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An Empirical Study on the Relationship between Electricity Consumption and Economic Development in Different Industries: The Case of Yunnan Province, China

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Abstract:

Many scholars have clearly demonstrated a significant correlation between electricity consumption and economic development. However, numerous studies have focused primarily on using various models and algorithms to analyze this relationship within a region, often neglecting the indicative role of electricity consumption by different industries in regional economic development. To better understand the relationship between industrial electricity consumption and regional economic development, and to explore its indicative role, this study examines Yunnan Province, China. The study collects annual electricity consumption data for 11 industries from 2011 to 2023, along with corresponding economic development data. Using statistical methods such as principal components analysis (PCA), Pearson correlation analysis, and linear regression models, the study deeply analyzes the relationship between electricity consumption by different industries and economic development within the region, and their indicative role on economic development. The results show that transportation, warehousing, and postal services (TWP), along with public utilities and management organizations (PM), are key industries indicating regional economic development. The indicative equations for Regional GDP (100 million yuan) are: $Y = 72.66X + 502116.97$ (TWP) and $Y = 154.19X - 388931.23$ (PM). The indicative equations for GDP per capita (yuan) are: $Y = 72.66X + 502116.97$ (TWP) and $Y = 154.19X - 388931.23$ (PM). Based on the analysis results, this study proposes four recommendations for electricity allocation and economic development in Yunnan Province, which can serve as a reference for future related research.

Keywords: Electricity consumption; GDP; Regional development; Economic policy; Yunnan Province

Introduction

Electricity, as a vital energy source, has significantly influenced the trajectory of human social development [1-2, 36]. With the escalating trend of economic globalization, individual nations are increasingly dependent on electricity [3, 26]. The relationship between electricity consumption and economic growth is critical in shaping sustainable development strategies for national economies [4-5, 13]. As a key parameter in the “barometer” of a country’s economic development, power data is highly valued by both

the power sector and economic decision-making departments for its economic signaling, decision-making support, and policy guidance [6, 22]. Electricity indicators are more real-time, objective, and precise compared to economic indicators such as the value added of the three major industries, trade deficit, and unemployment rate [7, 34]. Furthermore, there are two distinct advantages of using electricity data to forecast the economy. Firstly, since electricity cannot be stored, the lag in data statistics can be minimized

to the greatest extent possible. Secondly, it is evident that all aspects of the modern economic system are intricately linked to electricity [8, 21]. Changes in electricity consumption in a region can reflect not only the effectiveness of the region's economic policies but also the evolving trends of the region's market economy [9, 24]. Therefore, studying the correlation between electricity consumption and economic development allows for a direct or indirect understanding of the economic development status of a region.

Numerous related studies have been conducted on the relationship between electricity consumption and economic development. For instance, American researchers employed time series analysis to investigate the relationship between electricity consumption and gross national product (GNP) in the United States, finding a one-way causal relationship between the two variables [10]. This study was groundbreaking as it established the relationship between electricity consumption and economic development for the first time. Additionally, some researchers utilized dynamic and static regression models to examine residential and industrial power consumption in Maryland, discovering that residential power consumption is dependent on per capita income [11]. Similarly, researchers have employed various theoretical models and methods to conduct numerous empirical studies on the relationship between electricity consumption and economic growth. Nasreen studied this relationship in the Philippines and Thailand using an error correction model and concluded that income, price, and electricity consumption are positively related in Thailand, whereas a reverse causal relationship exists in the Philippines [12]. Altinay and Karagol used an improved structural model to decompose the relationship between energy consumption and economic growth in Turkey from 1960 to 2008, encompassing oil, electricity, coal, and renewable energy. They found that Turkey's energy consumption patterns shifted with changes in the economic structure [13]. Shahbaz employed data from Pakistan (1971-2008) to examine the relationship between per capita electricity consumption and per capita real GDP using the Granger causality test, revealing that the relationship is significant [14].

Although many studies have established the

relationship between electricity consumption and economic growth in various regions, few have focused on the changes and differences in electricity consumption across different industries and their indicative relationship with regional economic development. Therefore, this study analyzes electricity consumption data from various industries and corresponding economic data from 2011 to 2023 in Yunnan Province, China. The objectives are to understand the development trends in electricity consumption across different industries in Yunnan Province and to use statistical methods to determine the relationship between industry-specific electricity consumption and economic development. The findings of this study will provide a crucial foundation for the efficient operation of various industries and facilitate the coordinated development of regional electricity usage and economic growth. Additionally, the research conclusions will offer valuable insights for power planning, infrastructure development, resource allocation, and economic policy formulation.

2 Materials and Methods

2.1 Data collection

The power data utilized in this study spans from 2011 to 2023 and originates from the China Southern Power Grid Yunnan Power Grid Co., Ltd. (internal data provided by the Yunnan Academy of Macroeconomic Research). Economic data for the same period is sourced from the annual reports of the Yunnan provincial government. The study categorizes electricity consumption data across 11 industries as follows: agriculture, forestry, animal husbandry, and fishery (AFAF, primary industry); industry (secondary industry); and tertiary industry sectors including construction business (CB), transportation, warehousing, and postal services (TWP), information transmission, software, and information technology services (ISI), wholesale and retail trade (WR), accommodation and catering industry (AC), financial industry (FI), real estate business (RB), leasing and business services (LB), and public utilities and management organizations (PM). Economic indicators primarily encompass regional GDP, value-added of the primary industry (VAPI), value-added of the secondary industry (VASI), value-added of the tertiary industry (VATI), and GDP per capita.

2.2 Statistical Analyses

All statistical analyses and graphical representations were conducted using the open-source software R [15]. This study assesses the overall relationship between electricity and economic development through the electricity elasticity coefficient (EEC), defined as the ratio of the growth rates of electricity consumption to gross national product over time [16]. To explore the complex relationships between power consumption and economic development across different years, a principal component analysis (PCA) was performed using the ‘FactoMineR’ package [17]. Pearson correlations, implemented via the ‘Hmisc’ package [18], were employed to examine associations between electricity consumption and economic development. Additionally, linear regression models were utilized to investigate the relative impacts and interrelationships of electricity consumption across various industries on economic development, aiming to identify the most influential industries indicative of economic growth [19-20].

3 Results

3.1 Trends in electricity consumption of different industries and regional economic development

The electricity consumption trends across the 11

industries examined in this study indicate overall growth over time, with industry, AFAF, and PM showing particularly significant increases (Fig. 1). Except for industry, CB, and FI, the share of electricity consumption in all other industries has steadily risen over time (Fig. 2). The growth rates of these industries exhibit considerable volatility, suggesting that regional electricity consumption growth is unstable and influenced by external factors (Fig. 3).

Regional GDP, VAPI, VASI, VATI, and GDP per capita demonstrate an increasing trend over time (Fig. 4). Specifically, VATI's proportion has shown a gradual increase over time, while VASI and VATI proportions have decreased gradually (Fig. 4). The growth rates of Regional GDP, VAPI, VASI, VATI, and GDP per capita display irregular fluctuations, indicating unstable regional economic development (Fig. 4). Fig. 5 illustrates that the Electricity Elasticity Coefficient (EEC) varies across sectors: the primary industry's EEC fluctuates significantly and shows a notable increase over time, averaging 1.83 annually; the secondary industry's EEC exhibits higher variability and declines significantly over time, averaging 0.15 annually; meanwhile, the tertiary industry's EEC fluctuates less and shows a slight increase over time, averaging 0.96 annually.

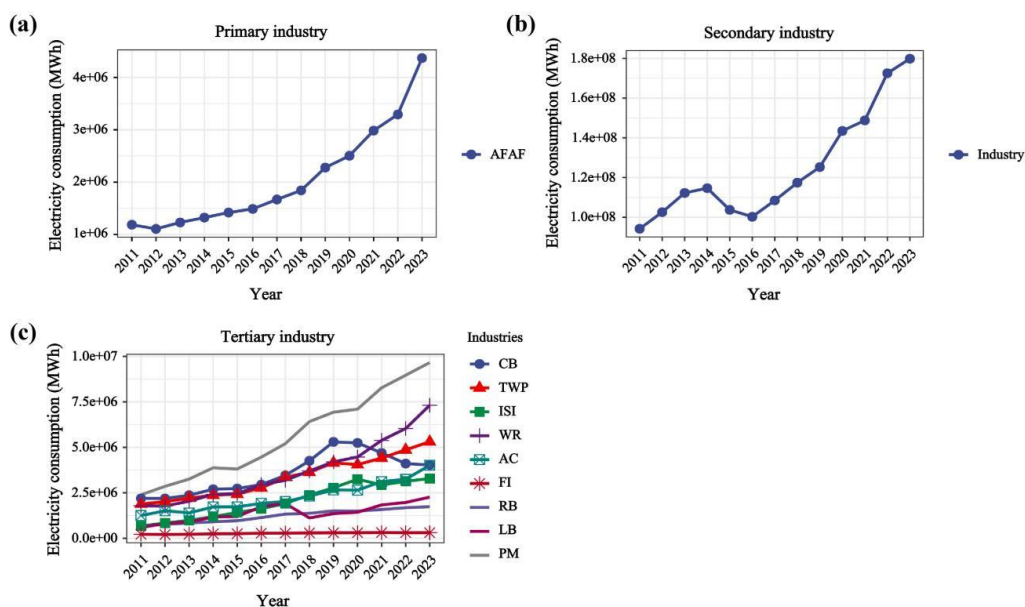


Figure 1 Electricity consumption of different industries in Yunnan Province from 2011 to 2023

(a), (b), and (c) respectively represent primary

industry, secondary industry, and tertiary industry.

“AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to “agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation, warehousing, and postal services”, “information transmission, software, and information

technology services”, “wholesale and retail trade”, “accommodation and catering industry”, “financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

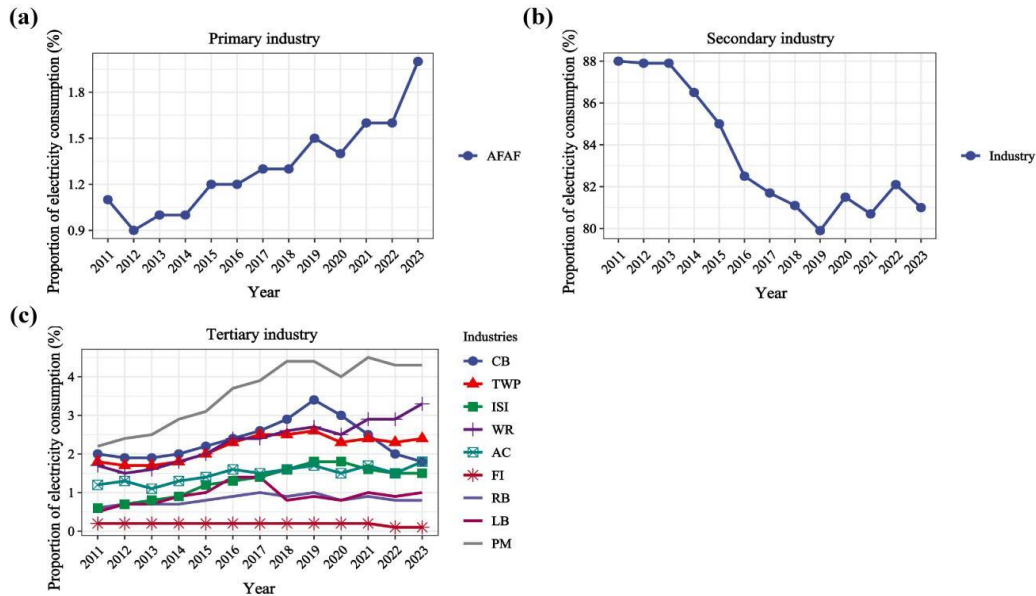


Figure 2 Proportion of electricity consumption of different industries in Yunnan Province from 2011 to 2023

(a), (b), and (c) respectively represent primary industry, secondary industry, and tertiary industry. “AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to “agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation, warehousing, and postal services”, “information

transmission, software, and information technology services”, “wholesale and retail trade”, “accommodation and catering industry”, “financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

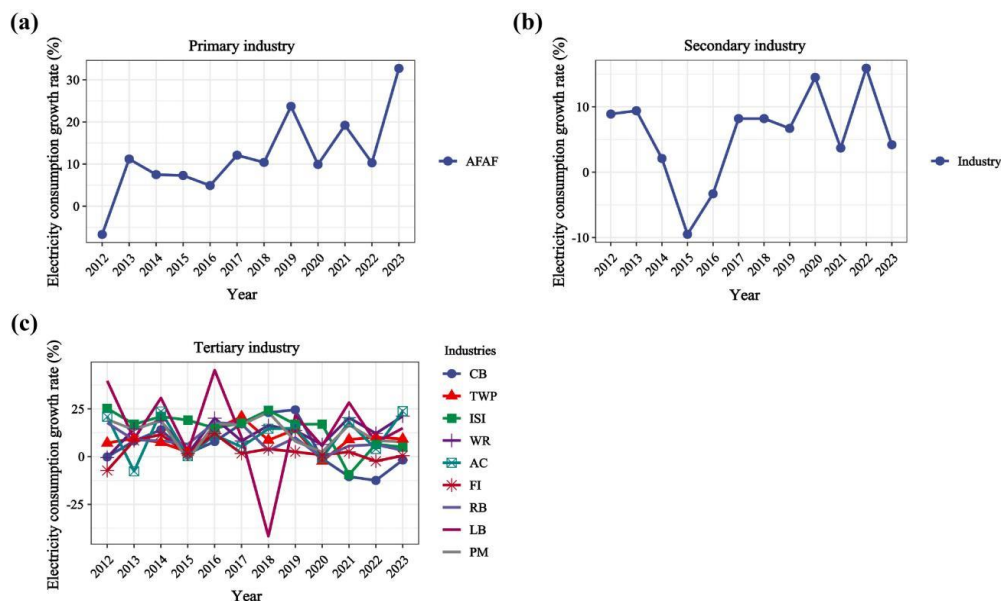


Figure 3 Electricity consumption growth rate of different industries in Yunnan Province from 2011 to 2023

(a), (b), and (c) respectively represent primary industry, secondary industry, and tertiary industry. “AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to “agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation, warehousing, and postal services”, “information

transmission, software, and information technology services”, “wholesale and retail trade”, “accommodation and catering industry”, “financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

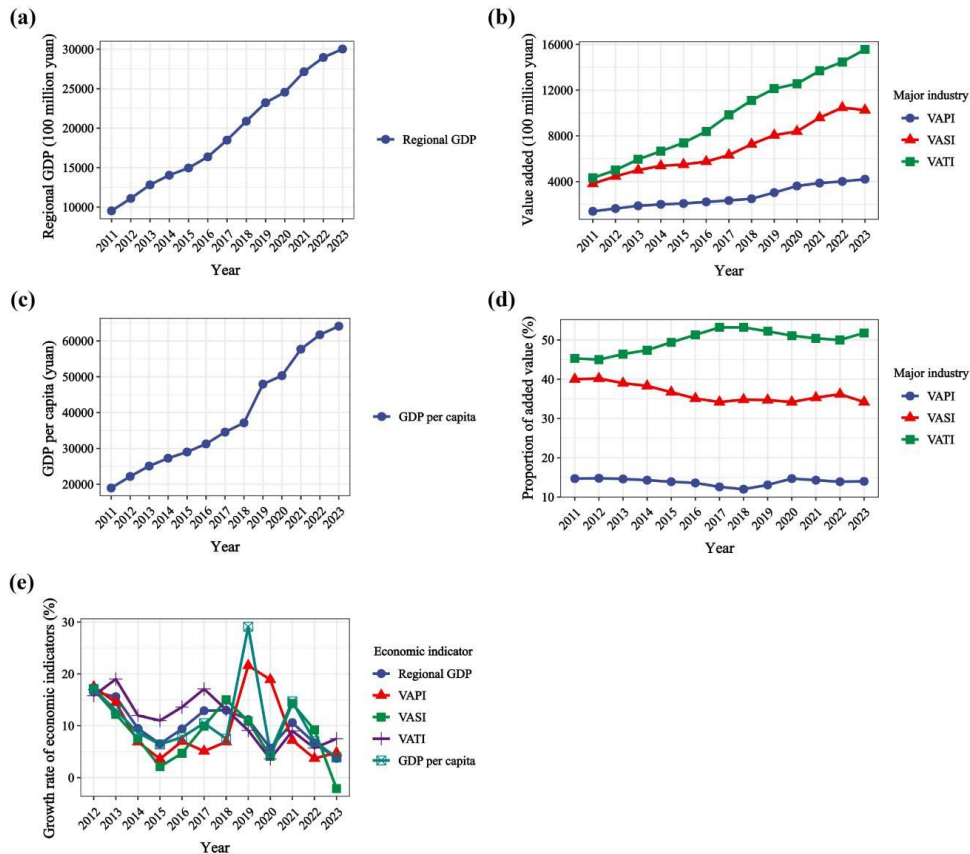


Figure 4 Trend of economic indicators in Yunnan Province from 2011 to 2023. “VAPI”, “VASI”, and “VATI” respectively represent value-added of the primary industry, value-added of the secondary industry, and value-added of the tertiary industry

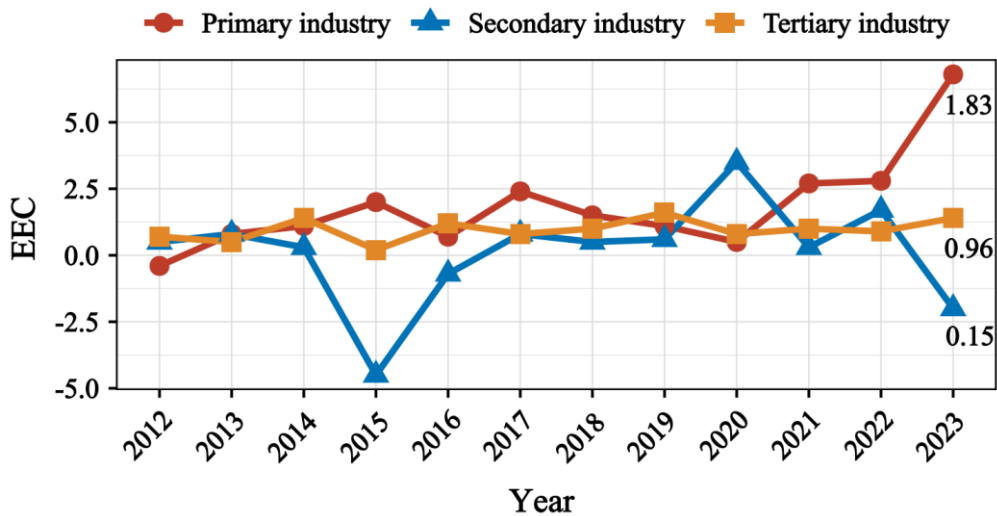


Figure 5 Electricity elasticity coefficient (EEC) in Yunnan Province from 2012 to 2023

3.2 Year-to-year differences and correlations between electricity consumption and economic indicators in different industries

Principal component analysis (PCA) was utilized for data dimensionality reduction to explore the inter-annual relationships between industry electricity consumption and economic development. Based on the PCA results (PC1: 99.66% and PC2: 0.28%), this study categorizes the 13 years from 2011 to 2023 into four groups: (1) 2011-2015; (2) 2016-2019; (3) 2020-2021; and (4) 2022-2023 (Fig. 6). Years classified into the same group exhibit similar relationships between industry electricity consumption and economic development. Among the 11 industries, Industry (PC1 = 0.992), WR (PC1 = 0.059), and TWP (PC1 = 0.037) have the greatest degree of

influence (Table 1). The Pearson correlation coefficients reveal that the industries most strongly correlated with regional GDP are PM (1.00), WR (0.97), and AC (0.97) (Fig. 7). The strongest correlations with GDP per capita are found in PM (0.99), WR (0.98), AC (0.98), and TWP (0.98) (Fig. 7). The industries most strongly correlated with VAPI are PM (0.98), WR (0.97), AC (0.97), and TWP (0.97) (Fig. 7). The industries most strongly correlated with VASI are PM (0.98), WR (0.97), AC (0.97), TWP (0.97), and RB (0.97) (Fig. 7). The industries most strongly correlated with VATI are PM (0.99), TWP (0.99), and RB (0.99) (Fig. 7). Combining the results of the above analyses, it is evident that the electricity consumption in PM, WR, AC, and TWP sectors is a key factor reflecting the economic development of the region.

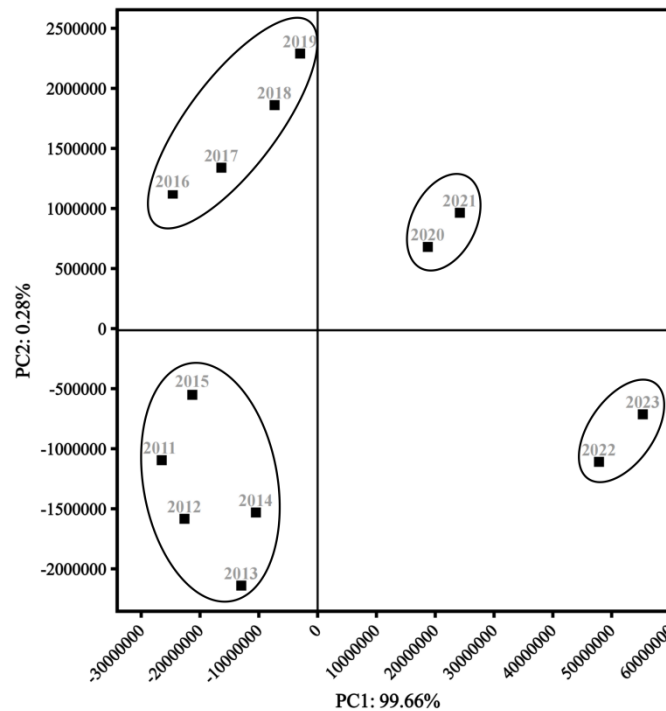


Figure 6 Principal component analysis of electricity consumption and economic indicator of different industries in Yunnan Province from 2011 to 2023

Table1 PC1 value of different industries

Industries	PC1	Industries	PC1
AFAF	0.034	AC	0.028
Industry	0.992	FI	0.001
CB	0.025	RB	0.011
TWP	0.037	LB	0.013
ISI	0.030	PM	0.080
WR	0.059		

Note: “AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to

“agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation,

warehousing, and postal services”, “information transmission, software, and information technology services”, “wholesale and retail trade”, “accommodation and catering industry”,

“financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

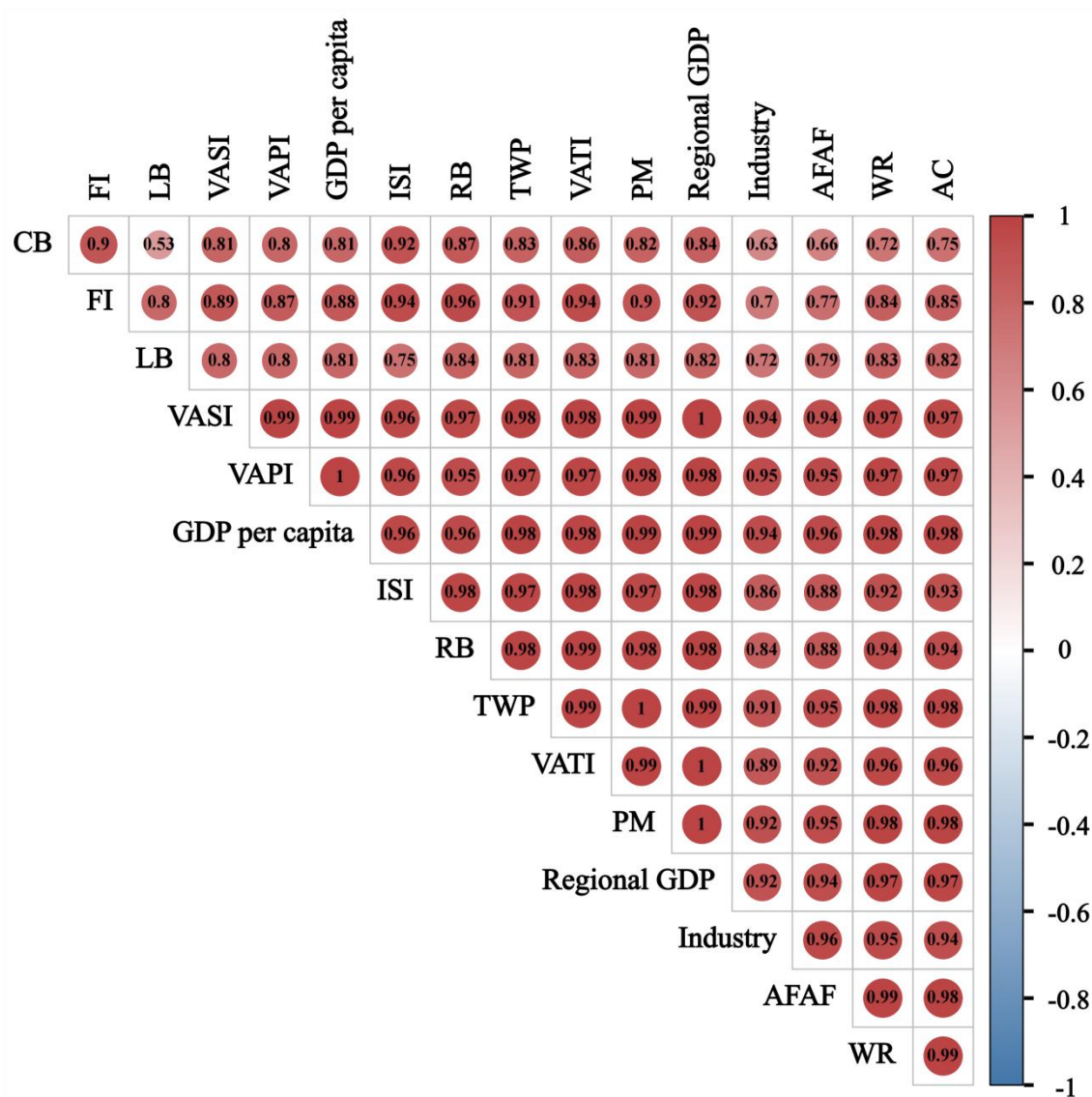


Figure 7. Pearson correlation coefficients of agriculture, forestry, animal husbandry and fishery (AF AF), industry, construction business (CB), transportation, warehousing and postal services (TWP), information transmission, software and information technology services (ISI), whole sale and retail trade (WR), accommodation and catering industry (AC), financial industry (FI), realty business (RB), leasing and business services (LB), public utilities and management organizations (PM), regional GDP, value-added of the primary industry (VAPI), value-added of the secondary industry (VASI), value-added of the tertiary industry (VATI) and GDP per capita.

3.3 Linear regression model of electricity consumption of different industries and economic indicators

Regional GDP exhibited significant linear regression with electricity consumption across all

11 industries. The most significant relationships were with PM ($Y = 349.00X - 1140591.96$, $F = 1656.7$, $P < 0.001$, $R^2 = 0.99$), TWP ($Y = 164.61X + 145136.83$, $F = 681.36$, $P < 0.001$, $R^2 = 0.98$), and RB ($Y = 52.52X + 207341.80$, $F = 324.88$, $P < 0.001$, $R^2 = 0.97$) (Fig. 8). GDP per capita also

showed significant linear regressions with electricity consumption in all 11 industries. The most pronounced relationships were with PM ($Y = 154.19X - 388931.23$, $F = 474.73$, $P < 0.001$, $R^2 = 0.98$), TWP ($Y = 72.66X + 502116.97$, $F = 317.79$, $P < 0.001$, $R^2 = 0.97$), WR ($Y = 109.57X$

- 609989.66 , $F = 252.84$, $P < 0.001$, $R^2 = 0.96$), and AC ($Y = 51.82X + 247425.74$, $F = 233.36$, $P < 0.001$, $R^2 = 0.96$) (Fig. 8). A comprehensive analysis reveals that the electricity consumption in the PM and TWP sectors is a key factor indicative of regional economic development.

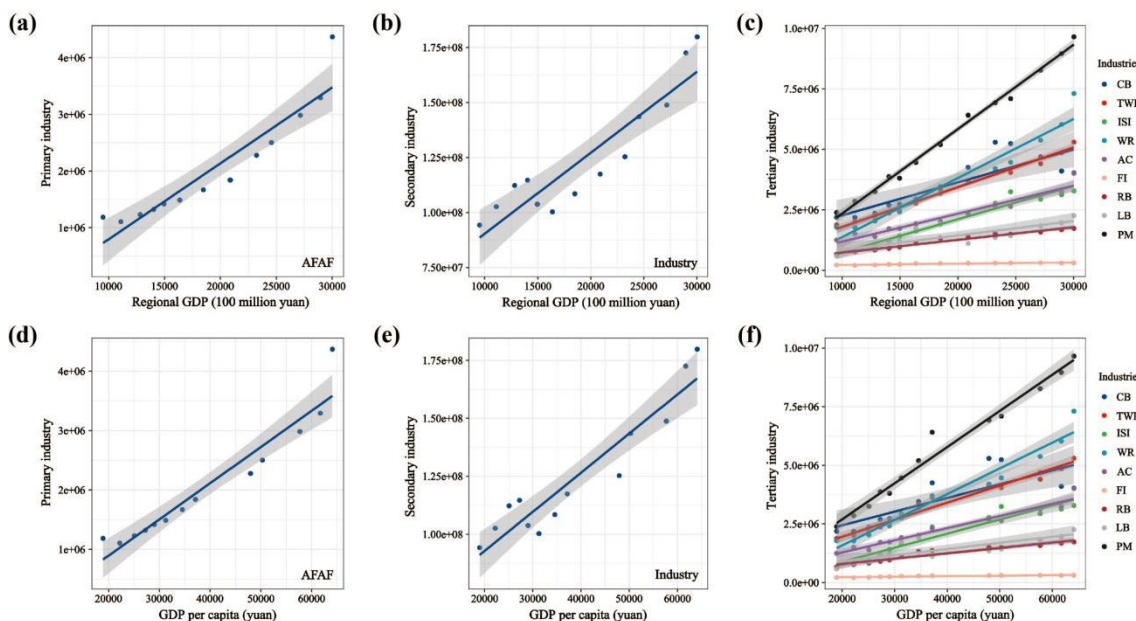


Figure 8 Linear regression model between electricity consumption of different industries and regional economy. “AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to “agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation, warehousing, and postal services”, “information transmission, software, and information technology services”, “wholesale and retail trade”, “accommodation and catering industry”, “financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

Table 2 Fitting equation and index between electricity consumption of different industries and regional GDP

Regional GDP (100 million yuan)				
Industries	Regression equation	F	P	R ²
AFAF	$Y = 133.99X - 545432.95$	78.26	<0.001	0.88
Industry	$Y = 3680.10X + 53529729.70$	57.97	<0.001	0.84
CB	$Y = 136.14X + 911799.59$	26.27	<0.001	0.71
TWP	$Y = 164.61X + 145136.83$	681.36	<0.001	0.98
ISI	$Y = 137.61X - 640799.34$	253.93	<0.001	0.96
WR	$Y = 244.28X - 1071592.41$	188.54	<0.001	0.94
AC	$Y = 115.73X + 25243.68$	188.48	<0.001	0.94
FI	$Y = 5.13X + 170013.86$	59.11	<0.001	0.84
RB	$Y = 52.52X + 207341.80$	324.88	<0.001	0.97
LB	$Y = 59.63X + 247460.78$	22.25	0.001	0.67
PM	$Y = 349.00X - 1140591.96$	1656.73	<0.001	0.99

Note: “AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to “agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation, warehousing, and postal services”, “information transmission, software, and information technology

services”, “wholesale and retail trade”, “accommodation and catering industry”, “financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

Table3 Fitting equation and index between electricity consumption of different industries and GDP per capita.

GDP per capita (yuan)				
Industries	Regression equation	F	P	R ²
AFAF	$Y = 60.96X - 325657.61$	118.05	<0.001	0.92
Industry	$Y = 1686.38X + 59094844.93$	88.66	<0.001	0.89
CB	$Y = 58.37X + 1274149.65$	20.72	0.001	0.65
TWP	$Y = 72.66X + 502116.97$	317.79	<0.001	0.97
ISI	$Y = 60.18X - 320202.99$	133.44	<0.001	0.92
WR	$Y = 109.57X - 609989.66$	252.84	<0.001	0.96
AC	$Y = 51.82X + 247425.74$	233.36	<0.001	0.96
FI	$Y = 2.18X + 184405.79$	36.38	<0.001	0.77
RB	$Y = 22.81X + 335879.05$	125.62	<0.001	0.92
LB	$Y = 26.21X + 381131.67$	20.67	0.001	0.65
PM	$Y = 154.19X - 388931.23$	474.73	<0.001	0.98

Note: “AFAF”, “CB”, “TWP”, “ISI”, “WR”, “AC”, “FI”, “RB”, “LB”, and “PM” correspond to “agriculture, forestry, animal husbandry, and fishery”, “construction business”, “transportation, warehousing, and postal services”, “information transmission, software, and information technology services”, “wholesale and retail trade”, “accommodation and catering industry”, “financial industry”, “real estate business”, “leasing and business services”, and “public utilities and management organizations”, respectively.

Discussion

The growth rate and proportion of different industries in Yunnan Province exhibit fluctuating trends, indicating that overall electricity consumption is unstable (Figs. 1-3). This instability complicates the power sector’s ability to formulate accurate power supply plans [21-22]. Therefore, the power sector should promptly update electricity-related big data, improve forecasting methods, and enhance the accuracy of power supply planning [7, 23]. This approach will enable real-time, precise electricity supply, avoiding resource waste while ensuring the economy’s normal operation [5, 24]. The regional GDP growth rate in Yunnan Province shows a significant downward trend, indicating a post-pandemic economic slowdown, which will likely increase unemployment. In response to this adverse situation, both enterprises and the government should shoulder their social responsibilities and respond proactively (Fig. 4). For enterprises, this could involve increasing investment in research and development to improve production technology, thereby reducing

costs and seeking new profit growth points [1, 25]. For the government, it is crucial to formulate policies to stimulate consumption and boost market demand [26-27]. Additionally, the government should strive to create employment opportunities and expand reemployment channels, enabling the unemployed to find new jobs relatively quickly.

Under circumstances where technological levels and industrial structures remain largely unchanged, the primary method for expanding production is through extensive growth [28]. In this scenario, the growth rate of electricity consumption tends to synchronize with the actual GDP growth rate, resulting in the electricity consumption elasticity coefficient approaching 1. When the industrial structure is continuously adjusted and becomes more rational, or when social development is in the early stages of industrialization, the scope of electricity use expands, and some primary energy sources are replaced by electricity [29]. At this point, the growth rate of electricity consumption will significantly exceed the actual GDP growth rate,

with the electricity consumption elasticity coefficient tending to be greater than 1. As the industrial structure transitions to a more advanced state, the focus of production shifts from pursuing output to emphasizing energy conservation [30]. With the implementation of energy-saving and environmental protection measures, electricity use efficiency continues to improve, and the electricity consumption per unit of GDP decreases significantly [31]. In this case, the growth rate of electricity consumption will be substantially lower than the actual GDP growth rate, resulting in the electricity consumption elasticity coefficient tending to be less than 1.

This study finds that the electricity consumption and economic indicators of different industries in Yunnan Province from 2011 to 2023 exhibit an overall steady growth trend. However, the growth rates and changes in proportions vary significantly among the different industries. Specifically, the Electricity Elasticity Coefficient (EEC) is 1.83 for the primary industry, 0.15 for the secondary industry, and 0.96 for the tertiary industry (Fig. 5). Additionally, the sectors of transportation, warehousing, and postal services (TWP), along with public utilities and management organizations (PM), demonstrate strong indications of regional economic development (Figs. 7-8 and Tables 1-3). For Yunnan Province, this means that focusing on the development trends of TWP and PM can effectively predict regional economic growth.

Based on the research conclusions, this study offers the following targeted policy recommendations to promote the coordinated development of China's electricity consumption and economy, aiming to provide references for future related research:

(1) Accelerate industrial structure adjustment to promote healthy economic development

The current urgent need for economic development is the optimization and upgrading of the industrial structure. Government departments should base their efforts on energy demand and the existing industrial foundation, focusing on industrial upgrading. This includes transforming and upgrading traditional high electricity-consuming industries, vigorously developing advanced low-energy-consuming industries and strategic emerging industries, and promoting the

transition of resource-intensive industries to technology-intensive and service-oriented industries [32-33]. Efforts should be made to shift sectors with low electricity efficiency to those with high efficiency, striving to build a modern industrial system that meets the development requirements of a new industrialization path [34-35]. It is also essential to cultivate and develop emerging strategic industries and low-energy-consuming industries, combining the enhancement of independent innovation capabilities with the improvement of the modern industrial system. This involves accelerating the formulation and release of special plans and supporting policies in the fields of energy conservation, environmental protection, new energy, new materials, and production services [36]. Encouraging enterprises to increase investment in research and development, promoting industrialization, and pioneering a new path of industrialization are crucial steps. The central region should seize the opportunities of regional rise and industry transfer, establishing and implementing a scientific development perspective, accelerating the transformation of the economic development mode, and advancing strategic economic structural adjustments. With a focus on technological and institutional innovation, the region should actively develop advanced manufacturing and high-tech industries. Emphasis should be placed on the development of emerging industries such as new energy, energy conservation, environmental protection, and circular economy to reduce industrial electricity consumption and promote sound and rapid economic development [37].

(2) Transform energy development methods and adjust energy consumption structure

Energy is the foundation of economic development. Transforming energy development methods and adjusting the energy consumption structure are critical tasks [38]. The key to transforming energy development methods is to develop a diversified economy and reform the methods of energy production and utilization, guided by the principles of prioritizing conservation and protecting the environment. The main goal is to optimize the energy structure and build a modern energy industry system. The conflict between rapidly growing internal demand and increasing external pressure affects China's

economic development [11, 34]. China is currently at a crucial stage of industrialization and urbanization, and future energy and electricity consumption is expected to continue growing. Relevant government departments should acknowledge the reality of resource and environmental constraints, transform energy development methods, achieve fundamental changes in the economic development mode, and embark on a path of energy conservation and low-carbon development [2, 33].

(3) Innovate technological equipment and improve electricity efficiency

Many industrial enterprises suffer from outdated production processes, low power supply efficiency, poor power supply quality, and inefficient electricity management. To improve electricity utilization, these enterprises should adopt rational electricity usage, save electricity, and convert waste energy into electrical energy [8, 12]. Due to production process constraints, large electromechanical equipment in many mining and industrial enterprises exhibit significant energy consumption. Enterprises should actively upgrade machinery and equipment, use energy-saving transformers, innovate production technology, and introduce variable frequency drive technology to reduce power losses during supply and consumption processes without affecting normal production [29]. China's coal coking industry is vast, and its metallurgical steel and cement industries rank among the top globally in terms of quantity and production. The extensive waste heat and pollutant gases generated during production represent major energy waste and environmental pollution when released into the air. Enterprises should efficiently collect and utilize this waste heat, converting it into electrical energy for reuse. This approach not only reduces environmental pollution but also generates a substantial amount of electricity, promoting energy reuse [26, 36].

(4) Increase investment in electricity saving and improve reward and penalty mechanisms

Relevant government departments should swiftly enhance the reward and penalty mechanisms for electricity usage and improve energy-saving subsidy mechanisms. For enterprises and products that exceed national and regional unit product energy consumption (electricity consumption) limits, government departments should intensify

the implementation of differential and punitive electricity pricing, strictly enforce desulfurization electricity pricing, and study policies for denitrification electricity pricing in coal-fired power plants [25]. For enterprises implementing energy-saving technologies, relevant departments should allocate specific funds in the fiscal budget to support energy-saving projects, high-efficiency energy-saving products, new energy-saving mechanisms, energy management capacity building, and pollution reduction monitoring systems through subsidies and rewards. Increasing investment in energy-saving equipment retrofit projects will alleviate the investment pressure brought by process upgrades in industrial enterprises. Additionally, the government should promptly develop catalogs and corresponding tax incentive policies for energy-saving, water-saving, resource recycling, and environmentally friendly products (equipment and technology) [23, 31]. This includes implementing policies for the exemption of corporate income tax on energy-saving and environmental protection projects and investment tax credits for special energy-saving and environmental protection equipment. These measures will motivate industrial enterprises to upgrade traditional equipment and encourage them to reform electricity usage technologies [2, 5, 27].

Conclusion

(1) The close relationship between electricity demand and economic development in Yunnan Province

Electricity demand in Yunnan Province is strongly correlated with economic development, exhibiting distinct phase characteristics and generally consistent overall trends. The growth rate of electricity consumption in the TWP and PM sectors is more sensitive and precedes economic indicators, with fluctuations in electricity consumption growth being more pronounced than those in economic growth. Changes in the provincial economic structure are also related to shifts in electricity consumption patterns, with the latter typically changing in the same direction as the former.

(2) The recent discrepancy between electricity demand and economic growth rates in Yunnan Province

The synchronous decline in both electricity consumption growth and economic growth rates across the province is a recent phase-specific phenomenon, with the decline in electricity consumption being more pronounced, thereby widening the gap between the two. The industrial structure adjustment during Yunnan Province's stage of industrialization has had differentiated impacts on the economy and electricity demand, which is the fundamental reason for the current discrepancy between economic and electricity consumption growth rates. The new changes in the relationship between electricity and the economy under the new normal indicate that structural adjustments have made positive progress as the economy enters a new stage of transformational development. It is necessary to acknowledge this recent phase-specific phenomenon of the widening gap between electricity consumption and economic growth rates in Yunnan Province as a reference for the next phase of electricity consumption analysis and forecasting.

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Author contributions

B.-w.Z. and X.-q.Y. conceived the ideas and designed methodology; S.-q.Y. and Y.-t.X. collected the data; X.-q.Y. analyzed the data; S.-q.Y. and X.-q.Y. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Declaration of conflicting interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

All data from this study are included in the supplementary materials.

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