

Energy Intensity Trends and Scenarios for China's Industrial Sectors – a Regional Case Study

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Abstract:

Due to its rapid industrialization and urbanization, China faces the daunting challenge of sharply growing energy and resource consumption. It is now indispensable for the nation to alter its course of development into more sustainable paths in terms of energy and resource efficiency. In this paper, we discuss the energy intensity of the industrial sectors of the Yangtze River Delta, consisting of Shanghai City and the neighboring province of Jiangsu, the fastest economically developing region of the country, and argue possible strategies for energy efficient industrial activities there. We first examine the historical trends of energy intensity associated with industrial sectors and study the factors affecting the evolution of these trends by applying decomposition analysis. We then argue that if Business as Usual (BAU) development patterns are continued, energy intensity level in both regions may surpass China's policy targets in 2010, and GDP growth as well as energy consumption exceed possible pathways under policy target by 2020. Thus, appropriate measures are urgently needed to lower energy intensity and consumption. Based upon these analyses as well as the Chinese government's policy orientation, we propose two options as alternative scenarios for improving practices in energy-intensive industries, particularly targeting the cement and steel production sectors. These options are: 1) diffusion of highly energy efficient technologies into these industries and 2) promotion of a circular economy and industrial symbiosis. We highlight that these options can potentially lead to energy savings and reductions in resource consumption associated with industrial activities and can serve as a regional model for more sustainable industrial activities in China.

Keywords— BAU Scenarios, Circular economy, Divisia analysis, Energy intensity, Technology diffusions.

1. Introduction

China has been enjoying continuous economic growth over the last few decades attendant to its rapid industrialization. Urbanization is also taking place at an unprecedented pace, and demands for resources and materials used in urban infrastructures are a driving force behind the increasing production of materials such as cement. Such economic growth and urbanization has brought a variety of challenges, such as resource overconsumption, massive stocks of resources in urban areas, environmental pollution and societal inequality. Given the sharply increasing amount of energy and resources being consumed, the Chinese government aims to take a proactive approach to pursue sustainable development. Its 11th Five-Year Plan (FYP) identifies three main challenges: 1) emerging bottlenecks of natural resources and energy supplies, 2) environmental and ecological degradation and 3) social conflicts caused by unbalanced development (Yabar et al. 2009). To tackle these challenges, China introduced the concept of a

“circular economy” (CE) (Zhang et al 2009).

Among others, increasing energy consumption is the primary concern in China. Importantly, the industrial sector (secondary industries) plays a crucial role in Chinese economic development and accounts for more than 40% of the country’s gross domestic product (GDP) (NBSC 2008). China’s cement and steel industries, which are two of the most energy-intensive industries and the contributors to growing energy consumption in China, have demonstrated especially sharp increases in production over the last few decades. Though China has made significant improvements in overall energy intensity and resource consumption in the last two decades, its energy intensity is still high compared to other nations, such as Japan.

Notably, the production of steel has more than tripled and the production of cement has doubled since the year 2000, and these trends are likely to continue in the years to come. Particularly, urbanization, one of the most notable characteristics of China’s recent history, will continue to be a driving force for the increasing demand for materials, such as cement and steel, as they are indispensable components of urban infrastructure. Shen et al. (2005) conducted empirical studies in China and demonstrated that both cement and steel productions increased exponentially in relation to urbanization ratio.

Given the predicted increase in cement and steel production in coming decades, significant technological improvements and appropriate policy implementations are obviously critical to achieving the government’s policy goal of a 20% improvement in energy intensity by 2010 from the base year 2005 and a 50% improvement by 2020 from the base year 2000. Energy intensity improvement is also crucial for the reduction of CO₂ emissions, especially when the government pursues another policy target of reducing CO₂ emissions per unit of GDP by 2020. Energy efficiency improvement in the industrial sector is thus becoming a critical issue in China. In effect, China has carried out overall energy intensity analyses at the country level (Lin et al. 2006, Chai et al. 2009, Zhao, Ma and Hong 2010), but as yet, regional level analyses are limited. Given that regional industrial activities are increasingly essential for performance at the country level, it is highly important to discuss energy intensity trends and future prospects at the regional and individual provincial level as well.

The Yangtze River Delta in China, which is the geographical focus of this study, comprises 16 cities in the triangular-shaped area of Shanghai, southern Jiangsu Province and northern Zhejiang Province. It is one of the fastest growing regions in China and has experienced a tremendous change of land use (Long et al. 2006). The area accounted for 22% of the country’s gross secondary industrial production outputs and 30% of national tertiary industrial output in 2004 (Chinese Statistical Bureau 2005). For instance, crude steel production in Jiangsu Province between 1997 and 2007 grew by almost 10 times, from 4.75 to 47.21 million tons, while cement production during the same period expanded from 40.31 to 118.50 million tons (NBSC 2008).

Such industries will be likely to continue to play an important role in the regional gross domestic product.

Given the continuing growth of industrial activities, the pursuit of energy efficient industrial systems in the region could serve as a model for other regions in China in the coming decades. In this study, we pay special attention to industrial sectors of two important administrative areas of Shanghai City and Jiangsu Province that have different socioeconomic conditions and industrial structures. Shanghai City is a typical large industrial and business-oriented city and Jiangsu Province has several main cities, such as Suzhou, and its economy is developing very rapidly as it undergoes industrialization and the secondary industry constitutes the core economic activities.

In this paper, we aim to analyze the actual trends in energy intensity and consumption status in Shanghai City and Jiangsu Province and then argue possible options for more energy and resource efficient industrial systems in the region. First, we examine chronological trends of energy intensity and factors involved in the change in energy intensity both in Shanghai City and Jiangsu Province by applying Divisia analysis. Subsequently, taking into account China's policy orientation and major forces driving socioeconomic development, such as chronological trends in demographics and economies, we discuss possible energy consumption status of the case study areas in 2010 and 2020. We demonstrate that energy intensity policy targets in China by 2010 and 2020 likely cannot be attained if Business as Usual (BAU) development continues. We then argue that alternatives such as promotion of technology diffusion and a circular economy in industrial sectors shall play important roles in directing sustainable industrial activities while showing potential energy and resource input savings for the cement and steel industries. Particularly given that local or regional practices are of increasing importance for realizing sustainable development at the country level, the analyses for the two different administrative areas shall provide useful information about a development pathway for energy efficient industrial systems in China.

2. Energy Intensity and Policies in China

The industrial sector plays a central role in China's economy. The iron and steel sector is the country's second largest industrial user of energy and the largest industrial source of CO₂ emissions (IEA 2008). The steel industry in China, in particular, has experienced a dramatic increase in production since the year 2000. Since steel production alone is the main industrial contributor to greenhouse gas emissions and the cause of SO_x and NO_x emissions, technology improvements with appropriate policies both aiming at energy efficiency and pollution minimization must be implemented. Improving energy and resource consumption efficiency in the industrial sector is crucial to the nation's environmental efforts as a whole.

In the period from 1980 to 2000, China achieved not only remarkable economic growth, but also continuous improvement in overall energy intensity. In fact, in this period China quadrupled its GDP while its energy consumption only doubled, improving the energy intensity by 50% (NBSC 2008). The success in decreasing energy intensity in these two decades has been attributed to policy reforms aimed at efficiency and productivity (Sinton, Levine and Wang 1998). Since the middle of the 1990s, marked efficiency improvements have been achieved in energy-intensive industries such as metallurgy, cement, paper, textiles, oil and coal processing, and electrical power generation (Hu et al. 2005, Liao et al. 2007).

However, during the 10th Five Year Plan (FYP) between 2001 and 2005, the trend reversed and energy intensity began to increase after 2001. Many studies explain this increase as being due to significant structural changes within the industrial sector (Ma and Stern 2008), i.e., the expansion of secondary industries became focused on energy-intensive sectors, especially cement and steel. In other words, energy efficiency gains were insignificant compared to production increases in those energy-intensive sectors.

In addition to the structural shift in the economy to more energy-intensive industries, another notable factor that explains the energy intensity increase in China is that a decline was seen in the ratio of industrial technical innovation in (Andrew-Speed 2009). At the country level, these analyses of energy intensity and the factors involved in the intensity changes have been vigorously conducted, but energy intensity analysis at the regional level has been lacking. In the following section, we analyze the status of energy intensity in Shanghai City and Jiangsu Province.

3. Energy Intensity Trends in Shanghai City and Jiangsu Province

3-1 Divisia Analysis

We carried out an analysis of energy intensity trends in Shanghai City and Jiangsu Province. Technically, the energy demand in the production sector can be decomposed into the total output and energy intensity of each sector:

$$E_t = \sum_{p \in P} E_t^p = \sum_{p \in P} \frac{E_t^p}{Y_t^p} Y_t^p = \sum_{p \in P} \alpha_t^p Y_t \cdot s_t^p \quad (1)$$

where t is the year, α^p is the energy intensity of sector p , Y is the gross regional product (GRP), Y^p is the added value of sector p , and s^p is the output share of sector p in the GRP. Dividing both sides by Y yields the energy intensity decomposition equation:

$$\frac{E_t}{Y_t} \equiv I_t = \sum_{p \in P} \alpha_t^p \cdot s_t^p \quad (2)$$

We then determine the sources of changes of the energy intensity using the “Divisia” index approach (Choi and Ang 2003):

$$\Delta I = \sum_{p \in P} S^{p*} (I_{t+1}^p - I_t^p) + I^{p*} (s_{t+1}^p - s_t^p) \quad (3)$$

where S^{p*} and I^{p*} are weight functions. This equation indicates that energy intensity changes can be decomposed into intensity effect and change in the output share of primary, secondary and tertiary industries (i.e., structural change effects). For example if energy intensity within a sector decreases due to technological progress (i.e., intensity effect), then the total energy intensity would decrease if other factors remain equal. Likewise, if the share of energy intensive sectors such as the cement industry increase (a structural change), the total energy intensity would increase, if other things remain equal. Historical data on energy consumption by sector and GRP were obtained from published statistical data (NBSC 2008, SMSB 2006, and JPSB 2009). All GRP values were adjusted to base year 2000.

3-2 Results of Divisia Analysis and Implications

1) Shanghai City

The results of aggregate Divisia decomposition analysis for the years from 1996 to 2005 in Shanghai City are presented in Fig. 1. In the Divisia analysis, negative values for Divisia (I) and Divisia (S) demonstrate the advantageous effects of energy intensity improvements and structural changes, respectively, in comparison with the previous year while positive values show disadvantageous effects. The figure indicates that the energy intensity effect was the main component affecting overall energy intensities in Shanghai City. Notably, except for the time around year 2000 when energy intensity worsened compared to the previous year, continuous improvement in energy intensity is observed. In general, improved energy efficiency in the industry sector, assumingly driven by stricter regulations by the government, has contributed to overall reduction of energy intensity. Indeed, the government, for example, provided some guidance and policies which actually eliminate inefficient facilities for cement productions (Price and Galitsky 2006).

Figs. 2 and 3 demonstrate the effect of energy intensity by sector (primary, secondary and tertiary) and that of industry structural change, respectively. The trends visible in Figs. 2 and 3, show that secondary industry was the main driver for improvement in both intensity and structural changes. Of the two factors, energy intensity improvement within secondary industries seems to have been the primary contributor to the overall change. One factor that probably caused energy intensity improvement for the secondary sector can be technological

advancement. It is assumed that the technology level in Shanghai City is relatively high because of its large scale of factories, large inflows of foreign capital, and the area's export orientation. For example, one large company, the *Bao* steel group corporation, dominates the steel industry in Shanghai City. Large scale manufacturing tends to possess energy efficient technologies and its export orientation demands continuous efficiency improvement to stay competitive. The other potential factor that improves energy intensity is structural change within secondary industries. High-tech industries in Shanghai City have grown rapidly (Zhang et al. 2008), while the share of cement and steel industries have already saturated around 2007 (SMSB 2009). Because high-tech industries are less energy intensive than heavy industry, the increase share of such industries improves the energy intensity of secondary industry.

As for structural effects, recently Shanghai City has been developing as a rather business-oriented city, with secondary industry's share of output gradually decreasing. GDP share of secondary industries in Shanghai City decreased from 57% in 1995 to 46% in 2008, while that of tertiary industries grew from 41 to 54% during the same period, indicating that tertiary industry constitutes Shanghai City's industrial core (NBSC 2009). In addition, the scale of output of the production of these materials in Shanghai City is much smaller than in Jiangsu Province. This could indicate that the cement and steel industries in Shanghai City have stabilized or become saturated recently.

2) Jiangsu Province

Due to a lack of energy data available before the year 2000, the Divisia analysis was conducted for the period between 2001 and 2008, for which official data is available. As the data in Fig. 4 illustrates, a remarkable deterioration of the aggregate effects of energy intensity and structural changes is observed in the period from 2003 through 2005, which came later than the case in Shanghai City. From Figs. 4, 5 and 6, worsening in secondary industries appears to be the main driver for overall deterioration during the period caused by changes in both intensity and structure of secondary industry. In fact, these figures imply that rapid growth in the steel and cement industry could have caused the deterioration in energy intensity and structural effects of the secondary industry. However, after 2005, these two effects suddenly came to have negative values, indicating efficiency improvement. Given that the share of secondary industry stabilized (JPSB 2009), these improvements suggest technological progress started to occur in the energy consuming industries in Jiangsu Province around that time.

However, if the energy intensity trends in Jiangsu Province and Shanghai City are compared, it can be seen that there is yet much room for energy intensity improvement in Jiangsu Province, as shown in Fig. 7. A steady improvement has been observed in the energy intensity of secondary industry in Shanghai City whereas the improvement is relatively slim in Jiangsu

Province. In fact, there are many small cement and steel factories with relatively energy-inefficient technologies in the Jiangsu Province (China Cement Association 2008), whereas one large, energy efficient steel company, the *Bao* steel group corporation, dominates the Shanghai City market, making it likely that outdated facilities are becoming rare in Shanghai. Equally importantly, the outputs of cement and steel production have been growing steadily in Jiangsu Province and it is possible that facilities of any efficiency, including the least efficient types, are being installed in order to catch up with rapidly growing demand, making energy intensity improvements rather slow. In addition, the share of secondary industries to total GDP has continued to increase, i.e., 52% in 2000 to 55% in 2008, making secondary industries the core of the area's industrial activities.

With all these elements in mind, replacement of these outdated technologies with highly energy efficient technologies will be an important step for the industry in coming decades. The figures provide a rationale for making efforts toward a fast and effective diffusion of Best-Available Technologies (BAT) into production processes in the region.

4. Business as Usual Development and Policy Targets

4-1 BAU Energy Demand Analysis

We studied the aspect of energy intensity both in Shanghai City and Jiangsu Province in the previous section. Next, we analyze the business as usual (BAU) development scenario and examine the approximate values and likely trends for total energy consumption of Shanghai City and Jiangsu Province in relation to China's policy targets both in short term (by 2010) and the mid-term future (2020). As driving forces associated with energy demand growth, we examined GDP growth, population and industries' technological levels. With such information, we intend to argue energy consumption status in 2010 and 2020, and discuss whether or not energy consumption assuming the industry continues BAU is likely to meet policy targets set by the Chinese government.

Given the heterogeneity in terms of socio-economic conditions in China, it may not be practical to set an equal target for all provinces. In fact, there is a slight difference in target values depending on the municipal governments. The 11th Five-Year plan in Jiangsu Province individually set a target of 20.75 % improvement in energy intensity between 2005 and 2010. Acknowledging such slight differences across provinces, we hereby argue in relation to the overall targets (e.g. 20% reduction in energy intensity) as essential milestones.

The BAU scenario uses the current trends as a basis for GDP growth forecasts, population growth, and elasticity (percentage change in energy consumption to achieve 1% change in the national GDP). Under this scenario, the production of materials such as cement and steel are

assumed to proceed at the current pace without big changes in industrial practices and lifestyles, and only nominal changes are assumed for technology innovations in industries. In principle, the government sets the target of 7.5 % annual growth of GDP on average in elasticity.

First, we estimate the likely socio-economic conditions, such as GRP (Gross Regional Product) and Population, in Shanghai City and Jiangsu Province for 2010 and 2020. For forecasting GRP and population, we estimate parameter values for the following regression equations using the Vector Auto-regression (VAR) model, using the past 30-year data from 1978 to 2008 which is the longest data officially available, both for Shanghai and Jiangsu (SMSB 2006 and JPSB 2009):

$$GRP_t = \alpha_0 + \alpha_1 GRP_{t-1} + \alpha_2 GRP_{t-2} + \mu_t + \nu \quad (4)$$

$$Pop_t = \beta_0 + \beta_1 Pop_{t-1} + \beta_2 Pop_{t-2} + \mu_t + \nu \quad (5)$$

where α , β are the parameters estimated from the past data since 1978, and μ , ν are error terms. Note that it is predicted that population in China shall grow at least until 2020 (Liang et al. 2007). Hence, we considered that the regression analyses above based upon the past data, all of which turned out to be statistically significant, would be relevant for the purpose of this study.

For energy consumption, data is available only between 1990 through 2007 for Shanghai City. Hence, we estimated energy consumption status between 1978 though 1989 by applying official elasticity values available. Based upon these data, we demonstrate the following regression using ordinary least squares for only Shanghai:

$$Energy_t = \gamma_0 + \gamma_1 \ln(GRP_t) + \gamma_2 (GRP/Pop)_t + \gamma_3 Intensity_{t-1} + \gamma_4 trend + \sigma_t \quad (6)$$

where γ is a parameter estimated from the past data since 1978 and σ is an error term. The results show that all the parameters are statistically significant with expected signs. Together with the values of the forecasted GRP and population, we also computed future values of energy consumption for Shanghai based on the regression equation (6).

In the case of Jiangsu Province, official data on energy consumption is available only between 1995 and 2008, while population and GRP data are available for the past 30 years. Hence, regression analysis used for the case of Shanghai City is not valid due to the lack of energy data. We thus look into the actual energy consumption trend from 2005 through 2008 and analyze the trend in relation to the policy target by 2010 and the gap between actual growth trend of energy and GRP and the possible pathways with the mid-term policy target in 2020.

4-2 Results and Implications

The result of the analysis of the BAU scenario for energy consumption and intensity by 2010 in Shanghai City is shown in Figs. 8. The government's energy consumption targets in the 11th FYP aim to reduce energy intensity by 20% in the period from 2005 to 2010. Note that data in 2008, 2009 and 2010 in Fig. 8 is derived from the calculation above and energy intensity is presented in the form of ratio relative to the value of 2005. The result indicates that the intensity target of 20 % reduction by 2010 is unlikely to be achieved in Shanghai City although improvement in the intensity has been observed to some extent.

Based on China's mid-term target to quadruple GDP while doubling energy consumption for the period 2000-2020 (i.e. 50% improvement in energy intensity), we analyzed the possible energy demand pathways in Shanghai at 2020, by connecting the starting point (energy consumption in 2000) and the policy target in 2020 in terms of GRP and energy consumption, with the assumption that both GRP and energy consumption will grow at the same ratio annually. Fig. 9 illustrates the gap between actual growth trend of energy and GRP growth and the possible pathways with the policy target to be met in 2020. It clearly indicates that both GRP and energy consumption has been growing at much higher ratio than the assumed pathway in Shanghai City.

In fact, according to our regression analysis, the energy intensity level will be improved by 33 % in 2020, compared with the base year of 2000, with the calculated assumption that GRP shall grow approximately by 9.8 times while energy consumption level expands by about 6.6 times. Again, despite the improvement of energy intensity, the analysis forecast that the mid-term policy target of 50 % energy intensity reduction by 2020 will not be an easy task.

A study has also forecast energy consumption levels assuming BAU scenarios in Shanghai City using its own models and concludes that the energy demand in Shanghai City in 2020 will be 3.91 times that of 2005, indicating that energy demands under the BAU scenario certainly will not meet the policy target (Li et al. 2009). The important message from the analyses, including our approach, is that the energy demand level under the BAU scenario will likely not meet policy targets if the current conditions continue. Given that Shanghai City possesses one large scale, energy efficient company and that cement and steel production trends and the impacts of such industries upon the whole economy (GRP) in Shanghai City have been gradually decreasing relative to other industries such as services, the message that there will still be a gap between the achieved levels and the target is particularly striking.

As for Jiangsu Province, the actual energy consumption trend in relation to the policy target by 2010 is illustrated in Fig. 10 and the gap between actual growth trend of energy and GRP and the possible pathways with the policy target by 2020 is shown in Fig. 11. According to Fig.10,

energy intensity level appears to have been improving towards the policy target set in 2010. Nonetheless, as indicated in Fig. 11, there is a big gap between actual growth trend of energy and GRP growth and the possible pathways based on the policy target to be met in 2020. The gap appears much higher than the case of Shanghai City. This indicates that though the indicator “energy intensity” shows rather good performance, actual energy consumption as well as GRP growth, in effect, is quite huge. Energy consumption grew 2.7 times between 1995 and 2008, while energy growth in Shanghai City in the same period was about 2.4 times. After all, multi-lateral observation and analysis are essential in this regard, rather than relying upon a single indicator (energy intensity).

As illustrated in Figs. 9 and 11, both GRP and energy consumption have been growing much faster than the expected mid-term targets both in Shanghai City and Jiangsu Province. This analysis clearly implies that there is a big gap between the BAU development scenario paths and policy targets. To argue energy consumption aspect comprehensively, it is necessary to extend our viewpoints to various areas such as industrial practices, urban systems such as transportation, and even lifestyle changes. This paper, however, focuses primarily on the industrial sector. Though industries’ energy intensity has recently been basically improving in both Shanghai City and Jiangsu Province as indicated in the Divisia analysis, further innovations and paradigm shifts are needed to reduce energy consumption associated with industrial activities, given the likely continuing growth in the energy intensive industrial sectors.

In order to discuss the scale of likely growth in such material productions, we also forecast possible production levels and trends of both cement and steel in Jiangsu Province in 2020. To predict cement and steel production, we estimated the following regression equation using historical data available for the years 1978 to 2006:

$$Y_t^i = \alpha_0 + \alpha_1 pop_t + \alpha_2 gdp / pop + \alpha_3 region + \alpha_4 (gdp / pop \times region) + \varepsilon_t^i \quad (7)$$

where Y denotes the amount produced in region i in year t , α_0 through α_4 are estimated parameters, and ε is an error term. The third and fourth terms on the right-hand side capture the regional differences between Shanghai City and Jiangsu Province. Using these estimated parameter values together with the *Pop* and *GRP* forecasts shown in equations (4) and (5), we predict the possible future stream of cement and steel production.

The results imply that the production levels of both cement and steel will likely accelerate considerably in 2020, indicating that the cement and steel production in Jiangsu Province will likely increase from the current production of 119 and 47 million tons in 2007 to approximately 846 and 485 million tons in 2020, respectively. Predicted values based on the BAU scenario shall vary depending on the forecasting method applied and various socio-economic factors

taken into account, but the important implication from these results which we intend to highlight here is that future energy consumption associated with the production of cement and steel will sharply increase with the rapid rise in production unless energy intensity is drastically improved.

5. Options and Strategies for Industrial Sectors

In this section we discuss possible options for sustainability and energy-efficiency that should be promoted in the industrial sector particularly addressing cement and steel industries, which is required of to improve energy intensity and bridge the likely gap between the BAU development scenario and the policy targets. By taking into consideration the results of the Divisia analyses, BAU development analysis as well as Chinese policy orientations, we discuss two promising options; 1) diffusion of best-available technologies (BATs) and 2) promotion of a circular economy with industrial symbiosis.

5-1 Diffusion of Best-available Technologies

We demonstrated that energy demand assuming BAU will not be able to meet policy targets. Given that secondary industry accounts for a large part of total energy consumption, energy efficiency improvements or reductions in energy intensity in the industry are fundamentally critical. Energy intensity in secondary industries should be improved, especially in Jiangsu Province where the secondary industry is and will remain the core industry for some time. Small steel plants account for 83% of the total plants in China and are 48% less energy efficient than large plants, in general (Wang et al. 2007). As explained in section 6-1, there is also a big difference in energy efficiency between ordinary facilities applied in China and Best-available technologies (BATs). Replacing outdated and small facilities with new and best-available technologies is thus fundamentally important to improved energy intensity and should be accelerated.

Towards the policy target for 2010 and 2020, the adoption of world's best energy-efficient technologies for cement and steel industries must be pursued, driven by technology transfer from other countries or self-efforts within China. Appropriate policy schemes must be applied to facilitate the introduction and diffusion of BATs to replace the current technologies in secondary industries. For example, financial incentives should be effectively provided to relevant industries so that the industries are able to pursue the smooth adoption of BATs.

5-2 Circular Economy and Industrial Symbiosis

This option introduces a wider scope of resource circulation by including the use of wastes from urban areas and industrial sectors in the production lines of the cement and steel industries. The option is based on China's recent policy orientation, referred to as the circular economy (CE). The CE model is intended to decouple economic growth from environmental pressures. "The Chinese Circular Economy Promotion Law" became active in January, 2009 (Mo, Wen and Chen 2009). This model focuses on improving resource productivity and eco-efficiency while enhancing the quality of life of the citizens (Zhang et al. 2009). The objective of the CE model is to promote resource circulation at the industry level (small-sized circulation), the eco-industry level (mid-sized circulation) and the city/provincial level (regional circulation) to maximize the potential of resource utilization.

Promotion of eco-industry, by utilizing municipal wastes such as plastics and organic wastes as well as by-products from industries can help reduce the volume of raw materials used and increase resource productivity (product outputs per resource inputs). In addition, organic wastes, such as sewage sludge, can be used not only as raw material for making cement, but also as alternative carbon neutral fuels. Such practices of by-product utilization particularly at the region level are still under development in China and the practices may be applied and facilitated in the near future, as this idea is fully in line with the circular economy concept pursued by the Chinese government.

6. Prospects of Proposed Options

6-1 Diffusion of Best-available Technologies

There is great potential for improvement in energy efficiency, particularly in the Jiangsu Province, if current industrial technologies and processes are replaced by BATs. In fact, the cement and steel industries are likely to continue growing in Jiangsu Province, as opposed to the case in Shanghai City where cement and steel production have recently become saturated and stabilized (NBSC 2008). Hence, we focus our analysis upon Jiangsu Province's case in order to discuss the degree of improvement achievable by introducing BATs.

This option (technology diffusion) assumes the introduction of the world's best energy efficient technologies for cement and steel industries. The analysis is based on the Intergovernmental Panel on Climate Change (IPCC) approach (Tanaka 2008), where energy efficiency performance is measured in terms of absolute energy consumption, energy intensity, and diffusion and penetration of specific energy-saving technologies.

Potential energy savings by use of efficient technologies

We first investigated the types and capacities of existing facilities in the cement and steel

industries in Jiangsu Province. For the steel industry, we confirmed that ten steel companies operate in the province as of 2007. We investigated the types of facilities used in the blast furnace process (the most energy consuming process of all steel making processes) of the ten companies, based on production capacities of over 3000 m³, between 2000 and 3000 m³, between 1000 and 2000 m³ and less than 1000 m³. We confirmed that out of the nine companies for which we could get data, two had facilities with capacities over 3000 m³, one had facilities with a capacity between 1000 and 2000 m³, while the other six companies had facilities with capacities less than 1000 m³.

The energy efficiency of blast furnace facilities depending on capacity compared to that of BATs (Worrell et al. 2008) and production status in Jiangsu Province as of 2007 is illustrated in Table 1. Assuming that all the facilities of the nine companies discussed above are replaced by facilities employing BATs, we calculated the potential energy savings in Jiangsu Province, using the data in Table 1. The potential energy savings is equivalent to almost 3.25 million tce (tons carbon equivalent), which is estimated to be almost 15 % of the total energy consumption in Jiangsu Province as of 2008. This clearly indicates that adoption of BATs theoretically has great potential in reducing the energy consumption of the steel industry. Moreover, as shown in Table 1, small-scale plants, which are in principle energy inefficient, account for around 28% of total plants. If policies can address both the issues of innovation and replacement of technologies, the potential energy savings are very promising.

As for the cement industry, we confirmed that there are 386 factories located in Jiangsu Province as of 2008, with a total production capacity of 125 million tons (China Cement Association 2008). We also identified that depending on the factory, there are five types of facilities employed, as defined by the China Cement Association. Broadly categorized, there are, in principle, two types of production facilities in the clinker process in cement production: 1) Rotary Kilns and 2) Shaft Kilns. Four of the five types of facilities in Jiangsu Province fall into the category of Rotary Kilns, while the remaining type is categorized as a Vertical Shaft Kiln.

A study indicated that typical thermal energy intensities of facilities using the clinker process, (the most energy intensive process in the cement industry) in China are between 3.3 and 6.1 GJ per ton of cement production for rotary kilns and between 4.5 and 6.1 GJ per ton for vertical shaft kilns (Price and Galitsky 2006). This illustrates that, depending on the facility, there is a fairly wide range of energy intensities for cement industry facilities in China. Price and Galitsky (2006) also showed that China's overall energy intensity in the cement industry was 4.8 GJ per ton while international best practice for dry process cement kilns is 3.0 GJ per ton.

Given the difference between the energy efficiency of existing facilities and BATs, together with the total amount of cement production in Jiangsu Province, there is great potential for energy savings in the cement industry. What's important is the smooth and effective

development of international technology transfer so as to diffuse BATs into regions such as Jiangsu Province. Barriers to spur technology transfer and development in China, such as lack of financial mechanism, have been studied (Price and Galitsky 2006, Lin et al. 2006) and it is thus indispensable to design effective policies to overcome such barriers.

6-2 Loop-closing Systems for Industrial Symbiosis

In the second option, saving of resource inputs and energy consumption associated with industrial activities is a primary concern. The idea is the core principle of circular economy and loop-closing models within industrial sectors or through urban-industry linkages. The Chinese government has been trying to encourage the implementation of the circular economy concept at different levels of enterprises: Eco-Industrial Parks (EIPs), cities, provinces, and regions. However, resource-circulation or circular economy practices at the city and regional level are still in the infant stage, but will have great potential in the near future, thus making this option promising.

Japanese Practices for Loop-closing Systems and Implications

Some examples of promising practices at the industry level can be found in Japan. “Eco-towns” have been developed by governmental initiative to promote the utilization of by-products, wastes and recovered materials from industries for production purposes (Morioka et al. 2005). In fact, similar type of by-product utilizations at industrial complexes have already been promoted in China at Eco Industrial parks (EIPs) designated by the government. EIPs, such as Suzhou National New and High-Tech Industrial Development Zone located in Jiangsu Province, have been actively operated (Zhang et al. 2009). However, following practices observed in Japan are not well developed and some can be effectively applied.

One example is the promotion of by-product recycling driven by the steel (or cement) industries themselves. Nippon Steel Corporation, the largest steel maker in Japan, has been developing the capacity to promote a recycling system for by-products they generate. Production of one ton of iron usually generates 600 kg of byproducts such as slag, dust, and sludge. These by-products are used as raw materials in the steel works or utilized by other industries for cement production or as roadbed material. Recently, by-product recycling rates as high as 98% have been achieved by the company (Nippon Steel Cooperation 2008). Slag and fly-ash (about 68%) are conveyed to the cement industry and other by-products (30%) are reused in steel making processes within the company.

As another example, wastes from urban areas and households can also be utilized in industry. In fact, plastic wastes are utilized intensively in the steel industry. As of 2007, about 150 thousand tons of plastics, accounting for about 30% of the plastic wastes collected by

municipalities in Japan, were used in Nippon Steel operations. Household waste and sewage sludge can be used as raw materials and an alternative energy in the cement industry, as well. In Japan's cement industry, inclusion of sewage sludge as a raw material increased from 2.649 million tons in 2004 to 3.038 million tons in 2008 and use of plastics for fuel grew from 283 tons to 427 tons during the same period. Combining all the waste and by-products used as alternatives to raw materials and fuel, an average of about 448 kg of wastes and by-products are applied to produce one kg of cement in Japan (Japan Cement Association 2006).

These practices in Japan can be partly promoted in the industrial systems in China in coming years. Particularly, by-products and wastes utilizations at the region level combining industries and urban systems have yet to be developed and thus shall have a big potential in near future. Besides suitable technologies, effective linkages between industries and urban systems are highly essential.

Potentials of Wastes and By-products Utilization in Case study areas

In the resource-circulation option, we can assume similar types of by-product utilization and resource-circulation in Shanghai City and Jiangsu Province. A comprehensive study forecast that the amount of municipal wastes to be generated in Shanghai City would be 5.956 million tons in 2015 and 7.134 million tons in 2020, demonstrating a sharp increase from 4.233 million tons in 2000 (World Bank 2005). In the 12 cities in Jiangsu Province that have populations over 0.75 million, the predicted amounts of municipal wastes in 2015 and 2020 are 8.896 and 10.656 million tons, respectively, again a sharp increase from 5,284 million tons in 2000. It is also estimated that the ratio of plastics in wastes by weight in 2000 averaged about 13% and will be about 14% in 2030 (World Bank 2005). Applying these estimations, we can predict that the generation of plastic wastes in Shanghai City and Jiangsu Province will likely be about 0.999 and 1.492 million tons in 2020, respectively. Hence, utilization of plastics can be a promising option in industries both in Shanghai City and Jiangsu Province.

In coming years, this option will hold promise in fostering a sustainable industrial society under the driving force of the CE policy in China, given increasing wastes volumes and the fact that large scale loop-closing option is still under development in China. Technological and social system settings are of critical importance to make such loop-closing systems work. For instance, plastic wastes from households should be effectively sorted, collected and transported to such industries. For this sorting and collection to be successfully run, public awareness must be also raised.

Though we proposed two options individually, these two options are compatible each other and should be pursued simultaneously. For example, bridging the technology gap between large- and small-scale plants can also increase the use of end-of-life products, including iron and

steel waste and plastic wastes, which will accomplish further savings in energy and resource use. This example clearly indicates the importance of an integrated approach.

7. Discussion and Conclusions

This paper examined energy consumption in industrial sectors in two economically viable regions in China: Shanghai City and Jiangsu Province. First, Divisia analyses identified that energy intensity increases in secondary industries was a primary factor behind the energy intensity increase of the overall economy in the last decade for Shanghai City and Jiangsu Province. There is great potential for improving energy intensity in secondary industries particularly in Jiangsu Province by replacing outdated and inefficient technologies in energy-consuming industries.

In the BAU development scenario, we discussed that Shanghai City will likely miss the short-term target of 20% energy intensity improvement by 2010. We found that both GDP and energy consumption level have been growing at much higher pace than the possible pathways towards the mid-term targets of quadrupling its GDP while doubling its energy consumption, under the BAU development patterns both in Shanghai City and Jiangsu Province.

As secondary industry still constitutes the core economic activity, it is important for China to design strong and effective policies that will facilitate the replacement of outdated production technologies with new and highly energy-efficient technologies. It is also essential that policies be effectively combined with the current promotion of circular economy concepts to advance both by-product exchange among industries and the use of wastes from the urban sector, creating the loop-closing systems and a circular economy.

Given that practices at the regional level are increasingly important in China, regional scenario studies such as the current paper can serve as the basis and provide a model to pursue sustainable development at the country level as well. In future studies, it is also important to combine the industrial scenario with other factors such as urban systems, making the regional scenario studies more comprehensive.

Acknowledgments

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Table 1

Potential Energy savings in iron making, Jiangsu Province (Blast furnace process, 2007)

Blast Furnace Capacity (Category)	Annual Production Capacity (10 ⁶ tons)	Energy Intensity (kgce/t) ^a	BAT Energy Intensity (kgce/t)	Unit Savings Potential (kgce/t)	Total Saving Potential by category (10 ⁶ tce) ^b
>3000 m ³	25.6602	466.2	414.9	51.3	1.32
2000-3000 m ³	5.9497	483.9	414.9	69.0	0.41
1000-2000 m ³	-	512.8	414.9	97.9	-
<1000 m ³	12.5134	536.7	414.9	121.8	1.52
Total	44.1233				3.25

^akgce/t = kilograms carbon equivalent per ton^b10⁶ tce = million tons carbon equivalent**Data and Reference sources:**

The Editorial Board of China Steel Yearbook (2008)

Worrell et al (2008), for energy intensity data for Best-available technologies

Figures:

Fig. 1 Effects of energy intensity and structural changes (Shanghai City)

(Note: The legend “Divisia (I)” indicates the change in energy intensity of industrial sectors. “Divisia S” represents the effects of industrial structure changes. “Divisia aggregate” represents the aggregation of the total effects of both Divisia (I) and Divisia (S).)

Fig.2 Effects of intensity by sector (Jiangsu Province)

Fig. 3 Effects of industrial structure changes (Shanghai City)

Fig. 4 Effects of energy intensity and structural changes (Jiangsu Province)

Fig. 5 Effects of intensity by sector (Jiangsu Province)

Fig. 6 Effects of industrial structure changes (Jiangsu Province)

Fig. 7 Comparison of secondary industry’s energy intensity between Shanghai City and Jiangsu Province

Fig. 8 Energy consumption and intensity trends by 2010 (Shanghai City)

Fig. 9 GRP and energy consumption patterns and pathways to policy target by 2020 (Shanghai City)

Fig. 10 Energy consumption and intensity trends by 2010 (Jiangsu Province)

Fig. 11 GRP and energy consumption patterns and pathways to policy target by 2020 (Jiangsu Province)

Figure 1

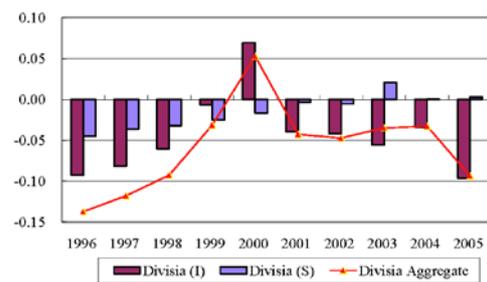


Figure 2

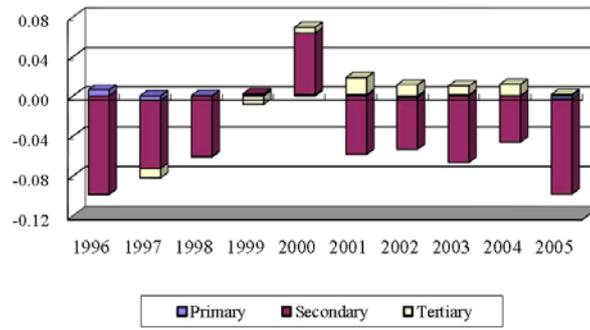


Figure 3

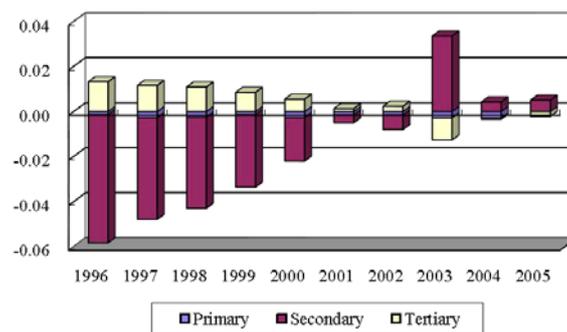


Figure 4

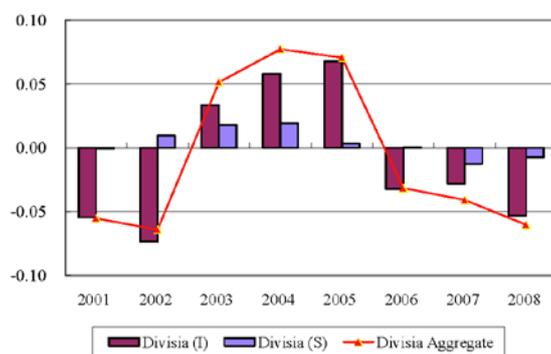


Figure 5

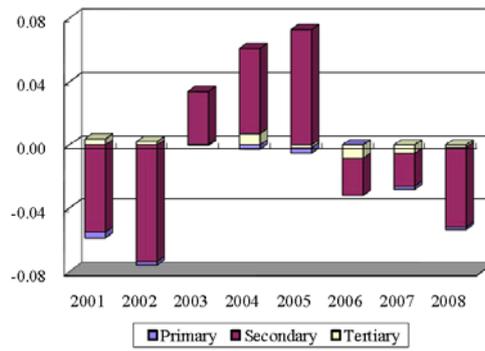


Figure 6

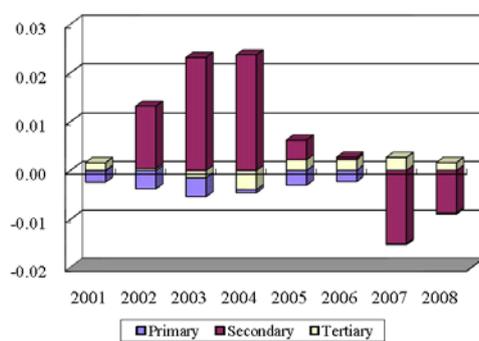


Figure 7

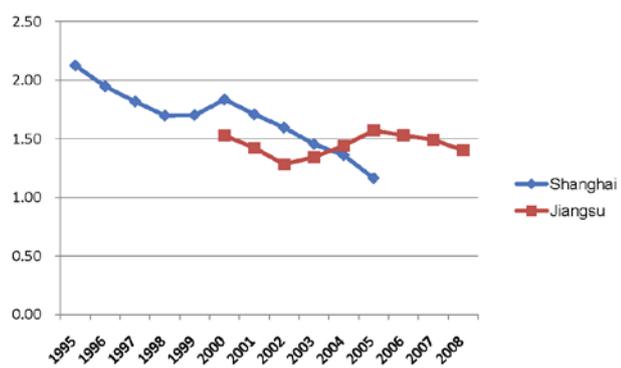


Figure 8

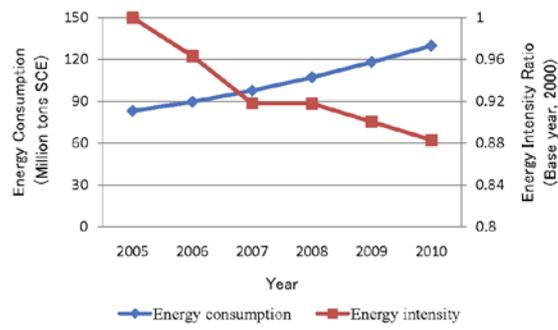


Figure 9

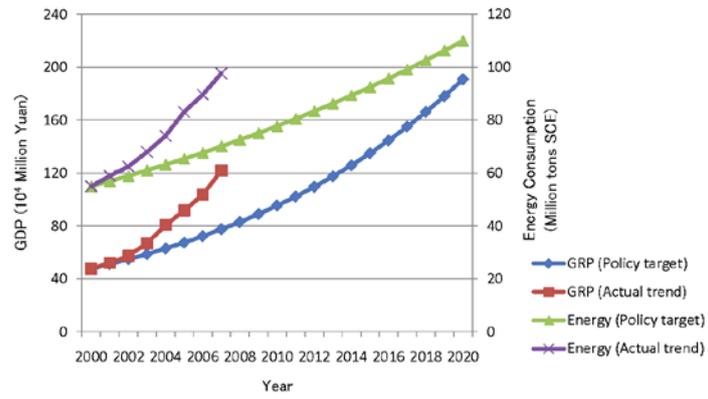


Figure 10

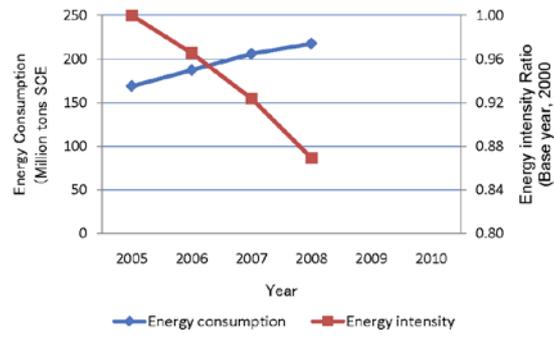


Figure 11

