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Factors Enabling the Decoupling of China's Energy-related Emissions from Its Economic Growth

Where is China on the Environmental Kuznets Curve?

Li Yong, Andreas Oberheitmann

Summary

Economic growth has been one of the most important political goals in China since the reforms introduced by Deng Xiaoping in the late 1970s. The successful increase in economic welfare in China was accompanied by a decoupling of economic growth and energy-related emissions of carbon dioxide (CO_2) and sulphur dioxide (SO_2). The absolute values of these emissions has increased considerably. Two questions arise against this backdrop: what are the main factors behind the decoupling of economic growth and these energy-related emissions, and what is the impact of each of these factors on the rise in emissions? This paper aims to determine and analyse these factors, which are population, per-capita income, total CO_2 or SO_2 intensity of the primary energy supply, and the energy intensity of GDP.

Factor decomposition reveals that the growth in per-capita income and the reduction in energy intensity have the largest balancing impact on energy consumption and emissions in China. The relationship between economic development and emission levels, however, is not linear over time, but follows a path commonly described by the Environmental Kuznets Curve: emissions decrease while per-capita income grows. In China, this phenomenon occurred between 1998 and 2000 and led to a curve much like the typical inverted U-shaped Environmental Kuznets Curve until 2001. Seen from a 2005 perspective, however, this merely turned out to be a structural break.

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1 Introduction

One of the most important objectives of economic policy in China is to fuel economic growth – the motor of development – and subsequently to increase the nation's wealth as the most populous country on earth, with more than 1.3 billion inhabitants. This goal has had priority for the Chinese government (Zhang 2005). The successful balance of the past 25 years shows almost a tenfold increase in real GDP, which rose from 1.8 trillion RMB in 1980 to 17.3 trillion RMB in 2005 (see Table 1).

In the same period of time, an annual 1.1% demographic growth rate and an annual 8.2% increase in per-capita income led to rising demand in private households in every category of consumption, including energy for transport purposes, amongst other things (Suding 2005). This remarkable economic and welfare-related growth in China was accompanied by a 4.0% p.a. reduction in the energy intensity of real GDP.

Table 1: Development of selected macro-economic variables in China (1980-2005)

	1980	1990	2000	2001	2002	2003	2004	2005	1980-2005 (% p.a.)
Primary energy supply (million t. sce)	621	970	1156	1274	1452	1685	2009	2158	5.1
Real[1] GDP (billion RMB)	1809	3756	9038	11033	12205	13612	15422	17276	9.4
Population (million)	987	1143	1267	1276	1285	1292	1300	1306	1.1
Per-capita income (RMB)	1833	3286	7128	8645	9501	10534	11864	13228	8.2
PES/Capita (t sce)	0.629	0.848	0.912	0.998	1.130	1.304	1.545	1.652	3.9
PES/GDP[1] (t sce/1000 RMB)	0.343	0.258	0.128	0.115	0.119	0.124	0.130	0.125	-4.0
CO_2 emissions (million t)	1538	2391	2771	3036	3503	4150	5012	5291	5.1
SO_2 emissions (million t)	12	19	20	20	19	22	23	26	3.1

Source: National Bureau of Statistics of China (various issues).
BP (2006), our own calculations. Sce = standard coal equivalents.
1) in terms of 1998 pricing.

This decoupling of economic growth from energy consumption led to a moderate annual increase in primary energy consumption and energy-related greenhouse gas emissions of carbon dioxide (CO_2) of 5.1% p.a. in China. Due to end-of-pipe technologies (filters for desulphurisation), the substitution of high-sulphur coal for low-sulphur coal and a slight surge in coal washing, regional sulphur dioxide (SO_2) emissions only moderately increased by 3.1% p.a. between 1980 and 2005 (see Table 1). By the year 2020, the Chinese government plans to have quadrupled real GDP compared with the 2000 values (Suding 2005). Without any improvements in energy efficiency, primary energy consumption would also quadruple. To avoid considerable negative environmental, political and economic side effects, the Chinese government is aiming at reducing specific types of energy consumption and promoting the notion of a "resource-saving society" (Oberheitmann 2005).

What are the main factors behind this decoupling of economic growth and energy-related emissions in China? This paper aims at determining and analysing these factors as well as putting them into the macro-economic context of a growing energy demand for industrial and residential purposes and transport (Chapter 2). In order to assess the individual impact of these factors on the development of CO_2 and SO_2 emissions in China, they will be mathematically decomposed (Chapter 3). The correlation between per-capita income and energy-related emissions is especially strong. This relationship, however, is not linear over time, but can be described using the Environmental Kuznets Curve hypothesis. Chapter 4 illustrates China's Environmental Kuznets Curve, analyses the developments which are responsible for this inverted U-shaped curve in the time between 1998 and 2000 and critically looks back on this phenomenon from the year 2005. Chapter 5 summarises the paper and draws various conclusions.

2 Main factors in the development of CO_2 and SO_2 emissions in China

By definition, the development of the absolute emission levels in China can be split up into four main factors: population, per-capita income, total CO_2 or SO_2 intensity of energy use and the energy intensity of GDP. The level of CO_2 emissions in China can be calculated by the formula:

(1) $$CO_{2,t} = \eta_t \cdot \gamma_t \cdot Ycap_t \cdot P_t$$

where CO_2 = CO_2 emissions (million t),
η_t = energy intensity of GDP (t sce / 1000 RMB GDP),
γ_t = total CO_2 intensity of energy use (t / t sce),
Ycap = Gross Domestic Product per capita (RMB) in terms of 1998 prices,
P = population,
t = time.

The total CO_2 intensity of energy use γ_t is a function of the consumption of the individual primary energy sources multiplied by the corresponding emission factors and divided by the total energy use:

(2) $$\gamma_t = \frac{\sum_{i=1}^{4} \left(c_i \cdot E_{i,t}\right)}{\sum_{i=1}^{4} E_{i,t}}$$

where $E_{i,t}$ = primary energy consumption,
c_i = CO_2 and SO_2 factors respectively (t of the emission per t sce) of the individual primary energy sources (i) in China and for (i) being
1 = coal
2 = mineral oil
3 = natural gas

4 = hydro-electric power, nuclear energy and other renewables,[1]

t = time.

The SO_2 emissions are calculated in the same way using the specific SO_2 intensity of the primary energy supply. In the following, the four definitional factors of China's CO_2 and SO_2 emissions will be analysed.

2.1 Per-capita income and population

GDP is a product of per-capita income and population. Assuming a constant per-capita income, GDP would increase with the growth rate of the population. As both per-capita income (8.2% p.a.) and population (1.1% p.a.) levels grew between 1980 and 2005, the rise in GDP is 9.4% p.a. (Table 1). The growth in income has had a

Table 2: Development of selected urban household data in China (1981-2005)

	1981	1985	1990	1995	1998	1999	2000	2001	2002	2003	2004	2005	2005 v. 1995 (%)
Selected household survey data													
Household size (persons/household)	4.24	3.89	3.5	3.23	3.16	3.14	3.13	3.10	3.04	3.01	2.98	2.96	-8.4
Average income (RMB/year)[1]	633	1006	2983	4117	5458	5712	6035	8645	9501	10534	11864	13228	221.3
Disposable income per capita (RMB)	136	232	716	3396	4332	4477	4775	5309	7703	8472	9422	10493	209.0
used for water. electricity, fuels (RMB)	3.98	6.35	20.4	140.7	235.42	250.35	285.57	330.99	357.00	404.25	451.49	516.31	267.0
Urban p. capita net living space (m^2)	7.20	10.00	13.70	16.30	18.70	19.40	20.30	20.80	22.80	23.70	25.00	26.10	60.1
Coal consumption per household (kg/year)	1.018	1.053	721	666	651	647	403	398.97	179.93	190.41	187.37	198.07	-70.3
Electric appliances per 100 urban households:													
Ventilators	43.0	74.0	135.5	167.35	168.37	171.73	167.91	170.74	182.57	181.58	179.56	172.18	2.9
TV sets (black and white)	57.0	67.0	52.36	27.97	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-
TV sets (colour)	0.6	17.0	59.04	89.97	105.43	111.57	116.56	120.52	126.38	130.5	133.44	134.8	49.8
Washing mashines[2]	6.0	48.0	78.41	88.97	90.57	91.44	90.52	92.22	92.9	94.41	95.9	95.51	7.4
Refrigerators	0.2	7.0	42.33	66.22	76.08	77.74	80.13	81.87	87.38	88.73	90.15	90.72	37.0
Freezers	n.a.	n.a.	n.a.	2.87	4.8	5.37	6.52	6.62	6.81	6.97	6.73	6.68	132.8
Air-conditioning	n.a.	0.1	0.34	8.09	20.01	24.48	30.76	35.79	51.5	61.79	69.81	80.67	897.2
Electric cooking devices[3]	n.a.	19.0	46.18	84.14	95.98	101.82	101.94	107.87	96.02	101.19	106.38	107.20	27.4

Source: National Bureau of Statistics of China (various issues).
1) In terms of 1998 prices.
2) Including manually and semi-automatically operating devices.
3) Electric rice cookers, etc.

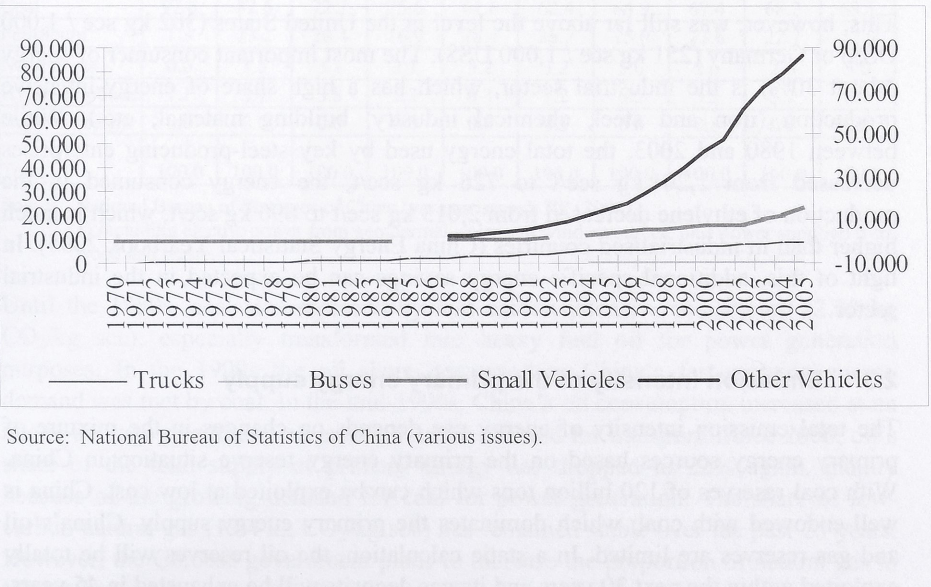
1 Nuclear energy (0.4%) and other renewable energy sources (< 0.05%) only made a small contribution to China's primary energy supply in 2001.

positive impact on the demand for goods and services in China. According to their income elasticities, the demand for goods and services increased, leading to a growth in energy consumption. As an example, the urban per-capita net living space increased by 60.1%, rising from 16.3 m^3 to 26.1 m^3 between 1995 and 2005, and thus – assuming linear growth – induced a considerable increase in the demand for energy required for heating purposes. The demand for electrical household appliances grew enormously, especially for refrigerators, air-conditioning systems and colour TVs (see Table 2).

Against this backdrop, primary energy consumption per capita in China increased by 3.9% p.a. from 629 kg sce in 1980 to 1,652 kg sce in 2005. Compared to Germany (5,765 kg sce) or the US (11,081 kg sce), however, this is still a very low figure for specific energy consumption. Several other factors indicate a further rise in energy consumption in the near future, *inter alia* the growing demand for transport and motorisation in China (see Figure 1).

Due to the increase in disposable income and China's WTO entry with subsequent lifts of import tariffs on passenger cars, the import of cars will continue to grow. As the imported cars are larger than the domestic vehicles on average, it may lead to an additional growth in the demand for fuel for transport purposes in China, even though the imported cars generally have a higher standard environmentally (viz. Euro IV for imported cars compared to Euro III for domestic cars).

Figure 1: Development of motorisation in China (1970-2005, in 1,000 units)



Source: National Bureau of Statistics of China (various issues).

2.2 Energy intensity of GDP

This growth in the demand for energy in China is counterbalanced by a decrease in energy intensity since the 1980s. Structural changes, investments in energy efficiency and environmental-policy measures have led to a 3.9% p.a. decrease in the energy intensity of GDP in China over the past 25 years (Table 1). For the entire economy, the energy intensity of production in China decreased from 343 kg sce / 1,000 RMB real GDP in 1980 to 125 kg sce / 1,000 RMB real GDP or 1,034 kg sce / 1,000 US$ real GDP in 2005 (Table 3).

Table 3: Development of selected specific energy and emission variables in China (1952-2005)

	1952	1960	1970	1980	1990	2000	2001	2002	2003	2004	2005	2005 v. 1980 [1]
	Energy intensity (t sce)											
per 1,000 US$ GDP	0.318	1.01	0.725	0.525	1.349	1.059	0.956	0.985	1.025	1.078	1.034	2.8
	Total emission intensity (kg/kg sce)											
CO_2	2.839	2.827	2.687	2.477	2.465	2.397	2.383	2.413	2.463	2.495	2.452	-0.2
SO_2	0.03	0.03	0.027	0.019	0.020	0.017	0.016	0.013	0.013	0.011	0.012	-3.0

Source: National Bureau of Statistics of China (various issues).
1) In terms of 1998 prices.
2) Including manually and semi-automatically operating devices.
3) Electric rice cookers, etc.

This, however, was still far above the level in the United States (302 kg sce / 1,000 US$) or Germany (251 kg sce / 1,000 US$). The most important consumer of energy (about 30%) is the industrial sector, which has a high share of energy-intensive production (iron and steel, chemical industry, building material, etc.). While between 1980 and 2003, the total energy used by key steel-producing enterprises decreased from 1,201 kg sce/t to 726 kg sce/t, the energy consumed in the production of ethylene decreased from 2,013 kg sce/t to 890 kg sce/t, which is much higher than in industrialised countries (China Energy Statistical Yearbook 2005). In light of this, additional specific energy savings can be expected in the industrial sector.

2.3 Emission intensity of the primary energy supply

The total emission intensity of energy use depends on changes in the mixture of primary energy sources based on the primary energy reserve situation in China. With coal reserves of 120 billion tons which can be exploited at low cost, China is well-endowed with coal, which dominates the primary energy supply. China's oil and gas reserves are limited. In a static calculation, the oil reserves will be totally exploited within the next 20 years and its gas deposits will be exhausted in 45 years.

China's oil production had more and more difficulty meeting the growing domestic oil demand in the 1990s. In fact, China has been a net importer of crude oil ever since 1993. Theoretically, with 700 gigawatts at its disposal, China has the world's largest hydro-electric power potential. However, only 380 GW, or 56%, can be technically exploited and 220-280 GW, or 33-41%, can be economically exploited (Andrews-Speed et al. 1999).

The structure of China's primary energy consumption has changed significantly over the past 50 years. In 1952, almost 98% of its total energy consumption was from coal. The share of the carbon-intensive coal (2.88 kg CO_2/kg sce) dropped to 68% in 2005 (see Table 4). However, since 2000, the share of coal has been increasing again slightly.

Table 4: Development of China's primary energy supply [1] (1952-2005)

	1952	1970	1980	1990	2000	2001	2002	2003	2004	2005
	in million t sce									
Coal	47.1	252.8	447.0	729.9	701.0	774.5	925.4	1125.8	1370.7	1451.3
Petroleum	0.6	40.3	125.8	163.5	323.6	331.8	356.4	394.7	455.7	467.7
Natural gas	0.0	4.7	19.0	20.3	36.2	40.3	43.4	44.1	51.9	64.7
Hydro-el. power	0.5	8.3	23.5	51.2	71.9	89.7	93.1	91.7	114.3	129.7
Nuclear energy	0.0	0.0	0.0	0.0	5.4	5.7	8.1	14.0	16.3	16.9
Total[1]	48.3	306.1	615.2	964.9	1138.1	1242.1	1426.5	1670.3	2008.9	2130.3
	in per cent									
Coal	97.6	82.6	72.7	75.6	61.6	62.4	64.9	67.4	68.2	68.1
Petroleum	1.3	13.2	20.4	16.9	28.4	26.7	25.0	23.6	22.7	22.0
Natural gas	0.0	1.5	3.1	2.1	3.2	3.2	3.0	2.6	2.6	3.0
Hydro-el. power	1.1	2.7	3.8	5.3	6.3	7.2	6.5	5.5	5.7	6.1
Nuclear energy	0.0	0.0	0.0	0.0	0.5	0.5	0.6	0.8	0.8	0.8
Total[1]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: National Bureau of Statistics of China (various issues); BP (2006).
1) including electric power from geothermal, solar and wind resources, plus power supplied from wood and waste.

Until the 1980s, coal was replaced by less carbon-intensive mineral oil (2.25 kg CO_2/kg sce), especially transformed into heavy fuel oil for power generation purposes. In the 1990s the oil share decreased as China's fast-growing energy demand was met by coal. In the mid-1990s, China's oil consumption increased at an above-average rate due to an increase in the demand for transport. Since 2000, oil's share of the total supply of primary energy has dropped to 22% again, mainly because of the growing demand for coal for power generation. The share of low-carbon natural gas (1.64 kg CO_2/kg sce) has remained stable over the past 25 years. However, the Chinese government plans to increase the proportion of natural gas in the total primary energy supply substantially. Currently, the main bottleneck due to transport has been relieved as the large West-East pipeline has been operating since 2005. However, to prepare for future shortages, a port for landing liquefied natural gas (LNG) was built in Guangdong to supply South China with gas. At present, LNG is relatively expensive. Zero CO_2-intensive hydro-electric power generation was promoted over the whole period until 2005, leading to a rise and fall in its share of the total primary energy supply.

In 1991, nuclear energy was introduced in China to close the regional gap between supply and demand for coal. Nuclear power plants have been built in those regions with relatively small coal reserves but a high energy demand. The first nuclear power plant in Qinshan (Zhejiang province) was built exclusively with Chinese technology. China now has eleven nuclear power plants in Guangdong and Zhejiang with a total capacity of 9.1 GW, accounting for about 1% of the total installed capacity. Most of these plants were built as joint ventures. Currently, nuclear energy makes up 0.8% of the total primary energy supply. An additional capacity of 3.3 GW is planned (or already under construction) for the period up to 2011 (IAEA 2006), amounting to a total capacity of 12.4 GW one year after the current Five-Year Plan (the 11^{th}) has ended.

Other renewable energy sources only accounted for 0.12% of China's total power-generation capacity in 2001, viz. 0.4 GW. The capacity of the most important source, wind energy, increased, but from a very low level. However, in absolute terms, apart from hydro-electric power and the use of firewood in remote areas (which is not included in the energy statistics), renewable energy use in China is negligible for China's primary energy sector.

As a result of fuel substitution and energy efficiency gains, the total CO_2 intensity in China decreased from 2.839 kg CO_2 per kg sce primary energy consumption in 1952 to 2.452 kg CO_2 per kg sce in 2005 (Table 3). The yearly reduction was 0.2% between 1980 and 2005 and 1.0% over the 25-year period. As gas only has a very low SO_2 factor (0.000013 kg SO_2 per kg sce[2]), the substitution of coal by natural gas and the installation of desulphurisation devices have led to above-average emission reduction of SO_2. Hence, the decrease in the total SO_2 intensity in China was 52.7% or 3.0% p.a. between 1980 and 2005.

2.4 Other factors

Apart from the factors identified in the definition applied, the energy use and the development of emissions in China are influenced by other parameters, such as the development of energy prices (especially in the power sector) and environmental policy, which are not explicitly included in this analysis. The producer and consumer tariffs in China's power sector are both based on catalogue prices, which

2 Coal has a SO_2 factor of 0.024 kg SO_2/kg sce.

are approved by Central Government. For various economic and political reasons (provision of cheap energy for the population, protection of infant industries, etc.), the price of electricity in China is still kept very low. The Chinese Government undertook several measures to liberalise the electricity market and cut down subsidies. This led to an increase in the price of electricity, but in comparison the price is still too low as price increases for other commodities and other primary energy inputs are much higher. In particular, the prices of coal, petroleum and petroleum products increased considerably more than the electricity price (Lawrence Berkeley National Laboratory 2004). However, at the end of the 1990s, electricity prices increased and led to investments in energy efficiency and energy conservation.

Although economic development is the primary goal of Chinese policy, the 10th Five-Year Plan (2001-2005) formulated quantitative environmental goals. These were to be achieved by 2005:

- the energy consumption of 10,000 RMB GDP at 1990 prices is to be reduced to 2.2 tons of standard coal equivalent (at 1990 rates);
- energy conservation and reductions in the use of energy are to be 340 million tons of standard coal. Accordingly, the annual energy conservation ratio is to be 4.5%;
- the conservation and substitution of fuel oil and finished oil are to reach 16 million tons and 5 million tons respectively (Oberheitmann 2005).

The overall energy-efficiency goal set by the Chinese government in the 10th Five-Year Plan was a challenging one. In terms of 1998 prices, the energy consumption per 1,000 RMB GDP in 2001 was 0.115 t. A decrease to 0.096 t/1,000 RMB GDP in 2005 would have represented a specific energy-intensity reduction of 16.4% in 2005 in comparison to 2001. In retrospect, however, the overall energy intensity only decreased by 3.9% between 2001 and 2005 (see Table 3).

The current – 11th – Five-Year Plan (for 2006-2010) aims at further enhancing economic strength, changing economic growth patterns, optimising the structure of industry, improving the public service system, strengthening the capability for sustainable development and accelerating reform so as to bring about sustainable, fast and sound development of the national economy and achieve overall progress for society. These goals are, *inter alia*, to be reached by taking the following measures:

- eliminating the four major bottlenecks of sustainable development (resources, science and technology, talents and system),
- addressing development problems in rural areas and the west of the country,
- appropriately handling major socio-economic issues, i.e. economic growth patterns, industrial structure, balanced development between urban, rural areas and different regions, resources and environmental protection, talents and

science and technology education as well as developing a harmonious society (Zhang 2005).

Against the backdrop of a fast-growing economy and related safety problems concerning energy production, e.g. in the oil sector, the Chinese Government launched China's "Programme of Action for Sustainable Development". The programme proposes the following measures to achieve a sustainable energy policy:

- paying attention to saving energy resources, increasing energy efficiency and promotion of clean coal technologies through the promotion of a "resource-saving society", and
- adjusting the structure of energy resources, raising the ratio of clean energy resources, and development and exploitation of renewable and new sources of energy (Oberheitmann 2005).

In terms of the definitional factors for CO_2 and SO_2 emissions determined above, these measures simply aim at reducing the energy intensity of GDP by "saving energy resources, (and) increasing energy efficiency" as well as reducing the CO_2 intensity of the primary energy supply by "adjusting the structure of energy resources and raising the ratio of clean energy resources …".

3 Decomposition of the development of China's CO_2 and SO_2 emissions

To analyse the impact of the individual effects that the main factors had on the level of emissions of CO_2 in China, they will be mathematically decomposed for the period from 1995 to 2005. The decomposition can be expressed by the following equation:

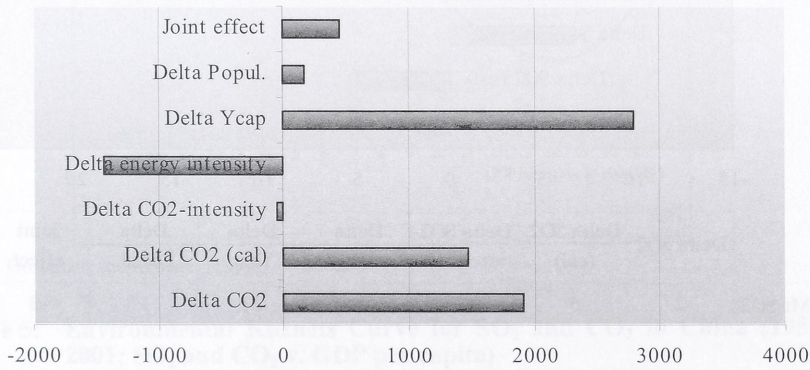
$$(3)\quad \Delta CO_2 = \Delta\gamma \cdot \eta_{2000} \cdot Ycap_{2000} \cdot P_{2000} + \gamma_{2000} \cdot \Delta\eta \cdot Ycap_{2000} \cdot P_{2000} + \gamma_{2000} \cdot \eta_{2000} \cdot \Delta Ycap \cdot P_{2000} + \gamma_{2000} \cdot \eta_{2000} \cdot Ycap_{2000} \cdot \Delta P_{2000}$$

For a long period of time, the joint effect, i.e. the impact on CO_2 emissions that cannot be explained by any of the aforementioned factors alone (population, per-capita income, energy intensity of GDP and CO_2 intensity of the primary energy supply), but only by their cumulative impact, will be too high. To minimise the joint effect, the factors are weighted with the 2000 values. The function for the SO_2 emissions is the same except for the emission intensity of the primary energy supply. Other factors such as energy prices or structural changes were not taken into account in this decomposition. Consequently, the decomposition should not be taken as a perfect cause-effect chain. This mathematical approach can vividly demonstrate the importance of each of the factors, however.

Figure 2 reveals the impact of the individual factors. The growth in per-capita income is the largest contributor to the growth in CO_2 emissions in China. China's CO_2 emissions grew by 1,914 million tons between 1995 and 2005. If the other factors were kept constant, then the CO_2 emissions would have increased by about 2.8 billion tons. China's moderate population growth only contributed to the increase in CO_2 emissions to a small degree (170 million t). The impact of China's economic development on the CO_2 emissions was counterbalanced by two factors, viz.

- energy-efficiency improvements, and
- a reduction in the overall CO_2 intensity by substituting coal with lower-carbon primary energy sources (e.g. natural gas or mineral oil) or non-carbon sources (e.g. nuclear energy, hydro-electric energy and other sources of renewable energy).

Figure 2: Decomposition of China's CO_2 emissions (1995-2005, in million t)



	Delta CO2	Delta CO2 (cal)	Delta CO2-intensity	Delta energy	Delta Ycap	Delta Popul.	Joint effect
Mt CO2	1914	1468	-59	-1436	2792	170	446

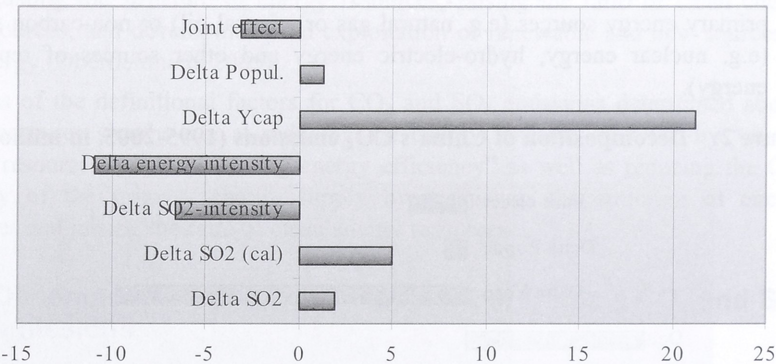
Source: our own calculations.

The largest contribution to the moderate increase in CO_2 emissions in China between 1990 and 2005 was made by reducing the macro-economic energy intensity through investments in energy efficiency (-1.4 billion t). Its impact is nearly 25 times larger than the impact of fuel substitutions (-59 million t).

About 67% of China's CO_2 emissions growth is explicitly influenced by the changes in energy intensity, CO_2 intensity, per-capita income and population. The joint effect (i.e. the difference between the calculated CO_2 emission levels and the actual figures) cannot be explained by any of these factors alone, but only by all four factors taken together and amounts to 446 million t CO_2.

Equation (3) can also be used for the decomposition of China's SO_2 emissions if the total CO_2 intensity of energy use is replaced by the respective SO_2 intensity. The decomposition of China's SO_2 emissions in Figure 3 reveals a structure similar to that for CO_2. However, the impact of fuel substitution is much larger than for CO_2 because of the large difference in the SO_2 intensity for natural gas (see above).

Figure 3: Decomposition of China's SO_2 emissions (1990-2001, in Mt)



	Delta SO2	Delta SO2 (cal)	Delta SO2-intensity	Delta energy	Delta Ycap	Delta Popul.	Joint effect
Mt SO2	2	5	-7	-11	21	1	-3

Source: our own calculations.

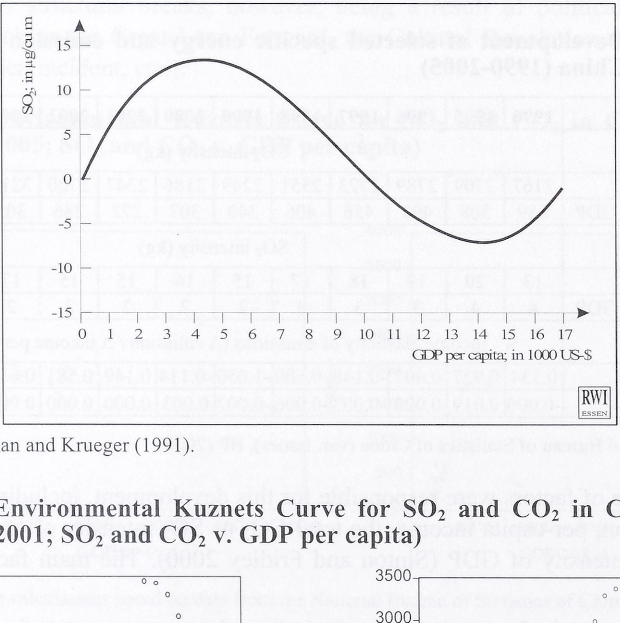
4 The development of income and pollution: China's Environmental Kuznets Curve

The correlation between economic development and emission levels is not linear over time, however; in fact, it follows a path which is commonly described by the Environmental Kuznets Curve (see Figure 4).

The Environmental Kuznets Curve hypothesis claims that pollution levels increase with economic development and welfare, but decrease when a certain level of income is exceeded. This correlation is reflected in an inverted or U-shaped curve or a semi-inverted S-shaped curve of pollution and income for different countries on a different development level at the same point in time (see Figure 4) or even for a single country over a fixed period of time. Grossman and Krueger (1991) first proposed this hypothesis based on Kuznets' (1955) findings on the empirical evidence for an inverted U-shaped curve representing the relationship between per-capita income and income inequality.

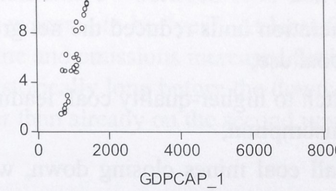
Arrow et al. (1995) explained that the inverted U-curve was due to structural changes in the composition of economic output and increased environmental regulation. Certain other authors included international trade and the impact of trade policy in the analysis (Grossman and Krueger (1991), Lucas et al. (1992)).

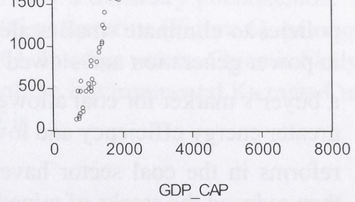
Figure 4: The Environmental Kuznets Curve (SO_2 v. GDP per capita)



Source: Grossman and Krueger (1991).

Figure 5: Environmental Kuznets Curve for SO_2 and CO_2 in China (1952-2001; SO_2 and CO_2 v. GDP per capita)





Source: our own calculations based on data from the National Bureau of Statistics of China (var. issues), BP (2006).

Figure 5 shows the Environmental Kuznets Curve for SO_2 and CO_2 in China as their relationship to GDP per capita between 1952 and 2001. In the case of CO_2, in particular, it reveals the typical inverted U- or semi-inverted S-shaped curve with a steady increase in CO_2 emissions above the growth rate of GDP, rising from a low level of 370 RMB per capita in 1952 to a turning point of about 6,000 RMB in 1997. The CO_2 emissions started to increase again in 2001 at a level of 7,000 RMB.

The U-shaped curve is the result of growing per-capita income but decreasing CO_2 and SO_2 emissions; in other words, when the income elasticity of emissions becomes negative. This was the case for the years 1998 to 2000 with respect to CO_2 and SO_2 emissions in China (see Table 5).

Table 5: Development of selected specific energy and emission variables in China (1990-2005)

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	CO_2 intensity (kg)											
per capita	2167	2709	2789	2723	2551	2249	2186	2347	2720	3213	3856	4051
per 1,000 RMB GDP	659	508	493	456	406	340	307	272	286	305	325	306
	SO_2 intensity (kg)											
per capita	13	20	19	18	17	15	16	15	15	17	17	20
per 1,000 RMB GDP	4	4	3	3	3	2	2	2	2	2	1	1
	Income elasticity of emissions (Δ emission / Δ income per capita)											
CO_2	0.134	0.927	0.407	-0.148	-0.600	-1.050	-0.114	0.149	0.581	0.638	0.646	0.205
SO_2	-0.006	0.019	0.000	-0.003	-0.006	-0.007	0.003	0.000	0.000	0.002	0.001	0.002

Source: National Bureau of Statistics of China (var. issues), BP (2006).

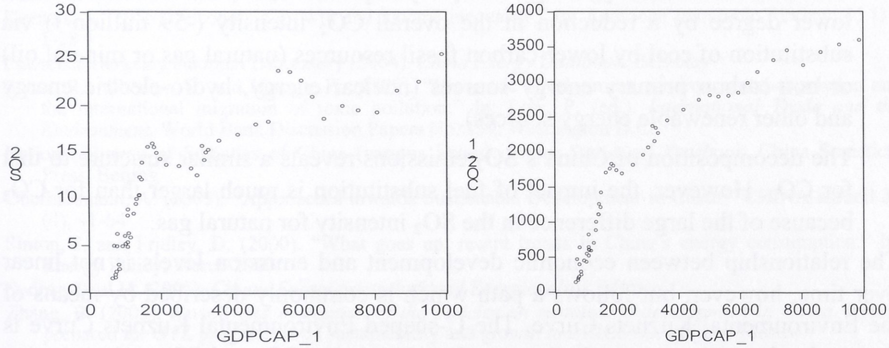
A wide range of factors were responsible for this development, including the size of the population, per-capita income, the total CO_2 or SO_2 intensity of energy use and the energy intensity of GDP (Sinton and Fridley 2000). The main factors were as follows:

- a slowdown in heavy industry, including the power sector, in response to economic growth slowing down,
- bankruptcies and mergers of state-owned companies that were inefficient (in their use of energy),
- policies to eliminate small-scale power generation units reduced the net growth in power generation and slowed growth in coal use,
- a buyer's market for coal allowed for a switch to higher-quality coal, leading to greater energy efficiency and lower coal consumption,
- reforms in the coal sector have led to small coal mines closing down, which then reduced the stocks of mined coal,

- changes in the structure of the economy, moving away from energy-intensive industries and towards energy-extensive high-technology and service sectors offering higher value added,
- a reduction in the residential use of coal in favour of electricity and gas,
- relatively high electricity prices leading to investments in energy efficiency and energy conservation.

Looking at the past, there were several other years with negative income elasticities with respect to emissions in China's Environmental Kuznets Curve, viz. 1957, 1963, 1968, 1976, 1980/81 and 1989. These individual negative elasticities may be interpreted as structural breaks, however, being a result of political changes or incidents (such as the Great Leap Forward, the Cultural Revolution, Mao's death, the Tian'anmen incident, etc.).

Figure 6: Environmental Kuznets Curve for SO_2 and CO_2 in China (1952-2005; SO_2 and CO_2 v. GDP per capita)



Source: our own calculations based on data from the National Bureau of Statistics of China (var. issues), (2006).

The question that remains is whether the four-year period of negative income elasticities with respect to emissions that led to a shape like an Environmental Kuznets Curve – between 1997 and 2000 – was only a transitory phenomenon. The answer seems to be "yes". At least from the 2005 perspective (Figure 6), per-capita income and emissions increased further after 2001. In other words, China is likely to be historically long before the downward slope of the Environmental Kuznets Curve rather than already on the second upward part of it.

5 Summary and conclusions

China's tremendous economic development brought about a huge economic welfare gain for the population in terms of GDP per capita. These economic benefits, however, were gained at a cost – the negative implications for the regional environment (SO_2 emissions) and the global one (CO_2 emissions). The main factors responsible for the development of emissions in China are the size of the population, its per-capita income, the total CO_2 or SO_2 intensity of energy use and the energy intensity of GDP. After analysing these factors by decomposing the development of China's emissions, the following can be stated:

- The growth of per-capita income is the largest contributor to the growth of CO_2 emissions in China. If the other factors had been kept constant, the CO_2 emissions would have increased by 2.8 billion tons.
- China's moderate population growth only contributed to a small degree to the increase in CO_2 emissions (370 million t).
- The negative effect of China's economic development on the CO_2 emissions was counterbalanced by energy efficiency improvements (-1.4 billion t) and to a lower degree by a reduction in the overall CO_2 intensity (-59 million t) via substitution of coal by lower-carbon fossil resources (natural gas or mineral oil) or non-carbon primary energy sources (nuclear energy, hydro-electric energy and other renewable energy sources).
- The decomposition of China's SO_2 emissions reveals a similar structure to that for CO_2. However, the impact of fuel substitution is much larger than for CO_2 because of the large difference in the SO_2 intensity for natural gas.

The relationship between economic development and emission levels is not linear over time, however, but follows a path which is commonly described by means of the Environmental Kuznets Curve. The U-shaped Environmental Kuznets Curve is the result of growing per-capita income, but decreasing CO_2 and SO_2 emissions, i.e. when the income elasticity of emissions is negative. This negative elasticity was the case for the years 1997 to 2000 with regard to CO_2 and SO_2 emissions in China.

The population, per-capita income, the total CO_2 or SO_2 intensity of energy use and the energy intensity of GDP all have a large influence on the shape of this curve, but there further factors are also identifiable that are not included in the calculation presented (prices, environmental policy, etc.). About 67% of the development of China's CO_2 emissions is explicitly influenced by the changes in energy intensity, CO_2 intensity, per-capita income and population. 23% of the emissions can only be explained by the joint effect.

In the past, there were various individual negative income elasticities of emissions in China (in 1957, 1963, 1968, 1976, 1980/81 and 1989). These may be interpreted as structural breaks, however. The development that took place between 1997 and 2000 was not the turning point of China's Environmental Kuznets Curve, although one might have expected this in 2001. Seen from the 2005 perspective, at least, the four-year negative elasticity was only a transitory phenomenon (i.e. a structural break as well). China is still on the upward part of its Environmental Kuznets Curve as its level of emissions and per-capita income are both increasing.

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