Investigating the Impact Factors of Residents' Electricity Consumption Behavior Against the Background of Electricity Substitution

Zhou Peng, Lifang Wang, and Min Cao

***Abstract*—In recent years, northern China has suffered from the severe haze in autumn and winter, a phenomenon to which coal-fired heating appliances contribute significantly. To reduce pollution and achieve sustainability in the electricity industry, government departments have proposed the "Electricity Substitution" strategy, and the State Grid Corporation has also proposed the "coal-to-electricity" transformation movement. Against this background, our study aims to identify the impact factors of electricity consumption behavior among customers who have completed this transformation. Based on customers' monthly electricity consumption data in Shaanxi from 2017 to 2019 and on-site survey results, this paper constructs a multiple regression model and utilizes SPSS25.0 to analyze the relationship between residents' electricity consumption and related factors. The research results revealed that after the implementation of the "coal-to-electricity" transformation, residential customers' electricity consumption tended to rise. Consequently, winter temperature, appliance power, and heating area negatively correlate with residents' electricity consumption. Simultaneously, customers' habits, subsidies, and electricity pricing positively correlate with residents' electricity consumption. Finally, this paper offers some practical management suggestions for power companies based on the analysis.**

***Index Terms*—electricity substitution; residential customer energy consumption; impact factor; multiple regression model**

I. INTRODUCTION

WITH the continuous advancement of industrialization and urbanization, large-scale smog weather has recently appeared in northern China in autumn and winter, severely contaminating the atmosphere and being hazardous to human health [1]. For instance, the number of days with air quality below the standard of Xi'an in 2018 was 177 days, the annually PM2.5 concentration was 73mcg/m^3, which exceeded the WHO standard and the Chinese atmospheric standard respectively by 630% and 387%; the Pm10 concentration was 130mcg/m^3, exceeding both standards by 550% and 225%; and the daily concentration of CO is 4.9 mg/m^3, which exceeds the Chinese standard by 123% [2–4]. These numbers (As shown in Fig 1 indicate that the air-pollution problem is drastic to be solved.

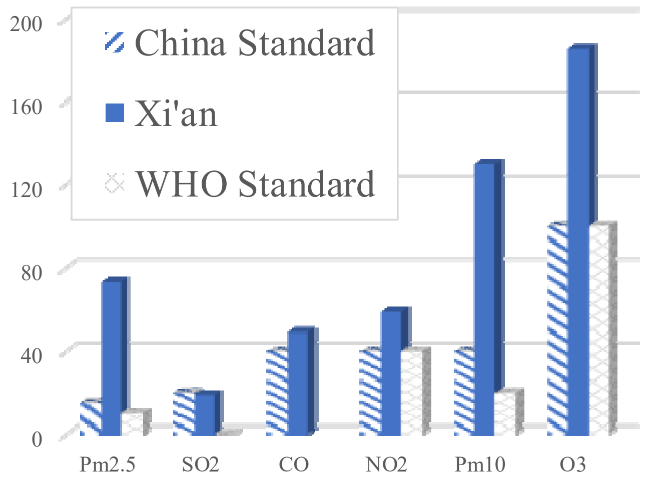

Fig.1. Airborne Pollutant Concentration

The causes of large-scale haze are primarily natural and human factors. The main human factors are automobile exhaust, coal-fired heating, and industrial exhaust emissions. Due to residents' heating needs during the heating season, large-scale coal-fired heating has become one of the main culprits of haze raging in autumn and winter [5].To reduce reliance on coal and increase the utilization rate of renewable energy, the relevant departments have proposed energy substitution measures to reduce coal-related pollution and relieve severe haze weather. The Shaanxi Provincial Government promulgated the 13th "Five-Year Plan" in 2015, which specified the guidelines for the abatement of scattered coal and the promotion of electric energy substitution (EES) [6]. In the same year, the State Grid Shaanxi Electric Power Company has introduced guidance for the management of scattered coal and the construction of supporting electric facilities. The "coal-to-electricity" (C2E) method to convert heating devices from coal to electricity was also proposed in 2015 [7]. As of the end of 2019, Shaanxi Province has completed such substitution for 476,000 residential customers. Due to the continuous deepening of the sustainable development strategy and C2E, residential customers' heating methods have changed accordingly. The large-scale application of electric heating has induced a series of transformations in residential customers' electricity consumption behaviors, such as variation of electricity usage times, changes in electricity usage periods, selection of heating devices, and other factors. To further respond to the call for sustainable

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development, this paper will study the impact factors of residential customers' electricity consumption behavior (CECB) against the background of energy substitution based on the electricity consumption and habits of "coal-to-electricity" customers in Shaanxi Province.

The remainder of the article is organized as follows. Section 2 reviews previous studies on power substitution and CECB. Section 3 presents the selected methodology, data sources, and preprocessing. Section 4 presents the analysis process. Section 5 discusses the estimated results. The conclusions, policy implications and suggestions are provided in Section 6.

II. Literature Review

A. Energy Substitution

Since James first proposed the concept of energy substitution in 1957 [8], this subject of study has been continuously developed and enriched for more than half a century. With the sustainable development of the power industry, the concept of EES has gradually become the subject of research by various scholars.

At present, the depth and breadth of EES research are profound. Katharine et al. analyzed the status quo of global warming, providing a rigorous scientific basis for EES by comparing the emissions of coal-fired heating and gas-fired heating [9]. Amagai et al. and Masjuki et al. also noted the urgency of EES by examining the pollutant emissions of Japan and Malaysia [10], [11]. Chen et al. analyzed the development of C2E projects in Beijing and verified such projects' feasibility through quantitative analysis of emission reduction effects [12]. Scholars such as Zheng et al. and Zhang et al. have also remarked on and verified the feasibility of EES in China [13], [14]. Several scholars have also proposed diverse clean energy types to achieve energy sustainability [15–17]. Cai et al. conducted theoretical experiments on winter haze and heating conditions in 58 cities in China, then recommended policy replacing heating equipment [18]. Shu et al. introduced C2E projects in North China and analyzed the effect of that transformation [19].

Many scholars have also assessed and verified the remarkable effect of C2E and indicated that EES still has room for optimization [12], [14], [20]. With the deepening of EES research, scholars have shifted their focus from the feasibility and implementation effects of EES to its impact factors and related policies [14], [18], [21–24]. Kemfert et al. explored the relationship between EES policies and climate policies and pointed out that in Europe, the market is not yet fully competitive; these policies have proven to be complementary [25]. Wang et al. conducted a survey of 1030 customers in Hebi City regarding their willingness to accept C2E and pointed out that income, location, energy cost, and education level are the key impact factors affecting residents' EES [26]. Furthermore, many scholars have focused on predicting the development of EES [23], [27], [28].

Although there has been abundant and wide-ranging research about EES, most studies have focused on feasibility studies, energy research, policy analysis, and innovation, whereas research from the perspective of residential electricity consumption is relatively limited.

B. Residents' Electricity Consumption Behavior

Studies regarding customer electricity consumption have attracted considerable attention in recent years. Mary et al. proposed that residents' electricity consumption is affected by psychological factors, electricity consumption habits, environmental factors and cultural factors [29]. Thomas et al. applied factor analysis and multiple regression models to investigate residents' electricity consumption behavior [30]. Using data from the U.S. Resident Energy Survey, they identified that income, electricity price and natural gas accessibility account for 54% of the impact on residential electricity consumption. Han et al. and Wen et al. both employed a quantile regression model to analyze the various influencing factors of residents' electricity consumption; both proved that income was a vital factor in the assessment of residents' electricity consumption [31], [32], while Ming et al. adopted the rank-sum ratio combined with the LMDI algorithm to offer the same conclusion [33]. Wang et al. analyzed residents' electricity consumption behavior in various areas in Thailand and proposed that demographic factors are the key factors affecting residents' electricity consumption [34]. Wei et al. also adopted the logarithmic average D index technique to quantitatively analyze the contribution of different factors to the growth of power consumption in China [35]. The results highlighted that the economy of scale effect was the critical factor for the growth of power consumption, with its cumulative contribution reaching 117.76%. Al-Ghandoor et al. applied multiple linear regression models combined with fuzzy neural networks to analyze the impact factors of Jordan's industrial electricity consumption [36]. That research proposed that the types of industrial products and capital applications were the two most crucial factors.

At present, research in this field is mainly focused on the innovation of analytical methods and application scenarios. However, as a populous country, China is challenged with an unprecedentedly broad scope of work. Therefore, changes in residents' electricity consumption are bound to affect the overall sustainable development situation. Studies focused on customers' electricity consumption behavior after EES in China are relatively rare in current research.

Although prior research has provided substantial theoretical analysis and implemented diverse analytical methods for EES and CECB in China, the research on the influence factors of customers’ electricity behavior after China's EES remains scarce. Therefore, this paper will analyze the residential electricity customers of Shaanxi Province who have finished C2E to explore the impact factors of customers' electricity consumption behavior.

III. Research Methodology

A. Variable Selection

Response Variable Selection

In the current research, although the response variables chosen by different scholars vary due to research emphasis, analytical methods, and magnitudes, the similarity of electricity consumption behaviors leads to a certain degree of similarity in selecting response variables.

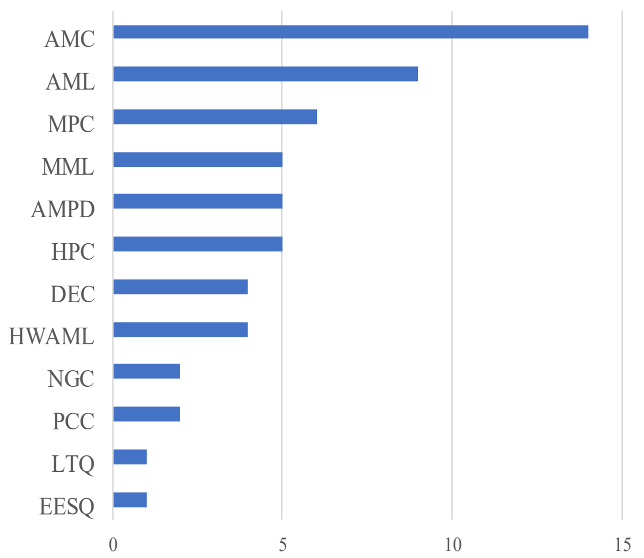

Fig.2. Frequency Statistical Method Result

Hence, this paper adopts the frequency statistical method to analyze 58 studies on the impact factors of electricity consumption behavior with high IF. The results are shown in Fig. 2. In 58 relevant studies, the annual electricity consumption (AEC) appears to be the most selected response factor, with a frequency of fourteen. The annual maximum load (AML) is second, with 9 occurrences. The monthly power consumption (MPC) is third, at 6 occurrences. Hourly power consumption (HPC), the annual maximum peak-valley difference (AMPD), and the monthly maximum load (MML) tie for fourth position with a frequency of 5 instances each. The remaining factors were adopted fewer than five times each, including daily electricity consumption (DEC), hours with annual maximum load(HWAML), natural gas consumption (NGC), per capita consumption (PCC), load transfer quantity (LTQ) and electric energy substitution quantity (EESQ).

Statistical results indicate that although the diversity of response variables selection resulting from differences in research emphasis, analytical methods, and magnitudes is evident, power consumption and maximum load are still the focus of most research.

For residential customers who have already implemented C2E transformation and have had their coal-fired heating equipment replaced by electric heating equipment, their CECB probably transforms due to the transformation of their heating equipment. Therefore, this paper initially identified annual electricity consumption (AEC) as a response variable. However, due to the considerable number of customers within each electricity consumption range, it is impractical to input those data for direct analysis. Statistically, if we analyze data with a diverse range without any processing, it will generate more discrete values than usual. The variance and standard deviation will also worsen. For this article, the response variable selection should focus on the changes in customers' electricity consumption behavior after the impact factors change, as the necessity of considering the disparity in the electricity consumption of residential customers at different scales still exists. To guarantee that the response variable can reflect the influence of different factors of CECB, we identify the annual electricity consumption growth rate as the response variable.

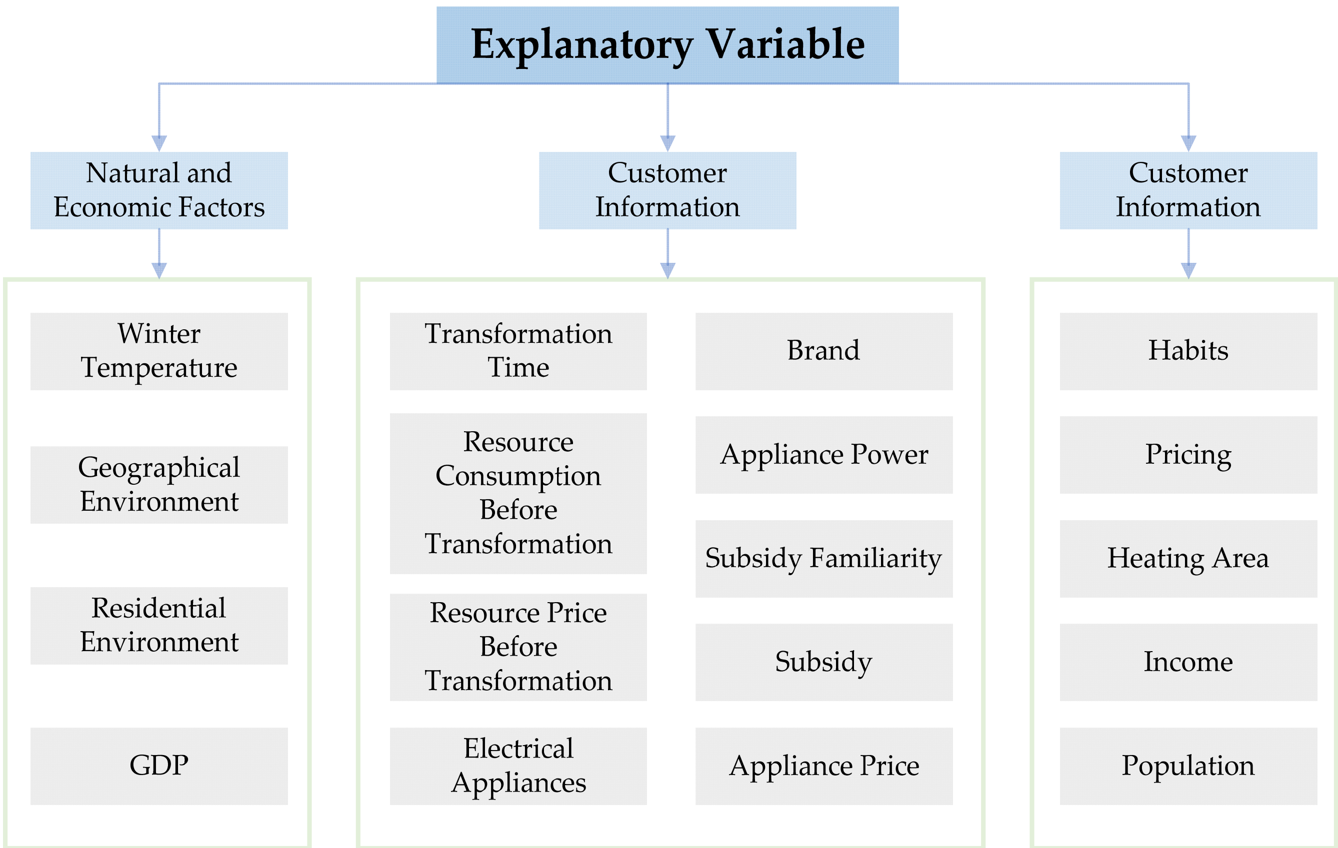

Fig. 3. Explanatory Variable Chart

Explanatory Variable Selection

This paper proposes five natural or economic factors (NAEF) and four customer information factors (CIF) through documentary analysis to ensure the scientificity and operability of the explanatory variables.

Considering the development of EES and implementation of C2E in Shaanxi, we also propose eleven C2E-related factors through the Delphi method in this study. To achieve scientificity, measurability, comprehensiveness, typicality, and independence in identifying explanatory variables, we eliminated several dependent and statistically insignificant influencing factors after a trial survey regarding the electricity consumption behavior of residents who have implemented C2E transformation.

For example, we eliminated the summer temperature for its high correlation with the winter temperature. The equipment brand was also eliminated due to its insignificance after analysis. Ultimately, this paper identifies 17 influencing factors based on a trial survey combined with relevant research and expert interviews, which we have divided into three categories, as shown in Fig. 3:

1) Natural and Economic Factors

Natural and economic factors mainly refer to the geographic environment and economics of the place where residential customers live, including winter temperature, geographical environment, residential environment, and income. In previous studies, scholars have often considered "location" and "geographical location". However, due to the high correlation between these two factors and other factors such as winter temperature and summer temperature, identifying all four factors as explanatory variables is counter to the principle of independence. Theoretically, the temperature level directly affects the CECB of residential customers, yet neither "location" nor "geographical location" directly reflects the temperature. Hence, in accordance with the principle of independence, both "average winter temperature" and "average summer temperature" are selected as explanatory variables. Simultaneously, due to the focus on heating seasons, the changes in the heating equipment of C2E customers mainly result in consumption changes in winter; this paper therefore selects winter temperature as an explanatory variable instead of summer temperature.

2) Residents' Electricity Consumption-Related Factors

Factors related to residents' electricity consumption mainly refer to the residential environment and heating demand where residents live, including "habits", "pricing", "heating area", "population" and "insulation conditions".

"Pricing" refers to different types of electricity prices. To improve electricity consumption, the government has promulgated several types of electricity pricing policies. Nevertheless, customer reaction to different types of pricing remains ambiguous. Given this circumstance, this paper selects "electricity pricing" as an explanatory variable to analyze whether customers are sensitive to this factor.

Different heating areas require appliances capable of heating the surroundings, which eventually leads to the diversity of CECB. Hence, the "heating area" is one explanatory variable.

Considerable prior literature has demonstrated that CECB significantly varies by the number of people in a household. Therefore, this paper adopts "number of people" to study its impact on the CECB.

"Insulation condition" has an indirect but critical impact on residential customers; households with insulation layers tend to have positive comments on C2E projects, which leads to increased reliance on electrical equipment. Since 99.1% of customers' homes had installed insulation layers in the data collection stage, this paper's analysis eliminates this factor.

3) "Coal-to-electricity"-related factors

"Coal-to-electricity" (C2E) refers to the various effects of C2E transformation, which is this paper's emphasis, including "transformation time", "resource consumption before transformation", "resource price before transformation", "electrical appliances", "brand", "equipment power", "subsidy familiarity" and "subsidy".

The C2E project involves a massive number of customers in Shaanxi, so it is impossible to implement C2E all at once. Thus, various regions and customers have different transformation times. Customers with earlier transformations have had more time to adapt to new heating appliances and develop new customer habits. Therefore, "transformation time" is selected to analyze how customer behavior varies for different C2E implementation time.

This paper identifies "electrical appliances", "brand" and "appliance power" as explanatory variables because customers' willingness to adapt their appliances, as well as their frequency and method, varies, with different functions and power. This paper selects this factor to study how customers respond to different electrical appliances and attempt to find their favorite appliance.

Given the sustainability background, the government has recently promulgated numerous subsidy policies to promote electrical heating appliances. Customers have varying familiarity with those policies. This paper proposes "subsidy familiarity" and "subsidy" as explanatory variables under this circumstance to analyze whether customers have received a subsidy and whether their familiarity with subsidies will affect their electricity consumption.

B. Model Construction

Most scholars prefer principal component analysis (PCA), analytic hierarchy process (AHP), grey relational analysis, and regression analysis in power demand and power load analyses. For this paper, linear regression modeling is selected for analysis due to the use of moderate variables, since each variable has a standard range and the purpose of this research is to fully explore the relationship between the data to explore how each factor influences residents' electricity consumption behavior.

In statistics, multiple linear regression is a linear approach to modeling the relationship between a dependent variable and one or more explanatory variables.

Let y be the independent variable (the response variable) and x be the dependent variable (the explanatory variable). This paper sets β as the unknown coefficient, c as the unknown constant, and ε as the random error. This is the general standard form of a multiple linear regression model; however, we have more than one explanatory variable in this case. Thus, for multiple explanatory variables, modeling is as follows:

$$\begin{cases} y_1 = c + \beta_1 x_{11} + \beta_2 x_{12} + \cdots + \beta_m x_{1m} + \varepsilon_1 \\ y_1 = c + \beta_1 x_{21} + \beta_2 x_{22} + \cdots + \beta_m x_{2m} + \varepsilon_1 \\ \qquad \vdots \\ y_1 = c + \beta_1 x_{n1} + \beta_2 x_{n2} + \cdots + \beta_m x_{nm} + \varepsilon_1 \end{cases} \quad (1)$$

After calculating the unknown coefficients and constants with the least square method, the regression equation for multiple variables is constructed:

$$y_1 = c + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_m x_m + \varepsilon \quad (2)$$

IV. RESULTS

A. Data Collection and Preprocessing

This paper's research subject, customers in Shaanxi who had finished C2E transformation by the end of 2019, included 402,500 customers. Due to difficulties in collecting data from such a massive number of customers, this paper applies a sample survey to collect customer data. This paper selects customers in Shaanxi who have finished C2E transformation because they tend to have more familiarity with and acceptance of C2E transformation. Moreover, it is more accurate to analyze their behaviors because they have likely cultivated new behavioral characteristics through using electrical appliances after the transformation. Thus, we eliminate customers whose electricity activity is inactive and abnormal due to scientific concerns.

After determining the research subject, this paper first conducted a small-scale first-round survey of 50 people and revised the questionnaire based on the survey results.

Second, we selected 200 households for the second-round survey to obtain more specific requirements for us in revising the questionnaire.

We repeatedly revised the questionnaire to ensure that it is both scientific and practical. Finally, we conducted a formal survey with a sampling range of 995 households in Shaanxi. Although customer selection was randomized, these customers reflect the whole group due to how we determine the research subject. We reclaimed 750 valid answered questionnaires with an efficiency of 75.4%. Customers' uncertainty about relevant information was the main reason for invalid questionnaires.

Experts in electric power marketing selected survey objects that would appropriately represent C2E. To guarantee the validity of the collected data, we conducted on-site investigations with the help of State Grid's professional personnel. Therefore, there is no need to test the data’s reliability and validity since its authenticity is assured.

Following that process, this paper conducted character transformation and standardized the data by the zero-mean method to ensure the same scale. We also utilized "box plots" to eliminate and modify outliers. After the completion of the data collection and preprocessing process and model and data preparation. The next step is to analyze the impact factors of CECB.

TABLE I
ROTATED COMPONENT MATRIX

Variable	Components					
	1	2	3	4	5	6
Pricing	-0.269	-0.174	-0.241	-0.624	0.081	0.094
Heating Aera	0.503	0.133	0.163	-0.234	-0.262	-0.213
Resource Consumption Before Transformation	-0.068	-0.054	0.868	-0.106	-0.172	0.063
Resource Price Before Transformation	0.142	0.089	0.862	0.026	-0.005	0.072
Electrical Appliances	0.289	-0.471	-0.029	-0.334	0.000	0.179
Appliance Power	0.723	-0.127	0.228	0.191	0.181	0.241
Brand	0.423	0.011	-0.193	0.010	-0.042	0.015
Appliance Price	0.821	0.011	0.086	0.196	-0.002	0.092
Population	0.436	0.233	0.030	-0.088	-0.151	-0.151
Geographical Environment	0.305	0.569	0.219	0.249	-0.097	0.093
Residential Environment	-0.040	0.015	-0.091	-0.018	0.830	0.024
Income	0.071	0.260	0.220	-0.106	-0.583	0.338
Transformation Time	0.004	0.203	0.212	-0.414	0.422	-0.184
Habits	-0.009	0.096	-0.078	0.293	0.206	-0.691
Subsidy Familiarity	0.036	0.261	0.090	0.278	0.037	0.601
Subsidy	0.005	-0.024	-0.181	0.713	0.068	-0.010
Summer Temperature	0.154	0.923	-0.006	-0.054	-0.066	0.087
Winter Temperature	-0.061	0.892	-0.060	-0.084	0.049	0.054
GDP	0.510	-0.010	0.070	0.405	0.101	-0.429

Pearson Correlations

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	PC	*1.0*	-.192**	-.192**		-.155*	-.264**				-.152*		.278**		.254**	-.375**	.161*
2	PC	-.192**	*1.0*		-.199**	-.150*		-.219**	-.361**		-.155*		-.174*		-.166*		-.321**
3	PC	-.192**		*1.0*		.148*	.288**	.379**	.257**	-.160*							.239**
4	PC	-0.1	-.199**		*1.0*	.651**			.182**	-.217**	.147*						
5	PC	-.155*	-.150*	.148*	.651**	*1.0*	.309**	.245**	.242**		.173*						.158*
6	PC	-.264**		.288**		.309**	*1.0*	.604**	.180**				-.190**	.141*			.247**
7	PC		-.219**	.379**		.245**	.604**	*1.0*	.283**		.149*						.445**
8	PC		-.361**	.257**	.182**	.242**	.180**	.283**	*1.0*	-.157*	.274**			.191**		.204**	.244**
9	PC			-.160*	-.217**			-0.1	-.157*	*1.0*	-.332**	.140*					
10	PC	-.152*	-.155*		.147*	.173*		.149*	.274**	-.332**	*1.0*		-.207**			.141*	
11	PC									.140*		*1.0*					
12	PC	.278**	-.174*				-.190**				-.207**		*1.0*		.185**		.183**
13	PC						.141*		.191**					*1.0*	.207**		
14	PC	.254**	-.166*										.185**	.207**	*1.0*		
15	PC	-.375**							.204**		.141*					*1.0*	
16	PC	.161*	-.321**	.239**		.158*	.247**	.445**	.244**				.183**				*1.0*

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

	Label	Variable	Label	Variable
For simplicity, this paper labeled all explanatory variables as 1-16	1	Electricity Consumption Growth	9	Residential Environment
	2	Pricing	10	Income
	3	Heating Aera	11	Transformation Time
	4	Resource Consumption Before Transformation	12	Habits
	5	Resource Price Before Transformation	13	Subsidy Familiarity
	6	Appliance Power	14	Subsidy
	7	Appliance Price	15	Winter Temperature
	8	Geographical Environment	16	GDP

Fig. 4. Correlation Analysis Result

B. Correlation Analysis

This paper adapts factor analysis to identify variables with an insufficient degree of correlation to avoid including factors that are selected empirically and not suitable for mathematical calculation. In factor analysis, usually, when the absolute value of a factor's loading is less than 0.5, it should be eliminated for its insufficient correlation with the response variable.

As shown in Table.1., population, electrical appliances, and brand are three factors be eliminated for their insufficient loading value.

To avoid the multicollinearity problem, we employed the Pearson correlation coefficient (after this referred to as the correlation coefficient) to analyze the degree of correlation among the selected explanatory variables. The correlation coefficient always lands between -1 and +1.

A value of +1 is a total positive linear correlation, 0 is no linear correlation, and −1 is a total negative linear correlation[37]. The stronger values indicate either tendency; the larger number is the absolute value of the correlation coefficient.

As shown in Fig. 4, basically all explanatory variables and explained variables are correlated to some degree, which provides a correlation basis for this research. Most of the variables have relatively low correlation coefficient scores, indicating that most explanatory variables are relatively independent. Therefore, the probability of severe multicollinearity in the regression model is relatively low.

TABLE II
COLLINEARITY STATISTICS

Factors	Tolerance	VIF
Pricing	0.714	1.401
Heating Aera	0.768	1.303
Resource Consumption Before Transformation	0.486	2.058
Resource Price Before Transformation	0.471	2.124
Appliance Power	0.554	1.804
Appliance Price	0.487	2.052
Geographical Environment	0.671	1.490
Residential Environment	0.794	1.259
Income	0.743	1.346
Transformation Time	0.918	1.090
Habits	0.808	1.238
Subsidy Familiarity	0.866	1.155
Subsidy	0.834	1.199
Winter Temperature	0.881	1.135
GDP	0.650	1.537

Although most correlation analysis values are low, there are still some cases where the correlation coefficient is more significant than 0.6. To avoid the problem of multicollinearity, this paper conducts a collinearity diagnosis.

As shown by the collinearity diagnosis, there is a high degree of collinearity between "resource consumption before transformation" and "resource price before transformation". Moreover, the collinearity between "appliance price" and "appliance power" is also high. Hence, this paper eliminates these two pairs of variables due to their strong positive correlation.

C. Regression Analysis

To discover the impact factors of CECB, we adopt multivariable regression models to analyze how explanatory variables affect CECB. As shown in the table, the significance of the regression model is exceptionally high. This model's R2 is not sufficiently high, although it is suitable for this model to analyze impact factors due to the high authenticity of data that we have collected. Therefore, apart from its dissatisfactory R2 and simulation degree, the model can still reflect various influencing factors. Based on the above analysis, we decided to analyze correlation coefficients, explore the factors that significantly impact annual electricity consumption changes and analyze those factors.

After the data cleaning and standardization, this paper obtained the correlation coefficient table by inputting those data into the multiple linear regression model with SPSS25.0.

TABLE III
MODEL SUMMARY[B]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.595[A]	0.354	0.306	19.29179%	0.909

A. Predictors: (Constant), All Explanatory Variables
B. Dependent Variable: Electricity Consumption Growth

TABLE IV
ANOVA[A]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	38770.607	15	2584.707	6.926	.000[B]
Residual	70161.905	188	373.202		
Total	108932.512	203			

A. Dependent Variable: Electricity Consumption Growth
B. Predictors: (Constant), All Explanatory Variables

The unstandardized coefficient of customer habits is 6.94, which is the highest influencing factor and is positively correlated with the dependent variable. Next is geographic location, with a value of -3.721, implying its negative correlation with the dependent variable. Following these are average winter temperature, subsidy policy familiarity, equipment power, electricity pricing, subsidy, transformation time, GDP, household income, electrical appliance price, heating area, residential environment, and resource consumption before C2E.

However, after the coefficients were standardized, the ranking of variables changed as follows: average winter temperature, equipment power, heating area, habits, subsidy, pricing, appliance price, GDP, transformation time, geographical environment, income, subsidy familiarity, resource consumption before the transformation, residential environment. For instance, average winter temperature ranks highest, with a value of -0.3, which negatively correlates with the dependent variable. Appliance power follows average winter temperature, with a value of -0.25.

Statistically, a variable can be identified as significant when its sig<0.05. Surprisingly, some variables in this ranking failed the significance test, implying that these variables have an insignificant influence on the response variable despite their moderate rankings.

TABLE V
COEFFICIENTS RESULT

Model	Unstandardized Coefficients		Standardized Coefficients	Sig.
	B	STD. ERROR	Beta	
(Constant)	14.270	13.739		0.300
Pricing	-2.108	1.002	-0.145	0.037
Heating Aera	-0.051	0.019	-0.177	0.009
Resource Consumption Before Transformation	-0.015	0.034	-0.028	0.656
Appliance Power	-2.069	0.638	-0.250	0.001
Appliance Price	0.090	0.062	0.120	0.152
Geographical Environment	-3.721	3.592	-0.074	0.301
Residential Environment	0.030	2.656	0.001	0.991
Income	-0.163	0.297	-0.037	0.584
Transformation Time	0.657	0.509	0.078	0.199
Habits	6.940	2.915	0.155	0.018
Subsidy Familiarity	-2.986	5.002	-0.037	0.551
Subsidy	1.847	0.773	0.152	0.018
Winter Temperature	-3.248	0.673	-0.300	0.000
GDP	0.171	0.104	0.117	0.103

The significance test revealed six factors with a sig value less than 0.05: electricity pricing, heating area, equipment power, customer habits, subsidy, and average winter temperature. Hence, it is acceptable to identify these six factors as the impact factors of this regression model.

With the monthly electricity consumption data from November 2017 to November 2019, this paper proposes the following model:

$$U_{yearly} = c - 0.3 * x_1 - 0.25 * x_2 - 0.177 * x_3 + 0.155 * x_4 + 0.152 * x_5 - 0.145 * x_6 + \varepsilon \quad (3)$$

Where:

U_{yearly} represents the annual rate of change in electricity consumption;

C represents a constant, which is 14.270 in this paper.

X_1 represents the winter temperature value, and its unit is

Celsius.

X_2 represents the sum of all equipment power in one household; its unit is kW/h.

X_3 is the heating area represented as m2.

X_4 represents the customers' habits: A value of 1 indicates that the resident chooses to turn on appliances during the period from 8 am-8 pm; a value of 2 indicates appliance usage from 8 pm-8 am; and a value of 3 indicates appliance use throughout the whole day.

X5 represents the subsidy factor: The values of 0, 1, 2, 4, 7, 8, respectively, correspond to a one-time purchase subsidy, electricity fee subsidy, boiler removal subsidy, free heating appliance, and other subsidy policies

X_6 represents the type of electricity pricing factor: The values are 0, 1, 2, 4 and correspond, respectively, to none, electric heating price, peak-valley price, and step price.

ε is a random error.

V. Discussion

The regression result shows that AEC tends to increase after C2E transformation. Impact factors have various effects on annual electricity consumption. All explanations of how impact factors influence AEC are shown in table 6.

The most crucial factor is the average winter temperature. The higher the winter temperature is, the lower the growth rate of electricity consumption, which is highly realistic. Customers are less willing to turn on heating appliances when the winter temperature is relatively high, and vice versa. Due to the objectiveness of this factor, this paper directly uses the data from the Meteorological Bureau.

The appliance power factor has a negative correlation coefficient, which implies its negative correlation with power consumption. For power consumption increments, we should promote facilities with higher heating capacity but lower power in consideration of customers' cost tolerance.

There is limited action possible for the heating area factor for us because it is a fixed characteristic of the customers' homes. Thus, we would utilize the result in combination with other factors for analysis.

Customer habits have a negative correlation with the dependent variable. According to the value of the customer habit factor, customers who are accustomed to using electrical appliances all day show a more considerable increase in power consumption after transformation. In contrast, those who consume electricity during the daytime or nighttime show relatively minor increases in consumption.

From the subsidy perspective, customers show considerable interest in the free heating equipment policy, and they are more willing to use electrical appliances. Similarly, customers are more responsive to the electricity price subsidy policy than one-time subsidies. Considering this result, corporations should make more efforts to promote free heating equipment and electricity price subsidies with the goal of eventually increasing electricity consumption.

As shown by the electricity pricing factor analysis, customers who adopt electric heating pricing generally have higher electricity consumption. Therefore, to increase electricity consumption, we should emphasize electric heating pricing to promote electricity pricing policies.

TABLE VI
EXPLANATION OF SIX IMPACT FACTORS

Variable	Coefficient	Value	Explanation
Winter Temperature	-0.3	From -20 to 30	This factor reflects the average local temperature in winter,with a value of less than 30 ℃ and greater than -20 ℃
Equipment Power	-0.25	Greater than or equal to 0	This factor reflects the sum of all equipment power in one household,with a value greater than or equal to 0kW/h
Heating Area	-0.177	Greater than or equal to 0	This factor reflects the sum of the indoor heating area, with a value greater than or equal to $0m^2$
Habits	0.155	1	*1* refers to customers who are used to using heating equipment from 8:00 a.m. to 8:00 p.m
		2	*2* refers to customers who are used to using heating equipment from 8:00 p.m to 8:00 a.m
		3	*3* refers to customers who are used to using heating equipment all day long
Subsidy	0.152	0	*0* refers to customers who have enjoyed no subsidy policy
		1	*1* refers to customers who have enjoyed one-time purchase subsidy
		2	*2* refers to customers who have enjoyed electricity fee subsidy
		3	*3* refers to customers who have enjoyed both one-time purchase subsidy and electricity fee subsidy
		4	*4* refers to customers who have enjoyed boiler removal subsidy
		7	*7* refers to customers who have enjoyed free heating appliance policy
		8	*8* refers to customers who have enjoyed other subsidy policies
Pricing	-0.145	0	*0* refers to customers who have not adopted any special pricing policy
		1	*1* refers to customers who have adopted electric heating pricing
		2	*2* refers to customers who have adopted peak-valley pricing
		3	*3* refers to customers who have adopted both electric heating pricing and peak-valley pricing
		4	*4* refers to customers who have adopted step pricing
		5	*5* refers to customers who have adopted both electric heating pricing and step pricing
		6	*6* refers to customers who have adopted all three special pricing

VI. CONCLUSIONS

A. Conclusions

This paper collected data from customers who have finished C2E transformation through questionnaires and on-site surveys and then identified impact factors by consulting professionals and conducting documentary analysis. Next, through the multiple linear regression model, this paper evaluated the various effects of all proposed factors on residents' electricity consumption behavior against the background of electricity substitution. The results showed the following:

1) This paper analyzes the 17 impact factors through multiple regression analysis. Among the 17 impact factors proposed by frequency and documentary analysis, six significantly impact residents' electricity consumption behavior, including winter temperature, appliance power, and heating area. The remaining factors were eliminated due to insufficiency.
2) This paper also determines the negative correlation between residents' electricity growth and three factors: electricity pricing, appliance power, and heating area. In contrast, customer habits and subsidies are both positively correlated with residents' electricity growth.
3) This paper proposes that residential electricity consumption tends to increase after C2E transformation, indicating the positive effects of EES and C2E on residential customers' electricity consumption.

Consequently, this paper provides strong theoretical support for establishing EES-related subsidy policies and optimizing power marketing services. We also expect that this paper will enhance power companies' flexibility and agility when providing services. Hopefully, if utilized by power companies, this paper will help them enhance customer satisfaction and ultimately improve resource allocation efficiency.

B. Suggestions

To achieve sustainability in the power industry and increase power companies' revenue against the EES background, we provide the following suggestions for power companies:

1) Improve the promotion of electric heating equipment, and focus on promoting heating equipment with lower power consumption for customers whose heating area is small. This paper has proven that customers with a smaller heating area have more sensitivity to equipment power, which implies that focusing on satisfying these customers is more efficient.
2) Strengthen the propaganda about electric heating power pricing and actively promote the construction of supporting facilities.
3) Optimize relevant subsidy policies, such as increasing the implementation rate of the free heating appliance policy, promoting electricity price subsidies, optimizing the one-time subsidy policy, and accelerating subsidy issuance speed.

By analyzing the impact factors of residential customers' electricity consumption behavior under EES, this paper identifies key factors that provide some theoretical support for further implementation of EES strategy.

APPENDIX

All abbreviations in the paper are shown below:

C2E	Coal-to-Electricity
CECB	Residential Customers' Electricity Consumption Behavior
EES	Electric Energy Substitution
AEC	Annual Electricity Consumption
AML	Annual Maximum Load
MPC	Monthly Power Consumption
MML	Monthly Maximum Load
HPC	Hourly Power Consumption
AMPD	Annual Maximum Peak-Valley Difference
HWAML	Hours with Annual Maximum Load
DEC	Daily Electricity Consumption
PCC	Per Capita Consumption
NGC	Natural Gas Consumption
CIF	Customer Information
NAEF	Natural and Economic Factors
PCA	Principal Component Analysis
AHP	Analytic Hierarchy Process

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