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The Energy Footprint of China's Textile Industry: Perspectives from Decoupling and Decomposition Analysis

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Abstract: Energy is the essential input for operations along the industrial manufacturing chain of textiles. China's textile industry is facing great pressure on energy consumption reduction. This paper presents an analysis of the energy footprint (*EFP*) of China's textile industry from 1991 to 2015. The relationship between *EFP* and economic growth in the textile industry was investigated with a decoupling index approach. The logarithmic mean Divisia index approach was applied for decomposition analysis on how changes in key factors influenced the *EFP* of China's textile industry. Results showed that the *EFP* of China's textile industry increased from 41.1 Mt in 1991 to 99.6 Mt in 2015. *EFP* increased fastest in the period of 1996–2007, with an average annual increasing rate of 7.7 percent, especially from 2001 to 2007 (8.5 percent). Manufacture of textile sector consumed most (from 58 percent to 76 percent) of the energy among the three sub-sectors, as it has lots of energy-intensive procedures. *EFP* and economic growth were in a relative decoupling state for most years of the researched period. Their relationship showed a clear tendency toward decoupling. Industrial scale was the most important factor that led to the increase of *EFP*, while decreasing energy intensity contributed significantly to reducing the *EFP*. The promoting effect of the factors was larger than the inhibiting effect on *EFP* in most years from 1991 to 2015.

Keywords: energy footprint; textile industry; decoupling; decomposition analysis

1. Introduction

Energy-related greenhouse gas (GHG) emissions have raised a great deal of concern in recent decades, as GHGs have an adverse environmental impact [1]. The world's consumption of energy increased from 4661 Mt in 1973 to 9425 Mt in 2014 according to statistics of the International Energy Agency [2]. The statistics also showed that the industry sector occupied approximately 30.5% of the world's total energy (i.e., coal, oil, natural gas, electricity) consumption in 2014. The concentration of energy saving technologies and energy efficiency assessment methods in industry sectors has increased significantly in order to reduce GHGs emissions.

The textile industry is a significant contributor to many national economies, encompassing both small and large-scale operations worldwide [3]. The global fiber production has increased rapidly with the growing consumption of textiles and clothing. It is reported that global fiber production was approximately 97.8 million tons in 2016 [4]. Energy is the essential input for every operation along the industrial manufacturing chain of textiles. In general, the textile industry is not considered an energy-intensive industry compared with the metal smelting industry or the raw chemical materials and chemical products manufacturing industry. However, the textile industry comprises a large number of plants, which together consume a significant amount of energy.

China has been the world's largest producer and exporter of textiles and clothing since 1994 according to WTO trade statistics [5]. The fiber production of China's textile industry occupies more than 50 percent of the global fiber production [6]. The textile industry is a recognized traditional pillar industry in China. Specifically, China's textile industry contributes to increasing employment and income, promoting urbanization and social development. However, it also consumed large quantities of energy in the past thirty years of rapid development. China's textile industry is facing great pressure to reduce industrial energy consumption. During the 13th Five-Year-Plan period (i.e., from 2016 to 2020), the energy consumption per unit industrial value-added of China's textile industry must decrease by more than 18 percent [6].

Globally, the textile industry has become one of the industries concerned with sustainable initiatives. Several studies have paid attention to energy consumption in the textile industry. Rasul [7] and Kruska et al. [8] elucidated the rational use of energy in textile industry. In addition, Rasul presented in detail a number of feasible options for energy conservation measures in the textile industry. Kruska et al. introduced innovative technologies of energy use in textile industry. Abdel-Dayem et al. [9] and Muneer et al. [10] investigated the potential of solar energy utilization in the textile industry. Palanichamy et al. [11] shared the experiences of economic and efficient measures of energy conservation in the textile industry situated in Tamilnadu State, India. They also studied energy use in the Indian textile industry and presented the energy-efficiency potential availability, as well as suggesting some energy policies suitable for the Indian context to achieve the estimated energy-savings potential [12]. Tang et al. [13] established models for the ratio of energy consumption to yarn production over a full yarn package based on an analysis of power distribution during yarn winding in ring spinning. Ozturk [14] estimated the energy consumption and energy cost for the Turkish textile sector with a survey and analyzed the relationship between the energy usage and textile production. Kocabas et al. [15] analyzed energy consumption within the context of the European Union's Integrated Pollution Prevention and Control (IPPC) Directive on a large-scale textile mill in Turkey. Zabaniotou et al. [16] described the development of alternative energy in the textile industry by energy recovery from cotton ginning waste. Palamutcu [17] calculated the actual and estimated energy consumption using production ratios of electric energy in the various stages of the cotton textile process in Turkey. Hong et al. [18] examined the energy conservation situation in the Taiwanese textile industry and identified the areas for making energy savings to provide an energy efficiency baseline. Martínez [19] used energy intensity, specific energy consumption, and carbon emission intensity and measured energy efficiency performance in the German and Colombian textile industries. Hasanbeigi et al. [20] compared energy intensity for five major sub-sectors of the textile industry in Iran. Peng et al. [21] analyzed the overall textile industry energy efficiency gap between China and the US and measured the longitudinal changes in the energy efficiency of China's overall textile industry and subsectors. Lin et al. [22] measured the rebound effect in China's textile industry and revealed that energy efficiency improvement is conducive for energy savings to a certain degree, but is not the only way for China's textile industry to realize energy savings and emission reduction. Huang et al. [23] analyzed the energy-related GHGs emissions in China's textile industry and analyzed the emission characteristics.

Industrial energy consumption information is one of the key references for the establishment of national energy policies in order to achieve energy reduction targets. This paper aims to contribute to the understanding of energy consumption in China's textile industry, the main factors that affect the energy utilization, and the degrees of influence of these factors. This paper also focuses on the relationship between energy consumption and industry development. It will fill the gaps in this research area and provide a scientific reference for policy interventions on energy management for the sustainable energy consumption of China's textile industry.

2. Methodology and Data Sources

2.1. Energy Footprint

Measurement of energy is the most important issue for industrial products from the viewpoints of efficiency and cost. The energy footprint (*EFP*) is one way to measure that energy consumption [24]. There exist various definitions of *EFP*. The *EFP* can be measured in local or global hectares, and in units of energy/functional unit [25,26]. In this paper, we measured *EFP* in units of energy and followed the definition of the demand for non-renewable energy resources [25]. The *EFP* of China's textiles industry can be calculated as follows:

$$EFP = \sum E_i \quad (1)$$

where E_i is the consumption amount of energy i (Mt standard coal equivalent (SCE)).

Energy footprint intensity (*EFPI*) is an indicator that measures changes in energy efficiency. It can be calculated as follows:

$$EFPI = \frac{EFP}{TIOV} \quad (2)$$

where *TIOV* is the abbreviation of total industrial output value of China's textile industry (Billion U.S. dollars (USD)).

2.2. Decoupling Indicator

A decoupling index is a proper technique to determine the link between environmental pressure and economic growth. The decoupling index of *EFP* from economic growth in the textile industry is defined as exploring the relationship between textiles production-related energy consumption and the textile industry economy [27]. In this paper, the decoupling indicator can be calculated according to Equation (3) [28].

$$D_r = \frac{t}{g}(1 + g) \quad (3)$$

where D_r is the resource (i.e., energy) decoupling indicator, and t is the yearly decrease rate of *EFPI*. When *EFPI* decreases, t is defined as a positive value. When *EFPI* increases, t is defined as a negative value. g is the yearly increase rate of *TIOV*. When *TIOV* increases, g is defined as a positive value. When *TIOV* decreases, g is defined as a negative value.

There are three grades (see Table 1 and Figure 1) of decoupling state according to the values of D_r , t , and g . Absolute decoupling means the textile industry economy (i.e., *TIOV*) growth is achieved with decreasing *EFP*. Relative decoupling means that *EFP* increases with *TIOV* growth but the increasing rate of *EFP* is smaller than that of *TIOV*. A typical non-decoupling means that *TIOV* growth is achieved with increasing *EFP* and *EFP* increases faster than *TIOV*.

Table 1. Decoupling judgments on *EFP* from economic growth in the textile industry.

Decoupling State	Economy Increase	Economy Decrease
Absolute decoupling	$D_r \geq 1$	$D_r \leq 0$
Relative decoupling	$0 \leq D_r \leq 1$	$0 \leq D_r \leq 1$
Non-decoupling	$D_r \leq 0$	$D_r \geq 1$

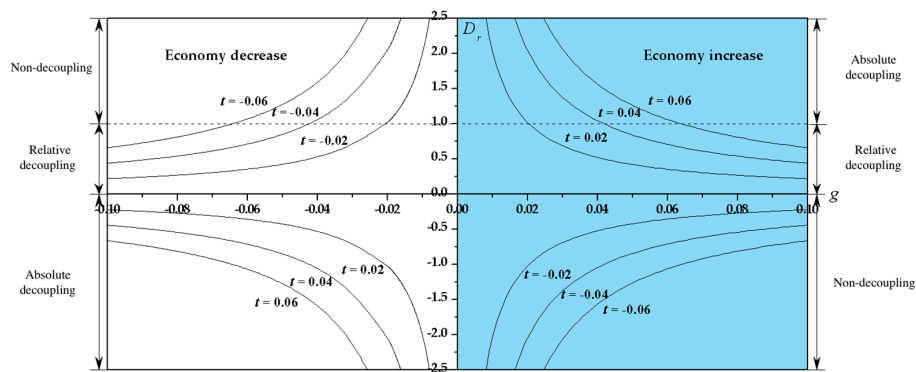


Figure 1. The framework for decoupling states.

2.3. Decomposition Model

Index decomposition analysis is an effective approach to identify key factors (e.g., industry scale, energy efficiency, energy structure, etc.) responsible for environmental stresses change and the impact mechanism. The logarithmic mean Divisia index (LMDI) approach is a widely used decomposition method due to its desirable properties in the context of decomposition analysis, such as theoretical foundation, adaptability, as well as ease of result interpretation [29,30]. In this paper, we use LMDI method to provide a clear view on the degree of influence of the driving factors. Equation (1) can be further expressed as follows:

$$EFP = \sum TIOV \times \frac{TIOV_j}{TIOV} \times \frac{E_j}{TIOV_j} \times \frac{E_{ij}}{E_j} = V_T \times S_j \times I_j \times ES_{ij} \quad (4)$$

where $TIOV_j$ is the total industrial output value of sub-sector j of China's textile industry (Billion USD). E_j is the total consumption of energy in the sub-sector j (Mt SCE). E_{ij} is the amount of energy consumption i in the sub-sector j (Mt SCE). V_T represents the industry scale factor. S_j represents the industry structure factor. I_j represents the energy efficiency factor. ES_{ij} represents the energy structure factor.

The change of EFP during a period t is equivalent to the sum of effects linked to change in each factor. It can be expressed as follows:

$$\Delta EFP = EFP_t - EFP_0 = V_{T-eff} + S_{j-eff} + I_{j-eff} + ES_{ij-eff} \quad (5)$$

where ΔEFP is the change of EFP from the base year (i.e., year zero) to year t . EFP_t is the energy footprint of year t . EFP_0 is the energy footprint of the base year. V_{T-eff} , S_{j-eff} , I_{j-eff} , and ES_{ij-eff} represents the effect of each factor, respectively. They can be calculated from the following expressions:

$$V_{T-eff} = \sum \frac{EFP_{ij}^t - EFP_{ij}^0}{\ln EFP_{ij}^t - \ln EFP_{ij}^0} \times \ln \frac{TIOV^t}{TIOV^0} \quad (6)$$

$$S_{j-eff} = \sum \frac{EFP_{ij}^t - EFP_{ij}^0}{\ln EFP_{ij}^t - \ln EFP_{ij}^0} \times \ln \frac{S_j^t}{S_j^0} \quad (7)$$

$$I_{j-eff} = \sum \frac{EFP_{ij}^t - EFP_{ij}^0}{\ln EFP_{ij}^t - \ln EFP_{ij}^0} \times \ln \frac{EFP_{ij}^t}{EFP_{ij}^0} \quad (8)$$

$$ES_{ij-eff} = \sum \frac{EFP_{ij}^t - EFP_{ij}^0}{\ln EFP_{ij}^t - \ln EFP_{ij}^0} \times \ln \frac{ES_{ij}^t}{ES_{ij}^0} \quad (9)$$

2.4. Data Sources

This analysis covers the years 1991–2015. China's textile industry has three sub-sectors (see Figure 2): Manufacture of Textile (MT); Manufacture of Textile Wearing Apparel, Footwear and Caps (MTAFC); and Manufacture of Chemical Fibers (MCF). The China Energy Statistical Yearbook (1992–2016) releases sectors' yearly industrial energy consumption data collected from terminal factories. We used these aggregate data directly for *EFP* calculation. The statistical data of *TIOV* were collected from the China Statistical Yearbook (1992–2016).

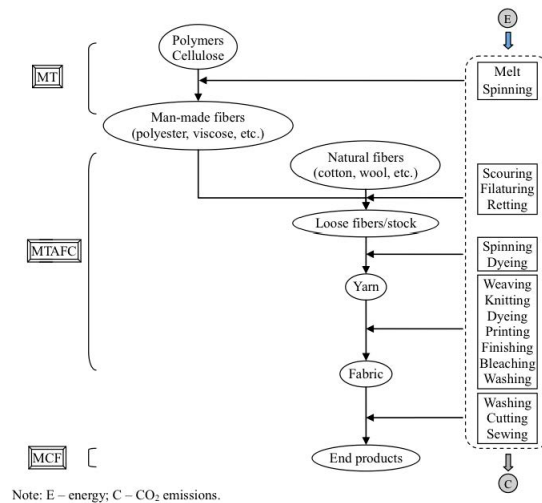


Figure 2. General schematic presentation of textile industrial production and sectors. MT: Manufacture of Textile; MTAFC: Manufacture of Textile Wearing Apparel, Footwear and Caps; MFC: Manufacture of Chemical Fibers.

3. Empirical Analysis

Figure 3 displays the *EFP* of China's textile industry calculated according to Equation (1) with the collected data. It can be seen that the *EFP* of China's textile industry increased dramatically from 1980 to 2015. The average annual increasing rate is 4.6 percent. There are three increasing periods, 1980–1995, 1996–2007, and 2008–2015, as shown in Figure 3. The peak values of the three periods appeared in 1995 (5107 Mt SCE), 2007 (8815 Mt SCE), and 2013 (10246 Mt SCE). The average annual increasing rates were 6.3 percent, 7.7 percent, and 2.2 percent, respectively. The MT sector consumes most of the energy among the three sub-sectors, followed by MCF sector and MTAFC sector.

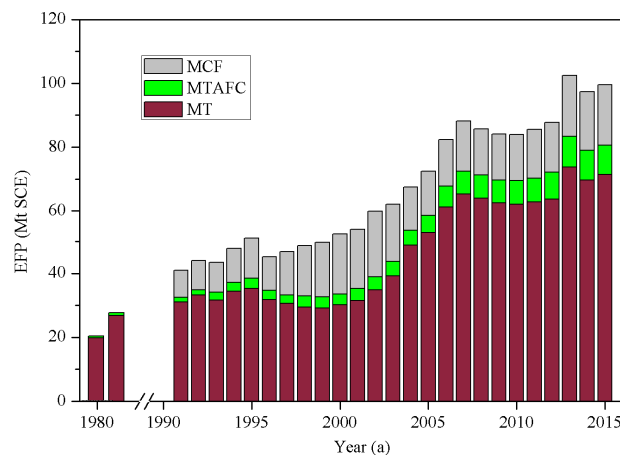


Figure 3. Energy footprints (*EFPs*) of China's textile industry and the sub-sectors.

From Figure 4 we can see that *EFPIs* of China's textile industry and the three sub-sectors decreased, especially from 1995 to 2015. The *EFPI* of MTAFC was smaller than that of MT and MCF. *EFPI* of MCF was the largest before 2004 and there was a sharp decrease from 2002 to 2004. The average *EFPI* of China's textile industry showed a similar trend to that of MT.

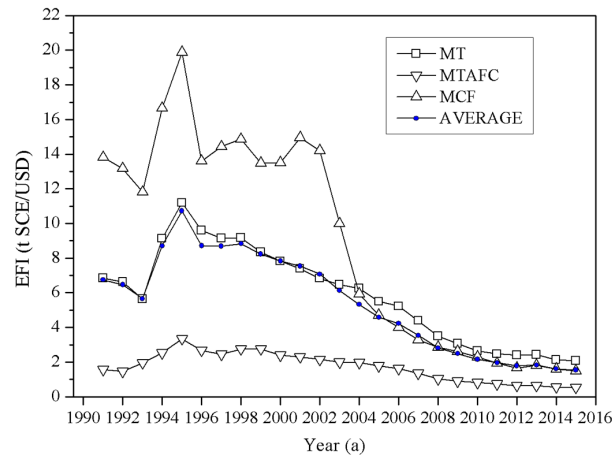


Figure 4. Energy footprint intensities (*EFPIs*) of China's textile industry and the sub-sectors.

The economy of China's textile industry increased largely from 1991 to 2015. From Figure 5 we can see that most years are in a relative decoupling state. Five years (2008, 2009, 2010, 2014, 2015) achieved absolute decoupling and three years (1994, 1997, 1998) were in the non-decoupling state. China's textile industry has witnessed a clear tendency toward decoupling, moving from non-decoupling to absolute decoupling.

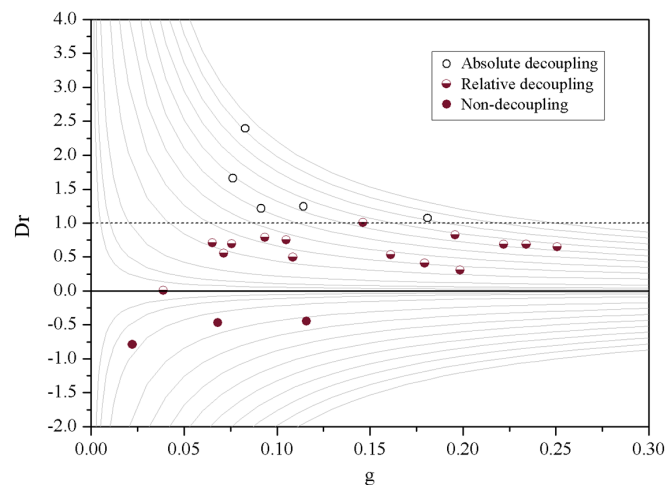


Figure 5. Decoupling of *EFP* from economic growth in China's textile industry.

Figure 6 shows the decomposition results of contribution values for the change of the *EFP* of China's textile industry. As can be seen from Figure 6, I_j and S_j are inhibiting factors in the growth of *EFP* while V_T and ES_{ij} are the promoting factors. I_j contributed significantly to reducing the *EFP*. The smaller it is, the more effectively it inhibits. The inhibiting effect on *EFP* increasing from S_j is not very significant compared with I_j . V_T is the most important factor that led to the increase of *EFP*. ES_{ij} had the least effect among the four effect factors. The promoting effect was larger than the inhibiting effect on *EFP* in most years during the study period. Therefore, the changes of *EFP* were positive in value and *EFP* increased.

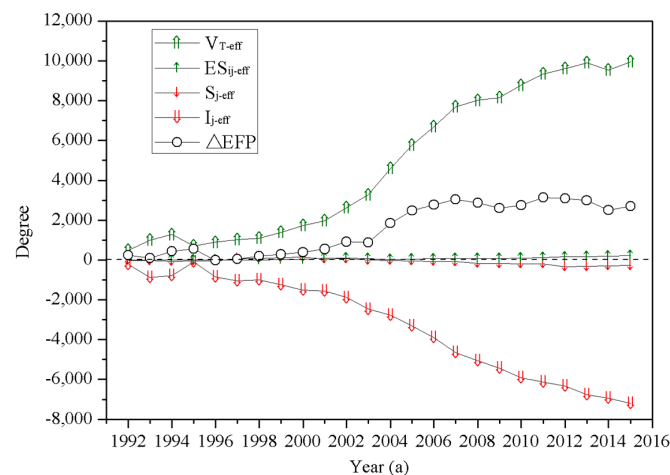


Figure 6. Contribution values of effect factors for the change of EFP.

4. Discussion

After nearly forty years of rapid development in industry scale and technologies since China's reform and open, the textile industry has been equipped with completed industrial production chains. As one of the most complicated manufacturing industries, the textile industry is characterized by specialized production and is comprised of fragmented and heterogeneous sectors that are dominated by small- and medium-sized enterprises. Spinning, weaving, dyeing, and finishing are typical operations that are intensive in terms of energy consumption. These procedures belong to the MT sector, as shown in Figure 2. Therefore, the EFP of MT was much larger than that of the other two sub-sectors.

Spinning. The term “spinning” can refer to the operations (e.g., melt-spinning, dry-spinning, and wet-spinning) of making synthetic fibers or the whole process (including opening, carding, combing/drawing, roving, spinning, and winding) of making yarn from different types of natural fibers. Generally, spinning is named as the activity of yarn manufacturing, and is classified as conventional (e.g., ring spinning) and unconventional (e.g., rotor, wrap, air-jet, and self-twist spinning). In spinning, the electricity is consumed in melting polymers, driving machines, air conditioning, and lighting, but the highest electricity consumption occurs in driving machines [31].

Weaving. At this stage, many kinds of yarns are used to produce woven fabrics by processes such as winding, warping, sizing, drawing in (weaving preparation), and weaving. In order to increase the woven fabric production, high-productivity shuttleless looms such as water jet looms and air jet looms have successfully been put into practice. Energy consumed in weaving mainly includes two types of energy: electrical and heat. Machines, air conditioning, lamps used for illumination, fans, and compressors consume electrical energy, while heat is consumed by processes such as sizing and sometimes by air conditioning [32]. Generally, heat energy is obtained from burning fossil fuels such as coal, diesel oil, fuel oil, and natural gas.

Dyeing and Finishing. Fibers, yarns, and fabrics can be dyed with a wide range of machines and technologies. Dyeing and finishing processes consist of many interwoven unit operations, and the processes generally go through repeated wet and dry operations. High temperature is always an essential condition in dyeing and finishing. Heat is the largely consumed energy in dyeing and finishing, and it is applied via steam or heat conduction oil coil in heating dye liquor, heat setting, drying, etc. Coal and natural gas are two conventional fuels used to heat water and conduction oil, and electrical energy is used in powering the dyeing and finishing machinery.

The energy efficiency of China's textile industry during the earlier developing period (1980–1995) was low. The industry scale increased rapidly, and large quantities of textile products were manufactured for exports with energy-intensive machines. Thus, both the TIOV of China's textile industry and energy consumption increased rapidly. EFP and China's textile industry economy did

not reach decoupling (i.e., non-decoupling). Besides, *EFPI* had a volatile trend, interchanging intervals of increase and decrease along this period.

China's textile industry experienced a recession from 1996 to 2000, which consequently restrained the energy consumption. There was a sharp decrease for *EFPI* in 1996. In 2001, China joined the World Trade Organization and became its 143th member. This highly affected the exports of textiles and apparel. The average annual increasing rate of *EFPI* was 8.5 percent from 2001 to 2007—the largest in the research period. Global financial crisis occurred in 2008 and led to a slight recession in China's textile industry from 2008 to 2010. The average annual decreasing rate of *EFPI* was 1.2 percent from 2007 to 2010. With the recovery of global demand and the promotion of the domestic consumption of clothing, the industrial production of textiles and clothing increased and resulted in *EFPI* increasing from 2011.

Chinese government has made great efforts in improving the energy efficiency of China's textile industry to reduce energy consumption. The goals of energy intensity decreases are specified in the “Five-Year Plan” of China's textile industry. For example, 15 percent per GDP decrease in the 10th Five-Year Plan (2001–2005), 20 percent per GDP decrease in the 12th Five-Year Plan (2011–2015), and 18 percent per GDP decrease in the 13th Five-Year Plan (2016–2020). Many policies and standards were also issued to restrict energy consumption in the manufacturing of fibers, textiles, and end-products (e.g., apparel, home textiles). For example, “Entry criteria on printing and dyeing industry (2010)”, “HJ/T 185-2006 Cleaner production standard-Textile industry (Dyeing and finishing of cotton)” and “HJ/T 429-2008 Cleaner production standard-Chemical fiber industry (Polyester fiber)”. Eliminating energy intensity production equipment and popularizing energy saving technologies in textile companies, such as energy recovery from waste hot water and steam, rapid enzymatic single-bath treatment (REST), and cold pad-batch process are meaningful to reduce the energy intensity.

Figure 7 shows the energy structure of China's textile industry. Coal and coke, electricity, heat, and petroleum products (e.g., kerosene, diesel oil, fuel oil) are the main contributors to energy consumption in China's textile industry. With the popularization of automated machines to offer better productivity and quality, the consumption of electricity increased largely from 1991 to 2015. However, thermal power that consumes coal and coal products is still the dominant source of electricity consumed in China's industry. For example, thermal power accounted for approximately 75 percent of China's total electric production in 2014 [33]. Though the direct consumption of coal and coal products decreased, China's textile industry still consumed large quantities of coal and coal products, as the indirect consumption increased rapidly. This also caused huge CO₂ emissions in China's textile industry [34].

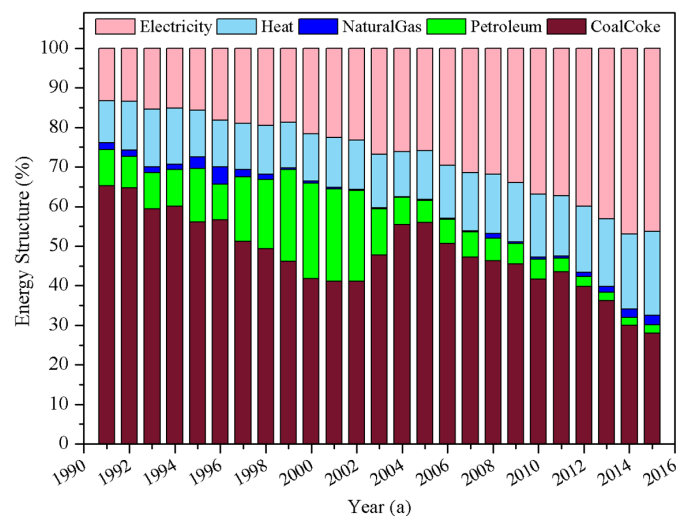


Figure 7. Energy structure of China's textile industry.

5. Conclusions

Energy consumption is a key factor that affects the sustainable development of China's textile industry. A detailed analysis of energy consumption in China's textile industry can provide essential information for the establishment of energy policies. This paper measured the *EEP* of China's textile industry from 1991 to 2015 and investigated the relationship between *EEP* and economic growth in the textile industry. Key factors that influence the *EEP* of China's textile industry were also quantitatively analyzed. The results showed that the *EEP* of China's textile industry increased more than one time from 1991 to 2015. The average annual increasing rate in the period of 1996–2007 was the largest. Industrial scale expansion is the main factor promoting the large increase of energy consumption in China's textile industry. The MT sector consumes most of the energy among the three sub-sectors, as many energy intensive procedures concentrate in this sector.

Decoupling analysis indicated that *EEP* and economic growth in China's textile industry were in a relative decoupling state for most years in the research period. The promoting effect of the factors was larger than the inhibiting effect on *EEP*, increasing in most years from 1991 to 2015. Increasing demands for textiles and clothing promote the industrial production of fibers, yarns, fabrics, and end products that consume larger quantities of energy. Energy consumption restriction policies and the popularization of energy saving technologies promote the decoupling of energy consumption from economic growth, diminishing the gap between promoting factors and inhibiting factors.

With the increasing demand on domestic and foreign markets, China's textile industry is expected to continue its rapid growth in the near future. Industrial scale will still promote the increase of *EEP*. Energy efficiency improvement is the core to reduce energy consumption. Technology upgrading is a necessary process to reduce the energy consumption. It will also improve the industrial productivity. Industrial structure optimization is another important mission for the government to reduce the *EEP* of China's textile industry. At present, the industry structure factor contributed little to the inhibition of *EEP*'s increasing trend. Policies and standards should be strengthened to reduce the proportion of the energy intensive sector and promote high value-added textile products manufacturing with less energy intensity.

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