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Energy and Emissions: Local and Global Effects of the Rise of China and India

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Abstract

Part 1 of the paper reviews recent trends in fossil fuel use and associated externalities. It also argues that the recent run-up in international oil prices reflects growing concerns about supply constraints associated with declining spare capacity in OPEC, refining bottlenecks, and geopolitical uncertainties rather than growing incremental use of oil by China and India.

Part 2 compares two business as usual scenarios with a set of alternate scenarios based on policy interventions on the demand for or supply of energy and different assumptions about rigidities in domestic and international energy markets. The results suggest that energy externalities are likely to worsen significantly if there is no shift in China’s and India's energy strategies. High energy demand from China and India could constrain some developing countries’ growth via higher prices on international energy markets, but for others the ‘growth retarding’ effects of higher energy prices are partially or fully offset by the ‘growth stimulating’ effects of the larger markets in China and India. Given that there are many inefficiencies in the energy system in both China and India, there is an opportunity to reduce energy growth without adversely affecting GDP growth. The cost of a decarbonizing energy strategy will be higher for China and India than a fossil fuel based strategy, but the net present value of delaying the shift will be higher than acting now. The less fossil fuel dependent alternative strategies provide additional dividends in terms of energy security.

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Introduction

Sustainability issues do not normally manifest themselves for decades because either population growth rates or per capita income growth rates are relatively slow. But such issues become difficult to ignore when growth rates are not slow – as in China in a last two decades. China's rapid transformation from an agricultural based economy to the manufacturing workshop has been accompanied by a corresponding change in the spatial concentration and location of the population from relatively low density rural areas to very high density urban areas. This transformation is having a significant impact on the quantity and quality of natural resources available as inputs into the production process and consumption, as well as the ability of the environment to absorb the waste byproducts deposited in the air, water, and soil. The recent acceleration of growth in India is beginning to generate similar problems.

Development strategies targeting high growth in gross domestic product (GDP), by relying on low-cost, low efficiency, and highly polluting technology are likely to put pressure on available natural resources and sinks[1] over time. A major *one-time opportunity* is emerging in Asia to shift efficiently to a path that does not lock-in inefficient resource use. This opportunity arises from the *massive investments* expected in the next 50 years (on the order of trillions of dollars) to accommodate the urbanization of the population (and the simultaneous reduction of poverty and the backlog of service provision) (World Bank, 2003).

Addressing emerging domestic and local problems will be the primary national motivation for taking action. However, there is also likely to be an *international dimension* to the problem if *externalities* are generated on international resources and sinks as needs grow beyond their domestic counterparts. This will generate costs for other countries, and may even provoke conflict, if domestic and international institutions for collective action do not emerge in a timely manner[2].

Although this statement of the interaction between growth and natural resources applies to a wide range of natural resources and asset management issues in China and India, this paper focuses exclusively on the issue of managing and meeting energy needs for growth so as to minimize negative consequences for health, and the environment – locally and globally.

The objective of this paper is to shed some light on the following set of issues:

- What is likely to be the demand for energy – particularly oil and coal – under a *business-as-usual (BAU)* scenario in **China and India** in 2020 and up to 2050?

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[1] Sinks absorb pollution and waste.

[2] Developing the institutions to identify and enforce appropriate criteria (that take into account the scale and distribution of externalities, as well as the use of option values) for these investments will determine whether the cumulative investment program is welfare enhancing internally or not, due to path dependency and the potential for lock-in to inefficient paths. However, the topic of institutional development is not covered in this paper.

- What are likely to be the associated levels of emissions that could have damaging consequences at the local level (such as particulate matter), regional level (such as ozone, sulfur and acid rain), and global level (CO_2 in particular)?

- What domestic interventions in the development of the energy producing and energy using sectors might make a significant difference in the energy path relative to a business as usual scenario?

In addition to the introduction and conclusion, the paper is organized in two parts. Part 1 provides a review of the problems associated with the recent trends in overall energy use and its composition in China and India, with some discussion of the associated trends in local and global emissions. This section also includes a brief discussion of the extent to which energy use in China and India has affected the recent run-up in international energy prices.

The crux of the story in this part is that high growth in the manufacturing sector and in the electricity producing sector in both countries, but particularly in China, is fueling rapid growth in fossil fuel energy use – primarily coal. Even though India is more diversified in energy sources because of its greater reliance on traditional biomass, both countries have limited, cheap domestic energy resources for electricity generation other than coal in the near future. The heavy reliance on coal is associated with the expansion of various types of local pollutants (such as suspended particulate matter, sulfur/SO_2, etc.) contributing to health problems (with impacts particularly in cities), and ozone and acid rain (with impacts particularly in rural areas). Attempts to reduce local emissions in China by curtailing coal production and consumption had some success for a few years in the late 1990s without restricting the growth of GDP[3]. But this decoupling could not be sustained because high growth in the economy was generating power shortages and other dislocations, necessitating the resumption of coal use even if it was inefficiently produced.

The industrial policy decision to support motorization (i.e., greater dependence on automobiles and road transport) because of its multiple linkages to other sectors, has resulted in both countries experiencing a surge in the demand for oil (gasoline, diesel and other oil products). This and the dramatic growth in aviation in both countries have resulted in a rapid growth in oil imports with implications for the balance of payments and energy security. The recent rise in global oil prices is partially a result of the growth in energy use in China and India. Together the two of them account for 40 to 50 percent of the increase in the global use of oil since 2001, even though they only account for 9–10 percent of aggregate global use of oil. However, this growth in oil use in China and India has been partially offset by the deceleration or drop in oil use in countries traditionally dependent on oil. As a result, aggregate global use of oil has not grown substantially in the last few years relative to the previous few years. But, because of the tightening of oil supplies (due to the declining spare capacity in Organization of the Petroleum Exporting Countries (OPEC), insufficient investment in exploration and refining capacity, and to geo-political problems) the inventory model of price forecasting no longer works. In fact, international prices are growing far faster than can be explained

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[3] Output or GDP is not an ideal measure of welfare, but it is an indicator most commonly focused on by policy makers.

by demand increases alone, indicating the presence of supply constraints and increased uncertainty.

Part 2 describes[4] a couple of scenarios for the trajectory of energy and emissions in China and India up to 2050. The reference case is designated as a **business as usual scenario** (BAU) with a high growth variant (BAU-H). These are compared with a set of **alternate scenarios** (ALT) based on interventions on the demand and supply side of energy use which result in *substantially more energy efficiency and lower global and local emissions* relative to the BAU cases. The underlying assumptions of these scenarios are provided as well as their implications for global energy markets (including energy prices) and global emissions under different assumptions on the presence or absence of rigidities/frictions in energy markets. Potential feedback effects on national and global GDP growth rates are also discussed briefly. This section also includes some rough estimates of the **investment requirements** of the different scenarios and implications for additional financing if growth constraints are to be avoided.

The crux of the story is that to improve the welfare of their citizens and generate a steady stream of employment to accommodate the growing labor force, both China and India will have to maintain high GDP growth rates for many decades. With the demographic shift of the population to urban areas and the growing per capita income of the urban population, the demand for electricity will be increasing rapidly. At present, the most abundant and cheapest domestic fuel source for electricity production in both China and India is coal. There will also be a growing demand for mobility in both countries which is likely to be increasingly satisfied through growing road and air traffic – both heavy consumers of oil.

Thus, the two business as usual scenarios (BAU) presuppose heavy reliance on fossil fuels for the next couple of decades with adverse consequences for local emissions (suspended particulates, sulfur, ozone, etc.), as well as global emissions (greenhouse gases—particularly CO_2). The reference BAU scenario assumes annual growth rates of 6.5–7.5 percent in China and 5–6 percent scenarios in India over the next decade or two with both rates tapering to 3-4 percent a year by 2050. The high growth rate scenarios (7.5–9 percent per annum in China and 7–8 percent per annum in India) are based on recent performance and extrapolation of government assumptions for upcoming five-year plans. These BAU scenarios will put pressure on international energy markets—particularly if there are rigidities in the rate at which supply can expand (because of institutional and logistical difficulties in developing coal in India and China, and/or international oil market uncertainties regarding the returns to investment—for example in oil refineries etc. — as well as, reliance on high-cost alternate sources for oil—such as tar sands, etc.). The higher world energy prices will have repercussions on China and India resulting in some reallocation of investment away from higher productivity non-energy sectors and the growth of less energy intensive activities. The impact of higher world energy prices on other parts of the world will be mixed. Growth rates will be adversely affected by higher prices, but these will be partially or fully offset by growing exports to the larger markets in rapidly growing China and India – particularly in the high growth rate scenarios.

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[4] Based on background work commissioned to simulate and analyze selected scenarios.

The alternate, policy-based scenarios (ALT) are designed to explore the extent of two potential decouplings. First, *decoupling energy growth from GDP growth* through a combination of increased energy efficiency and structural shifts away from energy-intensive manufacturing. Second, *decoupling emissions growth from energy growth* through fuel switching from coal to gas (or clean coal), or from fossil fuels to nuclear energy or renewables. Traditionally, the presumption is that the higher cost of investment in alternatives to fossil fuels will be prohibitive and therefore best delayed until technological innovations reduce their costs to avoid adversely affecting GDP growth rates. The cumulative financial cost reducing benefit of this delayed investment, however, may be offset by the increased cumulative emissions cost associated with prolonged reliance on fossil fuels. In the IMACLIM-R model used for the simulations in this paper, “learning by doing” is built-in; therefore earlier investments in novel technologies will accelerate the rate at which one moves down the cost curve thereby reducing the aggregate financial burden. In the reference case, as well as scenarios with rigidities in adjustment in global (local) energy markets, some external financing becomes necessary if growth rates are not to be adversely affected in China and India. However, in the high growth rate scenario, enough savings are generated (particularly in China, less so in India) to potentially self finance a larger part of the higher cost of investment in energy efficiency and the shift away from carbon based fuels.

PART 1 – The Level and Composition of Energy Use and Emissions in China and India

For many purposes (such as, to analyze the energy intensity of an economy and so forth), it is sufficient to focus on the level of aggregate energy use. Local and global emissions from energy use, however, are sensitive to the composition of energy used (different fuels) and not simply to its level.

1.1 Emerging Concerns

There are many issues involved in managing energy supply and demand in China and India. However, a few broad concerns are emerging that are of particular interest.[5]

A. Demand for Fossil Fuel Energy Is Exceeding Domestic Supply Capabilities

At the aggregate level China and India currently consume about 12 and 5 percent of the world's energy, respectively. In terms of composition, China's consumption of coal is slightly less than its own production of coal – the balance being exported (table 1). On the other hand, China's consumption of petroleum is increasingly larger than its production—the balance being imported. For most other fuels, domestic consumption and production are still roughly in balance. India's domestic production of coal and oil satisfies an even smaller part of its consumption and the imbalance is growing—particularly in oil (table 1).[6] Both countries produce gas, but gas consumption does not yet account for a significant share of energy use.

Table 1: Energy Balance in China and India (1980-2003)

		Production and Stock Change (Mtoe)							Consumption (Mtoe)						
Country	***Year***	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	***Total***	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	***Total***
China	***1980***	316	107	12	5	180	0	***620***	313	89	12	5	180	0	***599***
	1985	405	130	13	8	189	0	***744***	401	93	13	8	189	0	***704***
	1990	545	136	16	11	200	0	***908***	535	110	16	11	200	0	***872***
	1995	691	149	19	16	206	3	***1084***	673	158	19	16	206	3	***1075***
	2000	698	151	28	19	214	4	***1115***	664	222	26	19	214	4	***1149***
	2003	917	169	36	24	219	11	***1377***	862	270	35	24	219	11	***1422***
India	***1980***	50	11	1	4	148	1	***215***	53	34	1	4	148	1	***241***
	1985	71	31	4	4	162	1	***274***	76	48	4	4	162	1	***296***
	1990	97	35	10	6	176	2	***326***	104	63	10	6	176	2	***360***
	1995	124	39	17	6	189	2	***377***	134	84	17	6	189	2	***432***
	2000	143	37	21	6	202	4	***414***	159	114	21	6	202	4	***506***
	2003	157	39	23	6	211	5	***441***	173	124	23	6	211	5	***542***

Source: IEA (2005a).

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[5] This review of problems is based primarily on secondary source literature. In the past few years, the International Energy Agency (IEA) in Europe, the U.S. Department of Energy, and others (such as the Asia Pacific Energy Research Center) have produced many reports on energy in China and India to identify key drivers of energy and emissions trajectories and the role of different policy strategies.

[6] See also Annex Figure A1 and A2, and Annex Table A1 (a and b).

At present, China is the second-largest energy consumer in the world following the U.S. Its total energy use, however, is still only half that of the U.S., and its per capita consumption levels are only about 10 percent of that in the U.S.[7] Because China's population is more than four times the size of the population in the U.S., China's per capita energy consumption level has only to double (i.e., increase to 23 percent of the U.S. level) for it to become the world's largest consumer of energy.

In 1980 China had one of the highest energy intensities[8] in the world using GDP at market prices (see table 2) – almost 7 times as high as the US and almost four times as high as in India. Using purchasing power parity figures lowers the relationship the US from 6.72 to 1.64, but increases it relative to India from 3.8 *(6.72 / 1.77)* to 5.0 (*1.64 / 0.33)*. In fact, measured relative to GDP in PPP, China and India both appear more efficient than the USA. However, given that most energy use is in tradable / marketed sectors and the evidence of continuing inefficiency in industry (World Energy Council, 1999), it still seems that the scope for and returns to economizing on China's and India's energy use are potentially large.

Another important aspect of energy intensity in China and India is the change over time. In the 23 year period from 1980 to 2003 energy intensity in China declined by an extraordinary 4.8 percent per annum[9]— more than double the 2 percent per annum decline in the US and almost 24 times faster than the anemic 0.2 percent per annum decline in India. As a result, China's energy intensity dropped by half relative to the US, while India's increased by 50 percent relative to the US. This significant pattern of change over more than two decades (both within the two countries, as well as, relative to the US) is the same whether one uses GDP at market prices or purchasing power parity prices (see last row of table 2).

Table 2: Changes in Energy Intensity in China, India, and the U.S.

		Based on GDP at market prices (constant 2000 US$)			Based on GDP at purchasing power parity prices (PPP) (constant 2000 international $)		
		China	India	U.S.	China	India	U.S.
Energy Intensity*	1980	101,936	26,805	15,174	24,922	5,051	15,157
	2003	33,175	25,460	9,521	8,076	4,761	9,561
Growth Rate	**1980-2003**	**-4.76%**	**-0.22%**	**-2.01%**	**-4.78%**	**-0.26%**	**-1.98%**
Relative to U.S.	1980	6.72	1.77	n.a.	1.64	0.33	n.a.
	2003	3.48	2.67	n.a.	0.84	0.50	n.a.
Change in Ratio	**1980-2003**	**0.52**	**1.51**	**n.a.**	**0.51**	**1.49**	**n.a.**

** Total Primary Energy Consumption (Btu) per unit of output*
Note: n.a.= not applicable; PPP = purchasing power partity
Source: Adapted from EIA (2003a) and World Bank (2005a).

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[7] Energy data is taken from the U.S. Energy Information Administration (USEIA) International Energy Annual 2003 and population data comes from the World Bank's World Development Indicators (2005a).

[8] The amount of energy consumed per unit of economic output.

[9] Most of the reduction in energy intensity in China since 1978 is attributed to technological change, not structural shifts from heavy to light industry (Lin, 1996).

B. Limited Low-Cost Domestic Energy Resources Other Than Coal for the Production of Electricity

China's use of electricity more than doubled in the decade between 1986 and 1995 and then again by 2003 (National Bureau of Statistics, 2005). China has the fastest growing electric power industry in the world – fueled primarily by coal. Hydroelectric generating capacity is a particularly important source of electric power only in the central and western regions. Industry is the largest consumer of electricity, followed by the residential sector, and then the agricultural sector.

India has an installed electricity generation capacity of 112,000 MW which is about 10 percent that of the U.S. (Energy Information Administration, 2005a). Approximately 70 percent of India's electricity comes from coal. Unlike China, India does not have a large supply of high-quality coal, nor of gas for electricity generation. So more and more high quality coal and gas has to be imported. Industry is the largest consumer of electricity, followed by the agricultural sector and then the residential sector.

As in the case of China, India's power sector continues to face a considerable demand-supply gap, and the supply it has is of poor quality (low voltage and grid instability). Peak shortage in power is estimated in the range of 13 percent (Indian Ministry of Power, 2003), even though the peak is probably lower than it would have been with more reliable supply. Transmission and distribution (T&D) losses[10] in some states (such as Maharashtra) amount to around 40 percent of total electricity generated centrally.

C. Strategic/Security Concerns over Growing Oil Imports for Transportation

In China, deficiencies in existing oil pipeline infrastructure (to link the remote hinterland to the primary centers of demand in the rapidly industrializing coastal regions) meant that economic agents in these centers found it cheaper to import fuel oil and diesel from abroad than to rely on domestic sources of oil and oil products even when the country was a net exporter of oil.

In addition, in the last decade China has committed itself to a strategy of emulating the U.S.'s dependence on motorization as the dominant mode of transportation. This strategy was only in part determined by mobility considerations. It was primarily driven by industrial policy considerations.[11] The automobile industry is seen as a

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[10] The losses can be of a *technical* nature (such as line losses due to poor maintenance, overloading, poor standards of equipment, low power factors at off peak hours etc.), or of a *commercial* nature (such as illegal tapping of low tension lines, faulty energy meters/unmetered supply, and uneven revenue collection). Some of the problems with loss reduction are lack of energy audits, lack of segregation of losses into technical and commercial losses, and lack of transparency in meter reading and billing. Available data cited above does not distinguish between the two types of losses even though the commercial losses, such as theft, are a loss to the utility but not to the power available for consumption.

[11] The 16th Conference of the National Congress of the Communist Party of China and the 8th Conference of the National People's Congress established the strategic role of automobile industry as a pillar of its economy. For details, see the web site of the Automotive Sub-Council of the China Council for the Promotion of International Trade, http://www.autoccpit.org.

potential engine of growth for the economy as a whole because of its multiplier effect through buyer-supplier linkages.

This strategy shift has seen less energy-intensive vehicles, such as bicycles and pedi-cabs, replaced by more energy-intensive vehicles, such as motorcycles, cars and trucks. The rate of growth of the vehicle fleet – which averaged 5.7 percent per annum through 1999 – accelerated dramatically to 26.5 percent per annum in the last five years, though there are now signs that the growth rate is beginning to moderate. Automobile ownership in China is still only eight to ten per thousand people, in contrast to the approximately 400 per thousand people in Japan, and the approximately 500 per thousand people in the U.S.[12] However, a tenfold growth in ownership of automobiles over the next 30 years in China is quite conceivable given the expected growth in household incomes and current government policies. The average number of vehicle miles traveled per household and the volume of freight transported by truck traffic is also expected to expand dramatically: *within urban areas*, as urban sprawl increases and jobs and residences disperse across a larger area, increasing distances between them; and *between urban centers*, as commercial and industrial entities rely increasingly on the flexibility provided by the growing highway network (relative to railways) linking China's cities, and connecting the coasts to the hinterlands. The penetration of fuel efficient hybrid technology in the vehicle fleet is still very low.

Some cities in India, such as Delhi, have exhibited similar explosive growth in automobile ownership and use as in China. Overall, however, India's reliance on the road sector for passenger and commercial traffic is much lower because it started much later. But the recent growth of the middle class in India, and the government's decision to dramatically expand the highway network is likely to fuel a growing dependence on the road sector. Both China and India have seen, in addition, an explosive growth in air traffic – another major consumer of oil products.

1.2 Energy Use and Fossil Fuel Emissions in China and India in the Period 1980–2004

China is the largest producer of coal in the world. In 2004, its production was almost double that of the U.S. (2.2 billion short tons versus 1.1 billion short tons) (EIA, 2006). China's estimated total coal resources are second only to the former Soviet Union although proven reserves ranked third in the world. China is a net exporter of coal and likely to remain so for at least another decade.

In 2003, coal accounted for 67 percent of China's *primary energy production* of 1,216 million tons of oil equivalent (Mtoe), oil for 12 percent, natural gas for 3 percent, hydro for 2 percent, and biomass and other waste for 16 percent (table 5.1). China has a growing nuclear power sector, but its output accounts for less than one percent (0.8 percent) of energy production in 2003. More recently, China has moved aggressively to expand nuclear, wind and solar power generating capacity, as well as new technologies

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[12] Vehicle ownership figures in Japan and the United States are higher, at 570 per 1,000 people in Japan and 780 per 1,000 people in the United States. Vehicle ownership includes not just automobiles but also buses, pickups, and trucks – but not motorcycles (World Bank, 2005a).

for coal gasification, etc. In *final energy consumption* coal dominates other energy resources, accounting for 72 percent of fossil fuel consumption, and even in *primary energy consumption* it dominates at 58 percent of total.

In 2003, India's total *primary* energy production was estimated at 441 Mtoe, with coal accounting for 36 percent of the supply mix, oil for 9 percent, gas for 5 percent, hydroelectric power for 1 percent, nuclear for 1 percent, and biomass energy and other renewable for 48 percent (table 1).[13] The use of commercial fuels, such as coal and oil, is growing rapidly in tandem with economic expansion (industrialization and growing per capita income). Nonetheless, unlike China, more than 60 percent of the Indian households still depend on traditional energy sources such as fuelwood, dung, and crop residue for their energy requirements (TERI, 2004).

The increasing use of fossil fuels (particularly coal and oil) in both countries is also generating harmful emissions – particulates (with primarily **local** effect on health in urban areas), sulfur and nitrogen (with primarily **regional** effects via ozone and acid rain on agriculture and ecosystems), and CO_2 (with primarily a **global** effect via carbon on global warming).

A. Global Externalities – China Is on Track to Become the World's Largest Emitter of Greenhouse Gases, with India as the Next Largest Emitter among Developing Countries

Currently the U.S. is the world's largest emitter of carbon emissions from energy. However, China is expected to overtake the U.S. in the next decade plus. China's carbon emissions are driven by the rapid growth in the use of fossil fuels – particularly coal and oil (gas not being a significant contributor yet). CO_2 emissions from India are a quarter of those from China, but also growing due to the dependence on fossil fuels, particularly for electricity production. As evident in figure 1, CO_2 emissions in both countries track coal use quite closely.

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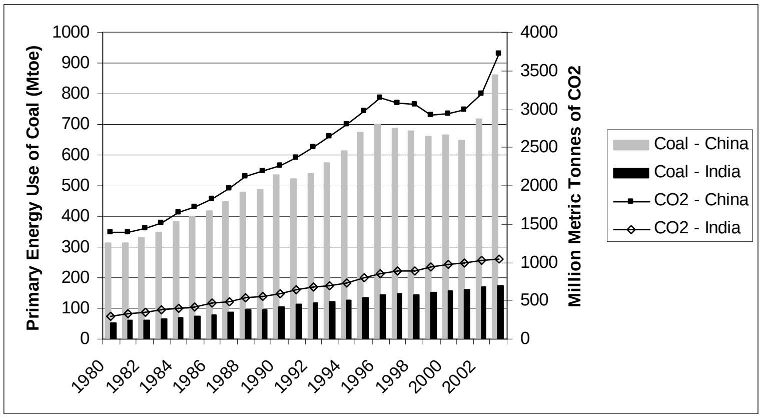
[13] 30 years earlier, before the major expansion of commercial electricity production, traditional biomass accounted for 66 percent of India's total primary energy supply. At that time traditional biomass was also a major source of energy in China – approximately 30 percent (IEA 2005a).

Figure 1: Primary Energy Use of Coal and Total CO_2 Emissions from Fossil Fuel Consumption (1980-2003) in China and India



Source: IEA (2005a, b).
Note: CO_2 = carbon dioxide; Mtoe = million tons of oil equivalent.

What socioeconomic factors are driving CO_2 emission changes in China and India? Recent literature covering the period 1980–96/97[14] has suggested that *economic growth was the single largest driver of increased emissions in both countries*[15]. Over time the gross emission increases have been significantly offset by improved energy efficiency in China, but much less so in India (as noted earlier in the discussion on energy intensity in the two countries). Decarbonization, i.e. lowering CO_2 emissions by reducing the emission factor[16] through use of better technology and expanding the use of fuels with lower carbon content, was not a significant factor during this two decade period in either country. However, its importance in India has increased in the 1990s.

B. Local Externalities—Growing Public Health Costs from Severe Air Pollution (Arising Mainly from Coal Combustion But Also from Vehicular Exhaust) Is Driving Domestic Policy Responses

As noted earlier, not only is heavy reliance on fossil fuel (particularly coal) associated with the expansion of CO_2, it is also associated with the expansion of various types of local pollutants (such as suspended particulate matter, sulfur dioxide SO_2, NOx, etc.) contributing to health problems, particularly in cities, and ground level ozone[17] and acid rain, that particularly affect rural areas and natural ecosystems.

Sulfur dioxide (SO_2) and soot released by coal combustion are the two major air pollutants that form acid rain, which now falls on about 30 percent of China's total land

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[14] For China, see Sinton, Levine, and Wang (1998), Van Vuurena et al (2003), and Zhang (2000). For India, see Paul and Bhattacharya (2004). See also Annex Table A2 and A3.

[15] These articles use different decompositions and techniques and as such are not strictly comparable, even though they cover roughly the same time period. Thus, in the India study the "economic" component includes the consequences of labor force increases, whereas in the China study it is part of the "population" component. As a result, the studies suggest that different variables such as "population growth" in China and "structural changes" in India also increased energy emissions.

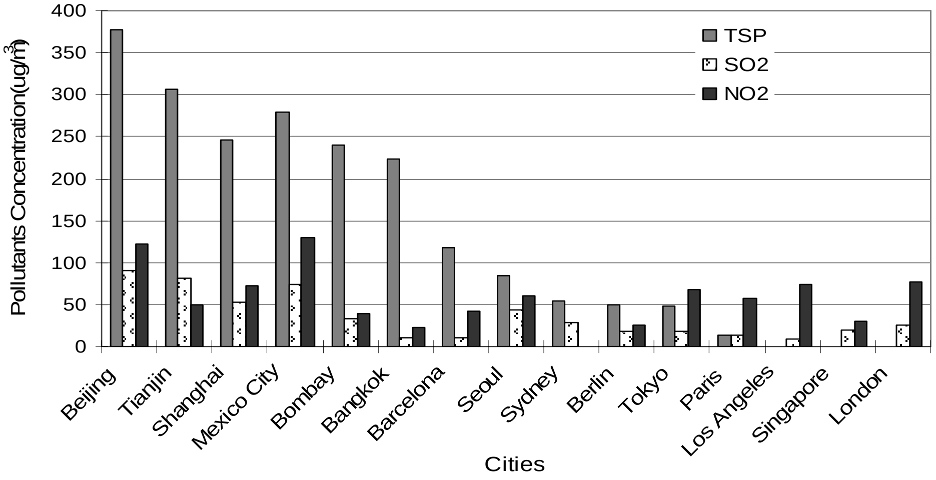
[16] Emissions per unit energy.

[17] Ozone and other photochemical oxidants are formed by the action of ultra-violet (UV) light from the sun on nitrogen. Its production and concentration are dependent on the presence of NOx and ultra-violet light.

area (USEIA 2003c)—areas which are also affected by an ozone generated natural haze. In India too, acidic precipitation is becoming increasingly common. According to the Envioronmental Information System of India, soils in the northeast region, parts of Bihar, Orissa, West Bengal and coastal areas in the south already have low pH values. If immediate mitigative measures are not taken, further aggravation from acid rain may cause these lands to become infertile or unsuitable for agriculture. Studies in India show a decrease in mean wheat yield of 13 to 50 percent within 10 kilometers of thermal power stations with capacities of 500 to 2000 MW respectively (Mitra and Sharma, 2002). Similar studies in China have concluded that the deteriorating air quality has reduced optimal yield by 5–30 percent for about 70 percent of the crops grown there (Chameides et al, 1999).[18]

Industrial boilers and furnaces based on coal are the largest single *point sources* of urban air pollution[19], and road transport the main *mobile source* of air pollution. Depending on what pollutant one focuses on, a different set of 10–20 cities are amongst the most polluted in the world in terms of air pollution. Many Chinese and Indian cities are amongst these cities (see figure 2).[20]

FIGURE 2: Air Quality Comparison of Some World Cities, Year 2000 (Average Annual Levels, Particulates [TSPs], SO_2, NO_x)



Source: Hao and Wang (2005).
Note: NO_2 = nitrogen dioxide; SO_2 = sodium dioxide; TSP = total suspended particulates.

One can speak meaningfully about pollution in a city, a locality, or a river – because *pollution per unit area* is a function of localized air sheds and watersheds. But there is no equivalent measure for an area as large as a country – so there is no such metric for the average level of pollution in China or India. Instead it is more useful at the

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[18] Assuming sufficient water and nutrients, simulations of the crop-response models demonstrate that atmospheric aerosols lead to lower crop yields through a decrease in total surface solar irradiance—thereby affecting the marginal productivity of other inputs.

[19] China's State Environmental Protection Agency (SEPA) estimates that "industrial pollution accounts for over 70 percent of the national total, including 72 percent for sulfur dioxide (SO<->2<->) emissions, and 75 percent for flue dust (a major component of suspended particulates)".

[20] Earlier studies include the report released in 1998 by the World Health Organization (WHO).

country level to estimate *the total number of people exposed to different levels and types of pollution.*

In 2003, more than half (58.4 percent) of China's urban population was exposed to average annual amounts of PM10 in excess of 100 micrograms per cubic meter, which is the Chinese standard (and twice the U.S. standard). Air pollution is estimated to have led to damages valued at 394 billion Yuan[21] and 300,000 cases of chronic bronchitis in 660 Chinese cities in that year (World Bank, 2007). In the case of India, Cohen et al (2004) reported an estimate of 107,000 excess deaths in 2000.[22]

Addressing domestic emissions is a major national motivation for taking action. Attempts to reduce local emissions in China by curtailing coal production and consumption had some success in reducing SO_2 and other local emissions for a few years in the late 1990s (Hao and Wang, 2005). Reductions in SO_2 tracked the apparent dip in coal consumption and CO_2 emissions in China (see figure 1 and Annex Figure A3). Even though GDP grew by a third (+33.7 percent) in the period 1997–2001, there was almost no increase in CO_2 emissions (+0.2 percent) – in contrast to a 14 percent increase that would have been predicted based on emissions to GDP ratios in the period 1980 to 1997. SO_2 concentrations (mg/m^3) also dropped by approximately 40%. This drop gave rise to much optimism regarding the potential for 'decoupling' the growth in emissions and energy requirements from the growth of GDP. Several factors – including faulty statistics – explain this apparent decoupling. Their relative weight is still being debated. But the closing of a large number of small and inefficient coal producers was one important factor in this decoupling (Sinton and Fridley, 2000, 2003; Sinton, 2001).

But this decoupling could not be sustained. With low power tariffs, blackouts, and power shortages arising from 9–10 percent per annum GDP growth, it has been necessary to use all power generating capacity, no matter how inefficient. As a result both SO_2 emissions (particularly in northern cities) and CO_2 emissions resumed an upward trend.

1.3 Energy Use in China and India and International Energy Markets

The decision to encourage more reliance on roads for passenger and freight movements has resulted in a surge in the demand for oil (gasoline, diesel and other oil products) in both China and India. This has resulted in the growth of oil imports with national implications for balance of payments and energy security, and global implications for world energy markets. This section addresses the latter issue and argues that the recent growth in energy use in China and India does account for a significant part of the incremental increase in global energy use, but that the annual growth in global energy use has not been unusual relative to the past and as such is not the key component

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[21] With each death costed at 1 million Yuan (Table 4.5, p.74 World Bank 2007).

[22] Other partial studies corroborate these findings. In China, the consequences of current air pollution levels are apparent in public health statistics for some cities: "approximately 4,000 people suffer premature death from pollution-related respiratory illness each year in Chongqing; 4,000 in Beijing; and 1,000 in both Shanghai and Shenyang. If current trends persist, Beijing could lose nearly 80,000 people, Chongqing 70,000, and other major cities could suffer tens of thousands in cumulative loss of human life through 2020. With industry expected to maintain rapid growth during the next 20 years, a steep decline in pollution intensity will be necessary just to keep emissions constant" (Dasgupta et al, 1997). In India, Delhi has been identified as the city having the highest mortality figure of about 7,500 deaths per annum. (Brandon and Hommann, 1995; WHO, 2002; World Bank, 2005a).

in the recent surge in oil prices. Rather it is the tightening of oil supplies in the context of diminished spare capacity and growing geopolitical uncertainties that is driving the increase in oil prices in the last couple of years.

Since the late 1980s nominal oil prices[23] have been relatively *stable and flat.* There were two exceptions: a momentary spike (reflecting uncertainty) during the Gulf crisis of 1990–91 with prices soaring +50 percent above the average price in the period May 1990–91 average; and a longer-lasting perturbation during the Asian crisis of 1997–98 (when per-barrel prices dropped by some US$12.9 between January 1997 and December 1998). The latter reflected a negative demand shock, caused mostly by the decline in oil demand in Asia, and the modest slow-down of economic activity in Europe and Japan. But the price drop also reflected a lag in the Organization of the Petroleum Exporting Countries' (OPEC's) downward adjustment of its production. This drop in price was followed during 1999 and 2000 by a symmetrical catch-up in prices under the combined effect of successive cuts in production by OPEC and the renewed growth in global economic activity. Between 2002 and 2004 oil prices entered a period of *gradual but sustained increase, and* since 2004 oil prices have surged. The time profile and determinants of the recent price trend have nothing in common with the two events in the 1990s, nor with either of the two former oil shocks in the 1970s[24] (IMF, 2005), which were characterized primarily by abrupt geopolitical supply disruptions .

The more gradual, but steady increase of the oil price in the period 2002-2004 has been driven by buoyant growth in global demand in the context of a worldwide economic expansion. Global GDP (in constant terms) has exhibited fluctuating but high annual growth rates from 2002 to 2004 in the range of 3 percent – 4 percent and only a slight slow-down in late 2004 and throughout 2005.[25] Global crude oil use grew from 77.6 million barrels a day (mbd) to 84.2 mbd between first quarter of 2002 and the last quarter of 2004 and despite signs of a slow-down throughout 2005, continued to increase compared to 2004 (+1.1 mbd on average), indicating the relative inelasticity of oil use with respect to higher prices in the short-run.[26]

Organization for Economic Co-operation and Development (OECD) countries are responsible for the largest share in crude oil use over this period (relatively steady at ~ 60 percent). China's oil use grew from 6.06 percent (1st quarter of 2002) to 7.87 percent (4th quarter of 2004) of global crude oil use. As such, it is responsible for the highest increase in global oil use over its early 2001 level, averaging 0.25 mbd initially then expanding to 2.1 mbd (equivalent to 37 percent of the global increase). Furthermore, although crude oil use in industrialized countries was decreasing slightly, in parallel with a moderate slow down of their economic activity in 2001, the Chinese economy's momentum was large enough to offset the decline and generate a net increase in oil use. Since 2005, as the world economy began slowing down (and oil use in industrialized countries was levelling-off), economic growth in China was still strong enough to sustain some growth in oil use. A similar story applies for India, although it offers much less spectacular

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[23] For the purposes of this section (unless otherwise indicated), oil price is to be understood as crude oil spot price, in nominal terms. The (monthly-averaged) arithmetic mean of Dubai, Brent and WTI grades is used.

[24] Average annual prices rose by 250 percent between 1973 and 1974 and by 133 percent between 1978 and 1979, in reaction to the abrupt and significant supply restrictions linked to geopolitical events.

[25] Source: World Bank (2006).

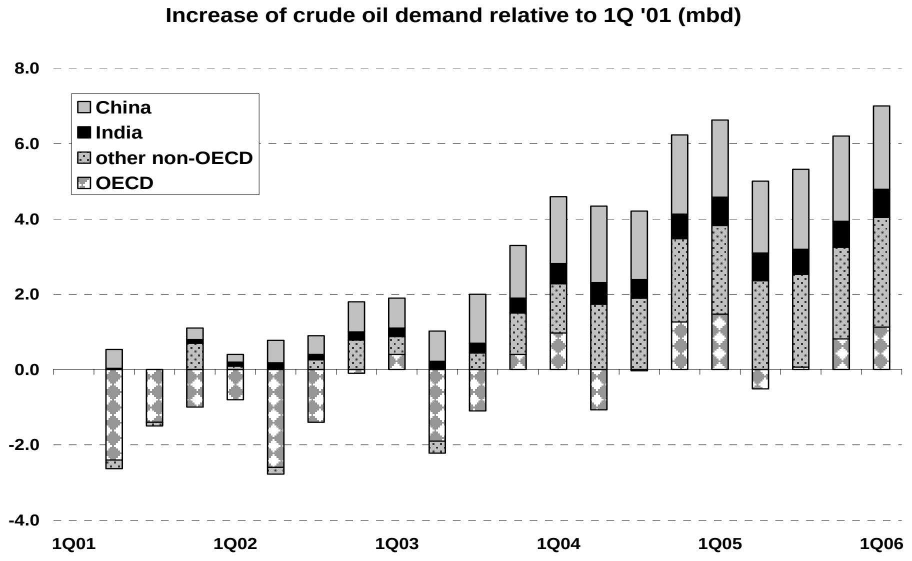
[26] Source: IEA, Oil Market Reports.

figures. India accounts for only 3–4 percent of global use and 7 percent of the average increase in global oil use since early 2001.

Thus, China and India account for a large portion (40–50 percent) of the *incremental* increase in global oil use (see figure 3), but they still account for only 9–12 percent of *aggregate* global oil use. In addition, the recent growth in oil use in China and India has been partially offset by the deceleration or drop in the use of oil in traditionally oil-dependent countries. As a result, aggregate use of oil has not grown as dramatically in the last few years as it did in the 1990s.[27]

Until early 2005, the supply of oil (and draw-down of inventories) has been able to more or less keep up with rising demand. But since then, with OPEC spare production capacity declining, the market has been under pressure, although this eased somewhat toward the end of 2005. All along the supply chain, this tightness has magnified many short-term developments and problems that were not concerns in a period of ample supplies, and has contributed to high volatility. Figure 4 shows that OPEC's spare production capacity started dropping steadily since mid-2002 bringing the market closer to binding constraints on the supply of cheap oil. Since Jan 2004 this spare capacity has been below 3 mbd. Rough calculations by the International Monetary Fund (IMF) suggest that a level of spare capacity on the order of 5 mbd may help stabilise the market by reducing volatility by 50 percent (IMF 2005). With geo-political uncertainties associated with output from Iraq, Nigeria, and the República Bolovariana de Venezuela (see grey part of the bars in figure 4), and underinvestment (both up and downstream) in the supply chain, the extent of the drop in spare capacity is even higher.

FIGURE 3: Increase of Crude Oil Use Relative to First Quarter 2001 (mbd)



Source: IEA Oil Market Report (various issues).
Note: mbd = million barrels per day; OECD = Organisation for Economic Co-operation and Development.

Figure 4: OPEC Spare Production Capacity (mbd)

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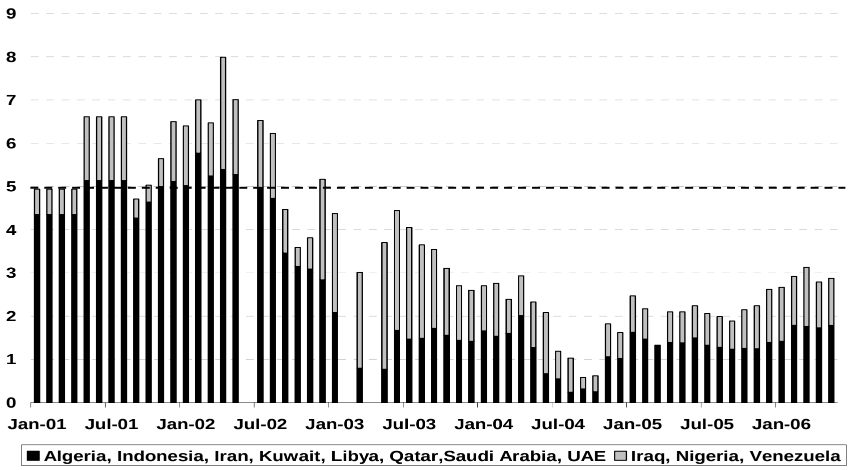
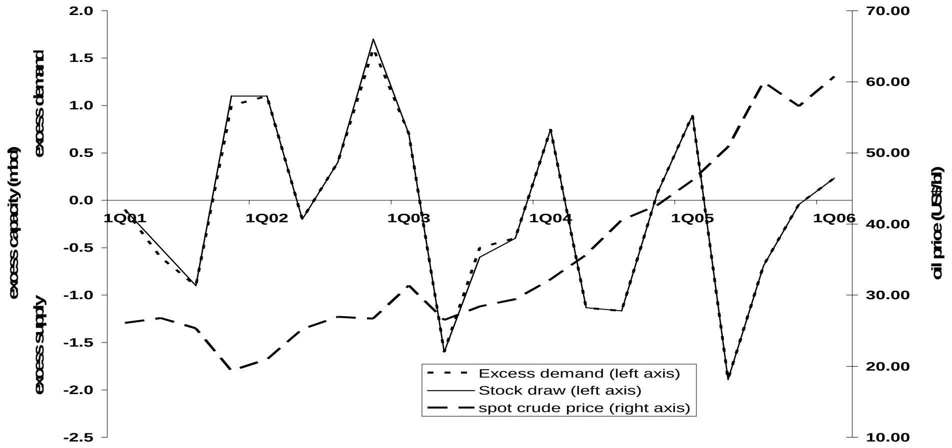
[27] During the 1990s, overall crude oil demand increased 1.61 percent annually.; by contrast, from 2000 to 2005, it increased by less than half that rate (0.74 percent).



Source: IEA Oil Market Report (various issues).

This upward movement of prices has not slowed even after OPEC adopted an accommodative stance in mid-2004 – to enable OECD commercial crude oil stocks to be replenished fully and to ease the potential fear of supply shortages in the context of a slowdown of non-OPEC production. Thus, supply and demand equilibrium – as captured in the inventory model of the oil market[28] – has ceased to fully predict crude oil prices in the last few years (see figure 5 -- with market fluctuations in excess demand, but a steady rise in prices).

Figure 5: World Oil Market – Excess Demand, Stock Drawdown and Crude Oil Spot Prices



Source: IEA Oil Market Report (various issues), and IEA (2006).

The dramatic acceleration in oil prices since 2004 arose because supply was much more inelastic than it was in the past as a result of the decline in spare capacity combined

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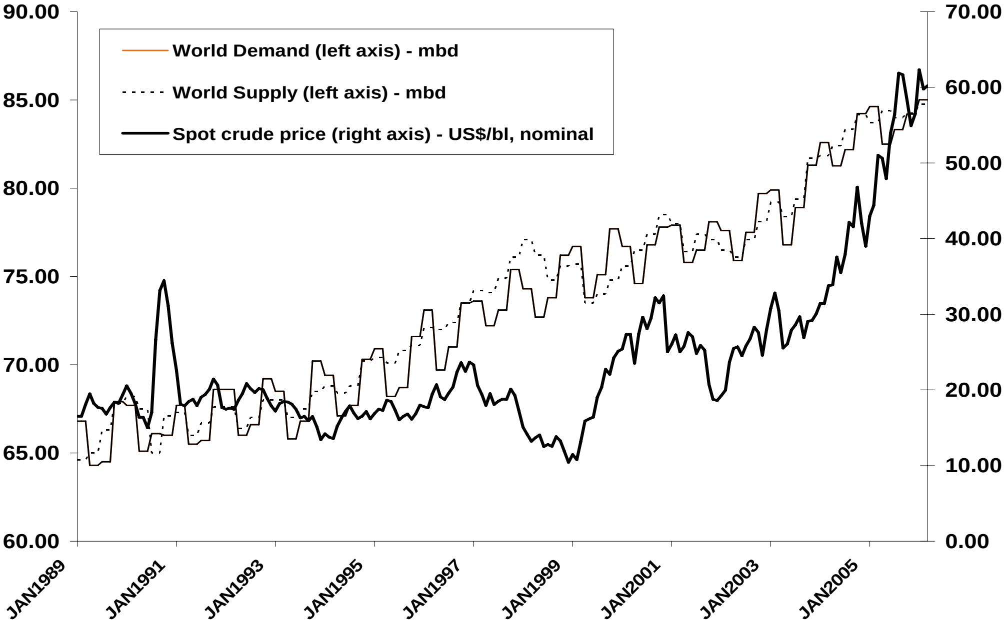
[28] The so-called inventory model focuses on the dynamics of production, consumption and stock fluctuation, and its relationship to inventory movements to explain the evolution of prices of a commodity. In the context of the oil market, oil stocks levels (including strategic reserves) in OECD countries have been shown to be highly correlated to oil prices (Merino and Ortiz, 2005). The inventory model can be applied to the oil market for short-term forecasting purposes (Ye et al., 2005) or for heuristic purposes to disentangle the relative weight of different factors involved in price formation (Pindyck, 2001; Merino and Ortiz, 2005).

with increased geopolitical uncertainties. It is difficult in this context, to assign a very large weight to the impact of the growth of oil use in China and India on international oil prices. The acceleration of demand for oil, particularly in China (less so in India), could be characterized as a demand shock. But at best it is a shock that is displacing demand from other sources in the context of supply constraints. There has not been a major acceleration in the global use of crude oil since 2004 even though it has been growing steadily since 1995 (see figure 6).

Figure 6: Global Demand for Crude Oil (mbd) and Average Spot Prices (US$)



Source: IEA Oil Market Report, various issues, Energy Prices and Taxes - Crude Oil Spot Prices (US$/bbl) Vol. 2006 release 01.

Prices currently are being formed in a setting increasingly driven by expectations of future tightness in the market fuelled by concerns regarding medium-term prospects for cheap energy supplies such as:

- the slowdown of growth in non-OPEC production (despite high oil prices), which is expected to peak in about 5–10 years,
- the erosion of (OPEC) spare production capacity noted above, which is already under the pressure from increasing social unrest and political developments, and
- inadequate spending on exploration and the maintenance of existing oil fields, as well as, insufficient spending on appropriate refinery capacities in the context of a re-specification of demand, causing an extra pressure on demand for lighter products.

PART 2 – Simulation of Energy and Emissions Trajectories in China and India up to 2050

Both China and India will have to maintain high GDP growth rates for many decades to improve the welfare of their citizens and to generate a steady stream of employment to accommodate the growing labor force. This growth will be fuelled by energy. Many analysts of energy use in China and India note that China and India's own production of fossil fuel energy is not likely to grow at the same high rate as expected consumption of fossil fuel energy. As a result, they are expected to become increasingly dependent on energy imports. How dependent will be a function of whether they stay with current low cost but polluting energy options, or move aggressively to adopt a new, more balanced and diversified energy strategy – which is explored in this section.

In forecasting energy use in the medium term (up to 5 years) it is common to take GDP growth and its underlying structure as exogenously determined, and use an econometrically estimated elasticity of energy use with respect to GDP to determine likely energy use. This parameter tends to have a value substantially less than unity for most high income OECD countries, specially since the 1970s. That is when they started shifting to a post-industrial service-based economic structure – in part as a reaction to earlier oil price shocks in the 1970s. The value of the parameter is close to or greater than unity for most developing countries (Zhang 2000, Liu 2004). In the 1990s, however, the value of this parameter had dropped to 0.7–0.8 for India—substantially lower than in the 1970s. This parameter has been even less stable for economies undergoing substantial structural changes, such as in China—where it has varied from under 0.5 to over 1.0.[29] In fact, reliance on these extra low numbers for China in the 1990s caused IEA and other observers of the China scene to dramatically underestimate energy demand in China in the post 2000 period[30] (IEA 2002). Based on more recent economic and energy statistics (for 2002–2004), China is again exhibiting developing country patterns of energy demand growth with an energy elasticity of GDP greater than one.[31]

To go beyond estimating aggregate energy needs within a five-year period requires use of more complicated models. To differentiate growth in different energy categories (for example, fossil fuel versus renewables, or subcategories of each) a more disaggregated model of the economy is required that provides structural detail on differential changes within the energy sector and how it responds to relative prices, changes in the technology and productivity of different sectors, etc. This requires a multi-sectoral simulation model. Many energy simulation models have a 20 to 30 year horizon because the underlying capital stock for energy production is long-lasting and long-term implications of current investments do not show up in shorter time horizons. Even more

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[29] As noted earlier, this anomaly of elasticities as low as 0.5 in China has not yet been satisfactorily explained. It appears to have resulted from a combination of faulty statistics, improved efficiency associated with new industrial technologies plus some structural change/fuel switching (low hanging fruit), and draconian command economy measures (closing profitable, employment generating town and village industrial enterprises (TVIEs) that were heavily reliant on producing dirty coal).

[30] In IEA's World Energy Outlook 2002, the projected total primary energy demand in China for 2010 was 1,302 Mtoe, whereas actual demand had already reached 1,422 Mtoe by 2003.

[31] Elasticity of energy consumption averaged 1.47 over the period 2002 -2004, according to National Bureau of Statistics of China (2005).

detailed and longer time horizons are required to analyze the consequence of current investments for future emissions. Different fuels have different emissions coefficients and fuel switching can significantly affect aggregate emissions even for the same level of energy use. The externalities associated with some energy related emissions are also a function of the cumulative emissions – i.e. *concentrations* of long-lasting pollutants, such as CO_2, not just annual emissions. This requires models with horizons of at least 50 years,[32] which is what we use in this section. It is important to note in analyzing the results of these models that they are not forecasts, nor probability distributions of likely outcomes. Instead, the results are heuristic illustrations of the consequences of selected types of actions. The usefulness of the results depends on the appropriateness of the models and scenarios selected to analyze a given problem.

2.1 Choice of Simulation Models

In simulating energy and emissions for individual countries some analysts rely on top-down economy wide models, while others rely on bottom-up sectoral / technological models. The former models tend to generate a lot of trade-offs because they implicitly presume that all sectors are operating at their production frontiers, which is often not the case in developing countries. The latter models tend to generate more technical win-win opportunities, but do not adequately take into account feedbacks or offsetting effects in the rest of the economy/energy system. Because of the relative strengths and weaknesses of these two types of approaches, it is increasingly common to use a system of models that are *soft-linked*[33] (i.e. that link top-down economy-wide general equilibrium models with bottom-up, partial equilibrium models with more technological and sectoral detail) to simulate alternate scenarios for country-specific analysis.

Multi-regional global models are used to simultaneously simulate developments in large countries, such as China and India, to trace the global consequences of these developments for different energy markets as well as global emissions. A number of such multiregional global models are available (MERGE[34], MINI-CAM[35], AIM[36], etc.). This section uses estimates generated by the IMACLIM-R model at the International Research Center for Environment and Development (C.I.R.E.D).[37]

The IMACLIM-R model is a general equilibrium model with sub-sector detail on the *energy producing* sectors (fossil fuels—coal, oil and gas—and non fossil fuels—nuclear, hydro, biomass and other renewables), the *energy transforming* sectors (such as electricity), and key *energy using* sectors (such as industry, construction, transportation, and the residential sector). All other sectors are collapsed into an aggregate *composite*

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[32] Many climate change models operate with five-year increments over a couple of centuries.

[33] Creating a "system of models" where the output of one well calibrated model is fed in as an input into another well calibrated model instead of establishing a single set of internally consistent equations in a more comprehensive model that is not fully calibrated.

[34] For the Model for Evaluating Regional and Global Effects (MERGE), see Kypreos (2000).

[35] For the Mini Climate Assessment Model (MiniCAM) from the Pacific Northwest National Laboratory (PNNL) in the USA, see Edmonds et al (1994, 1995).

[36] For the Asian Pacific Integrated Model (AIM) from the National Institute of Environmental Studies (NIES) in Japan, see Morita et al (1994).

[37] For the IMARCLIM-R model from Centre International de Recherche l'Environnement et le Développement (C.I.R.E.D) in Paris, see Crassous et al (2006).

sector for ease of analysis. Growth is determined partly exogenously determined (population, savings), and partly endogenously (endogenous productivity growth, variations in the terms of trade, exhaustion of cheap fossil fuel resources, etc.). Each year a static Walrasian equilibrium is solved and the structural evolution of the economy is endogenized (for example, a scenario in which there is a lot of investment on transportation and in which consumers have a strong preference for mobility will generate different structural growth over time from a scenario with the opposite assumptions).

Compared with other existing economy-energy models, the IMACLIM-R model contains a few advantages:

(i) It explicitly incorporates technical information on the demand and supply sides of the energy sectors, including end-use efficiency and asymptotes to efficiency gains (often neglected in models using elasticities applied to final energy demand) and the ability to simulate "learning by doing" and the incorporation of capital stock vintages for long-lasting investments to more realistically trace the path of investment and technological adoption.

(ii) It ensures consistency between this technical information and the characteristics of the economic context, including the prevailing set of relative prices.[38]

(iii) It is based on a modeling compromise between models generating long-term optimal trajectories under perfect foresight (which tend to underestimate the role of social and technical inertia in economic adjustments) and models generating disequilibrium dynamics with a lot of hysterisis[39] and knife-edge pathways. IMACLIM-R is a growth model that allows transitional disequilibrium. The model has the ability to incorporate shorter-term transitional imbalances (due to the interplay of imperfect foresight at a given point in time and the inertia in the economic system) and the ability to adapt [see point (i)]. But, it also contains all the feedback mechanisms required to enable it to structurally recover over the long run, a Solow-like long-term pathway resulting from demographic changes, productivity growth, capital accumulation, and changes in the terms of trade. As such, long-term growth does not depend on inter-temporal optimization with rational expectations;[40] rather it relies on imperfect foresight about future prices and quantities – which is explicitly modelled for investment allocation and technology choices in the electricity sector.

(iv) It allows international capital flows between regions as a function of the divergence between domestic savings and total desired amount of investments

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[38] The reaction to prices, in IMACLIM-R, is also dependent upon technical information, such as the existence of asymptotes in energy efficiency, which is more credible than constant coefficients in the production function, especially when prices move over a large range.

[39] A mechanism that generates large losses in terms of cumulative GDP.

[40] Although the model describes behavior in terms of current prices, this does not necessarily signify the absence of expectations. First, it is assumed that people react to existing prices as the best available information at the time decisions are made. Second, the elasticities which govern these reactions are supposed to mimic real behavior and incorporate implicitly a broader set of parameters such as inertia, risk aversion, etc.

in each of 9 global regions (with China and India each representing a separate region). The model is **savings-driven**. A region's (country's) aggregate savings rate is determined exogenously by long-term demographic trends and age structure rather than short-term interest rate adjustments. All savings are invested. Desired amounts of investment are computed from (imperfectly) expected increases in future demand. There is no reason for the two sides to be balanced within a region. As a result, a region with excess savings becomes a capital exporter, and a region with a deficit of savings to finance its investment needs becomes a capital importer. The international pool gathers the exports of regions with excess savings and reallocates the money to regions with insufficient savings proportional to the total amount of unmet domestic investment needs. This scheme mimics a financial market where regions with insufficient savings introduce policies / create assets that are likely to attract foreign capital from regions with excess savings.[41]

2.2 Choice of Scenarios

A reference or **base case** designated as the *business as usual scenario* **(BAU)** is simulated for this paper.[42] For convenience of exposition only the results of this case are described in detail. All others are presented summarily and in relation to the BAU. The GDP growth rates assumed in the BAU are on average 6.5–7.5 percent per annum in China over the next decade or two, and 5–6 percent per annum in India both tapering to 3% - 4% by 2050. These average growth rates for the future are somewhat lower than recent performance because of presumed institutional and technical constraints within the economies—resulting in inefficiencies in the allocation of resources and limiting their ability to sustain very high growth rates for a prolonged period. However, a variant of the BAU is also simulated. Designated as **BAU-H**, it assumes GDP growth rates approximately 1.0–1.5 percentage points higher per annum for both countries (7.5-9.0% for China and 7-8% for India over the next decade or two). These more optimistic growth rates are based on recent performance and extrapolation of government assumptions for upcoming five-year plans. Both the BAU and BAU-H assume continued heavy reliance on fossil fuels for the next couple of decades with adverse consequences for local emissions (suspended particulates, sulfur, ozone, etc.), as well as global emissions (greenhouse gases—particularly CO_2).

The policy-based **alternate scenarios (ALT)** are designed to explore the extent to which a package of policies[43] can result in two potential *decouplings*: First, *decoupling energy growth from GDP growth* through reduced energy intensity – either as a result of increased energy efficiency, and/or a structural shift away from energy-intensive manufacturing in economic activity. Second, *decoupling emissions growth from energy*

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[41] A region can control the export/ import of capital by maintaining its terms of trade artificially low/high. However such a policy can be implemented in the model only through an exogenous assumption (higher net capital exports are consistent with lower terms of trade) – i.e. some countries can be modeled as having a fixed pre-determined net export of capital.

[42] The base year for the projections is 2001 rather than 2005 as in other models used in this book. The reason is that IEA data for country specific energy details (which are used in the IMACLIM-R simulations) are produced with a lag of a couple of years and it was important to ensure that the economic parameters and energy details used in the simulations were mutually consistent in the base year and tested for a year or two out of sample.

[43] For more information on policy options see Shalizi (2005).

growth through fuel switching – i.e. increasing reliance on fuels with fewer carbon emissions such as from coal to gas (or clean coal), or from fossil fuels to nuclear energy or renewables (and associated simultaneous improvements in energy efficiency). The decouplings are not themselves policies nor are they totally independent of each other. Rather they are an analytically convenient way of describing the extent to which the policies have been effective in increasing the economy's energy efficiency and reducing its generation of harmful emissions.

Three sets of policy scenarios are simulated:

1. **Demand-side scenarios** (designated with a **D**) that include actions geared towards improvement of end-use efficiency/energy saving,[44] over and above the energy efficiency improvements already incorporated in the BAU case (described later in the KAYA diagrams in Figure 9). The additional improvements are (a) a 25 percent improvement in overall energy efficiency in the “composite” sector (including both ‘pure efficiency’ and structural change in the economy with an increase in the share of services in GDP) relative to the base case, (b) an additional 1.1 percent per annum efficiency gain in residential/household energy using equipment—leading to an eventual 60 percent improvement relative to the base case, and (c) a 50 percent improvement in the fuel-efficiency of cars by 2050 compared to the base case.

2. **Supply-side scenarios** (designated with an **S**)[45] that include a higher share of hydroelectricity and nuclear power in both India and China than under the BAU cases which already incorporate some expansion of non-fossil fuels sectors. The additional improvements include (a) a 20 percent increase in hydroelectric capacity relative to the base case, and (b) a 30 percent increase in the share of nuclear power in new investments for power generation, (c) the share of biofuels is progressively increased to 10 percent of the total amount of fuels produced by China and India. The shares of wind and solar energy increase significantly from a very low base but not enough to offset the reduction in the use of traditional biomass. (d) Energy efficiency is also increased by 15 percent in the use of coal for industry and by 8 percent in the use of coal for electricity generation in the new capital stock installed after 2005.

3. **Supply and demand side scenarios** (designated with an **S&D**) that combine the efficiency improvements and fuel-switching measures above, and are in line with Chinese and Indian energy strategies. (Sarma, Margo, and Sachdeva, 1998; Liu, 2003).

The BAU and ALT scenarios are each simulated in two different contexts: (a) the base case used for reference purposes (i.e., BAU and BAU-H) which assumes, perhaps

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[44] The IEA suggests that end use efficiency improvements are the source of the greatest potential in managing energy demand and mitigation of CO$_{<->2<->}$ emissions. Over the 2002–2030 period, improvements in end-use efficiency could contribute to more than 50 percent in the reduction in emissions for a group of 11 IEA countries (Australia, Denmark, Finland, France, Germany, Japan, Italy, Norway, Sweden, U.K. and U.S.) for which IEA has complete time series data (see Bradley, 2006).

[45] Note that fuel switching is often also accompanied by simultaneous improvements in energy efficiency.

unrealistically, that there are no constraints to adjusting to short term signals on energy markets (i.e., there is no barrier/friction/rigidity that might constrain timely adjustment of prices and quantities within China and India, or internationally); and (b) where there are constraints to timely adjustment in response to growing energy needs – either (i) on the deployment of domestic coal supply in India and China, or (ii) on the evolution of future oil and gas markets, due to unexpected geopolitical or resource shocks in the global oil markets, or due to difficulties of the world oil and gas industry (including refineries) in developing the necessary production capacities in time. This second, perhaps more realistic, set of scenarios are designated with the subscript f for friction (i.e., scenarios BAU-f and BAU-H-f).

Whether the energy demand in China or India will put pressure on international fossil-fuel energy markets and the price of energy depends upon:

- the volume of fossil fuel (particularly oil and gas) imports by China and India – which will be determined by the pace and energy structure of their economic growth, and by the nature and actual efficiency of their policies and institutional capacity to promote domestic energy supplies,

- the nature of the overall imbalances in international energy markets, given that these imbalances can arise either from the fundamentals of the oil and gas markets (such as inadequacy of investment in refining or transporting capacity), or as a result of shocks caused by geopolitical tensions.

These different scenarios generate a series of outcomes that can be compared. The particular outcomes of interest in this study are: (i) the energy requirements in the economy, (ii) the global emissions associated with these energy requirements (focused on CO_2), (iii) the local emissions associated with these energy requirements (focused on SO_2)[46], and (iv) investment requirements associated with the different energy trajectories. These simulations also enable us to compare the consequences of accelerated or delayed investments in shifting from the base case (BAU) to additional policy actions (ALT) scenarios, and explore the potential for self financing versus additional external financing requirements that might be needed.

2.3 The Reference Scenarios

A. When There Are No Adjustment Problems in the Energy Sector Internationally or in China and India (The “No Friction” Case) – ***<u>BAU and BAU-H</u>***

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[46] The variable total suspended particulates (TSP) which is most often used in health analysis ex post, is difficult to project ex ante and therefore not included. SO2 emissions can be projected with the help of the simulation model and are included in the findings. However, it is not possible to assess their health implications because of the problem discussed earlier in the section on local externalities. It requires projecting the spatial distribution of emissions and the density of the population exposed in different localities -- which is not possible at the level of aggregation used in IMACLIM-R.

The two base scenarios reflect the rapid energy and emissions growth associated with fast and very fast GDP growth in China and India over the next few decades. These scenarios provide the benchmark energy and emissions trajectories against which the costs and benefits of additional policy interventions can be discussed in the next section.

Country implications:

In **China**, <u>in terms of key energy using sectors</u>, *industry and services* account for the largest share of **final energy use** over the study period, increasing for the next two decades to over 60 percent before declining to below current shares by 2050. The share of *residential use* also declines from 31 percent to 25 percent, while the share of *transportation* (relying almost exclusively on refined petroleum products) doubles in the period to 20 percent (see table 3). <u>In terms of fuels</u>, *electricity* represents an increasing proportion of final energy use – with its share almost tripling. The shares of *gas* and *refined petroleum products* increase by two percentage points each, and the shares of *coal* and *traditional biomass* drop substantially. The role of coal in final energy use declines as services grow relative to industry, and the role of traditional biomass in final energy use diminishes as commercial electricity replaces it.

Though electricity represents only one-third of final energy use by 2050, the heavy reliance on coal (80 percent) for electric power generation at the mid-century explains why coal retains a prominent share in China's energy balance. By 2050, China's reliance on coal for **primary energy use** still remains high (63 percent in the BAU scenario and 65 percent in the BAU-H scenario). Primary energy use (not final energy use) determines the extent of polluting emissions. In the BAU scenario, *primary energy use* in China will double in the 20 year period 2001–2020[47] and quadruple by 2050. In the higher growth scenario (BAU-H), the increase in CO_2 emissions will be somewhat higher at 2.5 fold by 2020 and 5.2 fold by 2050.

In **India**, final energy demand from industry and services grows from 33 percent to 48 percent, and that for transportation from 10 percent to 16 percent. However, final energy demand from the residential sector drops from 57 percent to 36 percent (table 3).

Similar to the Chinese situation, the switch to electricity increases the share of coal in primary energy demand from one third in 2001 to almost 58 percent in 2050. Coal's share expands relative to hydropower and traditional biomass. In the BAU scenario, there will be a 1.6 fold increase in *primary energy demand* in India by 2020[48] and 3.8-fold by 2050. In the BAU-H scenario the increases will be significantly larger: 2.2 and 7.9 folds by 2020 and 2050 respectively.

Table 5.3: Sectoral and Fuel Shares of Energy Consumption in China and India

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[47] These simulations follow official Chinese government estimates for the 11th five-year plan and beyond.

[48] These simulations follow official Indian government estimates for the 10th five-year plan and beyond.

	China			India		
	2005	2020	2050	2005	2020	2050
Total Final Consumption (Mtoe)	**921.7**	**1683.2**	**2685.1**	**400.3**	**609.4**	**1268.1**
By sector						
Industry and Services	58.5%	62.2%	54.6%	32.7%	39.3%	48.3%
Transportation	10.2%	14.4%	20.8%	10.4%	12.3%	16.0%
Residential Use	31.2%	23.5%	24.6%	56.9%	48.4%	35.7%
By fuel mix						
Coal	38.0%	37.4%	25.5%	11.5%	13.0%	12.0%
Refined pdcts	25.0%	27.4%	27.8%	27.5%	27.7%	25.7%
Gas	2.6%	3.4%	4.4%	2.7%	3.0%	3.3%
Electricity	13.3%	20.3%	35.8%	9.9%	17.3%	37.5%
Renew & biomass	21.1%	11.5%	6.6%	48.3%	38.9%	21.5%
Total Primary Energy Use (Mtoe)	**1223.1**	**2483.5**	**4436.5**	**515.6**	**845.8**	**2068.8**
Coal	54.3%	58.9%	62.7%	29.2%	37.8%	57.9%
Oil	23.1%	22.6%	20.5%	25.0%	22.6%	17.7%
Natural Gas	2.5%	3.5%	3.4%	3.8%	5.3%	4.5%
Nuclear	0.5%	0.5%	2.4%	0.8%	0.1%	2.1%
Hydro	3.7%	3.0%	3.1%	3.7%	3.9%	1.9%
Renewables	15.9%	11.5%	7.9%	37.6%	30.3%	15.9%

Global Implications

Oil prices: At present, China accounts for 6 percent of world oil use; this share rises to 11 percent in 2050 in the BAU case. Note that the share of China's oil consumption in total world oil consumption stabilises after 2030 because oil use in other developing countries grows faster. In the same period India's global share increases steadily from 3 percent to 5 percent in the BAU case (see Figure 7).[49]

In the base case the model simulations generate (in 2001 dollars) a price of oil in 2020 of $61.90 (or $62.47 in the BAU-H scenario) which is less than the actual price prevailing in 2006[50]. However, as noted in the discussion in part 1, the recent run-up in oil prices does not reflect a steady state price. Thus, there is a big difference between the high value of oil prices during a short period of time and a steady, permanent high value. The US$62 per barrel in 2020 (or the US$ 133 per barrel in 2050 shown later in figure 7) should therefore be compared with a counterfactual steady state price independent of the recently observed short-term volatility. This normal price would probably be in the range of US$40–$50 per barrel in 2006 (not US$75 in July 2006).[51]

By 2050 there is a five-fold increase in crude oil price in the five decade period between 2001 and 2050 (from 25 US$/bl to 133 US$/bl in 2001 prices). This is a significant increase but it is not outlandish relative to historical experience.[52] It is only double current prices of $70-$75/bl. But as noted earlier this may not be a steady-state price. So going back further in time, one finds that the price of a barrel of oil in 1970 was

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[49] China and India's early 00's share of global oil use -- at 6 percent and 3 percent respectively -- is substantially less than their current share of global energy -- at 12 percent and 5 percent respectively (see first paragraph in section on level and composition of energy use).

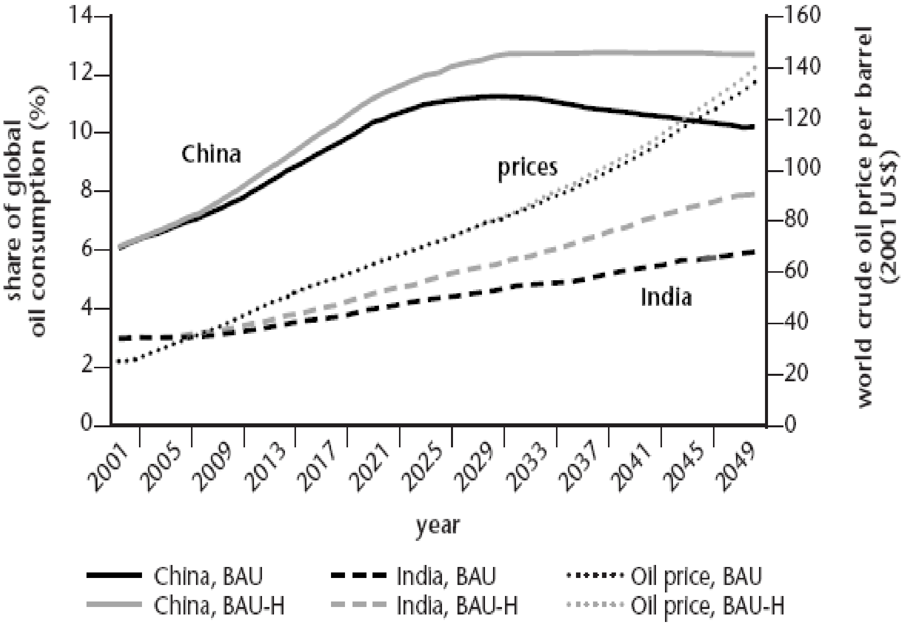
[50] The conversion ratio from 2001 dollars to 2004 dollars is 1.065 and to 2005 dollars is 1.092.

[51] Oil price formation in IMACLIM does not incorporate a risk-component (which has been shown recently to play a major role), so crude oil prices in the short run may be lower than prices observed recently on the oil market.

[52] Nor is it outlandish relative to some other projections. The US Department of energy's projections in its International Energy Outlook 2006 includes a high scenario with oil prices reaching $96 a barrel (in 2004 prices) by 2030.

only $9.0 in constant 2004 dollars (or $1.8 in nominal prices of 1970).[53] In 2004, before the recent spike in oil prices as a result of tightness in the oil market and geopolitical uncertainties, the price was $36.4 – i.e., a fourfold increase in a little more than three decades.[54]

Figure 7: China's and India's Shares of World Oil Consumption and Trajectory of World Oil Prices, BAU and BAU-H Scenarios



Source: Author's calculations based on simulation model.
Note: BAU = business-as-usual scenario; BAU-H = BAU with high growth.

Is it plausible that alternate fuel technologies will not displace demand for oil at such high prices? This question cannot be answered definitively. The growth in oil prices by 2050 is driven by the continuing growth in the demand for mobility (particularly road and air transportation) all over the world. This generates substantial growth in the use of oil for which there will be few substitutes in the near future – unlike in the power sector where there are many renewable alternatives to fossil fuels. In simulating the model the market penetration of biofuels or hydrogen as alternatives to oil for transport is assumed to be limited in the time period under review.[55] With the exception of ethanol from sugarcane (and to a lesser extent from corn) all other biofuels are at early stages of research and experimentation. Hydrogen and coal liquification are not yet commercially viable technologies and may not be so for another decade or two, and it will take another couple of decades before the necessary infrastructure can be put into place to allow a substantial part of the fleet to be converted to the use of these alternate fuels. Thus,

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[53] BP (2006).

[54] The 1970 price for Arab light crude was even less at $1.26 in 1970 prices equivalent to $7 in 2005 prices. In 2003, its price was $40 or almost six times as much (IEA, 2006).

[55] As noted in the discussion on supply measures implemented in the model biofuel penetration is assumed to reach 10 percent of fuels in China and India. For the world as a whole the penetration rate is even lower at 3 percent of fuels over the next 50 years based on World Energy Outlook (IEA, 2004).

relying on knowledge of currently practical or likely to be practical technologies within the next two decades the simulation clearly shows that the upward trend in oil prices will continue, linked to supply conditions.[56]

Because of the adaptation built into the model, a **gradual** price increase does not generate a significant loss in GDP, whereas a **spike** in oil prices (Hamilton, 2003), will generate significant losses in GDP – at least in the short run, when the economy does not have the requisite ability to adjust. Over time the economy returns to its long-run trajectory. As noted by Manne (1978), if there is either perfect expectations or progressive adaptation over the long run in a world with no erratic shocks, then one cannot expect large GDP variations because energy is a small fraction of the economy. This is no longer the case when there are shocks and surprises[57]. To analyze the behavior of IMACLIM-R in response to a spike in oil prices a simulation was run assuming a US$35 per barrel increase in world oil prices over two years relative to the long-term price trajectory. At the peak, GDP losses reach -3.2 percent in China (-1.6 percent in two consecutive years) and -7 percent in India (-3.5 percent in two consecutive years).

Emissions: In the BAU case CO_2 emissions from energy use more than double by 2020 relative to 2005 and quadruple by 2050 to reach 3.6 giga tones carbon (GtC) in China. They almost double by 2020 and quintuple by 2050 to reach 1.6 GtC in India. China and India's combined emissions in 2050 will be 44 percent of world emissions in that year compared to approximately 20 percent in 2005. SO_2 emissions in both countries follow trajectories very similar to the CO_2 emissions.

The overall conclusion is that the high growth of energy use in China and India is not likely, *alone,* to cause structural imbalances in international energy markets. The main negative outcomes are in terms of local and global (CO_2) emissions (and, beyond 2050 in terms of the acceleration of the exhaustion of overall reserves of conventional and non-conventional oil reserves).

What happens to these variables when GDP growth rates are higher in India and China? In the BAU-H case China's share in world oil use increases to 14 percent and India's to 8 percent by 2050. But the price of oil increases only marginally to $62.47 (relative to $61.90 in the BAU case) by 2020 and to $139.8[58] (relative to $133 in the BAU case) by 2050. With the higher GDP growth rates in China and India (BAU-H), the rest of the world experiences a 2 percent higher GDP relative to the BAU scenario, induced by the faster economic growth in the Asian Giants.

In the BAU-H scenario global *primary energy* requirements will be 16 percent higher by 2050. Carbon emissions, however, will be 19.8 percent higher. The faster growth in *carbon emissions* relative to primary energy reflects a 5.3 percent increase in

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[56] Note that this oil price profile already incorporates an increasing role for non-conventional, more expensive petroleum sources.

[57] As noted earlier, assuming "no surprise" and "no friction" in the BAU scenarios may not be realistic. However, these scenarios provide a useful benchmark against which to evaluate the case in which there are adjustment problems (rigidity and friction), so that prices and quantities do not adjust rapidly and smoothly.

[58] In the BAU-H scenario, oil prices are only US$6.8/bl (+5.1 percent) higher than in the BAU scenario in 2050 . The reason for this minimal difference is that, by construction of the scenario energy policies are deployed in a timely and efficient manner in the coal sector in China and India to meet their growing energy needs. The rise in transportation demand for oil is significant but not enough to generate drastic imbalances on the oil market.

the carbon content of the world aggregate energy supply because most of the regions in the world are not able to avoid a higher use of coal and other fossil fuels to meet their higher energy demands. In the higher growth scenario China and India's CO_2 emissions in 2020 more than double to (2.2GtC and 0.7GtC respectively), and grow six fold by 2050 (to 4.9 GtC and 11 fold to 3.2 GtC respectively). Together, India and China will account for 60 percent of world total CO_2 emissions by 2050. Thus, comparing the BAU and BAU-H scenarios leads to the unsurprising result that – in the absence of alternative policies to accelerate energy efficiency and decarbonisation – *energy use* and *CO_2 emissions* will be higher, the higher the rate of growth of GDP.

Because CO_2 persists in the atmosphere for very long periods, it is the cumulative emissions (i.e. concentrations) not annual emissions that matter[59] – e.g. for purposes of analyzing rising temperatures and global warming. It is in analyzing such issues that the advantage of using the longer 50 year time horizon becomes apparent. If the analysis were restricted only to the period 2020, we would see that the higher GDP growth rates in the BAU-H scenarios generate cumulative CO_2 emissions that are only 9 percent higher in China and 17 percent higher in India relative to the BAU case. But by 2050 the differences are dramatic: 22 percent higher in China and 79 percent higher in India (or 34 percent higher combined) and this with only an average 0.75-1.25 percent per annum higher growth rate in GDP over the 50 year period 2001-2050[60].

B. When There Are Rigidities (Frictions) in the Deployment of Coal Capacities in China and India, and Oil and Gas Capacity Internationally – ***BAU-f and BAU-H-f***

This second set of BAU reference simulations (designated with an 'f') examine whether domestic constraints in China and India on the deployment of coal, and/or geopolitical or technical constraints on the international supply of oil affects the trajectory of the variables discussed above.

The constraints on the development of coal and oil are assumed to occur through (i) an inability to deploy adequate capacity in time to meet the growing demand—leading to capacity shortages, and (ii) an increase in extraction costs (on the order of 20 percent plus).[61] These constraints are not transitional (as they were in 2004 in China), but structural – in the sense that they slowdown the pace of deployment of new capacity from 2010 up to 2050.

Country Implications

At the country level the results are significant—particularly for India, which is more constrained with respect to domestically available fossil fuel resources: GDP losses

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[59] This is less the case for SO_2 emissions or other emissions that dissipate more rapidly over time.

[60] The 1.0 to 1.5 percent higher growth rates (between the BAU and BAU-H scenarios) cited in the section on business as usual simulations refer to the first couple of five-year plan periods after 2005. The simulation is frontloaded and the growth rates taper off to 3 percent to 4 percent by 2050. Thus over the 50 year period the compound average growth rate (between the BAU and BAU-H scenarios) is only 0.75-1.25 percent.

[61] There are many possible causes for the decrease in investment productivity in the fossil fuel sectors and their relative magnitude is very region-dependent (time-lag between exploration investment, discovery and effective production is correlated with bad surprises about the ultimate size or quality of resources, the obstacles to exploitation of tar sands and shale oils, revision of official reserves, country risk and institutional instability, etc.).

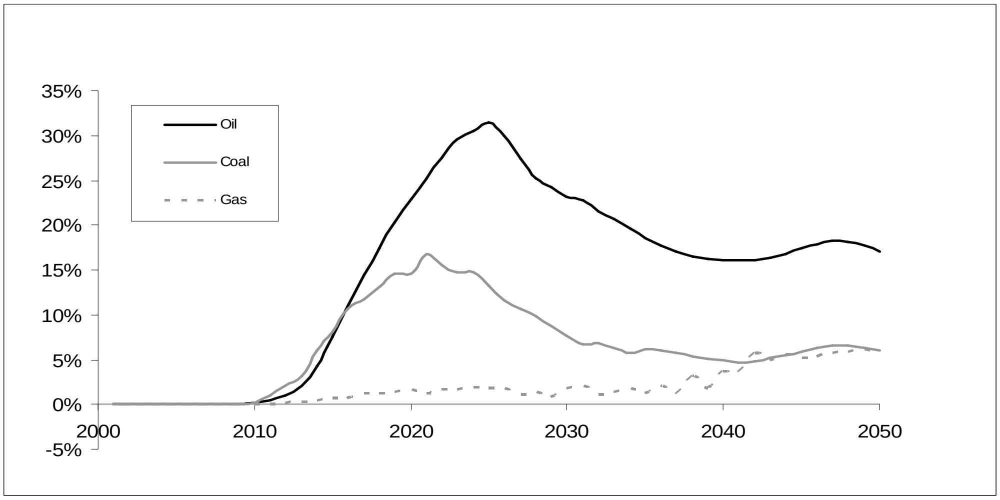
increase up to –8 percent by 2030 (relative to the BAU level) and stabilize at this value. The effects are much more moderate for China where GDP losses grow to –2 percent of the BAU level by 2020 and plateau at –2.5 percent of GDP from 2030 onwards. As a result, India's CO_2 emissions in 2050 are 6 percent lower than in the no friction case (3 percent for China), reflecting essentially a contraction of the economic activity while (final) energy intensity of GDP and its carbon content remain virtually the same.

The losses arise from higher domestic energy prices (including the impact of the price of coal on power) that propagate throughout the input-output matrix and affect both the profitability of energy-intensive sectors and the purchasing power of households. This results in a reallocation of investments across sectors (See Annex Box 1). Dynamically, the higher prices in the energy sector make it relatively more attractive for new investment at the expense of the more productive "composite" sector, which affects domestic growth. In addition, the increase of the oil import bill (due to lower domestic supply of coal, and/or higher international oil prices) worsens the terms of trade.

Global Implications

The constraints described at the beginning of this section affect international energy prices significantly in the BAU-f scenario (see Figure 8): in the 15 years (from 2010 to 2025) world energy prices – oil and coal – peak at 15 percent above the BAU scenario, with coal reaching its peak more gradually than oil. Thereafter prices decline—a sign that economies are able to adapt to part of the increase—and stabilize prices around +5 percent for coal and +15 percent for oil.

Figure 8: Increase in World Prices for Different Fossil Fuels Energy Resources in BAU-f Case Relative to BAU



This in turn affects world GDP – but only marginally (losses reaching –0.1 percent in 2050). The same happens to total cumulative primary energy demand (-1.0 percent in the period 2001 to 2050), and total cumulative carbon emissions (-1.4 percent over the period). The carbon intensity of both GDP and energy demand decrease, primarily because the share of coal and oil in the primary energy mix drops sharply relative to other energy sources such as gas, renewables and nuclear.

2.4 The Policy Intervention Scenarios (ALT-D, ALT-S, ALT-S&D)

The alternative policy intervention scenarios show that it is possible to increase energy efficiency and reduce emissions substantially without significantly compromising GDP growth.

Country Implications

The ALT (policy-based) scenarios result in a substantial reduction in energy use and CO_2 emissions[62] in both China and India (table 4). The combined effect of measures acting on demand and measures acting on supply is much stronger than the affect of either set of measures alone. More importantly, their positive impact on reducing annual *energy use* and *emissions generated* are significant and increase over time with marginal negative impacts on *GDP* (see Figure A4).

A. Measuring the extent of energy and emissions decoupling from GDP growth

KAYA diagrams are a convenient way of presenting the time profile of the extent to which the two decouplings mentioned earlier have been achieved. The horizontal axis shows the extent of improvement in *energy intensity* in an economy (i.e., energy used per unit of output) and is read going from right to left. The vertical axis shows the extent of improvement in *carbon intensity* (decarbonization) in the economy (i.e., carbon emitted per unit of energy) and is read going from top to bottom. In the KAYA diagrams presented below (see figure 9) the light black lines refer to the BAU and BAU-f scenarios; the dashed lines to the scenarios induced by measures acting on demand only ALT-D and ALT-D-f; the dash plus dots lines to the scenarios induced by measures acting on supply only ALT-S and ALT-S-f; and the heavy black lines to scenarios induced by combining measures acting on supply and demand ALT-S&D and ALT-S&D-f.[63]

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[62] And even more so for SO_2 emissions that have local consequences but are not cited in the tables above.

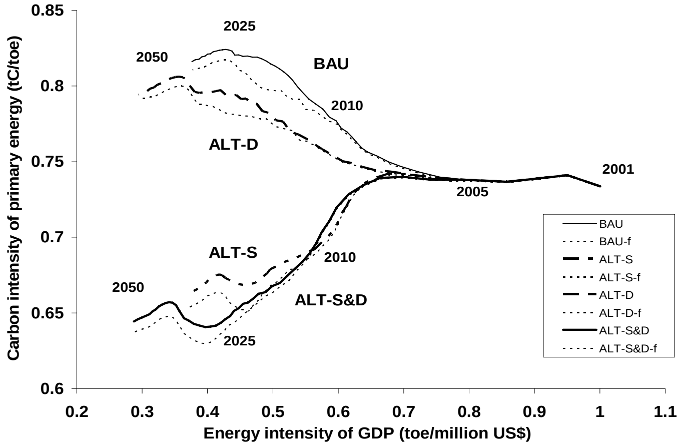
[63] For brevity we do not show the comparable KAYA diagrams for the BAU-H case – because the patterns for each country is the same.

Table 4: Summary of ALT Scenarios Relative to BAU for China and India, 2005-2050

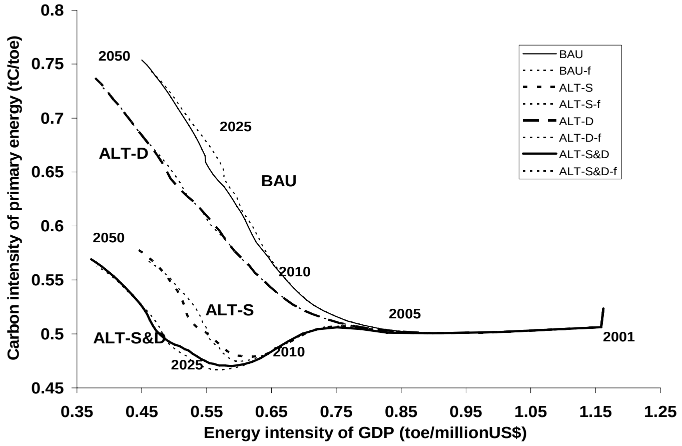
Country		**GDP** *(trillions 2001 US$)*			**Primary Energy Use (Mtoe)**			**CO2 emissions (GtC)**			**Energy Investment (billion 2001 US$)**		
		2005	**2020**	**2050**	**2005**	**2020**	**2050**	**2005**	**2020**	**2050**	**2005**	**2020**	**2050**
China	**Without friction**												
	No change in policy -- BAU	***1.62***	***4.46***	***11.75***	***1223.12***	***2483.52***	***4436.51***	***0.90***	***1.96***	***3.61***	***71.53***	***119.68***	***113.28***
	Demand -- ALT-D	99.8%	99.4%	100.8%	99.1%	90.3%	78.8%	99.0%	88.7%	76.7%	99.8%	96.7%	76.0%
	Supply - - ALT-S	99.9%	99.5%	99.5%	98.7%	95.8%	98.4%	98.5%	83.1%	79.8%	101.2%	116.3%	121.7%
	Demand & Supply -- ALT-S&D-f	99.7%	98.6%	99.2%	97.8%	86.7%	75.9%	97.6%	72.8%	59.9%	101.0%	114.3%	92.2%
	With friction												
	No change in policy -- BAU-f	100.0%	98.2%	97.4%	100.0%	97.1%	97.2%	100.0%	96.6%	97.0%	100.0%	94.3%	92.9%
	Demand -- ALT-D-f	99.8%	97.7%	98.6%	99.1%	88.3%	76.9%	99.0%	86.6%	74.8%	101.2%	110.5%	114.7%
	Supply - - ALT-S-f	99.9%	97.5%	97.1%	98.7%	93.5%	95.6%	98.5%	80.5%	76.9%	99.8%	91.2%	72.9%
	Demand & Supply -- ALT-S&D-f	99.7%	96.8%	97.2%	97.8%	84.9%	74.0%	97.6%	71.2%	58.0%	101.0%	108.3%	89.1%
India	**Without friction**												
	No change in policy -- BAU	***0.61***	***1.35***	***4.59***	***515.61***	***845.84***	***2068.79***	***0.26***	***0.49***	***1.56***	***18.44***	***36.64***	***74.13***
	Demand -- ALT-D	99.8%	99.4%	100.9%	99.1%	94.1%	84.8%	99.1%	92.8%	82.9%	99.9%	95.2%	84.1%
	Supply - - ALT-S	99.9%	99.8%	101.4%	98.4%	93.8%	99.3%	98.1%	77.3%	76.4%	102.2%	113.4%	124.9%
	Demand & Supply -- ALT-S&D-f	99.7%	99.0%	101.2%	97.5%	88.7%	83.7%	97.2%	71.6%	63.2%	102.1%	110.5%	103.5%
	With friction												
	No change in policy -- BAU-f	100.0%	96.9%	92.6%	100.0%	98.8%	95.1%	100.0%	97.8%	94.0%	100.0%	98.6%	91.2%
	Demand -- ALT-D-f	99.8%	96.7%	94.8%	99.1%	92.9%	81.1%	99.1%	90.7%	78.7%	102.2%	113.1%	114.6%
	Supply - - ALT-S-f	99.9%	97.7%	93.8%	98.4%	93.2%	95.5%	98.1%	75.6%	72.0%	99.9%	92.9%	77.9%
	Demand & Supply -- ALT-S&D-f	99.7%	97.2%	95.4%	97.5%	88.1%	80.6%	97.2%	70.3%	60.3%	102.1%	109.3%	96.5%

Figure 9: KAYA Diagrams of the Extent of Energy and Emission Decoupling in China and India in the Case of Final Energy Consumption

(a) China



(b) India



In the business as usual (BAU) strategy for China and India *there is a strong reduction in energy intensity* built-in to reflect the modernization of industry and adoption of new technology. However, carbon intensity increases in both countries – but more significantly in India. China shows a slight improvement in carbon intensity, but only towards the latter part of the 50 year period under review.

Relative to the BAU case, ALT-D measures to *reduce demand* only (by increasing energy efficiency) extend the extent to which energy intensity of GDP is reduced and ensure that carbon intensity does not grow as much as it does in the business as usual cases. But the time profile of the two decouplings is very similar to the BAU cases in both China and India. In **China**, demand-side policies, reduce emissions by 0.84GtC relative to the 3.6 GtC of emissions in 2050 (a 23 percent reduction). In **India** demand-side policies reduce emissions by 0.27 GtC relative to 1.6 GtC in 2050 (i.e., by 17 percent). Interestingly measures to only change demand do not lead, at the end of the period to an impressive departure from the BAU pathway; this is due to two main factors often disregarded in other analysis: first there are technical asymptotes on efficiency gains and only additional structural changes of the consumption patterns can trigger additional decoupling. Second, increased efficiency is partially offset by a significant rebound effect – particularly in transportation (people drive more as cars become more energy efficient), which relies almost entirely on fossil fuels.

Relative to the BAU case, ALT-S measures to only *change supply* (i.e., the structure of fuels supplied to the economy) do not extend the extent to which energy intensity of GDP is reduced (unlike the demand measures) in either China or India. However, in the case of China they do significantly alter the time profile and the extent to which the carbon intensity is reduced. In the case of India, after an initial shift away from carbon, carbon intensity starts increasing once again (unlike China) because the share of traditional biomass for household residential use is much higher at the outset of the process in India relative to China (48 percent versus 18 percent respectively). Thus, the greater shift from traditional biomass to commercial electricity for household residential use results in a displacement of less carbon emitting biomass by more carbon emitting fossil-fuel based electricity – despite the increased penetration of nuclear and nontraditional renewables such as wind and solar energy for the production of power. However, in **India,** supply-side policies bring *CO_2 emissions* down by 30 percent in 2050(from 1.56GtC to 1.19GtC), which is larger than the 20 percent in China (from 3.6 GtC in the BAU case to 2.88 GtC).

Combining demand-reducing measures with fuel-switching measures, ALT-S&D results in both a lowering of energy intensity and a lowering of carbon intensity relative to either set of measures alone, and quite significantly relative to the business as usual case. By 2050 the combined measures reduce *energy intensity of GDP* by 24 percent in China and 17 percent in India, and *carbon intensity of energy* by 21 percent in China and 25 percent in India relative to the BAU scenario.

Global implications

The repercussions of these ALT policy scenarios on world energy prices are mixed. The improvements in fuel efficiency of transport in China and India lower global oil prices by a couple of percentage points. The improved efficiency in coal use and the substitution towards nuclear and renewable fuels in generating electricity has a more significant impact on world coal prices which drop by some 5 percent to 10 percent by

2050. This has a positive impact on India which may have to import more coal in the future. These effects are more pronounced in the scenarios with rigidity/friction.[64]

The ALT policy scenarios have a much more significant impact on *cumulative* emissions. The effect grows over time and extends beyond 2050. However, even by 2050 in cumulative terms, demand-side policies in China reduce CO_2 emissions by about 15 percent (18GtC) and supply-side policies by ~18 percent (21GtC). The combination of supply- and demand-policies reduces emissions by 32 percent (36 GtC) or almost one-third relative to the 116GtC cumulative CO_2 emissions in the baseline scenario. The overall impact of policies on CO_2 emissions in **India** is of similar *relative* magnitude. In cumulative terms, demand-side policies in India reduce CO_2 emissions by about 12 percent (4.5GtC) and supply-side policies by about 22 percent (8GtC). The combination of supply- and demand- policies reduces emissions by 31 percent (11GtC) or almost one third relative to the 37GtC cumulative CO_2 emissions in the baseline scenario.

B. Scale of Additional Investment and Financing Requirements to Increase Energy Efficiency and Lower Carbon Intensity (ALT scenarios) Relative to the Business as Usual Strategy (BAU Scenarios)

As noted earlier in the section on energy and emissions trajectories of ALT scenarios, implementing either demand or supply-side measures reduces energy and emissions relative to the BAU case. The measures do not offset each other, so implementing both sets of measures reduces energy and emissions substantially more than either alone. And this reduction continues throughout the period up to and beyond 2050. This is not the case for energy investments (see last block of Table 4).

Implementing measures to only reduce the demand for energy lowers investment requirements in all periods relative to the BAU case, whereas measures to only change the structure of fuel supply increases investment requirements substantially relative to the BAU case. However, combining the two sets of measures results in an intermediate time profile of investment requirements which, in aggregate, is higher in the early period[65] and lower in the later period relative the BAU case. That is the requirement for additional energy investments drop by 2050 (and in the case of China they drop to a level below the BAU equivalent). The reason for this is that fuel switching will require a smaller amount of investment when demand is lower.[66]

A key point in this analysis is that net capital flows are fixed exogenously. Thus, the increases in investment in the energy sector must be financed either by reducing net capital outflows or by diverting other domestic investment. Our simulations assume the

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[64] Note that the differences between ALT/policy scenarios relative to the business as usual reference case are smaller than the differences between scenario with rigidity / friction and the corresponding base-case.

[65] By 114 percent in China in 2020 (equivalent to an additional $13 billion in 2001 prices) and 110 percent in India in 2020 (equivalent to an additional $4 billion in 2001 prices).

[66] Note: when friction and rigidities are introduced, the aggregate energy investment required in the BAU-f case is also lower than in the BAU case because GDP is lower.

former for India, which permits its GDP growth relative to BAU, but at the expense of a deterioration in net assets—the welfare implications of which the model ignores. For the sake of illustration, we make the opposite assumption for China: investment is diverted and GDP falls marginally compared with BAU, but asset accumulation proceeds unchecked.[67] The moral is that although the need for the extra investment in the ALT runs is real, the results given for GDP are very poor indicators of likely welfare consequences. The latter depend on the decline in output, on the decline in net assets, and, of course, on the benefits of curtailing emissions.

From a country perspective, the higher initial cost of investment of alternatives to fossil fuels is a concern (see Figure A5) as it might adversely affect GDP growth rates. Therefore the standard response is to delay adopting cutting edge technologies till additional technological innovations reduce their costs.[68] Accordingly, another scenario was simulated to explore the consequences of delaying interventions. Delaying the implementation of policies will save money now but will result in a larger energy sector and therefore in higher investment requirements in the future to reach a target emissions level by a specified period. However, these higher investment requirements will be more affordable because they will represent a lower share of a larger GDP given the intervening growth in the economy. This supports the initial intuition regarding the economic benefits of delaying interventions. However, the environmental benefits of these policies will show up later and never quite fully catch up with the benefits generated by earlier implementation of the policies. Even though both the costs of investment and the benefits of emissions reduction are shifted into the future, the net present value of the two policies is not the same. There is a price of carbon for which the two streams of costs and benefits will be equivalent. As an example, in the scenario with rigidities (f), ***the ALT-S&D-f interventions today are cost effective relative to BAU-f at fairly low carbon prices*** of US$5 per tonne of CO_2 (tCO_2) in 2020 and US$6.7 per tonne of CO_2 (tCO_2) in 2050 for China -- (and US$7.8 per tCO_2 in 2020 and US$10.5 per tCO_2

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[67] The way capital flows are treated in the IMACLIM-R model affects overall policy costs. The model generates results 'as if' in parallel with decarbonization policies, the government provides incentives so that private savings are increasingly invested in the domestic economy instead of being exported (formally fully equivalent alternatives are to receive additional foreign aid, or to redirect towards the domestic economy part of the revenues of capital invested abroad or part of the income received from migrants abroad). The current simulations rely on the following assumptions: (i) decarbonisation implies higher capital costs and higher consumer prices (at least during the transition period), (ii) in the case of China, the government maintains high capital outflows, that offset large revenues earned from very large exports of goods and services—a policy which is not in effect in India, (iii) the equations on capital balance in the model completely determine whether the additional costs of the energy systems will hamper growth or not: In the case of China, if capital exports remain high, additional investment in the energy system crowds out domestic investment in the other sectors. In the case of India, the need for additional investment is partly fulfilled by reducing capital exports, thereby avoiding the crowding-out effect, (iv) as a consequence of these critical assumptions on capital flows, (ALT) policies are more "costly" in China than in India.

To explore this matter a simulation was run in which China exports less capital net (equivalent to receiving additional gross capital inflows to offset the same capital exports as in the BAU case). This enables China to allow additional domestic savings to flow into the energy sector thereby financing additional energy investments, without crowding out other investments, in a manner analogous to India.

[68] In the IMACLIM-R model used for the simulations in this paper, "learning by doing" is built-in, therefore earlier investments in novel technologies will accelerate the rate at which one moves down the cost curve thereby reducing the aggregate financial burden.

in 2050 for India). Discounting with rates up to 8 percent per annum this is equivalent to a carbon price today of US$4.3 per tCO_2 for China -- (and US$6.7 per tCO_2 for India). These prices are well below the US$11–12 per tCO_2 that actually prevailed in the first quarter of 2006 on the project-based segment of the carbon market (Clean Development Mechanism – CDM) -- ***which means there is no reason to delay***. Delaying action by a decade requires a higher price of carbon today to generate the same returns. This higher carbon price, however, is above current market prices, especially for India (US$20/$tCO_2$) and therefore not cost-effective. As a result, *the cumulative 'financial cost reducing' benefit of delaying investments does not fully offset the increased cumulative emissions cost associated with prolonged reliance on fossil fuels*.[69]

Finally, in contrast to the scenarios in the ALT in the BAU reference cases, in the BAU-H (high growth rate) variants, enough savings are generated (particularly in China, less so in India) to self finance the higher cost of investment in energy efficiency and the shift away from carbon based fuels. However, even in the high growth rate scenarios, when rigidities in local and global energy markets are introduced into the scenarios, some external financing is required if growth rates are not to be adversely affected in China and India. This external financing is justified from a global efficiency perspective because – in contrast to mature economies in the industrial countries where there is a large capital stock or where firms are operating at their production frontiers – the benefit/cost ratio of more expensive clean/low carbon energy investments in China and India is higher since in these countries there are multiple, joint benefits (local and global emissions reductions), and many sectors are currently operating inside their production frontiers. In addition, investment costs will be lower for the "new" capital formation taking place now in China and India, than for retrofitting "old/aging" capital or prematurely retiring them[70] whether in China and India, or in industrial countries.

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[69] This paper does not evaluate the extent of international carbon trading that might evolve post Kyoto.

[70] Of course, once fully depreciated, the capital stock in mature economies will also have to be replaced by more energy and emissions efficient technologies.

Conclusions

The first half of the paper documents a number of emerging concerns in China and India associated with the level and composition of energy used and emissions generated:

- Demand for fossil fuel energy is exceeding domestic supply capabilities in both countries.

- With modernization of the economy and growing per capita income, the demand for electricity is growing very rapidly in both countries. There are limited low cost domestic energy resources other than *coal* for the production of this *electricity*.

- Strategic/security concerns have emerged over growing *oil* imports, in response to the growing demand for mobility/*transportation* – particularly road transport and aviation.

- Growing fossil fuel use for energy is generating harmful emissions with global and local consequences:

    - China is on track to become the world's largest emitter of greenhouse gases, with India as the next largest emitter among developing countries.

    - Growing public health costs from severe local air pollution (particulate matter, SO_2, ground level ozone, and acid rain) are driving domestic policy responses.

This section also reviewed the impact of growing energy demand in China and India on international energy markets – focused on oil. The acceleration of the demand for oil, particularly in China (less so in India) can be characterized as a demand shock in global markets in the context of supply constraints. The impact on oil prices is more nuanced. Global use of crude oil has been growing steadily since 1995. The surge in oil use in China in the last couple of years has been partially offset by the decline in oil use in other countries. Thus, *the dramatic acceleration in oil prices since 2004 has not been associated with a corresponding acceleration in global oil use, but rather with growing concern about supply constraints associated with declining spare capacity in OPEC, refining bottlenecks, and geopolitical uncertainties.*

The findings in the second part of the paper regarding some general concerns expressed about China and India's growth and reliance on fossil fuel energies can be summarized as follows:

- Energy externalities (local, regional and global) are likely to worsen significantly if there is no shift in China and India's energy strategy.

  Local and global emissions are in fact higher

  (i) in the high GDP growth rate scenarios (BAU-H) relative to the low GDP growth rate scenarios (BAU);

  (ii) for the scenarios in which there are adjustment costs (friction) relative to the scenarios in which there are no adjustment costs;

  (iii) for both sets of the BAU scenarios relative to all the corresponding ALT scenarios.

- Many countries in the developing world (as well as immediate neighbors of China and India) worry that high energy demand from China and India will hurt their growth via higher prices on international energy markets**.**

  This proposition is also confirmed, but with a caveat: In some scenarios, and for some groups of countries, the '*growth retarding'* effects of higher energy prices are partially or fully offset by the *'growth stimulating'* effects of the larger markets in China and India.

- China and India themselves worry that shifting their energy strategy to fuels with lower emissions will reduce externalities and the pressure on energy prices in world energy markets—but at the expense of growth in China and India.

  To the extent that energy is a complementary input in the production of GDP, then any restriction on the use of energy will of necessity affect the rate of growth of GDP. Given, however, that there are a lot of inefficiencies in the energy system in both China and India, then in principle there is an opportunity to reduce energy growth *without* adversely affecting GDP growth. Some of the more energy-efficient options are competitive cost-wise with current inefficient energy options. So these are likely to be adopted through standard market forces and incentives *where there is adequate competition*. However, many other energy efficient options are more costly and likely to crowd out investments outside the energy sector, thereby slowing down growth. This will occur particularly when domestic savings and finances are limited.

  To the extent that in China, and to a lesser extent in India, domestic savings continues to exceed domestic investment this constraint is less binding, provided countries have the option to redeploy savings (that are currently exported) to domestic investment into more costly energy-efficient technologies. However, transitional difficulties will require external financing and technical assistance. Comparing comparable scenarios suggests that (i) the adoption of energy efficiency options, and (ii) the shift to low or no carbon fuels will not cause a significant slowdown in the growth rate of China and India.

- The cost of a decarbonizing energy strategy will be higher for China and India than a fossil fuel based strategy. However, the bulk of additional investment requirements (but not all) can be self-financed (i) without additional transfers from developed countries, and (ii) without compromising growth in China or India. Growth globally may decline a bit but the amount in quantitative terms is likely to be insignificant.

The magnitude of the overall economic costs of decarbonizing energy strategies by comparison with a fossil fuel based development pathway for China and India are very sensitive to:

a- the content of the baseline: (i) the degree of optimism about the domestic capacity to develop coal supply fast enough, and (ii) prospects for oil price movements in the baseline scenario.

b- the degree of technical optimism regarding the potential for new demand and supply policies.

c- the macro economic context of the deployment of these strategies, in particular policies linked to external capital flows.

d- the time horizon.

The general message is that over a long time horizon it is possible to define decarbonizing strategies which do not compromise GDP growth in either country. However, in all cases transition difficulties are experienced, between a few years and several decades. Additional financing is necessary to cope with these transitional difficulties, and they may come either from a change in macro-economic policies (less capital exports, consistent with higher terms of trade and lower goods exports) or new funds provided by new sources of public/external capital, or through a carbon trading system.

The paper also shows that GDP, energy, and emissions growth rates are lower in the scenarios with friction[71] compared to the reference cases. This is true both in the business as usual (BAU) and policy alternative (ALT) scenarios. *The scenarios with friction are probably more realistic than the scenarios without friction.* ***The benefits of ALT scenarios are more significant when there is friction*** (surprises and adjustment costs) than when there is no friction. As a result, because of uncertainties associated with adjustment rigidities, ***the ALT scenarios*** -- which presume more investment in energy

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[71] Where there are constraints to timely adjustment – either (i) on the deployment of domestic coal supply in India and China, or (ii) on the evolution of future oil and gas markets, due to unexpected geopolitical or resource shocks in the global oil markets, or due to difficulties of the world oil and gas industry (including refineries) in developing the necessary production capacities in time.

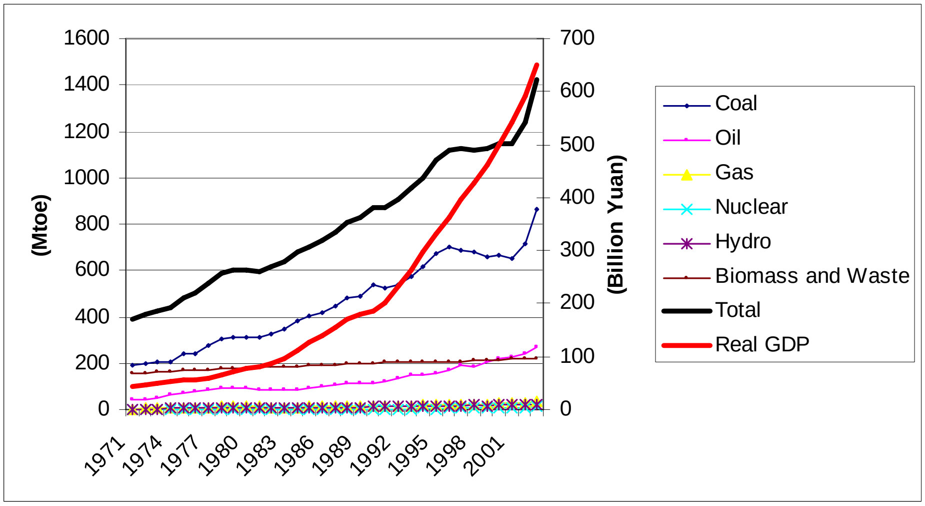
and emissions efficiency technology -- ***will provide an additional dividend in terms of energy security***. This is particularly important for India, given its greater dependence on imports for oil, gas, and high-quality coal.

Finally, the paper shows that the high growth of energy use in China and India will lead to higher oil prices, but this is not likely in itself to cause structural imbalances in international energy markets so long as the price changes are *gradual* (that is not the case with shocks and rigidities). The main negative outcomes are in terms of local and global (CO_2) emissions (and, beyond 2050 in terms of the accelerated exhaustion of reserves of conventional and non-conventional oil).

Further research is required to link new generation multiregional global models with endogenous growth (such as IMACLIM-R) to more disaggregated models currently being developed or augmented in China and India. This will provide a richer framework to test specific policies tailored to the unique opportunities and constraints in each country. It will also allow analysis of equity issues as well as spatial consequences of different types of interventions.

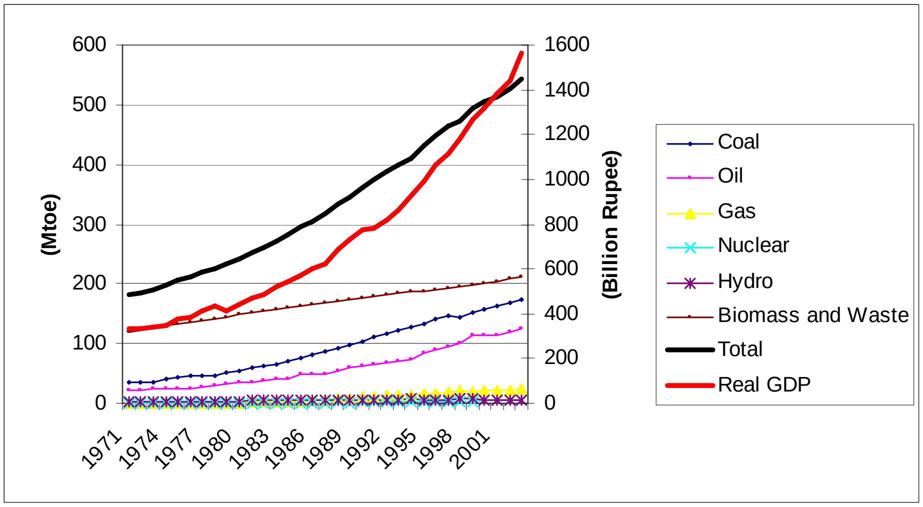
Annex

Figure A1: Primary Energy Use in China (Mtoe)



Source: Energy data from IEA (2005a) and real GDP (constant local currency) data from World Bank (2005a)

Figure A2: Primary Energy Use in India (Mtoe)



Source: Energy data from IEA (2005a) and real GDP (constant local currency) data from World Bank (2005a)

Table A1 (a and b): Energy Balance in China and India (1980-2003)

(a) China

	Production and Stock Change (Mtoe)							Consumption (Mtoe)							Net Export (Mtoe)						
Year	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	Total	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	Total	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	Total
1980	316	107	12	5	180	0	620	313	89	12	5	180	0	599	3	18	0	0	0	0	21
1981	315	103	11	6	182	0	616	311	84	11	6	182	0	594	3	19	0	0	0	0	22
1982	332	104	10	6	184	0	636	329	83	10	6	184	0	613	3	20	0	0	0	0	23
1983	352	106	10	7	186	0	661	348	85	10	7	186	0	637	3	21	0	0	0	0	24
1984	387	116	11	7	187	0	708	384	88	11	7	187	0	676	3	29	0	0	0	0	32
1985	405	130	13	8	189	0	744	401	93	13	8	189	0	704	4	37	0	0	0	0	41
1986	423	131	14	8	191	0	767	418	98	14	8	191	0	729	5	33	0	0	0	0	38
1987	454	135	14	9	193	0	805	446	105	14	9	193	0	767	8	31	0	0	0	0	38
1988	488	140	15	9	195	0	847	478	112	15	9	195	0	809	9	28	0	0	0	0	37
1989	495	139	16	10	198	0	857	486	116	16	10	198	0	826	9	22	0	0	0	0	31
1990	545	136	16	11	200	0	908	535	110	16	11	200	0	872	10	26	0	0	0	0	36
1991	535	140	17	11	202	0	906	523	121	17	11	202	0	874	12	19	0	0	0	0	32
1992	555	143	16	11	203	0	929	541	132	16	11	203	0	904	14	11	0	0	0	0	25
1993	588	138	17	13	205	0	961	576	146	17	13	205	0	957	12	-8	0	0	0	0	4
1994	630	144	18	14	205	4	1015	615	145	18	14	205	4	1002	15	-2	0	0	0	0	13
1995	691	149	19	16	206	3	1084	673	158	19	16	206	3	1075	18	-9	0	0	0	0	9
1996	722	158	21	16	207	4	1128	700	172	19	16	207	4	1119	22	-14	1	0	0	0	9
1997	707	156	21	17	208	4	1113	685	191	19	17	208	4	1124	22	-35	2	0	0	0	-11
1998	698	156	24	18	209	4	1109	678	188	22	18	209	4	1119	20	-31	2	0	0	0	-9
1999	685	161	26	18	213	4	1106	661	205	24	18	213	4	1124	23	-43	2	0	0	0	-18
2000	698	151	28	19	214	4	1115	664	222	26	19	214	4	1149	35	-71	2	0	0	0	-34
2001	705	161	31	24	216	5	1142	648	227	29	24	216	5	1149	57	-66	2	0	0	0	-6
2002	765	168	34	25	217	7	1216	716	244	32	25	217	7	1241	49	-76	2	0	0	0	-25
2003	917	169	36	24	219	11	1377	862	270	35	24	219	11	1422	55	-101	1	0	0	0	-45

(b) India

	Production and Stock Change (Mtoe)							Consumption (Mtoe)							Net Export (Mtoe)						
Year	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	Total	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	Total	Coal	Oil	Natural Gas	Hydro	Biomass and Waste	Nuclear	Total
1980	50	11	1	4	148	1	215	53	34	1	4	148	1	241	-3	-23	0	0	0	0	-26
1981	56	17	2	4	151	1	230	60	36	2	4	151	1	253	-3	-20	0	0	0	0	-23
1982	58	22	2	4	154	1	241	62	39	2	4	154	1	261	-4	-17	0	0	0	0	-20
1983	63	27	3	4	156	1	254	66	40	3	4	156	1	271	-3	-13	0	0	0	0	-16
1984	68	30	3	5	160	1	266	71	42	3	5	160	1	281	-3	-12	0	0	0	0	-15
1985	71	31	4	4	162	1	274	76	48	4	4	162	1	296	-4	-17	0	0	0	0	-21
1986	77	32	5	5	165	1	285	80	48	5	5	165	1	305	-4	-16	0	0	0	0	-20
1987	82	32	6	4	169	1	294	86	50	6	4	169	1	317	-5	-18	0	0	0	0	-23
1988	89	34	7	5	171	2	307	94	55	7	5	171	2	334	-5	-22	0	0	0	0	-27
1989	92	36	9	5	173	1	316	97	60	9	5	173	1	346	-6	-24	0	0	0	0	-29
1990	97	35	10	6	176	2	326	104	63	10	6	176	2	360	-7	-27	0	0	0	0	-34
1991	106	34	11	6	180	1	338	112	65	11	6	180	1	375	-6	-31	0	0	0	0	-37
1992	111	30	13	6	182	2	344	118	68	13	6	182	2	388	-7	-38	0	0	0	0	-45
1993	115	30	13	6	185	1	351	123	70	13	6	185	1	398	-7	-40	0	0	0	0	-47
1994	118	36	13	7	187	1	362	127	74	13	7	187	1	410	-9	-39	0	0	0	0	-48
1995	124	39	17	6	189	2	377	134	84	17	6	189	2	432	-10	-45	0	0	0	0	-55
1996	131	37	18	6	190	2	384	142	89	18	6	190	2	447	-11	-52	0	0	0	0	-63
1997	134	38	20	6	193	3	394	147	94	20	6	193	3	463	-14	-56	0	0	0	0	-69
1998	131	37	21	7	195	3	395	144	101	21	7	195	3	472	-13	-64	0	0	0	0	-77
1999	138	37	20	7	198	3	404	152	113	20	7	198	3	494	-15	-75	0	0	0	0	-90
2000	143	37	21	6	202	4	414	159	114	21	6	202	4	506	-15	-77	0	0	0	0	-93
2001	148	37	21	6	205	5	422	162	115	21	6	205	5	514	-14	-78	0	0	0	0	-92
2002	151	38	23	6	208	5	431	168	119	23	6	208	5	527	-16	-80	0	0	0	0	-97
2003	157	39	23	6	211	5	441	173	124	23	6	211	5	542	-15	-85	0	0	0	0	-100

Source: IEA Energy Balances f Non-OECD Member Countries - Extended Balances Vol. 2005 release 01

Table A2: Breakdown of the Contributions to CO_2 Emissions Growth in China, 1980-1997

Total (net) change in CO_2 emissions (MtC)	488.65
Due to economic growth	799.13
Due to population expansion	128.39
Due to change in energy intensity	-432.32
Due to change in fossil fuel carbon intensity	3.93
Due to penetration of carbon free fuel	-10.48

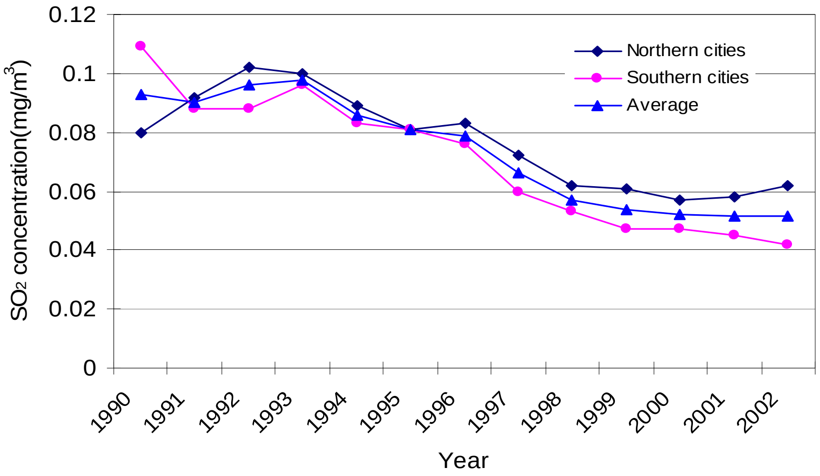
Sources: Sinton et al. (1998), Van Vuurena et al (2003) and Zhang(2000)

Table A3: Breakdown of the Contributions to CO_2 Emissions Growth in India, 1980-1996[72]

Factors	1980 – 85	1985 – 90	1990 – 96	1980 – 96
Total (net)	133.72	179.01	270.32	583.04
Economic (G) – *due to expansion of GDP*	97.38	168.07	259.64	511.11
Structural (S) – *due to sectoral shifts in GDP*	27.08	28.85	31.94	92.68
Intensity (I) – *due to changing energy intensity per unit of output*	-3.05	-13.98	9.01	-13.18
Emission (E) – *due to changing emissions coefficient per unit of energy*	12.96	-3.93	-30.26	-7.58

Source: Paul and Bhattacharya (2004)

Figure A3: Average Annual Ambient SO_2 Levels in Chinese Cities



Source: Hao and Wang (2005)

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[72] CO_2 emissions are treated as the product of four variables: emissions coefficient per unit of energy (E), energy intensity per unit of output in different sectors (I), the share of the different sectors in GDP (S), and the scale of economic activities in all sectors (G). Applying this approach, changes in CO_2 emission in a given period can be decomposed into effects of changes in the four factors.

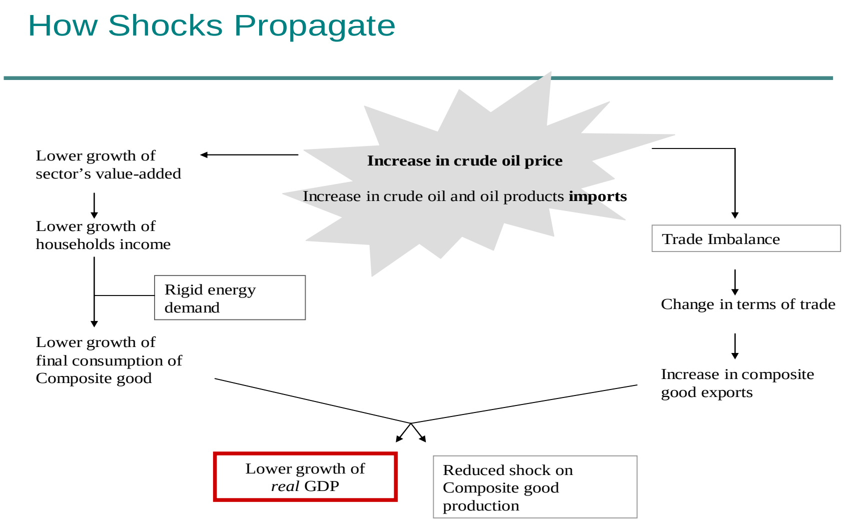
Box 1: How do higher prices arising from rigidities and friction affect the Chinese and Indian economies and the world economy?

The basic mechanisms at play in the short term transmission of energy difficulties in China and India are shown in the **Diagram 1** below.

First, domestically, higher energy prices adversely affect household purchasing power with a deflating impact on the economy (dynamically, the higher prices in the energy sector make it relatively more attractive at the expense of the more productive composite sector, thereby affecting domestic growth).

Second, internationally, the increase of the oil import bill (due to lower domestic supply of coal or nuclear energy, and/or higher international oil prices) worsens terms of trade. This lowers the activity losses in China and India, but transfers part of the impact to other regions.

Diagram 1:

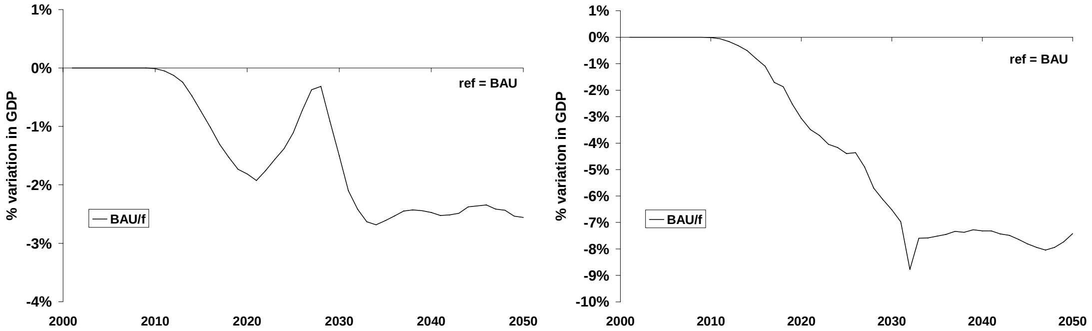


A lower growth rate is induced in most world regions through two channels: smaller total world market and change in terms of trade. In the scenario without frictions, the resulting overall impact of higher growth rates in China and India on other regions is roughly neutral, because the costs of higher oil prices for oil importing countries is compensated by the positive impact of larger markets in China and India.

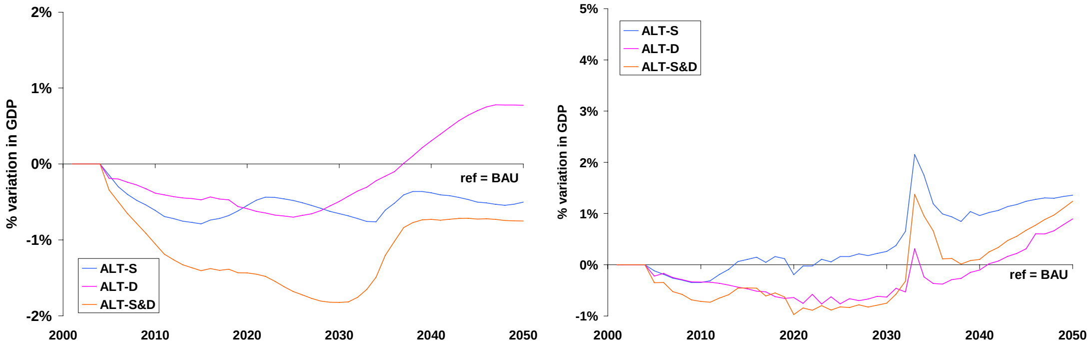
Figure A4: Impact of Rigidity/Friction and Policy Alternatives on <u>*GDP*</u> Trajectories

China **India**

Comparison of scenarios with rigidities/frictions in the fossil fuel markets BAU-f relative to normalized BAU w/o rigidities/frictions



Comparison of ALT policy scenarios vs normalized BAU (in the case without rigidities in the fossil fuel markets)



Comparison of ALT-f policy scenarios vs normalized BAU-f (in the case with rigidities in the fossil fuel markets)

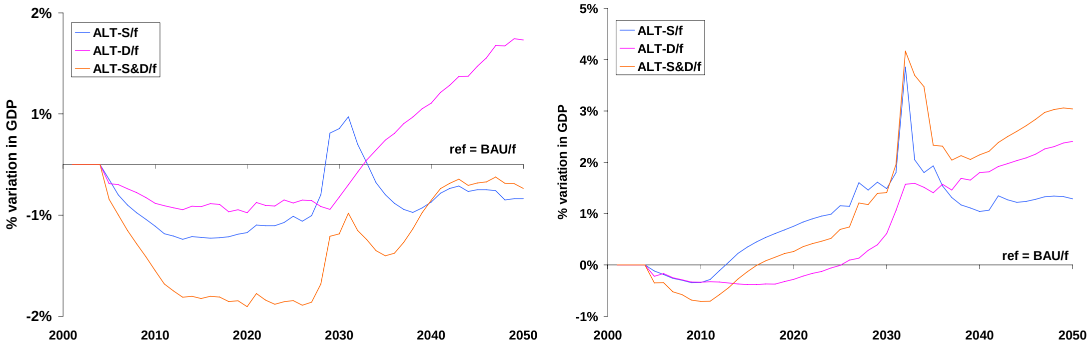
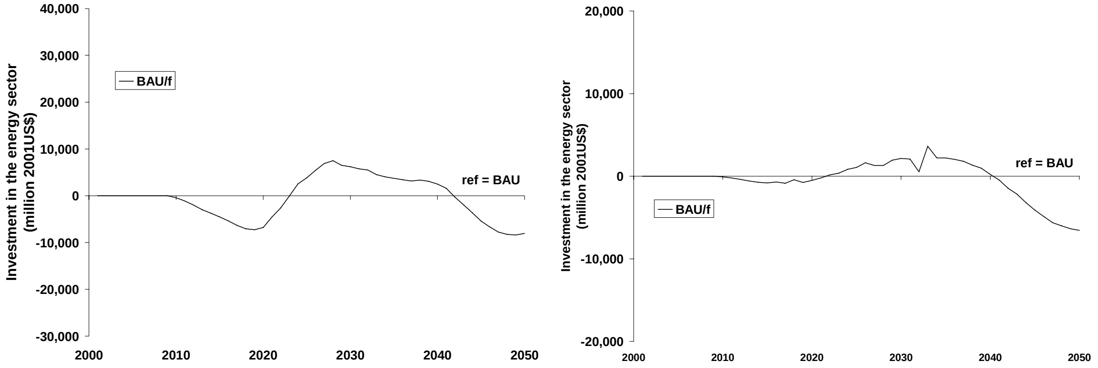


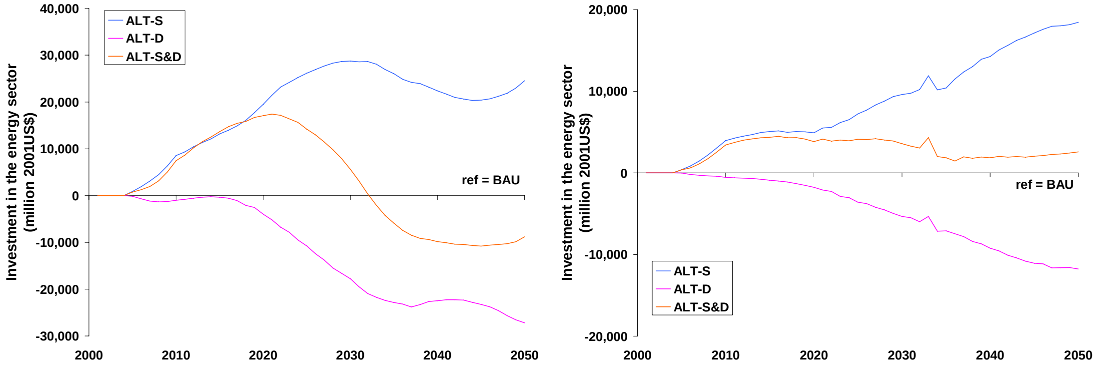
Figure A5: Impact of Rigidity/Frictions and Policy alternatives on ***Energy Investment*** Trajectories

China **India**

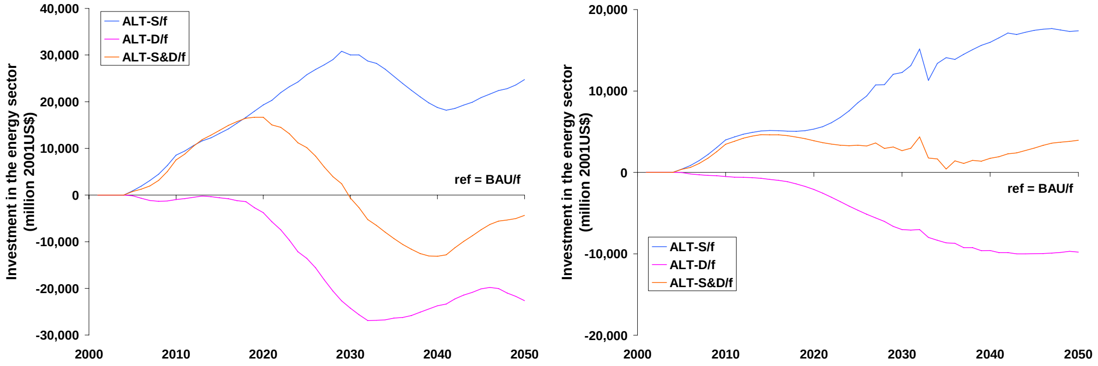
Comparison of scenarios with rigidities/frictions in the fossil fuel markets BAU-f relative to normalized BAU w/o rigidities/frictions



Comparison of ALT policy scenarios vs normalized BAU (in the case without rigidities in the fossil fuel markets)



Comparison of ALT policy scenarios vs normalized BAU (in the case without rigidities in the fossil fuel markets)



References

Asia-Pacific Energy Research Centre (1998), “Energy Overview of China.”

Asia Pacific Energy Research Center (2004), “Energy in China: Transportation, Electric Power, and Fuel Markets.”

BP (2006), "Quantifying Energy: BP Statistical Review of World Energy", available online at www.bp.com/statisticalreview.

Bradley, R (2006). “Transforming the Way We Use Energy”, presentation at the World Bank Energy Week, Washington D.C.

Brandon, Carter J. and Kirsten Hommann (1995), “The Cost of Inaction”, internal document of the South Asia Environment Unit, The World Bank, Washington D.C.

Chameides, W. L., H. Yu, S. C. Liu, M. Bergin, X. Zhou, L. Mearns, G. Wang, C. S. Kiang, R. D. Saylor, C. Lou, Y. Huang, A. Steiner, F. Giorgi (1999), “Case Study of the Effects of Atmospheric Aerosols and Regional Haze on Agriculture: An Opportunity to Enhance Crop Yields in China through Emission Controls?”, *Proceedings of the National Academy of Sciences of the United States of America*, 96(2), pp. 13626–13633.

Cohen, Aaron J., H. Ross Anderson, Bart Ostro, Kiran Dev Pandey, Michal Krzyzanowski, Nino Künzli, Kersten Gutschmidt, Arden Pope, Isabelle Romieu, Jonathan M. Samet and Kirk Smith (2004), “Mortality Impacts of Urban Air Pollution”, in Ezzati M, Rodgers AD, Lopez AD, Murray CJL (ed). *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors.* Vol. 2, pp. 1353–1433.

Crassous, Renaud, Jean-Charles HOURCADE, Olivier SASSI, Vincent GITZ,

Sandrine MATHY, Meriem HAMDI-CHERIF (2006), “IMACLIM-R: A Modeling Framework for Sustainable Development Issues”, International Research Center on Environment and Development.

Dasgupta, Susmita, Hua Wang, and David Wheeler (1997), “Surviving Success: Policy Reform and the Future of Industrial Pollution in China.” *PRDEI.*

Edmonds, J.A., M.A. Wise, and C. MacCracken (1994), “Advanced Energy Technologies and Climate Change: An Analysis Using the Global Change Assessment Model (GCAM)” prepared for the U.S. Department of Energy, Richland, Washington: Pacific Northwest Laboratory.

Edmonds, J.A., M. Wise, and D. Barns, (1995), "Carbon Coalitions: The Cost and Effectiveness of Energy Agreements to Alter Trajectories of Atmospheric Carbon Dioxide Emissions." *Energy Policy,* 23, pp. 309-336.

Government of India, Ministry of Power (2003), Statistics 2003. http://powermin.nic.in/ JSP_SERVLETS/internal.jsp

Hao, Jiming and Litao Wang (2005), "Improving Air Quality in China: Beijing Case Study", Journal of the Air and Waste Management Association 55, pp.1298–1305.

Hamilton, J. D. (2003), "What Is An Oil Shock?", *Journal of Econometrics,* 113, pp 363–398.
Hieber, Saskia (2003), "International and Chinese Projections for Future Energy Demand in China", Summary for Round Table, *Securing Energy; China's Policy and its Wider Strategies Implications.*

International Energy Agency (2005c), Emissions of CO_2, CH_4, N_2O, HFC, PFC, FS_6 Vol. 2005 release 01.

International Energy Agency (2002), *World Energy Outlook*, France: Stedi.

International Energy Agency, Oil Market Report, various issues.

International Energy Agency (2004), *World Energy Outlook*, France: Stedi.

International Energy Agency (2005a), Energy Balances of Non-OECD Member Countries—Extended Balances Vol. 2005 Release 01.

International Energy Agency (2005b), CO_2 Emissions from Fuel Combustion Vol. 2005 Release 01.

International Energy Agency (2006), Energy Prices and Taxes—Crude Oil Spot Prices (US$/bbl) Vol. 2006 Release 01.

International Monetary Fund (2005), "Will the oil market continue to be tight?", *World Economic Outlook,* Chapter IV, Washington D.C.

Jiang, Kejun (2004), "Methodology to Model the Future Energy Scenario for China", presented at UNFCCC Workshop on Emissions Projections of Annex I Parties, Bonn, Germany.

Jiang, Kejun (2005), "Modeling Energy and Environment in China", presented at DEC Climate Change Workshop, World Bank, Washington, D.C.

Jiang, Kejun (2006), "Management of Energy Resources in China", present at Annual Bank Conference on Development Economics, Tokyo, Japan.

Kypreos, K (2000), “The MERGE Model with Endogenous Technological Change” Proc. Workshop on Economic Modelling of Environmental Policy and Endogenous Technological Change. Amsterdam, The Netherlands. November 16-17 .

Larson, Eric B. et al. (2003), “Future Implications of China’s Energy Technology Choices”, *Energy Policy* 51, pp.1189–1204.

Lin, Xiannuan (1996), *China's Energy Strategy: Economic Structure, Technological Choices, and Energy Consumption,* Westport, CT: Praeger Publishers.

Lin, Xiannuan and Karen R. Polenske (1995), "Input-Output Anatomy of China's Energy-Demand Change, 1981–1987," *Economic Systems Research,* 7(1), pp.67–84.

Liu, Gang (2004), “Estimating Energy Demand Elasticities for OECD Countries: A Dynamic Panel Data Approach”, Discussion Paper No. 373, Statistics Norway, Research Department.

Liu, Shijin (2003), “Challenges and Development Goals of China’s Energy Industry in 2020”, presented at China Development Forum 2003, China’s National Energy Strategy and Reform.

Maddison, A. (1995), *Monitoring the World Economy: 1820–1992,* OECD Development Center, Washington D.C.

Manne, Allen (1978). "Energy-Economy Interactions: the Fable of the Elephant and the Rabbit?" in R. Pindyck (ed.), *Advances in the Economics of Energy and Resources,* vol. 1: The Structure of Energy Markets, Greenwich, Connecticut: JAI Press.

Merino, A. and A. Ortiz (2005), “Explaining the So-Called “Price Premium” in Oil Markets”, *OPEC Review,* 29(92), pp. 133–152.

Mitra, A. P. and C. Sharma (2002), “India Aerosol: Present Status”, *Chemosphere,* 49, pp. 1175–1190.

Morita, Tsuneyuki, Mikiko Kainuma, Hideo Harasawa and Keiko Kai (1994), Asian-Pacific Integrated Model for Evaluating Policy Options to Reduce Greenhouse Gas Emissions and Global Warming Impacts, National Institute for Environmental Studies: Japan.

National Bureau of Statistics of China (2005), Statistics Yearbook 2005. Beijing.

Paul, Shyamal and Rabindra N. Bhattacharya (2004), “CO_2 emission from energy use in India: A Decomposition Analysis”, *Energy Policy,* 32, pp.585–593.

Pindyck, R. S. (2001), “The Dynamics of Commodity Spot and Futures Markets: A Primer”, *Energy Journal,* 22(3), pp. 1–29.

Sarma, E. A. S, J. N. Margo, and A.S. Sachdeva, “India's Energy Scenario in 2020”, paper presented at the 17th World Energy Congress, Houston, Texas, September 1998

Sinton, Jonathan E., Mark D. Levine and Qingyi Wang (1998), “Energy Efficiency in China: Accomplishments and Challenges”, *Energy Policy,* 26 (11), pp.813–829.

Sinton, Jonathan (2001), “Accuracy and Reliability of China’s Energy Statistics”, *China Economic Review,* 12(4), pp.373–383.

Sinton, Jonathan E. and David G. Fridley (2000), “What Goes Up: Recent Trends in China’s Energy Consumption”, *Energy Policy,* 28, pp.671–687.

Sinton, Jonathan E. and David G. Fridley (2003), “Comments on Recent Energy Statistics from China”, *The Sino Sphere Journal,* 6(2), pp. 6–14.

Shalizi, Zmarak (2005), “Sustainable Development and the Wise Use of Natural Resources in China”, presented at the 21st Century Forum, Beijing, China.

Shukla, P. R., Rajesh Nair, Manmohan Kapshe, Thomas Hamacher, Tom Kram (2001), “Long-term Energy Scenarios for India”, a Collaborative Project of Indian Institute of Management, Ahmedabad Max Planck Institute for Plasma Physics Netherlands Energy Research Foundation (ECN).

The Energy and Resources Institute (2003), *TERI Energy Data Directory and Yearbook 2003,* New Delhi: Teri Press.

The Energy and Resources Institute (2004), *TERI Energy Data Directory and Yearbook 20004,* New Delhi, India: Teri Press.

U.S. Energy Information Administration (1997), “China: An Energy Sector Overview.”

U.S. Energy Information Administration (2003b), “China: Environmental Issues.”

U.S. Energy Information Administration (2003c), “An Energy Overview of the People’s Republic of China.”http://fe.doe.gov/iinternational/EastAsia_and_Oceania/chinover.html.

U.S. Energy Information Administration (2004), *<I>International Energy Annual 2004.<I>*

U.S. Energy Information Administration (2005a), *International Energy Annual 2003*. http://tonto.eia.doe.gov/bookshelf/SearchResults.asp?title=International+Energy+Annual&submit=Search&product

U.S. Energy Information Administration (2005b), “China: Country Brief.”

U.S. Energy Information Administration (2006), *International Energy Outlook 2004.* http://www.eia.doe.gov/iea/.

Van Vuurena, Detlef, Zhou Fengqib, Bert de Vriesa, Jiang Kejun, Cor Gravelandb, and Li Yun (2003), "Energy and emission scenarios for China in the 21st century—exploration of baseline development and mitigation options", *Energy Policy*, 31, pp. 369–387.

World Bank (2001a), "China: Opportunities to Improve Energy Efficiency in Buildings." Washington D.C.

World Bank (2001b), "The Bank's Assistance to China's Energy Sector." Washington D.C.

World Bank (2003), *World Development Report 2003: Sustainable Development in a Dynamic World*, New York: Oxford University Press.

World Bank (2005a), World Development Indicator. http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20899413~menuPK:232599~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html

World Bank (2005b), "For a Breath of Fresh Air: Ten Years of Progress and Challenges in Urban Air Quality Management 1993–2002", Washington DC.

World Bank (2006), Global Economic Monitor.

World Bank (2007), The China Environmental Cost Model, conference volumn.

World Energy Council (1999), Energy Efficiency Policies and Indicators.

World Health Organization (2002), The World Health Report, Geneva.

Ye, M., Zyren J. and J. Shore (2005), "A Monthly Crude Oil Spot Price Forecasting Model Using Relative Inventories", *International Journal of Forecasting*, 21(3), pp. 491–501.

Zhang, Zhongxiang (2000), "Can China afford to commit itself an emissions cap? An economic and political analysis", *Energy Economics,* 22, pp. 587–614.