How Did the Changes in Industrial and Energy Structure Influence Energy Consumption in Shandong, China?

Sheng-Wen Tseng and Yen-Yu Chen

Abstract—**The Gross Regional Product (GRP) of Shandong ranks third in China, but its energy and coal consumption rank first. However, in the past studies, no effort was made to analyze the influence of Shandong energy conservation and emission reduction policies on energy consumption changes. To make up for this gap, the revised divisia index and the energy consumption structure methods were used in this study to analyze the driving force of changes in energy consumption in Shandong from 2005 to 2016. The results of this research show that: Firstly, the control of energy-intensive industries and strong energy conservation policies had become the main driving forces for energy density reduction. Secondly, the energy structure optimization policies only increased the proportion of hydro, nuclear and new energy production to replace a proportion of oil, but could not effectively reduce the consumption and proportion of coal. The continuous increase in coal consumption offset the energy conservation effect by key industries during the Twelfth Five-Year Plan period. It is clear that a reduction in the amount of coal used and an increase in the proportion of hydro, nuclear and new energy (especially in the industrial sector) is at the core of the energy problems in Shandong. Policy recommendations are proposed that are based on the findings of this study.**

Index Terms—**Industrial structure, energy conservation, energy consumption, Shandong, China.**

I. Introduction

China ranks first in CO_2 emission in the world [1]. To take responsibility and respond to global climate change, the Chinese government proposed Intended National Determined Contributions (INDC) for 2030 at the Paris 2015 United Nations Climate Change Conference. The 2030 energy conservation and emission reduction targets would include a reduction of CO_2 emissions per unit of GDP by 60-65% of the 2005 levels, and non-fossil energy would account for 20% of primary energy consumption [2]. The core issues of carbon reduction are total energy consumption and GDP unit energy use (that is, energy intensity). Therefore, the Chinese government has established a decomposition mechanism to assign an energy conservation objective to each province through the allocation of policy indicators in order to effectively reduce energy consumption and energy intensity in every province [3].

However, in the developed provinces of eastern China, rapid economic growth means that energy demand continues to increase, and the pressure on the allocated energy conservation objective is greater. Shandong Province is an example, the GRP ranks third in China (after Guangdong and Jiangsu), but energy consumption and coal consumption in the province ranks first. This shows energy use efficiency in the province is very low [4].

Interestingly, according to the Shandong Province Eleventh, Twelfth and Thirteenth Five-Year Plans, the energy density has not only decreased, but has also reached the policy objective in the case of significant growth in energy consumption. Therefore, the research question for this study would be: How can Shandong Province effectively reduce energy density in the case of energy consumption growth and what would be the main driving force behind such a density reduction?

In the remaining sections of the paper, we first review previous literature on energy consumption in various provinces and regions of China. We then review energy conservation and emission reduction policy of Shandong province between 2005 and 2018. We subsequently provide details on methodology and data processing. Section V presents the analysis of the changes of energy intensity, energy efficiency index and energy consumption structure and energy conservation and amount of energy conservation of Shandong Province. Finally, Section VI concludes our findings and policy implications.

II. Literature Review

The need to allocate quotas to the different provinces in China to meet the country's energy conservation and emission reduction objectives has resulted in many studies being made about the energy consumption in various provinces. The main targets of existing studies include two categories, the first being the developed eastern provinces which have energy shortages. These include Zhejiang [5], Jiangsu [6], Guangdong [7]-[9]), Shanghai [10], [11] and Shanxi [12]. The second category includes Xinjiang [13], the Municipality of Chongqing [14], and Yunnan [15] located in the western region.

From the research theme point of view, the existing research can be divided into the following three categories: (1) analysis of factors affecting CO_2 or air pollution emissions, (2) the verification of factors affecting energy consumption and energy efficiency changes, and (3) the response strategy of local governments to the central government energy policy. Firstly, in many of the papers the factors that influenced CO_2 emission and air pollution were discussed and it was pointed

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out that less energy density would result in less CO_2 emission and air pollution [6]-[9], [11], [13]-[15]. Others pointed out that optimizing an energy mix (such as developing new energy) could effectively reduce CO_2 emission [7], [11].

Secondly, a few of the analyses verified the variable factors that affect energy consumption and energy efficiency. Jiang *et al*. [5], in a study of Zhejiang, pointed out that industrial structure optimization (especially with an increase in the proportion of tertiary industry) can inhibit the growth of energy consumption. Interestingly, urbanization can also help reducing energy consumption and is more effective than the effect of industrial structure [5]. Song *et al*. [11] pointed out, in their analysis of the transportation sector in Shanghai, that "the energy consumption per unit conservation traffic volume had an upward trend, whereas the energy consumption per unit output value trended to decline" [11].

Finally, there were several discussions of how local governments respond to the central government's energy conservation policy. Kostka and Hobbs [12] analyzed the response strategies of the Shanxi provincial government to the central government's energy efficiency objectives during the Eleventh Five-Year Plan period. They pointed out that local government officials had achieved these efficiency objectives by bundling them with the interests of significant political influence groups [12].

However, existing studies still have the following research gaps:

1) The growth of GRP and energy consumption in Shandong is high, but means by which the energy density can be significantly decreased have not been studied.
2) Most provincial level energy consumption research focuses on CO_2 emissions issues, and the published work on the factors which influence energy efficiency does not include analyses of those factors affecting energy density and industrial structure.
3) So far, published work involving analysis of the factors that influence energy consumption only address influences that affect the overall industry, no account being taken of the effects of overall industry plus the associated individual sub-industries.

There is clear evidence to support the statement in (1) above, in that Shandong Province has actively implemented many measures of industrial structure adjustments and energy structure optimization during the Eleventh Five-Year Plan period (2006 - 2010). Therefore, we hypothesize that the changes in energy consumption are mainly due to industrial and energy structure factors. To fill these research gaps, the revised divisia index [16], [17] and the energy consumption structure methods will be used in this study. This approach makes it possible to simultaneously analyze the effects of industrial structure and energy density, and analyze the driving force behind the changes. This was done using data from the 2005 - 2016 (the Eleventh Five-Year Plan and Twelfth Five-Year Plan periods) in Shandong. In addition, because previous studies did not take the factors influencing overall and individual sub-sector energy conservation effects into account, the overall industry in Shandong was broken down into six sectors: primary, industry, construction, transportation, storage, post & telecommunications services, wholesale, retail trade, accommodation & catering, and others.

III. Energy Conservation and Emission Reduction Policy of Shandong Province

Restraining the growth of energy consumption is difficult and the Shandong Provincial Government has proposed various policies for energy conservation and emission reduction since the Eleventh Five-Year Plan period (2006 - 2010). In the "Shandong Province Eleventh Five-Year Plan" promulgated in 2006, measures were introduced that included adjusting industrial structure, strengthening energy construction, optimizing energy consumption structure, setting energy conservation objectives, and encouraging the development of new energy industries to achieve a reduction of unit energy use (energy intensity) by 22% [4]. In the same year, the Provincial Government also announced the "Shandong Province Eleventh Five-Year Plan for Environmental Protection", and further established specific regulations on energy conservation and emission reduction, pollution prevention, environmental monitoring and law enforcement systems [18] (see Table I).

In 2007, two extra measures were introduced, "Opinions of Shandong Province on Further Strengthening Energy Conservation and Emission Reduction" and "The Shandong Province Comprehensive Implementation Program for Energy Conservation and Emission Reduction", to clarify the regulations for specific measures of industrial restructuring, energy conservation and emission reduction objectives, as well as energy conservation and emission reduction management for individual industries [19], [20]).

In 2009 the "Regulations of Shandong Province for Energy Conservation" were enacted which not only stipulated "Giving First Priority to Energy Conservation in Energy Development Strategy" (Article 3), but also included industrial, construction, transportation and public institutions as key energy conservation industries (Article 7) [21]). In addition, the National Development and Reform Commission also approved the "Development Plan for the High-efficiency Ecological Economic Zone of the Yellow River Delta" proposed by the Provincial Government in the same year. In the coastal areas of the Yellow River estuary in Shandong Province, the "Plan" has established measures to reduce the objective of energy consumption per unit of GDP, as well as the promotion of optimization of energy structure, improvement in the energy efficiency and active use of new energy [22].

In response to the central government's environmental policy, the Shandong Provincial Government implemented three major policy tools including industrial restructuring, energy structure optimization (especially the development of new energy industries) and energy consumption industry regulation (especially the improvement of energy efficiency) during the Eleventh Five-Year Plan period, to achieve the energy conservation and emission reduction objectives

required by the central government. It is worth mentioning that the excellent results of energy conservation and emission reduction during the Eleventh Five-Year Plan period (2006 - 2010), resulted in the Shandong Province receiving a commendation from the State Council in September, 2011 [23].

In 2011, the National Development and Reform Commission formulated a "Development Plan for the Shandong Peninsula Blue Economic Zone" that proposed objectives and specific measures for development of the Shandong Peninsula Blue Economic Zone in 2011 - 2020. In the Energy Construction Section of the "Plan", the "Acceleration of Clean Energy Development, Optimization of Energy Structure, and Improvement of Utilization Efficiency to build a Safe and Stable Energy Supply System" was specifically proposed [24]. In March of the same year, in the "Shandong Province Twelfth Five-Year Plan", it was proposed that energy conservation, emission reduction and non-fossil energy shall account for the primary energy consumption objective by 2015. For the optimization of the energy structure, the plan proposed a policy of focusing on the development of renewable energy sources (solar, wind, nuclear, geothermal, and biomass energies) and reducing the proportion of coal-based thermal power. In another aspect, the "Plan" proposed the policies of adjusting the industrial structure, increasing the proportion of service industry and improving renewable energy consumption in an attempt to promote emission reduction through an adjustment of industry and energy structure [25].

Under the guidance of the central government's energy conservation and emission reduction policy and the "Shandong Province Twelfth Five-Year Plan" [26], the Shandong Provincial Government formulated the "Shandong Province Twelfth Five-Year Plan for Energy Conservation Planning" in 2011 - 2012 [25], the "Comprehensive Implementation Program of Shandong Province Twelfth Five-Year Plan for Energy Conservation and Emission Reduction" [27], the "Implementation Program of Shandong Province One Thousand Enterprises for Energy Conservation and Carbon Reduction Actions" [28], the "Shandong Province Twelfth Five-Year Plan for Environmental Protection" [29] and the "Implementation Program of Shandong Province Twelfth Five-Year Plan for Controlling Greenhouse Gas Emissions" [30]). For these, the Shandong Provincial Government proposed a series of objectives and measures, including (1) a 2015 energy conservation target of 0.85 tce/10^4 RMB (17% lower than that in 2010), (2) a greenhouse gas emission reduction objective, (3) the promotion of energy conservation and emission reduction by industrial restructuring, (4) the 661 Energy Conservation Action Plan, (5) a program that promotes energy conservation and carbon reduction action for one thousand key energy consumption enterprises, and (6) the development of new energy industries. The Shandong Provincial Government has also included industries such as construction, transportation, public institutions, agriculture, as well as other commercial and civilian industries as key areas for energy conservation. Improvements in energy efficiency and the reduction of greenhouse gas and other polluting emissions from these industries has already started [25], [27]-[30].

To reduce greenhouse gas emissions and improve environmental air quality, the Shandong Provincial Government started implementing three phases of "Shandong Province 2013 - 2020 Atmosphere Pollution Prevention and Control Planning" in 2013. The "Plan" includes six policy tools: (1) Active adjustment of the energy structure, (2) Vigorous adjustment of the industrial structure, (3) Deepening of the pollution control of key industries, (4) Strengthening the comprehensive improvement of dust emission, and (5) Strengthening the reduction and control of motor vehicle emissions, and (6) Strengthening the construction of green ecological barriers and restoring the damaged ecological environment [31]-[33].

During the Twelfth Five-Year Plan period (2011 - 2015), the implementation of three major policy tools, industrial restructuring, energy structure optimization (especially the development of new energy industries) and key industry controls, was continued. This was specifically for the improvement of energy efficiency, reduction of greenhouse gas emission, reduction of pollutant emission and the ecological compensation system. However, the proportion of non-petrochemical energy accounted for only 2.67% of energy consumption, and did not achieve the planned objective of 3% [34]. Therefore, the energy conservation and emission reduction results for the Twelfth Five-Year Plan period were only assessed as "Completed Grade" by the National Development and Reform Commission of State Council in December 2016, unlike those in 2011 which had received wide commendation [35].

In 2016, Shandong Province ranked first in China in terms of coal consumption, as well as the emission of sulphur dioxide, nitrogen oxides, and carbon dioxide in 2015 [36]. The central government was therefore particularly strict setting the "Shandong Province Ecological Environmental Indicators" during the Thirteenth Five-Year Plan period. The Shandong Provincial Government set fourteen indicators to improve the quality of resources and the environment, and introduced six policy tools including industrial restructuring, construction of development priority zones, the development of a low-carbon ecological economy, strengthening of key pollution prevention and control, and system repair and restoration to protect and improve the ecological environment [34]. In the same year the "Shandong Province Regulations on Atmospheric Pollution Prevention and Control" were formulated to prevent pollution of the atmosphere and protect and improve the atmospheric environment. The "Regulations" focus on source management, including the transformation of economic development methods, adjustment of energy and industrial structure, the promotion of a loop economy and clean production, improvement of the greening rate and forest coverage, and implementation of five methods of green transportation and green building to reduce the production and emission of atmospheric pollutants [37].

In response to the pressure anticipated from energy and

the environment over the next 15 years, the Shandong Provincial Government proposed the 2016 - 2030 "Shandong Province Energy Medium to Long Term Development Planning" in 2016. In the "Plan", the Shandong Provincial Government has formulated the 2020 and 2030 policy objectives on five levels, total energy consumption/production, energy structure, energy efficiency, ecology, and people's livelihood, and proposed many action plans, including adjustment of energy consumption structure, optimization of the energy development layout, optimization and adjustment of industrial structure, and promotion of key areas of energy conservation, etc. [36].

In 2017, the "Shandong Province Thirteenth Five-Year Plan for Ecological Environment Protection" and the "Shandong Province Work Program for Low-carbon Development (2017-2020)" [38], [39] were formulated in response to the central government's environmental policy indicators for the period 2016 to 2020. The Shandong Provincial Government also proposed eight major types of project. These included atmosphere pollution prevention and control, comprehensive watershed management, soil pollution prevention and control, rural environmental protection, total emission reduction, ecological protection and restoration, environmental safety prevention and control, as well as projects for competence and team building. All these projects will help improve pollution prevention and safety control of water, air, and soil [38]. Four policy tools were also formulated for the "Shandong Province Work Program for Low-carbon Development (2017-2020)", these included (1) Multi-path Carbon Reduction, (2) High-carbon Industry Transformation, (3) Five Major Action Plans, and (4) Improving the Protection Mechanism. These tools will help to achieve the carbon reduction objectives set for Shandong Province by the central government [39].

In 2018, under the guidance of new central government policy "Opinions of Comprehensively Strengthening the Ecological Environmental Protection and Resolutely Fighting the Battle against Pollution," and "Three-year Action Plan to Win the Blue Sky Defence War", the Shandong Provincial Government proposed "Shandong Province Wins the Blue Sky Defence War Program and the 2013 - 2020 Atmosphere Pollution Prevention and Control Planning Phase 3 (2018 - 2020)" [33]. In this policy, the Shandong Provincial Government proposed three tasks: (1) optimizing structure and layout, (2) strengthening comprehensive pollution prevention and control, and (3) improving the atmospheric environmental management system, to achieve a significant reduction of atmospheric pollutants and greenhouse gas emission within three years [33]. Also in 2018, the Provincial Government established the "Shandong Province New Energy Industry Development Planning (2018-2028)" to stimulate new kinetic energy development (including new energy vehicles, nuclear power, smart grids and energy storage, heat pumps, solar energy, wind energy, biomass energy, hydrogen energy, flammable ice, ocean energy), to achieve a 9% and 15% proportion of new energy consumption in 2022 and 2028 [40].

In summary, in response to the central government's environmental policy indicators and to solve the energy conservation and emission reduction pressures, Shandong Province has formulated a series of energy, industry and environmental policies since 2006. The main core of these policies is the adjustment of industrial structure, the optimization of energy structure (especially the development of new energy), and the source management of pollution emissions in key areas.

TABLE I: ENERGY CONSERVATION AND EMISSION REDUCTION POLICY IN SHANDONG

Year	Policy
2006	The Eleventh Five-Year Plan for the National Economic and Social Development of Shandong Province
2006	Shandong Province Eleventh Five-Year Plan for Environmental Protection
2007	Opinions of Shandong Province on Further Strengthening Energy Conservation and Emission Reduction
2007	Shandong Province Comprehensive Implementation Program for Energy Conservation and Emission Reduction
2009	Regulations of Shandong Province for Energy Conservation
2009	Development Plan for the High-efficiency Ecological Economic Zone of the Yellow River Delta
2011	Development Plan for the Shandong Peninsula Blue Economic Zone
2011	The Twelfth Five-Year Plan for the National Economic and Social Development of Shandong Province
2011	Shandong Province Twelfth Five-Year Plan for Energy Conservation Planning
2011	Comprehensive Implementation Program of Shandong Province Twelfth Five-Year Plan for Energy Conservation and Emission Reduction
2012	Implementation of the Shandong Province One Thousand Enterprises for Energy Conservation and Carbon Reduction Program Action
2012	Shandong Province Twelfth Five-Year Plan for Environmental Protection
2012	Implementation of the Shandong Province Twelfth Five-Year Plan for Controlling Greenhouse Gas Emissions Program
2013	Shandong Province 2013 - 2020 Atmosphere Pollution Prevention and Control Planning Phase 1 Action Plan (2013 - 2015)
2016	The Thirteenth Five-Year Plan for the National Economic and Social Development of Shandong Province
2016	Shandong Province Regulations for Atmosphere Pollution Prevention and Control
2016	Shandong Province 2013 - 2020 Atmosphere Pollution Prevention and Control Planning Phase 2 Action Plan (2016 - 2018)
2016	Shandong Province Energy Medium to Long Term Development Planning
2017	Shandong Province Thirteenth Five-Year Planning for Ecological Environment Protection
2017	Shandong Province Work Program for Low-carbon Development (2017 - 2020)
2018	Shandong Province Wins the Blue Sky Defence War Program and the 2013 - 2020 Atmosphere Pollution Prevention and Control Planning Phase 3 Action Plan (2018 - 2020)
2018	Shandong Province New Energy Industry Development Planning (2018 - 2028)

IV. METHODOLOGY

A. Decomposition Analysis Method

The energy intensity for Gross Regional Product (GRP) can be expressed as,

$$EI_t^{GRP} = E_t^{tot}/Q_t \quad (1)$$

where EI_t^{GRP} represents the energy intensity for GRP in year t; E_t^{tot} represents the total energy consumption of overall

industry in year *t*; and Q_t represents the real GRP value of overall industry in year *t*.

The energy intensity for primary, industry, construction, transportation, storage, post & telecommunications services, wholesale, retail trade, accommodation & catering, and other sectors. can be expressed as,

$$EI_t = E_{it}/Q_{it} \quad (2)$$

where EI_t represents the energy intensity in year *t*; E_{it} represents the energy consumption of the sub-industrial sector *i* in year *t*; and Q_{it} represents the real industrial value of the sub-industrial sector *i* in year *t*.

The industrial share of GRP is shown in (3).

$$Q_{it}/Q_t \quad (3)$$

where Q_{it} represents the regional product for each sub-industrial sector; and Q_t represents the real GRP value of overall industry in year *t*.

The industrial share of energy consumption is shown in (4).

$$E_{it}/E_t^{tot} \quad (4)$$

where E_{it} represents the energy consumption for each sub-industrial sector; E_t^{tot} represents the total energy consumption of overall industry in year *t*.

Based on the expanded Ang and Choi [16] and Ang [17], the change in total energy intensity is as,

$$DTEI = TEI_t / TEI_0 = EIE * ISE \quad (5)$$

where $DTEI$ represents the change in total energy intensity of two period; TEI_t represents the total energy intensity in year *t*; TEI_0 represents the total energy intensity in base year 0; EIE represents the energy intensity effect; ISE represents the industrial structure effect.

$$EIE = \exp\left[\sum_i w_i * \ln(EIE_{it}/EIE_{i0})\right] \quad (6)$$

$$ISE = \exp\left[\sum_i w_i * \ln(ISE_{it}/ISE_{i0})\right] \quad (7)$$

where w_i represents normalized weight function; EIE_{it} represents the energy intensity of the sub-industry i in year *t*; EIE_{i0} represents the energy intensity of the sub-industry *i* in base year 0; ISE_{it} denotes the industrial structure of the sub-industry *i* in year *t*; ISE_{i0} refers to the industrial structure of the sub-industry i in base year 0.

The normalized weight function w_i was defined by Ang and Choi [16]. The index decomposition model of the energy demand behavior for each sub-industry can be expressed as,

$$E_{it} = \frac{E_{it}}{Q_{it}} * Q_{it} = EIE_{it} * Q_{it} \quad (8)$$

By defining $DTEI = E_{it}/E_{i0} = EIE * ISE$ based on Ang and Choi [16], the energy intensity effect of the sub-industry *i* can be expressed in (7), and the industrial structure effect of the sub-industry *i* can be expressed as in (8).

$$EIE = EIE_{it}/EIE_{i0} \quad (9)$$

$$ISE = Q_{it}/Q_{i0} \quad (10)$$

where Y^{i0} denotes the industrial value of the sub-industry *i* in base year *0*.

The energy conservation rate of each sub-industrial sector in year *t* can be shown in (11). The amount of energy conservation of each sub-industrial sector in year *t* is shown in (12).

$$EIE_{i(t-1)} - EIE_{i(t)} \quad (11)$$

$$E_{it} * (EIE_{i(t-1)} - EIE_{i(t)}) \quad (12)$$

B. Data Sources and Processing

The data used in this paper were collected from various issues of the Shandong Statistical Yearbook (2006 - 2017) [41] and the China Energy Statistical Yearbook (2006 - 2017) [42]. The GRP data and industrial value was measured at 10^8 RMB Yuan at constant 2005 prices. The energy consumption data was converted into standard coal consumption at 10^4 tce.

The types of energy consumption in Shandong were aggregated into three groups: coal, oil (including natural gas) and hydro, nuclear and new energy. The Shandong economy was aggregated into six industrial groups: primary sector, industry sector, construction sector, transportation, storage, post & telecommunications services sector, wholesale, retail trade, accommodation & catering sector and others sector.

V. Results

A. Changes of Energy Intensity in Shandong

Fig. 1 shows the trend of energy density in Shandong from 2005 to 2016. The energy density of the overall industry in Shandong showed a downward trend that decreased significantly from 1.32 (tce/10^4RMB) in 2005 to 0.58 (tce/10^4RMB) in 2016, with a difference of -0.74 (tce/10^4RMB). During the Eleventh Five-Year Plan period (2006 - 2010), it decreased significantly, from 1.23 (tce/10^4RMB) in 2001 to 0.87 (tce/10^4RMB) in 2005, with a difference of -0.36 (tce/10^4RMB). During the Twelfth Five-Year Plan period (2011 - 2015), the decrease was from 0.69 (tce/10^4RMB) in 2001 to 0.58 (tce/10^4RMB) in 2005, with a difference of -0.11 (tce/10^4RMB) (see Fig. 1). During the Eleventh Five-Year Plan period (2006 - 2010), a series of energy conservation and emission reduction policies in Shandong Province had clearly resulted in an effective reduction in energy density. However, during the Twelfth Five-Year Plan period, the effects of emission reduction policies were limited and the decline in energy density slowed down (see Fig. 1).

Fig. 1 also shows that the energy density of industry, transportation, storage, post & telecommunications services and others sectors was higher than that of the overall industry, and the downward trend of the industry sector was consistent. In addition, the energy density of others sector was the highest among all sub-industries between 2007 and 2010. The question of which sub-industry was the main factor affecting overall energy density, the proportion of industrial structure, and the proportion of energy consumption, needs

further exploration.

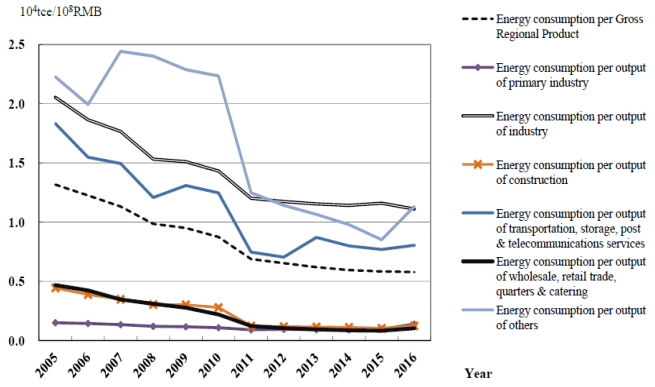

Fig. 1. Changes of energy intensity in Shandong.

B. Changes of Industrial Share of GRP and Energy Consumption

Fig. 2 and Fig. 3 show the changes of GRP industrial proportion and energy consumption industry proportion in Shandong. Fig. 2 shows that although the industrial proportion of the industry sector decreased from 63% in 2005 to 55% in 2016, its energy consumption proportion had always been above 85%. This showed that although the contribution of the output value of the industry sector had been decreasing continuously, the proportion of energy consumption has not been effectively reduced. The proportion of output value of transportation, storage, post & telecommunications services sectors was maintained at 5% - 7%, but the proportion of its energy consumption had always ranked second, at about 6% - 8%.

Secondly, the structural change trends of the various industries (see Fig. 2) show that the adjustment of industrial structure and increase of service industry proportion policies proposed for the Shandong Province during the Eleventh and Twelfth Five-Year Plan periods were indeed effective. But the energy conservation measures for the industry sector and transportation, storage, post & telecommunications services sectors had not reduced the energy consumption proportion of the two sectors.

Moreover, the proportion of output value of others sector decreased from 1% in 2006 to 1% in 2007. The proportion then maintained at about 1% between 2007 and 2011, and increased from 1% in 2011 to 2% in 2012 (see Fig. 2). Inversely, the proportion of energy consumption of others sector increased from 2% in 2007 to 3% in 2008. The proportion then maintained at about 3% from during 2008 and 2010, and then decreased from 3% in 2010 to 2% in 2011 (see Fig. 3). These resulted in the extremely high energy intensity value over 2.0 from 2007 to 2010 (see Fig. 1).

In conclusion, the industry and transportation, storage, post & telecommunications services are the sectors with higher energy consumption in Shandong and in this study focus was therefore continued on the analysis of overall industry and these two sectors.

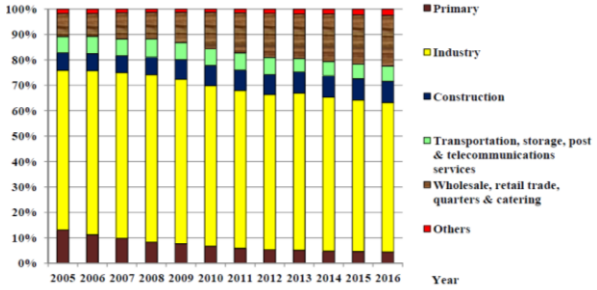

Fig. 2. Industrial share of GRP in Shandong.

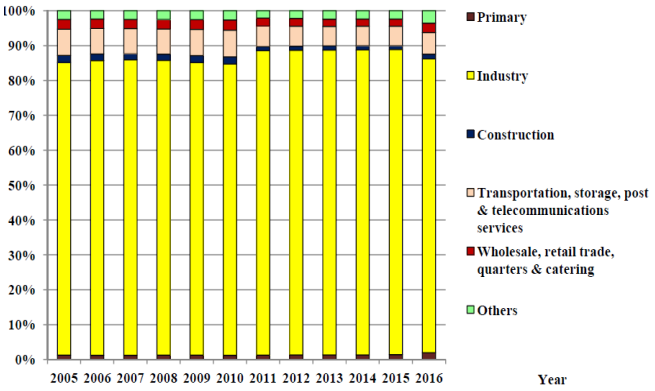

Fig. 3. Industrial share of energy consumption in Shandong.

C. Changes of Energy Efficiency Index and Energy Consumption Structure

Fig. 4 and Table II show the trends and changes of total energy density, and the energy density and industrial structure effects of overall industry. According to Fig. 4, the energy density effect is the main driving force for reducing energy density in Shandong. Table II shows that the energy density effect change during the Eleventh Five-Year Plan period was -0.2089, but only -0.0254 during the Twelfth Five-Year Plan period, even lower than the change in the industrial structure effect. Secondly, the change in industrial structure effect during the Eleventh Five-Year Plan period was -0.0552, and it decreased to -0.0388 during the Twelfth Five-Year Plan period. The changes in energy density effects and industrial structure effects led to changes of -0.2508 in the total energy density of overall industry during the Eleventh Five-Year Plan period in Shandong Province, which was much higher than the -0.0446 during Twelfth Five-Year Plan period. Therefore, these showed that the energy intensity effect was the major factor for reducing the total energy intensity in Shandong between 2005 and 2016.

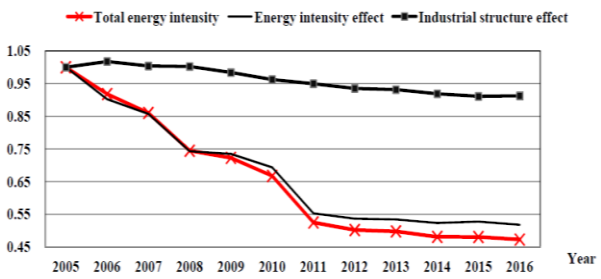

Fig. 4. Tendency of energy intensity of overall industry.

TABLE II: CHANGES IN THE ENERGY EFFICIENCY INDEX FOR OVERALL INDUSTRY

Period	Total energy intensity	Energy intensity effect	Industrial structure effect
11th Five-Year Plan (2006-2010)	-0.2508	-0.2089	-0.0552
12th Five-Year Plan (2011-2015)	-0.0446	-0.0254	-0.0388

Fig. 5 shows the energy consumption structure of the overall industry in Shandong where it can be seen that although the proportion of hydro, nuclear and new energy increases year by year and the proportion of oil decreased, the proportion of coal was always higher than 70%. The consumption of coal continued to grow, especially during the Twelfth Five-Year Plan period, and the proportion remained above 70%.

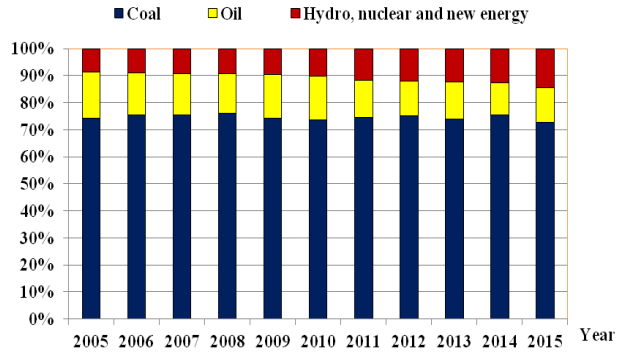

Fig. 5. The share of fuel type of overall industry.

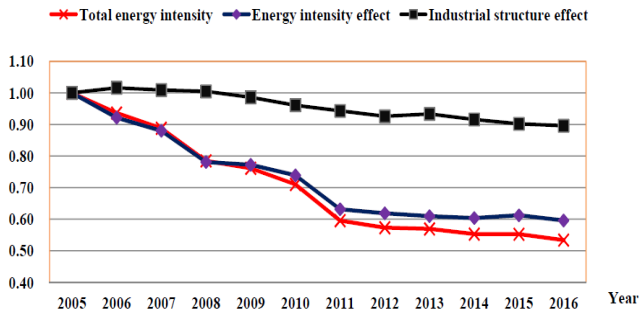

Fig. 6. Tendency of energy intensity of industry sector.

TABLE III: CHANGES IN THE ENERGY EFFICIENCY INDEX FOR INDUSTRY SECTOR

Period	Total energy intensity	Energy intensity effect	Industrial structure effect
11th Five-Year Plan (2006-2010)	-0.2261	-0.1823	-0.0552
12th Five-Year Plan (2011-2015)	-0.0432	-0.0191	-0.0410

Fig. 6 and Table III show the trends and changes in total energy density, energy density effect and the industrial structure effect of the industry sector. According to Fig. 6, the energy density effect is the main driving force for reducing energy density in Shandong. Table III shows that the energy density effect change during the Eleventh Five-Year Plan period was -0.1823, but only -0.0191 during the Twelfth Five-Year Plan period. Secondly, the change in industrial structure effect during the Eleventh Five-Year Plan period was -0.0552, and it decreased to -0.0410 during the Twelfth Five-Year Plan period. The change in the energy density and industrial structure effects was similar to the situation of overall industry and led to a total energy density change of -0.2261 during the Eleventh Five-Year Plan period of the industrial sector. This was much higher than the -0.0432 during the Twelfth Five-Year Plan period.

Fig. 7 shows the energy consumption structure of overall industry in Shandong. Although the proportion of hydro, nuclear and new energy increases year by year and the proportion of oil decreases, the average proportion of coal was higher than 80%. Although the proportion of coal in 2015 was less than 80%, its consumption was still higher than in 2017 and exceeded 28,000 (10^4 tce).

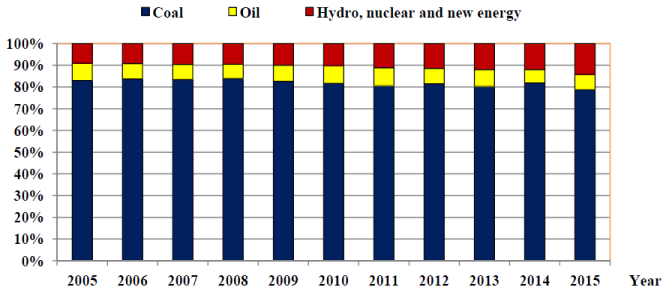

Fig. 7. The share of fuel type of the industry sector.

Fig. 8 and Table IV show the trends and changes in total energy density, energy density effects, and the industrial structure effects of the transportation, storage, post & telecommunications services sectors. Fig. 8 displays that the energy density effect is the main driving force for a reduction of total energy density in Shandong. In Table IV it can be seen that the energy density effect change during the Eleventh Five-Year Plan period was -0.0163, and only 0.0034 during the Twelfth Five-Year Plan period, and is even lower than the change in the industrial structure effect. Secondly, the change in the industrial structure effect during the Eleventh Five-Year Plan period was only -0.0552, and the value was positive at 0.0034 even during the Twelfth Five-Year Plan period. Interestingly, from the aspect of the industrial structure effect, the change during the Eleventh Five-Year Plan period was -0.0053, which increased to -0.0115 during the Twelfth Five-Year Plan period.

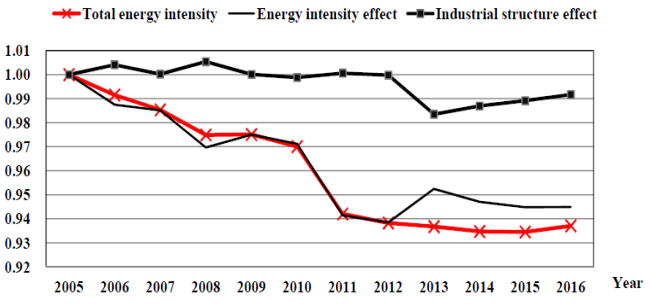

Fig. 8. Tendency of energy intensity of transportation, storage, post & telecommunications services sector.

TABLE IV: CHANGES IN THE ENERGY EFFICIENCY INDEX FOR TRANSPORTATION, STORAGE, POST & TELECOMMUNICATIONS SERVICES SECTOR

Period	Total energy intensity	Energy intensity effect	Industrial structure effect
11th Five-Year Plan (2006-2010)	-0.0215	-0.0163	-0.0053
12th Five-Year Plan (2011-2015)	-0.0075	0.0034	-0.0115

Fig. 9 presents the energy consumption structure of the transportation, storage, post & telecommunications services sector in Shandong. Although the proportion of hydro, nuclear and new energy increased gradually from 1% in 2005 to 5% in 2015, the proportion of oil was always higher than 94%.

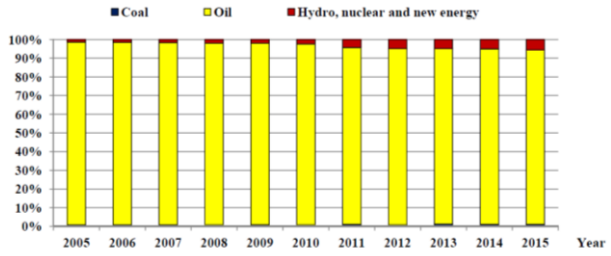

Fig. 9. The share of fuel type of the transportation, storage, post & telecommunications services sector.

D. Energy Conservation Rate and Amount of Energy Conservation

Table V shows the annual average energy conservation rate during the Eleventh and Twelfth Five-Year Plan periods. The average annual energy conservation rate of the overall industry during the Eleventh Five-Year Plan period was as high as 6.13%, but it decreased to 3.32% during the Twelfth Five-Year Plan period, and was 4.38% during the entire study period. From the aspect of all the industrial sectors, the top three with higher annual average energy conservation rates were the Industry, transportation, storage, post & telecommunications services sectors as well as wholesale, retail trade, and accommodation & catering. Here the average industry energy conservation rate during the Eleventh Five-Year Plan period was 5.22%. However, this decreased to 2.53% during the Twelfth Five-Year Plan period, and was 3.67% during the entire study period. This was followed by the transportation, storage, post & telecommunications services sectors, where the average annual energy conservation rate during the Eleventh Five-Year Plan period was 0.58%, but this decreased to 0.53% during the Twelfth Five-Year Plan period, and was 0.50% over the entire study period. Wholesale, retail trade, accommodation & catering sectors came third, where the average annual energy conservation rate during the Eleventh Five-Year Plan period was 0.42%. This decreased to 0.39% during the Twelfth Five-Year Plan period, and was 0.37% during the entire study period.

Energy conservation as analyzed by the revised divisia index method is shown in Table VI. The results of the study showed that for the first year of every Five-Year Plan period (for example, 2006 and 2011) and the following year (2008 and 2010) of the policy intensive introduction of the Eleventh Five-Year Plan period, energy conservation for overall industry, the industry sector, and transportation, storage, post & telecommunications services sector increased significantly. Energy conservation during the Eleventh Five-Year Plan period was better than during the Twelfth Five-Year Plan period. In the last year of the Twelfth Five-Year Plan period (2015), the energy conservation of overall industry and the primary and industry sectors were even negative. During the study period, the total energy conservation of overall industry reached 10,090.03 (10^4tce), the total energy conservation of the industry sector and transportation, storage, post & telecommunications services sectors ranked as the top two, with values of 9,936.71 (10^4tce) and 103.54 (10^4tce) respectively.

TABLE V: AVERAGE ANNUAL ENERGY CONSERVATION RATE IN SHANDONG

Period	Overall	Primary	Industry	Construction	Transportation, storage, post & telecommunications services	Wholesale, retail trade, quarters & catering	Others
11th Five-Year Plan (2006-2010)	6.13	0.08	5.22	0.19	0.58	0.42	0.00
12th Five-Year Plan (2011-2015)	3.32	0.04	2.53	0.25	0.53	0.39	0.47
Study period (2006-2016)	4.38	0.01	3.67	0.19	0.50	0.37	0.18

Unit: %

TABLE VI: AMOUNT OF ENERGY CONSERVATION IN SHANDONG

Period	Overall	Primary	Industry	Construction	Transportation, storage, post & telecommunications services	Wholesale, retail trade, quarters & catering	Others
2005-2006	1720.05	0.16	1691.69	1.18	23.47	1.86	1.68
2006-2007	974.82	0.29	968.34	0.92	4.78	3.94	-3.46
2007-2008	2447.99	0.52	2411.32	1.34	32.10	2.42	0.29
2008-2009	217.23	0.14	224.99	0.36	-12.13	2.92	0.96
2009-2010	914.67	0.32	897.30	1.14	9.24	6.15	0.53
2010-2011	2819.05	0.82	2746.76	3.44	51.86	7.88	8.30
2011-2012	351.40	-0.16	342.12	0.16	5.21	2.41	1.66
2012-2013	229.64	0.17	251.86	0.25	-25.16	0.57	1.95
2013-2014	187.30	0.07	174.12	0.26	10.00	1.45	1.41
2014-2015	-252.78	-0.21	-260.56	0.14	4.44	0.55	2.85
2015-2016	480.67	-3.21	488.79	-0.42	-0.28	-0.21	-3.99
2005-2016	**10,090.03**	**-1.10**	**9936.71**	**8.77**	**103.54**	**29.94**	**12.18**

Unit: 10^4tce

VI. Conclusion and Discussion

Shandong is the largest energy and coal consuming province in China and is under tremendous pressure to conserve energy and reduce emissions. However, even with high growth and energy consumption, it was possible to reduce the energy density during the Eleventh Five-Year Plan period. Therefore, this study was started with a review of the Shandong energy conservation and emission reduction policies in effect since 2006. The gaps in previous research were identified and the revised divisia index and energy consumption structure methods were used to analyze the driving force behind changes in energy consumption between 2005 and 2016, which included the Eleventh and Twelfth Five-Year Plan periods. The main conclusions of this Study can be summarized and discussed as follows:

1) Even though energy consumption continues to grow, the control of energy consuming industries (including the industry sector and transportation, storage, post & telecommunications services sector) and strong energy conservation policies (energy density effect) by the Shandong Provincial Government have become the main force for reducing the energy density in Shandong Province. In particular, during the Eleventh Five-Year Plan period, energy conservation and energy efficiency policies (energy density effect) of the two sectors of industry, and the transportation, storage, post & telecommunications services sectors, led to a decline in energy density in the Province that exceeded policy objectives, and these efforts received commendation from the State Council. However, during the Twelfth Five-Year Plan period, the energy density effect of these two sectors weakened and slowed the decline in energy density. A search for reasons for this revealed that the Shandong energy structure optimization policy merely increased the proportion of hydro, nuclear and new energy to replace a proportion of oil, but did not effectively reduce the consumption and proportion of coal. Coal has always been responsible for more than 70% of the overall energy consumed by industry, and the average proportion has even been as high as 80% in industry. The continuous increase in coal consumption offset the energy conservation efforts made by key industries during the Twelfth Five-Year Plan period.

2) Structural changes in the industrial sector (not counting overall industry) and the transportation, storage, post & telecommunications services sector, had less affect on energy density during the Eleventh Five-Year Plan period than energy conservation policies (energy density effect). However, during the Twelfth Five-Year Plan period, industrial structure changes (industrial structure effect) contributed more to the reduction of energy density than energy conservation policies (energy density effect). In other words, the influence of the policy of industrial restructuring (industrial structure effect) gradually increased and reduced energy density during the Twelfth Five-Year Plan period, especially in the transportation, storage, post & telecommunications services sector.

3) It was found that in the first year of every Five-Year Plan period (for example, 2006 and 2011) and the following year (2008 and 2010) of the introduction of the Eleventh Five-Year Plan period when the policies were intensively applied (2008 and 2010), energy conservation by overall industry, industry sector, and transportation, storage, post & telecommunications services sector increased significantly. This showed that for the first year, and the year after promulgation of important industrial policies or energy conservation and emission reduction policies, the enforcement power was much stronger, and this led to a significant increase in the energy conservation by key industries.

4) In this study it was found that energy conservation policies (energy density effects) were the main driving forces behind the reduction of energy density in Shandong, which is consistent with many conclusions drawn in other analyses of energy consumption changes in China [8,43-46]. However, in this study it was shown that although the proportion of tertiary industry in Shandong Province (including transportation, storage, post & telecommunications services, wholesale, retail trade, accommodation & catering, and others sectors) had increased from 17% in 2005 to 27% in 2016, and the proportion of secondary industry had dropped from 70% in 2005 to 63% in 2016, the growth of energy consumption had not been curbed. This differs from the conclusion drawn by Jiang *et al*. [5]. A search for reasons for this showed that the proportion of energy consumption in the secondary industry had always accounted for more than 85%, and the proportion of coal consumption accounted for 80% of the energy consumption of the industrial sector. This meant the changes in industrial structure and energy consumption had not effectively reduced energy consumption in the Shandong Province.

The economic development of the Shandong Province is high but the energy supply is insufficient. A simultaneous increase in energy self-sufficiency and a reduction of energy density is needed. According to the conclusions reached in this study a continuous improvement in energy intensity and an optimization of energy structure is necessary. This can be achieved in the following three ways: (1) A reduction in the use of coal. This is the core of the present Shandong energy problem. A reduction in the proportion of coal in the industrial sector and an increase in the proportion of hydro, nuclear and new energy is the key to the use of the three tools: improving energy efficiency, optimizing energy structure and modifying industrial structure to reduce energy density. (2) Continuous expansion of the scale of the new energy industry to increase energy self-sufficiency and optimize the energy structure. (3) Continued implementation of high-intensity energy conservation policies for the industry sector, and transportation, storage, post & telecommunications services sector to improve energy efficiency and slow the growth of energy consumption. Looking into the future, because a reduction of the use of fossil energy is a key to energy conservation and emission reduction in Shandong, follow-up research recommendations should analyze the influence of a development strategy for hydro, nuclear and new energy in Shandong Province and the effectiveness of energy

conservation and emission reduction.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Sheng-Wen Tseng initiated the extended study, supervised the project and was responsible for the development of energy conservation and emission reduction policy for Shandong. Sheng-Wen Tseng conceived and designed the basic frame, carried out the main body of methodology, wrote the paper, and reviewed the work. Yen-Yu Chen analyzed the data. All authors had approved the final version.

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