Analysis of energy consumption in China's manufacturing industry

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Abstract. Due to the gradual increase in the energy consumption, energy shortage has become apparent in China. In this study, an index model for energy consumption is developed by collecting data from the manufacturing industry of China from 1994 to 2015, and using the method of maximum deviation. A short-term change point analysis of the energy consumption index trend is conducted based on grey relational analysis; and the change points occur in 2000 and 2008. The results indicate a decreasing trend of the energy consumption index in the manufacturing sector, and the downward trend is relatively notable from 2001 to 2008. However, the total energy consumption between 1994 and 2015 remains high as the production soared. So the Chinese government should strengthen the functions of government supervision and management, and China's manufacturing industry must focus on independent innovation to solve the existing problems.

1. Introduction
Due to extensive development and high energy consumption, China has become the largest energy consumer. The energy consumed by the manufacturing industry accounts for more than half of the country's total consumption. Energy shortages and low efficiency have constrained the pace of China's move from a manufacturer of quantity to quality. In the context of the new industrialization, the focus of constructing global manufacturing power lies in sustainable development. Therefore, the analysis and assessment of the paper is of practical significance to recommend corresponding policies.

2. Literature Review
Energy efficiency and consumption intensity are foci of studies. Chen measured the energy efficiency of 30 industries in China's manufacturing using a stochastic frontier approach and concluded that the energy structure significantly affected the energy efficiency [1]. Lundgrena and Marklund used the same approach to assess the energy efficiency of Swedish manufacturing [2]. It was believed that the energy intensity should not be used as an indicator of energy efficiency. Zhang found an energy rebound effect by using index decomposition model[3]. The determination of ways to improve energy efficiency and reduce energy intensity has been a hot topic in recent years. The research of Yin showed that technological innovation was the most effective way to reduce energy consumption [4]. Xiao and Wei obtained similar results [5]. Ma adopted a multiple linear regression model to prove that
advanced manufacturing could promote the regional energy intensity decline [6]. Li pointed out that there was a significant double threshold effect between manufacturing upgrades and the energy consumption structure [7]. Lin and Li adopted a data envelopment analysis model to evaluate the role of government in promoting green development, the research found that the Chinese government should adopt more stringent enforcement measures [8]. The study of Liu, using stakeholder analysis, examined the effort of the government to promote reduction of energy consumption in China, and found that guaranteed energy savings model was crucial, which could allow the government to improve the design and deployment of related mechanisms [9].

Grey relational analysis (GRA) can be applied in various fields. In recent years, the specific application of this method in the manufacturing industry has mainly focused on scientific and technological investments and the evaluation of sustainable development in the manufacturing industry. Goyal and Grover used fuzzy grey relational analysis (FGRA), which is more logical, and easy to understand, to rank the advanced manufacturing system (AMS) alternatives [10]. Rao and Singh presented three examples to illustrate the potential of improved grey relational analysis (GRA) to solve decision-making problems of the manufacturing environment [11]. In Jayant and Giri’s research, GRA is used to facilitate decision making in the selection of a green global manufacturing strategy [12].

In short, the issue of energy consumption in the manufacturing industry is related to economic and social aspects. Scholars have drawn many conclusions with theoretical and practical value and made recommendations. However, there is relatively little research in literature on the energy consumption index. Therefore, the method of maximum deviation is used in this study to measure the energy consumption index of China's manufacturing industry. The change point is determined using the grey relational analysis and the energy consumption in China's manufacturing industry is explored, which is not only of practical significance but also of theoretical value.

3. Data Sources and Process
In this paper, we use methods of maximum deviation and grey relational analysis. The manufacturing energy consumption data for 1994–2015 are mainly acquired from the China Statistical Yearbook, China Energy Statistics Yearbook, and China Industrial Statistics Yearbook. Take these data as a sample and use the method of maximum deviation to analyze the energy consumption trend of the manufacturing industry in China.

Based on scheme set $A = \{1994, 1995, \ldots , 2015\}$, a total of 22 decision schemes exist, that is, $n = 22$. The index set $G = \{G1, G2, \ldots , G10\}$, that is, $m = 10$, where $G1$ denotes the energy consumption per unit of output, $G2$ is coal consumption, $G3$ is coke consumption, $G4$ is crude oil consumption, $G5$ is the fuel consumption, $G6$ is kerosene consumption, $G7$ is diesel consumption, $G8$ is fuel oil consumption, $G9$ is gas consumption, and $G10$ is electric power consumption, all measured on a per unit of output basis. Because all these ten indices are cost indices, we can construct the standardization evaluation matrix according to the Eq. (1) and obtain the weighted vector $Z = (Z_{ij})_{n \times m}$ based on the equation described earlier:

$$w = (0.0942, 0.0914, 0.1000, 0.1044, 0.0947, 0.1073, 0.1179, 0.0940, 0.0974, 0.0986)^T$$

Based on the weights, the multi-index comprehensive evaluation value is calculated. Specific index values are shown in Table 1.
Table 1. Energy consumption index of the manufacturing industry.

| Year | Energy Consumption Index of Manufacturing |
|------|-----------------------------------------|
| 1994 | 0.9428                                  |
| 1995 | 0.8449                                  |
| 1996 | 0.8247                                  |
| 1997 | 0.7220                                  |
| 1998 | 0.7455                                  |
| 1999 | 0.7023                                  |
| 2000 | 0.5934                                  |
| 2001 | 0.5238                                  |
| 2002 | 0.4656                                  |
| 2003 | 0.3748                                  |
| 2004 | 0.2726                                  |
| 2005 | 0.2262                                  |
| 2006 | 0.1824                                  |
| 2007 | 0.1314                                  |
| 2008 | 0.0934                                  |
| 2009 | 0.0763                                  |
| 2010 | 0.0462                                  |
| 2011 | 0.0267                                  |
| 2012 | 0.0200                                  |
| 2013 | 0.0204                                  |
| 2014 | 0.0145                                  |
| 2015 | 0.0092                                  |

4. Selection of Change Points and Analysis

4.1. Selection of Change Points

Figure 1 shows the trend of China's energy consumption index of manufacturing from 1994 to 2015 according to the data in Table 1. Using the data in Table 1 and grey relational analysis, the change point of the data series can be determined.

![Figure 1. Trend of the energy consumption index of manufacturing.](image)

Table 2. The results of change point detection (part 1).

| T  | Dissected Time Series | η (T) | T* | Change Point |
|----|----------------------|-------|----|--------------|
| 5  | 1999–2015/1994–1998  | 8.4953|    |              |
| 6  | 2000–2015/1994–1999  | 6.6943|    |              |
| 7  | 2001–2015/1994–2000  | 8.8612|    | 2000         |
| 8  | 2002–2015/1994–2001  | 0.0410|    |              |
| 9  | 2003–2015/1994–2002  | 8.2850|    |              |
| 10 | 2004–2014/1985–2003  | 0.0000|    |              |
Table 3. The results of change point detection (part 2).

|   | Dissected Time Series   | η (T)  | T*   | Change Point |
|---|------------------------|--------|------|--------------|
| 5 | 1994–2010/2011–2015    | 0.8273 |      |              |
| 6 | 1994–2009/2010–2015    | 2.0875 |      |              |
| 7 | 1994–2008/2009–2015    | 2.5114 | 8    | 2008         |
| 8 | 1994–2007/2008–2015    | 4.6802 |      |              |
| 9 | 1994–2006/2007–2015    | 3.7227 |      |              |
| 10| 1994–2005/2006–2015    | 0.0000 |      |              |

The numerical results of the energy consumption index of Chinese manufacturing are based on the grey relational analysis of T's relative relational grade. The maximum point in Table 2 is the 7th point, that is, the change of the time series occurs in 2000. The other change point is shown in Table 3. The maximum point is the 8th point. Because the change point is in the second part of the series, we use the latter half column as reference sequence; therefore, the time sequence of the change point occurs in 2008. Thus, the time series in Figure 1 can be divided into three parts: 1994–2000, 2001–2008, and 2009–2015. Figure 1 shows that China's energy consumption index of manufacturing shows a downward trend from 1994 to 2015. Before 2000, the index trend experiences two fluctuations. After 2001, the energy consumption index shows a significant decrease from 0.5 to 0.1. The index has been below 0.1 since 2009; the space for decline is smaller and the rate of decline slows down. Therefore, it is reasonable to select 2000 and 2008 as change points.

4.2. Analysis

From 1994 to 2000, the government of China issued a series of energy policies to deal with the surge in energy consumption due to the extensive development of the manufacturing industry. These policies, more detailed than before, covered a wide range of areas and focused on the benefit rather than quantity. Because of the successive implementation of the Provisional Regulations on Resource Tax and Regulations for the Collection of Mineral Resource Compensation Fees in 1994, the energy costs of manufacturing companies have risen. Therefore, it was imperative to reduce the energy consumption per unit of output. In addition to collecting relevant resource taxes from companies, the government also issued relevant laws and regulations. The Coal Law (1996) regulated the use of coal by people and the Save Energy Law (1998) made provisions for the control of the energy use, definition of legal responsibility, and management of energy conservation. Other regulations have also been issued such as the Detailed Rules for the Implementation of the Mineral Resources Law (1994), Electric Power Law (1995), and Regulations on the Supply and Use of Electricity (1996). In addition, Relevant government departments issued a circular on supporting the renewable energy development in 1999. The Economic and Trade Commission issued the second batch of catalogues to eliminate backward production capacity, processes, and products. These policies, to a certain extent, promoted the optimization of the energy structure and reduced the energy consumption of the output value of manufacturing units.

In the beginning of the 21st century, the demand for crude oil and international oil price increased substantially and rapidly due to the rapid growth of the global economy. As a huge developing economy, China’s domestic power supply became tight. The increasing energy pressure forced the Chinese government to increase crude oil imports [13]. In response to the contradiction between the energy pressure and economic growth, the government issued and revised many documents on energy conservation based on the original energy policy to strengthen the control over the energy consumption. On the one hand, the policies announced during this period were strict with relevant industry norms to guide companies to reduce the consumption of non-renewable energy. Some notices were issued by the government in 2003, such as 108 oil and natural gas industry standards. The Environmental Impact Assessment Law, which came into effect in September 2003, has effectively prevented and mitigated damage to the environment caused by heavy pollution projects in the manufacturing industry. In the notice of implementation of resource conservation activities from 2004, it was proposed to take a new industrialization pathway with low resource consumption, low environmental pollution, and good economic results, which encouraged the use of advanced
technologies to transform traditional industries and enhance the power load management of high-energy-consuming industries while saving electricity. The staged energy-saving targets and key fields were clarified in the Long-Term Special Plan for Energy Saving. The focus of these policies shifted from controlling energy consumption to promoting the rational consumption of energy, urging manufacturing companies to increase their own energy use efficiency, which is beneficial to saving energy resources. On the other hand, the government encouraged the development and consumption of renewable energy. From 2003 to 2005, the government issued a series of notices supporting the construction of the wind power industry such as the preparation of pre-feasibility study reports for wind farms and the management of wind measurement projects. The Renewable Energy Law was implemented in 2005 to promote the utilization of renewable energy and to provide channels for the increase of the energy supply, thus ensuring energy security and achieving sustainable development. Overall, China was in the stage of deepening the reform of its energy system from 2001 to 2008 and its macroeconomic control system continuously improved.

Since 2009, China has entered a new stage of improvement of the energy system. The government revised previous laws and policies according to new problems that emerged in the new period. The Circular Economy Promotion Law (1999) also came into effect. Sustainable economic and social development demand the sustainable development of energy; therefore, the 11th Five-Year (2006–2010) Plan and 12th Five-Year (2011–2015) Plan further constrained the growth of the energy consumption per unit of production value in manufacturing. The 12th Five-Year Plan put forward the concept of “advocating conservation priorities, diversifying development, protecting the environment, adjusting the energy structure, and building an economical and clean modern energy industry system”, focusing on promoting the implementation of circular economy transformation in high-energy-consuming industries and increasing the proportion of wind energy and biomass in primary energy consumption with preferential fiscal and taxation policies. Since 1994, the relevant energy-saving policies implemented by the Chinese government have passed the test of time. The overall energy consumption index continued to decline from 2009 to 2015 and stabilized after 2011. This result shows that China's energy policy in the manufacturing industry has been effective for 20 years.

5. Suggestions
The overall trend of the energy consumption index of the manufacturing industry from 1994 to 2015 decreased year by year. From 1994 to 2000, the numerical changes in manufacturing energy consumption index showed repeated fluctuations, but the release and implementation of a series of energy utilization policies began to guide energy consumption toward high efficiency and environmental protection [14]. From 2001 to 2008, China’s manufacturing industry, under the supervision of policies and markets, gradually changed the extensive resource consumption pattern by opening the sources and regulating the flow and the overall energy consumption index of the manufacturing industry has maintained a clear declining trend. From 2009 to 2015, the energy consumption index remained stable with a slight decline. However, the total energy consumption between 1994 and 2015 remained high as the production soared. Therefore, the issue of energy waste has not been fundamentally solved and the energy-saving measures in China's manufacturing industry have a long way to go, and we put forward suggestions for both national and manufacturing levels.

From the national level, the government should improve the energy legal system and strengthen the functions of government supervision and management. First, the government should clarify the legal status of the energy conservation law in the constitution, take the energy conservation law as the core, and improve the energy legal system. Second, the government can establish an effective energy saving incentive mechanism to affect the earnings of enterprises and fully mobilize the enthusiasm of enterprises to participate in energy conservation. From the manufacturing level, the most important thing is to enhance independent innovation. The manufacturing industry should consider the improvement of the capability of independent innovation as an important task for its development, guide enterprises to commit to intelligence development, and use technology to further improve the efficiency of energy use. Not only can this help to ease the energy shortage but also to sustainably develop the manufacturing industry.
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