# China and India in Energy Markets and its Implication for Global Greenhouse Gas Emissions

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Abstract:

*We describe several scenarios for economic development, energy use, and greenhouse gas emissions in China and India based on the MIT Emissions Prediction and Policy Analysis (EPPA) model, a computable general equilibrium model of the world economy. Historic indicators for economic growth, energy use, and energy intensity in China and India are discussed. In the Baseline scenario, energy use in China is projected to increase from around 60 EJ in 2005 to around 110 EJ in 2025, and energy use in India from around 20 EJ in 2005 to 40 in 2025. Alternative scenarios were developed to consider: (1) How fast might energy demand grow in China and India and how does it depend on key uncertainties? (2) Do rising prices for energy affect growth in the region? (3) Would growth in China and India have a substantial effect on world energy markets? (4) Would development of regional gas markets have substantial effects on energy use in the region and on gas markets in other regions? We also consider the implications for greenhouse gas emissions in these scenarios. Briefly, we find that with more rapid economic growth energy demand in China could reach 235 EJ and in India 95 EJ by 2025, more than twice the level in the Baseline; rising energy prices place a drag on growth of countries in the region of 0.2 to 0.6% per year; world crude oil markets could be substantially affected by demand growth in the region, with the price effect being as much as $15 per barrel in 2025; and development of regional gas markets could expand gas use in Asia while leading to higher gas prices in Europe. Greenhouse gas emissions in China and India grow from 9.3 $GtCO_2e$ in 2005 to 16.4 $GtCO_2e$ in 2025 in the Baseline scenario. Depending on the scenario, GHG emissions range from 12.5 to 36.9 $GtCO_2e$. In the high case emissions from these two countries would be almost half of the global GHG emissions by 2025.*

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More information about the EPPA model and its applications can be found at:
http://web.mit.edu/globalchange/www/reports.html

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## 1. Introduction

China and India are among the fastest-growing regions of the world and their share of the global economy and of energy use has increased substantially over the past years. Thus, continued economic growth in these countries will strongly affect the world demand for energy and the resulting global greenhouse gas (GHG) emissions. The goal of this paper is to provide several illustrative scenarios of economic development, energy use and GHG emissions in China and India. For this purpose the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005) is used. It is a computable general equilibrium (CGE) model of the global economy, and has been widely used to study climate change policy and its implications for energy system and technology development. We extend our previous study of East Asian region (Paltsev and Reilly, 2007) focusing on China and India development and expanding our analysis to GHG emissions, both carbon dioxide ($CO_2$) emissions from fossil-fuel use and non-$CO_2$ GHGs related to energy use, agricultural activities, waste disposal, and other industrial processes .

The phenomenon of fast growth in China and its implications for energy demand have attracted considerable attention from researchers (see, for example, Adams and Shachmurove, 2007; Winters and Yusuf, 2007; Zhao and Wu, 2007). There is substantial disagreement on how fast China will grow in the next 10 to 30 years. As pointed out by Altman (2007), some experts predict sustained fast growth. Other experts appeal to an economic convergence theory, which would have growth slowing in developing economies as they catch up with industrial economies, and face diminishing returns as they adopt the most advanced technologies available. At that point, they would need to start to innovate themselves, move to advanced product markets, and compete with industrial countries in these markets. Still other observers wonder whether the political situation in China will remain stable and whether the stresses of rapid growth on the environment and on natural resources there might not undermine growth.

India has also been successful in its recent economic growth and expanding its exports and imports. By contrast with China, India has concentrated on expansion in services sector rather than in merchandise trade. In addition, the agriculture sector in

India has a bigger share of the economy: agriculture production is 16% of total value of output in India compared to 9% in China.

The paper is organized in the following way. In the next section recent trends in economic performance and energy use in China and India are described. Section 3 presents the EPPA model, which is used for scenario development. In Section 4 the baseline scenario is considered. Section 5 then examines several alternative scenarios, where different assumptions about growth rates, energy efficiency, and energy prices are considered. In Section 6 we consider implications for greenhouse gas emissions and Section 7 concludes.

## 2. Economic and Energy Indicators, 1970–2000

In the thirty years since 1970 China's economy has increased 6.8 times and India's economy has increased 4.1 times. As a result, the share of China and India in the world economy rose from 8% to about 18% between 1970 and 2000, as shown in Table 1. Annual production and consumption numbers for fossil fuels for 1970–2000 provided in Table 2 show similar increases. Fossil-fuel energy production increased from 10 to 37 exajoules (EJ) in China and from 2 to 9 EJ in India. At the same time, fossil fuel use increased from 9 to 35 EJ in China and from 3 to 17 EJ in India. The global share of fossil fuel use by China and India also increased substantially, from 6% in 1970 to 15% in 2000. These aggregate data for fossil fuels do not show the fact that most of the increase in production has been in coal, at a time when China and India imported more and more oil.

Fossil-fuel energy intensity (defined as fossil fuels energy use per unit of gross domestic product) shows very different patterns in these two countries (Table 3). China's fossil energy intensity fell by about 45% between 1970 and 2000, while in India energy intensity rose by 25% over the same period. Many of the industrial regions of the world have shown a long-term decline in energy intensity, but that pattern is not as consistent in other countries. Various factors likely affect these trends. Through at least some period of development, growth is likely to become more energy intensive as it involves rapid growth of energy-intensive industry such as steel and cement. In addition, the shift from non-commercial fuels during the development process shows up as an increase in measures of commercial energy intensity, even though total energy use may not be rising as rapidly. Non-commercial fuels are often used very inefficiently. Also, their use is often underreported, and so if energy use were fully accounted, the shift to commercial fuels could easily result in falling energy intensity.

Another important factor in increasing energy use is that as income increases, household demand for energy for air conditioning, appliances, and transportation also likely contributes to increasing energy intensity. Energy pricing and industrial policy can also play an important role. Some of the most energy-intensive industries (iron ore, aluminum) have moved from industrial countries to developing countries, especially to those with lower energy prices. In sum, though, the intensity of fossil fuel use is the relevant measure in terms of the region's impact on fossil-fuel markets.

In recent years, various observers have attempted to explain the underlying causes of energy efficiency changes, with a particular focus on China. Zhang (2003) concludes that China's decline in energy intensity between 1980 and 2000 is due to an increase in energy efficiency rather than a structural economic shift. Crompton and Wu (2005) identify technical and structural changes as the main cause for this decline in China. Fisher-Vanden et al. (2004, 2006) show a similar decline in energy intensity in China (considering data up to 2000). Hang and Tu (2007) provide data for China up to 2004 and show that aggregate energy intensity has reversed its trend and has been increasing since 2001. In their analysis, they consider coal, oil, and electricity intensities, in addition to aggregate energy intensity. Electricity intensity was relatively stable from 1985 to 2004 (with some reduction from 1990 to 1999 and a relatively small increase from 1999 to 2004). Oil intensity shows only a very slight decline, while aggregate energy intensity is mainly driven by the changes in coal intensity.

Figure 1 illustrates the data for China's energy intensity from different studies. The original units have been indexed relative to 1985. All studies agree on an impressive decline in China's energy intensity between 1995 and 2000, but between 2000 and 2004 the increase in energy consumption was faster than the increase in GDP. Underlying the structural and technological changes in China were large shifts in the organization of the economy as the country moved from a planned economy to one that was more driven by market forces, including adjustments to energy pricing. A significant problem in any analysis of China's energy situation is data quality. Large changes in reported energy use and production have been reported for some years but closer evaluation suggests problems with data and reporting. There are also not good estimates on quantities of fuel that flow through black markets and are not reported at all, and thus concerns about how this omission may distort historical energy use trends.

As one looks forward, the outlook for energy-intensity change in China and India is far from clear. China appears to have reversed the declining trend, or at least stagnated. The great improvement in energy intensity in China was likely related to economic reform, whose effect may have run its course or at least depends on how reforms will continue in the future. Energy intensity in India continues to increase, although the intensity increase from 1990 to 2000 was very low, and so perhaps the structural transition from increasing to falling energy intensity (assuming such a pattern exists), is near.

Figure 2 shows the data for 1970-2004 and the reference scenario projections for 2015-2030 for fossil fuels use from a recent World Energy Outlook by International Energy Agency (IEA, 2006). For comparison, we provide the data for China, India and other major regions of the world. In 1970, China's fossil fuel use was similar to Japan, while Europe's use was 5 times higher, and USA's use is 5.5 times higher. India's fossil fuels use was one-quarter of Japan's use. Thirty years later, China's consumption of fossil fuels is similar to Europe's (with largest increase in China from 2000 to 2004) and India's fossil fuels use is similar to Japan's. China is projected to surpass the USA and become the largest fossil fuels user around 2015, at the same time when India is projected to surpass Japan. Of course, the history of ex-USSR, whose fossil fuel use was similar to Europe's in 1990 but only about half of it in 2000, tells that political instability and other factors can affect growth projections in a substantial way.

Figure 3 provides the similar numbers for $CO_2$ emissions (IEA, 2006). Because of reliance on coal, which has a higher carbon content than other fossil fuels, China becomes the largest emitter earlier, even before 2010. India is also expected to surpass Russia's and Japan's fossil fuel $CO_2$ emissions earlier than in the case of fossil fuels use. There is some uncertainty about GHG inventories in China and India. Tables 4 and 5 provide the data for $CO_2$ and non-$CO_2$ GHG emissions (in $CO_2$ equivalence). We divide the data from the Carbon Dioxide Information Analysis Center of Oak Ridge National Laboratory (CDIAC, 2007) into two categories: $CO_2$ emissions from fossil-fuel burning and emissions from gas flaring and cement production ("Other Sources $CO_2$" in Tables 4 and 5) to compare with the IEA (2006) numbers. CDIAC and IEA report similar numbers for China, but IEA reports lower emissions in India. Another thing to note is that non-$CO_2$ gases play an important role both in China and India, although, their projected growth by EPA (2006) is much slower than for $CO_2$ growth as projected by IEA (2006). As such, in these projections the ratio of non-$CO_2$ to $CO_2$ gases is decreasing in China from 0.56 in 1990 to 0.24 in 2015 and in India from 0.82 in 1990 to 0.46 in 2015.

## 3. The EPPA Model

To create illustrative scenarios of the future development of energy use and emissions in China and India, we use the EPPA model. It is a recursive-dynamic multiregional CGE model of the world economy (Paltsev et al., 2005). EPPA is built on the GTAP dataset, which accommodates a consistent representation of energy markets in physical units as well as detailed data on regional production and bilateral trade flows (Hertel, 1997; Dimaranan and McDougall, 2002). Besides the GTAP dataset, EPPA uses additional data for greenhouse gases (carbon dioxide, $CO_2$; methane, $CH_4$; nitrous oxide, $N_2O$; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, $SF_6$) and air pollutants (sulphur dioxide, $SO_2$; nitrogen oxides, $NO_x$; black carbon, BC; organic carbon, OC; ammonia, $NH_3$; carbon monoxide, CO; and non-methane volatile organic compounds, VOC) emissions based on United States Environmental Protection Agency inventory data and projects.

The EPPA model can be used as a stand-alone model of the global economy. It also is a component of the MIT Integrated Global Systems Model or IGSM, described in detail in Sokolov et al., (2005) and summarized in Box 1. For use in EPPA the GTAP dataset is aggregated into 16 regions and 21 sectors (shown in Table 4). Much of the sectoral detail is focused on energy production to better represent different technological alternatives in electric generation. The base year of the EPPA model is 1997. From 2000 it is solved recursively at 5-year intervals. The EPPA model production and consumption sectors are represented by nested Constant Elasticity of Substitution (CES) production functions (or the Cobb-Douglas and Leontief special cases of the CES). The model is written in the GAMS software system and solved using MPSGE modeling language (Rutherford, 1995). The EPPA has been used in a wide variety of policy applications (e.g., Jacoby et al., 1997; Reilly et al., 1999; Babiker, Metcalf, and Reilly, 2003; Reilly and Paltsev, 2006; Paltsev et al., 2007).

Because of the focus on climate and energy policy, the model further disaggregates the GTAP data for transportation and existing energy supply technologies and includes a number of alternative energy supply technologies that were not in widespread use in 1997 but could take market share in the future under changed energy price or climate policy conditions. Bottom-up engineering details are incorporated in EPPA in the representation of these alternative energy supply technologies. Advanced technologies endogenously enter only when they become economically competitive with existing technologies. Competitiveness of different technologies depends on the endogenously determined prices for all inputs, as those prices depend on depletion of resources, economic policy, and other forces driving economic growth such as savings, investment, energy-efficiency improvements, and productivity of labor. Additional information on the model's structure can be found in Paltsev et al. (2005).

## 4. Baseline Scenario

A key input in the baseline scenario is population, and for this purpose population projections of the United Nations (UN, 2001) are used, as shown in Table 7. China and India are the two most populous countries in the world, and as a result nearly one-third of the world population lives in these two countries. The UN projects greater slowing of population growth in China and India compared with other regions, resulting in a decrease of China & India's share in the total world population by 2050. India is projected to surpass China as the country with the largest population by 2050.

Another key element in scenario projections is the development of nuclear power and hydropower. Because of the political nature of expansion of these energy sources, the growth path of capacity for them is specified exogenously in EPPA, but in the case of hydropower is based on an assessment of unexploited resources. As mentioned, the EPPA base year is 1997; to be consistent with recent expansion of nuclear power and hydropower, the growth of these sources through 2005 is benchmarked to IEA (2006) data. The levels of production of both types of power shown in Table 8 are those projected by EPPA including this benchmarking.

Both types play some role (especially hydroelectricity in China) but they are still a small part of total energy use. Combined, these sources for the region amount to about 1.2 EJ compared with 47.5 EJ of fossil energy. To better compare electricity and fossil fuels, electricity sources such as nuclear and hydro are often reported in primary equivalent—the amount of fuel (coal, oil, gas) that would have been required to produce the same amount of electricity for a given conversion efficiency. Electricity conversion efficiencies are on average for most countries in the order of 30–35%. Thus, the primary equivalent of non-fossil sources is about three times that of electricity production. On this basis the region produced about 3.6 EJ of primary equivalent of nuclear power and hydropower, or still only about 8% of the fossil energy used.

The discussion of energy and emissions scenarios for China and India begins with the baseline scenario. To perform a sensitivity analysis of the baseline results, several alternative scenarios are examined, where different assumptions about growth rates, energy efficiency, and energy prices are considered. As mentioned above, there is a substantial difference in opinion about future economic growth in China and India. In the EPPA model, GDP growth depends on population growth, labor productivity, capital accumulation, economic behavior of the agents, and other parameters of the model. Population growth and labor productivity are exogenous parameters, while decisions about production, consumption, and investment are based on economic optimization. Investments become capital in the next period.

Annual real GDP growth rates for China and India, as well as the total world growth rates for the baseline scenario are presented in Table 9. As with other components of EPPA, the period from 1997 to 2005 is benchmarked to historical data or to short-term projections where data are not yet available. The baseline has GDP growth slowing in China and India. Annual performance of countries in the region for 1997 to 2000 has been quite varied (Table 10), and this is clearly a large uncertainty into the future. If economic performance of the 2000–2005 period were sustained over the longer term, then economic growth would be much more rapid than in the baseline case.

Figure 4 (panels a and b) shows the resulting energy consumption by fuel type for China and India. Renewables include hydroelectricity, solar and wind, and electricity from biomass and biomass liquids. Much non-commercial biomass currently used in many of these countries for cooking and home heating is not reported. Additional biofuels that are simulated in EPPA are commercial biofuels, primarily ethanol-based fuels that compete with petroleum products. Through the time horizon of this analysis (i.e., 2025), hydropower is the most significant renewable energy form, accounting for all renewables in 2000–2005 and around 90% in 2010–2020. Some advanced biofuels begin to appear toward 2025 as oil prices rise.[1] Primary electricity (nuclear, hydro, and other renewable electricity) is reported in primary equivalent.

In the baseline, total energy use in China and India combined is projected to increase from 75 to 145 EJ between 2005 and 2025, almost 100% rise in 20 years. Of course, in the 20 years from 1980 to 2000, the region's energy use increased by 140% and so this is actually a slowing rate of growth. China & India's GDP is projected to grow by 143% in the baseline between 2005 and 2025. From these figures can be derived an implied aggregate energy-use elasticity for China & India with respect to GDP, which is 0.66.

In this projection, energy use grows most rapidly in India, where it increases 2.2 times. In China it grows 1.9 times from 2005 to 2025. Given this increase in energy use and GDP growth, the income elasticity of energy demand {varies from 0.55 to 1.23 in India. Do you mean it is 0.55 in China and 1.23 in India? Otherwise I don't understand this wording.} Adams and Shachmurove (2007) point out that a typical expectation is that energy elasticity in developing countries exceeds unity, in other words, energy consumption rises proportionately more rapidly than GDP. Of course, the actual experience of developing countries has varied as reflected in the historical changes in energy intensity discussed previously. In particular, until 5 years ago, the income elasticity of energy was considerably less than 1.0 in China.

With regard to fuels, all fuel use grows rapidly in China and India, as shown in Figure 4, but coal use expands more quickly because China and India are large coal users.

[1] The EPPA model was designed to be simulated over 100 years and with a focus on greenhouse gas mitigation. In the longer term and under stringent climate policies, other renewables, especially biofuels, play a larger role.

One result is that the region's share of world coal consumption rises from 41% to 48% between 2005 and 2025, and of total energy from 17% to 21%, even as its share of oil and gas changes little (Table 11).

Among the forces in EPPA that affect overall energy efficiency and fuel demand are the sectoral composition and non-price changes in fuel demand. A leading influence on sectoral composition is the change in patterns of consumer demand with economic development. These sectoral shares are determined by many factors, including changes in relative factor prices, intermediate demand, final demand, and international trade. A CGE model like EPPA, which is based on CES functions, tends to be share preserving. As noted in Paltsev et al. (2005), additional adjustments are made from period to period to reflect the way that consumption is expected to change as per capita income increases. In addition, fuel shares for China households, which now often use much coal, are adjusted over time to switch to other fuels as incomes rise. In terms of production sectors, a vintaging structure in EPPA keeps some portion of capital fixed in a particular technology.

Fossil-fuel price indexes for the baseline scenario are given in Table 12, where 2005 is equal to 1.00. These are producer prices absent any excise taxes or trade and transport margins. The EPPA model determines relative prices, and the price projection for any particular year is most appropriately viewed as a 5-year average because the model simulates the economy in 5-year time steps. The EPPA model includes a sub-model for depletion of natural gas, oil, and coal on the basis of supply and demand conditions, and so prices are endogenously determined as an interaction of demand and supply in regional and world markets. Coal and gas, as is the case with most goods in EPPA, are modeled as "Armington" goods, where domestic and imported goods are not perfect substitutes (Armington, 1969), and thus prices differ by country. However, crude oil is modeled as a homogenous good, giving a single world price.

Coal prices are projected to rise in China by about 20% by 2025, while in India the prices are expected to rise by 37%. The natural gas price increase is also the biggest in India, where it is projected to rise by nearly 180% compared with about 100% in China. Crude oil prices are projected to double. For a sense of actual fuel prices, the index values can be multiplied by the average 2002–2006 base prices ($40/barrel for oil,

$5.40/thousand cubic feet for natural gas, $26.70/short ton for coal).[2] In this regard, the crude oil price is already substantially higher than the recent 5-year average.

Historically, crude oil prices have been highly variable and can be strongly affected by political events. The price as of the Fall of 2007 is over $90/barrel. The US Energy Information Administration (EIA, 2007) projects a price of $56/barrel in 2025 in their reference case and IEA (2006) projects $55/barrel in 2030, and thus both imply substantial declines in the price from current levels. The leading energy agencies use either energy models or expert judgments in derivation of their oil price projection. The price in the EPPA model is determined endogenously based on interaction of supply and demand in the entire world economy, considering all economic sectors, not just energy sectors. Similar to other projections there is some fall back in the price from current levels in the nearer term However, based on fundamental forces of supply and demand as represented in the EPPA model, the crude oil price in the baseline scenario rises to $80/barrel by 2025, higher than the large energy agencies but still a fall back from current levels. In any case, long range planning should consider the possibility of a fairly wide range of prices for the future, rather than focus on a narrow consensus range.

Net imports of fossil fuels (in US dollars) by China and India increase substantially in the projections. Coal and oil imports double while natural gas imports triple from 2000 to 2025 in dollar terms. However, if one looks at these energy trade "deficits" remain little changed as a share of GDP. They amount to less than 1% of GDP in 2005–2025, [except for oil imports to India (around 1.5% of GDP) I don't get this—wouldn't you add the 3 together to calculate a total energy trade deficit? ]. At the same time in the baseline scenario, the EPPA model projects that the net export surplus in manufacturing and services, as a share of GDP, will increase in 2005–2025 from 6.5% to 7.4% in China and from 3.7% to 4.9% in India.

## 5. Alternative Scenarios

The baseline scenario is one possible realization of future China and India's economic growth and energy use, and clearly such projections hold uncertainties. Several

[2] These are US average prices for 2002–2006 computed from DOE Energy Information Administration price data.

alternative scenarios are therefore constructed to represent these uncertainties and to help understand better how energy markets might affect energy use and economic growth in the region (Paltsev and Reilly, 2007). An outline of the alternative scenarios is provided in Table 11 with shorthand scenario titles.

Economic growth is clearly one of the major drivers of energy demand and is an important uncertainty. Therefore, high and low economic growth scenarios are considered. In addition, as already noted, the last 5 years of China's experience show a switch to an increase in energy intensity. To consider this effect, a scenario is built in which the non-price-induced energy efficiency improvement in EPPA (which in the baseline was improving at 1% a year) is eliminated.

Then, a scenario is considered where energy prices return to their approximate 2000 levels and are held there. Perhaps such lower energy prices are possible, but a major purpose of this scenario is to understand whether projected rising energy prices slow economic growth in the region.

Finally, a gas market scenario (in which a fully integrated regional gas market emerges) is motivated by the fact that the Asian region has substantial gas resources, but its lack of pipelines and liquefied natural gas (LNG) facilities currently limits use, especially in countries like China and India. In this scenario it is assumed that broader regional markets in natural gas develop, implying that infrastructure impediments are overcome, and the large resources of gas in the region and from surrounding areas are made available for use in China, India, and other import-dependent countries in East Asia.

### 5.1 Effects of economic growth and China energy efficiency on energy use

To construct different scenarios of GDP growth, ranges of historical growth are considered. With regard to China, the range of recent growth as shown in Table 8 has been wide, but for the last 5 years growth has exceeded 10 % per year. Some researchers question China national statistics (see, for example, Zhang, 2003; Adams and Shachmurove, 2007) and note that China statistics might have underestimated GDP in the past, and that the reported economic growth (NBSC, 2005) in recent years might be higher than actual growth as the statistics catch up with the previous underreporting

(Zhang, 2003). This claim is rejected by China authorities on the basis that high economic growth in China has been sustained for more than a decade. In recent years, India also shows high economic growth rates. IMF (2007) projects a sustained future economic growth in India at 6-7% per year.

The evidence would seem to suggest mostly higher economic growth than in the baseline; however, high- and low-growth cases are considered. In the high-growth case it is assumed that China grows at an annual average of 9.8% and India at 8% over 2005–2025. In the low-growth case, China and India grow at an annual average of 3%.

High growth in both China and India lifts their total energy use to 330 EJ in 2025, while slow growth in China and India leads to an increase to only 112 EJ by 2025, compared with the baseline of about 145 EJ in 2025. The corresponding numbers for China are 235, 79, and 107 EJ. Figure 5, panels a and b, shows energy use by the type of fuel for China in high- and low-growth scenarios. The corresponding numbers for India are 95, 34, and 37 EJ, with a break down by fuel type provided in Figure 6.

The 330 EJ level in China and India combined is about 4.5 times as high as 2005 levels whereas the 112 EJ is about a 50% increase from 2005 levels. Coal and oil use both grow substantially. China alone is a major factor in these differences. When varying GDP growth in China alone is simulated, energy use in 2025 for the entire region of China and India ranges from 272 EJ (high growth, China alone) to about 116 EJ (low growth, China alone). Figure 5, panels c and d, provide the numbers for China for these scenarios. High growth in China alone would increase energy use by 127 EJ in 2025, nearly 70% of the increase seen if both countries grow at the more rapid pace of the high-growth scenario. A high GDP growth in India alone results in an increase in energy use in the combined region by around 30% in comparison to the high growth scenario in both countries.

Section 2 described historic trends for energy intensity in China. There are two factors that primarily affect energy intensity in the EPPA model. The first is an exogenous factor conventionally referred to as Autonomous Energy Efficiency Improvement (AEEI). AEEI reduces the energy required in each sector to produce the same amount of output, assuming that other things (such as energy prices) are unchanged. The second is substitution caused by changing relative prices. In an actual forward simulation of the model, "other things" change endogenously, and these changes also affect energy efficiency. Actual energy efficiency of production of each sector in forward simulations is thus a combination of the exogenous AEEI factor, and endogenous effects through changes in fuel and other prices. AEEI can thus be seen as a reduced-form parameterization of the evolution of non-price-induced changes in energy demand. It is often assumed that AEEI represents technical change, but it should be seen as broadly representing other changes such as in the structure of production within the aggregate sectors, and as such may tend to increase rather than reduce energy intensity. (For more discussion about AEEI in the EPPA model, see Paltsev et al., 2005 and Kasahara et al., 2007.)

As shown in Figure 5, panel e, with no AEEI improvement in China, energy use in China increases to 138 EJ, a 31 EJ increase from the baseline (with India's energy use unchanged). While not as dramatic as the high-growth effect, this scenario may not provide a high bound on the energy-intensity effect. Even when the energy efficiency improvement is removed in China, energy intensity still falls by around 0.5% annually over the period because of price and structural changes (compared with an average reduction in energy intensity in 2005–2025 of around 1.5% in the baseline scenario). The effect on energy use is not as strong as if intensity actually rises, as has occurred over the past 5 years.

### 5.2 Effects of Low Energy Prices and Gas Trade Markets on Energy Use in East Asia

While EPPA simulates fuel prices as an interaction of supply and demand, it is structured such that one can instead set a exogenous price path and examine the implications for energy demand. To set the prices in this way, the model ignores resource constraints and assumes that all the fuel demanded at the given price is forthcoming. As a result, the regional energy supply projections and energy trade are not particularly meaningful because they may imply large fuel resources in regions where few resources are believed to exist. Thus this exercise is more useful for examining energy demand and the implications for economic growth of rising energy prices. If lower prices materialized, this would more likely result from some combination of reduced energy demand elsewhere in the world (perhaps in part because of stringent policies on greenhouse gas emissions that reduced demand) or greater expansion of production in regions that are known to have large fuel resources (such as the Middle East, Russian Federation, or other countries of the Former Soviet Union).

In any case, as shown in Figure 7, panel a, if energy prices are stable rather than rising, total energy demand in China is projected to increase to 108 EJ from 107 in the baseline. In India an increase is larger to 43 EJ (as shown in Figure 8 panel a), whereas in the baseline, rising prices keep use to about 37 EJ. Since the baseline had oil and gas prices rising faster than coal, it is not surprising to see more of the increase in oil and gas use.

While the fact that economic growth leads to higher energy use is generally well recognized, the potential effect of energy prices on economic growth is not often modeled. The general equilibrium structure of the EPPA model provides a consistent framework for assessing these effects. Table 14 shows that the energy price increases projected in the baseline would substantially slow economic growth compared with a case where fuel prices did not rise. The growth penalty is as much as 0.6% per year in India and about 0.2% per year in China.[3]

As discussed above, natural gas markets in the baseline scenario are modeled such that international prices do not fully equalize, and therefore changes in domestic demand can have a larger effect on domestic prices. In the gas trade markets scenario the Armington specifications for natural gas are relaxed. The trade in gas is modeled in a similar fashion to trade in crude oil (which is a homogenous product with perfect substitution for imports across different regions of the world). In this scenario three regional markets are in fact assumed for natural gas, in each of which gas is a homogenous product: Asia (Asia, Former Soviet Union, Middle East, Australia and New Zealand), Europe (Europe and Africa), and Americas (North and South America). “Armington-type” trade between the three regional gas markets remains. The motivation for the regional markets is that pipelines can serve to link markets that are geographically

[3] Some caution is warranted in these calculations because of possible terms-of-trade effects that might stem from the location of the energy source, which, as discussed in the text, is not well resolved given the nature of the fuel price override in EPPA.

close. Whether this result accurately describes emerging global gas markets depends on how fast LNG infrastructure and pipelines can be developed (especially whether terminals and pipelines will be built to keep pace with demand), and LNG production facilities can expand.

The main implication of a developing regional gas trade is that China and India's gas use in 2025 expands from 4.4 EJ in the baseline to 14.5 EJ in the gas trade markets scenario (with an increase in China from 2.7 to 11.6 EJ and in India from 1.7 to 2.9 EJ). Most of this expansion displaces coal use, which falls from about 100 EJ to 86 EJ in 2025. Thus, it appears that gas penetration is somewhat limited by the Armington assumption and, if this is realistic, by limits on transportation. A more fully integrated regional gas market would lead to much more gas use in the region. However, even with this significant expansion of gas use, coal retains the largest share (by energy content) of energy used in the region.

### 5.3 Energy Prices in Alternative Scenarios

At the outset it was argued that China and India are large and rapidly growing and so prospects there could affect energy markets globally. One way to measure China and India's impact on energy markets is to examine energy prices. As noted previously, EPPA models a single world market for oil but national/regional markets for other fuels. Therefore, the impact on the world oil price is one direct measure of China and India's effects on global energy markets. For coal and gas a stronger effect is expected within the Asian region, but a more limited transmission of the effect is likely to other regions. Tables 15 and 16 give prices for coal and gas in China in India and the world oil price under the alternative scenarios outlined above.

Taking first the world oil price in Table 15, the price index for crude oil reaches 2.33 in the high-growth scenario, compared with 1.97 in the low-growth scenario, and 2.03 in the baseline. Crude oil has been selling in the $60–70 range in 2006 and 2007. The baseline has it falling back from that level in the near term but rising to around $80 by 2025, given a base year crude price of $40 per barrel. With high growth both in China and India, the price in 2025 is projected to approach $93 a barrel; with low growth in China and India, the price might reach only $79. Thus in these simulations, growth prospects in China and India together could lead to a near-$15 swing in the world oil price. Growth prospects in China alone could lead to about a $10 swing in the global oil price. With no energy efficiency gain in China, the effect on oil prices is smaller. The low-price scenario arbitrarily sets energy prices at a low level by assumption.

Turning to the effects of alternative scenarios on coal and gas prices in China and India, also shown in Tables 15 and 16, in general the impacts are larger than on the world oil price. This is expected because the Armington trade assumption means that the ability to substitute imported fuels for domestic production is limited. Thus, much more of the increased demand pressure falls on domestic markets. There is some small spillover on prices as a result of varying conditions in the other country. For example, with high growth in China alone, coal price index in China is 1.71 in 2025, but with high growth both in China and India, the coal price index in China rises to 1.72. As another example, varying economic growth in India results in China's price index to vary from 2.04 to 2.06. These spillovers can result directly from effects in the own-fuel market (the coal price is affected by increased demand for coal due to higher economic growth) and from interactions among markets (the higher price of imported gas or oil may lead to a shift to greater use of domestic coal and an increase in the domestic price).

The effects of varying scenarios of China and India's growth on coal and gas markets outside East Asia are much smaller. For example, for most of the scenarios, the EPPA model projects no substantial effects on the European or US coal price indexes. The greatest impact on energy demand is the high-growth scenario, which sees about a 1% increase in coal prices in Europe and the US, and an increase in gas prices of 4% in Europe and 3% in the US, relative to the baseline in 2025. Effects are much smaller in other cases.

Thus, if this Armington representation of the fuel markets is realistic, the transmission of changes in East Asia to other regional markets is limited, with the major effect occurring in the crude oil market.

Also shown in Tables 15 and 16 is the effect on prices of the development of regional gas trade markets. As expected, this reduces the price of gas in China and India fairly substantially because it makes available to them less expensive resources in the Russian Federation, other countries of the Former Soviet Union, the Middle East, and

Indonesia. The effect also spills over into the coal market, with the price index declining from 1.21 in the baseline to 1.15. The coal price in India is almost unaffected as most of gas expansion happens in China. Increased gas trade has almost no effect on the price of crude oil. The price effects are not surprising given that the main effect of regional gas trade markets was to increase gas use at the expense of coal—and less coal demand means a lower price.

Not shown in the table but of some interest is the fact that the development of regional gas trade markets results in an increased price of gas in Europe of about 10%. If gas in the Middle East, Russian Federation, and other countries of the Former Soviet Union is readily accessible to East Asia, this increases competition for the fuel and makes gas less available to Europe, which already has an extensive gas transportation network.

**6. GHG Emissions**

The previous section shows a wide range of energy use estimates in different scenarios varying from 112 EJ to 330 EJ in China and India. As a share of carbon free energy is very small there, fossil fuel related emissions estimates also show a wide range from 8.7 $GtCO_2$ to 26.5 $GtCO_2$ in 2025, mostly depending on economic growth projections, as shown in Figure 9 panel a. Most of energy- and climate-related models assume that the current economic growth in China and India is not going to be sustained and eventually this region's growth would slow down. Even assuming modest economic growth as in our Baseline Scenario, a share of China and India in global $CO_2$ emissions from fossil fuels is increasing from 21% in 2005 to 27% in 2025 (in the case when the rest of the world does not pursue any climate policy until 2025). If some combination of policies in developed world would keep their emissions at 2000 levels in 2010-2025 (this profile is denoted as "Rest&policy" in Figure 9), the China and India's share would increase to 44% of global emissions. With sustained economic growth at the present levels, China and India emit almost the same amount as the rest of the world in the "Rest&policy" scenario.

The addition of non fossil related $CO_2$ emissions and other GHGs does not change the relative picture substantially as shown in Figure 9 panel b, where GHG emissions from China and India vary from 12.5 $GtCO_2e$ to 36.9 $GtCO_2e$ in 2025 depending on economic growth assumptions. Note that the total global GHG emissions in 2000 are estimated at around 40 $GtCO_2e$. Again as in the case of fossil fuel $CO_2$ emissions, with sustained current economic growth almost half of global GHG emissions would come from China and India by 2025. A drastic increase in emissions depicted in Figure 9 brings up the following consideration for further research: in a country where income and wealth grow rapidly, energy intensity may also change rapidly to respond to the demands of better-quality environment from wealthier population. This reduction in energy intensity of GDP due to better efficiency or due to a structural change in the economy would alter energy use and related GHG emissions. Webster et al (2007) provides some insights into the alternative views to modeling trends in improving energy efficiency in the long run (up to 100 years), where we would expect that energy intensity changes as income changes.

## 7. Conclusions

The economies of China and India are growing rapidly and energy use in the region is becoming a substantial share of world energy demand. In the baseline scenario, energy use increases in China and India combined from around 75 EJ in 2005 to around 145 EJ in 2025, with an increase in China from 58 to 108 EJ and in India from 17 to 37 EJ from 2005 to 2025. Coal continues to play a leading role as an energy source in China and India, while oil and gas use is accelerated under different scenarios.

The environmental consequences of rapid economic and energy demand growth in China and India are enormous. In the Baseline Scenario the share of global fossil fuel related $CO_2$ emissions from China and India increases from 21% in 2005 to 27% in 2025. The share of all GHG emissions has a similar increase from 24% to 28%. $CO_2$ emissions from China and India are projected to increase from 5.8 $GtCO_2$ in 2005 to 11.6 $GtCO_2$ in 2025 if no climate policy is introduced. A corresponding increase in all GHG emissions is from 9.3 $GtCO_2e$ to 16.4 $GtCO_2e$. Notably the Baseline scenario assumes that economic growth slows substantially in these countries from the current rapid pace.

Alternative scenarios were developed to consider several specific questions including: How fast might energy demand grow in China and India and how does such growth depend on key uncertainties? Do rising prices for energy affect growth in the region? Would growth in China and India have a substantial effect on world energy markets? And, would development of regional gas markets have large effects on energy use and gas markets in other regions?

With regard to future energy demand growth, the most important single factor is the rate of economic growth. In the baseline scenario, annual GDP growth rates from 2005 to 2025 were approximately as follows: China 5%, India 3.5%. In the high-growth scenario that extended rates seen in recent history, growth was substantially higher: China 9.8% and India 8%. In this scenario, energy demand in China and India rises to 330 EJ in 2025. In the low-growth scenario, it rose to only 112 EJ compared with 145 EJ in the baseline. High growth in China alone could account for about 80% of the increase.

The effects of higher energy prices on growth in the region were found to be substantial. If, instead of rising at the rates projected in the baseline, prices were to fall back to year 2000 levels, annual average growth rates in the region would be 0.2–0.6% a year higher. The biggest growth impact is on India and the smallest on China.

A substantial impact of China and India's energy demand growth on world oil markets was seen. Among scenarios of low and high demand growth in China and India, the world oil price varied from about $79 to $93 a barrel in 2025. Different growth prospects in China alone could cause a swing in the world oil price in 2025 of about $10 a barrel. The effects on other fuel markets were considerably less, reflecting the lack of complete integration of these markets, at least as seen in the EPPA model.

Finally, it was found that if regional gas markets developed better links between Asia on the one hand and the Russian Federation and the Middle East on the other, gas use in China and India could grow substantially more than in the baseline, possibly increasing 3.25 times. This would occur mainly through switching of gas for coal. An interesting side effect of the development of gas markets is that they could lead to higher gas prices in Europe. In the simulation, European gas prices increased by about 10% with the development of regional trade because Asian demand more effectively competed with that from Europe.

Uncertainties in energy demand growth affect GHG emissions projections. If current economic growth in China and India sustained for two decades, GHG emissions there may increase to 36.9 $GtCO_2e$ in 2025, which is almost the level of the global GHG emissions in 2000. Low economic growth brings GHG emissions increase in China and India to 12.5 $GtCO_2e$ in 2025, in comparison to the baseline projection of 16.4 $GtCO_2e$.

The above results depend on several aspects of the EPPA model structure and on particular input assumptions that greatly simplify the representation of economic structure and decision making. The EPPA model draws heavily on neoclassical economic theory. While this underpinning is a strength in some regards, the model fails to capture many economic rigidities that could lead to unemployment or misallocation of resources; nor does it capture regulatory and policy detail. Still, given the many assumptions that are necessary to model national and global economic systems, the precise numerical results are not as important as the insights into the general direction of changes in the economy, components of the energy system, and the approximate magnitude of the price effects seen under alternative assumptions.

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***Table 1. Gross Domestic Product Adjusted for International Purchasing Power***

| ***Location*** | ***1970*** | ***1980*** | ***1990*** | ***2000*** |
|---|---|---|---|---|
| ***China, People's Rep. of*** | *663* | *1,100* | *2,209* | *4,483* |
| ***India*** | *470* | *637* | *1,098* | *1,924* |
| ***Total China&India*** | 1,133 | 1,737 | 3,307 | 6,407 |
| ***World*** | 13,583 | 19,767 | 27,058 | 36,406 |
| ***China&India's Share (%)*** | 8 | 9 | 12 | 18 |

Note: Data are in billion 1990 international Geary-Khamis dollars. Source: Maddison (2001).

***Table 2. Fossil Fuel Energy Production and Use (exajoules)***

| ***Location*** | ***1970*** | | ***1980*** | | ***1990*** | | ***2000*** | |
|---|---|---|---|---|---|---|---|---|
| | ***Prod*** | ***Use*** | ***Prod*** | ***Use*** | ***Prod*** | ***Use*** | ***Prod*** | ***Use*** |
| ***China, People's Rep. of*** | *9.9* | *9.4* | *18.0* | *16.5* | *28.9* | *26.5* | *36.4* | *34.9* |
| ***India*** | *1.9* | *2.5* | *2.9* | *3.4* | *6.3* | *7.1* | *9.0* | *12.6* |
| ***Total China&India*** | 11.8 | 11.9 | 20.9 | 19.9 | 35.2 | 33.6 | 45.4 | 47.5 |
| ***World*** | 197.1 | 187.1 | 254.8 | 247.5 | 292.6 | 284.7 | 329.4 | 323.5 |
| ***China&India's Share (%)*** | 6 | 6 | 8 | 8 | 12 | 12 | 14 | 15 |

Source: Calculated from IEA (2005).

**Table 3. Fossil-Fuel Energy Intensity Index (1970 = 1)**

| ***Location*** | ***1980*** | ***1990*** | ***2000*** |
|---|---|---|---|
| ***China, People's Rep. of*** | *1.06* | *0.85* | *0.55* |
| ***India*** | *1.03* | *1.23* | *1.25* |
| ***World*** | 0.91 | 0.76 | 0.64 |

Note: Fossil-fuel energy intensity is a ratio of fossil fuel use to GDP. For comparability, it is indexed to the 1970 level.

Sources: GDP: Maddison (2001); fossil-fuel use: IEA (2005).

**Table 4. GHG Emissions in China (mmt CO2e)**

| | ***CDIAC*** | | | ***IEA*** | ***EPA*** |
|---|---|---|---|---|---|
| | ***CO2 Total*** | ***Fossil-Fuel CO2*** | ***Other sources CO2*** | ***Fossil-Fuel CO2*** | ***Non-CO2*** |
| ***1990*** | 2401 | 2296 | 105 | 2289 | 1278 |
| ***1995*** | 3200 | 2963 | 237 | | 1439 |
| ***2000*** | 3340 | 3042 | 298 | | 1483 |
| ***2001*** | 3422 | 3092 | 330 | | |
| ***2002*** | 3628 | 3267 | 362 | | |
| ***2003*** | 4252 | 3822 | 430 | | |
| ***2004*** | 5011 | 4527 | 484 | 4769 | |
| ***Projections*** | | | | | |
| ***2005*** | | | | | 1638 |
| ***2010*** | | | | | 1734 |
| ***2015*** | | | | 7744 | 1892 |
| ***2020*** | | | | | 2019 |
| ***2030*** | | | | 10425 | |

Source: CDIAC (2007), IEA (2006), EPA (2006).

**Table 5. GHG Emissions in India (mmt $CO_2e$)**

| | ***CDIAC*** | | | ***IEA*** | ***EPA*** |
|---|---|---|---|---|---|
| | ***CO2 Total*** | ***Fossil-Fuel CO2*** | ***Other sources CO2*** | ***Fossil-Fuel CO2*** | ***Non-CO2*** |
| ***1990*** | 678 | 644 | 34 | 588 | 482 |
| ***1995*** | 908 | 874 | 34 | | 519 |
| ***2000*** | 1160 | 1109 | 51 | | 572 |
| ***2001*** | 1166 | 1110 | 56 | | |
| ***2002*** | 1231 | 1170 | 60 | | |
| ***2003*** | 1274 | 1211 | 63 | | |
| ***2004*** | | | | 1103 | |
| ***Projections*** | | | | | |
| ***2005*** | | | | | 631 |
| ***2010*** | | | | | 681 |
| ***2015*** | | | | 1620 | 737 |
| ***2020*** | | | | | 788 |
| ***2030*** | | | | 2544 | |

Source: CDIAC (2007), IEA (2006), EPA (2006).

## Table 6. Sectors and regions in the EPPA model

| ***Sectors:*** | ***Regions:*** |
|---|---|
| ***Non-Energy*** | ***Developed*** |
| Agriculture | USA |
| Services | Canada |
| Energy-Intensive Products | Japan |
| Other Industries Products | European Union+ |
| Industrial and Public Transportation | Australia & New Zealand |
| Household Transportation: Internal Combustion Vehicles | Former Soviet Union |
| Household Transportation: Hydrogen Vehicles | Eastern Europe |
| ***Energy*** | ***Developing*** |
| Coal | India |
| Crude Oil | China |
| Refined Oil | Indonesia |
| Natural Gas | East Asia |
| Electric: Fossil | Mexico |
| Electric: Hydro | Central & South America |
| Electric: Nuclear | Middle East |
| Electric: Solar and Wind | Africa |
| Electric: Biomass | Rest of World |
| Electric: Natural Gas Combined Cycle | |
| Electric: Natural Gas Combined Cycle with CO2 Capture and Storage | |
| Electric: Integrated Coal Gasification with CO2 Capture and Storage | |
| Synthetic Gas from Coal | |
| Hydrogen from Coal | |
| Hydrogen from Gas | |
| Oil from Shale | |
| Liquid Fuel from Biomass | |

Note: Agriculture, services, energy-intensive products, other-industries products, coal, crude oil, refined oil, and natural gas sectors are aggregated from GTAP data; industrial transportation and household transportation sectors are disaggregated as documented in Paltsev et al. (2004); hydropower, nuclear power and fossil-fuel electricity are disaggregated from the electricity sector (ELY) of the GTAP dataset; hydrogen vehicles, solar and wind power, biomass electricity, natural gas combined cycle, natural gas combined cycle with CO2 capture and storage, integrated coal gasification with CO2 capture and storage, synthetic gas from coal, hydrogen from gas, hydrogen from coal, oil from shale, and liquid fuel from biomass sectors are advanced technology sectors that do not exist explicitly in the GTAP dataset; advanced technology sectors are modeled as described in Paltsev *et al*. (2005); specific detail on regional grouping is provided in Paltsev *et al.* (2005).

**Table 7. China, India and World Population through 2050 (millions)**

| ***Location*** | ***2000*** | ***2025*** | ***2050*** |
|---|---|---|---|
| ***China, People's Rep. of*** | *1,282.0* | *1,479.5* | *1,471.7* |
| ***India*** | *1,008.9* | *1,351.8* | *1,572.1* |
| ***Total China&India*** | 2,290.9 | 2,831.3 | 3,043.8 |
| ***World*** | 6,056.7 | 7,936.7 | 9,322.3 |
| ***China&India Share (%)*** | 38 | 36 | 33 |

Source: UN (2001).

## Table 8. Nuclear Power and Hydropower Production in 2005 (exajoules)

| ***Location*** | ***Nuclear Power*** | ***Hydropower*** |
|---|---|---|
| ***China, People's Rep. of*** | *0.18* | *0.74* |
| ***India*** | *0.06* | *0.21* |
| ***Total China&India*** | 0.24 | 0.95 |
| ***World*** | 9.39 | 7.18 |
| ***China&India Share (%)*** | 3 | 13 |

Source: EPPA model's reference projections based on EIA (2006).

**Table 9. Annual Real GDP Growth Rates in the Baseline Scenario (%)**

| | ***China, People's Rep. of*** | ***India*** | ***World*** |
|---|---|---|---|
| ***1997–1999*** | 6.4 | 6.1 | 3.2 |
| ***2000–2004*** | 9.6 | 5.0 | 2.5 |
| ***2005–2009*** | 5.4 | 4.1 | 3.5 |
| ***2010–2014*** | 5.0 | 3.8 | 3.5 |
| ***2015–2019*** | 4.6 | 3.3 | 3.3 |
| ***2020–2024*** | 4.3 | 2.8 | 3.1 |

**Table 10. Recent Annual Real GDP Growth Rate in China and India (%)**

| *Year* | *China, People's Rep. of* | *India* |
|---|---|---|
| ***1997*** | 6.9 | 7.8 |
| ***1998*** | 6.0 | 4.9 |
| ***1999*** | 6.2 | 6.6 |
| ***2000*** | 8.6 | 5.4 |
| ***2001*** | 8.1 | 4.4 |
| ***2002*** | 8.9 | 5.8 |
| ***2003*** | 10.4 | 3.8 |
| ***2004*** | 12.7 | 8.5 |
| ***2005*** | 10.2 | 7.5 |

Source: Data for China for 1997–2004 - NBSC (2005), data for China for 2005 – IMF (2006), data for India - IMF (2007).

Note: China's growth reported by NBSC (2005) is 10.4% in 2003 and 12.7% in 2004 compared to 10.0% in 2003, 10.1% in 2004 reported by IMF (2006).

**Table 11. Energy Use in China and India as a Share of World Energy Use (%)**

| | *2005* | *2010* | *2015* | *2020* | *2025* |
|---|---|---|---|---|---|
| ***Coal*** | 0.41 | 0.43 | 0.45 | 0.46 | 0.48 |
| ***Oil*** | 0.10 | 0.10 | 0.11 | 0.12 | 0.12 |
| ***Gas*** | 0.04 | 0.04 | 0.03 | 0.03 | 0.03 |
| ***Total Energy*** | 0.17 | 0.18 | 0.19 | 0.20 | 0.21 |

Note: Nuclear, hydro, biomass, solar and wind use are included in the total energy figures.

**Table 12. Fossil Fuel Price Indexes (2005 = 1)**

| *Region* | *Fuel* | *2010* | *2015* | *2020* | *2025* |
|---|---|---|---|---|---|
| ***China, People's Rep. of*** | ***Coal*** | 1.05 | 1.10 | 1.15 | 1.21 |
| | ***Gas*** | 1.17 | 1.41 | 1.70 | 2.05 |
| ***India*** | ***Coal*** | 1.07 | 1.16 | 1.26 | 1.37 |
| | ***Gas*** | 1.25 | 1.62 | 2.13 | 2.80 |
| ***World*** | ***Crude oil*** | 1.21 | 1.45 | 1.74 | 2.03 |

Note: The prices of coal and gas differ by country. Crude oil is a homogeneous good and so has a single world price.

**Table 13. Illustrative Scenarios**

| Name | Description |
|---|---|
| ***Baseline*** | Emissions Prediction and Policy Analysis model's reference |
| ***High growth*** | High economic growth in China and India |
| ***Low growth*** | Low economic growth in China and India |
| ***High growth, China alone*** | High economic growth in China only |
| ***Low growth, China alone*** | Low economic growth in China only |
| ***No energy efficiency gain, China*** | No improvement in energy efficiency in China |
| ***High growth, India alone*** | High economic growth in India only |
| ***Low growth, India alone*** | Low economic growth in India only |
| ***Low energy prices*** | Low energy (coal, oil and gas) prices |
| ***Gas trade markets*** | Regional trade in gas in three markets: Asia (Asia, former Soviet Union, Middle East, Australia), Europe (Europe and Africa), Americas (North and South America) |

**Table 14. Annual Real GDP Growth Rate in Baseline and Low-Energy Price Scenarios (%)**

| | *China, People's Rep. of* | *India* |
|---|---|---|
| ***Baseline*** | | |
| ***2010*** | 5.4 | 4.1 |
| ***2015*** | 5.0 | 3.8 |
| ***2020*** | 4.6 | 3.3 |
| ***2025*** | 4.3 | 2.8 |
| ***Low Energy Prices*** | | |
| ***2010*** | 5.7 | 4.7 |
| ***2015*** | 5.2 | 4.3 |
| ***2020*** | 4.8 | 3.8 |
| ***2025*** | 4.5 | 3.4 |

**Table 15. Effects on Fossil Fuel Prices in China of Economic Growth, Energy Prices, Gas Markets, and Energy Efficiency (Index: 2005 = 1.00)**

| *Scenario* | | *China Alone* | | | *India Alone* | | *China and India* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Baseline* | *High growth* | *Low growth* | *No Energy Efficiency* | *High growth* | *Low growth* | *High growth* | *Low growth* | *Low energy prices* | *Gas trade* |
| *Coal Price Index in China* | | | | | | | | | | |
| *2005* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *2010* | 1.05 | 1.08 | 1.03 | 1.06 | 1.05 | 1.05 | 1.08 | 1.03 | 0.98 | 1.04 |
| *2015* | 1.10 | 1.19 | 1.06 | 1.13 | 1.10 | 1.10 | 1.19 | 1.06 | 0.98 | 1.08 |
| *2020* | 1.15 | 1.37 | 1.09 | 1.20 | 1.15 | 1.15 | 1.38 | 1.09 | 0.98 | 1.09 |
| *2025* | 1.21 | 1.71 | 1.12 | 1.29 | 1.22 | 1.21 | 1.72 | 1.12 | 0.98 | 1.15 |
| *Gas Price Index in China* | | | | | | | | | | |
| *2005* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *2010* | 1.17 | 1.40 | 1.07 | 1.22 | 1.17 | 1.17 | 1.40 | 1.07 | 0.82 | 1.13 |
| *2015* | 1.41 | 2.08 | 1.18 | 1.54 | 1.41 | 1.41 | 2.08 | 1.18 | 0.82 | 1.28 |
| *2020* | 1.70 | 2.86 | 1.31 | 1.94 | 1.71 | 1.70 | 2.86 | 1.31 | 0.82 | 1.46 |
| *2025* | 2.05 | 3.26 | 1.47 | 2.43 | 2.06 | 2.04 | 3.27 | 1.47 | 0.82 | 1.66 |
| *World Oil Price Index* | | | | | | | | | | |
| *2005* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *2010* | 1.21 | 1.24 | 1.20 | 1.22 | 1.22 | 1.21 | 1.24 | 1.20 | 0.82 | 1.21 |
| *2015* | 1.45 | 1.53 | 1.43 | 1.46 | 1.48 | 1.45 | 1.55 | 1.42 | 0.82 | 1.45 |
| *2020* | 1.74 | 1.90 | 1.69 | 1.76 | 1.80 | 1.73 | 1.95 | 1.69 | 0.82 | 1.73 |
| *2025* | 2.03 | 2.27 | 1.98 | 2.06 | 2.14 | 2.03 | 2.33 | 1.97 | 0.82 | 2.03 |

**Table 16. Effects on Fossil Fuel Prices in India of Economic Growth, Energy Prices, Gas Markets, and Energy Efficiency (Index: 2005 = 1.00)**

| *Scenario* | | *China Alone* | | | *India Alone* | | *China and India* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Baseline* | *High growth* | *Low growth* | *No Energy Efficiency* | *High growth* | *Low growth* | *High growth* | *Low growth* | *Low energy prices* | *Gas trade* |
| ***Coal Price Index in India*** | | | | | | | | | | |
| ***2005*** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ***2010*** | 1.07 | 1.07 | 1.07 | 1.07 | 1.08 | 1.07 | 1.08 | 1.07 | 0.98 | 1.07 |
| ***2015*** | 1.16 | 1.16 | 1.16 | 1.16 | 1.23 | 1.14 | 1.23 | 1.14 | 0.98 | 1.15 |
| ***2020*** | 1.26 | 1.25 | 1.26 | 1.26 | 1.48 | 1.22 | 1.49 | 1.22 | 0.98 | 1.24 |
| ***2025*** | 1.37 | 1.37 | 1.37 | 1.38 | 1.89 | 1.33 | 1.91 | 1.33 | 0.98 | 1.36 |
| ***Gas Price Index in India*** | | | | | | | | | | |
| ***2005*** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ***2010*** | 1.25 | 1.25 | 1.25 | 1.25 | 1.42 | 1.20 | 1.43 | 1.20 | 0.82 | 1.13 |
| ***2015*** | 1.62 | 1.62 | 1.62 | 1.62 | 2.36 | 1.48 | 2.37 | 1.48 | 0.82 | 1.28 |
| ***2020*** | 2.13 | 2.13 | 2.13 | 2.13 | 3.33 | 1.87 | 3.33 | 1.87 | 0.82 | 1.46 |
| ***2025*** | 2.80 | 2.79 | 2.80 | 2.81 | 3.79 | 2.44 | 3.79 | 2.44 | 0.82 | 1.66 |
| ***World Oil Price Index*** | | | | | | | | | | |
| ***2005*** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ***2010*** | 1.21 | 1.24 | 1.20 | 1.22 | 1.22 | 1.21 | 1.24 | 1.20 | 0.82 | 1.21 |
| ***2015*** | 1.45 | 1.53 | 1.43 | 1.46 | 1.48 | 1.45 | 1.55 | 1.42 | 0.82 | 1.45 |
| ***2020*** | 1.74 | 1.90 | 1.69 | 1.76 | 1.80 | 1.73 | 1.95 | 1.69 | 0.82 | 1.73 |
| ***2025*** | 2.03 | 2.27 | 1.98 | 2.06 | 2.14 | 2.03 | 2.33 | 1.97 | 0.82 | 2.03 |

**Figure 1. Energy Intensity Index in China (1985=1.00)**

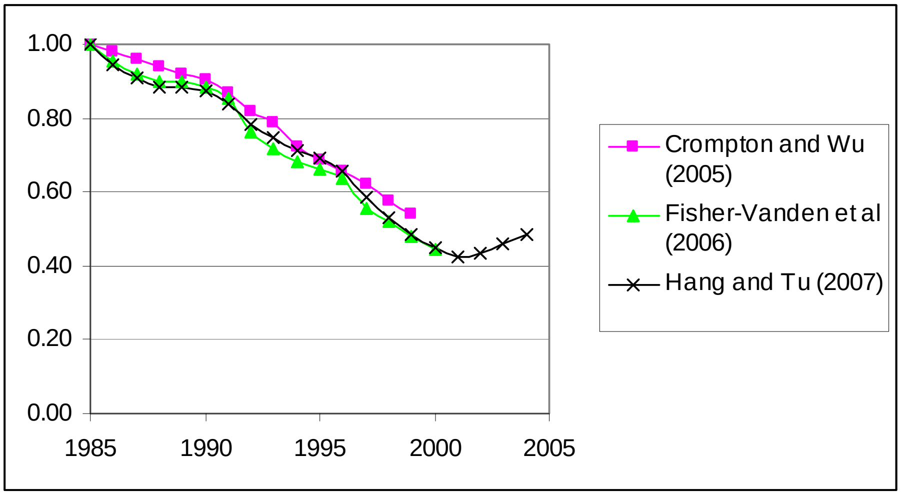
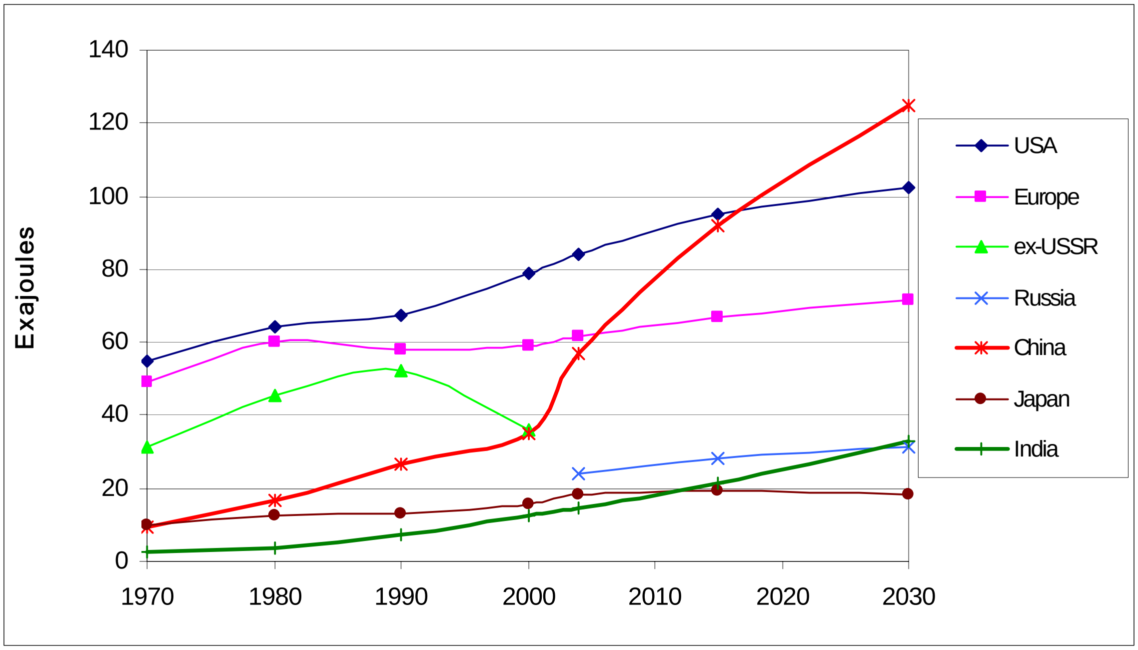
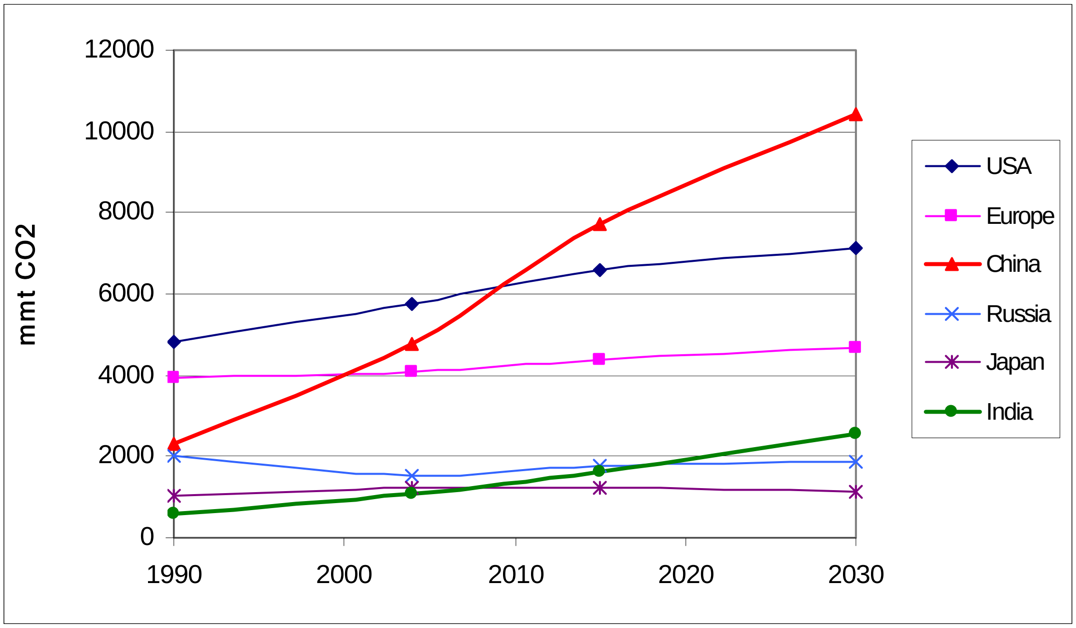


**Figure 2. Fossil Fuels Use: Historic Data (1970-2004) and Projections (2015-2030)**



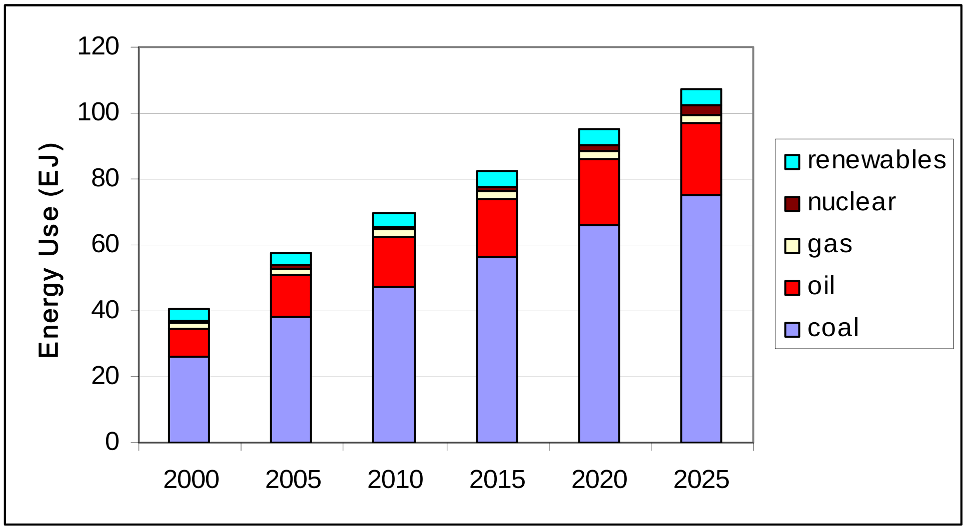

Source: IEA (2006)

**Figure 3. Fossil Fuels $CO_2$ Emissions: Historic Data (1990-2004) and Projections (2015-2030)**

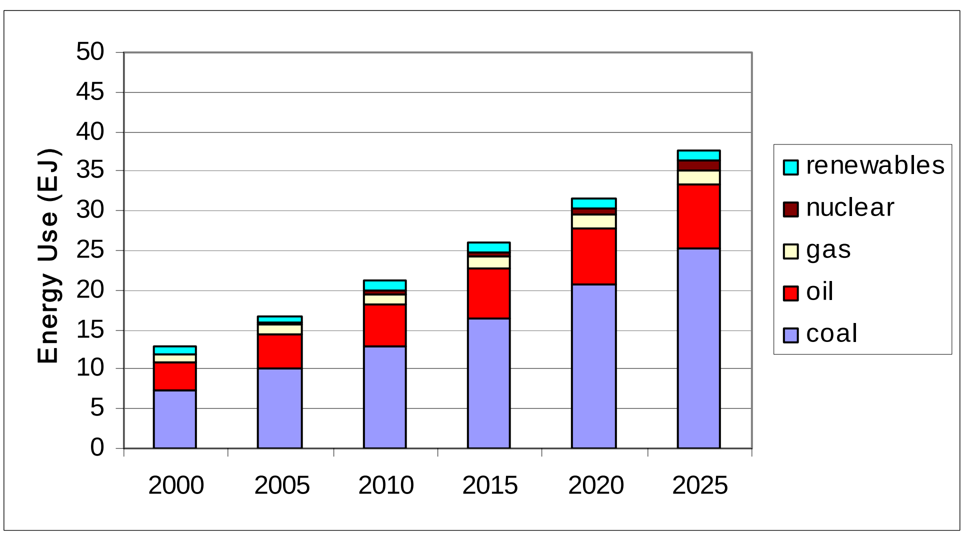



Source: IEA (2006)

**Figure 4. Energy Use in Baseline Scenario (exajoules)**

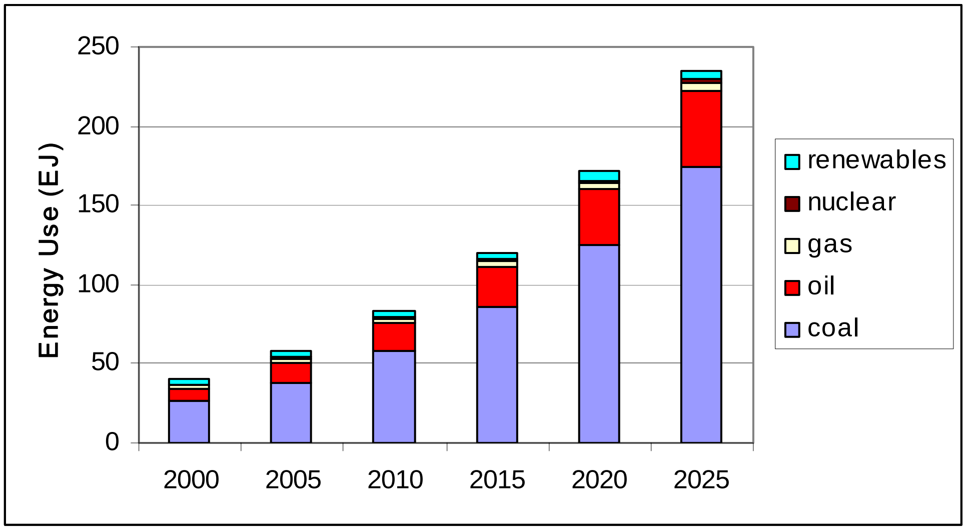



Panel a: China, People's Republic of

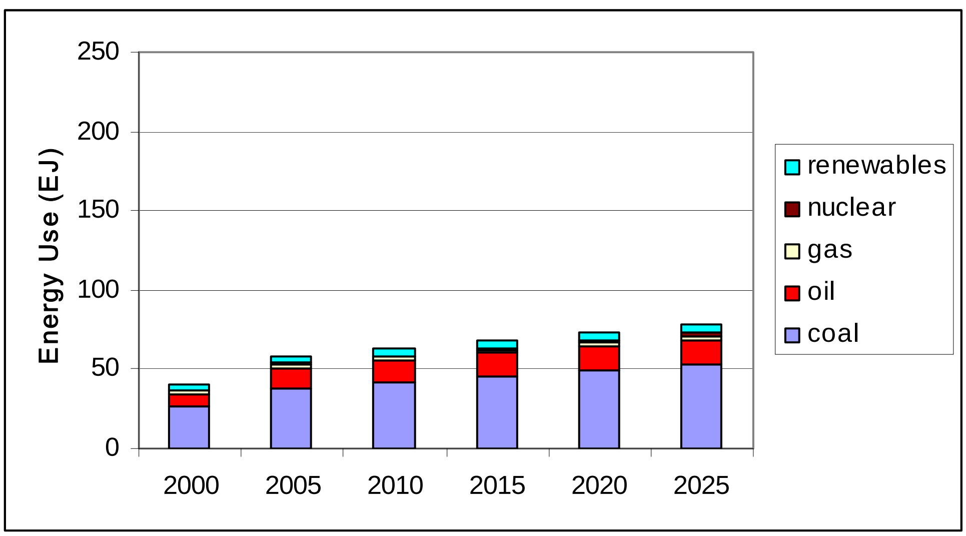



Panel b: India

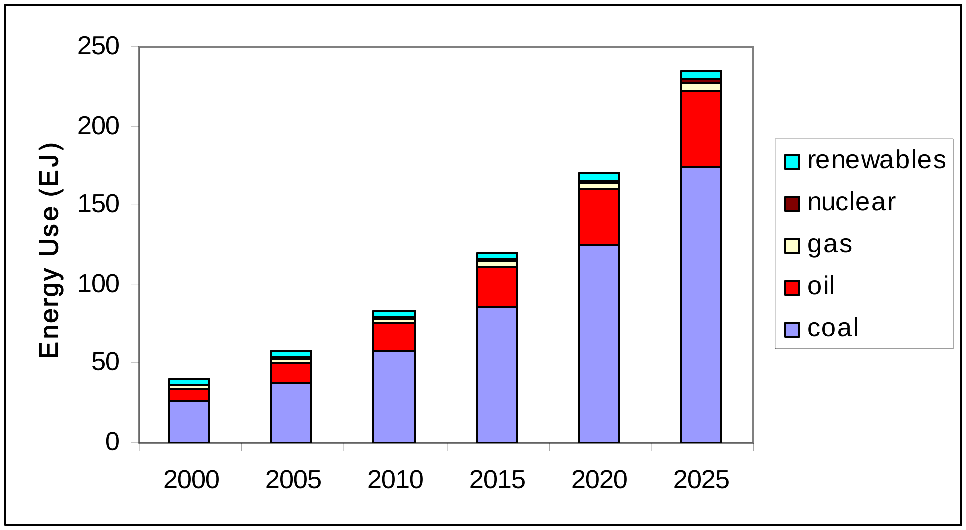
**Figure 5. Energy use in China under Scenarios of High And Low Growth, and No Energy Efficiency Gain in China (exajoules)**



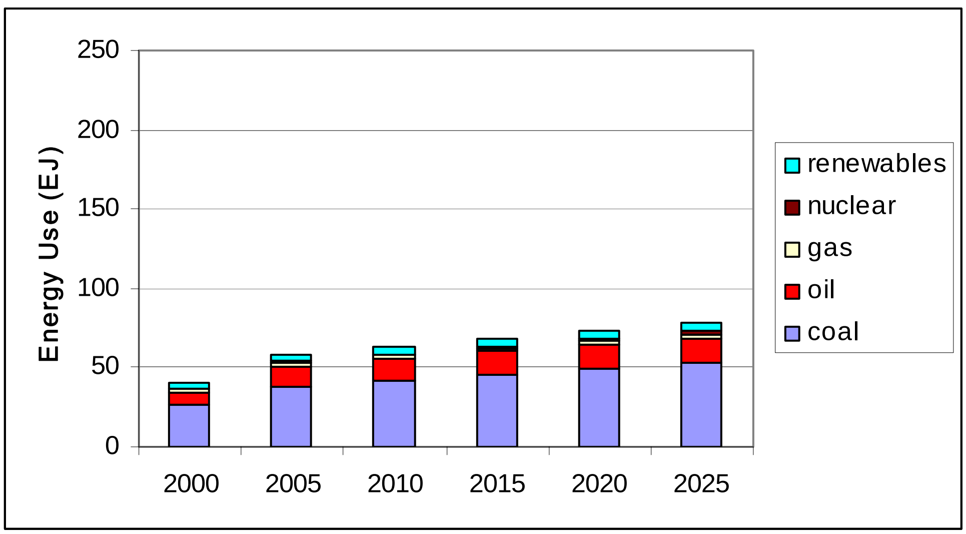

Panel a: High growth in China and India



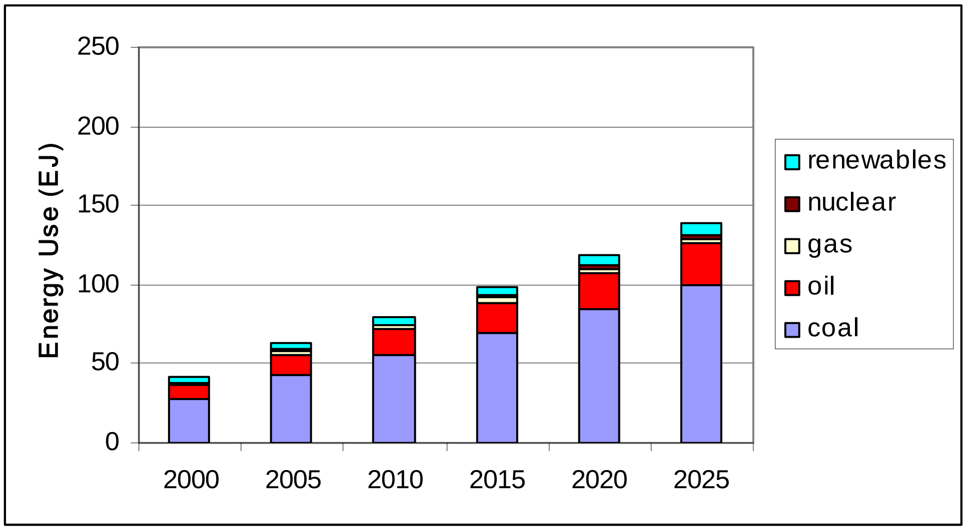

Panel b: Low growth in China and India




Panel c: High growth, China alone

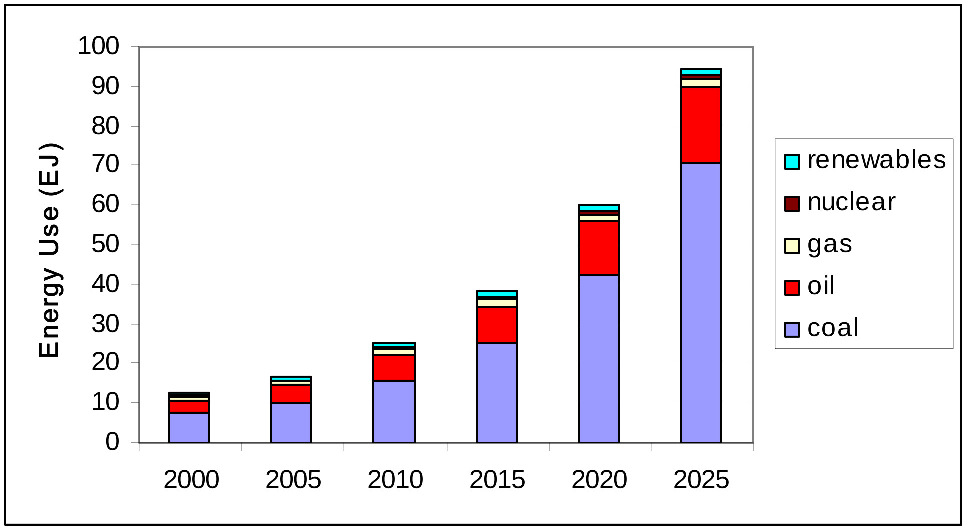



Panel d: Low growth, China alone

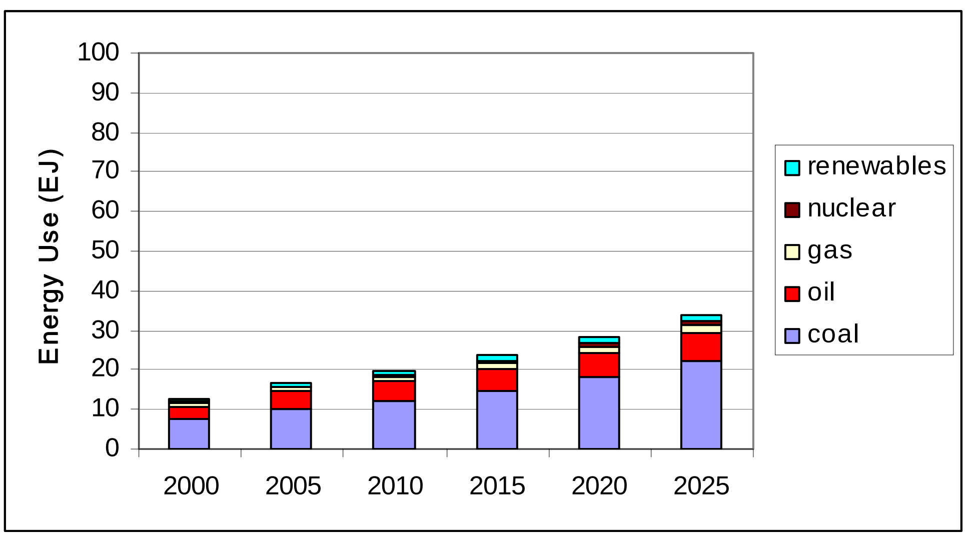



Panel e: No energy efficiency gain in China

**Figure 6. Energy use in India under Scenarios of High And Low Growth in China and India (exajoules)**

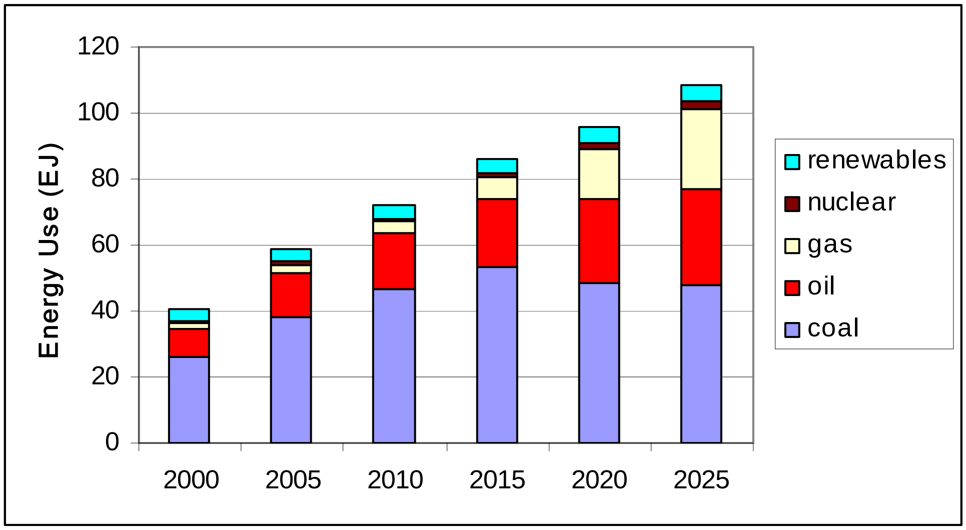



Panel a: High growth in China and India

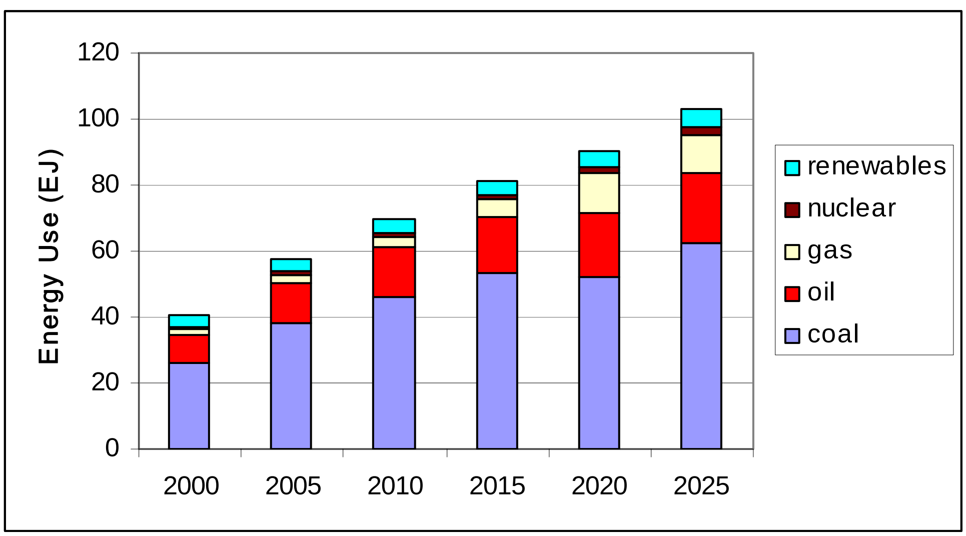



Panel b: Low growth in China and India

**Figure 7. Energy use in China in Scenarios of Low Energy Prices and Expanded Regional Gas Trade (exajoules)**

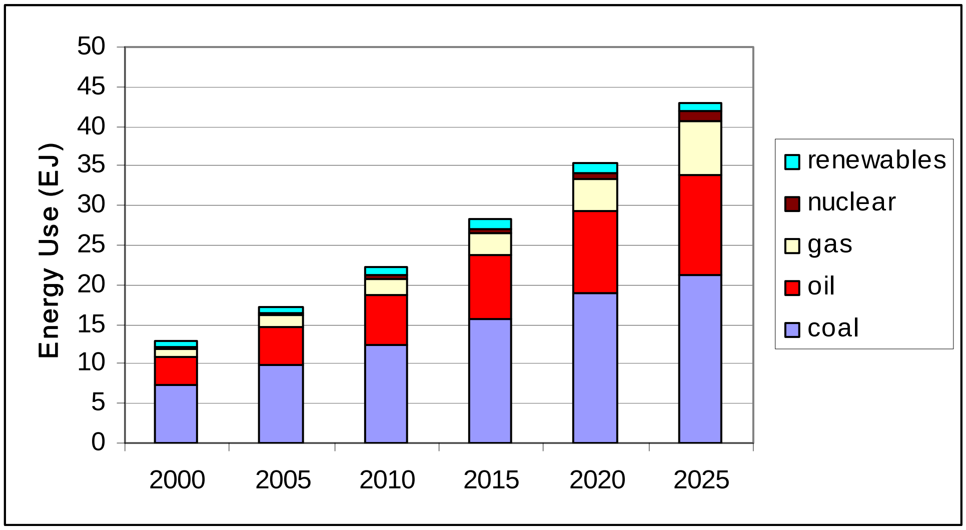



Panel a: Low energy prices

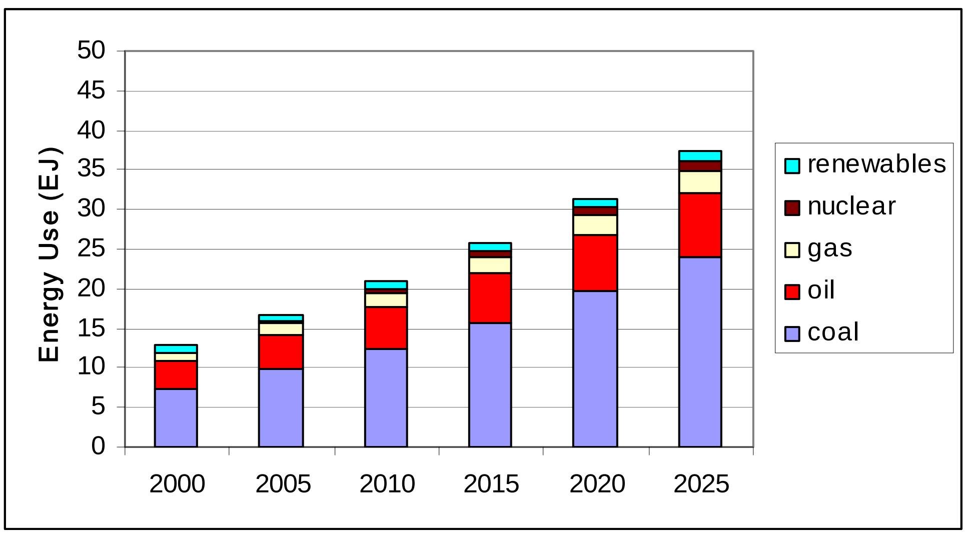



Panel b: Regional gas trade

**Figure 8. Energy use in India in Scenarios of Low Energy Prices and Expanded Regional Gas Trade (exajoules)**

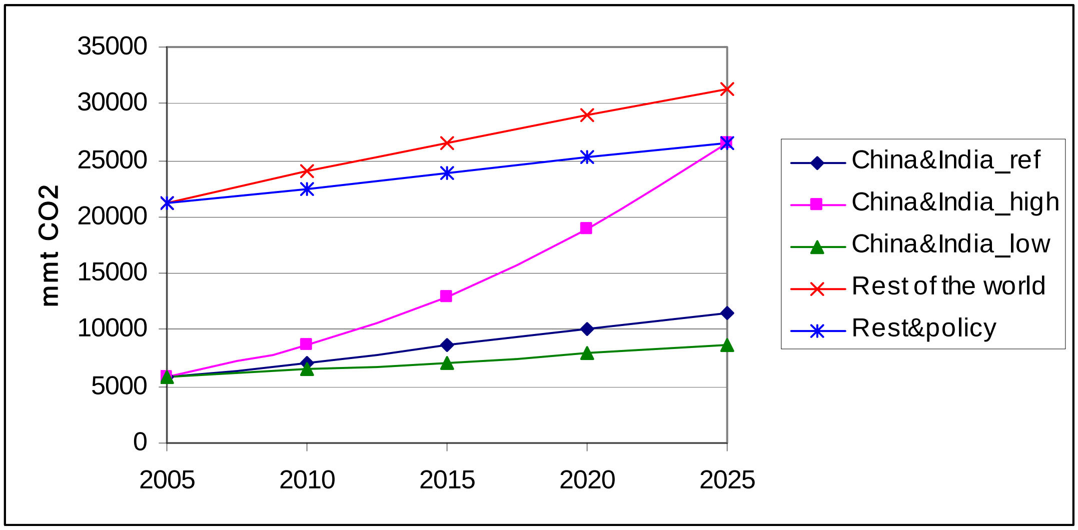



Panel a: Low energy prices

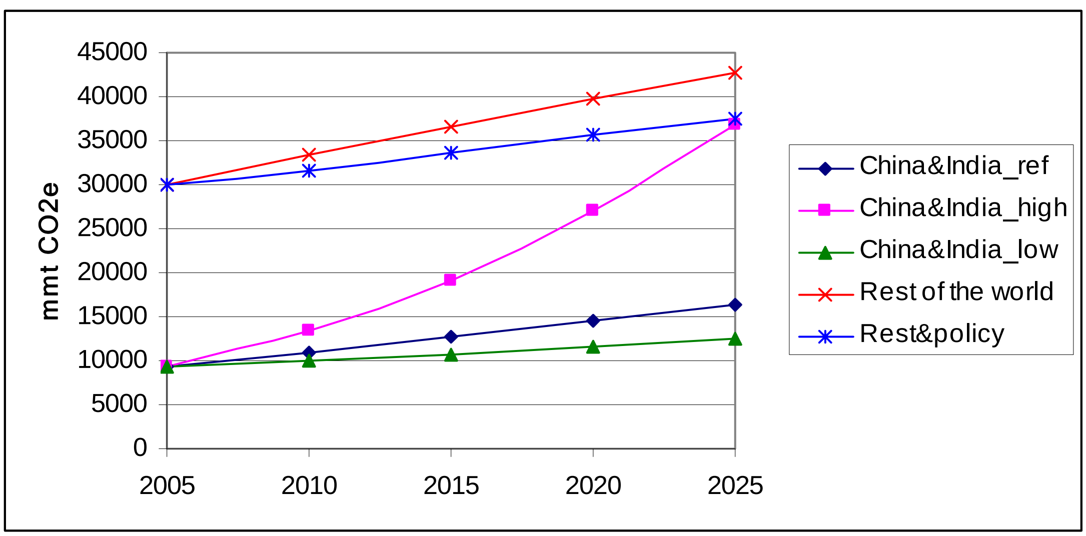



Panel b: Regional gas trade

**Figure 9. Emissions in China&India and rest of the world in different scenarios (mmt CO2e)**

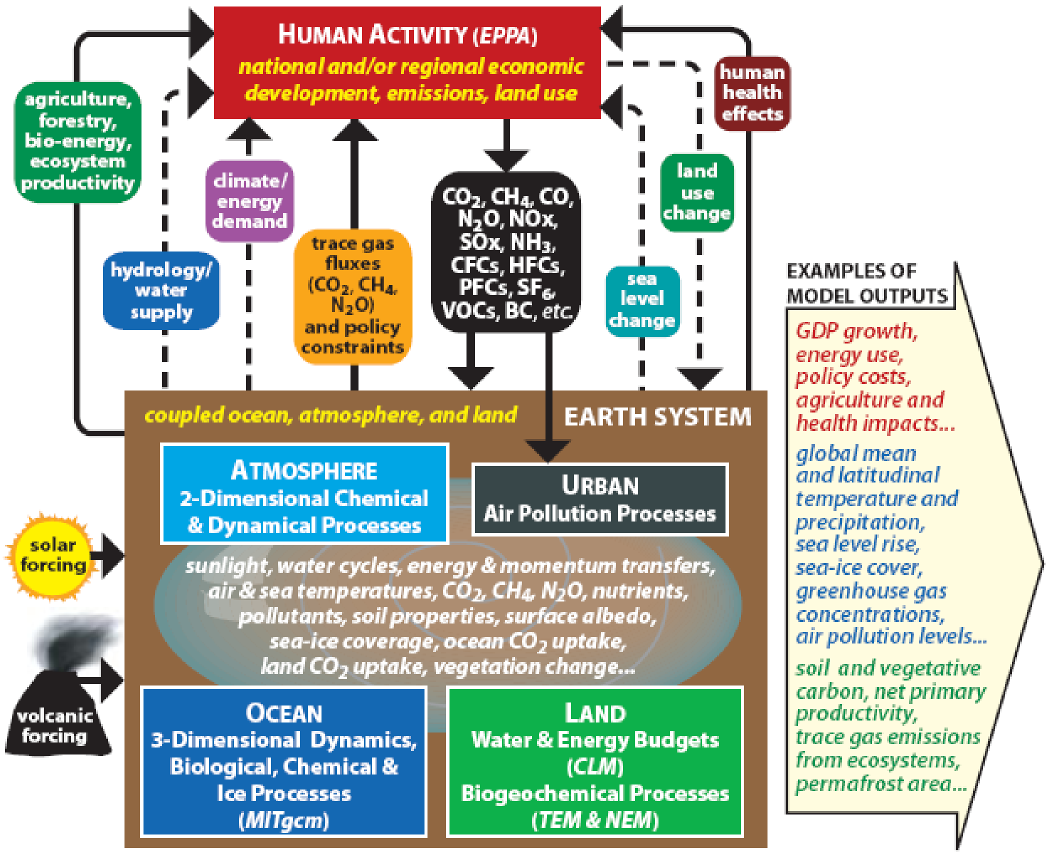



Panel a: Fossil fuel $CO_2$




Panel b: All GHG

**Box 1. The MIT Integrated Global Systems Model (IGSM).** The EPPA model is part of a complete model of the earth system model (depicted below) that includes models of the terrestrial systems, oceans, and the atmosphere. The configuration and capabilities of the IGSM2 are described Sokolov et al. (2005). It has been used in a variety of applications and its components and applications using the full system have been published in the peer reviewed literature. Additional reports, technical notes and journal articles describing the system and applications of it available at [http://web.mit.edu/globalchange/www/reports.html](http://web.mit.edu/globalchange/www/reports.html)




The schematic depicts the current framework and processes of the MIT Integrated Global System Model Version 2 (IGSM2).