Construction and Application of Urban Economic Barometer Indicator System Based on 3E Model

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Abstract: The definition and presentation of urban economic barometers vary. Energy, as one of the important infrastructure in cities, changes in energy demand are the "barometer" and "wind vane" of social development and economic operations. Therefore, in order to promote the optimization of urban energy, economic, and environmental policies, a "urban economic barometer indicator system based on the (energy-economy-environment) 3E model" has been constructed. Firstly, based on the overview of research on the relationship between energy, economy, and environment, and based on the theoretical framework of the "Sustainable Development Triangle" of energy economy environment, a multi-dimensional indicator system for urban economic barometers was constructed from three dimensions: energy utilization, economic society, and environmental friendliness. The definitions, calculation formulas, and forward and inverse properties of 10 indicators were clarified; Secondly, by integrating energy, economic, and environmental data, a carbon peak index evaluation model based on the Mann Kendall test method is constructed to provide reference for regional carbon peak evaluation and prediction; Finally, focusing on the needs of a certain high-tech zone, we will carry out the application of the urban economic barometer indicator system based on the 3E model, providing data and information support for urban managers to plan development ideas, formulate policy measures, and implement regulatory management.

Keywords: Energy-Economy-Environment; Big data; Carbon Peak Index Evaluation Model; Urban Economic Barometer

1 Introduction

China's rapid economic and social development, continuous industrialization process, and strategic goals such as "3060" and "new power system" have been proposed and implemented. Cities are essential carriers of national economic development, and energy, economy, and environment are the three major systems of urban operation. The coordinated and sustainable development among the three is the foundation of urban development. The relationship between energy, economy, and environment has always been a focus of attention for scholars at home and abroad, and the coordinated development of energy, economy, and environment under the influence of the three relationships has attracted much attention[1-5]. The research on the relationship between energy, economy, and environment is mainly divided into three themes: the relationship between energy and economy; The relationship between economy and environment; The relationship between energy, economy, and environment[6-8].

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With the application of mobile Internet technology in more and more industries, related massive heterogeneous data has given birth to "3E" big data of cities (energy, economy, environment), and urban "3E" big data has emerged as the times require. Data is an essential basis for improving enterprise management level, understanding the laws of industry development, and promoting the scientific development of cities. It opens new ideas for studying urban "3E" issues and provides new tools and methodologies. It is urgent to use big data technology to explore the value behind urban "3E" big data. After the "dual carbon" goal was proposed, how to provide analysis and decision support for urban managers to solve urban energy, economic and environmental problems based on the "3E" big data of the city has become the focus[9-13].

This article systematically reviews the literature on the relationship between energy, economy, and environment. Based on the "Sustainable Development Triangle" theoretical framework of the energy economy environment, a multi-dimensional indicator system for urban economic barometers is constructed from three parts: energy utilization, economic and social, and Environmentally friendly. Finally, energy, economy, and environmental data are integrated for application verification in a specific high-tech zone. Ultimately, provide auxiliary decision-making support for urban managers to improve their energy and carbon dual control management system and develop precise energy management measures.

2 Theoretical Framework of the "Sustainable Development Triangle" of Energy Economy Environment

In 2020, carbon dioxide emissions generated by energy consumption in China accounted for about 88% of the total emissions, among which the power industry accounted for about 41% of the total carbon dioxide emissions of the energy industry. To achieve carbon peak and carbon neutrality goals, it is necessary to control the growth of carbon emissions. China is still in the stage of industrialization, and the demand for energy will continue to grow, posing enormous challenges.

Energy is the core infrastructure of urban construction, the economy is the center and support of all development, and environment is an important basis for development, which is the key to economic and social sustainable development. From the perspective of the energy economy relationship, energy is the material foundation of economic and social development. The supply guarantee, supply cost, and industrial development of energy have an impact on economic activities, and economic and social development will promote the large-scale utilization of energy; From the perspective of the energy environment relationship, the development and utilization of energy will have an impact on the environment, and environmental protection goals will require the direction and speed of energy transformation; From the perspective of the economic environment relationship, the economic development mode and industrial structure affect the energy consumption structure, and then affect the ecological environment. The ecological Carrying capacity is limited, and environmental damage and pollution will offset some of the economic development achievements(see figure 1).

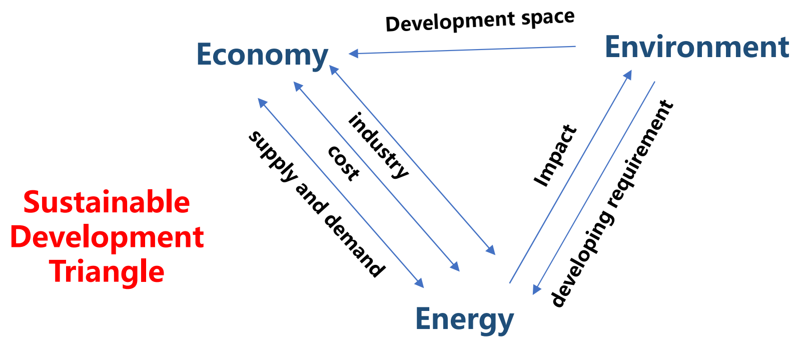

Figure 1. Theoretical framework of the "Sustainable Development Triangle"

3 Construction of Urban Economic Barometer Indicator System Based on 3E Model

Based on the theoretical framework of the "Sustainable Development Triangle" of the energy economy environment, a "barometer" indicator system for the urban economy is constructed from three dimensions: energy utilization, economic and social, and environmental friendliness. This is to analyze the regional energy utilization situation, economic and social development trends, and carbon peak situation, providing an important reference basis for urban managers to formulate policies.

3.1 Energy utilization

The energy utilization dimension is an evaluation of the energy utilization effectiveness of a city (region), reflecting the effective utilization of input energy by the city (region). The main evaluation indicators are as follows.

3.1.1 Comprehensive energy consumption

During the statistical reporting period, the actual consumption of various energy resources by a city (region) in producing a certain product or providing a certain service is calculated using prescribed calculation methods and units and is usually converted into standard coal for measurement. The comprehensive energy consumption is calculated according to formula (1):

$$E=\sum_{i=1}^{n}(E_i \times k_i) \tag{1}$$

In the formula, E represents comprehensive energy consumption; n is the number of kinds of energy consumption; E_i is the i-kind energy consumption; k_i is the coefficient of standard coal of the i-kind energy.

3.1.2 Per unit output value of comprehensive energy consumption

The ratio of comprehensive energy consumption to the output value or added value of a city (region) during the statistical reporting period. Calculate the per unit output value of comprehensive energy consumption according to formula (2):

$$E_G=\frac{E}{G} \tag{2}$$

In the formula: E_G is the per unit output value of comprehensive energy consumption; G is the output value or added value.

3.1.3 Energy utilization efficiency

Energy utilization efficiency is the ratio of the effective utilization of energy in a city (region) to the actual consumption of energy. It reflects the level of energy consumption and utilization efficiency, i.e. the degree of effective energy utilization. Calculate energy utilization efficiency according to formula (3):

$$\eta=\frac{E_{EU}}{E_{AC}}\times 100\% \tag{3}$$

In the formula: η is the energy utilization efficiency; E_{EU} is the efficient energy consumption; E_{AC} is the actual energy consumption.

3.1.4 Decrease rate of energy consumption per unit output value

Reflect the rational utilization of energy in cities (regions) under economic efficiency constraints. The decrease rate of energy consumption per unit output value is calculated according to formula (4):

$$R_{DEC}=\left(1-\frac{P_{RP}}{P_{BP}}\right)\times 100\% \tag{4}$$

In the formula: R_{DEC} is the decrease rate of energy consumption per unit output value; P_{RP} is the energy consumption of output value during the reporting period; P_{BP} is the energy consumption of output value in the base period.

3.2 Economic and social

The economic and social dimensions are evaluated from the perspectives of energy and economic development, electricity and economic development, reflecting the degree of dependence of urban (regional) economic development on energy consumption. The main evaluation indicators are as follows.

3.2.1 Energy consumption elasticity coefficient

A comprehensive indicator that reflects the dependency relationship between economic development and energy consumption growth in a city (region) during a certain period. It is the ratio between the average growth rate of energy consumption and the average growth rate of the national economy during the same period. The energy consumption elasticity coefficient is calculated according to formula (5):

$$C_{ECE}=\frac{AGR(E)}{AGR(GDP)} \tag{5}$$

In the formula, C_{ECE} is the energy consumption elasticity coefficient; $AGR(E)$ is the average growth rate of energy consumption; $AGR(GDP)$ is the average growth rate of the national economy.

3.2.2 Electricity consumption elastic coefficient

A comprehensive indicator that reflects the dependency relationship between economic development and electricity consumption growth in a city (region) during a certain period, is the ratio between the average growth rate of electricity consumption and the average growth rate of the national economy during the same period. The electricity consumption elastic coefficient is calculated according to formula (6):

$$C_{PCE}=\frac{AGR(P)}{AGR(GDP)} \tag{6}$$

In the formula, C_{PCE} is the electricity consumption elastic coefficient; $AGR(P)$ is the average growth rate of electricity consumption.

3.3 Environmentally friendly

The environmental friendliness dimension evaluates the proportion of electricity consumption to final energy consumption, renewable energy utilization, and carbon peaking in a city (region), reflecting the green and high-quality development of the city (region). The main evaluation indicators are as follows.

3.3.1 Proportion of electricity consumption to final energy consumption

It is an important indicator to measure the structure of final energy consumption, and conducive to promoting the consumption of clean electricity. It is also one of the important indicators for measuring the degree of urban (regional) electrification. The proportion of electricity energy to final energy consumption is calculated according to formula (7):

$$\eta_E=\frac{Q_E}{E} \tag{7}$$

In the formula: η_E is the proportion of electricity consumption to final energy consumption; Q_E is convert final electricity consumption into standard coal; E is convert comprehensive energy consumption into standard coal during the statistical period.

3.3.2 Utilization rate of renewable energy

Utilization rate of renewable energy refers to the ratio of renewable energy utilization to total energy consumption in a city (region) (demand side). The utilization rate of renewable energy is calculated according to formula (8):

$$R_{REU}=\frac{E_{RE}}{E}\times 100\% \tag{8}$$

In the formula: R_{REU} is the utilization rate of renewable energy; E_{RE} is the amount of renewable energy converted into usable energy.

3.3.3 Total energy carbon emissions

The total energy carbon emissions, reflects the carbon emissions of cities (regions). The total energy carbon emissions are calculated according to formula (9):

$$C=C1-C2-C3 \quad (9)$$

In the formula: C is the total energy carbon emissions; C1 is energy carbon emissions; C2 is the emission reduction of new energy generation; C3 is the emission reduction of new energy vehicles.

(1)Energy carbon emissions

C1 mainly refers to energy carbon emissions. Based on the actual situation of regional power supply, excluding the carbon emissions from clean electricity generation, the proportion of regional clean energy is β. Calculate energy carbon emissions according to formulas (10), (11), and (12):

Energy carbon emissions C1=Indirect carbon emissions from electricity+ Carbon emissions from natural gas combustion (10)

Indirect carbon emissions from electricity=Power consumption×(1-Proportion of clean energy)× Electricity emissions factor (11)

Carbon emissions from natural gas combustion =Natural gas consumption ×Lower calorific value× Carbon content perunit calorific value ×Oxidation rate $\times\frac{44}{12}$ (12)

In the formula, the low calorific value of natural gas is 38.93×10^{-6} TJ/m^3, the carbon content per unit calorific value is 15.3 t-C/TJ, and the oxidation rate is 99%.

(2) Carbon emission reduction of new energy generation

C2 mainly refers to the carbon savings converted from the generation of new energy such as photovoltaic, wind power, and biomass. Note: New energy generation is not the online electricity consumption of enterprises. The carbon emission reduction of new energy generation is calculated according to formula (13):

Carbon emission reduction of new energy generation C2 =New energy generation ×Electricity emission factor (13)

In the formula, new energy generation mainly refers to the comprehensive generation of new energy such as urban (regional) photovoltaic and wind power; The electricity emission factor adopts 0.5703t CO_2/MWh.

(3) Carbon emission reduction of new energy vehicles

C3 mainly refers to the carbon emissions saved by replacing fuel vehicles on the same mileage. The emission reduction of new energy vehicles is calculated according to formulas (14), (15), (16), and (17):

$$\text{Carbon emission reduction of new energy vehicles C3}=CO_2\text{ emissions}+N_2O\text{ emissions}+CH_4\text{ emissions} \quad (14)$$

$$CO_2\text{ emissions}=\text{Charging capacity of new energy vehicles}\times\text{Average kilowatt hour mileage}\times\text{Fuel consumption per 100 kilometers}\times\text{Gasoline density}\times\text{Lower calorific value}\times\text{Carbon content}\times\text{Oxidation rate}\times\frac{44}{12} \quad (15)$$

$$N_2O\text{ emissions}=\text{Charging capacity of new energy vehicles}\times\text{Average kilowatt hour mileage}\times N_2O\text{ emissions factors}\times GWP \quad (16)$$

$$CH_4\text{ emissions}=\text{Charging capacity of new energy vehicles}\times\text{Average kilowatt hour mileage}\times CH_4\text{ emissions factors}\times GWP \quad (17)$$

In the formula, average kilowatt hour mileage is 5km/kWh, Fuel consumption per 100 kilometers for passenger cars with 7 seats and below is 8.9L, Gasoline density is 0.73kg/L, Lower calorific value is 44.8×10^{-6}TJ/kg, Carbon content is 18.9t-C/TJ, Oxidation rate is 98%, N_2O emission factors is 6mg/km, CH_4 emission factors is 57mg/km, the GWP of CH_4 and N_2O is =21 and =310.

(4)Carbon peaking index

The Mann Kendall test method is suitable for analyzing data with non normal distribution, incompleteness, or a few outliers, which are often encountered in time series analysis. Therefore, using the Mann Kendall test method[14] to construct a carbon peaking index evaluation model can effectively evaluate the regional carbon peaking situation.

Firstly, conduct trend analysis based on regional monthly electricity consumption data. Set the element time series $X_1,X_2,...,X_n$. n is an independent, identically distributed sample of random variables; For all $i,j\leq n$ and $i\neq j$, and X_i and X_j is different, and the test statistic S is calculated according to formula (18):

$$s=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}(X_j-X_i) \quad (18)$$

Among them, X_i and X_j are the observation values corresponding to the i and j time series, and. $i<j$. sgn() is a symbolic function according to formula (19):

$$\operatorname{sgn}(X_j-X_i)=\begin{cases}1 & (X_j-X_i)>0\\ 0 & (X_j-X_i)=0\\ -1 & (X_j-X_i)<0\end{cases} \quad (19)$$

When $n\geq8$, the S roughly follows a normal distribution. Without considering the existence of equivalent data points in the sequence, the standardized test statistic Z is calculated according to formula (20):

$$Z=\begin{cases} \frac{S-1}{\sqrt{V_{ar}(S)}} & S>0 \\ 0 & S=0 \\ \frac{S+1}{\sqrt{V_{ar}(S)}} & S<0 \end{cases} \quad (20)$$

In bilateral trend testing, for a given confidence level (significance level) α. If $|Z|\geq Z_{1-\frac{\alpha}{2}}$. At the significance test level α. A positive value for Z indicates an upward trend, while a negative value indicates a decreasing trend.

Secondly, based on regional monthly electricity consumption data and the aforementioned time series carry out mutation detection. Where S_k reflects the cumulative number of the jth sample $X_j>X_i(1\leq i\leq j)$, define the statistic S_k according to formula (21):

$$S_k=\sum_{j=1}^{k} r_j,\ r_j=\begin{cases} 1 & X_j>X_i \\ 0 & X_j\leq X_i \end{cases} (i=1,2,\ldots,j;j=1,2,\ldots,n) \quad (21)$$

The mean and variance of S_k are according to formula (22):

$$E[S_k]=\frac{k(k-1)}{4},V_{ar}[S_k]=\frac{k(k-1)(2k+5)}{72} \quad 1\leq k\leq n \quad (22)$$

By standardizing S_k, it can be concluded that, according to formula (23):

$$UF_k=\frac{(S_k-E[S_k])}{\sqrt{V_{ar}[S_k]}} \quad (23)$$

Set $UF_1=0$, given the significance level α. If $|UF_k|>U_\alpha$, it reflects a significant trend change in the arrays. All UF_k can form a curve. The reverse sequence UF_k can be according to formula (24):

$$UB_k=-UF_k,\acute{k}=n+1-j,j,\acute{j}=1,2,\ldots,n \quad (24)$$

Given the significance level, this article selects α=0.05, and the critical value is ±1.96.

Finally, based on the Mann Kendall test method, a carbon peak index evaluation model was constructed, and the specific evaluation rules were executed according to formula (25):

$$\text{Carbon peaking situation}=\begin{cases} \text{Carbon peaking index}>1.96,\text{Not reaching peak} \\ -1.96\leq\text{Carbon peaking index}\leq1.96,\text{Plateau} \\ \text{Carbon peaking index}<-1.96,\text{Peak reached} \end{cases} \quad (25)$$

4 General attributes of the urban economic barometer indicator system based on the 3E model

There are a total of 10 evaluation indicators for urban economic barometers referred to in this article, including three parts: energy utilization, economic and social, and environmental friendly. For different dimensions of indicators, measure whether they can be quantitatively calculated through relevant parameters, divide the indicators into qualitative indicators and quantitative indicators, and further clear and definite their value range, as well as examine the positive and negative relationship between the indicators and the evaluation system, that is, the increase in indicator values brings improvement or loss to urban (regional) energy, economic, and environmental benefits. In order to better characterize the quantitative/qualitative attributes, value ranges, and forward and inverse properties of the above urban economic barometer evaluation indicators, Table 1 summarizes the above indicators.

Table 1. Value range and forward and reverse of urban economic barometer evaluation indicators

Dimension	Index	Value range	Forward/Reverse
Energy utilization	Comprehensive energy consumption	0-∞	Reverse
	Per unit output value of comprehensive energy consumption	0-∞	Reverse
	Energy utilization efficiency	0-1	Forward
	Decrease rate of energy consumption per unit output value	0-1	Forward
Economic and social	Energy consumption elasticity coefficient	-	-
	Electricity consumption elastic coefficient	-	-
	Proportion of electricity consumption to final energy consumption	0-1	-
Environme-ntally friendly	Utilization rate of renewable energy	0-1	Forward
	Total energy carbon emissions	0-∞	Reverse
	Carbon peaking index	-	Evaluate according to formula (25)

5 Application of Urban Economic Barometer Indicator System Based on 3E Model

5.1 Analysis of Regional Industrial Structure Based on Energy Consumption Elasticity Coefficient

Taking the data of a certain high-tech zone as an example, by analyzing the ratio of energy consumption growth rate to GDP growth rate of various industries in the region in 2020, the energy consumption elasticity coefficient of each industry is obtained. The details have given in Table 2.

Table 2. Energy consumption elasticity coefficient of various industries in a certain high-tech zone

Type	Energy consumption elasticity coefficient
Manufacturing industry	-0.80
Information transmission, software and information technology services	0.06
Leasing and business services	0.36
Transportation, storage and postal services	0.69
Accommodation and catering	-1.23
Wholesale and retail	0.03
Finance	4.43

Real Estate	0.57
Construction	3.66
Agriculture, forestry, animal husbandry and fishery	-1.08

Through analysis(Table 2), the high value of energy consumption elasticity coefficient in the construction industry indicates that this industry is highly dependent on energy consumption; The low elasticity coefficient of energy consumption in the manufacturing industry indicates a significant decrease in the dependence of the industry's economic development on energy consumption. According to the goal of controlling the energy consumption at 4.8 billion tons of standard coal, the corresponding energy consumption elasticity coefficient needs to be reduced to below 0.45 in order to truly control the total energy consumption.

5.2 Evaluation of carbon peaking based on Mann Kendall test method

Taking the data of a certain high-tech zone as an example, based on regional carbon emission monitoring data, the carbon emissions and year-on-year growth rate of each partition in the region are monitored from the perspectives of energy carbon emissions, new energy generation emissions reduction, and transportation electricity substitution emissions reduction. The details have given in Table 3.

Table 3.Energy Carbon Emissions of a High tech Zone

Indicator Name	numerical value (t)	compared with the same period of the previous year
Energy carbon emissions	1058850.92	5.09%
Carbon emission reduction of new energy generation	15318.15	44.01%
Alternative emission reduction of transportation electricity	15249.12	49.62%

Based on the monthly electricity consumption data of a certain new area for 36 consecutive months, given the significance level, α=0.05 is selected, with a confidence level of 95%. It can be concluded that the limit value of the carbon peak index evaluation model is ± 1.96.

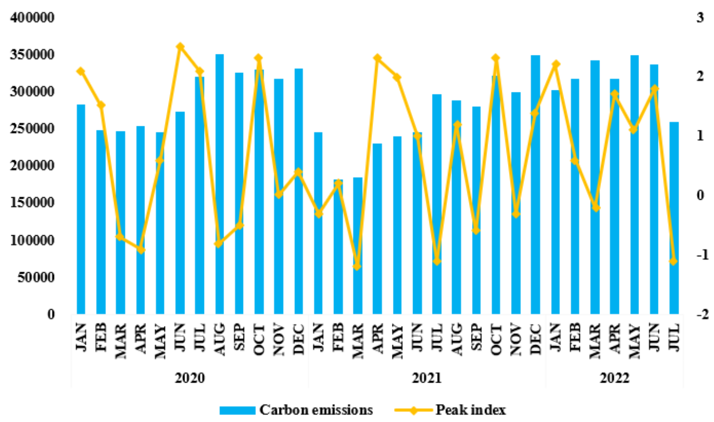

Figure 2. Carbon Peak Index of a High tech Zon

Through analysis(see Figure 2),, it can be seen that the carbon peak index in this region fluctuates between -1.5 and 2.5, and the region has not yet achieved carbon peak. It can provide support for the formulation of policies and measures related to regional carbon peaking in the future.

6 Conclusions

Currently, various parts of the country are committed to promoting the transformation of energy consumption structure from high-emissions to low-carbon in order to achieve the "dual carbon" goal. Studying the relationship between energy, economy, and environment is of great significance for the rational formulation of carbon reduction policies. This article is based on the theoretical framework of the "Sustainable Development Triangle" of energy economy environment. Its core is to construct an urban economic barometer indicator system from three parts: energy utilization, economic and social, environmental friendly, and economic society. It covers ten indicators and their definitions, calculation formulas, value ranges, and forward and reverse directions. It is demonstrated and applied in a high-tech zone from two aspects: economic society and environmental friendliness, and we can get some conclusions.

(1) Through the construction and application of the urban economic barometer indicator system based on the 3E model, we can give full play to the characteristics of energy big data, such as large quantity, multiple types, and high value. We can use energy analysis to describe the energy utilization status, use the energy of the whole industry to explore economic vitality and use data fusion to find ecological changes. We can use energy big data applications to play the role of "barometer" and "Weather vane" of economic development and the urban economic barometer indicator system can also provide data and decision-making support for urban managers.

(2) As the coupling relationship between economy and environment becomes closer, the role of energy in the coordinated development of the economy and environment becomes increasingly prominent. Building an urban economic barometer indicator system based on the 3E model can better adapt to the new relationship of the "energy economy environment" and lead to green social development.

(3) This article focuses on the construction of the urban economic barometer indicator system based on the 3E model. In subsequent research, comprehensive evaluation and optimization methods such as subjective weighting, Pareto noninferior solution, and normalization methods can be fully considered. At the same time, the application scenarios, simplicity, operability, and data accessibility of the above methods can be fully considered to achieve the benchmarking application of the indicator system in different regions and cities. Finally, the standardized application of the urban economic barometer indicator system will be achieved.

(4) The urban economic barometer indicator system can also be used as the core to construct a coordinated optimization model for urban energy economy environment, conduct research on the dynamic relationship between energy, economy, and environment, and provide guidance and support for the scientific and reasonable coordinated development of the urban energy economy environment (3E) system. At the same time, it can assist urban managers to adjust industrial structure, optimize energy consumption structure, formulate reasonable carbon reduction policies, and coordinate the relationship between economic growth and carbon reduction actively.

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