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Publication Date
2008

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Environmental Energy
Technologies Division

June 2007

This work was supported the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Taking out one billion tons of CO2: the magic of China's 11th five year plan?*

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Abstract

China's 11th Five-Year Plan (FYP) sets an ambitious target for energy-efficiency improvement: energy intensity of the country's gross domestic product (GDP) should be reduced by 20 % from 2005 to 2010 (NDRC, 2006). This is the first time that a quantitative and binding target has been set for energy efficiency, and signals a major shift in China's strategic thinking about its long-term economic and energy development. The 20% energy intensity target also translates into an annual reduction of over 1.5 billion tons of CO2 by 2010, making the Chinese effort one of most significant carbon mitigation effort in the world today. While it is still too early to tell whether China will achieve this target, this paper attempts to understand the trend in energy intensity in China and to explore a variety of options toward meeting the 20 % target using a detailed end-use energy model.

Keywords: energy intensity, carbon, China, five-year-plan, target, energy policy, end-use energy model, decomposition

1. Introduction

China's 11th Five-Year Plan (FYP) sets an ambitious target for energy-efficiency improvement: energy intensity of the country's gross domestic product (GDP) should be reduced by 20% from 2005 to 2010 (NDRC, 2006). This is the first time that a quantitative and binding target has been set for energy efficiency, and signals a major shift in China's strategic thinking about its long-term economic and energy development. The 20% energy intensity target also translates into an annual reduction of over 1.5 billion tons of CO2 by 2010, making the Chinese effort one of most significant carbon mitigation effort in the world today. The Europe's commitment under Kyoto is about 300 million tons of CO2 by 2012. China's 20% energy intensity target provides further evidence that the Chinese government is serious in its call for a new "scientific development perspective" (□□□□□) to assure sustainability in accordance with long-run carrying capacity of the natural environment.

This target for energy efficiency is likely to be difficult to achieve, considering that energy consumption has grown more rapidly than GDP in the last five years and, as a result, energy use per unit of GDP (energy intensity) has increased. This recent trend in energy intensity stands in sharp contrast to the trend observed from 1980 to 2000, when energy demand grew less than half as fast as GDP and energy intensity declined steadily. China's long-term development plan, which calls for a quadrupling of GDP and doubling of energy use from 2000 to 2020, was based on this earlier experience, as are projections of China's energy consumption by major international institutions (IEA, 2004; Zhou et al., 2003). However, if the recent trend continues, not only will it jeopardize China's development goals, but it will also create significantly greater adverse environmental impacts and major threats to long-run sustainability. Further, it could introduce a huge "unexpected" disturbance to the global energy and climate system. It is in recognition of the likely costs of "run-away" energy growth that China's leaders have decided to highlight the need of reducing energy intensity.

This analysis attempts to understand recent trends in energy intensity in China and to explore a variety of options China may adopt in order to meet the 20% target based upon a detailed end-use energy model. We do

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not intend to project social economic development such as price and consumer behavior. The results are presented in three sections in this report. The first section provides a detailed analysis of energy intensity trends in China during the last ten years, highlighting that the shift in industrial structure toward energy intensive sub-sectors such as steel and cement is the leading cause of the recent rebound in energy intensity in China. The second section provides an explorative analysis of possible scenarios through which efficiency gains could be achieved to reach the 20% target. The third section summarizes key energy use indices by sectors. Finally, a set of policy recommendations is presented.

2. Recent Trends in Energy Consumption in China

Between 1980 and 2000, China achieved a quadrupling of its GDP with only a doubling of energy consumption (Figure 1), effectively decoupling the relationship between economic growth and energy consumption. This was achieved through focused policies and management practices, dedicated investment in energy conservation projects, and establishment of energy conservation institutions around the country (Sinton et al., 1998; Lin, 2005).

The low energy elasticity before 2000 was a remarkable achievement, since it is widely accepted that growth in energy use is likely to be faster than economic growth in the early stage of economic development (Galli, 1998). In fact, no other major developing country has witnessed declining energy intensity (or an energy elasticity less than one) until much later in their development process. In the early stage of economic development, industrialization and urbanization tend to lead to extensive infrastructure and housing development: both are energy- and material-intensive activities. As a result, energy intensity tends to increase. In the later stage of economic development, demand for services often grows faster than demand for goods, leading to a shift in economic structure toward the service sector, which has much lower energy and material intensity. In addition, efficiency of energy and material use also tends to increase as better technology and materials become available. Thus, energy intensity tends to decline. This is a pattern observed across economies (Quah, 1997; Janicke et al., 1989; and Ausubel et al., 1993).

China's experience from 1980 to 2000 was an exception. However, energy and economic development in China over the last few years suggests that the relationship between energy and economic growth in China may have returned to the expected range of a typical industrializing country. Since 2001, China has experienced much faster growth in energy use than economic growth, with an elasticity reaching 1.6 in 2004. While the growth in energy has moderated to some extent in 2005, the growth rate of energy consumption from 2000 to 2005 maintained a high 9.5% annual average, slightly higher than that of GDP, resulting in an elasticity of just above one (NBS 2006).

This development, while not entirely surprising, nonetheless has alarming implications. At the current rate, China's energy growth could be much faster than anticipated, leading to energy shortages and mounting environmental problems that could undermine China's own development goals for 2020. The consequences for the global energy market could be equally dramatic, since China's energy demand in 2020 would be easily twice as large as expected. Given China's reliance on coal, China's emissions of greenhouse gases (GHG) are likely to be much larger than anticipated as well, further exacerbating the problem of global warming.

In this context, it is timely that China has set a target of reducing energy intensity by 20% within the next five years. Historical evidence suggests that such a target is extremely ambitious and may be very challenging to meet. A thorough analysis of factors affecting energy intensity over the last ten years may help shed some light on what would be the best ways to achieve such a goal.

2.1 Energy Intensity Trends

Figure 2 presents energy intensity trends in China by three main sectors as defined by China's statistical administration: primary (agriculture), secondary (industry and construction), and tertiary (transportation, telecommunications, post, and retail). The GDP values are the revised figures (NBS, 2005), adjusted to 2000. It can be seen that energy intensity for the secondary sector is much higher than that for the primary and tertiary sectors. The trend in aggregate energy intensity mirrors closely that for the industrial sector with both showing a rebound in energy use per unit of GDP after 2001, after steady declines since the mid-1990s.

2.2 Structural Trends

The dominance of the industrial sector in China is not surprising, since industrial energy intensity is not only much higher than that of the other two sectors, but also because industry remains the largest sector in the Chinese economy. After 25 years of rapid industrialization, the industrial share of GDP continues to increase, while the share of the tertiary (service) sector remains flat at 40% (Figure 3). The service sector share in China is not only much lower than developed countries but also lower than developing countries. For example, India's service sector comprised about 54% of the economy in 2005, while in the US, the share reached 76.5% in 2003 (World Bank, 2006). If the share of the service industry in China reached the Indian or US levels, China's energy intensity would drop 22% and 31%, respectively. While it may be difficult to boost the share of service industries in China to the levels in India or the U.S., structural shifts in the Chinese economy could nonetheless eventually contribute significantly towards the 20% reduction target for energy intensity.

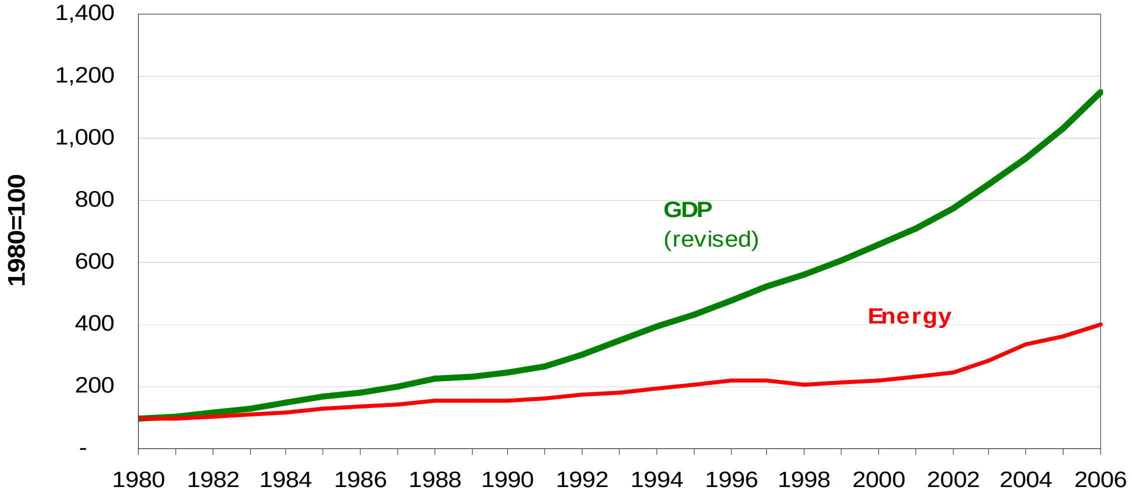

Figure 1: Energy consumption and GDP growth in China, 1980-2006

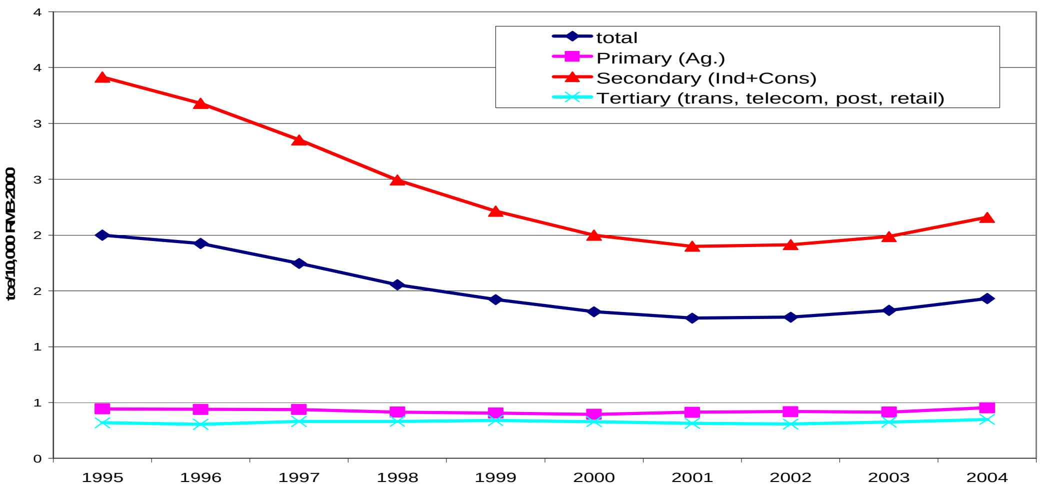

Figure 2: Energy intensity trends in China by three main sectors, 1995 to 2004[1]

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[1] China classifies energy use by agriculture, industry, tertiary, and residential sectors. Commercial building energy use is included in the tertiary sector.

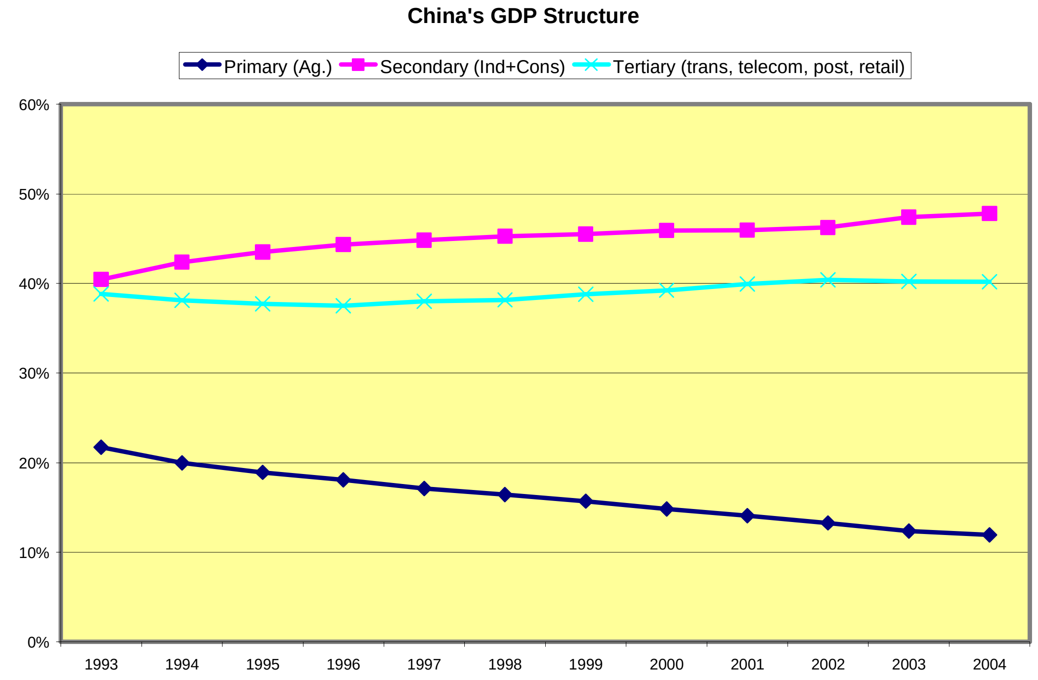

Figure 3: Sectoral shares of GDP in China, 1993-2004

2.3 Understanding Energy Intensity and Structural Shift Trends

In this section, the results of a decomposition analysis of energy intensity trends are discussed to identify the relative contributions of shifts in economic structure and changing efficiency of energy use. We used a variation of Laspeyres decomposition method presented in Sinton and Levine (1994), with a minor modification. Instead of using a constant base year, we use the preceding year as the base year to minimize the error introduced in the analysis. The modified equation is expressed as follows,

$$E^t = Q^t I^{t-1} + Q^t \sum_{i=1}^{N} S_i^{t-1} \Delta I_i + Q^t \sum_{i=1}^{N} \Delta S_i I_i^{t-1} + Q^t \sum_{i=1}^{N} S_i \Delta I_i$$

Where

E^t = energy actually consumed by industrial sector (in Mtce) in year *t*

Q^t = GDP or Value-Added (in 2000 yuan)

I_i^t = intensity of energy use in the *i*th sub-sector in year *t*

S_i = the *i*th sub-sector's share of GDP

i = reference number for sub-sector

t = the time period

N = number of sub-sectors

$\Delta I_i = I_i^t - I_i^{t-1}$

$\Delta S_i = S_i^t - S_i^{t-1}$

We first apply this methodology to aggregate data using only three sectors: the primary, the secondary, and the tertiary. Figure 4 illustrates the results of this analysis, showing the change in energy use due to inter-sector structural change and energy intensity change for each year.

It can be seen that energy intensity reduction within each sector was the dominant factor driving the decline in energy use in the late 1990s, leading to a drop in total energy intensity. However, since 2002, total energy intensity increased mostly due to the rebound in industry energy intensity (as shown previously in Figure 2). This rebound effect is particularly strong for 2003 and 2004.

Structural shift among the three sectors has always had a small positive effect on total energy intensity; that is, a growing share of the industrial sector tends to cause total energy intensity to increase, other things being equal.

At first glance, these results are counter-intuitive. In a rapidly expanding economy, new and more efficient technologies are typically deployed throughout the economy, which should lead to a reduction in energy intensity in industries. However, industrial energy intensity is determined by two factors: 1) energy efficiency in industrial sub-sectors, 2) the relative outputs of the sub-sectors. Thus, it is possible that overall industrial energy intensity could increase, even when energy intensities at the sub-sectors are declining because the relative outputs of energy intensive sub-sectors such as cement and iron and steel are rising.

Figure 5 shows that for nine major energy-intensive industries, energy intensities have declined steadily since the mid-1990s, with the exception of the electricity generation industry. This exception is likely to be caused by the heavy use of small and thus less efficient generators in the last few years when there were widespread electricity shortages, and the fact the profit margins could be eroding in the electric generation industry since the tariff has been held artificially low while fuel prices have gone up tremendously.

Further analysis of the effect of efficiency changes and structural shift among the nine industrial sub-sectors shows that from 1996 to 2003 there was steady efficiency improvement; however, the pace of efficiency gains slowed down somewhat since 2000 (see Figure 6).

In the meantime, the effect of structural shift within industrial sub-sectors – rapid growth in cement and steel production - increased in recent years, and since 2001 has overwhelmed the effect of efficiency gains. Since 2001 efficiency gains alone have not been nearly sufficient to compensate for the effect of heavy industrialization. For example, in 2003, the effect of efficiency gains in industries on energy use is about 30% of that due to structural shift among industrial sub-sectors. As a result, the overall energy intensity of industries is higher today than its recent low point in 2001.

2.4 Sub-Summary

In summary, the recent increase in energy intensity in China can be largely attributed to three main factors:

- Rapid growth in production of commodities in heavy industries (iron and steel, chemicals, cement, etc.).
- Overall growth of the industrial sector, relative to services and agriculture.
- Slow-down in energy efficiency improvement relative to structural changes.

The results of this analysis are consistent with the traditional understanding of economic development where energy intensity tends to rise in the early stage of industrialization due to rising demand for energy-intensive products, extensive infrastructure development, and urbanization. China simply has returned to normalcy in this regard, after two decades of exceptional experience.

This return to a more traditional development pattern represents a tipping point in the relationship between energy and economic development in China, and suggests that without major policy interventions both to boost efficiency gains and to accelerate the development of service industries, energy intensity of the Chinese economy could continue to rise or stay at the current level for some time to come. The rapid decline in energy intensity observed in the 1980s and 1990s is unlikely to return any time soon without such intervention. This calls for a major revision of current understanding of energy demand growth in China in the immediate future, since most projections of China's energy demand were based on a continuation of the trend experienced from 1980 to 2000. In other words, China's energy demand in the future could be much higher than projected.

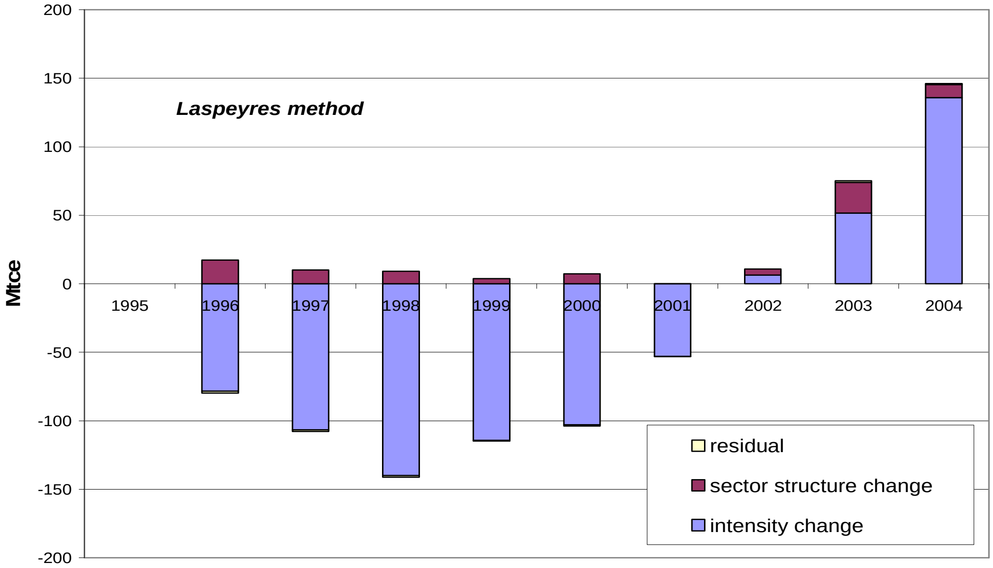

Figure 4: Inter-sector structural change versus energy intensity change

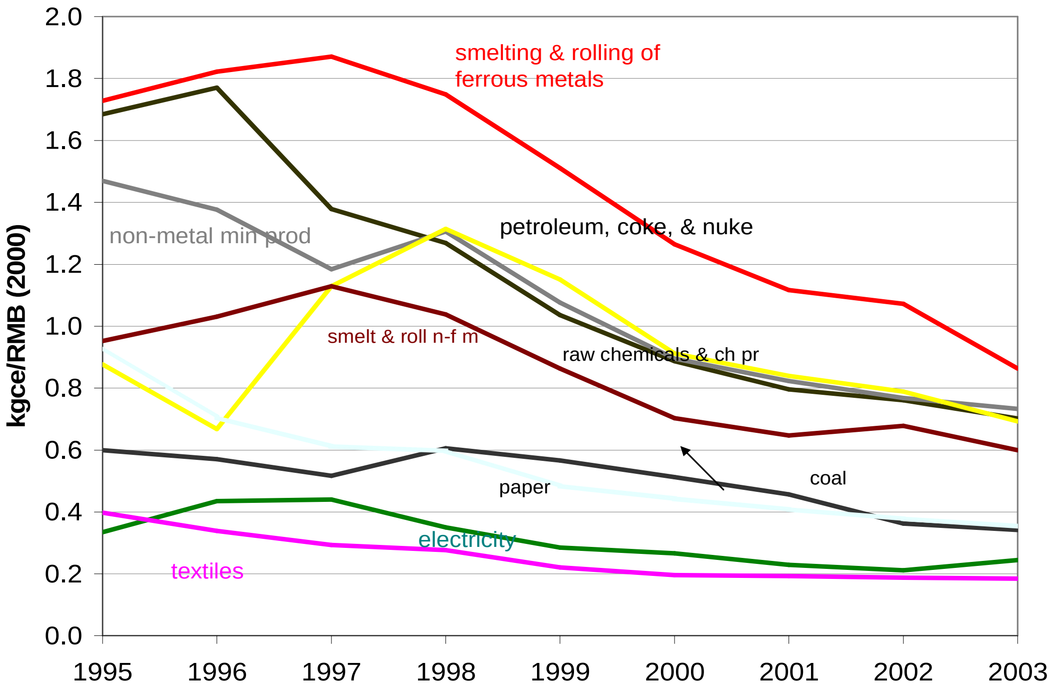

Figure 5: Energy intensities for major industry sub-sectors in China.

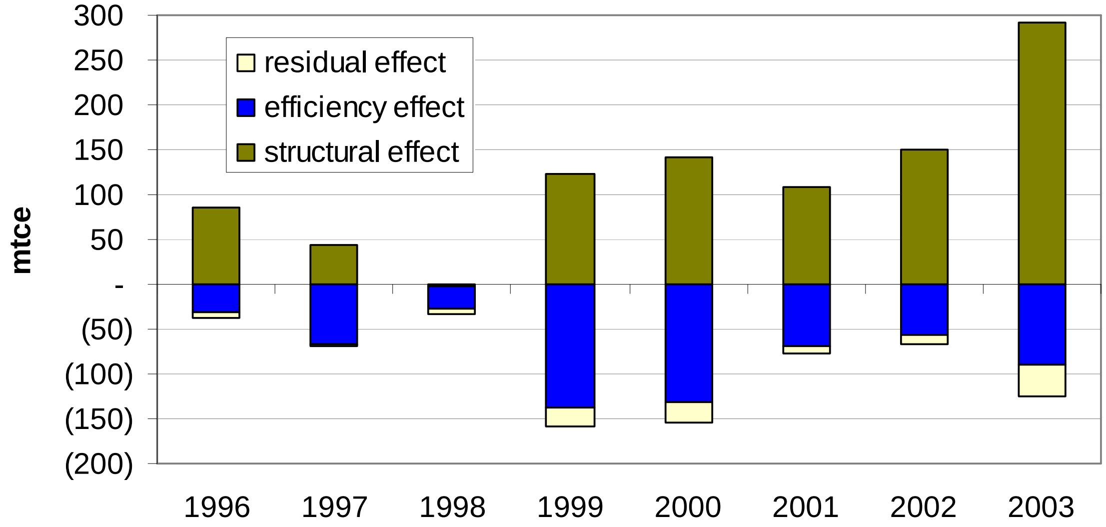

Figure 6: Effect of efficiency changes and structural shift among industry sub-sectors

3. An Analysis of Possible Scenarios Toward 20% Energy Intensity Target

In this section, we develop a series of scenarios to assess the feasibility of achieving the 20% target for energy intensity reduction from 2005 to 2010. The analysis is based on the China End-use Energy Model developed by the China Energy Group of the Lawrence Berkeley National Laboratory (LBNL). China's current development plan forms the basis of the baseline policy scenario (BPS) in the study. In addition to BPS, we develop several policy scenarios targeting efficiency opportunities in industries, appliances, and the power sector.

3.1 China's 11th Five Year Plan Energy Intensity Target

China's 11th Five-Year Plan (FYP) has set a binding target for energy efficiency: energy intensity of GDP should be reduced by 20% from 2005 to 2010. China's GDP grew at an average annual rate of 9.9% from 2000 to 2005. The 11th FYP aims for an average GDP growth rate of 7.5% from 2005 to 2010. Thus, a 20% reduction in energy intensity implies an annual growth rate (AGR) of 2.8% in energy use. However, both GDP and energy use have been growing much faster recently. In 2005, total energy consumption reached 2,225 million tons of coal equivalent (Mtce) (NBS 2006), a 9.5% increase from 2004, while the GPD growth rate was 9.9%. If China's energy/GDP elasticity remains at 1 and economic growth unfolds as forecast, total energy consumption in 2010 would reach 3,192 Mtce. To reach the 20% energy intensity target, it has to be reduced to 2,552 Mtce, or a reduction of 640 Mtce. Figure 7: presents two possible levels of energy consumption in 2010: 1) if GDP grows an average of 7.5% with an energy/GDP elasticity of 1 based on recent trends, and 2) if GDP grows an average of 7.5% and the 20% energy intensity reduction target is met.

3.2 Baseline Policy Scenario (BPS)

LBNL's Baseline Policy Scenario (BPS) incorporates the collective scope of technology choices, efficiency improvements, policy targets, fuel switching, production trends, equipment ownership and other elements of the development plan that China has proposed to shape its energy growth path to 2010. Underlying this scenario is the assumption that the GDP target of 7.5% annual average growth from 2005 to 2010 will be met. Within this scenario, intensity improvement goals are similar to those used in China Energy Development Strategy 2004 by the Development Research Center (RNECSPC, 2005). For a more detailed description of the model and key assumption, please refer to Lin (Lin et al 2006).

The BPS analysis shows that moderate technology improvement and restructuring of China's economy could lead China's energy demand to grow considerably slower over the next 5 years. Figure 8 illustrates the differences in 2010 primary energy consumption among three scenarios: 1) GDP growth of 7.5% with an energy/GDP elasticity of 1%, which approximates the business-as-usual scenario, 2) GDP growth of 7.5% and attainment of the 20% energy intensity reduction goal (EI reduction 20%), and 3) the BPS with energy demand growing at 5.0% and an elasticity of 0.67. The BPS energy demand growth rate exceeds the implied 11th Five Year Plan target of a 2.8% AGR for energy, so additional measures will need to be taken and more aggressive energy efficiency improvements will need to be implemented to bring the growth down further.

3.3 Policy Scenarios

The BPS case offers a systematic and complete interpretation of the social and economic goals proposed in China's national plan and incorporates moderate energy efficiency improvement in all sectors. Building upon the BPS case, three additional policy scenarios were prepared to assist the Chinese government to explore the potential approaches that might lead to achievement of the 20% energy intensity reduction goal. A rapid physical intensity decline in heavy industrial sub-sectors (moving 2020 targets to 2010) was addressed in the Aggressive Industrial Efficiency scenario. The Aggressive Industrial and Appliance Efficiency Aggressive scenario explores the possibility of further incorporating accelerated efficiency improvements in the building sector, particularly in appliances. The additional impact of a reduction in transmission and distribution losses and further thermal efficiency improvement is covered in the Aggressive Industrial, Appliance and T&D Efficiency scenario.

3.3.1 Aggressive Industrial Efficiency Scenario

Reduction of energy intensity across a host of industrial sectors holds great promise for achieving China's overall goal of reducing the energy intensity of GDP by 20%. The Aggressive Industrial Efficiency scenario demonstrates how an aggressive industrial energy efficiency improvement target in the 7 major heavy industry sectors (including glass, ethylene, ammonia, paper, cement, aluminum, and iron & steel) and other industries could provide a significant contribution towards achieving the 2010 target. In this scenario, the 2020 energy intensity targets for these sectors, as laid out in China's Energy Conservation Medium- and Long-Term Plan (NDRC, 2005) were brought forward to 2010. Figure 9 shows that such an acceleration of efficiency improvements in the 7 major energy consuming industrial sectors would reduce the energy growth rate from 5% in the BPS to 3.8%, thereby reducing total energy consumption from 2,833 Mtce to 2,677 Mtce in 2010.

3.3.2 Aggressive Industrial and Appliance Efficiency Scenario

Codes and standards for building and appliances have been found to be highly effective in promoting energy efficiency in many countries. Mixed approaches have been adopted in various countries, including combinations of standards for materials and equipment, to ensure retrofitted buildings also receive the most efficient technologies. Codes and standards are updated periodically to reflect changes in building practices and technologies. China has designed and promulgated new building codes and appliance standards. However, there is still a large gap with the standards in advanced counties.

The analysis encompasses both the standards levels being proposed, higher standards levels, and different levels of implementation (applying the 2020 target to 2010). It includes such measures as increasing the share of energy-efficient residential air conditioners sales from 50% to 60% of the market, and of highly efficient air conditioners from 10% to 20%. Such measures would further reduce the average growth rate of energy consumption by 0.1 percentage points, from 3.8% to 3.7%., bringing total energy consumption in 2010 to 2,668 Mtce. The small impact reflects the fact that these standards only apply to new appliances thus would not change the efficiency of existing appliance stock. Their impact increases over a longer period of time.

3.3.3 Aggressive Industrial, Appliance and T&D Efficiency

The effect of further efficiency improvement in power generation plants is covered in this scenario.

It includes increasing coal-fired power plant efficiency by 1 percentage point from other scenarios. Transmission & Distribution (T&D) losses are still significantly higher in China than those observed in developed economies. Energy efficiency improvements in transmission and distribution systems would not only reduce energy losses but also improve the reliability of the electricity distribution network. In this scenario, reduction of T&D losses by a further 1% has been assumed. Figure 10 shows that these efforts would further reduce the annual average growth rate of energy consumption to 3.5% to 2010, resulting in total energy consumption of 2,641 Mtce in that year

The cumulative impact of the three policy scenarios reduces the growth rate of China's energy use from 5% per year in the BPS case scenario to 3.5%, which in aggregate provides 85% of the reduction that is necessary to reach the goal of reducing the energy intensity of GDP by 20% in 2010 (Figure 11). The results suggest that energy efficiency improvement can play a critical role in reaching the energy intensity target; however, other macro-economic approaches are also necessary to shift the Chinese economy to more productive activities and sectors.

Total energy consumption, energy savings and the major assumptions of each scenario can be summarized in Table 1.

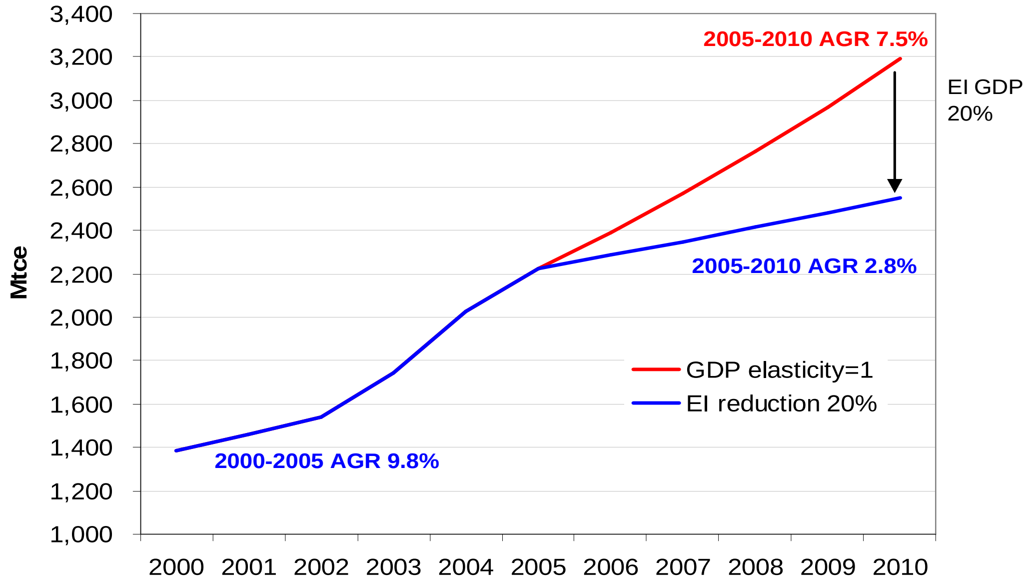

Figure 7: Energy Consumption Implied by the 11th Five Year Plan Energy Intensity Target

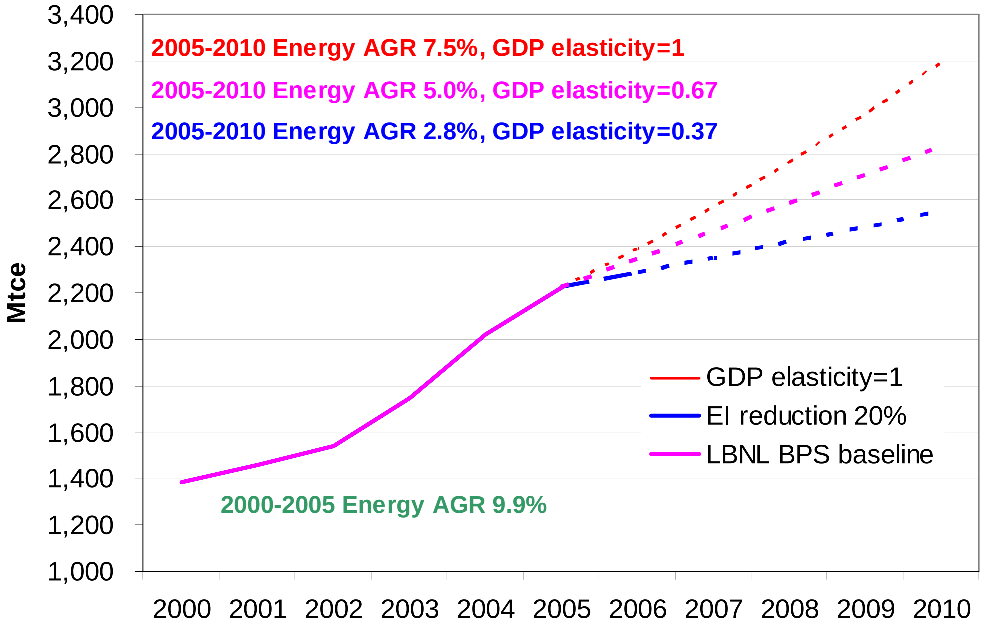

Figure 8: Energy Consumption Implied by the 11th Five Year Plan Energy Intensity Target and the BPS Scenario.

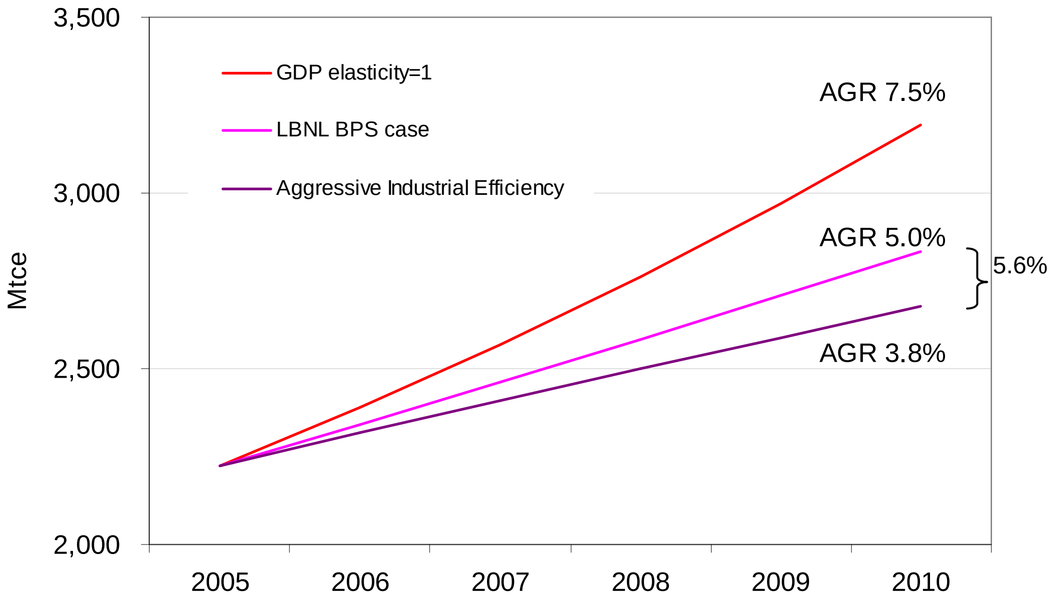

Figure 9 Achieving the 2020 targets for industrial energy intensities in 2010 would reduce energy growth rate from 5% to 3.8%

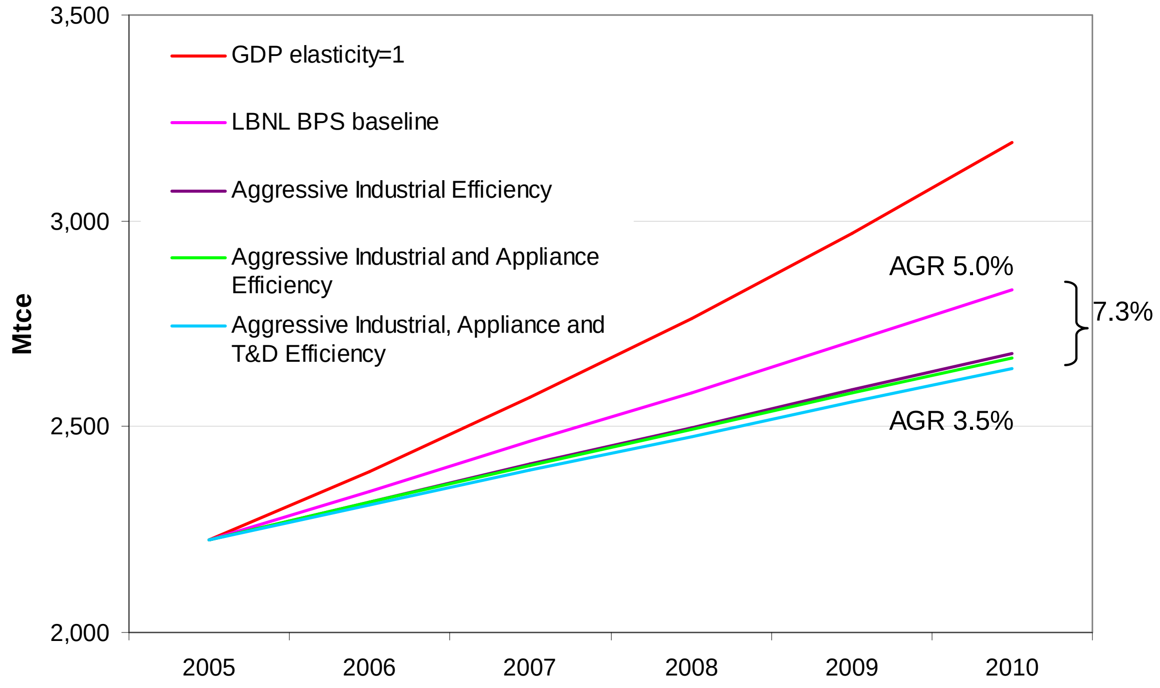

Figure 10: Additional improvement in T&D losses and thermal efficiency of power generation would reduce energy growth to a 3.5% annual average rate

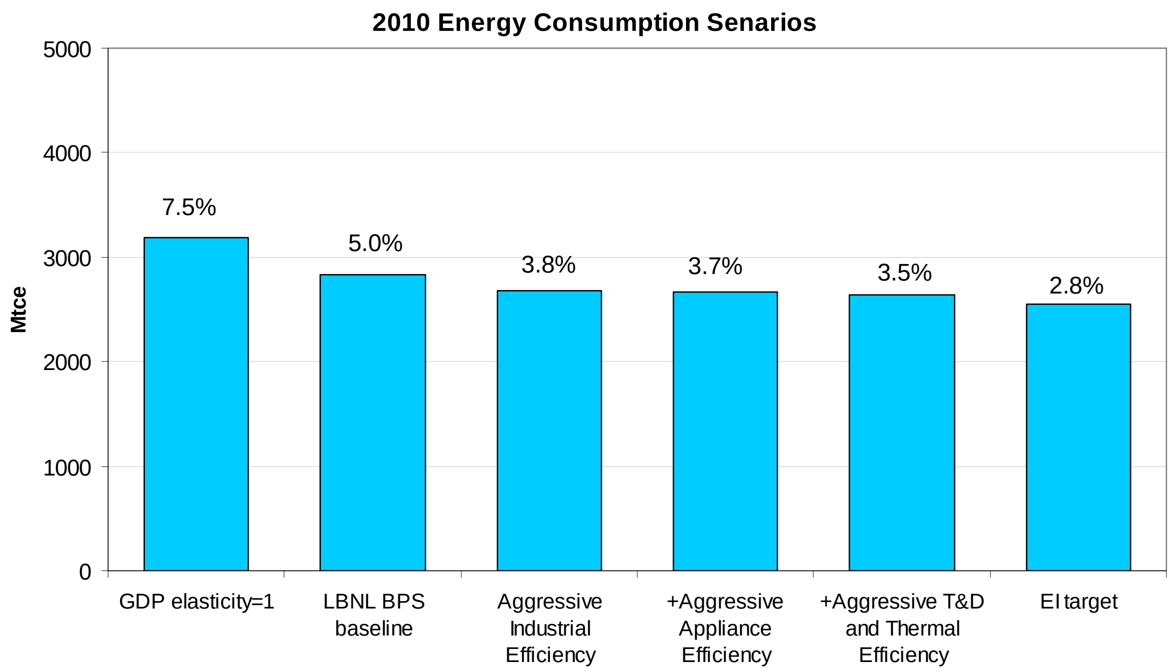

Figure 11: Efficiency can make a big difference

Table 1 Energy Consumption and Major Assumptions of the Scenarios

Scenario	Average Energy Demand Growth Rate	2010 Energy Consumption (Mtce)	Incremental Energy Savings (Mtce)	Cumulative Energy Savings (Mtce)	Major Assumptions
Business As Usual	7.5%	3200	(none)		
BPS	5.0%	2833	367	367	• GDP target • "moderate" improvement in energy efficiency
Aggressive Industrial Efficiency	3.8%	2677	156	523	• move 2020 target to 2010 in industry sector
Aggressive Industrial and Appliance Efficiency	3.7%	2668	9	532	• move 2020 appliances efficiency target to 2010
Aggressive Industrial, Appliance and T&D Efficiency	3.5%	2641	27	559	• +1% in coal fired plant efficiency • -1% in T&D loss
20% target achieved	2.8%	2552	89	648	

4. Sectoral Energy Consumption

Figure 12 illustrates the primary energy consumption for the BPS, Aggressive Industrial Efficiency, Aggressive Industrial and Appliance Efficiency, and Aggressive Industrial, Appliance and T&D Efficiency scenarios by sector between 2000 and 2010. The four scenarios show that energy demand in China in 2010 may range from 2,641 Mtce to 2,833 Mtce, with energy demand growth rates ranging from 3.5% per year (in aggressive energy efficiency improvement scenario) to 5% per year (in the BPS). The energy demand elasticity of GDP over this period to 2010 ranges from 0.47 to 0.67, much smaller than the value from 2000 to 2005 (Figure 13).

Historically, energy consumption in China has been dominated by industry, while the buildings and transportation sectors only represented smaller percentages of energy consumption. In developed countries, building energy consumption comprises a much larger share which is also expected to be the trend in China in the future. In 2005, industrial energy consumption accounted for 64% of the total, and it is expected to be 63% in the BPS case. With the aggressive energy efficiency improvement, the share of industry energy consumption could be reduced to 60%.

Figure 14 shows that China's economic energy intensity in 2000 stood at 0.139 kgce per RMB of GDP, in 2000 real RMB, based on newly revised GDP data (NBS 2005). Economic energy intensity rose to 0.142 kgce/ real RMB of GDP in 2005. In 2010, the BPS case results in a reduction of energy intensity to 0.127 kgce/RMB, while the Aggressive Industrial and Appliance Efficiency Scenario reduces it further to 0.119 kgce/RMB, and the Aggressive Industrial, Appliance and T&D Efficiency scenario to 0.118 kgce/RMB; this last figure represents a 17% reduction compared to 2005.

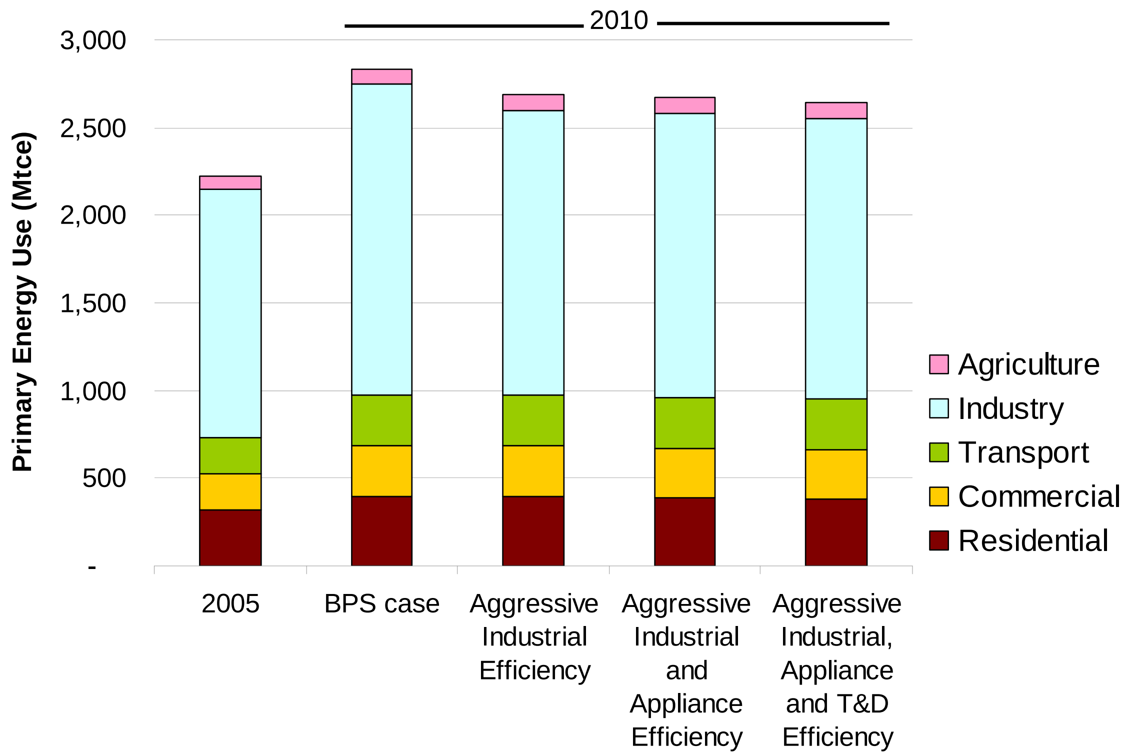

Figure 12 Primary energy consumption by sector in three scenarios

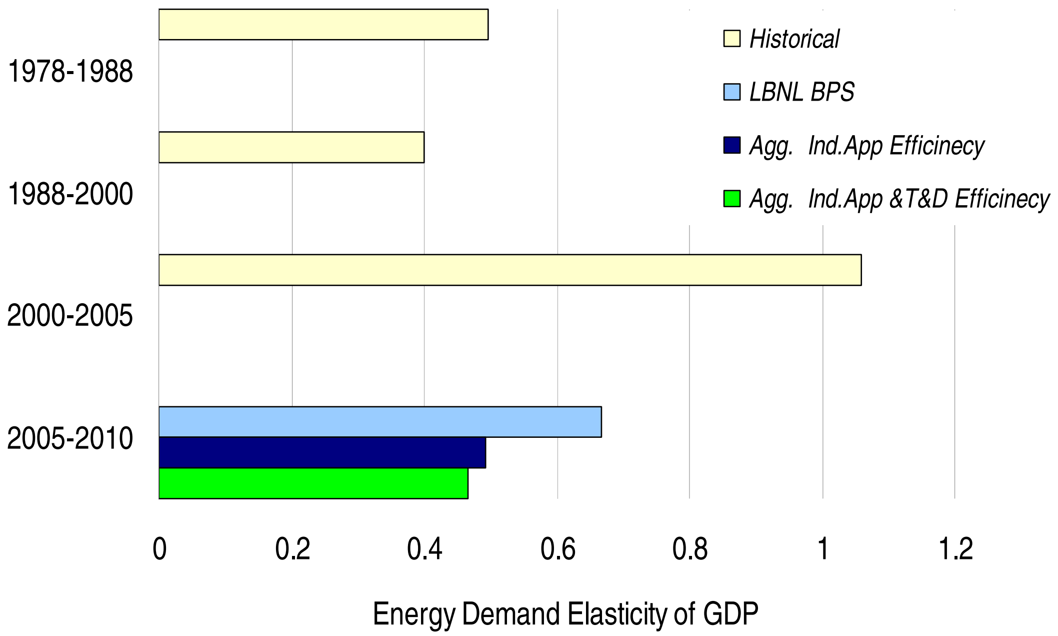

Figure 13 Energy Consumption Elasticity of GDP

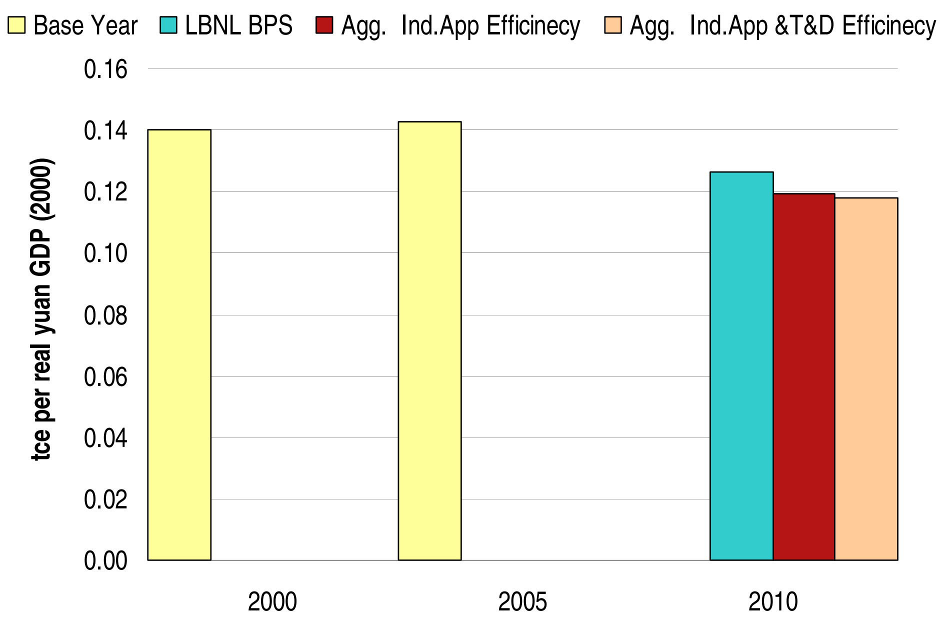

Figure 14 Energy Intensity

4.1 Industry

The modeling results illustrated in Figure 15 suggest that the energy demand of the industrial sector in 2010 in the Aggressive Industrial Efficiency scenario could be 9.4% lower compared to the BPS case, with the annual growth rate of energy demand in industry declining from 4.6% to 2.6%. While the amount of energy consumed rises in both scenarios, the overall proportion of energy-intensive industries in the total industry decreases. In some industries, energy efficiency improvement could lead to significant energy reduction. For example, the cement industry could achieve an additional 17% reduction in the Aggressive Industrial Efficiency scenario and the iron and steel industry could achieve an additional 10% reduction. The reduced energy demand in these two sectors alone totals 64.4 Mtce. At the same time, energy consumption in industries other than the major six cannot be ignored. These other sectors account for 43% of total industry energy consumption, so a 2% per year intensity reduction across these other sectors could lead to a reduction of 75.5 Mtce of energy consumption.

4.2 Buildings

As living standards rise, energy efficiency improvements in the building sector are likely to be offset by the growing demand for higher levels of energy services: more space heating and cooling, improved lighting, more hot water, and larger appliances. These responses to higher living standards make it difficult to reduce energy intensity in building sector. However, higher equipment efficiency and stronger implementation can together act to reduce primary energy consumption in the short term. The aggressive appliance efficiency scenarios incorporate these measures, the results of which are shown in Figure 16. In 2010, residential building energy consumption is 1.4% lower in the Aggressive Industrial and Appliance Efficiency scenario and 2.8% lower in the Aggressive Industrial, Appliance, and T&D Efficiency case compared with the BPS case. The annual average growth rate of energy demand is correspondingly reduced from 4.2% to 3.9% and 3.6%, respectively.

Energy consumption in the commercial sector shows similar results (Figure 17) declining by 3.5% in the Aggressive Industrial, Appliance scenario and 5.1% in Aggressive Industrial, Appliance and T&D Efficiency scenario compared with the BPS case, with the annual average growth rate declining from 7.3% to 6.6% and 6.2%, respectively.

The results also suggest that the energy consumption reduction in the buildings sector can be limited only if associated with efficiency improvements; there is less control over other factors driving the increase in energy consumption such as population growth, urbanization, increases in average per capita floor area, and higher living standards.

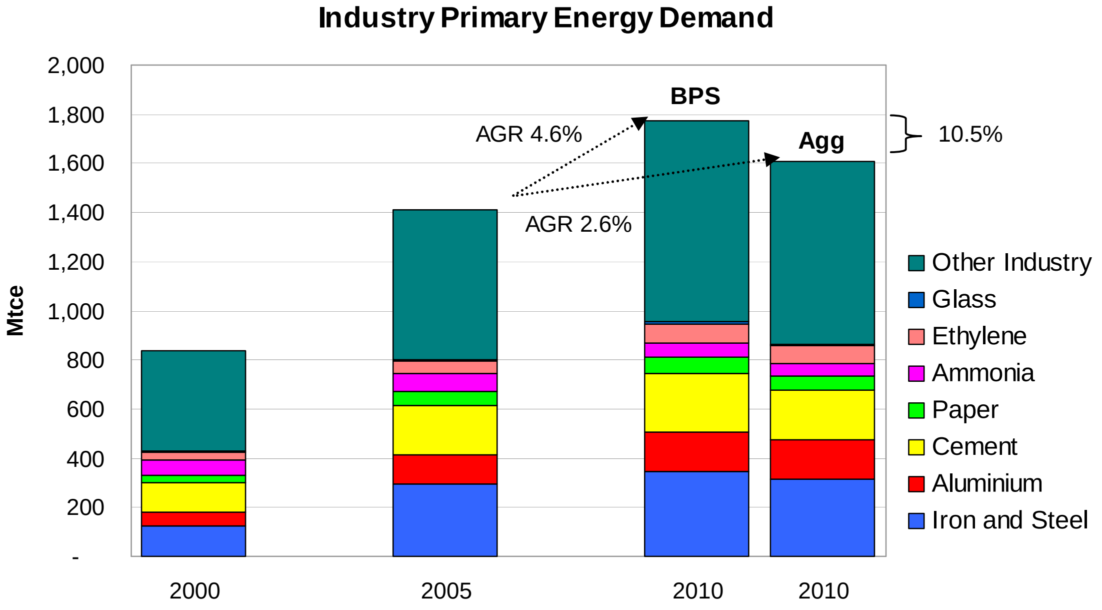

Figure 15 Aggressive energy efficiency improvement in Industry could lead to significant energy savings

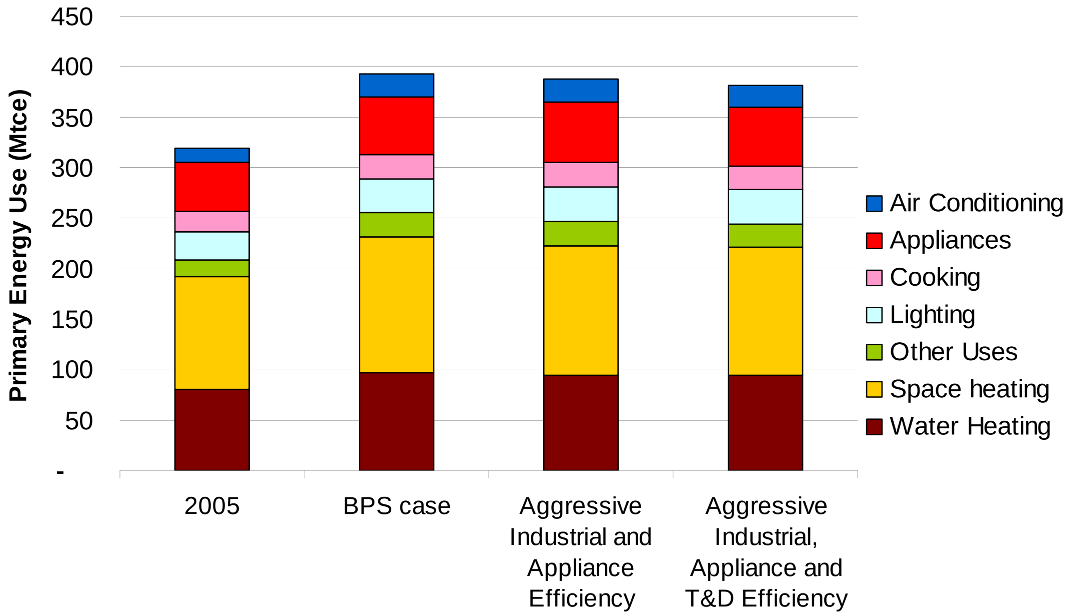

Figure 16 Residential building energy consumption by end use

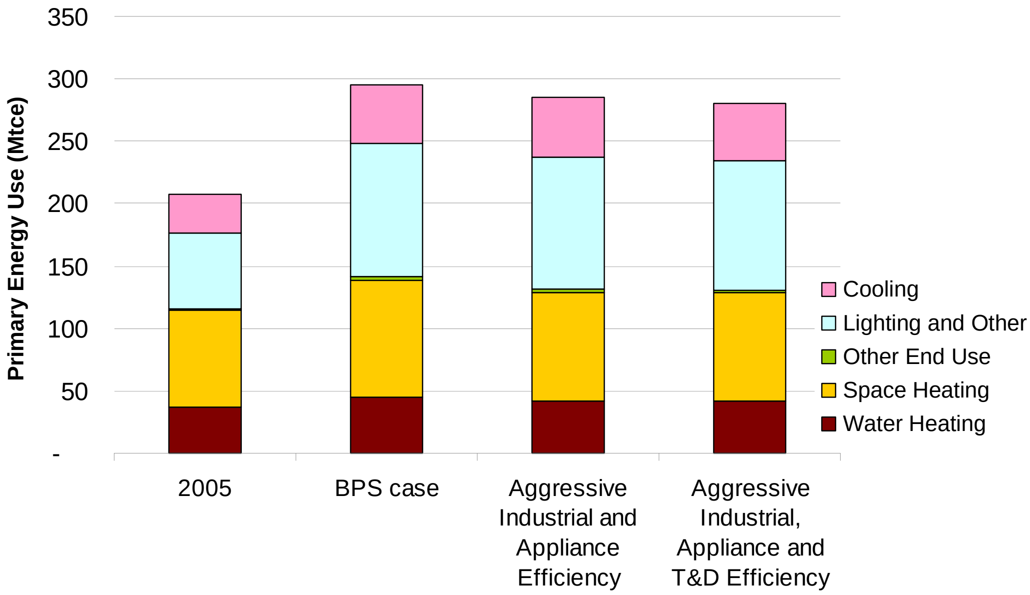

Figure 17 Commercial energy consumption by end use

5. Conclusions

China's 11th FYP set an extremely ambitious target of reducing the energy intensity of GDP by 20% by 2010. This is a particularly challenging goal in light of the recent increase in energy intensity in China. The results of this analysis show that this increase is caused by rampant growth in industries, especially energy-intensive industries such as cement, steel, and chemicals; and by a slowdown in energy efficiency improvement in recent years.

Thus, achieving the 20% target requires major policy changes that would both revitalize investment in energy efficiency throughout the Chinese economy and encourage the shift to less energy intensive and more economically productive sectors. Without major incentives to support energy-efficient technologies and discourage wasteful practices, it is almost certain that the target won't be met, as illustrated by energy and GDP statistics from China in the first half of 2006.

However, meeting the 20% target is still feasible. The efficiency potential explored in this report indicates that efficiency improvements in the industrial and buildings sectors could contribute substantially toward the 20% energy intensity reduction target, while structural changes in the economy also seem necessary. However, realizing such a potential requires adoption or vigorous implementation of a host of policies to promote energy efficiency improvement.

For the industrial sector, energy performance targets for energy-intensive industries should be used as a tool to spur innovation (Price et al., 2003) and to increase enterprise competitiveness. Promoting industry best practices and benchmarking could provide valuable information to enterprises to identify areas of improvement within their facilities. Financial and non-financial incentives should be provided to induce industrial firms to pursue such retrofit potentials. Equally, if not more, important is to ensure that all new and expanded facilities conform to industry best practices. In particular, the 1,000 Enterprise Energy Savings Program, which commits about 1000 large state-owned enterprises to specific energy saving targets, provides an excellent opportunity to showcase the potential to improve industry energy efficiency. Given sub-national developmental disparities in China, the central government could further improve aggregate energy efficiency by forbidding the transfer of old, inefficient equipment from coastal to inland areas.

For the building sector, China has developed an extensive set of building energy codes and minimum efficiency standards for appliances. However, local government agencies need to significantly increase the resources for enforcement actions in order to realize the full impact of the building energy codes. For appliances, national testing programs need to be instituted, and penalties for violations need to be raised significantly to ensure compliance to the existing appliance efficiency standards. In addition, these standards should also be tightened over time as more efficient technologies are developed, in order to deliver greater amount of societal and consumer savings.

Government agencies at all levels should take the lead in purchasing energy-efficient products and ensuring that all government-funded buildings meet the best energy performance code.

For the transportation sector, priority should be given to the development of efficient mass transit systems including bus rapid transit (BRT). An efficient and comfortable mass transit system is critical in stemming the switch to private cars, which could lock in high energy usage for years to come. At the same time, fuel economy and emissions standards for vehicles should be raised to mitigate the impact of rapidly rising vehicle sales on energy use and air quality.

To implement these programs, China needs to attract huge investment for the adoption of energy efficiency technologies and practices. China was successful in stimulating investment in energy efficiency in the past through a combination of low-interest loans, interest subsidies, and tax credits. It is time for China to revitalize these incentive programs.

Another source of funding for energy efficiency could be utility-based DSM programs, which has been extremely successful in the North America in slowing down demand growth. In the on-going utility sector reform, China should incorporate the principles of integrated resource planning (IRP) to put demand-side solutions on the equal footing with supply-side resources, and reward utilities for energy saved.

Setting energy prices to reflect costs of extracting, delivery, and use of energy would also help both China's effort to reduce energy intensity in the near future and to move toward a sustainable energy future. Maintaining artificially low prices not only encourages wasteful consumption of energy, but also deters the development of more efficient technologies and renewable energy.

The policy options outlined here have all been successfully implemented individually elsewhere in the world. They all aim to align the interests of energy consumers (such as steel mills) and providers (such as utilities) with societal interests of energy conservation, environment protection, and economic development. Once combined, they could unleash tremendous societal and market forces toward meeting China's goals of energy intensity reduction in the short term and sustainable development in the long term. China has demonstrated to the world in the 1980s and 1990s that it is capable of initiating path-breaking policy reforms with great success. Once again, with the new call for the development of "a harmonious society", China has the opportunity to lead a new path for the world.

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Appendix A. Sectoral Modeling Approaches

Two general approaches have been used for the integrated assessment of energy demand and supply – the so-called "bottom-up" and "top-down" approaches. The *bottom-up approach* focuses on individual technologies for delivering energy services, such as household durable goods and industrial process technologies. The *top-down* method assumes a general balance or macroeconomic perspective, wherein costs are defined in terms of changes in economic output, income, or GDP. Each approach captures details on technologies, consumer behavior, or impacts that the other does not. Consequently, a comprehensive assessment should combine elements of each approach to ensure that all relevant impacts are accounted for and that technology trends and policy options for reducing energy consumption or mitigating climate change are adequately understood.

This section describes the methodologies used to develop an end-use model to provide insights regarding the technologies that would be used, including energy intensity and saturation levels, to reach the energy consumption levels envisioned. A baseline scenario that incorporates targets stated in China's official plans and business-were-usual technology improvement was developed first and energy efficiency improvement scenarios was created to examine the influence of oil shortages. To keep the consistency of the storylines, key driver variables were kept the same.

The model consists of both the energy consumption sector and the energy production sector (transformation sector) including:

- residential buildings,
- commercial buildings,
- industry,
- transportation,
- agriculture, and
- transformation.

Sectoral energy consumption data are available in published statistics. We used China's energy statistics to prepare time series (1971-2002) of primary energy use (counting the losses occuring in transformation sector). After building the model from the bottom-up, we calibrated the data by comparing the results of energy use with the statistical data for the base year (top-down).

Key drivers of energy use and carbon emissions include activity drivers (total population growth, urbanization, building and vehicle stock, commodity production), economic drivers (total GDP, income), energy intensity trends (energy intensity of energy-using equipment and appliances), and carbon intensity trends. These factors are in turn driven by changes in consumer preferences, energy and technology costs, settlement and infrastructure patterns, technical change, and overall economic conditions.

Residential Buildings

Residential energy provides numerous services associated with household living, including space heating and cooling, water heating, cooking, refrigeration, lighting, and the powering of a wide variety of other appliances. Energy demand is shaped by a variety of factors, including location and climate. In developing countries such as China, it is important to divide households into rural and urban locales due to the different energy consumption patterns found in these locations. Within the locales, end uses were broken out into space heating, air conditioning, appliances, cooking and water heating, lighting, and a residual category.

The end uses were further broken out by technologies; some appliances were broken out into classes by level of service, associated with different levels of efficiency. Space heating varies by climate type, so it is broken out by North and Transition zones. For all end uses, appropriate devices and fuels were assigned, with saturation (rates of penetration) and energy efficiencies based on statistical and survey data pertaining to the base year (2000) and future values based on analysis of government plans, trends, and comparisons to other countries. Changes in energy demand in the model are in part a function of driver variables, e.g., GDP, population, household size and urbanization rate, which were determined exogenously and included in the model. Table A- 1 shows the breakouts.

The equation for energy consumption in residential buildings can be summarized as follows (some subscripts have been omitted for brevity of presentation):

Equation 1.

$$E_{RB,i} = \sum_{k}^{OPTION} \sum_{m}^{OPTION} \frac{P_{m,i}}{F_{m,i}} \times \left[\left(H_{m,i} \times \left(SH_i \right) \right) + \left(\sum_j p_{i,j} \times UEC_{i,j} \right) + C_i + W_i + L_i + R_i \right]$$

where, in addition to the variables above:

k = energy type

m = locale type (urban, rural)

$P_{m,i}$ = population in locale m in region i

$F_{m,i}$ = number of persons per household (family) in locale m in region i

$H_{m,i}$ = average floor area per household in locale type m in region i in m^2

SH_i = space heating energy intensity in residential buildings in region i in kWh/m^2-year

j = type of appliance or end-use device

$p_{i,j}$ = penetration of appliance or device j in region i in percent of households owning appliance (values in excess of 100% would indicate more than one device per household on average)

$UEC_{i,j}$= energy intensity of appliance j in region i in MJ or kWh/year
C_i = cooking energy use per household in region i in MJ /household-year
W_i = water heating energy use per household in region i in MJ /household-year
L_i = average lighting energy use per square meter in region i in kWh /square meter-year
R_i = residual household energy use in region i in MJ /household-year

Air conditioner and refrigerator end uses are detailed with stock turnover modeling, which includes information on initial stocks by vintage, energy efficiencies by vintage (allowing explicit modeling of the impacts of standards), efficiency degradation profiles, and lifetime or survival profiles.

Commercial Buildings

The commercial buildings sector is represented in a fashion similar to residential buildings. A subsectoral breakout includes retail, office, hotel, school, hospital, and other buildings. The key **end uses** by the subsectors listed above include space heating, space conditioning, water heating, lighting, and other uses. The end-uses were further broken out by technologies shown in Table A- 2.

Omitting repetitive subscripts for the energy intensity terms, this can be represented as:

Equation 2.

$$E_{RB} = \sum_{k}^{OPTION} \sum_{n}^{OPTION} \sum_{q}^{OPTION} \left[A_{CB,n} \times P_{q,n} \times \left(\sum_{k} \ Intensity_{q,n} \times Share_{k,q} \ / \ Efficiency_{k,q} \right) \right]$$

where, in addition to the variables listed above:

k	=	energy type (technology type)
q	=	type of end use
$A_{CB,n}$	=	total commercial floor area in commercial building type n in m^2
$P_{q,n}$	=	penetration rate of end use q in building type n
$Intensity_{q,n}$	=	intensity of end use q in building type n
$Share_{k,q}$	=	type of technology k for end use type q
$Efficiency_{k,q}$	=	efficiency of technology k for end use type q

Industry

The industry sector is divided into seven specific energy-intensive industries (iron and steel, aluminum, cement, glass, paper, ethylene, ammonia) and the residuals. **Physical energy intensities** in terms of energy use per ton (or other unit) of industrial product produced for each industrial sector are used. Physical production values are multiplied by industry average physical intensities and then summed to derive energy consumption values for the energy-intensive industries. Any other industrial production is treated as a remainder. Energy use in the other industry is simply the product of industry value-added GDP, and the residual energy use in industry per unit of GDP (**economic energy intensity**), given the total industry energy consumption from the statistical yearbooks.

The end-uses were further broken out by technologies shown in Table A- 3

Equation 3.

$$E_{I,i} = \sum_{k}^{OPTION} \left[\sum_{c}^{OPTION} Q_c \times EI_{c,k} \right] + G_v RI_k$$

where, in addition to the variables listed above:

c	=	commodity type
Q_c	=	quantity of energy-intensive commodity c produced,
$EI_{c,k}$	=	average intensity of energy type k for producing energy-intensive industrial commodity c in GJ/metric ton (or other physical unit),

G_v = Industrial value added GDP, and
$RI_{,k}$ = average intensity of energy type *k* for producing residual, i.e. remaining industrial GDP.[2]

Transportation

In a fashion peculiar to the transport sector, final energy is employed in a large variety of modes and technologies to provide a small range of end-use services, i.e., the transport of passengers and goods, ultimately representing a single service: *mobility*.

While for the other sectors the combination of fuel and technology is nearly always sufficient to determine the end-use service provided, this is not necessarily true for transport. Neither does the combination of the end-use and technology alone provide a level of detail adequate to accurately estimate end-use energy demand. For example trucks and locomotives used to haul freight can share the same engine technology and fuel and provide the same end-use service, but the associated energy intensity will be significantly different.

Transport could be broken out by *mode*:

- water (internal waterways vessels, sea transport vessels, international transport vessels)
- air (national and international air transport),
- rail (intracity and intercity transit)
- pipeline (subdivided by good delivered, when detail is available)

In China, urban and rural road transport exhibits very different energy intensities. Thus, it was broken out by urban and rural. The urban passenger module is divided into cars, taxis, motorcycles and buses, while the rural module is divided into cars and motorcycles; the highway module comprises primarily of buses which are subdivided into Heavy Duty, Medium Duty, Light Duty and Mini Buses. Similarly, freight transport has been broken out in the same fashion but with trucks instead of cars (see Table A- 4).

The physical energy intensities used are in terms of energy use per kilometer (km), per passenger-km, or per tonne-km.

This can be summarized as follows:

Equation 4.

$$E_{TR,i} = \sum_{k}^{OPTION} \sum_{t}^{OPTION} \sum_{r}^{OPTION} \sum_{j}^{OPTION} Q_{t,r,m,i} \times s_{t,r,j,i} \times f_{k,t,r,j,i} \times EI_{TR,k,t,r,j,i}$$

where, in addition to the variables above described:

j = transport technology class (e.g., vehicle classes)
$s_{t,m,i}$ = share of transport services *t*, delivered through the mode *m* employing the transport end-use technology *j*
$f_{k,t,m,j}$ = share of fuel *k* used for technology *j* in providing transport services of type *t*
r = mode type (road, rail, water, air, pipeline)
m = locale type (rural, urban)
$Q_{t,r,m}$ = quantity of transport service of type *t* in mode *r* and in locale *m* of region *i* in passenger-km and tonne-km, and
$EI_{TR,k,t,,m}$ = average energy intensity of energy type *k* for transport service of type *t* in mode *r* and in locale *m* in MJ/(passenger-km-year) and MJ/(tonne-km-year).
k = energy type
t = transport type (passenger, freight)

Turnover data series for rail, water, air and intercity highway are from the China Statistical Yearbooks and the Transportation Yearbooks for different years. However, such data do not exist for intra-city or intra-rural vehicle transport. Data on stocks and the usage pattern (such as average travel distance and the annual amount

[2] This residual can be derived based on historic and projected trends in the share of energy use or industrial sector GDP of light industries compared to energy-intensive industry in a country or region.

of the trips) were used to calculate the total turnover.

Agriculture

Energy use was modeled simply as the product of agriculture value-added GDP, and the energy use in agriculture per unit of GDP (economic energy intensity), given the total agriculture energy consumption from the statistic yearbooks. Historic agriculture energy consumption is available in the China Energy Databook.

Table A- 1 End-use structure of the residential sector

End use	Space Heating		Air conditioning	Lighting	Cooking and water heating	Appliances		
Category	North	Transition				Clothes Washer	TV	Refrigerator Three sizes
Technologies	electric heater gas boiler boiler stove district heating heat pump air conditioner		Ordinary efficient Highly efficient	Incandescent Florescent CFL	Electricity Natural gas LPG Coal Coal gas Other	Vertical Horizontal	Black Color	Ordinary efficient Highly efficient

Table A- 2 End-use structure of the commercial sector

End use	Space heating	Space cooling	Lighting and other applications	Water heating
Technologies	Electric heater Gas boiler Boiler Small cogen Stove District heating Heat pump	Centralized AC Room AC Geothermal Heat Pump Centralized AC by NG	Existing Efficient	Electric water heater Gas boiler Boiler Small cogen Oil boiler

Table A- 3 Subdivision of the industry sector

End use	Iron and Steel	Aluminum	Cement	Glass	Paper	Ethylene	Ammonia		
Category or feed stock				Flat		Naphtha Feed Stock	Coal and coke	NG	Fuel Oil
Fuels	Coal Coke Electricity NG Heavy oil	Coal Coke Electricity Diesel Heavy oil	Coal NG Electricity Heat H	Coal Heavy oil NG Electricity heat	Coal Heavy oil NG biomass Electricity heat	Naphtha Electricity heat	Coal Electricity heat	NG Electricity heat	Heavy oil Electricity heat

Table A- 4 Subdivision and end-use of the transportation sector

					Fuel
passenger	road	urban	Cars		Gasoline, diesel, NG, Hybrid
			Taxis		Gasoline, diesel, NG
			Buses	Heavy duty, medium duty, light duty, minibus	Gasoline, diesel, NG
			Motorcycles		Gasoline, diesel, NG

		rural	cars		Gasoline, diesel, NG
			motorcycles		Gasoline, diesel, NG
		highway	Buses	Heavy duty, medium duty, light duty, minibus	Gasoline, diesel, NG
	rail	Intercity			Diesel, electricity, Fuel oil, Steam
		local			Diesel, electricity, Fuel oil, Steam
	water	Inland			Diesel, Fuel Oil
		coastal			Diesel, Fuel Oil
	air	Domestic			Jet Kero, Avgas
		International			Jet Kero, Avgas
Freight	road	urban	Trucks		Diesel, Gasoline
		rural	Trucks		Diesel, Gasoline
			Tractor	Heavy duty, medium duty, light duty, minibus	Diesel
			Rural Vehicle	Three wheeler, four wheeler	Diesel
		highway	Trucks	Heavy duty, medium duty, light duty, minibus	Gasoline, Diesel
	rail	Intercity	Coal, oil, coke, other		Steam, diesel, electricity
		local			Steam, diesel, electricity
	water	Inland	Coal, oil and oil product, crude oil, other		Diesel
		coastal	Coal, oil and oil product, crude oil, other		diesel
		Ocean			Fuel oil
	air	Domestic			Jet Kerosene, Avgas
		International			
	Pipeline		Crude oil, oil products, NG, other Gas		electricity