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Trend Model for Regional Energy Consumption System Based on Theory of Synergetics

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Abstract. Trend model is a method of research on the evolution process of objects. Based on the synergetics, this paper raises a trend model for regional energy consumption systems by formula derivation and theoretical assumptions. This paper chooses Wuhan City as a case to construct the model and analyse the trend of its evolution. The results prove that the prediction effect of this model is good. The exponential smoothing method was chosen to compare with the trend model for the regional energy consumption system, and the result shows trend model raised in this paper makes good performance on the forecast.

1 Introduction

The global society, economy, environment, and politics of the 21st century are all experiencing significant changes. With the development of science and technology and also advancement of informatization, many complex and giant systems in different areas are coming into being, for example, a system like communication systems, national economic and managerial systems, business systems, and the system under study namely regional energy consumption system. The operation of the giant system can exert a significant impact on a nation and people[1]. Hence, it is necessary to research the development trend of the giant system.

In specific boundaries, a system with energy conversion is called a regional energy consumption system; for example, one place, one plant, one device, or one building can all be called a local energy consumption system[2]. The founder of general system theory, Bertalanffy, defines that a system implies a combination of various elements with mutual interaction[3]. A giant system has something in common: (1) Structure with multi-level and multi-function, lower-level part can be an element of higher-level structure; (2) Mutual connection and mutual impact between different unit thus exhibiting an extensive network; (3) The system can learn more and reorganize itself thus better its function and structure; (4) System is open and closely connected to the environment and can adapt itself in response to the development of environment. The regional energy consumption systems also show the characteristics above; besides, they share other attributes: (1) The sub-system is also complex and can cover broad areas like society, economy, energy, and environment; (2) All sub-systems are connected, and the connections are complex and not fully known.

The previous trend models mostly use the trend time series model to reflect the system change of variable time, namely, model based on curve fitting and parameter estimation[4]. These models are widely and effectively used in global economic regulation, business management, market estimation, pollution control, and weather forecasting. Nevertheless, these models are not effective for estimating giant system development due to the reasons listed here: (1) Giant system is continuous, complex, and diverse. The time series is the core of the time series model, and all the effects are related to time; thus, the mutual impacts between system variables are not accounted; for a system with many variables, variables are only analyzed with the change of time; thus the analysis results are not very satisfying; (2) Time series models do not conduct causality analysis for analysis target, and its mutual impacts complex adjustments are needed in order to improve the estimation precision, which makes the analysis more complex and arduous; (3) Time series models cannot describe the internal privity (named synergy) between sub-systems or elements.

In this investigation, optimization of the trend model is conducted by theoretic analysis and mathematical derivation combining the concepts from the theory of synergy, and this optimized model is used in regional energy consumption system. Besides, case study for Wuhan is conducted to illustrate the application of new model.

2 Basic principle of synergetics

Synergetics is a subject advanced by German physics professor H.Haken in 20th Century 70 years. He found synergetics by researching laser theory and absorbing modern cybernetics and information theory[5].

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Synergy is the most basic concept of synergetics. In synergetics, all systems are composed of elements, links, or subsystems. These subsystems interact by the conversion of material and energy or information transmission among these subsystems. In a certain external condition, a system can form an ordered structure, in space, time, and function, through the interaction of each of the elements, links, or subsystems within the system. A system composed of many subsystems is in a state of self-organization, having a certain structure or function if the mutual cooperation between the subsystems engenders synergistic effects[6]. Therefore, the trend model of giant systems can be investigated by studying the relationship between various elements or subsystems.

Synergetics also holds that the nature of different systems is diverse, but the qualitative behavior of new structures replacing old ones has similar or even identical mechanism. The problem of evolution trends of different systems can be transformed into the analysis of the formation and development mechanism of self-organizing systems; that is, how the system changes automatically from disorder to order and from lower order to higher order under certain conditions. As an interdisciplinary science, synergitics, plays an important role in the cross-domain analysis of system evolution trends.

The order parameter is another important concept of synergetics[7]. In the evolution process of a system, there are many control parameters, divided into fast variables and slow variables (also called fast relaxation coefficient and slow relaxation coefficient). Among them, the dominant are the slow variables - the order parameter. The fast variables are dominated by the slow variables. The order parameters governing the behavior of the system can characterize the system's ordered structure and type[8]. The order parameters also characterize the combined contribution of all subsystems for the cooperative movement at the same time. The order parameter has the following characteristics: (1) The order parameter is the macroscopic parameters used to describe the behavior of the whole system; (2) The order parameter is the product of the collective motion of micro subsystems, characterizing and measuring the synergetic effect; (3) The order parameters control the subsystems' behavior and dominate the system evolution.

The selection of order parameters can ascertain the macroscopic parameters that dominate the system. By eliminating the macroscopic parameters in a subordinate position in the system, the analysis of the evolutionary trend could be greatly simplified.

3 Synergistic trend model for regional energy consumption system

3.1 Trend model theoretical basis: system synergetic equation mathematics extension and optimization

In synergetics， the Haken Model can describe the interactions of different variables and the process of structure evolution in a specific external condition[9]. We start

$$\dot{q}_1 =- \lambda_1 q_1 - a q_1 q_2 \quad (1)$$

$$\dot{q}_2 =- \lambda_2 q_2 - b q_2^2 \quad (2)$$

From a classic case of Haken Model: consider the system consists of a force and a subsystem, the state variables and force denoted respectively by q_1, q_2. The equation can be expressed as follows: in the formula, a, b, λ_1, λ_2 are control parameters[10, 11]. Assuming $\lambda_2 \gg \lambda_1$, he draws conclusions that system 2 dominates system 1 by using the method of adiabatic elimination, which can also be expressed by the following equation.

$$F(q_1, q_2) = 0 \quad (3)$$

The equation establishes a relationship between q_1 and q_2, which is called a synergetic system equation. The system synergetic equation shows that universal connections existent in the system between the macro parameters. It might as well express the equation as geometrical meaning: in the system of two macroscopic parameters, the relationship between system evolution trend and parameters can be described by a curve in the two-dimensional space.

The extension to the operation status and evolution trend of a giant complex system with s macro parameters are described: It is a curve in the m-dimensional space. The system states that every moment corresponds to a point on the curve[12].

Hence, a hypothesis must be made that at least one variation of the s macro parameters changes monotonically with time to ensure the space points on the curve move smoothly and continuously with time and that each state point corresponds to one time. Actually, for a certain system, one or more of these macroscopic parameters can always be founded under certain external conditions within the research scope of evolutionary trend. For example, in a regional energy consumption system, the unit GDP energy consumption can be controlled to decrease monotonously over time. Hence, the m-dimensional space curve can be expressed by the following m-1 equations.

$$F_1(x_1, x_2 ... x_m) = 0 \quad i = 1, 2 ... m; \quad (4)$$

In the actual case, to solve or find expression of this s-1 equations is complex, if formula (4) is converted into parametric equation group, it will lay a foundation for solving and be associated with the time series model. The parametric equations are named as an s-dimensional system synergetic equation group.

$$x_i = x_i(u) \quad i = 1, 2 ... m; \quad (5)$$

According to the order parameter principle of synergetic, the synergetic equation of m-dimensional system can be optimized. A system with m macro parameters is established, in which n macro parameters are order parameters and m-n macro parameters are dominant parameters. Hence, the m-dimensional synergetic equation group can be described.

$$x_i = x_i(u) \quad i = 1, 2 \ldots n, n+1 \ldots m; \tag{6}$$

The expression of x_{n+1} to x_m can be obtained based on order parameter principle of synergetics.

$$x_j = x_j(u) = G_j(x_1, x_2 \ldots x_n) \mathrm{j} = \mathrm{n}+1, \mathrm{n}+2 \ldots \mathrm{m}; \tag{7}$$

On the explanation, x_{n+1} to x_m can be described by the n order parameters; thus, the m-dimensional system synergetic equation can be simplified to the n-dimensional order parameter synergetic equation group.

$$x_i = x_i(u) \quad i = 1, 2 \ldots n; \tag{8}$$

3.2 Synergetics connotation of “u”

It attempts to give “u” a synergetic meaning, combining it with the time series model and make the “u” characterize the degree of self-organized conduction, and suppose:

$$u = f(t) \quad u \in (0, 1) \tag{9}$$

When $t \to 0$, $u \to 0$; when $t \to +\infty$, $u \to 1$. According to the synergetic self-organization principle, we can get f '(t) >0. We might as well let “u” and “t” satisfy the relation like this：

$$u = 1 - e^{-at} \tag{10}$$

In formula (10), as a parameter, a>0, which is set to 0.05 by default. a can be changed according to the time span of the trend model study. When the time span is short, the larger the a value is, the more convenient the trend model analysis is. When the time span is long, a should take a smaller value.

Thus, u can be calculated through formula (10) and the relationship between the n order parameters and u can be established.

3.3 Trend model for regional energy consumption system

The general method of regional energy consumption systems trend model can be described.

(1) Identification and data collection of regional energy consumption system’s order parameters. There are two identification methods, one is qualitative analysis method, namely, through the definition of the order parameter, analogy or logical reasoning to identify order parameters. The other method is quantitative analysis method, such as relaxation coefficient method, maximum entropy method, principal component analysis method and analytic hierarchy process. The specific methods of this paper will not be introduced in detail;

(2) Establishment of n-dimensional order parameter coordination equation group of regional energy consumption system, determination of $u = f(t)$ expression, and solution of the $U(u_1\, u_2 \ldots u_k)$, according to the $T(t_1, t_2 \ldots t_k)$, where k is the number of discrete values of time;

(3) Curve estimation of x_1, x_2 ... x_n, respectively, according to formula (8);

(4) Fitting of formula (8);

(5) Establishment of trend model for regional energy consumption system, after accuracy calibration.

4 Wuhan City -- a case study of trend model for regional energy consumption system

4.1 Order parameter identification and data collection

According to the order parameter definition, the order parameters of Wuhan city regional energy system order parameter are determined in Table 1.

Table 1. Order parameters of Wuhan City energy consumption system.

Subsystem	Order parameters
Social subsystem	Population density
Energy subsystem	Unit energy consumption of industrial output Coal consumption ratio of industrial Electricity consumption of the whole society Energy consumption per GDP
Economy subsystem	Per capita GDP Investment in fixed assets

Access to relevant information, the basic data of relevant indexes from the year 2002 to 2013 can be obtained, some data (like Unit energy consumption of industrial output, Coal consumption ratio of industrial) are obtained by the calculation of basic data, the order parameter values are listed in Table 2.

Table 2. Initial data for the order parameters.

parameter / Symbol /Year	Population density (People/km^2)	Energy consumption per GDP (Tec/million yuan)	Per capita GDP (yuan)	Unit energy consumption of industrial output (Tec/million yuan)	Investment in fixed assets (million yuan)	Coal consumption ratio of industrial	Electricity consumption of the whole society (kWh)
Symbol	X1	X2	X3	X4	X5	X6	X7
2002	961.69	2.26	17971	1.3312	570.43	0.4033	1587842
2003	975.82	1.96	19569	1.3114	645.06	0.4146	1788280
2004	994.65	1.85	23148	1.3630	822.2	0.4383	1855802
2005	1009.95	1.38	26548	1.2172	1055.18	0.5351	2108743
2006	1029.97	1.32	30921	1.2106	1325.29	0.4941	2308126
2007	1057.04	1.26	36347	0.9685	1732.79	0.4799	2586728
2008	1055.86	1.18	46035	0.6261	2252.05	0.4583	2864338
2009	1071.16	1.11	51144	0.5923	3001.1	0.4469	3102749
20010	1152.38	1.06	58961	0.5813	3753.17	0.4342	3536311
2011	1179.46	1.02	68315	0.5196	4255.16	0.4497	3836469
2012	1191.23	0.79	79482	0.4149	5031.25	0.4313	4032605
2013	1203	0.76	89000	0.4180	6001.96	0.3959	4372338

4.2 Establishment of u=f (t) and the value of u

The time span of this paper is short, so it takes a larger value 0.1 for "a", then the value of u can be calculated in Table 3.

Table 3. The value of "$\boldsymbol{u}$".

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
t	1	2	3	4	5	6	7	8	9	10	11	12
u	0.095	0.181	0.259	0.323	0.394	0.451	0.503	0.551	0.593	0.632	0.667	0.700

4.3 The establishment of u=f (t) and the value

According to the formula (8), we analyzed the data from 2002 to 2011, using SPSS software, and did u and x_1, x_2... x_7 curve estimation respectively. Curve types include: linear, logarithmic, quadratic curve, cubic curve, compound, power, and exponential curve. The fitting curve types are determined ultimately in Table 4.

By fitting, we get the 7-dimensional order parameter of the synergetic equation group of the Wuhan City energy consumption system：

$$x_1 = 749.084u - 186.857u + 982 \quad (11)$$

$$x_2 =- 2.298u + 2.357 \quad (12)$$

$$x_3 = 217565.986u^3 - 40137.682u^2 + 21258.353u + 16072.173 \quad (13)$$

$$x_4 = 14.326u^3 - 19.308u^3 + 5.836u + 0.895 \quad (14)$$

$$x_5 = 25156.946u^3 - 9583.456u^2 + 2214.353u + 426.28 \quad (15)$$

$$x_6 = -0.813u^3 + 0.158u^2 + 0.334u + 0.364 \quad (16)$$

$$x_7 = 7268075.767u^2 - 1298640u + 1705903 \quad (17)$$

Table 4. The corresponding curve types of parameters and "$\boldsymbol{u}$".

Parameter	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Fitting curve types	quadratic curve	linear	cubic curve	cubic curve	cubic curve	cubic curve	quadratic curve

5 Test of trend model

Through the data analysis and calculation from 2002 to 2011, the 7-dimensional order parameters of the coordination equations of Wuhan energy consumption system are obtained.

Based on the equations, we predict the parameter values of each order in 2012-2013 and compared them with the actual values, as shown in Table 5.

Table 5. 2012 forecasting and real data forecasted by trend model for regional energy consumption system.

Parameter	Population density (People/km^2)	Energy consumption per GDP (Tec/million yuan)	Per capita GDP (yuan)	Unit energy consumption of industrial output (Tec/million yuan)	Investment in fixed assets (million yuan)	Coal consumption ratio of industrial	Electricity consumption of the whole society (kWh)
Predicted value	1190.90	0.8239	76988	0.4487	5107.76	0.41575	4074289
Actual value	1191.23	0.79	79482	0.4149	5031.25	0.4313	4032605
Relative error (%)	-0.03	4.3	3.1	8.1	1.5	-3.6	1.0

Table 6. 2013 forecasting and real data forecasted by trend model for regional energy consumption system.

Parameter	Population density (People/km^2)	Energy consumption per GDP (Tec/million yuan)	Per capita GDP (yuan)	Unit energy consumption of industrial output (Tec/million yuan)	Investment in fixed assets (million yuan)	Coal consumption ratio of industrial	Electricity consumption of the whole society (kWh)
Predicted value	1217.40	0.7511	85572	0.4332	5878	0.3971	4347659
Actual value	1203	0.76	89000	0.4180	6001.96	0.3959	4372338
Relative error (%)	1.2	-1.2	-3.9	3.6	-2.1	-0.3	0.5

To measure the description of the regional energy consumption system objectively, we use the exponential smoothing method of the time series forecasting model to do the same forecasting, the results in Table 7-8.

Table 7. 2012 forecasting and real data forecasted by exponential smoothing.

Parameter	Population density (People/km^2)	Energy consumption per GDP (Tec/million yuan)	Per capita GDP (yuan)	Unit energy consumption of industrial output (Tec/million yuan)	Investment in fixed assets (million yuan)	Coal consumption ratio of industrial	Electricity consumption of the whole society (kWh)
Predicted value	1228.47	1.00	67271.49	0.5540	4589.15	0.4199	3981065
Actual value	1191.23	0.79	79482	0.4149	5031.25	0.4313	4032605
Relative error (%)	3.1	26.6	-15.4	33.5	-8.8	-2.6	-1.3

Table 8. 2013 forecasting and real data forecasted by exponential smoothing.

Parameter	Population density (People/km^2)	Energy consumption per GDP (Tec/million yuan)	Per capita GDP (yuan)	Unit energy consumption of industrial output (Tec/million yuan)	Investment in fixed assets (million yuan)	Coal consumption ratio of industrial	Electricity consumption of the whole society (kWh)
Predicted value	1236.91	0.99	68186.85	0.5511	4681.07	0.4184	4030146
Actual value	1203	0.76	89000	0.4180	6001.96	0.3959	4372338
Relative error (%)	2.8	30.3	-23.4	31.8	-22	5.7	-7.8

From Table 5-8, we can see that the trend model of regional energy consumption system basis on synergetics has a better forecast effect, which can effectively describe the evolution trend of these systems.

With respect to the time series model, the trend model basis on synergetics was another notable feature, which can describe the system evolution trend with m-dimensional space curve. It means that if the future one of order parameter values can be determined, we can then determine the other macro parameter value. This formulation has a very important practical significance for energy management and energy policy.

Similar to the regional energy system of Wuhan City as an example, we will control the Energy consumption per GDP in 2015, making its control under a certain value, we can obtain other macroscopic parameters value in the synergetic trend model, such as per capita GDP, the electricity consumption of the whole society, etc. It will provide a basis for policy. Similarly, we can analyze whether the indicators of policy are expected to achieve compliance with the laws of science, according to the model.

The model makes good performance on description and prediction on the parameters, which change slowly in the trend significantly. However, from the table, we can see that the description of fluctuant macroscopic parameters, like coal consumption ratio of industrial, is not accurate enough.

6 Conclusion and Prospect

Through the construction, analysis, and comparison of trend model for Wuhan City regional energy consumption system, it proved the trend model of regional energy consumption system can effectively describe the trend of system's development and evolution, can comprehensively predict different macroscopic parameters, according to the characteristics of the self-organizing system. Eventually, a basis for energy management and energy policy can be provided by the model.

Although this paper raises a synergetic trend model for the regional energy system to one based on synergetics initially established model, there must exist a lot of space to optimize. Further study can be carried out on this model from the following aspects:

(1) The application of trend model for regional energy consumption system in energy management;

(2) Solution of the equation group mode without establishing the $u-t$ equation;

(3) The optimization of data selection and fitting curve way.

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