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Abstract

This study analyzes China's industrial energy consumption trends from 1996 to 2010 with a focus on the impact of the Top-1000 Enterprises Energy-Saving Program and the Ten Key Energy-Saving Projects. From 1996 to 2010, China's industrial energy consumption increased by 134%, even as the industrial economic energy intensity decreased by 46%. Decomposition analysis shows that the production effect was the dominant cause of the rapid growth in industrial energy consumption, while the efficiency effect was the major factor slowing the growth of industrial energy consumption. The structural effect had a relatively small and fluctuating influence. Analysis shows the strong association of industrial energy consumption with the growth of China's economy and changing energy policies. An assessment of the Top-1000 Enterprises Energy-Saving Program and the Ten Key Energy-Saving Projects indicates that the economic energy intensity of major energy-intensive industrial sub-sectors, as well as the physical energy intensity of major energy-intensive industrial products, decreased significantly during China's 11th Five Year Plan (FYP) period (2006-2010). This study also shows the importance and challenge of realizing structural change toward less energy-intensive activities in China during the 12th FYP period (2011-2015).

Keywords: ***Industry; Energy intensity; Decomposition***

1. Introduction

As a result of rapid economic growth, China's total primary energy consumption increased from 17.7 exajoules (EJ) in 1980 to 95.2 EJ in 2010 (NBS, 2010b, 2011c). Industrial energy consumption accounts for about 70% of China's total energy consumption (NBS, 2010a, 2011a, 2011b). The large share of industrial energy consumption is one of the main features of China's energy economy and warrants comprehensive analysis.

Several studies have used decomposition analysis to understand the energy economy of China's industrial sector. Sinton and Levine (1994) analyzed the relative roles of structural change and real energy intensity change[1] in China's industrial sector in the 1980s using a decomposition methodology and found that real intensity change was the main factor accounting for the reduction in industrial energy intensity in the 1980s. Zhang (2003) analyzed China's industrial energy consumption in the 1990s using a decomposition methodology and showed that a decline in real energy intensity was the main contributor to industrial energy savings in the 1990s. Zhang and Sun (2010) analyzed the change in energy intensity of selected industrial sub-sectors using a decomposition methodology and found that energy efficiency improvements were the major cause of reduction in industrial energy intensity over the period 1997-2007. A recent decomposition analysis (Xu and Zhang, 2011) of China's manufacturing industry shows that structural shift has more or less increased manufacturing industry's energy consumption since 2003 and real energy intensity change[2] is the driving force for energy savings.

In 2010, China published extensive revisions to its official national energy balances for the years 1996 to 2008 (NBS, 2010a, 2010b). These revisions primarily affected the reported numbers on coal production and consumption and, in addition to the 2005 revisions covering 1998 to 2003, basically eliminated what was originally reported as a decline in primary energy use in the late 1990s. The basis of the 2010 revisions was the result of the Second National Economic Census of 2008 (Ma, 2009). For the first time, the census scope was expanded to cover activities below the county level, providing the most comprehensive look at China's economy to date. The results of the census indicated a significant underestimation of energy consumption by enterprises and businesses at the lowest level, leading to an average 5% upward revision of annual primary energy consumption between 2000 and 2007 (NBS, 2008, 2010a). This upward revision was primarily due to increases in coal use in industry; in 2006, for example, coal use in industry was revised up by 130 million tonnes (NBS, 2008, 2010a). In addition to extensive revisions of coal production and consumption, the census also led to adjustments in the structure of reported petroleum product consumption, with a greater proportion of diesel fuel being allocated to transport use. These extensive revisions of China's official energy statistics warrant in-depth reanalysis of China's industrial energy consumption.

Industrial value-added measures the net economic contribution of each industrial sub-sector and thus is ideal for energy economy analysis (Zhao et al., 2010). However, most recent studies used published

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[1] Real energy intensity change is the change in "economic energy intensity of industrial sub-sectors, composed of physical energy intensity change and other non-structural factors" (Sinton and Levine, 1994).

gross output value data or industrial value-added data for selected years[3] because the industrial value-added data at the sub-sectoral level have not been officially released for 2004 and 2008 onwards. The years for which official data have not been released are critical for the analysis as they correspond to the dynamic and fast changing period of China's industrial energy economy. An in-depth analysis with accurate estimation of industrial value-added is helpful to understand the fast changing nature of China's industrial energy economy.

The main purpose of this study is to (1) examine whether China's industrial energy consumption trends in the 1980s and 1990s continued through the 2000s, especially given the revised Chinese energy statistics and our latest estimation of sub-sectoral industrial value-added; (2) examine whether the efficiency effect (or real energy intensity change) is still the main factor accounting for the energy intensity reduction in the Chinese industry; (3) assess the impact of the two major industry-related energy-saving programs and initiatives during China's 11th Five-Year Plan (FYP) period (2006-2010) on that country's recent industrial energy consumption.

2. Data

The main data used for this analysis are the latest officially[4] revised industrial energy consumption data (NBS, 2010a, 2011a, 2011b) and industrial value-added data by sub-sectors at the 2-digit level of industrial classification (DISNBS, various years; NBS, 2006, 2009, 2010b, 2010c, 2011c, 2011d, various years). Industrial value-added is calculated at 2005 constant prices.

The National Bureau of Statistics (NBS) publishes the *China Energy Statistical Yearbook* (CESY) annually. Final energy consumption by industrial sub-sector can be found in various issues of the CESY. Because coal dominates China's energy economy, China officially uses a coal equivalent calculation for its energy statistics (NBS, 2010a, 2010b). Final energy consumption by sector can be calculated using two conversion methods: the coal equivalent calculation method that includes the primary energy use in power generation and the calorific value calculation method that values electricity at its heat value (NBS, 2010a). In this study, if not otherwise noted, we adopt the coal equivalent calculation method following China's official energy statistics expressed in tonne of standard coal equivalent (tce)[5].

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[2] The term "technical effect" was used by Xu and Zhang (2011) in their paper.

[3] For example, Xu and Zhang (2011) used the arithmetic mean of industrial value-added of a sub-sector in 2003 and 2005 as an approximation of industrial value-added of that sub-sector in 2004.

[4] Some researchers have viewed official Chinese energy and economic statistics with skepticism (Gregg et al., 2008; Rawski, 2001). However, the official statistics remain the only main source of energy and economic data. To be consistent in this study, we primarily use the latest official statistical data.

[5] 1 tce is approximately equivalent to 29.3 gigajoules (GJ).

According to official Chinese statistics, industrial enterprises are classified into enterprises above a designated size and enterprises below a designated size[6]. The industrial value-added of the enterprises above the designated size is calculated using the production or income approach[7] (DISNBS, various years), while the industrial value-added of the enterprises below the designated size is estimated using the gross output value and the "industrial value-added rate". The majority of China's industry is comprised of enterprises above the designated size, accounting for about 87% of the total industrial value-added in 2004 (NBS, various years).

The total industrial value-added data can be found in the annual *Statistical Communiqué of the People's Republic of China on the National Economic and Social Development* (NBS, various years). The industrial value-added data at the sub-sectoral level for industrial enterprises above the designated size are usually reported in the annual *China Industry Economy Statistical Yearbook* (CIESY). From 2004 to 2006, China conducted its first national economic survey and published the three-volume *China Economic Census Yearbook* (CECY) 2004 (NBS, 2006) as well as the provincial economic census yearbooks. Because the CECY 2004 already included the industrial sector, the CIESY for the year 2004 was thus not published to avoid redundancy. However, CECY 2004 did not directly provide industrial value-added data at the sub-sectoral level, though it provided a lot of detailed information. Most studies thus used other economic indicators instead. We found that the sub-sectoral industrial value-added could be calculated from the officially released 2004 economic survey data. We adopted the income approach to calculate the sub-sectoral industrial value-added. We compared the total industrial value-added of the enterprises above the designated size calculated using the income approach with the officially published industrial value-added data (NBS, various years) and found that the difference was only 0.3%, which verified the validity of our calculation method. The industrial value-added of the enterprises below the designated size at the sub-sectoral level is estimated by assuming that the industrial value-added of the enterprises below the designated size has the same distribution by sub-sector as the enterprises above the designated size.

The industrial value-added by sub-sector from 2008 to 2010 is calculated based on the officially released annual growth rate of industrial value-added by sub-sector from 2008 to 2010 (NBS, 2009, 2010c, 2011d, various years), respectively.

3. Results and Analysis

3.1. Energy intensity, elasticity, and decomposition

[6] The designated size is defined as "all state-owned enterprises and those non-state-owned enterprises with annual revenue from their principal business of over 5 million RMB" (NBS, 2010b).

[7] In theory, production approach and income approach would give almost the same results if the data meet the statistical requirements.

Fig. 1 shows energy consumption and energy intensity of China's industrial sector from 1996 to 2010. China's industrial energy consumption increased significantly from 1996 to 2010, especially after 2002. By 2010, China's industrial energy consumption had increased 134% over the 1996 level. The energy intensity of China's industrial sector decreased overall from 1996 to 2010 but fluctuated during the period of 2003 to 2005. By 2010, China's industrial energy intensity decreased 46% below the 1996 level.

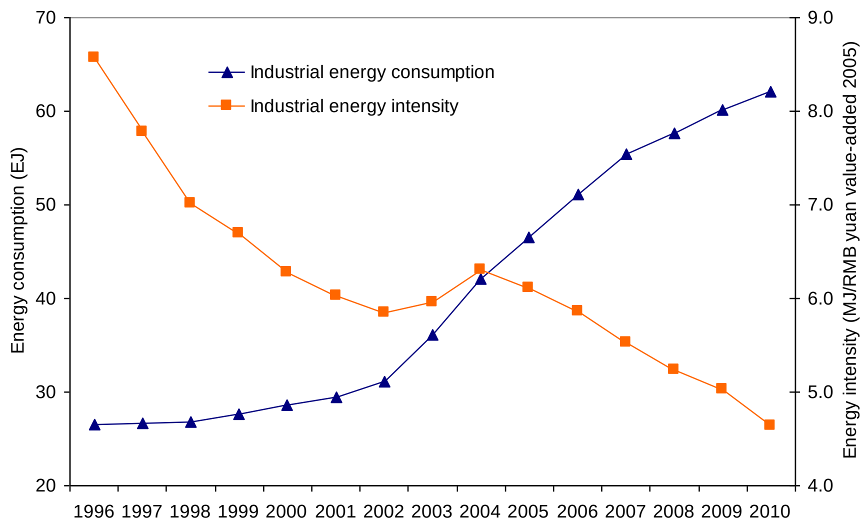

Fig. 1. China's industrial energy consumption and intensity, 1996-2010.

Source: Primary data from DISNBS (various years), NBS (2010a, 2010b, 2011a, 2011b, 2011c, various years). Calculations by authors.

Note: (1) RMB (Renminbi) is the official currency in China. The average exchange rate of the RMB yuan for the U.S. dollar in 2005 is 8.19 yuan per dollar (NBS, 2010b). (2) Industrial value-added is calculated at 2005 constant prices (NBS, 2010b, 2011c).

Fig. 2 shows the elasticity of industrial energy consumption during the period 1996 to 2010, which is defined as the ratio of the growth rate of industrial energy consumption over the growth rate of industrial value-added. As seen in Fig. 2, the elasticity was less than one in most years except in 2003 and 2004, indicating the growth rate of industrial energy consumption exceeded the growth rate of industrial value-added in 2003 and 2004.

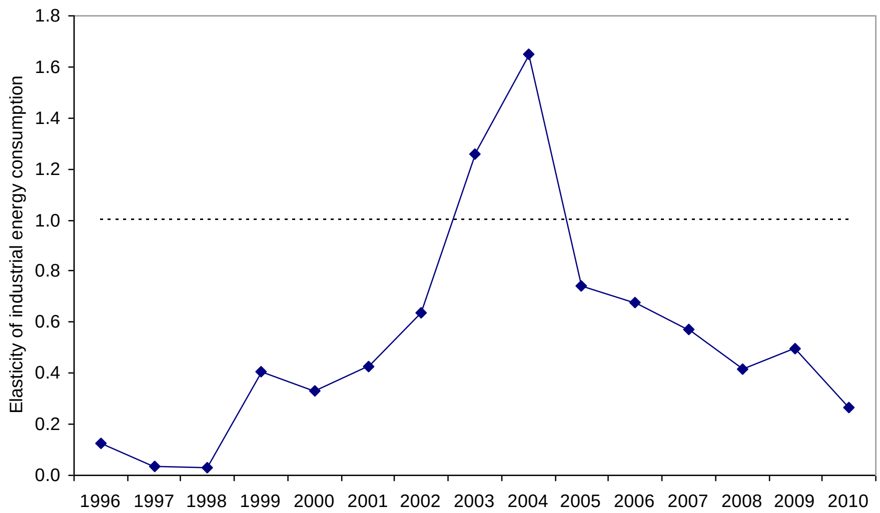

Fig. 2. Elasticity of energy consumption in China's industrial sector, 1996-2010.

Source: Primary data from DISNBS (various years), NBS (2010a, 2010b, 2011a, 2011b, 2011c, various years). Calculations by authors.

Based on changing trends in industrial energy intensity, the development of China's industrial sector from 1996 to 2010 can be divided into three periods: decreasing energy intensity from 1996 to 2002, increasing energy intensity from 2003 to 2005, and decreasing energy intensity from 2006 to 2010.

In order to understand the change in China's industrial energy consumption, decomposition was employed using the logarithmic mean Divisia index (LMDI) method proposed by Ang (2005). For zero or negative values which logarithmic functions cannot handle, the guidelines proposed by Ang and Liu (2007a, 2007b) were adopted. Fig. 3 and 4 show the decomposition of annual and cumulative changes in China's industrial energy consumption.

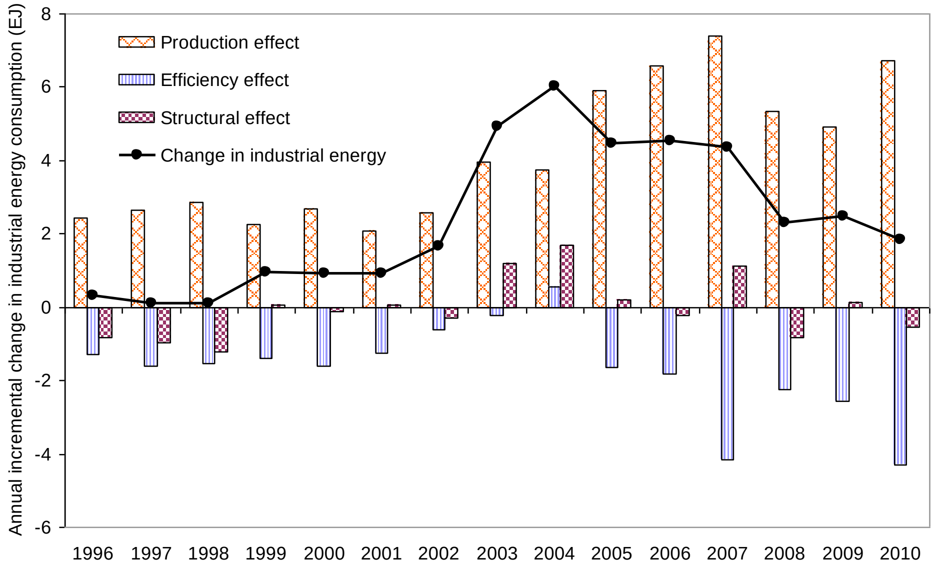

Fig. 3. Decomposition of the annual incremental change in China's industrial energy consumption, 1996-2010.

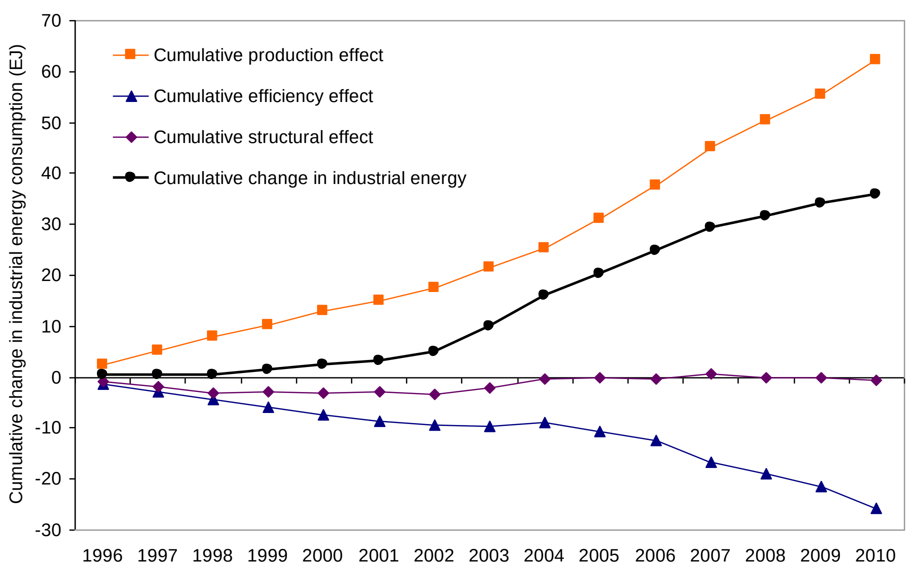

Fig. 4. Decomposition of the cumulative change in China's industrial energy consumption, 1996-2010.

Note: Cumulative change is the sum of annual incremental change from 1995 to a given year.

As shown in Fig. 3 and 4, the production effect (activity effect) was the main factor behind the rapid increase in total industrial energy consumption, which accords with the general principle that more production results in more energy consumption. The efficiency effect (real energy intensity change) significantly slowed the growth of industrial energy consumption, counteracting the rise in production.

The structural effect had a relatively small and fluctuating impact on industrial energy consumption. The cumulative structural effect from 1996 to 2010 was negligible [8].

It should be noted that the decreasing trend of energy intensity since 1996 was reversed in 2003 and 2004. In 2005, the value of the efficiency effect returned to largely negative and the value of the structural effect was positive but very small, which made industrial energy intensity fall below the 2004 level. From 2006 to 2010, efficiency improvement was the major factor for the decrease of the industrial energy intensity.

In order to better understand the energy intensity and decomposition results described above, we need to investigate China's economy and energy policies at the national level and look further into China's industrial sector at the sub-sectoral level.

China made great achievement in energy efficiency before 2002 (Levine et al., 2009; Lin, 1996; Liu et al., 2009), which was reflected by a significant reduction in industrial energy intensity from 1981 to 2002 (Levine et al., 2009; Price et al., 2001).

China's economy entered a new expansion period after 2002. China's domestic demand for energy-intensive commodities like steel and cement for building and infrastructure construction increased rapidly. The investment in China's energy-intensive industries grew dramatically (NDRC, 2004a). Analysis shows that the significant increase in industrial energy intensity from 2003 to 2005 was related to rapid growth in energy-intensive industries, especially the top six energy-consuming industrial sub-sectors [9] which accounted for about 70% of total industrial energy consumption but only about 30% of total industrial value-added.

Beginning in 2004, the Chinese government recognized that rapid growth in energy demand and supply caused serious economic and environmental problems and was not sustainable (Levine et al., 2009). The National Development and Reform Commission (NDRC) passed the *Medium and Long Term Energy Conservation Plan* in November 2004 (NDRC, 2004b). This plan set up detailed energy conservation targets and launched some important policy measures and initiatives such as the Ten Key Energy-Saving Projects (Ten Key Projects) which were incorporated into China's 11th FYP in 2005. In November 2005, the Chinese government set a mandatory target of 20% reduction in energy intensity [10] from 2005 levels by 2010 (Levine et al., 2009).

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[8] The structural change in this study characterizes the change of economic contribution of industrial sub-sectors to the overall industrial sector, measured in terms of sub-sectoral industrial value-added. The structural change below sub-sector level, such as the change of composition of different products within one sub-sector is not captured by the calculated structural change.

[9] The top six energy-consuming industrial sub-sectors in China are ferrous metals, chemicals, non-metallic minerals, fuel processing, power, and non-ferrous metals (NBS, 2010a, 2011a, 2011b).

[10] Measured as energy consumption per unit of GDP.

In April 2006, the Top-1000 Enterprises Energy-Saving Program (Top-1000 Program) was launched (NDRC, 2006b), aiming to improve industrial energy efficiency by targeting China's 1000 largest energy-consuming enterprises (Top-1000 Enterprises) which accounted for almost half of total industrial energy consumption and one-third of total energy consumption in China (Price et al., 2010; Price et al., 2011). In 2007, the Energy Conservation Law was revised to further promote energy efficiency. With the significant efforts to improve energy efficiency, energy intensity began to decrease again from 2005 over the 2004 level, which is clearly shown in Fig. 1. This decreasing trend continued through the entire 11th FYP period. From 2006 to 2010, China's energy consumption per unit of GDP decreased by 19.1%, just shy of the 20% target (NDRC and NBS, 2011). Our calculation shows China's industrial energy consumption per unit of value-added decreased by 24% in 2010 over the 2005 level.

3.2. Assessment of the impact of the Top-1000 Program and the Ten Key Projects

Based on energy intensity analysis, we assessed the impact of the two major industry-related energy-saving programs and initiatives in China during the 11th FYP period. Specifically, we assessed the energy savings of the Top-1000 Program using economic energy intensity and assessed the energy savings of the Ten Key Projects using physical energy intensity of major energy-intensive products.

3.2.1. Assessment of energy savings of Top-1000 Program

The Top-1000 Program was one of the key initiatives for realizing China's 20% energy intensity reduction goal during the 11th FYP period. The program set energy savings targets for China's Top-1000 Enterprises that are all found in the nine largest energy-consuming industrial sub-sectors in China[11]. China's Top-1000 Program was modeled on international target-setting programs called voluntary or negotiated agreement programs (Price et al., 2010; Price et al., 2011). The government provided guidance to the enterprises and established energy-savings targets for each enterprise.

The implementation plan of the Top-1000 Program was initially designed to realize energy savings of 100 million tce (Mtce), or 2.93 EJ between 2006 and 2010 in the Top-1000 Enterprises (NDRC, 2006b). In November 2009, NDRC reported that the Top-1000 Program had realized energy savings of 106.2 Mtce (3.11 EJ) by 2008 and thus had achieved its initial target in advance. In September 2011, NDRC reported that the Top-1000 Program had achieved total energy savings of 150 Mtce (4.40 EJ) from 2006 to 2010 (NDRC, 2011b).

[11] The nine energy-consuming industrial sub-sectors to which the 1000 largest energy-consuming enterprises (Top-1000 Enterprises) belong are ferrous metals, chemicals, non-metallic minerals, fuel processing, power, non-ferrous metals, coal mining, textiles, and pulp and paper.

Detailed calculations of the energy savings of the Top-1000 Program have not been released publicly. In addition, the detailed energy intensity and industrial value-added data for the Top-1000 Enterprises are also not publicly available. Thus, it is difficult to directly verify the reported energy savings. Therefore, we estimate the energy savings from a more general industrial sector perspective. In theory, the reported energy savings of the Top-1000 Enterprises can be checked by comparing the program results to the overall savings achieved by China's top nine energy-consuming industrial sub-sectors during the program period. The average energy intensity of the nine industrial sub-sectors to which the Top-1000 Enterprises belong is thus used in this analysis. The incremental energy savings of the nine industrial sub-sectors can be calculated by multiplying the industrial value-added of the nine industrial sub-sectors in year *y* by the difference of the average energy intensity of the nine industrial sub-sectors in year $y-1$ and year *y*. Table 1 shows the estimated energy savings of the nine selected industrial sub-sectors.

The Top-1000 Enterprises accounted for about 47% of the industrial energy consumption in 2004 (NDRC, 2006b). To make the comparison, we assume that 47% of the energy savings of the nine sub-sectors in each year were achieved by the Top-1000 Enterprises.

Table 1. Estimated energy savings of the nine selected industrial sub-sectors [a]

Item	2005	2006	2007	2008
Final energy consumption (EJ) [b]	37.27	41.03	44.67	46.18
Industrial value-added (trillion 2005 RMB) [c]	3.15	3.58	4.19	4.53
Energy Intensity (MJ/value-added 2005 RMB) [c]	11.83	11.47	10.66	10.20
Incremental energy intensity reduction (MJ/ value-added 2005 RMB) [c]	-	0.36	0.81	0.46
Incremental energy savings (EJ)	-	1.28	3.37	2.08
47% of the incremental energy savings (EJ) [d]	-	0.60	1.59	0.98

[a] *The nine industrial sub-sectors to which the 1000 largest energy-consuming enterprises (Top-1000 Enterprises) belong are ferrous metals, chemicals, non-metallic minerals, fuel processing, power, non-ferrous metals, coal mining, textiles, and pulp and paper.*

[b] *Coal equivalent calculation (NBS, 2010a).*

[c] *RMB (Renminbi) is the official currency in China. The average exchange rate of the RMB yuan for the U.S. dollar in 2005 is 8.19 yuan per dollar (NBS, 2010b). Industrial value-added is calculated at 2005 constant prices (NBS, 2010b).*

[d] *Assumption that 47% of the energy savings were achieved by the Top-1000 Enterprises.*

Source: Primary data from DISNBS (various years), NBS (2009, 2010a, 2010b, various years), NDRC (2006b). Calculations by authors.

Table 2 shows the estimated and reported yearly and total energy savings of the Top-1000 Program from 2006 to 2008. As shown in Table 2, the estimated yearly and total energy savings from 2006 to 2008 are close to the reported figures, indicating that the reported values are reasonable.

Table 2. Estimated and reported energy savings of Top-1000 Program in 2006-2008

Energy savings	2006		2007		2008		Total in 2006-2008	
	EJ	(Mtce) [a]	EJ	(Mtce) [a]	EJ	(Mtce) [a]	EJ	(Mtce) [a]
Estimated energy savings [b]	0.60	(20.5)	1.59	(54.1)	0.98	(33.3)	3.16	(107.9)
Reported energy savings [c]	0.59	(20.0)	1.48 [d]	(50.5) [d]	1.05	(35.7)	3.11	(106.2)

[a] *Mtce denotes million tonnes of standard coal equivalent and 1 Mtce is approximately equivalent to 0.0293 exajoules (EJ).*

[b] *Estimated by authors.*

[c] *Reported by NDRC (2007, 2009).*

[d] *Calculated by subtracting the energy savings in 2006 (NDRC, 2007) and 2008 (NDRC, 2009) from the total energy savings in the period of 2006 to 2008 reported in November 2009 (NDRC, 2009).*

This estimate shows the claimed achievement and effectiveness of the Top-1000 Program can be demonstrated in reported industrial subsector data, despite limited available data. It appears reasonable to conclude, then, that the Top-1000 Program achieved – and even exceeded – its target based on the overall national-level trends of the nine largest energy-consuming industrial sub-sectors.

3.2.2. Assessment of energy savings of the Ten Key Projects

The Ten Key Projects was another important energy efficiency initiative launched by the Chinese government during the 11th FYP period (NDRC, 2006a). The Ten Key Projects focused on the following ten areas: coal-fired industrial boiler (kiln) retrofits, district cogeneration, waste heat and pressure utilization, petroleum conservation and substitution, motors energy efficiency, energy system optimization, building energy conservation, green lighting, government agency energy conservation, and energy saving monitoring, testing and technology service system building. Thus, the Ten Key Projects include a very wide range of potential energy-savings areas and industry is one of the major components.

The overall target of the Ten Key Projects was to save about 240 Mtce (7.03 EJ) (excluding oil substitution) by the end of the 11th FYP period. Additionally, a goal was that the energy intensities of major products in key industries reach or approach the advanced international level achieved at the beginning of 21st century via the implementation of the Ten Key Projects (NDRC, 2006a).

It is reported that the Chinese central and local governments invested large amounts of funds into the Ten Key Projects (NDRC, 2011a). However, we could not find reporting on the official figures of the energy savings of the Ten Key Projects. In September 2011, NDRC released a series of summary reports of the programs and initiatives launched during the 11th FYP period, including the Ten Key Projects and the Top-1000 Program. In the Ten Key Projects summary report, NDRC pointed out that the target of the Ten Key Projects was to save about 240 Mtce (7.03 EJ) of energy, but did not report how much energy was actually saved. Instead, NDRC reported that the Ten Key Projects built up 340 Mtce (9.96 EJ) "energy savings capacity", which has essentially the same meaning as "energy savings potential"[12].

NDRC (2011a) reported that the implementation of the Ten Key Projects achieved economic and social benefits such as: (1) improving energy efficiency; (2) promoting advanced energy-saving technologies; and (3) developing energy conservation and environmental protection industries. However, as recently pointed out (Price et al., 2011), it is impossible to accurately evaluate the total effects of the Ten Key Projects because NDRC provided only very limited information about these benefits. Here we try to assess some of the energy savings from the very limited public information of energy intensity reduction reported by NDRC.

NDRC reported that the Ten Key Projects significantly improved energy efficiency (NDRC, 2011a). Table 3 shows the reported and estimated final energy intensity reduction of major energy-intensive products in China during the 11th FYP period. It should be noted that the energy intensities listed in Table 3 are all reported or estimated according to the reported figures, which are not necessarily consistent with the estimated energy intensities from our own research. For example, the comprehensive energy consumption per tonne of steel reported by NDRC is low, but it does not indicate that the energy intensity of steel production in China has now reached the advanced international level. Actually, it is mainly due to the large differences in energy statistical boundaries and calculation methodologies, such as China's practice of using a conversion factor of 1 kilowatt-hour (kWh) to 3.6 megajoules (MJ) for electricity in its comprehensive energy intensity calculation[13], which significantly reduces the reported energy intensity value.

Table 3. Reduction in physical final energy intensity of industrial products in 2006-2010

Energy intensity	2005	2006	2007	2008	2009	2010	Reduction rate by 2010 over the 2005 level (%)
Standard coal consumption rate for thermal power (MJ/kWh)	10.84[a]	10.76[b]	10.43[b]	10.11[b]	9.96[b]	9.76[a]	10.0[a]

[12] A literature review confirmed that the "energy savings capacity" is just an alternative expression of "energy savings potential". This statement is confusing and some people misinterpreted this statement, reporting that the Ten Key Projects "saved" 340 Mtce (9.96 EJ) of energy, e.g. Yang (2011).

[13] Before 2006, China used a conversion factor of 1 kWh to 11.8 MJ for electricity in energy intensity calculation.

Comprehensive energy consumption per tonne of steel (GJ/t)	20.34[a]	18.90[b]	18.52[b]	18.46[b]	18.15[b]	17.73[a]	12.8[a]
Comprehensive energy consumption per tonne of cement (GJ/t)	3.72[b]	3.52[b]	3.37[b]	3.03[b]	2.81[d]	2.81[c]	24.6[a]
Comprehensive energy consumption per tonne of ethylene (GJ/t)	28.89[b]	28.34[b]	28.03[b]	27.60[b]	26.67[b]	25.81[b]	10.7[e]
Comprehensive energy consumption per tonne of synthetic ammonia (GJ/t)	42.58[b]	43.45[b]	41.80[b]	41.80[b]	40.75[b]	39.75[b]	6.6[f]

Source: Primary data from CIEE (2012), ERI (2010), NDRC (2011a), SERC (2009, 2010), Zeng (2009, 2010), Zheng (2011). Calculations by authors.

Note: In current Chinese energy statistics, comprehensive energy intensity of industrial products is evaluated using calorific value calculation method. Energy intensity values listed in the table represent the average energy intensity levels of the enterprises above the designated size (which are the majority of China's industrial sector) and are used as a proxy for those enterprises below the designated size.

[a] *NDRC (2011a) reported.*

[b] *Reported by other sources (CIEE, 2012; ERI, 2010; SERC, 2009, 2010; Zeng, 2009, 2010; Zheng, 2011).*

[c] *Estimated using 2005 level and reported reduction rate by NDRC (2011a).*

[d] *A preliminary value reported by Zeng (2010) is slightly smaller than this value, 2010 level (NDRC, 2011a) is used here.*

[e] *CIEE (2012) reported. A reduction rate of 11.6% was reported by NDRC (2011a).*

[f] *CIEE (2012) reported. A reduction rate of 14.3% was reported by NDRC (2011a).*

Given the reduction in energy intensities, the incremental energy savings in year *y* can be calculated using the following formula:

$$E_y = P \cdot (I_{y-1}^{(p)} - I_y^{(p)})$$

where *P* is the output of one certain product in year *y*, $I_y^{(p)}$ is the physical energy intensity of the product in year *y*, and $I_{y-1}^{(p)}$ is the physical energy intensity of the product in year $y-1$, i.e. prior year of year *y*.

The annual output of each product is shown in Table 4, and annual and cumulative energy savings from 2006 to 2010 of each product are shown in Table 5.

Table 4. Output of major energy-intensive products in 2006-2010

Output	2006	2007	2008	2009	2010
Thermal power (TWh)	2369.6	2722.9	2707.2	2982.8	3331.9
Crude steel (Mt)	419.1	489.3	503.1	572.2	637.2
Cement (Mt)	1236.1	1361.2	1420.1	1644.0	1881.9
Ethylene (Mt)	9.4	10.3	9.9	10.7	14.2
Synthetic ammonia (Mt)	49.4	51.7	50.0	51.4	49.6

Source: NBS (2011c, 2011e).

Table 5. Estimated final energy savings [a] of the Ten Key Projects from 2006 to 2010

Item	2006 (EJ)	2007 (EJ)	2008 (EJ)	2009 (EJ)	2010 (EJ)	Cumulative from 2006 to 2010 (EJ)
Thermal power generation	0.208	0.878	0.873	0.437	0.684	3.08
Crude steel production	0.602	0.186	0.031	0.176	0.269	1.26
Cement production	0.254	0.199	0.480	0.372	0.000	1.30
Ethylene production	0.005	0.003	0.004	0.010	0.012	0.03
Synthetic ammonia production	−0.043	0.086	0.000	0.054	0.049	0.15
Total	1.026	1.352	1.388	1.048	1.015	5.83

[a] *Calorific value calculation.*

As shown in Table 5, a total of 5.83 EJ (199 Mtce) of final energy savings (calorific value calculation) could have been achieved if the energy intensity reduction of major energy-intensive products is solely attributed to the Ten Key Projects. As pointed out by Price et al. (2011), some of the energy savings of the Ten Key Projects most likely overlap with the savings of the Top-1000 Program.

We note that the estimated total final energy savings of major energy-intensive products (199 Mtce, or 5.83 EJ) is close to the target (240 Mtce, or 7.03 EJ). The estimate, combined with reporting "energy savings potential" instead of actual energy savings, indicates that evaluation of the Ten Key Projects (except major industrial products) is difficult given the broadness of the projects and the lack of effective target tracking and evaluating. As pointed out in a recent study (Price et al., 2011), program design of the Ten Key Projects could be substantially improved by following international best practice.

4. Conclusions

With rapid economic growth, China's energy consumption increased significantly since the 1980s. By 2010, China's annual industrial energy consumption increased by 134% over the 1996 level. From 1996 to 2010, China's industrial energy intensity generally decreased, but experienced large fluctuations during the period of 2003 to 2005.

Decomposition analysis shows that the production effect (activity effect) was the dominant factor for the rapid growth of China's industrial energy consumption. The efficiency effect (real energy intensity change) was the major factor that slowed the growth of industrial energy consumption. The efficiency effect slowed the growth of industrial energy consumption in most years during the period of 1996 to 2010, except in 2004. The structural effect had a relatively small and fluctuating effect on industrial energy consumption over the period of 1996 to 2010. The cumulative structural effect from 1996 to 2010 was negligible, indicating the challenge of the Chinese government's goal to achieve more structural change.

In 2005, the Chinese government set a mandatory target for energy intensity reduction for the 11th FYP period. This target effectively slowed the *growth* of industrial energy consumption, although it could not deter the overall increase in industrial energy consumption.

Since 2005, China's industrial energy intensity has continued to decline significantly. An assessment of the two major industry-related energy-saving programs and initiatives during China's 11th FYP period, specifically the Top-1000 Program and the Ten Key Projects, indicates that both economic energy intensity of major energy-intensive sub-sectors and physical energy intensity of major energy-intensive products decreased significantly. The contribution of the Top-1000 Program and the Ten Key Projects is large in terms of energy savings, although it is difficult to disentangle the impact of the Ten Key Projects from the Top-1000 Program because of the overlaps that occurred in these two programs.

China has made significant progress in industrial efficiency improvement. Energy efficiency improvement will still be a key policy strategy for the Chinese government to achieve its industrial energy intensity reduction target during China's 12th FYP period (2011-2015)[14]. The central government recognizes that structural change must also be addressed. As the physical energy intensities of energy-intensive products approach international advanced levels, structural energy savings will show more and more potential in energy intensity reduction. However, this analysis shows that structural effects have had a relatively small influence on energy consumption to date while the production effect has been the dominant influence. Thus, new policy strategies are needed to promote energy-saving structural change, as well to calm energy-intensive production.

[14] The Chinese government aims to achieve a 21% reduction over the 2010 level in industrial energy intensity (energy consumption per unit of industrial value-added) of the enterprises above the designated level (MIIT, 2012).

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