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Pathway to Reduce Industrial Energy Intensity for Energy Conservation at Chinese provincial Level

Shengnan Zhao, Yang Yu, and Shenghui Cui

***Abstract*—**Using logarithmic mean Divisia decomposition technique, this paper analyzes the change in industrial energy intensity of Fujian Province in China, based on data sets of added value and energy consumption for 35 selected industrial sub-sectors from 1999 to 2009. The change in industrial energy intensity is decomposed into intensity effect and structure effect. Results show that the industrial energy intensity of Fujian Province has achieved a reduction of 51% over the past ten years. The structural change, a shift in the mix of industrial sub-sectors, made overwhelming contribution to the reduction. The impact of energy efficiency's improvement was relatively small. However, the aggregate industrial energy intensity was very sensitive to both the changes in energy intensity and in production share of energy-intensive sub-sectors, such as production and supply of electric power, steam and hot water. Pathway to reduce industrial energy intensity for energy conservation in Fujian Province is proposed in the end.

***Keywords*—**Decomposition analysis, energy intensity, Fujian Province, industry

I. Introduction

FUJIAN Province is located in the southeast coast of China and bordered by Zhejiang to the north, Jiangxi to the west, and Guangdong to the south, covering about 1.24 million km^2. In 2009, there was a population of 36.27 million people [1] with an urbanization rate of 51.39%; the gross domestic product (GDP) reached 122.36 billion Yuan and the proportions of primary, secondary and tertiary industry were 9.7, 49.1, and 41.2%, respectively. Fujian Province's rapid economic development has stimulated the fast growth of energy production and consumption. As shown in Fig. 1, the energy production has increased from 4.61 Mtce in 1978 to 29.47 Mtce in 2009, with an annual growth rate of 6.0%, while the energy consumption grew with a higher rate of 8.33%, resulting in the increasingly energy supply gap. The lack of energy supply has become a threat for local long-term development. To achieve sustainable development, the local government has no other choices but energy-saving practices. The industrial sector plays a dominant role in total energy consumption in Fujian Province [2], and reducing industrial energy intensity is crucial to the whole province's energy conservation. Therefore, it is imperative for decision-makers to know which factors lead to the historic change in industrial energy intensity and which sectors have the greatest contribution to the change.

A better understanding of the factors affecting energy intensity can be obtained through a decomposition analysis of factors. Many scholars have decomposed energy intensity into sectoral structural effects (i.e. sectoral structural shifting) and efficiency effects (i.e. measured by sectoral energy intensities at lower level) [3], [4]. China's industrial energy intensity declined between 1997 and 2002, and efficiency effects possibly contributed to a majority of the decline, while the contribution from structural effects was less [5]. Efficiency effects at the firm level had contributed to 47% of the industrial energy intensity decline during 1997-1999 in China [6]. The changes in industrial energy intensities of Thailand over a period of 20 years (1981-2000) were analyzed, and the results showed that in the period 1981-1986, both structural effect and intensity effect led to a reduction in energy intensity, but in the period 1986-2000, these two factors acted in opposite directions and thereby negating the effects [7]. The energy intensity trends in Lithuanian economy as a whole as well as in separate economic sectors were analyzed based on logarithmic mean Divisia decomposition technique, and the results confirmed the fact that until year 2009, the intensity effect had been the major driving force reducing the need for energy, whereas the activity effect was the one increasing the need for energy [8]. Although decomposition analysis has become a flourishing research area in energy at home and abroad, but fewer studies are reported on regional level compare with country level. Given the above context, this study mainly contributes to present a picture of the underlying determinants of the change in industrial energy intensity of Fujian Province between 1999 and 2009, with an attempt to improving energy policy making for local government in the future and provide practical reference in the literature.

S. Zhao is with Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021 China ; Xiamen Key Lab of Urban Metabolism, Xiamen 361021 China (e-mail: snzhao@ iue.ac.cn).

Y. Yu is with Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021 China ; Xiamen Key Lab of Urban Metabolism, Xiamen 361021 China (e-mail: yyu@ iue.ac.cn).

S. Cui is with Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021 China ; Xiamen Key Lab of Urban Metabolism, Xiamen 361021 China (corresponding author to provide phone: 86-592-6190957; fax: 86-592-6190977; e-mail: shcui@ iue.ac.cn).

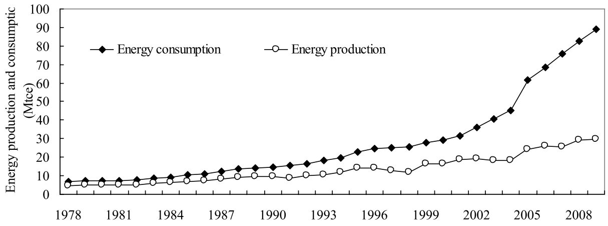

Fig. 1 Energy production and consumption in Fujian Province during 1978-2009

II. Decomposition Methods and Data

A. Methods

There are two broad categories of decomposition methodologies, namely structural decomposition analysis (SDA) and index decomposition analysis (IDA); reference [9] provided a full discussion of the advantages and disadvantages of each of these methodologies. Within the IDA group, there are still a number of different variant techniques, among which Divisia index method and Laspeyres index method are most often used by researchers [10]. The Divisia IDA is based on the concept of the Divisia index and includes the arithmetic mean Divisia index (AMDI) and the logarithmic mean Divisia index (LMDI). The Laspeyres IDA uses the concept of the Laspeyres index and encompasses basic Laspeyres index, Paasche index, Fisher ideal index, Shapley index and Marshall-Edgeworth index etc [11]. The selection of indexing method is arbitrary to a large extent, and there is little consensus as to which is the best method. Logarithmic mean Divisia index method (LMDI) is considered to be the preferred method, due to its solid theoretical foundation, adaptability, ease of use and result interpretation, along with other desirable properties [12]. We thus adopt the method in this study to analyze changes in industrial energy intensity of Fujian Province during the period of 1999-2009.

We assume that the industry is divided into n sub-sectors, and define the following terms:

i: the ith sub-sector (i=1, … ,n)

t: the tth year

E_t: total industrial energy consumption in year t

$E_{i,t}$: energy consumption of sub-sector i in year t

Y_t: total industrial production in year t

$Y_{i,t}$: production of sub-sector i in year t

$S_{i,t}$: production share of sub-sector i in total industry in year t ($=Y_{i,t}/Y_t$)

I_t: aggregate industrial energy intensity in year t ($=E_t/Y_t$)

$I_{i,t}$: energy intensity of sub-sector i in year t ($=E_{i,t}/Y_{i,t}$)

The aggregate industrial energy intensity can be specified as follows:

$$I = \frac{E}{Y} = \sum_i \frac{E_i}{Y} = \sum_i \frac{E_i}{Y_i} \times \frac{Y_i}{Y} = \sum_i I_i S_i \tag{1}$$

And the change in aggregate energy intensity between base year 0 and year t can be decomposed in the following format:

$$\Delta I_{tot} = I_t - I_0 = \Delta I_{\text{int}} + \Delta I_{\text{str}} \tag{2}$$

According to LMDI I approach [10], we have

$$\Delta I_{\text{int}} = \sum_i L(w_{i,t}, w_{i,0}) \ln(\frac{I_{i,t}}{I_{i,0}}) \tag{3}$$

$$\Delta I_{\text{str}} = \sum_i L(w_{i,t}, w_{i,0}) \ln(\frac{S_{i,t}}{S_{i,0}}) \tag{4}$$

Where, ΔI_{int} is intensity effect, expressing the impact of changes of energy intensities of industrial sub-sectors on the change of aggregate energy intensity from base year 0 to year t (i.e. $\Delta I_{tot.}$). ΔI_{str} is structural effect, representing the effect of a shift in the mix of industrial sub-sectors on ΔI_{tot}. And $L(w_{i,t}, w_{i,0})$ is the logarithmic weighting scheme, specified in the following:

$$L(w_{i,t}, w_{i,0}) = \frac{w_{i,t} - w_{i,0}}{\ln(w_{i,t} / w_{i,0})} \tag{5}$$

$$w_i = I_i \times S_i \tag{6}$$

B. Data

In this study, we primarily focus on the industrial enterprises above designated size (all state-owned industrial enterprises plus the non-state-owned industrial enterprises with annual sales revenue of over 5 million Yuan) for two reasons. First, these large-scale enterprises are dominant energy-consumers in industrial sector, and they accounted for about 84% of total energy consumption of industry in Fujian Province in 2009 [1]. The decline of energy intensity of these enterprises will probably become a breakthrough in reducing the aggregate industrial energy intensity. Second, the data at fine level of disaggregation are available for these enterprises.

We select 1999-2009 as our study period and use added value as the indicator of industrial production. The industrial sub-sector data on added value and energy consumption are collected from Fujian Statistical Yearbook 2010. Added values for each industrial sub-sector are converted to 1999 constant prices using ex-factory price index of associated industrial products. The total energy consumption of each sub-sector is the sum of the standard coal equivalents of raw coal, coke, gasoline, kerosene, diesel oil, fuel oil and electricity.

In Fujian Province, industrial sector has been disaggregated into 39 sub-sectors, which is roughly equivalent to the 2-digit standard industry classification (SIC) level. For this study, we have dropped the four sub-sectors of "Petroleum and natural gas mining", "Other mining industry", "Petroleum processing and coking", and ''Waste of resources and waste materials recycling industry'' because added value data for these sub-sectors are not officially released for some years. Such practice should not have significant impacts on final results due to minimal production shares of these sub-sectors in the whole industry. The 35 selected industrial sub-sectors are listed in Table 1.

TABLE I
INDUSTRIAL SUB-SECTORS INFORMATION IN FUJIAN PROVINCE

Code	Sub-sector name
A1	Coal mining and dressing
A2	Ferrous metals mining and dressing
A3	Nonferrous metals mining and dressing
A4	Nonmetal minerals mining and dressing
A5	Food processing
A6	Food production
A7	Beverage production
A8	Tobacco processing
A9	Textile industry
A10	Garments and other fiber products
A11	Leather, furs, down and related products
A12	Timber processing, bamboo, cane, palm fiber& straw products
A13	Furniture manufacturing
A14	Papermaking and paper products
A15	Printing and record medium reproduction
A16	Cultural, educational and sports articles
A17	Raw chemical materials and chemical products
A18	Medical and pharmaceutical products
A19	Chemical fiber
A20	Rubber products
A21	Plastic products
A22	Nonmetal mineral products
A23	Smelting and pressing of ferrous metal
A24	Smelting and pressing of nonferrous metal products
A25	Metal products
A26	Ordinary machinery
A27	Equipment for special purposes
A28	Transportation equipment
A29	Electronic equipment and machinery
A30	Electronic and telecommunications equipment
A31	Instrument, meter, cultural and office machinery
A32	Handicraft article and other manufacturing
A33	Production and supply of electric power, steam and hot water
A34	Production and supply of gas
A35	Production and supply of tap water

III. CHARACTERISTICS OF INDUSTRIAL ENERGY CONSUMPTION IN FUJIAN PROVINCE

In 1999, the industrial energy consumption in Fujian Province was 15.20 Mtce. This volume has increased to 53.43 Mtce in 2009, with an overall annual growth rate of 13.3% (see Fig. 2). Raw chemical materials and chemical products (A17), Nonmetal mineral products (A22), Smelting and pressing of ferrous metal products (A23), and Production and supply of electric power, steam and hot water (A33) are the largest sector consumers. They account for about 85% of the total energy consumption every year, but the production share of them declined from 26.4% in 1999 to 15.5% in 2009, indicating energy intensiveness.

Fig. 3 shows that the aggregate industrial energy intensity has dropped substantially over the period 1999-2009, falling from 2.34 tce/10,000 Yuan to 11.16 tce/10,000 Yuan. The intensity varied differently in different periods. The average annual decline rate was around 5% between 1999 and 2004, but exceeded 8% between 2005 and 2009.

There is wide disparity in terms of energy intensity of different sub-sectors because of the heterogeneous nature of the output (Fig. 4). Electronic and telecommunications equipment (A30) formed the lower bound of the energy intensity while Production and supply of electric power, steam and hot water (A33) in 2009 formed the upper limit. To give a sense of spread of energy intensity, Production and supply of electric power, steam and hot water's energy intensity was 400 times higher than that of Electronic and telecommunications equipment (A30) in 2009.

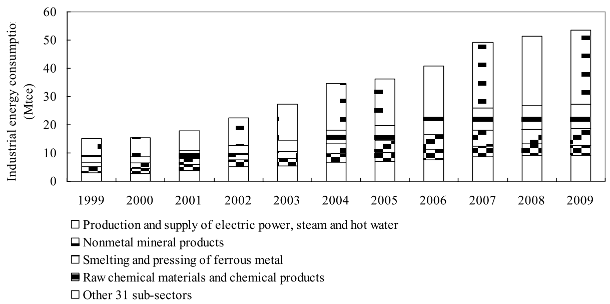

Fig. 2 Industrial energy consumption in Fujian Province

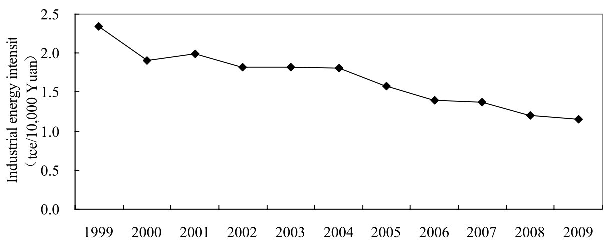

Fig. 3 Industrial energy intensity in Fujian Province from 1999 to 2009

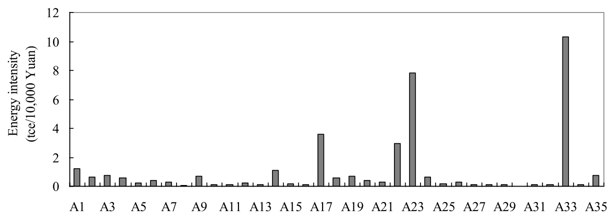

Fig. 4 Energy intensities of sub-sectors in Fujian Province in 2009

IV. RESULTS AND DISCUSSION

In this section, the decomposition analysis was carried out for two periods, namely 1999-2004 and 2004-2009, in order to ascertain what factors have the greatest impact on the change in Fujian Province's industrial energy intensity.

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A. The Roles of Explanatory Factors

During the first period 1999-2004, there was a smaller change in the aggregate energy intensity of about 23%. Fig. 5 clearly shows that the structural effect played the dominant role in decreasing aggregate energy intensity. The structural change, a shift in the mix of industrial sub-sectors, brought down the intensity to 77.8% of that prevailed in 1999, while the energy intensity effect led to a minor decrease in energy intensity by 0.9 % of 1999 level.

During the second period 2004-2009, there was a larger change in the aggregate energy of about 36%. Fig. 5 shows that the energy intensity effect acted more positively in reducing the aggregate energy intensity than in the last period and thus reduced the intensity to 84% of that prevailed in 2004. But even so, the role of structural change was still larger than that of the intensity improvement.

During the overall period 1999-2009, the aggregate energy intensity declined by 51% of 1999 level. The structural effect explained a larger share of the change of the aggregate energy than the intensity effect. This show that Fujian Province's polices on structure adjustment has acted effectively in reducing industrial energy intensity over the past ten years. This result is consistent with the study in [6] which found that with finer sectoral disaggregation, the structural effect became very significant over these few years.

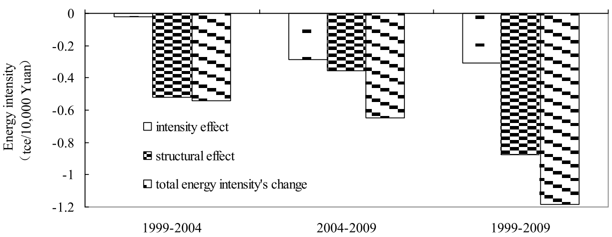

Fig. 5 Decomposition of factors affecting the aggregate industrial energy intensity in Fujian Province

B. Driving Forces for the Changes of Explanatory Factors

1. Intensity Effect

During the period 1999-2004, the intensity effect cut down the aggregate energy intensity by 0.9 % of 1999 level. This gain was obtained by the efforts jointly made by the different sub-sectors. We compared the contributions to the intensity effect across the 35 sub-sectors. The results showed that the performances of Nonmetal mineral products (A22), Raw chemical materials and chemical products (A17), and Production and supply of electric power, steam and hot water (A33) were outstanding (see Fig. 6 (a)). The energy intensities of Nonmetal mineral products (A22) and Raw chemical materials and chemical products (A17) respectively declined from 6.20 and 7.77 tce/10,000 Yuan in 1999 to 3.6 and 4.68 tce/10,000 in 2004, which made a largely positive contribution of 1197% to the intensity effect. On the other hand, the energy intensity of Production and supply of electric power, steam and hot water (A33) increased from 6.75 tce/10,000 Yuan in 1999 to 10.08 tce/10,000 Yuan in 2004, leading to a considerably negative contribution of 1607% to the intensity effect.

During the period 2004-2009, more sub-sectors made positive contribution to the intensity effect than last period (see Fig. 6 (b)). Among these, the performances of Papermaking and paper products (A14) and Nonmetal mineral products (A22) were outstanding. The energy intensities of these two sub-sectors respectively declined from 3 and 3.6 tce/10,000 Yuan in 2004 to 1.0 and 2.97 tce/10,000 Yuan in 2009, resulting in a positive contribution of 31% to the intensity effect.

During the overall period 1999-2009, the intensity effect brought down the aggregate energy intensity by 13.2 % of 1999 level. Nonmetal mineral products (A22), Raw chemical materials and chemical products (A17) played a largely positive role and Production and supply of electric power, steam and hot water (A33) acted negatively significantly (see Fig. 6 (c)).

Above analysis reflects that the aggregate industrial energy intensity in Fujian Province was very sensitive to the changes of energy intensities of energy-intensive sub-sectors, such as Nonmetal mineral products, Raw chemical materials and chemical products, as well as Production and supply of electric power, steam and hot water. In other words, the improvement of energy efficiency of energy-intensive sub-sectors is critical to the decline of the aggregate energy intensity.

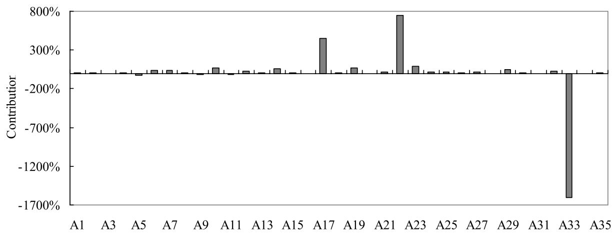

Fig. 6 (a) Subsectoral contribution to the intensity effect from 1999 to 2004 in Fujian Province

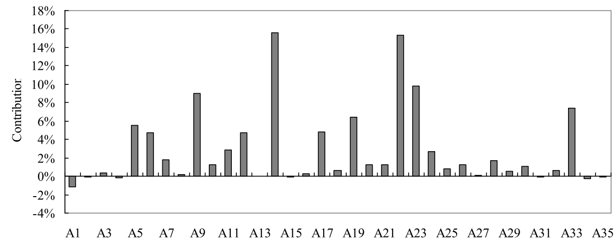

Fig. 6 (b) Subsectoral contribution to the intensity effect from 2004 to 2009 in Fujian Province

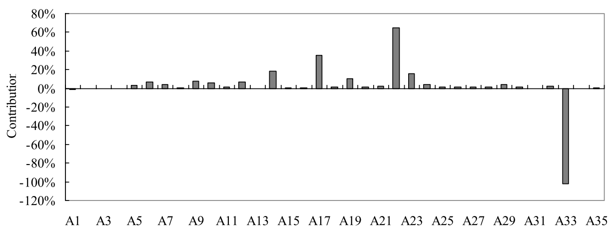

Fig. 6 (c) Subsectoral contribution to the intensity effect from 1999 to 2009 in Fujian Province

2. Structure Effect

During the period 1999-2004, the structural effect reduced the aggregate energy intensity by 22.1% of 1999 level. Different sub-sectors contributed differently to this gain. Fig. 7 (a) shows that the performances of the following three sub-sectors were outstanding: Production and supply of electric power, steam and hot water (A33), Smelting and pressing of ferrous metal (A23), and Raw chemical materials and chemical products (A17). The production shares of these three sub-sectors respectively declined from 13.52, 2.87 and 4.25% in 1999 to 8.53, 1.91 and 3.51% in 2004, resulting in a total positive contribution of 94.2% to the structural effect.

During the second period, the production shares of the above three sub-sectors continued to reduce to different extent, and together with Nonmetal mineral products (A22) , they were responsible for 109% of the structural effect (see Fig. 7 (b)).

Over the overall period 1999-2009, the structural effect decreased the aggregate energy intensity by 37.4 % of 1999 level. The largest contributors were Production and supply of electric power, steam and hot water (A33), Raw chemical materials and chemical products (A17), and Smelting and pressing of ferrous metal (A23) (see Fig. 7 (c)).

It can be concluded that the aggregate industrial energy intensity in Fujian Province was very sensitive to the changes in production shares of energy-intensive sectors. In other words, one of the most effective pathways to reduce aggregate industrial energy intensity is properly controlling the development of energy-intensive sub-sectors.

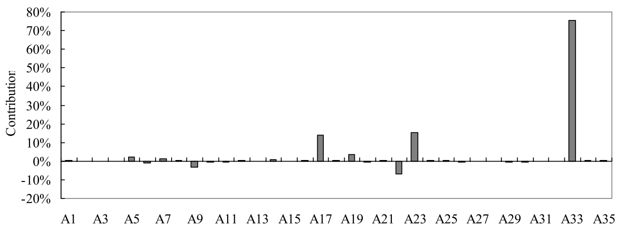

Fig. 7 (a) Subsectoral contribution to the structural effect from 1999 to 2004 in Fujian Province

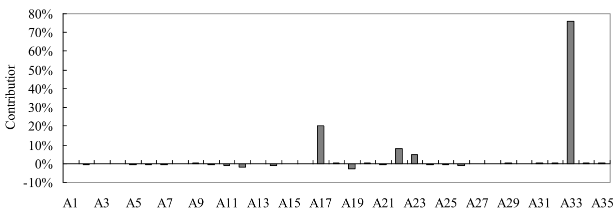

Fig. 7 (b) Subsectoral contribution to the structural effect from 2004 to 2009 in Fujian Province

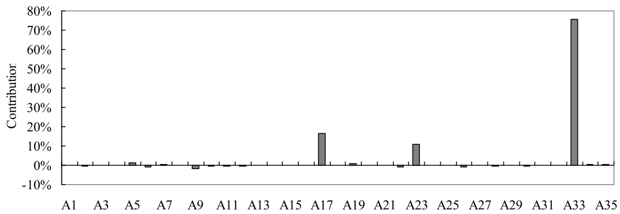

Fig. 7 (c) Subsectoral contribution to the structural effect from 1999 to 2009 in Fujian Province

V. Conclusions

This study examined Fujian Province's industrial energy intensity during 1999-2009 using the LMDI method. We identified the key factors that influence Fujian Province's industrial energy intensity. We found that the industrial energy consumption has increased from 15.20 Mtce in 1999 to 53.43Mtce in 2009, representing an annual average growth of 13.3%. Raw chemical materials and chemical products (A17), Nonmetal mineral products (A22), Smelting and pressing of ferrous metal products (A23), as well as Production and supply of electric power, steam and hot water (A33) are the most intensive sectors, and together account for about 85% of the total energy consumption annually.

Industrial energy intensity has declined from 2.34 tce/10,000 Yuan in 1999 to 1.16 tce/10,000 Yuan in 2009. Decomposition results show that this reduction was more attributed to the industrial structure adjustment. The role of energy efficiency improvement in sub-sectors was larger in the second period (2004-2009) than that in the first period (1999-2004).

The results also showed that the aggregate energy intensity was very sensitive to both the changes of energy intensities and the changes of production shares in energy-intensive sub-sectors, such as Production and supply of electric power, steam and hot water, Nonmetal mineral products, Raw chemical materials and chemical products, as well as Smelting and pressing of ferrous metal products.

Pathway to reduce industrial energy intensity for energy conservation in Fujian Province could be proposed: (1) give greater emphasis on energy-intensive sub-sectors, for example, Production and supply of electric power, steam and hot water, Nonmetal mineral products, Raw chemical materials and chemical products, as well as Smelting and pressing of ferrous metal products should be among the top priorities for introducing advanced technologies, updating the production process and enhancing energy efficiency and driving their energy intensities close to the international advanced level; (2) deepen structural adjustment across sub-sectors, such as speed up the development of Electronic and telecommunications equipment which is characterized by low energy-consumption and high added-value.

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