtained from household surveys (Barr et al., 2005; Dillman et al., 1983; Park and Kwon, 2017). However, measuring residents' energy-saving behavior and exploring the endogenous driving factors and pathways of residents' energy-saving are prerequisites for studying carbon emission reduction among residents. Residential users engage in energy-saving for two primary purposes: first, to reduce their utilities bills, and second, to realize their preferences for environmental behavior. These two approaches can yield markedly different outcomes. While the first method of energy-saving may result in a reduction of carbon emissions, behavior driven by cutting bills has limited potential. This is because households adopting energy-saving due to budget constraint tend to have inherently lower electricity consumption, thus offering limited potential for carbon reduction. Conversely, the second type of household, characterized by energy-saving behaviors driven by green and low-carbon preferences, presents greater potential for emission reduction. The scope for emission reduction in this context arises from the fact that some residents are more inclined to invest in energy-efficiency products, technologies, or other green alternatives to conventional electricity, rather than simply curtailing their energy consumption. This inclination creates more substantial opportunities for emission reduction. To delve deeper into the potential for emission reduction in residents' electricity consumption behavior, our intention is to categorize residents' energy-saving goals based on their environmental awareness. This classification will enable us to investigate the various electricity consumption patterns that residents with different characteristics may adopt under distinct energy-saving objectives.

The diverse electricity consumption patterns observed among residential users can be traced back to certain inherent characteristics of electricity as a commodity. Firstly, electricity is considered a necessity, and its consumption can be effectively modeled using the Engel curve. Traditionally, electricity was indispensable for households and was commonly viewed as a normal commodity in literature. However, recent efforts to reduce carbon emissions have altered this perception. Historically, conventional electricity, mainly sourced from fossil fuels, was associated with potential pollution, introducing negative connotations to conventional electricity. Hence, certain environmentalist groups perceive the overconsumption of electricity, particularly that derived from conventional sources, often referred to as "brown electricity," as environmentally detrimental. This psychological factor has consequently altered the cognitive preferences of this consumer segment towards conventional electricity. Consumer preferences play a pivotal role in shaping the indifference curve for a product, thereby defining its attributes as normal goods, inferior goods, or luxury goods. Over time, as a need is fulfilled, a luxury may become a necessity, and normal goods may transition into inferior goods. This study reveals an inconsistency in the attribute categorization of electricity among different households, serving as an intrinsic factor driving diverse consumption patterns among households.

In the past, studies on the electricity consumption behavior of Chinese residents primarily focused on their willingness to save energy. Some literature explores the habitual energy-saving and consumption-oriented energy-saving behaviors among Chinese residents separately. However, there has been limited attention devoted to analyzing the underlying causes of these habitual and consumption-oriented energy-saving behaviors, as well as the transitions between them. This study identifies a notable connection between high income levels and the shift of residents from habitual energy-saving consumption. Environmental awareness as a key driver of this behavioral shift. These two factors, environmental awareness and income level, propel residents from lacking energy-saving

preferences to developing such preferences and from engaging in habitual energy-saving to adopting consumption-oriented energy-saving.

The variable representing residents' environmental awareness is measured through the factor analysis method. A composite variable is constructed from a household resident's selection of energy-efficient appliances and their comprehension of their electricity contract and other relevant knowledge. This variable serves as a proxy for their preference for consumption-oriented energy-saving, supplanting the initial environmental preference variable. The primary objective of this study is to empirically demonstrate the impact of income and environmental awareness on residents' energy consumption behavior. Additionally, the study aims to explore the potential for Chinese residents to adopt green alternatives to conventional electricity consumption.

This study contributes to the literature in threefold. Firstly, while previous studies focused on either habitual or consumption-oriented energy-saving behavior, this study explores the factors influencing the shift in household energy-saving preferences from habit to consumption-oriented practices. It establishes that both income and energy-saving preferences collectively influence household electricity consumption and energy-saving choices, enriching the existing literature. Secondly, departing from the direct examination of household electricity consumption in prior studies, this research initiates its analysis from the commodity attribute of electricity. By employing the Engel curve, it reveals household electricity consumption patterns and the repercussions of the transformation of electricity attributes on the household consumption curve. The paper substantiates the transition between habitual energy-saving behavior and consumption-oriented energy-saving through both theoretical analysis and empirical testing. For households treating electricity as a commonplace commodity, the Engel curve remains monotonic. In contrast, households with a preference for energy conservation exhibit an inverted U-shape curve in correlation with increasing income. Lastly, the research findings demonstrate substantial potential among Chinese residents for consumption-oriented energy-saving,. It also validates the viability of green alternatives to conventional electricity among Chinese residents, providing theoretical support for government policy-making.

This article is organized as follows. Section 2 shows a comprehensive literature review. Section 3 describes the theoretical research foundation and proposes hypotheses, while Section 4 describes the data and variables. Section 5 refers to the model specification, including the FA technique, OLS and threshold models. Section 6 gives results of the ESA indicators we constructed and our main findings of the OLS model and threshold model and related discussions are included. Section 7 concludes the paper and gives policy implications.

## 2. LITERATURE REVIEW

Electricity consumption in China's residential sector has experienced significant growth in recent years. Reducing household electricity consumption and carbon emissions in this sector is crucial for enhancing the sustainability of energy-related infrastructure (Mack and Tampe-Mai, 2016). Currently, residential electricity consumption in China cannot directly contribute to the purchase of green electricity. Therefore, the most direct method to curtail household carbon emissions is through energy-saving behaviors.

The concept of energy-saving behavior encompasses more than the commonly mentioned method of reducing energy consumption which is referred to as habitual energy saving.

Furthermore, residents can achieve energy savings by purchasing energy-efficient products or adopting new technologies, without necessarily altering their household energy consumption habits (Gyberg and Palm, 2009; Wang et al., 2018a). Previous study also indicates that residents are generally not willing to change their comfortable living habits, which serves as a factor inhibiting their engagement in energy-saving behavior (Wang et al., 2011). Conversely, households are more inclined to achieve energy-saving objectives without necessitating a change in lifestyle. Ha and Janda (2012)

point out that purchasing energy-efficient products is one of the most representative energy-saving behaviors, which can achieve energy savings without changing residents' energy use habits. These purchases of energy-efficient products or green technologies can be considered as green alternatives to traditional energy sources.

Zhang et al. (2018) believes that individual characteristics play a crucial role in determining engagement in energy-saving behavior. These individual characteristics include both objective factors, such as socio-demographic traits, and subjective factors, primarily covering individual attitudes and preferences. Zhang et al. (2018) emphasizes that subjective individual characteristics, particularly residents' environmental awareness, values, and energy-saving knowledge, are predominant factors influencing households' energy-saving behavior. Hence, environmentally friendly behavior among residents primarily originates from their recognition of the environmental behaviors' benefits. Steg and Vlek (2009) propose that individual participation in environmental behavior is influenced by a comprehensive assessment of costs and benefits, including both egoism and altruism. Furthermore, Wang et al. (2018b) research indicates that the daily energy-saving behavior of urban residents is primarily driven by "altruism." Concerning household energy consumption, altruism manifests in households' preference for energy-saving aligned with environmentally friendly goals. Consequently, households employ various methods to realize their environmentally friendly behavior. Habitual energy-saving behavior is the most straightforward approach, as it involves direct consumption reduction. However, relatively wealthy households may be less inclined to restrict their consumption. Hence, for these households, opting for energy-efficient appliances or other advanced technologies proves to be a more popular choice.

Most explorations into residents' energy-saving behavior or energy consumption utilize the questionnaire survey. For instance, Wang et al. (2018b) conducted an investigation into the energy-saving behavior of urban residents in China. Using the theory of planned behavior, the study analyzed the motivations behind household energy-saving behavior and identified that altruism primarily drives most residents' energy-saving behavior. Similarly, Zhang et al. (2018) employed questionnaire data to construct a structural equation model. This model was then used to analyze the influence paths and effects of individual subjective and objective characteristics, external influencing factors, and energy-saving intentions on the formation of energy-saving behavior.

In Broek et al. (2019) research on household energy-saving behavior, He contends that policymakers should shift their focus from merely encouraging households to save energy to altering the social environment to promote households' adopting such behavior. He emphasizes the significance of variables beyond individual factors in shaping behavior. Ding et al. (2017) specifically underscores the objective characteristics of residents' energy-saving behaviors and examines the difference between urban and rural residents in energy-saving behaviors. On the other hand, Shrestha et al. (2021) concentrates on gender differences, attributing them to socialization, responsibility, and the choice of energy appliances.

Hong et al. (2019) investigates the impact of psychological factors and government subsidies on residents' energy-saving behavior, and also explored the interaction between these two factors. The studies mentioned above primarily concentrate on habitual energy-saving behaviors, specifically those directed towards reducing residents' energy consumption. In Trotta (2018)'s research, a broader exploration extends beyond habitual practices to encompass consumptive energy-saving. He examines consumptive energy-saving by categorizing it into energy-efficiency retrofit investments and energy-efficient appliance purchasing behaviors. However, in his study, these three behaviors are treated as parallel entities, potentially overlooking any inherent transformations among them.

As previously noted, habitual energy-saving behavior remains the predominant focus in current research. However, given the lower energy consumption of households sector in China compared to developed countries, depending solely on residents' habitual energy-saving may not be the optimal approach for steering households toward low-carbon patterns. In contrast, the adoption of advanced technologies and energy-efficient appliances presents a viable avenue for achieving carbon reduction

without markedly impacting household lifestyles. This study aims to explore the interaction between income and energy-saving awareness to promote a transition from habitual to consumption-oriented energy-saving in households.

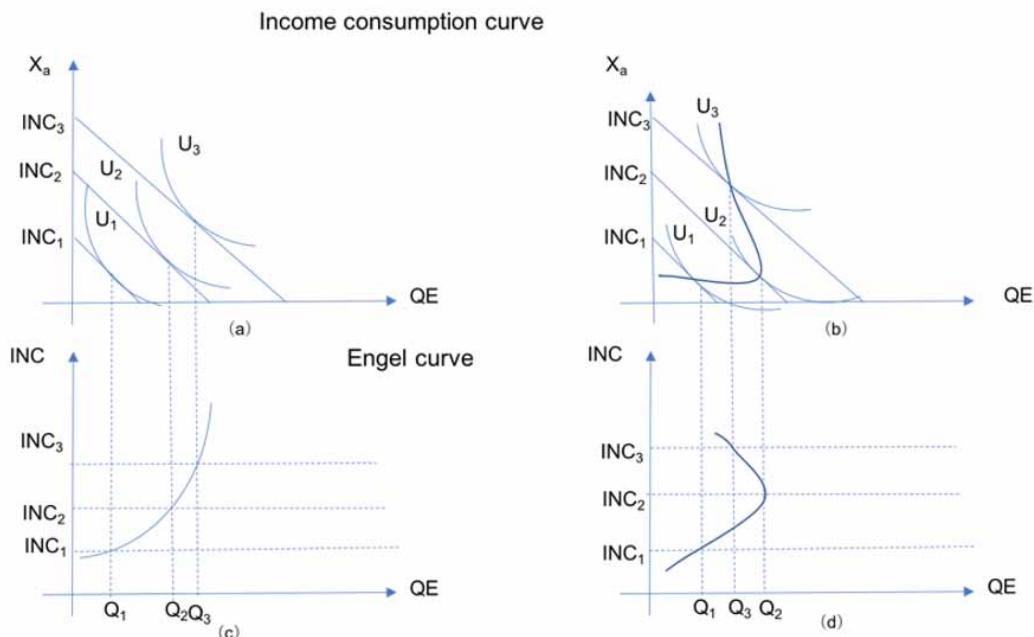
### 3. THEORETICAL FRAMEWORK: THE ENGEL CURVE OF ELECTRICITY CONSUMPTION

Electricity as a necessity conforms to the characteristics of normal commodities in economics; therefore, its income elasticity ranges from 0 to 1, implying that if households' income increases, *ceteris paribus*, they will consume more. However, this scenario may differ when considering substitutes for electricity, such as energy-saving products or any other products that reduce energy consumption due to green awareness. In other words, as households use more energy-saving products, their electricity consumption decreases. This leads to a situation where households tend to consume more energy-saving products as their income increases, ultimately reducing their electricity consumption.

All of the points above could be explained by the Engel curve. In the classic microeconomic theory, households with different preference curves will have utterly different consumption behaviors. Figure 1 shows two sets of income-consumption curves and Engel curves of households with different preferences.  $INC_1$ ,  $INC_2$ , and  $INC_3$  represent income budgets under different incomes.  $U_1$ ,  $U_2$ ,  $U_3$  are utility curves based on households' preferences. Figure 1(a) and Figure 1(b), named the income-consumption curve, show the substitution relationship between one specific commodity and any other commodities; Figure 1(c) and Figure 1(d) are called the Engel curve, which shows the relationship between households' consumption of a particular commodity and the income of households.

Scholars point out that there is always an limitation demand for households to purchase certain goods with the same characteristics due to the law of diminishing marginal utility (Bryant and Zick, 2005). Once the saturation of demand is reached, their expenditure for these goods would not increase as their income rise (Aoki and Yoshikawa, 2002). Therefore, demand saturation exists for

**Figure 1. Income-consumption curve and Engel curve for a group with different preferences, respectively**



every commodity, and consequently households' consumption for a specified commodity will not increase indefinitely.

The saturation of each good varies based on different individual preferences, represented through an indifference curve. Aguiar and Bils (2015), in their study on the Engel curve of food, argued that as the income of households increases, the proportion of their income spent on food decreases, while the proportion spent on other goods, such as luxuries, increases. This indicates that the demand of households shifts from low-elastic goods to high-elastic goods (Chai, 2018).

As illustrated in Figures 1(a) and 1(b), as the income of households increases from INC1 to INC3, the elasticity of their electricity demand decreases, and their consumption tends to be saturated. However, there is a special case where, as income increases, households' demand for conventional electricity turns to high-elastic 'green substitutes' instead of consuming more electricity, influenced by their green preferences or energy-saving awareness. In this case, the income consumption curve and Engel curve are depicted separately in Figures 1(b) and 1(d).

Chai (2018) suggested that the income elasticity of commodities would decline over time, causing former luxuries to become necessities. Similarly, once the consumption of a necessity reaches the saturation level, households' demand shifts to their 'luxury alternatives.' Simultaneously, this necessity becomes an inferior good with a negative elasticity, and the original luxuries tend to become necessities. This explains why commodities might appear as luxuries for households with lower income levels but become necessities for wealthy families (Chai et al., 2015).

This theory is applicable in this study, suggesting that households with a high income and a preference for green consumption or energy-saving awareness will undergo a process where conventional electricity transitions from being a normal commodity to an inferior one. They will shift their consumption towards other electricity substitutes, such as expensive high-efficiency appliances or green electricity, as illustrated in Figures 1(b) and 1(d). These preferences or choices of households will be collectively referred to as 'energy-saving awareness (ESA)' in the following sections.

Furthermore, as long as there is a significant difference in elasticity between two commodities, the process of changing the demand structure always exists with an increase in income, and it does not have to reach the commodity's saturation level. Therefore, this study aims to demonstrate that under the assumption of no green electricity service, individuals are likely to prefer paying more for high-efficiency appliances rather than electric power due to their energy-saving awareness. Thus, the first hypothesis is assumed as follows:

**H1:** The effect of income on households' energy consumption depends on their energy-saving awareness and the energy-saving awareness will reduce the income effect of electricity consumption.

Under this circumstance, if the income of the households with high ENVC continuously goes up, their consumption of electricity levels goes off and eventually hits a turning point. This turning point indicates that ESA is essential in leading households to consume less environmental unfriendly energy, especially fossil energy. On the other hand, if households' income stays at a high-level, but their ESA keep lower, there will be no turning points in their electricity consumption. So, the second hypothesis is proposed as follows:

**H2:** Households with high ESA will experience a decline demand for conventional electricity if their income level reached a certain point, while households with low ESA do not have the decline process.

To test our hypothesis, we employed the OLS model to estimate how households' income and their ESA impact their electricity consumption. The interactive effect between these two variables was also considered. To further analyze the mechanism of the interactive effect, a threshold model was

employed to investigate the impact of ESA on the households' income effect on energy consumption. Lastly, heterogeneity analysis was conducted to discern different consumption patterns between households with high and low ESA.

## 4. DATA AND VARIABLES

### 4.1 Data Description

The original data used in this study were sourced from the Chinese General Social Survey (CGSS), one of the most comprehensive and influential surveys in China. Constructed by the Department of Energy Economics at Renmin University of China, the survey covers various aspects. Sections A and E in CGSS primarily focus on household energy consumption. The original dataset included 3,863 households from 85 cities in China. To refine the data, redundant variables were removed, and only samples with complete information on energy consumption were retained. After this data cleaning process, the dataset retained household characteristics, such as family size, house size, annual family income, and household appliance information, including usage time, power, and energy efficiency. The final valid sample consisted of approximately 1,085 households.

While many existing researchers believed that economic indicators were crucial factors driving household energy consumption, leading to a parallel trend between energy consumption and economic indicators such as per capita income (Khribich et al., 2021; Liu et al., 2018), a micro perspective reveals that household electricity demand is determined by various factors. These factors include electricity tariffs, household income, external environment, and household preferences (Barr et al., 2005; Fabi et al., 2012; Lillemo, 2014; Steg, 2008).

In general, electricity price should be included in electricity demand models (Arisoy and Ozturk, 2014; Campbell, 2018). However, the current increasing block tariffs (IBT) of electricity in China do not significantly differ between blocks, especially for residential electricity tariffs. Consequently, although the current electricity price mechanism has adopted IBT, the actual average electricity price for households has a relatively small impact on power demand (Lin and Jiang, 2012; Mozumder and Marathe, 2007). Thus, this study does not include the price of electricity in its models.

Additionally, scholars argue that the income effect has a more significant impact on household consumption patterns compared to the price effect (Clements et al., 2006; Lavoie, 1994). Therefore, the level of household income will be regarded as the critical factor affecting household electricity consumption behavior in this study.

In addition to variables related to households' features, temperature indicators are considered as control variables to account for differences among different areas. The heating degree days (HDD) and cooling degree days (CDD) are included in the regression. These temperature indicators are sourced from the study of Wang and Lin (2021), utilizing data from the China Meteorological Administration (CMA) and the US National Oceanic and Atmospheric Administration. The data are at the province level and matched to the households' dataset.

### 4.2 Energy-Saving Awareness (ESA)

Besides the variables listed in Table 1, another essential variable of interest for this study is Energy-Saving Awareness (ESA). Energy-saving entails reduced electricity consumption, efficient energy usage, and lesser depletion (J Hong et al., 2019; Zhang et al., 2018). Energy-saving awareness generally refers to an individual's knowledge or perception of energy-saving, and households with such awareness intentionally reduce their overall energy consumption (Han and Cudjoe, 2020).

However, as one of the critical factors affecting household electricity consumption (Jun et al., 2021), the energy-saving awareness indicator is not directly available in the database. Therefore, this indicator needs to be constructed using existing variables. In this study, energy-saving awareness serves as our dependent variable and a proxy for individuals' energy-saving behavior and knowledge

**Table 1. The statistical description of the main variables**

<b>Abbreviation</b>	<b>Definition</b>	<b>Unit</b>	<b>Mean</b>	<b>SD</b>	<b>Min.</b>	<b>Max.</b>
<i>Q</i>	Annual electricity consumption of household	kWh	2160.10	1734.16	120.00	12000.00
<i>INC</i>	annual income of household	10kCNY	9.52	11.68	0.30	100.00
<i>INC</i> <sup>2</sup>	Square of households' annual income		226.80	942.21	0.09	10000.00
<i>POP</i>	Family size	Person	2.99	1.33	1.00	10.00
<i>SPACE</i>	House area	m <sup>2</sup>	120.03	90.29	12.00	990.00
<i>HDD</i>	Heating degree days	Day	162.97	44.84	54.00	310.00
<i>CDD</i>	Cooling degree days	Day	31.76	29.61	0.00	117.00

of energy issues. It will be constructed using the Factor Analysis technique. The required variables to construct the ESA are shown in Table 2.

## 5. METHODOLOGY

### 5.1 Construction of ESA and FA Technique

Charles Spearman first developed Factor Analysis in 1904 to investigate the structure of general intelligence. It is a statistical method used for dataset reduction, particularly useful for numerous variables with unknown correlations (Ahmadian et al., 2019; Daghdi et al., 2016; Ho, 2006). In existing literature, Factor Analysis is commonly employed for data mining due to its advantages (Li et al., 2020; Tucker and MacCallum, 1997).

This study selects four common household appliances owned by the majority of families to construct the Energy-Saving Awareness (ESA) indicator. These appliances include television, laundry equipment, air conditioner, and refrigerator, each characterized by three different features: usage time, power, and energy efficiency. Additionally, knowledge about households' electricity contracts is considered an essential factor, and three knowledge-related variables from the CGSS dataset are included.

**Table 2. The statistical description of the ESA indicator**

<b>Abbreviation</b>	<b>Definition</b>	<b>Mean</b>	<b>SD</b>	<b>Min.</b>	<b>Max.</b>
<i>PR</i>	The power indicator of a refrigerator	-0.03	0.95	-0.86	9.22
<i>ER</i>	Energy efficiency indicator of a refrigerator	0.01	1.01	-1.66	1.80
<i>PL</i>	The power indicator of laundry	-0.01	1.01	-0.74	12.31
<i>EL</i>	Energy efficiency indicator of laundry	-0.04	0.97	-1.46	1.20
<i>PT</i>	The power indicator of television	0.01	1.08	-0.81	14.17
<i>EA</i>	Energy efficiency indicator of air condition	0.00	1.00	-1.40	1.57
<i>PA</i>	The power indicator of air condition	-0.01	1.01	-0.52	11.77
<i>KL</i>	Knowledge of electric contract	-0.01	0.95	-8.81	0.19

The process to construct the ESA is described as follows. Each electrical appliance variable is first processed into two indicators, namely power indicator and energy efficiency indicator. The power indicator is the product of an appliance's power and frequency of use, and to eliminate the influence of the dimension, it has been standardized. The energy efficiency indicator is the standardized energy efficiency of electrical appliances. If there are multiple electrical appliances of the same sort, the average value will be taken first, and standardization processing will be performed.

Then FA is used to reduce the dimensionality of variables and obtain the main factors (Ahmadian et al., 2019; Daghie et al., 2016; Li et al., 2020). Afterward, we will calculate the total factor scores of each sample, and these scores are imported into our models as the indicator of ESA.

There are three critical points regarding the ESA-related variables that need mentioning. First, as most households have more than one identical appliance, the mean value of multiple identical devices is calculated to replace the original data. Second, we pre-process all ESA-related data to ensure that all variables are positively correlated with ESA. This ensures that the greater the variable's value, the more positive impact on ESA is expected. Lastly, all samples must have all four kinds of appliances simultaneously, and any samples missing one or more of them will be deleted.

## 5.2 Model Specifications

The OLS models are employed to estimate how the household's income and energy-saving awareness affect their electricity consumption, and how their interactive effect of annual income and energy-saving awareness work to the electricity consumption (Lin and Ge, 2021). Besides the two models, the OLS model with quadratic terms of annual income is also constructed, while the threshold model is used to split the samples and investigate how energy-saving awareness impacts the behaviors of consumers with varied incomes.

### 5.2.1 OLS Model

In all three models, the household's electricity consumption is considered the explained variable, while the household's income and ESA are the main explanatory variables. We also introduce control variables such as house area, family size, regional temperature variables, etc., that may affect households' electricity consumption which is also considered in previous literature (Li et al., 2019). Thus, the first linear regression model is constructed as follows:

$$QE_i = \alpha + \beta_1 INC_i + \beta_2 ESA_i + \theta X_i + \varepsilon_i \quad (1)$$

where QE is the household's annual electricity consumption, INC is the household's yearly income, ESA is the indicator of the household's energy-saving awareness and X is a vector of variables that could also affect the electricity consumption of households. Table 1 gives a statistical description of variables in Eq.(1). The subscript i represents the i-th household, and  $\varepsilon_i$  signifies the unobserved random error.

As mentioned, this paper tries to evaluate how the ESA moderates the impact of household's income on their electricity consumption; thus, we adopt the interaction term of annual income and energy-saving awareness to the regression model, and the linear equation is listed as follows:

$$QE_i = \alpha + \beta_1 INC_i + \beta_2 ESA_i + \beta_3 INC_i * ESA_i + \theta X_i + \varepsilon_i \quad (2)$$

From Eq.(9), we could evaluate the effect of income of households on electricity consumption is shown as:

$$\frac{\partial QE_i}{\partial INC} = \beta_1 + \beta_3 ESA_i \quad (3)$$

Also, we argue that households with different ESA may have different consumption behaviors, and they are possible to consume less electricity (which I mean here is the electricity generated by fossil energy) with their increasing income. Therefore, a non-linear effect of income is introduced into the model to demonstrate the inverted U-shaped curve between households' income and their electricity consumption. The equation is represented as follows:

$$QE_i = \alpha + \beta_1 INC_i + \beta_2 ESA_i + \beta_4 INC_i^2 + \theta X_i + \varepsilon_i \quad (4)$$

### 5.2.2 Threshold Model

The threshold model, as introduced by Hansen (2000), was developed to investigate an appropriate method for testing unstable regression coefficients (Hansen, 2000). Hansen argues that in some cases, subsamples are chosen based on categorical variables. It is expected when the categorical variables are dummy variables; however, sometimes, categorical variables are continuous. In such cases, a method to find the specific value of categorical variables should be employed, leading to the construction of the threshold model by Hansen. The original model is shown as follows (Hansen, 2000, 1999):

$$y_i = \beta'_1 x_i I(q_i \leq \gamma) + \beta'_2 x_i I(q_i > \gamma) + \varepsilon_i \quad (5)$$

and another way to represent Eq. (5) is:

$$y_i = \begin{cases} \beta'_1 x_i + \varepsilon_i, & q_i \leq \gamma \\ \beta'_2 x_i + \varepsilon_i, & q_i > \gamma \end{cases} \quad (6)$$

where  $I(\cdot)$  is the indicator function,  $q_i$  is the threshold variable. According to whether the threshold estimator  $q_i$  is larger or smaller than threshold parameter  $\gamma$ , the samples would be separated into two 'regimes' (Hansen, 1999).  $\varepsilon_i$  is the regression error.

This study tries to estimate if the households with different ESA and income would have different behavior patterns of energy consumption. Thus, the threshold model would be appropriate for this study. With this method, we could indicate the existence of a threshold value and find out the specific ESA value to segment the samples. Then, by comparing the coefficients we could find different consumption behaviors on both sides of the threshold. With the splitting of the samples, the group OLS regression models could be represented as:

$$QE = \begin{cases} \alpha_{11} + \beta_{11} INC_i + \beta_{21} ESA_i + \beta_{31} INC_i^2 + \theta_{11} X_i + \varepsilon_i & ESA_i \leq \gamma \\ \alpha_{12} + \beta_{12} INC_i + \beta_{22} ESA_i + \beta_{32} INC_i^2 + \theta_{12} X_i + \varepsilon_i & ESA_i > \gamma \end{cases} \quad (7)$$

where QE is the household's annual electricity consumption; INC is the household's annual income;  $INC^2$  is the square of the annual income; ESA is the indicator of the household's energy-saving

awareness and  $X$  is a vector of variables that could also affect the electricity consumption of households. The subscript  $i$  represents the  $i$ -th household, and  $\varepsilon_i$  signifies the unobserved random error.

## 6. RESULTS

### 6.1 Results of FA and Construction of ESA

Before conducting factor analysis (FA), it is essential to standardize the data to eliminate the influence of dimensions. Subsequently, several tests are applied to ensure the appropriateness of factor analysis for our study. The Kaiser-Meyer-Olkin measure assesses sampling adequacy, resulting in a value of 0.635 in our study. This value exceeds 0.6, indicating that the dataset is suitable for factor analysis. The Bartlett test further validates the Kaiser-Meyer-Olkin measure of sampling adequacy. Consequently, factor analysis is deemed appropriate in this study to construct the ESA indicator.

The results of the principal component analysis are presented in Table 2, where three factors have been selected, contributing to a cumulative variance of 0.5737. Table 2 also provides the cumulative contribution rates for each factor. Rotation results are outlined in Table 3, revealing that Factor 1 primarily represents the power and usage frequency of households' appliances. Factor 2 encompasses most of the information related to the appliances' energy efficiency, while Factor 3 largely represents households' knowledge of power contract selection. The observed results of the factor analysis align with our expectations, and the effective explanation of these three factors supports the validity of the factor analysis. Consequently, the comprehensive score obtained from the factor analysis can be used to construct the indicator of ESA.

### 6.2 Results of OLS Regression

Table 5 presents the results of the OLS regressions. Notably, the effects of household income, family size, house area, and temperature variables on household electricity consumption are all significant

**Table 3. Principal component factors**

Factor	Eigenvalue	Proportion	Cumulative
Factor1	2.07573	0.2595	0.2595
Factor2	1.49652	0.1871	0.4465
Factor3	1.01754	0.1272	0.5737

**Table 4. Rotated factor loadings and unique variances**

Variable	Factor1	Factor2	Factor3	Uniqueness
FP	0.0799	0.7455	0.0171	0.4375
FE	0.793	0.0666	-0.0344	0.3655
LP	0.0736	0.7587	0.0545	0.4116
PE	0.7853	0.1157	-0.016	0.3696
TP	0.0168	0.7183	-0.0141	0.4835
AE	0.7681	-0.0227	0.0404	0.4078
AP	0.1775	0.0893	0.5929	0.6089
KL	-0.0807	-0.0002	0.8199	0.3212

**Table 5. Regression results**

Variables	(1)	(2)	(3)
<i>INC</i>	19.191*** (4.26)	20.198*** (4.45)	43.110*** (3.92)
<i>POP</i>	244.830*** (6.22)	243.504*** (6.19)	235.194*** (5.95)
<i>SPACE</i>	1.268** (2.17)	1.275** (2.18)	1.332** (2.28)
<i>EDU</i>	-7.786 (-0.46)	-11.651 (-0.69)	-18.450 (-1.06)
<i>HDD</i>	6.318*** (2.81)	6.394*** (2.85)	6.338*** (2.83)
<i>CDD</i>	15.512*** (4.55)	15.467*** (4.54)	15.357*** (4.51)
<i>ESA</i>	-123.523 (-1.46)	-140.450* (-1.65)	-111.484 (-1.32)
<i>ESA*INC</i>		-112.292* (-1.89)	
<i>INC2</i>			-0.314** (-2.38)
<i>Constant</i>	-383.355 (-0.78)	-380.456 (-0.77)	-453.680 (-0.92)
Observations	1,085	1,085	1,085
R-squared	0.092	0.095	0.097

Standard errors in parentheses

\* p<0.1, \*\* p<0.05, \*\*\* p<0.01

at a 1% level across all three models. The initial column displays the findings of the basic model, indicating a significantly positive impact of household income on electricity consumption, with a coefficient of 1.599. However, ESA does not show significance in this model. Moreover, the signs of control variables align with expectations. An increase in family size is associated with a rise in household electricity consumption. Additionally, extreme weather conditions contribute to increased electricity consumption. Surprisingly, the educational level of surveyed individuals was not found to be significant. Two possible explanations for this result are considered: either respondents differ from the actual household decision-makers and cannot influence consumption behavior, or the education level of consumers does not directly impact their electricity consumption behavior.

The second column introduces interactive items based on the first column. Column (1) The coefficient of ESA in column (1) is not significant without the interaction item but has a negative direction. From column (2), we could observe that the sign of interaction term is significantly negative after adding the interaction term into the model, and the coefficient is -9.358. The significant interaction term shows that a household's ESA moderates households' income and electricity consumption. The

increase in household energy-saving awareness reduces the positive impact of households' income on households' electricity consumption.

Furthermore, based on Equation (2), the influence of households' income on residential electricity consumption is contingent upon a combination of the income coefficient, interaction term coefficient, and ESA value. The findings from the second specification reveal that the income coefficient is in opposition to the interaction term coefficient. As a result, the actual impact of income on electricity consumption hinges on the ESA value, which could be either positive or negative. This observation supports the earlier assumption that, when the ESA's value is positive and sufficiently high, the effect of income on electricity consumption might be negative. Additionally, the magnitude and direction of the control variables align with those in the first model. Consequently, the influence of income on electricity consumption could be negative due to the ESA. These results provide confirmation for Hypothesis 1 (H1), indicating that H1 is positive.

In the third specification, we introduce a non-linear model by incorporating the quadratic term of income. The outcomes indicate that the coefficient of the quadratic income term is significantly negative at a 5% level, while the coefficient of the linear income term remains significantly positive at 1%. This suggests the presence of an inverse U-shaped curve in the relationship between households' income and electricity consumption. To delve deeper into understanding how ESA influences the impact of households' income on electricity consumption, we further explore these dynamics through threshold models and group regression in the subsequent analysis.

### **6.3 Results of Robustness Check**

To validate the robustness of the results, we employed two methods for robustness checks. Firstly, we introduced fixed effects for regions to control for differences among the eastern, central, and western regions. The results are presented in the first three columns of Table 6. It can be observed that the results for income, the interaction term, and the square of income remain consistent in both sign and significance with the baseline regression. This confirms the robustness of the results. Additionally, we conducted a robustness check by substituting variables. We replaced household income with per capita income in the regression. The regression results showed that there were no significant changes in the significance of income, the interaction term, and the square of income. This further indicates the robustness of our regression results.

### **6.4 Results of Threshold Model**

The results of the threshold effect are shown in Table 7. We test the existence of the threshold effect and determine the number of thresholds that the model could have.

Table 7 reveals the threshold effect of the ESA variable on households' energy consumption and their annual income. To determine the optimal threshold model, we set the threshold parameter at 0, 1, 2, 3 and performed bootstrap estimations for each (Chang et al., 2009). The results indicate that the threshold estimator for the single threshold model is 0.194, and its F-statistic is significant at the 1% level. Both the double and triple threshold models also exhibit statistical significance at the 5% level. Consequently, we have chosen to adopt the single threshold model for our study.

We divided our samples based on whether the ESA is lower than 0.194, resulting in two distinct groups. One group comprises households with ESA lower than 0.194, with a sample size of 714. The other group includes households with ESA higher than 0.194, totaling 371 in sample size.

### **6.5 Results of Heterogeneity Analysis**

According to the results of the threshold models, the ESA's value is used to divide samples into two groups. Table 8 presents the results of the heterogeneity analysis, with the first, second, and third columns displaying results for the pooled samples, samples with ESA less than 0.194, and ESA greater than 0.194, respectively.

**Table 6. Robustness check**

	Add Regional Fixed Effect			Replace the Main Variable		
	(1)	(2)	(3)	(4)	(5)	(6)
INC	17.210*** (3.80)	18.206*** (4.00)	38.227*** (3.45)			
INC2			-0.274** (-2.07)			
INCP				32.448*** (2.94)	33.795*** (3.06)	80.089*** (2.81)
INCP2						-1.532* (-1.81)
ESA	-115.281 (-1.37)	-132.479 (-1.56)	-106.008 (-1.26)	-113.264 (-1.34)	-128.468 (-1.51)	-105.684 (-1.25)
ESA*INC		-119.448** (-2.02)				
ESA*INCP					-106.104* (-1.79)	
Control variables	YES	YES	YES	YES	YES	YES
Regional fixed effect	YES	YES	YES	YES	YES	YES
N	1085	1085	1085	1085	1085	1085
adj. R-sq	0.095	0.098	0.098	0.091	0.092	0.092

Standard errors in parentheses

\* p&lt;0.1, \*\* p&lt;0.05, \*\*\* p&lt;0.01

**Table 7. Results of threshold estimation**

Model	F Value	P Value	BS	Threshold Estimator	95% Confidence Interval
Single Threshold Model	11.992***	0.004	500	0.194	[-0.745, 0.558]
Double Threshold Model	10.875**	0.012	500	-0.209	[-0.745, -0.203]
				0.194	[-0.199, 0.473]
Triple Threshold Model	7.658**	0.02	500	-0.134	[-1.140, 1.589]

\*, \*\*and\*\*\* denote significance at 10%, 5% and 1% levels, respectively.

As shown in Table 8, the coefficient for first-order income is significantly positive in the low-ESA group, while the coefficient for the second-order income is insignificant. This suggests that annual income in this group is positively correlated with electricity consumption, meaning the higher their income, the more electricity they will consume. In the high-ESA group, both first-order and second-order coefficients of income are significant, with the first-order term being positive and the second-order term negative. Therefore, this group's relationship between income and electricity consumption represents an inverted U-shape, signifying that households with high-ESA will have a turning point in their energy consumption as their income changes.

**Table 8. Results of group regression**

Variables	(1)	(2)	(3)
	Pool	Lower ESA	Higher ESA
INC	43.110*** (3.92)	44.829*** (3.38)	44.260** (2.23)
INC <sup>2</sup>	-0.314** (-2.38)	-0.230 (-1.45)	-0.524** (-2.20)
POP	235.194*** (5.95)	290.583*** (5.94)	109.345 (1.64)
SPACE	1.332** (2.28)	0.655 (0.86)	2.643*** (3.00)
EDU	-18.450 (-1.06)	-18.368 (-0.82)	-24.303 (-0.90)
HDD	6.338*** (2.83)	3.152 (1.10)	13.052*** (3.73)
CDD	15.357*** (4.51)	11.831*** (2.72)	22.516*** (4.19)
ESA	-111.484 (-1.32)	2.812 (0.02)	-198.266 (-0.96)
Constant	-453.680 (-0.92)	109.767 (0.17)	-1,489.425* (-1.94)
Observations	1,085	714	371
R-squared	0.097	0.113	0.099

Standard errors in parentheses

\* p&lt;0.1, \*\* p&lt;0.05, \*\*\* p&lt;0.01

In a study on the Kuznets curve of environmental pollution, the per capita income peak was calculated through the inverted U-shaped curve between pollutant emissions and per capita income (Zheng et al., 2010). This study employs the same method to identify an income turning point of about 410,000 RMB, with samples above this income turning point accounting for 2.1% of the entire sample. In the high-ESA group, the samples above the income turning point account for 0.6%, implying that the potential consumer base for the green alternatives market represents 0.6% of the whole market.

For the control variables, we observed changes in the significance of these variables in the group regression, although the signs remain consistent. Specifically, the signs of house area and household population are both positive. However, when compared with the full sample regression, household population (POP) in the high-ESA group is no longer significant, while house area (SPACE) continues to show significance. This suggests that the electricity consumption behavior in this group is a result of overall planning, indicating that each family member has a diminishing marginal impact on electricity consumption. On the contrary, in the low-ESA group, house area (SPACE) is insignificant, but population (POP) remains significant.

We interpret this as indicating that family members in the low-ESA group pay more attention to their individual needs when using appliances, resulting in a lack of effective electricity consumption

behavior. Consequently, the marginal consumption of each family member remains constant. Therefore, the increase in population in low-ESA group households has a positive and significant impact on their electricity consumption. This result reinforces the idea that the ESA variable we constructed and the threshold effect used for group regression effectively distinguish the characteristics of households in the electricity market.

Furthermore, the energy-saving preference of the high-ESA group is evident in their response to temperature. Initially, the pooled regression in Table 8 reveals that both Heating Degree Days (HDD) and Cooling Degree Days (CDD) have significantly positive impacts on households' energy consumption, aligning with previous studies (Zhang et al., 2020).

Moving to column (2), it becomes apparent that the temperature variable HDD is not significant in the low-ESA group but is significant in the high-ESA group. This suggests that the number of low-temperature days in the low-ESA group has no significant effect on household electricity consumption. We attribute the lack of significance in the low-ESA group to the prevailing collective or central heating method in the colder areas of northern China. Collective heating is calculated as a separate charge and is not included in household electricity consumption. Conversely, the high-ESA group is significant on the HDD variable, possibly indicating that households in this group have adopted other heating methods due to their energy-saving preference.

Regarding the CDD variable, it has a significant positive effect in both the high-ESA and low-ESA group models. Notably, the coefficient of CDD in the high-ESA group is twice that of the low-ESA group. We interpret a larger coefficient as indicating a greater difference in electricity consumption under normal weather conditions and extreme weather conditions. This implies that, in non-extreme weather, the high-ESA group consumes less electricity, while in extreme weather conditions, some energy consumption is unavoidable. A lower coefficient in the low-ESA group suggests that the change in power is not as obvious during extreme weather, indicating that consumers in this group may also use temperature adjustment equipment, such as air conditioning or heating, during non-extreme weather. Consumers in the high-ESA group are more likely to use such devices in extreme weather.

## 6.6 Discussion

The results of the regression validate the hypotheses proposed in the theoretical section. In regressions with interaction terms, the coefficient of the interaction term is significantly negative, confirming that energy-saving awareness moderates the impact of residents' income on their electricity consumption. The negative significance of the interaction term also confirms that energy-saving awareness reduces the income effect on electricity consumption. Therefore, Hypothesis 1 has been validated.

Furthermore, the results of heterogeneity analysis also demonstrate that the relationship between income and household electricity consumption varies across different Energy-Saving Awareness groups. The grouped regressions in the heterogeneity analysis correspond to electricity consumption models for households with different environmental preferences. Aligned with Figure 1, the income-consumption and Engel curves for high and low ESA groups are delineated in (a) and (c). From (a) and (c), it can be observed that for households with lower ESA, electricity remains a normal good and is not substituted by its green alternatives. This implies that for these households, the higher the income, the greater the electricity consumption. Energy-saving preferences do not influence the relationship between income and electricity consumption in this group. In other words, households in this group lack the incentive to replace normal electricity with other green products. Figures (b) and (d) in Figure 1 illustrate consumption behavior for high ESA households. The relationship between income and household electricity consumption for the high ESA group follows an inverted U-shaped curve. When the income of these households reaches the turning point, the elasticity of income to electricity consumption becomes negative. We posit that the main reason for this negative elasticity is the presence of substitutes for electricity in the market, and these substitutes exhibit a luxury attribute when income is low. When household income is at a lower level between INC1 and INC2, due to income constraints, even if the household has energy-saving preferences, they will

still consume more conventional electricity products to meet daily needs. During this period, the consumption of normal electricity increases with income growth, exhibiting similar characteristics for both high and low ESA groups. Later, when income surpasses the turning point, high ESA residents, due to their energy-saving preferences, will no longer allocate a portion of their income to consume normal electricity. Instead, they will use it to consume green substitutes for electricity, such as energy-efficient appliances, green housing, and green electricity. During this period, normal electricity consumption by high ESA households is considered inferior, and the elasticity of income to normal electricity becomes negative. Therefore, the results and analysis of the study validate the establishment of Hypothesis 2.

The decline in electricity consumption after the income turning point demonstrates the potential for consumption-oriented energy savings among residents with energy-saving awareness. That is, their potential to consume green alternative products for electricity. Unlike the low ESA population, high ESA residents, after an increase in their income, possess more emission reduction potential. Although the direct impact of ESA on electricity consumption is not significant in the regression results, the presence of a threshold effect proves that ESA indirectly influences residents' electricity consumption behavior by mediating the income effect.

## 7. CONCLUSION AND POLICY IMPLICATIONS

Carbon neutrality has been widely discussed in the energy consumption area recently. Emission from households occupies a vast part and therefore, households' consumption behavior and energy preferences are need to be considered. This study tries to figure out if Chinese households have the trend to transfer their demand for conventional electricity to the green consumption substitutes. Some scholars believe without limitation, households' demands of energy will increase as their income rise (Khribich et al., 2021; Liu et al., 2018). Engle curve proves that household demands for necessities have a ceiling and their demand structure are changing along with other features (Jackson&L.F.,1984). Therefore, households demand for conventional electricity which is a necessary for daily life may also experience a process of transferring from normal goods to inferior goods just like food. To verifying these hypotheses, this study constructs an indicator of households' energy saving awareness by analyzing the households' green choice for appliances and their relative knowledge. And also, households' income level is a vital factor to lead this evolving process.

Our results demonstrate that the household's ESA will twist their consumption of environmental unfriendly energy once their income achieves a high-level and their consumption is not a linear related to their income level but a negative quadratic relationship which means households with high-ESA will decrease their energy consumption when their income reach the certain point. The reasons for the demand decline vary. It may because households who with high ESA preference may choose more energy-efficient household appliances or other green alternatives.

Furthermore, we would like to extend the concept of green alternatives in this study, which is also one of the motivations of this study and also a direction for future research. Green electricity is one of the most effective alternatives to conventional electricity. Like other technologies and energy-saving products, it can effectively reduce carbon emissions from household energy consumption. However, the implementation of green electricity faces the challenge of cost, similar to the high-efficiency household appliances and other advanced technologies. Our research has shown that if households are affluent enough, the transformation of habitual energy-saving behaviors into consumption-based energy-saving behaviors is feasible. This implies that green electricity, as a substitute for conventional electricity, also has potential in the consumer market. The inverse U-shaped relationship between household income and electricity consumption in China suggests that some individuals have surpassed the income constraints and have the potential and capacity to consume higher-priced green alternatives. However, this is still a conjecture. Therefore, in the next step of our research, we will continue to explore

the consumption capacity and acceptance of green electricity as a green substitute for conventional electricity among Chinese households.

In light of the research findings and the preceding discussion, several policy implications are proposed to enhance the promotion of sustainable energy consumption:

Firstly, recognizing that households with incomes below the turning point struggle to transform their consumption patterns despite having energy-saving awareness, policymakers should integrate residential energy-saving efforts with existing social welfare programs. Implementing tiered subsidy programs and targeted financial incentives for households below the inflection point, as identified in the study, can spur the adoption of energy-efficient appliances and other green alternatives, and help to shift consumption patterns towards more sustainable practices.

Secondly, recognizing the impact of energy-saving awareness on adjusting household energy consumption patterns, policymakers should customize information and education activities to specific population groups. Given the diverse levels of awareness and preferences for energy efficiency across demographic segments, comprehensive research is essential. Policymakers need insights into the characteristics and preferences of different demographic groups to enable more effective advocacy and education. Targeting areas where household income exceeds the turning point can particularly promote the adoption of green alternatives, aligning with the nuanced needs of higher-income households.

Thirdly, given the demonstrated potential for the development of green alternatives to conventional electricity in China, the government should integrate energy efficiency, clean energy technologies, and other energy-saving alternatives with existing tax policies. By providing corresponding tax incentives for energy-saving technologies, including the purchase and use of energy-efficient appliances, advanced energy-saving technologies, and renewable energy, policymakers can significantly influence consumer choices. These incentives make alternatives to conventional electricity more financially appealing, especially for households with incomes beyond the inflection point. Aligning financial benefits with sustainable choices enables policymakers to actively encourage a transition to greener and more environmentally friendly energy consumption practices nationwide.

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*Qiao Qiao was born in 1989 and previously worked in the dispatch department of the State Grid Corporation of China. She is currently pursuing a PhD in Collaborative Innovation Center for Energy Economics and Energy Policy at Xiamen University, where her research focuses on electricity markets, renewable energy integration, consumer behavior, and related topics. Her expertise in electricity markets includes studying market mechanisms, policy design and implementation, and competition, with the goal of improving market efficiency and reliability while balancing power supply and demand. In terms of renewable energy integration, Qiao seeks to develop methods for better integrating renewable energy sources like solar and wind into power grids and addressing the challenges posed by their variability. Additionally, Qiao investigates how consumers engage with electricity markets and ways to encourage greater participation. Overall, her research aims to advance energy policy management and promote the use of renewable energy in power systems.*

*Boqiang Lin is the corresponding author of this article. He obtained a Ph.D. degree in Economics from the University of California, Santa Barbara. He is a “Changjiang Scholar” Distinguished Professor, honored by the Ministry of Education of China in 2007. He is the Dean of China Institute for Studies in Energy Policy, Xiamen University; a Chief Scientist of Tan Kah Kee Innovation Laboratory; and a Distinguished Researcher at the State Key Laboratory of Physical Chemistry of Solid Surfaces. His research and teaching focus on energy economics, management, and policy. He aims to cultivate Ph.D. graduates for academic positions at prestigious universities under the 985/211 initiatives and famous financial and economic institutions. His research is guided by addressing national major demands and solving practical problems, to enhance support for national energy policies and public influence.*