A Comparative Study on the Energy Efficiency of Provinces Based on Data Envelopment Analysis

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Abstract

Energy is an important factor of production and subsistence, and is also the driving force for national economic development. Energy development and utilization, as well as the optimization and adjustment of energy structure, seems to be of great significance to the healthy development of the national economy and sustainable development particularly, in the case of higher pressure about resources and environment capacity. According to the characteristics of energy consumption, this paper built an energy efficiency evaluation model, considering the total energy consumption, the total number of employees and the depreciation of fixed assets as the investment indicators, the regional GDP and the positive environment output as the output indicators at the same time, employed a method of DEA based on relevant data of each region in 2009, and made an empirical study as well as comments on China's 26 provincial-level administrative regions' energy efficiency situation, so as to put forward opinions and suggestions to improve energy efficiency.

Keywords: energy efficiency; data envelopment analysis; factor analysis; energy conservation

I. Introduction

Energy is an important factor of production and subsistence, and is needed throughout various activities of economic development and social progress. As a country that produces and consumes large amounts of energy, China has been facing an increasingly prominent contradiction between economic development and resources & environment with the rapid economic and social development in recent years: "there is a large amount of energy consumption, as well as serious shortage; energy consumption structure is irrational, while high-quality energy consumption is in a low proportion; there is an irrational economic structure, with high energy consumption and extensive industrial economy accounting for too large proportion of the national economy; long-term coal-based energy production and consumption caused tremendous damage to the environment ", etc., energy issues have brought serious negative impact on economic and social development, and have been the bottleneck to constrain China's economic transformation and sustainable development. As a result, it is imperative to solve the energy problem.

This paper intends to use the data envelopment analysis (hereinafter referred to as DEA) method to establish an evaluation model of energy efficiency to evaluate energy efficiency of the provinces, in order to not only help us fully understand the status quo and discover problems of energy consumption, but also to provide references for policy makers.

Researches on energy efficiency at home and abroad mainly include:

Jonathan E. Sinton (2001) said that some private, small enterprises' energy production statistics are not accurate, China's energy statistics may be with bias, and China's energy efficiency should be in an upward trend in recent years with the exclusion of these factors. Thomas G. Rawski (2001) came to the conclusion that "China's energy efficiency has not been significantly improved in the past 10 years" through the empirical research on China's economic development. Richard Bradley and Ming Yang's (2006) study suggested that: although China has made some achievements in energy conservation, but the growth rate of energy consumption is still faster than the economic growth rate, and China's energy efficiency is still low. In this view, China must strictly implement the policy of energy conservation in order to achieve sustainable development.

Wang Qingyi (2003) considered that the meaning of improving energy efficiency that is consistent with the connotation of energy conservation, and therefore the fundamental way for China to achieve targets of energy saving and emission reduction is to improve energy efficiency. Xu Guoquan & Liu Zeyuan (2007) established a total-factor model of energy efficiency based on DEA, and analyzed the total-factor energy efficiency of China's eight economic zones from 1998 to 2005 through a comparative study, and then concluded that China's Regional Total-Factor Energy Efficiency and Regional level of development was in a "U -type " relationship. Wei Chu et al (2007) noted that the concept of energy efficiency lacked a unified standard, and there were some defects in its evaluation itself, resulting in a variety of results calculated in different researches, and therefore it was impossible to determine the current status of energy efficiency. Wu Qi et al (2009) built a DEA efficiency evaluation model that could deal with non-desired energy outputs based on total-factor energy efficiency framework, and through empirical studies found that this model could be effectively applied to the evaluation of energy efficiency, but also provide useful inspiration for the Chinese to develop policies to achieve targets of energy saving and emission reduction. Yang Jisheng (2009) believed that increasing energy efficiency is the fundamental way to realize sustainable economic development and to reduce pollution emissions, and based on analysis of the nonlinear smooth transition model concluded that there was non-linear smooth transition in the mechanisms of energy prices' impact on energy efficiency, and then further pointed out that the main guiding factor of mechanism transition is the relative changes of energy price indicator at home and abroad.

Easy to see that current researches are mostly on change trends of energy efficiency, the relationship between energy efficiency and economic growth as well as the impact factors of energy efficiency, and evaluation of regional energy efficiency is involved although, but the data lag behind and can not well explain the current status of China's energy efficiency, and there is no evaluation for the progress made in the regional energy conservation either. Therefore, this article attempts to make use of relevant data in 2009, evaluates the energy efficiency of China's 26 provincial administrative regions[1], in order to identify energy conservation achievements of each region, and points out problems that may exist so as to specify the key directions and to provide policy basis for future work.

II. The Theoretical Model to Evaluate Energy Efficiency

Referring to Wu Qi and WU Chunyou (2009), this paper takes the method of total-factor energy input, and defines the energy efficiency as: the ability to minimize resource inputs and environmental impact given the economic output. Easy to know, here the energy efficiency is of an integrated one of economic efficiency and environmental efficiency, in which economic efficiency means the economic output per unit of energy consumption while environmental efficiency means pollution emissions per unit of energy consumption.

Energy efficiency can be evaluated in parametric methods (such as SFA and DFA) and non-parametric methods (such as DEA). Since the DEA method can effectively handle the case of multiple outputs, and can adjust the direction as well as the amount of relevant indicators for non-effective units indicated by the projection principle, but also can avoid subjectivity, simplify algorithm, reduce errors. Therefore, this study uses DEA method to build the evaluation model of energy efficiency, and concrete steps are as follows:

1. Determine Decision Making Units

According to the DEA method, this paper considers 26 provincial regions of China as decision-making units, in order to identify the advantages and problems of each administrative region in terms of energy use in 2009, and to point out its potential as well as improvement direction.

2. Select Evaluation Indicators

According to the previous analysis, this study involves the following indicators:

(1) Energy resources. To measure energy input of decision-making units, it is represented by the total energy consumption.

[1] Given the availability and integrity of data, this paper doesn't study the following regions: Tianjin, Jilin, Jiangsu, Hainan, Tibet, Hongkong, Macao and Taiwan area.

(2) Human resources. To measure human resource investment of decision-making units, it is represented by the total number of employees. In order to reflect changes in human resources and to make a more objective description of human resources invested, the total number of employees here is expressed by the arithmetic average of the last and present period.

(3) Capital resources. Many studies took the capital stock as an indicator to measure capital investment, but because of issues related to capital utilization, in fact, not all of the capital are used for energy utilization process, whereas depreciation of fixed assets reflects the current physical capital consumption, so this study selects the current depreciation of fixed assets to measure capital investment of decision-making units.

(4) Economic output. To measure economic output of decision-making units, this is represented by the GDP.

(5) Environmental impact. To measure the amount of pollution emitted by decision-making units in the use of energy, it includes gas, waste water and solid waste. Here sulfur dioxide emissions, dust emissions, industrial dust emissions and chemical oxygen demand emissions, ammonia emissions and industrial solid waste emissions are in this selection, where sulfur dioxide emissions, dust emissions and chemical oxygen demand emissions and ammonia emissions include both life emissions and industrial emissions, indicator values as the summation of the two.

3. Construct the Indicator System

According to the relevant definitions and the corresponding energy efficiency indicators, the indicator system is shown as in Figure 1 in this study.

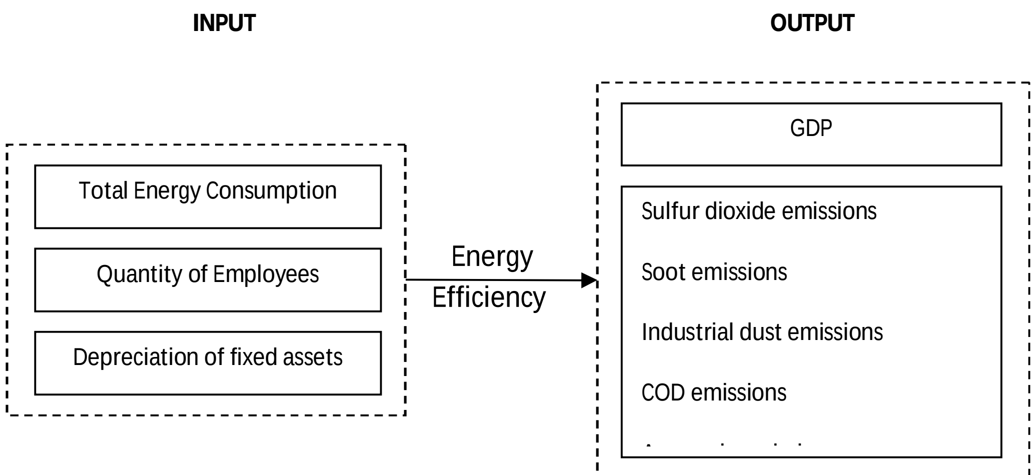

Figure 1 Indicator System for Energy Efficiency Evaluation

III. Empirical Analysis: A Comparative Study of Regional Efficiency

1. Collect Data

From "China Statistical Yearbook 2009", "China Statistical Yearbook 2010" and "China Energy Statistical Yearbook 2010", the total energy consumption, depreciation of fixed assets, the total number of employees, gross regional product, sulfur dioxide emissions, dust emissions, industrial dust emissions and chemical oxygen demand emissions data, ammonia emissions and industrial solid waste emissions are got.

2. Handle Indicators

When using routine DEA model to investigate the decision-making units' energy efficiency with respect to the production frontier surface, output indicators are generally desired ones such as output value, etc., while pollutant emissions and other undesired outputs are improper for this method, so it is needed to process and convert the undesired output indicators. This study uses a linear transfer function $b_j^{'} = -b_j + v$ (in which v is large enough to ensure that target indicators are converted to positive values) to transform the undesired pollutant emissions, and then $b_j^{'}$ will be added to the routine DEA model as the desired output.

It is not difficult to find that too many environmental output indicators will affect the determination of v's value, and then bring inconvenience to the data processing. Moreover, in DEA evaluation models the number of the decision-making units is at least two times the number of input and output indicators, and the greater the difference between the two numbers, the closer the evaluation result is to the real situation, so if the number of decision-making units is fixed, the input and output indicators should not be too many. Therefore, it is necessary to make a dimension reduction for environmental impact indicators. This paper uses SPSS17.0 to do factor analysis, and results show that:

Bartlett ball test statistic χ^2 is 89.746, significant probability is 0.000, KMO value is 0.785, so the null hypothesis that indicators are unrelated is rejected, suitable for factor analysis. Seeking initial public factor characteristic values, variance contribution rate and the cumulative variance contribution rate by principal component analysis, the results show that when the number of factors is 3, common factors' cumulative variance contribution rate is 88.532%, indicating that the extracted common factors can explain 88.532% of the six original variables, mostly preserving the original variables' information, with good representation. Composite scores of decision-making units are calculated based on the public factor loading matrix, that is, environmental outputs, also known as comprehensive environmental impact indicators. According to the undesired output values, take $v = 2$, then the undesired outputs are converted to the desired outputs, named positive environmental outputs (detailed calculations and data are not shown).

3. Process Data and Analyze Results

Take regional GDP and positive environmental output as output indicators, take the total energy consumption, the total number of employees and depreciation of fixed assets as input indicators, use Deap 2.1 software for data processing, and energy efficiency values of China's 26 provincial regions in 2009 will be obtained, which are shown in Table 1.

Table 1 Energy Efficiency of China's 26 Provinces In 2009

REGION	Comprehensive energy efficiency (crste)	Technical efficiency (vrste)	Scale efficiency (scale)	Returns
BEIJING	1.000	1.000	1.000	-
HEBEI	0.912	0.980	0.930	drs
SHAN1XI	0.743	0.752	0.987	irs
NEIMENGGU	1.000	1.000	1.000	-
LIAONING	0.828	0.854	0.970	drs
HEILONGJIANG	0.882	0.883	1.000	-
SHANGHAI	1.000	1.000	1.000	-
ZHEJIANG	0.969	1.000	0.969	drs
ANHUI	0.837	0.852	0.982	irs
FUJIAN	1.000	1.000	1.000	-
JIANGXI	0.775	0.835	0.928	irs
SHANDONG	0.871	0.967	0.901	drs
HENAN	0.972	1.000	0.972	drs
HUBEI	0.764	0.774	0.987	drs
HUNAN	1.000	1.000	1.000	-
GUANGDONG	0.953	1.000	0.953	drs
GUANGXI	0.840	0.879	0.955	irs
CHONGQING	1.000	1.000	1.000	-
SICHUAN	0.750	0.758	0.990	drs
GUIZHOU	0.678	0.703	0.964	irs
YUNNAN	0.898	0.930	0.965	drs
SHAN3XI	0.990	1.000	0.990	drs
GANSU	0.702	0.708	0.991	irs
QINGHAI	1.000	1.000	1.000	-
NINGXIA	0.966	0.969	0.997	irs
XINJIANG	0.820	0.851	0.963	irs

Note: 1. "drs" means decreasing returns to scale; "-" means constant returns to scale; "irs" means increasing returns to scale.

2. crste = technical efficiency from CRS DEA; vrste = technical efficiency from VRS DEA; scale = scale efficiency = crste / vrste; returns = returns to scale.

Source: According to data from "China Statistical Yearbook 2009", "China Statistical Yearbook 2010" and "China Energy Statistical Yearbook 2010", with some data management, converted by the function and software processing.

From the evaluation results, in 26 provincial regions studied, Chongqing is the same with Beijing, Inner Mongolia, Shanghai, Fujian, Hunan and Qinghai, whose energy efficiency is DEA effective in 2009; while other areas are DEA non-effective, this indicates that the scale does not match the input and the output in these areas, and they need to expand (areas with increasing returns to scale) or shrink (areas with decreasing returns to scale) their scale; the lowest energy efficiency is in Guizhou, less than 0.7; in addition, the energy efficiency of Shan1xi, Jiangxi, Sichuan and Gansu is relatively low, not over 0.8. Compared with the conditions in 2006 (Wu Qi, 2009), Chongqing has been among the ranks of areas with energy efficiency DEA effective, which shows a series of energy policies including ones about energy conservation implemented in Chongqing are highly effective.

For the areas with comprehensive efficiency DEA non-effective, when their scale is changeable, the technical efficiency and scale efficiency can be examined respectively. The technical efficiency of Zhejiang, Henan, Guangdong and Shan3xi is 1, while their scale efficiency is less than 1, that is, technical efficiency rather than scale efficiency is effective, indicating that for these regions in terms of their technology, if the output is fixed then there is no reduction for input, while if the input is fixed then there is no increase for output; Heilongjiang is scale effective rather than technology effective, indicating that its energy use has achieved the economies of scale, but it doesn't not have the best technology. The rest 14 administrative regions are neither scale effective nor technical effective, that is, there are redundant inputs or insufficient outputs in these regions, and opportunities exist that the same amount as current inputs will bring more outputs, or even less inputs will bring the same amount as current outputs.

In a perspective of returns to scale, the seven DEA effective regions and Heilongjiang are in a stage of constant returns to scale; Shan1xi, Anhui, Jiangxi, Guangxi, Guizhou, Gansu, Ningxia and Xinjiang are increasing returns to scale, which means that if the number of all inputs are increased by the same proportion, then a greater proportion of returns will be received in these areas; while the rest of the regions are decreasing returns to scale, indicating that in these administrative regions, if we increase investment, then the growth proportion of output will be less than the one of investment, that is, the output efficiency of input is relatively low.

Separately take the regional GDP and positive environmental output as output indicators, with input indicators unchanged, by DEA analysis we can obtain 26 provincial regions' economic energy efficiency and environmental energy efficiency in 2009, as shown in Table 2.

Table 2 Economic Energy Efficiency and Environmental Energy Efficiency of 26 Provinces in 2009

REGION	Comprehensive energy efficiency	Economic energy efficiency	Environmental energy efficiency
BEIJING	1.000	1.000	0.371
HEBEI	0.912	0.912	0.038
SHAN1XI	0.743	0.743	0.034
NEIMENGGU	1.000	1.000	0.157
LIAONING	0.828	0.828	0.074
HEILONGJIANG	0.882	0.872	0.174
SHANGHAI	1.000	1.000	0.301
ZHEJIANG	0.969	0.969	0.119
ANHUI	0.837	0.836	0.190
FUJIAN	1.000	1.000	0.228
JIANGXI	0.775	0.761	0.302
SHANDONG	0.871	0.871	0.041
HENAN	0.972	0.972	0.061
HUBEI	0.764	0.764	0.130
HUNAN	1.000	1.000	0.074
GUANGDONG	0.953	0.953	0.062
GUANGXI	0.840	0.839	0.170
CHONGQING	1.000	0.999	0.192
SICHUAN	0.750	0.750	0.101
GUIZHOU	0.678	0.648	0.175
YUNNAN	0.898	0.869	0.227
SHAN3XI	0.990	0.980	0.227
GANSU	0.702	0.611	0.380
QINGHAI	1.000	0.661	1.000
NINGXIA	0.966	0.691	0.874
XINJIANG	0.820	0.787	0.201

Source: According to data from "China Statistical Yearbook 2009", "China Statistical Yearbook 2010" and "China Energy Statistical Yearbook 2010", with some data management, converted by the function and software processing.

From the above table, we can find that: among areas with comprehensive energy efficiency effective, Beijing, Inner Mongolia, Shanghai, Fujian and Hunan are effective in economic energy efficiency; Qinghai is effective in environmental energy efficiency; and Chongqing is DEA effective in neither economic energy efficiency nor environmental energy efficiency. Compared the economic energy efficiency and environmental energy efficiency, the economic energy efficiency is higher than the environmental energy efficiency for all the regions except Qinghai and Ningxia, indicating that most regions in China pay more attention to economic development than environmental protection, and the economy is rather efficient while serious environmental pollution is much at the same time. This is not only because economies generally consider energy conservation as beneficial result indicators to be actively pursued, but there are also causes from system, namely China's current energy-saving and emission reduction rigid targets are unreasonable, uncoordinated and can not effectively mobilize the masses, especially cannot mobilize their enthusiasm and initiative to reduce emissions effectively.

According to the regional energy input redundancy and insufficient amount of positive environmental output, we can get the energy saving potential of the regions as shown in Table 3.

Table 3 Regional Potential of Energy Conservation by Comparison in 2009

REGION	Energy resource input	Redundancy of input	Saving potential	Positive environment output	Insufficient amount of output	Reduction potential
BEIJING	6570	0.000	0.0000	3.001314	0.000	0.0000
HEBEI	25419	0.000	0.0000	1.193383	1.695	1.4203
SHAN1XI	15576	403.680	0.0259	0.555212	2.333	4.2020
NEIMENGGU	15344	1494.112	0.0974	1.816802	1.072	0.5900
LIAONING	19112	158.267	0.0083	1.637541	1.251	0.7640
HEILONGJIANG	10467	0.000	0.0000	2.243128	0.645	0.2875
SHANGHAI	10367	845.928	0.0816	2.820782	0.068	0.0241
ZHEJIANG	15567	0.000	0.0000	2.285693	0.603	0.2638
ANHUI	8896	0.000	0.0000	2.084379	0.804	0.3857
FUJIAN	8916	0.000	0.0000	2.505342	0.383	0.1529
JIANGXI	5813	0.000	0.0000	2.157121	0.731	0.3389
SHANDONG	32420	0.000	0.0000	1.641342	1.247	0.7597
HENAN	19751	0.000	0.0000	1.493687	1.395	0.9339
HUBEI	13708	0.000	0.0000	2.184487	0.704	0.3223
HUNAN	13331	0.000	0.0000	1.207958	1.681	1.3916
GUANGDONG	24654	0.000	0.0000	1.885731	1.003	0.5319
GUANGXI	7075	0.000	0.0000	1.480905	1.408	0.9508
CHONGQING	7030	0.000	0.0000	1.664524	1.224	0.7353
SICHUAN	16322	0.000	0.0000	2.032986	0.856	0.4211
GUIZHOU	7566	0.000	0.0000	1.627341	1.261	0.7749
YUNNAN	8032	0.000	0.0000	2.241333	0.647	0.2887
SHAN3XI	8044	0.000	0.0000	2.249728	0.639	0.2840
GANSU	5482	0.000	0.0000	2.561473	0.327	0.1277
QINGHAI	2348	0.000	0.0000	2.888591	0.000	0.0000
NINGXIA	3388	664.502	0.1961	2.839246	0.049	0.0173
XINJIANG	7526	228.053	0.0303	1.699972	1.189	0.6994

Note: energy-saving potential = redundancy of energy resource inputs / energy resource inputs, which means the potential to improve energy efficiency from the perspective of a reduction in energy inputs; reduction potential = insufficient amount of positive environmental outputs / positive environmental outputs, which means the potential to improve energy efficiency from the perspective of an increase in positive environmental outputs (namely to reduce pollutant emissions).

Source: According to data from "China Statistical Yearbook 2009", "China Statistical Yearbook 2010" and "China Energy Statistical Yearbook 2010", with some data management, converted by the function and software processing.

As can be seen from Table 3, under the current level of output, in Shan1xi, Inner Mongolia, Liaoning, Shanghai, Ningxia and Xinjiang, there are different levels of energy input redundancy, namely energy wastage, it also suggests the energy conservation in these areas can be improved, but their energy-saving potential is relatively small, Ningxia is 19.61% as the greatest, the least is only 0.83% in Liaoning.

With fixed input, in addition to Beijing and Qinghai, other regions are insufficient in positive environmental outputs, that is, these regions have different degrees of emission reduction potential, in which Shan1xi, Hebei and Hunan ranks the first three places, with potentials up to 420.2%, 142.03% and 139.16% respectively, the least reduction potential is in Ningxia and Shanghai, respectively 1.73% and 2.41%.

From Table 3 it is not difficult to find that, in addition to Beijing and Qinghai, the rest DEA effective regions have a certain degree of energy input redundancy or insufficient positive environmental output. So, strictly speaking, only Beijing and Qinghai are DEA effective in energy efficiency, other areas are weak DEA effective. In weak DEA effective areas, Inner Mongolia and Shanghai have both energy inputs redundant and insufficient positive environment output, indicating that there is increased space in energy saving as well as emission reduction in Inner Mongolia and Shanghai, with energy-saving potential of 9.74% and 8.16% respectively, emission reduction potential 59% and 2.41%, separately; just as Fujian and Hunan, Chongqing has no energy input redundancy, but has insufficient positive environmental output, that is, under the current level of technology, there is no wasted energy phenomenon but potential for emission reduction, whose emission reduction potential is up to 73.53%.

IV. Conclusions and Suggestions

Based on the above analysis, I believe that each region must consider the special conditions and the level of local economic development, and implement practical and effective policies and measures conducive to explore the local potential, so as to effectively improve energy efficiency, and to promote endogenous economic growth. For DEA non-effective regions, such as ones in decreasing returns to scale stage, Hebei, Liaoning, Zhejiang, Shandong, Henan, Hubei, Guangdong, Sichuan, Yunnan and Shan3xi, because they consumed too many resources (especially energy) in the process of economic development, and caused a greater impact on the environment, they should integrate resources to achieve economies of scale rather than blindly increase resource inputs. Shan1xi , Anhui, Jiangxi, Guangxi, Guizhou , Gansu, Ningxia and Xinjiang are increasing returns to scale, and Anhui, Jiangxi, Guangxi, Guizhou and Gansu have only insufficient positive environment output but no energy input redundancy, suggesting that these regions have potential to increase products and to reduce emissions, but have inadequate resource investment at present, resulting in poor output and energy efficiency. For these regions, an effective way to improve energy efficiency is to increase the resource inputs, reduce emissions and recycle waste.

Improving energy efficiency should start with transforming existing traditional industries, introducing advanced technology and developing strategic emerging industries, specific suggestions are as follows:

First, transform existing traditional industries. Emphasize the strength and structure of energy technology investment, speed up industrial restructuring and upgrading, phase out high energy consumption , high pollution and low-end industries gradually, improve energy efficiency of existing traditional industries, make efforts to achieve the optimal allocation of energy resources, and maximize the effective role of science and technology investment in improving energy efficiency.

Second, introduce advanced technologies and enhance the capacity of digesting and absorbing them by expanding opening up and undertaking industrial transfer. For relatively closed middle and west regions, they should strengthen the open efforts, increase scientific research and human capital investment, and enhance the ability to learn new technologies; while the more developed eastern regions should also implement targeted technical assistance. Especially for the relatively backward western regions, they should make scientific plans and layouts, improve industry standards and thresholds, and try to control or even avoid high energy consumption, high pollution industries into the region.

Third, vigorously develop strategic emerging industries. Strategic emerging industries are in an important strategic position in the economic and social development, which is a deep integration of emerging technologies and new industries, and they can both support the current economic and social development and lead the future sustainable development, representing the direction of technological innovation as well as industrial development, with green, low-carbon, environment-friendly features. Therefore, we should vigorously develop strategic emerging industries, and boost the flow of energy from the inefficient sectors to the efficient ones, in order to improve the allocation efficiency of energy between industries.

Fourth, improve the pricing system of various energy resources, and truly liberalize energy goods prices, making it to market, in order to stimulate public enthusiasm and initiatives for energy conservation. For example, we can improve the "coal and electricity price linkage" mechanism, and actively create conditions to realize the price of coal and electricity determined by market.

Fifth, update the concept of development, and implement energy structural changes. Improve existing mining, processing and transporting of energy technology facilities, improve energy efficiency of high energy consumption sectors such as industry and transportation, and focus on the development of wind energy, hydrogen energy and other renewable energy; promote "four in one" ecological agriculture model, and scientifically and efficiently use limited space to promote energy ecosystem’s virtuous cycle, trying to achieve unity and harmony of energy, ecology, economy and social benefits; step up publicity efforts to raise awareness of new energy and new technology, and by speeding up the construction of ancillary facilities to achieve promotion and popularization of new technologies, such as promoting rural biogas, encourage peasants to use biogas to achieve recycling of agricultural resources and agricultural production harmless.

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