

The Relation between Energy, Economy and Environment in China's Industrial Sector: Based on Energy Saving

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Abstract—Energy saving is important for our society, and industry should be focused because of its high energy consumption. This paper used the grey correlation degree method to discuss the relation between economic development, environmental protection and industrial energy consumption in China, gave harmonious development model for 3E (Energy – Economy - Environment) system, and computed contribution rate for energy consumption decrease based on industrial indexes. Results show that energy utilization efficiency of industry is low, industrial energy consumption promotes the increase of waste, industrial added value blocks the decrease of energy consumption intensity, and the decrease of industrial energy consumption intensity is vital. Hence, energy saving of industry is imperative, which can be achieved by measures in industry restructuring, technology research, administration mode, legal construction, and recycling economy.

Index Terms—Industrial Energy Consumption, Energy-Economy-Environment Compounding System, Industrial Energy Saving, Grey Correlation Analysis

I. INTRODUCTION

In 2010, the proportion of three industries in China was 10.1 percent, 46.8 percent and 43.1 percent, respectively, and industrial added value accounts for 85.7 percent of secondary industry. Industry is still the most important economic sector and energy consumer, which energy consumption shares more than 70 percent of the society. Consequent environment problem is getting more and more severe in our times depending on fossil energy. So, to cope with global climate change, with the trend of energy-saving and emission-reduction, energy consumption per unit of output value and environmental pollution with economy development should be further reduced. A new harmonious road for energy, economy and environment should be fished out.

At present, research fruits about energy consumption of China are classified in four aspects:

The first is about the relation between energy consumption and economic growth. Ref. [1] re-examined the energy-GDP relationship for the US for the period 1946–2000 by redefining energy in terms of exergy, and inferred that output growth does not drive increased energy consumption. Ref. [2] uses multivariate co-integration Granger causality tests to investigate the correlations between carbon dioxide emissions, energy

consumption and economic growth in China, and concluded that exclusive pursuit of economic growth will increase energy consumption. Ref. [3] examined the relationship between energy consumption and economic growth for six Central American countries, and the Granger-causality results indicated the presence of both short-run and long-run causality from energy consumption to economic growth which supports the growth hypothesis.

The second is about energy utilization efficiency. Improving energy efficiency was taken as an inevitable choice for the protection of national energy security and sustained economic growth in [4]. Early understanding of energy efficiency was to provide the same energy services by reducing energy inputs in [5]. Ref. [6] gave the clear description of the systematic process of energy utilization efficiency, and employed data envelopment analysis to evaluate energy utilization efficiency between China and Taiwan from 2002 to 2007.

The third is about energy consumption structure. Ref. [7] estimated the scale of fossil energy subsidies of China in 2007 with price-gap approach and discussed the possibility and potential of improving energy consumption structure. Ref. [8] analyzed the situation and trend of China's energy consumption structure, and indicated that China will not enter the oil era, natural gas and non-fossil energy will rapidly develop. Ref. [9] thought a full analysis of factors that may relate to energy intensity (e.g. energy consumption structure, economic structure) should be conducted before making energy policies. In order to decrease energy intensity, Chinese government must continue to promote the upgrade of economic structure.

The fourth is about energy use in view of environmental protection. Ref. [10] constructed synergy evaluation model about energy, economy, society and environment. Ref. [11] thought that in practice, traditional administrative system in China has changed, which has always favored economic growth over environmental protection. Also, China has to evolve a low carbon industrialization model. Ref. [12] took it as the key to the success of sustainable development initiatives.

Although above fruits studied energy use in different respects and gave much reference for further research, little was focused on industrial sector of China. As the most important field for energy saving, its contribution rate should be decomposed. This paper will analyze industrial energy use in view of energy saving. The rest is organized as follows: the second part makes grey

correlation analysis between industrial energy consumption, economic growth and environmental protection; in section 3, one harmonious development model for energy-economy-environment compounding system is designed; then, in the fourth part, contribution rate is decomposed during energy consumption decrease based on industrial indexes; at last, conclusions and proposals are brought forward.

II. GREY CORRELATION ANALYSIS OF INDUSTRIAL ENERGY CONSUMPTION WITH ECONOMIC GROWTH AND ENVIRONMENTAL PROTECTION

Grey correlation analysis finds out otherness and similarity among elements by distance between the reference sequence and comparative sequence. Based on geometrical shape closeness of behavioral sequence, this method determines influence degree between factors and contribution degree of factors to behavior.

A. Selection of Index

In light of too short time span for full historical data, evaluation indexes mustn't be too much, or the correlation will be demonstrated impertinently. Industrial final energy consumption is adopted to reflect the index of industrial energy consumption, which is worked out based on coal consumption of power generation, industrial added value to reflect the index of economic development, and industrial three-waste discharge to be the index of environmental protection. Corresponding data can be seen in Table 1.

B. Assignment of Reference Sequence and Comparative Sequence

After needed data is prepared, the analysis may move on with industrial energy consumption as the reference sequence, and industrial added value and three-waste discharge (output) as comparative sequence.

C. Non-dimensional Treatment of Data

Time sequences, with different unit, need pretreatment to make elements in original sequences be dimensionless value. Practicable pretreatment methods include initialization, equalization, and standardization. For the

selected sequences are growing steadily, the first one is adopted, which operation is to divide the first number by all the data in the same sequence. Then, one new sequence with development rate of fixed base can be obtained.

D. Computation of Correlation Coefficient

Suppose initialized industrial energy consumption sequence be $\{x(t)\}$, and others are $y_i(t)$ ($i=1,2,3,4$; $t=1995, \dots, 2010$) respectively. Correlation coefficient between $x(t)$ and $y_i(t)$ in certain year t is denoted by $L_i(t)$, then

$$L_i(t) = \frac{\min_i \min_t |x(t) - y_i(t)| + \zeta \max_i \max_t |x(t) - y_i(t)|}{|x(t) - y_i(t)| + \zeta \max_i \max_t |x(t) - y_i(t)|} \quad (1)$$

where, $\zeta \in [0,1]$ is resolution ratio and let it be 0.5 as usual; $\min_i \min_t |x(t) - y_i(t)|$ is two-level minimum difference, in which \min_t is the first-level minimum difference, indicating the minimum distance between points in $y_i(t)$ and $x(t)$, and \min_i means that after \min_t is found in each curve, the minimum of \min_t is got among all the curves $i=1,2,3,4$; $\max_i \max_t |x(t) - y_i(t)|$ is two-level maximum difference, which meaning is similar to the minimum one.

E. Computation of Correlation Degree

After correlation coefficients between each sequence and industrial energy consumption in each year are added up and averaged, then correlation degree r_i can be computed as follows:

$$r_i = \frac{1}{n} \sum_{t=1}^n L_i(t) \quad (2)$$

TABLE I. ORIGINAL DATA OF INDUSTRY ENERGY CONSUMPTION, GROSS VALUE ADDED AND THE THREE WASTE

Year	Industrial energy consumption (10 ⁴ tce)	Industrial added value (10 ⁸ RMB Yuan)	Discharge of industrial waste water (10 ⁸ ton)	Discharge of industrial SO ₂ (10 ⁴ ton)	Production of industrial solid waste (10 ⁴ ton)
1995	96191	24951	222	1405	64474
1996	90566	29448	206	1397	65897
1997	90922	32921	188	1363	65750
1998	91252	34018	201	1600	80043
1999	94459	35861	197	1460	78442
2000	97597	40034	194	1615	81608
2001	100690	43581	203	1567	88840
2002	106377	47431	207	1562	94509
2003	123122	54946	212	1791	100428
2004	143607	65210	221	1891	120030
2005	158767	77231	243	2168	134449
2006	174225	91311	240	2238	151541
2007	189032	110535	221	2140	175632
2008	196832	130260	217	1991	177721
2009	205322	135240	209	1694	203943
2010	211626	160867	212	1705	240944

Data resource: China Statistical Yearbook 1996-2011, China Energy Statistical Yearbook 2008-2011.

Results are shown in Table II.

TABLE II.
CORRELATION DEGREE BETWEEN INDUSTRIAL ENERGY CONSUMPTION
AND OTHER FACTORS

Item	Added value	Waste water	SO ₂	solid waste
Correlation degree	0.6461	0.8308	0.9055	0.8244

F. Interpretation of the Result

It can be seen from Table 2 that industrial energy consumption has correlations with industrial added value and three-waste discharge (output) in varying degrees, which seems valuable to put energy into use. It, however, has the lowest relation with industrial added value, that is, present energy utilization efficiency in industrial sector is a bit low and certain energy input can't cause proportional output. For example, in 2010, China's energy consumption per industrial added value of 10⁴ RMB Yuan is at the level of 1.72 tce (ton of standard coal equivalent). But, there is great correlation degree between industrial energy consumption and three-wastes discharge (output). That of discharge of industrial SO₂ reaches 0.9055, which shows that industrial energy use helps the increase of three-waste output. What's more, main energy source in China is coal that needs further processing or clean energy substituting, aiming to reduce waste output in using. From the prospect of environmental protection merely, lessening fossil energy will make environmental situation distinctly.

III. HARMONIOUS DEVELOPMENT MODEL OF ENERGY-ECONOMY-ENVIRONMENT SYSTEM

Energy system, economy system and environment system can still constitute energy-economy-environment (3E) compounding system because of the close relation among them, although they in themselves are very complex. One sub-system may produce positive effect to others, and negative effect as well. This compounding system embodies its economic characteristic, so economy sub-system is its core. further, the core of economy sub-system is industry.

Based on principle in dynamics, running orbit of compounding system can be portrayed in Logistic Equation:

$$\frac{dS}{dt} = kS\left(1 - \frac{S}{C}\right) \quad (3)$$

where, S is the state of compounding system, k denotes its variance ratio, C indicates restrictions about energy and environment, and t shows time sequence.

Any system will maintain its optimum steady state finally, in which promoting and restricting effects between each element are balanceable. Influence produced by economy and energy sub-system is restricted within the capacity of environment sub-system. Utilization speed of fossil energy in energy sub-system is not more than that of finding them. Energy sub-system can support the development of economy sub-system. Generally, compounding system will go through the following four stage, as shown in Equation 3.

The first stage is balanced period, which is pre-industrial phase. In this period, demand of energy is steady, most of which is woody material, and environment system has better self-control effect.

The second is deteriorating period, which is industrial intermediary and preceding phase. With the development of human society, demand of fossil energy is getting high, which produces damage to environment gradually. Damage exceeds slowly its self-adjust ability. Worsening indication comes into being and will be intensified.

The third stage is transforming period, which is industrial middle and later phase. Excessive exploitation makes fossil energy less and less. To achieve sustainable development and maintain human being's economic development, man should break through the ties of stock of fossil energy and environmental damage, and widen environment capacity. In this period, a part of non-fossil energy, such as nuclear energy, wind energy, and solar energy, gets exploited. Environment system is getting better and produced damage is restored gradually.

The fourth stage is new balanced period, which is post-industrial phase. In this period, non-fossil energy starts to be popularized, consumption of fossil energy falls sharply and environment system returns as in the first period.

It is not wise to pull economic growth by high energy input, but under the background of recovering slowly from global economic crisis, the development mode with industry as the main body will continue, which also go on causing inharmonious factors for China's economy. In 3E system, energy and environment part belongs to natural system, and economic part is in the lead. Transforming from imbalance to balance is realized by human being's action affecting the former two. So, global management should be made by putting industry into the whole social economic system, exerting more positive feedback effect, and leading actively the energy and environment sub-system along the harmonious road. These positive feedback effects consist mainly of structure modification, technical progress, exploitation of new energy, and strengthening of administration, etc. Harmonious development model of 3E compounding system can be seen in Fig. 1.

IV. CONTRIBUTION RATE DECOMPOSITION IN ENERGY CONSUMPTION DECREASE BASED ON INDUSTRIAL INDEXES

Enhancing energy utilization efficiency and reducing energy consumption intensity are important measures to save energy. Factor de-

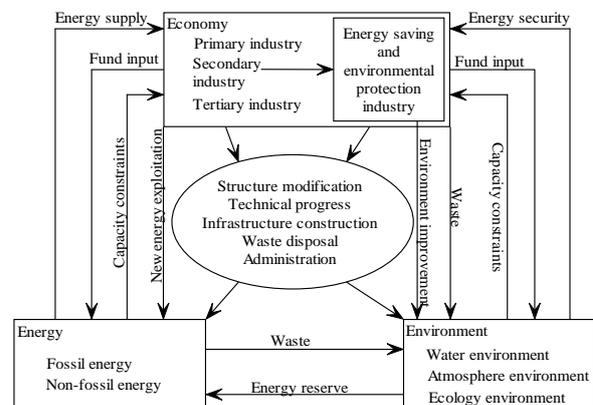


Figure 1. Coordination development model of 3E system

composition method is the main tools to decompose quantitatively influencing factors in field of energy and environment research. Here, the Laspeyres' factor decomposition is adopted to analyze contribution rate of industry in reducing comprehensive energy consumption intensity of China.

Comprehensive energy consumption intensity (*CECI*) can be decomposed as follows:

$$CECI = \frac{GEC}{GDP} = \frac{GEC}{GEC_I} \times \frac{GEC_I}{GDP_I} \times \frac{GDP_I}{GDP} \quad (4)$$

where, *GEC* represents general energy consumption, *GDP* means general domestic production, *GEC_I* implies general energy consumption of industry, and *GDP_I* shows industrial added value.

Equation 4 makes it clear that *CECI_I* can be decomposed into product of three factors, that is, reciprocal of the percentage of industrial energy consumption, industrial energy consumption intensity (denoted by *CECI_I* in the following text), and the percentage of industrial added value. Then variation of *CECI* will come from effect of them, which are denoted by *Effect_{Rio(UEC)}*, *Effect_{CECI(I)}*, *Effect_{Rio(GDP)}*, respectively.

$$\begin{aligned} \Delta CECI &= CECI^T - CECI^0 \\ &= Effect_{Rio(UEC)} + Effect_{CECI(I)} + Effect_{Rio(GDP)} \end{aligned} \quad (5)$$

The expression of each decomposed item is as follows:

$$Effect_{Rio(UEC)} = \left[\left(\frac{GEC}{GEC_I} \right)^T - \left(\frac{GEC}{GEC_I} \right)^0 \right] \times \left(\frac{GEC_I}{GDP_I} \right)^T \times \left(\frac{GDP_I}{GDP} \right)^T \quad (6)$$

$$Effect_{CECI(I)} = \left[\left(\frac{GEC_I}{GDP_I} \right)^T - \left(\frac{GEC_I}{GDP_I} \right)^0 \right] \times \left(\frac{GEC}{GEC_I} \right)^0 \times \left(\frac{GDP_I}{GDP} \right)^T \quad (7)$$

$$Effect_{Rio(GDP)} = \left[\left(\frac{GDP_I}{GDP} \right)^T - \left(\frac{GDP_I}{GDP} \right)^0 \right] \times \left(\frac{GEC}{GEC_I} \right)^0 \times \left(\frac{GEC_I}{GDP_I} \right)^0 \quad (8)$$

where, superscript *T* and 0 represent the terminal and initial moment in comparison, respectively. It can be proven easily that the above decomposition method is complete, with no residuals item. Final decomposition result is listed in Table III.

TABLE III.
RELATION BETWEEN CHINA'S COMPREHENSIVE ENERGY CONSUMPTION INTENSITY AND THE OTHER THREE INDEXES

Contribution rate in time span (%)	<i>Effect_{Rio(UEC)}</i>	<i>Effect_{CECI(I)}</i>	<i>Effect_{Rio(GDP)}</i>
2005-2006	0.14	106.36	-6.51
2005-2007	-0.09	111.02	-10.93
2005-2008	3.16	105.71	-8.87
2005-2009	-0.09	104.28	-4.19
2005-2010	-2.21	114.12	-11.91

Data resource: China Statistical Yearbook 2006-2011, China Energy Statistical Yearbook 2006-2011.

From Table III, factors influencing *CECI* in the five years obey the following uniform tendency:

Transversely in each time span, percentage of industrial energy consumption has negligible effect on variation of *CECI*, the reduction of industrial energy consumption intensity takes indubitable and decisive role in the decrease of *CECI*, and on the contrary, industrial added value produces negative effect, that is, more industrial added value will block the further decrease of *CECI*, which means that industry restructuring is imperative and secondary industry and industry should slowly give its leader position to tertiary industry. So, how much energy is used by industry is not the key, while industrial added value seems more important, because the current industrial energy consumption is a little high, and too much energy is input when certain output is produced, which leads to the negative effect for reducing *CECI*.

Verticality in each time span, industrial energy saving still has heavy responsibilities on its shoulders. Its absolute decrease of energy consumption intensity is always more than that of *CECI*, and it has been the important force in achieving the energy saving objective. Also, both positive effect from *CECI_I* and negative effect from the percentage of industrial value added are on the down, the positive effect of percentage of *GEC_I*, however, tells its spiraling tendency. Hence, energy saving must be one important and arduous task. In the near future, rebounding may happen out of accidental factor. In the medium-term and long-term future, with continual and further adjustment of industry and economy structure, industrial energy consumption will keep going down. Percentage of industrial added value won't be important any longer, which effect and that of percentage of industrial energy consumption are on the shift. Equilibrium point between their positive and negative effect must be reached. In the long-term future, the effect of industrial energy consumption will on the lead. In that time, industrial energy consumption has reached a comparatively lower level, and potential of more decrease is getting small.

V. CONCLUSIONS

Energy plays important supporting role in industrial development. Fossil energy occupying an leading position, however, goes against environmental protection. So, energy is the key to solve the problem among them. Industry not only is the undoubted driving force for China's economic progress, but also obligatorily assumes required energy-saving duty. China should move on along the principle of energy saving making progress, progress making energy saving, and energy saving while developing. Under the premise of continuous increase of industrial added value, the whole society forges ahead harmoniously, saving energy by measures about industry restructuring, technology research, administration mode, legal construction, and recycling economy.

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