Evaluation of China's Renewable Energy Development Level under the Concept of Green Development Based on Coordination Degree Model

Wenjian WU [1, a] *, Jingwen LI [2, b]

[1] *Chongqing University of Science and Technology, Chongqing, China*
[1] *Chongqing University of Science and Technology, Chongqing, China*
[a]*Corresponding author e-mail: [a]2014003@cqust.edu.cn*
[b]*e-mail: 1131035276@qq.com*

Abstract

Under the concept of green development, the development of renewable energy needs to be coordinated with the economic and environmental systems. This paper has evaluated the development level of renewable energy in China from 2010 to 2018. For this purpose, a renewable energy-economy-environment coordination degree model has been carried out based on energy-economy-environment system coordination model, and used by the entropy weight method from three levels of total amount, quality and structure. The results show that: the renewable energy development level was an upward trend, and the coordination degree of internal quality of the system fluctuated. Compared with the environment, the binary-coordination degree between renewable energy-economic system was lower, which reflects that the development of renewable energy was greatly affected by economic factors. The overall coordination degree of the ternary-system was high and unstable, indicating that the green development level of renewable energy is not stable enough.

Keywords—*Green development; Renewable energy; Coordination Degree Model*

1. INTRODUCTION

In recent years, the development of renewable energy has become the main strategic measure to promote global economic development, alleviate environmental pressure and reduce carbon emissions, and is strongly supported by the Chinese government. With the promotion of a series of policies, the scale of renewable energy development and utilization has expanded rapidly. The cumulative installed capacity of hydro power, wind power and photovoltaic power generation has ranked first in the world. However, it is still facing the problems of difficult market absorption, low development efficiency and low utilization, which are bound to reduce environmental benefits and hinder long-term economic development. One of the main causes is the uncoordinated development of renewable energy system, environment and economic system. In order to avoid disorderly construction and blind development, it is urgent to measure the green development level of renewable energy system.

In the existing literature, the measurement of renewable energy development level mostly focuses on the estimation of environmental benefits [1], economic benefits [2] and the rationality of energy structure [3].[4] considered four indicators of economy, technology, resources and environment in the comprehensive evaluation module of renewable energy. The development of renewable energy needs to be coordinated with environment and economy. More attention has been paid to the coordination among energy, economy and environment. The impact mechanism of energy utilization on environment and economy was studied by static evaluation indexd [5], model construction [6] and dynamic evolution [7-8]. However, non renewable energy and renewable energy have great differences in the force and direction of economic and environmental systems, which need to be treated differently. In this regard, [9] stablished a new system evaluation of renewable energy, economy and environment to evaluate the coordination of three systems in China from 2005 to 2011.

Renewable energy has always been considered as a green development mode. Limited by technological progress, if the development of renewable energy is not coordinated with the market demand, too much

disordered renewable energy would easily lead to the resources waste and the environmental friendliness. The development of renewable energy should also conform to the concept of green development. Based on the existing the energy-economy-environment(3E) system theory, this paper evaluated the comprehensive development level of renewable energy from the two levels of its own system and the coordination degree with the environment and economic system.

2. R3E SYSTEM THEORY WITH GREEN DEVELOPMENT IDEA

2.1. green development requirements

Green development was first put forward by the United Nations Development Programme in 2002, aiming at building a green system in the whole word. The 18th National Congress of the Communist Party of China regards green development as one of the five development concepts in China, and the 19th National Congress of the Communist Party of China lists "adhering to the harmonious coexistence of man and nature" as the thought and basic strategy of socialism with Chinese characteristics in the new era. Although the current concept of green development is not unified,a more consistent view is formed, that is to achieve harmonious coexistence between man and nature. The concept of green development takes harmony between man and nature as its value orientation, green low-carbon cycle as its main principle, and ecological civilization construction as its basic starting point [10]. The symbiosis and coordination of economy, society and environment is one of the requirements of green development.

2.2. 3E system

3E system studies the relationship among energy, economy and environment. The main points are as follows:

①The economic development needs the guarantee of energy system. When the economic system develops to a certain extent, it is often accompanied by the transformation and upgrading of industrial structure and technology, so as to improve the consumption proportion and structure of energy system.

②Environmental system provides support for the development of economic and energy system, and the development of economic system and energy system often causes damage to the environmental system to a certain extent. At the same time, the development of economic system provides sufficient financial support for the environmental system and energy system.

③Coordinating the relationship among the three can make the economic development, environmental

protection, rational development and utilization of energy proceed simultaneously.

2.3. renewable energy-economy-environment(R3E)

Different from traditional fossil energy, under the current environmental constraints, human development of renewable energy stimulates industrial transformation and economic growth; Economic development provides support for the development of renewable energy. Renewable energy substitutes for traditional fossil energy, which has a positive external effect on the environment. Synergism holds that coordination leads to order and non coordination leads to disorder. Therefore, the disordered renewable energy construction can only increase the system entropy, which is not conducive to the long-term economic development. If wind power, photovoltaic power and other renewable energy can not be absorbed by the terminal, then its environmental effect can not be guaranteed. Therefore, the development of renewable energy needs to keep a harmonious and optimized state with the development of economy and environment. Coordination is a state of harmony and optimization among composite systems, subsystems and elements of subsystems. Therefore, the ideal coordination state should be a state in which the development of each subsystem tends to be consistent R3E.

This paper will evaluate the comprehensive and coordinated development of renewable energy, environment and economic system.R3E coordinated dispatch includes three aspects: 1) coordination degree of unitary system, that is, coordination degree of economic system, coordination degree of environmental system and coordination degree of renewable energy system. 2) The coordination degree between the two systems is the coordination degree between the economic system and the environmental system, the coordination degree between the renewable energy system and the economic system, and the coordination degree between the renewable energy system and the environmental system; 3) The overall coordination degree of ternary system is calculated.

3. COMPREHENSIVE EVALUATION INDEX SYSTEM

3.1. Index selection

Economy and environment are regarded as the most important system and factors in the renewable energy system. The research results of some representative literatures are used for reference, based on the national economic, environmental and renewable energy statistical indicators and available data, and the typical and high-frequency indicators of the index system of R3E system is constructed by the United Nations Commission on sustainable development,the world bank and other

authoritative institutions, which has three target layers and three first-class index layers. The comprehensive evaluation system of coordinated development is composed of 25 specific indicators. In the renewable energy subsystem, the production index reflects the development and utilization efficiency. The economic subsystem reflects the economic efficiency of energy and the allocation efficiency of renewable energy by the index of quantity, quality and structure of economic activities. In the environmental subsystem, the environmental improvement efficiency of renewable energy is reflected by the environmental status, governance cost and efficiency. The details are shown in Tab.2.

3.2. Method

Let E_1, E_2 and E_3 represent the development level of economic system, environmental system and renewable energy system respectively, and E represent the overall development level. H_i is the coordination degree of a single subsystem, and H is the coordination degree of the whole system. The overall coordination degree of the system is measured by comprehensive index method.

1) Standardization of index value

In order to eliminate the differences caused by dimension and quantity level, the original data is standardized without dimension, and then the standardized values are used for comparative analysis. The standardization method used in this paper is min-max data standardization method.

Suppose that there are m evaluation indexes and n data samples in the original evaluation index system (n refers to n different years),the index set of the overall sample can be expressed as x={x$_1$,x$_2$,...,x$_n$},and each sub sample is described as x$_i$={B$_{i1}$,B$_{i2}$,...,B$_{im}$}, i=1,2,...,n,j=1,2,...,m.B$_{ij}$ is the j-th evaluation index value of year i.Matrix B is used to represent the standard value of all samples,B={b$_{ij}$},where b$_{ij}$ is the j-th evaluation index value of year i.The next step is to standardize b$_{ij}$ data.Find out the maximum value B$_{max(J)}$ and minimum value b$_{min (J)}$ of index J$_{n*m}$.

B$_{ij}$ is compared with b$_{ij}$.For R3E coordinated dispatching evaluation system,it is not only to find out the minimum and maximum values of each index data according to the index data of economic system, environmental system and renewable energy, but also to carry out the standardized calculation of each value combined with the index polarity trend.

For the positive index, the formula is

$$B_{ij} = \frac{b_{ij} - b_{min(j)}}{b_{max(j)} - b_{min(j)}} \tag{1}$$

For the reverse index, the formula is

$$B_{ij} = \frac{b_{max(j)} - b_{ij}}{b_{max(j)} - b_{min(j)}} \tag{2}$$

B$_{ij}$ is the standardized value of i area.

2) index weight

The entropy method is used to determine the weight of each index layer. If the entropy is smaller, the information is larger, and the index plays a greater role in the comprehensive evaluation, the weight should be higher, and vice versa. The specific calculation steps are as follows:

Y$_{ij}$ is processed to get the weight of B$_{ij}$

$$Y_{ij} = \frac{B_{ij}}{\sum_{i=1}^{m} B_{ij}} \tag{3}$$

the information entropy of index j is obtained

$$S_j = -(\frac{1}{\ln m})\sum_{i=1}^{m}(Y_{ij} \ln Y_{ij}) \tag{4}$$

When Y$_{ij}$=0, lnY$_{ij}$=0

The weight ω_j of index j can be expressed as:

$$\omega_j = \frac{1 - S_j}{\sum_{j=1}^{n}(1 - S_j)} \tag{5}$$

The comprehensive and coordinated development level of the j-th evaluation object can be obtained:

$$E_i = \sum_{j=1}^{n} \omega_j Y_{ij} \qquad \text{where} \qquad \sum_{j=1}^{n} \omega_j = 1 \tag{6}$$

3) the overall development level of R3E system

Assuming that economic system, environmental system and renewable energy system are equally important, the overall coordinated development level (E) of the system is as follows:

$$E = \frac{E_1 + E_2 + E_3}{3} \tag{7}$$

4) R3E system coordination degree

Firstly, the development speed of each subsystem (dE$_i$/dt)and the whole system(dE/dt)are calculated.Then the corresponding coordination degree H$_i$ is calculated.

$$(\frac{dE_i}{dt}) = \frac{(E_i)_t - (E_i)_{t-1}}{(E_i)_{t-1}} \tag{8}$$

Suppose that H$_i$ represent the coordination degree of the subsystem and reflect the development speed of the subsystem.

$$H_i = \begin{cases} \exp(\frac{dE_i}{dt} - \frac{dE}{dt}), & \frac{dE_i}{dt} < \frac{dE}{dt} \\ 1, & \frac{dE_i}{dt} = \frac{dE}{dt} \\ \exp(\frac{dE}{dt} - \frac{dE_i}{dt}), & \frac{dE_i}{dt} > \frac{dE}{dt} \end{cases} \tag{9}$$

5) standard setting of system coordination coefficient

The coordination coefficient reflects the coordination degree of each subsystem. According to the coordination status of the system, the coordination degree of R3E system is divided into the following five types, and the specific evaluation criteria are shown in Tab.1.

TAB.1 CLASSIFICATION OF COORDINATION DEGREE [0-1] INTERVAL OF R3E SYSTEM

Interval grade	Evaluation grade
(0,0.4]	Extremely incongruous
(0.4,0.6]	uncoordinated
(0.6,0.8]	Grudging coordination
(0.8,0.9]	coordinate
(0.9,1.0]	Very coordinated

4. RESULTS

The data are from China Statistical Yearbook, Environmental Statistical Yearbook, environmental statistical annual report, etc.After data standardization and weight is   calculated in formula (3-6) (Tab.2).

TAB.2 INDEX WEIGHT OF R3E SYSTEM

Target	First level	Secondary index layer	Efficacy	S_i	ω_j
Economy	total	GDP (100 million RMB)	+	0.602	0.050
		GDP per capita (RMB)	+	0.632	0.047
	Structural	primary industry	+	0.582	0.053
		the secondary industry	+	0.658	0.043
		the service sector; the tertiary industry	+	0.568	0.055
	quality	GDP growth rate (%)	+	0.251	0.095
		Growth rate of resident consumption level (%)	+	0.739	0.033
environment	total	total water resources (100 million m^3)	+	0.720	0.035
		environmental pollution control investment (10million RMB)	+	0.814	0.024
		industrial pollution control investment (10million RMB)	+	0.611	0.049
	structure	SO_2 emission (10 MT)	-	0.870	0.016
		CO_2 emission (10MT)	-	0.947	0.007
	quality	Proportion of total investment in environmental pollution control in GDP (%)	+	0.856	0.018
renewable energy	total	Hydro power production (100 million KWh)	+	0.632	0.027
		Hydro power generation (100 million KWh)	+	0.697	0.025
		Installed capacity of hydro power (10 million KW)	+	0.622	0.026
		Grid connected wind power (100 million kwh)	+	0.624	0.026
		Wind power production (100 million KWh)	+	0.407	0.025
		Installed capacity of grid connected wind power (10million kW)	+	0.518	0.026
		Installed capacity of solar power generation (10million kW)	+	0.470	0.025
	quality	Growth rate of hydropower installed capacity (%)	+	0.644	0.026

		Growth rate of installed capacity of grid connected wind power (%)	+	0.627	0.025
		Proportion of hydro power in power energy production (%)	+	0.856	0.026
		Proportion of wind power in power energy production (%)	+	0.632	0.026

5. DISCUSSION

5.1. the development level of renewable energy system

According to the above evaluation system, the development level of Chinese R3E system from 2010 to 2018 is as shown in Figure1.The results show that:From 2010 to 2018,the economic development level gradually slowed down, and the development speed of environmental system fluctuated greatly. Under this background, the development level of renewable energy system showed an increasing trend year by year, but the growth rate in 2011 had a short slowdown. It can be seen from Fig.1 that the overall development level of renewable energy and R3E system is relatively close. The economic development level fluctuates greatly. This is in line with the development level of economy, environment and renewable energy since 2010.The main reason is that Chinese economic growth slowed down in 2011, and the damage to the environment gradually declined. Traditional fossil energy is transformed into renewable energy.
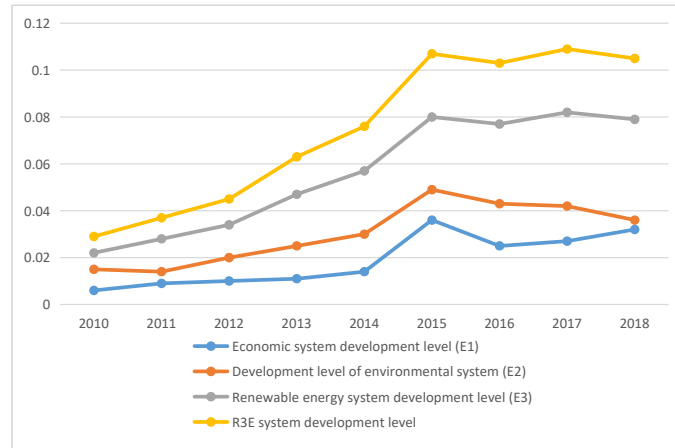

**Fig.1** development level of each subsystem and R3E system (2010-2018)

5.2. coordination degree of renewable energy system

Compared with the environment-economy systems, the coordination degree of renewable energy system fluctuates greatly, which has the highest coordination degree in 2014, is the lowest in 2011.The system coordination degree is low, and the growth rate of renewable energy is 0.7527 in 2015,which is the fastest growth rate. It can be seen that the development speed of renewable energy is too fast to reduce the internal coordination degree of the system.

The reasons for the fluctuation of the coordination degree of renewable energy system may be as follows: First, from 2012 to 2016, the coordination degree of renewable energy has been increasing and the overall level is high, which is closely related to government strong support. During the 12th Five-year Plan period, the development of the renewable energy plays a great importance, vigorously promotes the technological progress and industrial development, and creates more opportunities, so to the coordination of renewable energy continuously improve.

Second, in 2015, renewable energy utilization was 436MT of standard coal, accounting for 10.1% of the total primary energy consumption. By the end of 2015, the installed capacity of hydropower, grid connected wind power and solar power generation in China would be 32000,13075 and 42180000 KW respectively. The improvement of system coordination in 2016 is inseparable from the large-scale construction of renewable energy in recent years, and is a coordinated state in the other years. In 2011,it was in an extremely uncoordinated state(0.490) which was due to the low coordination degree between the environmental system and the renewable energy system at that time, affected the overall coordination degree of R3E.
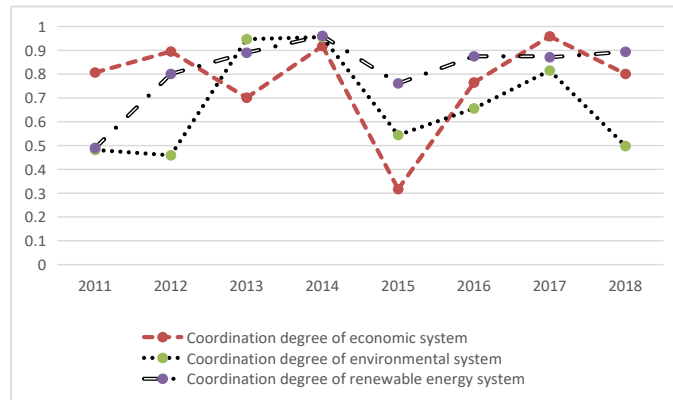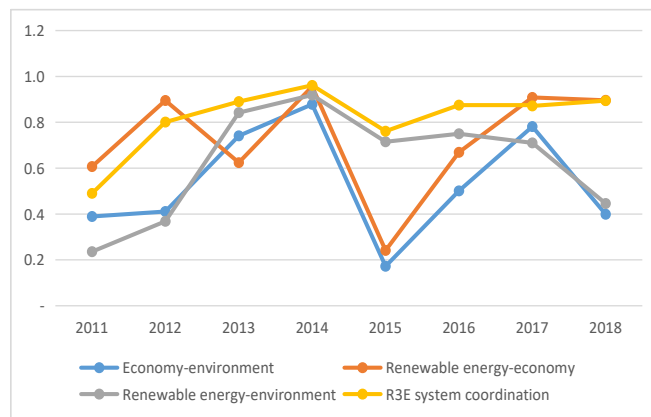
Fig. 2 evaluation results of coordination degree of Chinese economy, environment and renewable energy system (2011-2018)

5.3. coordination level of renewable energy - economy system

The coordination degree of renewable energy and economic system in China is relatively high, showing a similar trend, but it has been in a state of fluctuation. Specifically, when the economic development is at a high level, the development level of new energy is relatively high, and vice versa. In 2011,2013,2015 and 2016, the coordination degrees were 0.607,0.624,0.241and0.669, respectively, which were in a barely coordinated state. In 2017,it was in a very coordinated state (0.908),reflecting the mutual influence and restriction between renewable energy and economic growth. At the same time, it also reflects the effect of relevant policies to change the energy consumption structure and develop renewable energy to stimulate economic growth.

5.4. Coordination level of renewable energy- environment system

It is found from the data in Fig.3 that the coordination degree between renewable energy and environment is similar to that between renewable energy and economy, but lower than that between renewable energy and economy. From 2011 to 2014, uncoordinated (0.236) reached very coordinated (0.919), and then decreased to barely coordinated (0.446) in 2018.The unstable coordination state indicates that the environmental effect of renewable energy in China has not been released. On the contrary, it also increases the burden of environmental governance. This is related to the low proportion of renewable energy terminal consumption. In recent years, although the installation and construction of renewable energy in China has been accelerated, the phenomenon of abandoning wind and electricity caused by the difficulty of absorption is more serious, so the environmental effect of replacing traditional fossil energy is naturally weaker.

Fig.3 evaluation results of R3E binary and ternary system in China (2011-2018)

5.5. comprehensive and coordinated development level of R3E

As shown in Fig.3,it has a high degree of coordination in 2014,which is in a very coordinated state respectively. Most of However, with the rapid development of

environmental system and renewable energy system, the coordination degree of R3E system also increased rapidly. Some reasons for this change are:

1) In recent years, the rapid economic development requires the increasing amount of energy resources obtained from the environment. A large number of wastes

metabolized by economic development are discharged into the environment, resulting in the environment deterioration. The initial development of renewable energy has weaker economic effect.

2) The coordination degree of R3E system is on the rise from 2012 to 2014.China actively and steadily develops hydropower, comprehensively and coordinately promotes wind and photovoltaic generation, speeds up the development bio-energy and geothermal energy, and constantly increases the proportion of renewable energy consumption. The development and utilization of renewable energy can alleviate the pressure on the demand for fossil fuels, reduce the consumption rate of non renewable energy, and the harm of fossil fuels to the environment. With the vigorous development of renewable energy industry, new jobs are added, the transformation of economic development mode is promoted, and the coordination degree of R3E system is improved.

6. CONCLUSION

This paper constructs a comprehensive evaluation index system of renewable energy development from the perspective of system coordination, and comprehensively evaluates the development level of Chinese renewable energy system from 2010 to 2018.

First, from 2010 to 2018, the development level and speed of Chinese renewable energy system are very fast, but the coordination level of the total amount and structure of the system gradually tends to be stable, indicating that the renewable energy gradually develops from the total amount to the quality.

Second, the coordination degree of renewable energy, economy and environment is similar. The coordination degree between renewable energy-environment system is higher than that between renewable energy-economy system. It reflects that the production and construction speed of renewable energy is higher than the consumption speed. Since 2011,the coordinated development level of economy and renewable energy is higher than that of other subsystems, indicating that economic structure is transforming from extensive to intensive.

Third, the development of renewable energy is not stable in coordination with the environment and economic system. It reflects that economic development is facing increasingly severe resource and environmental constraints in China. It is necessary to gradually reduce the use of traditional energy and promote the sustainable development of renewable energy industries such as water, wind and solar energy.

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