nzec carbon capture & storage

WP2 – Future Energy Technology Perspectives

2.1 Future Energy Service Demands

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1 Introduction

Coal is China's primary fuel for power generation and will almost certainly remain so for the foreseeable future. At present China's installed capacity of power generation plant totals about 700GWe with over 70% of that based on coal. By 2020, this is projected to rise to be nearly double and still dominated by coal. Although major programmes are in place in China to improve energy efficiency, to increase deployment of renewable energy technologies and to increase the installed capacity of nuclear plant, coal-fired power plant will continue to be built in large numbers for many years to come. An energy systems analysis exercise with application of China MARKAL model will be undertaken to provide a perspective on the energy technologies that may be deployed in China to 2050 to meet its energy needs. To achieve this target, energy service demand projection and technology assessment are undertaken firstly in order to provide updated input for the model.

Energy service demand projection mainly focuses on high energy-intensive industrial sectors such as iron & steel, cement, ammonia, and aluminium, and transportation sector. The main reasons to select these high energy-intensive sectors is they share around 40% of total final energy consumption in China and most of them are large stationary carbon emission sources which are attractive for CO2 capture. Although transportation now only shares 10% in the total final energy consumption, it is expected to increase fast in future. Due to shortage of oil in China, the oil import dependency is projected to exceed 60% by 2020. To ensure energy security, one of the main focuses of this study is to simulate poly-generation technology with capture to provide liquid synfuel or hydrogen from coal for the transportation sector. Therefore it is important to project future energy service demand for the transportation sector. Based on the historical data, the relationship between energy service demands and key factors such as GDP, population, industrial structure etc. will be analyzed. China now is experiencing industrialization; energy demand has increased dramatically in recent years. It is important to not only look at China's historical trend but also to compare them with OECD countries to see what lessons can be learnt. China's future energy service demands will be projected based on the aforementioned analysis and assumptions for future social and economic growth.

2 Analysis of China's Historical Energy Service Demands

2.1 Industry Sector

2.1.1 Iron and Steel

From 1978 to 2006, China's steel production increased from 31.78 million tonnes to 419.15 million tonnes, with an annual growth rate of 9.65% and the elasticity to GDP of 0.99. However, this growth process went through two different historical periods: from 1978 to 2000, the steel production grew in a steady phase, with an annual growth rate of 6.56 %, and the relative elasticity to GDP was 0.68; But from 2000 to 2006, steel output maintained a sustained and rapid growth, with an annual growth rate of 21.78%, the relative elasticity to GDP amounted to 2.15. Such a rapid growth in steel production was mainly because of urbanization and industrialization process step by step in recent years, leading to infrastructure construction, real estate and mechanical and electronic manufacturing developed in a high-speed. In terms of per capita output, China's per capita steel output rose from 0.03 tonnes in 1978 to 0.1 tonnes in 2000, and to 0.32 tonnes in 2006, with the average annual growth rate of 8.44% from 1978 to 2006. But the increase was 21.04 % between 2000 and 2006, much higher than that during the period 1978 to 2000 (5.23%).

Figure 2.1 The Historical Trend of China's Steel from 1978 to 2006

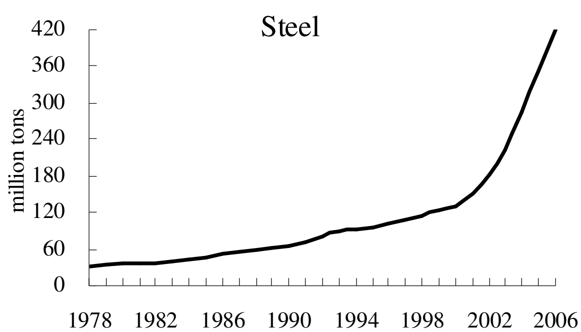
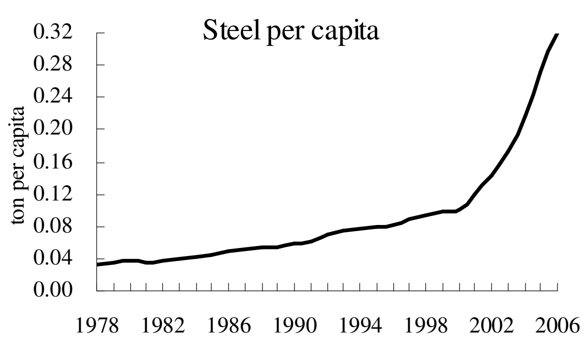


Figure 2.2 The Historical Trend of China's Steel per capita from 1978 to 2006



2.1.2 Cement

From 1978 to 2006, China's cement output increased from 65.24 million tonnes to 1236.76 million tonnes, with an annual growth rate of 11.08% and the elasticity to GDP of 1.14, very close to the world average stage. From 1978 to 2000, the annual growth rate of cement was 10.59%, and the elasticity to GDP was 1.1; and during the period of 2000 to 2006, the annual growth rate was 12.91 % and the elasticity to GDP was 1.27. In terms of per capita output, China's per capita output of cement increased from 0.068 tonnes per capita in 1978 to 0.471 per capita in 2000, and 0.941 per capita in 2006, with the average annual growth rate of 9.21 % during 1978 to 2000, 12.22% from 2000 to 2006 and 9.85% on average from 1978 to 2006.

Figure 2.3 The Historical Trend of China's Cement from 1978 to 2006

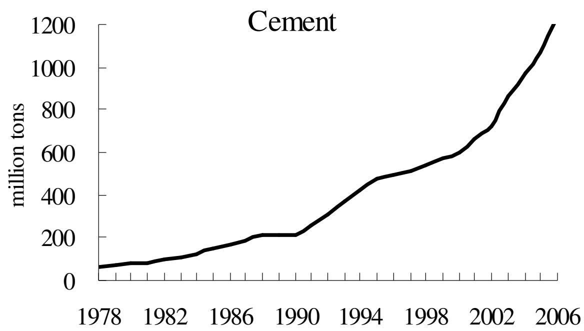
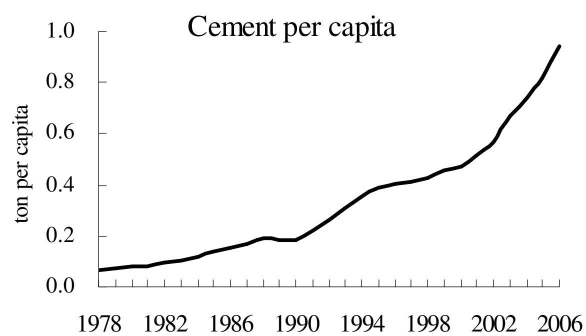


Figure 2.4 The historical trend of China's cement per capita from1978 to 2006



2.1.3 Ammonia

China's annual output of ammonia was 49.37 million tonnes in 2006, making it the highest globally. The ammonia per capita output was 37.56kg, similar to the world's average level. During 1978 to 2000, the annual growth rate of ammonia was 4.86%, with the elasticity to GDP of 0.51; while from 2000 to 2006, the annual growth rate was 6.6% and the elasticity to GDP was 0.65. From 1978 to 2006, the annual growth rate was 5.23 %, and the elasticity to GDP was 0.54. In terms of per capita output, from 1978 to 2006 China's per capita production of ammonia increased from 12.29kg per capita to 26.54kg per capita in 2000, and till 2006 it reached 37.56 kg per capita. From 1978 to 2006, the annual growth rate was 4.07%, while it was 3.56% for the period of 1978 to 2000, and 5.96% for the period of 2000 to 2006.

Figure 2.5 The Historical Trend of China's Ammonia from 1978 to 2006

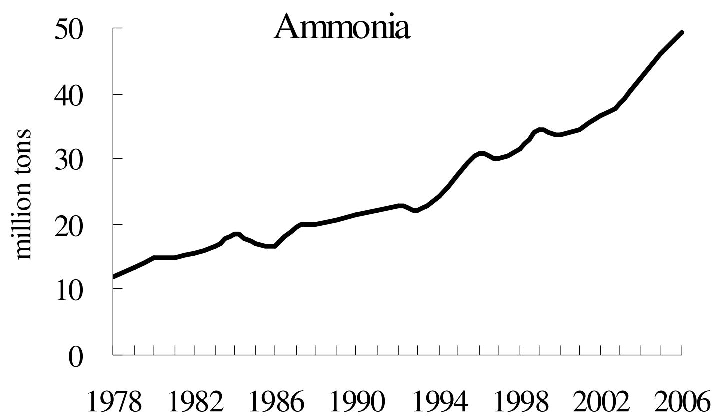
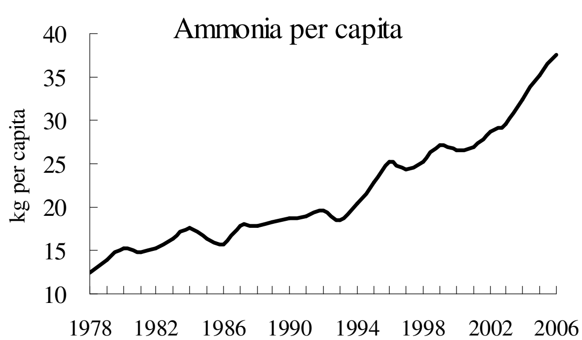


Figure 2.6 The Historical Trend of China's Ammonia per capita from 1978 to 2006



2.1.4 Aluminium

From 1978 to 2006, China's electrolytic aluminium output increased from 300 tonnes to 9.35 million tonnes, with an annual growth rate of 13.07% and the elasticity to GDP of 1.35. China became the world's largest aluminium producer in 2002. In the same way as the growth of the iron and steel industry, the growth of electrolytic aluminium experienced two different historical periods: it kept a steady growth from 1978 to 2000, with an annual growth rate of 11.01% and the elasticity to GDP of 1.15; it entered a rapid growth phase from 2000 to 2006, with an annual growth rate of 11.01% and the elasticity to GDP of 2.07. From 1978 to 2000, China's electrolytic aluminium output per capita increased from 0.31 kg per capita to 2.36 kg per capita, and it reached 7.11 kg per capita till 2006. From 1978 to 2006, the annual growth rate of aluminium production per capita was 11.82□. The annual growth rate from 1978 to 2000 was 9.63%, and 20.21% from 2000 to 2006.

The rapid growth of aluminium production led to a great pressure on energy and raw materials. Therefore, since 2005 Chinese government has taken a series of macro-control policies, including abolishment of the export tax rebate and imposing export tariff of 5% for aluminium. These macro-control policies would certainly have a deterrent effect on aluminium production growth to a certain extent. However the rapid development of automobile industry etc. led to a strong demand for aluminium in the domestic market. Therefore, aluminium output per capita still maintained a rapid growth in recent years, and narrowed the gap between China and the world average rapidly.

Figure 2.7 The Historical Trend of China's Aluminium from 1978 to 2006

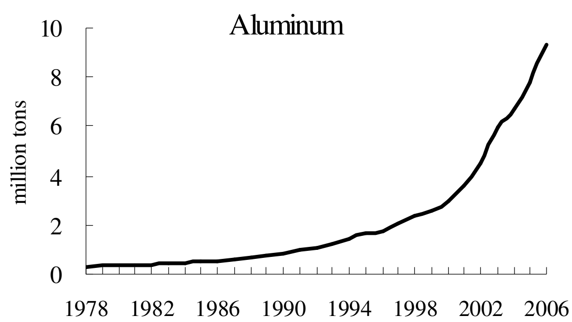
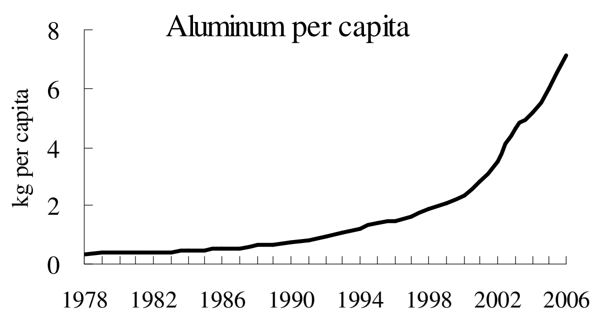


Figure 2.8 The Historical Trend of China's Aluminium per capita from 1978 to 2006



2.1.5 Paper

From 1978 to 2006, China's paper and paperboard production increased from 4.39 million tonnes to 68.63 million tonnes, with the elasticity to GDP of 1.06 and an annual growth rate of 10.32%, significantly higher than that of developed countries of 1.1% -2.9%. Similar to the iron and steel and the electrolytic aluminium industries, the growth of paper and paperboard production also went through two different historical periods: from 1978 to 2000, paper and paperboard production stayed in a steady growth stage with an annual growth rate of 8.2 % and the elasticity to GDP of 0.85. During 1995 to 2000, China's paper and paperboard production was even on a downward trend, and the elasticity to GDP was actually -0.28%. This was mainly because of the closing of many small paper mills in the period of "Ninth Five-Year Plan", in order to control water pollution. At the same time, due to the success of China's accession to WTO, a large amount of imported paper and paperboard came on to the market. From 2000 to 2006, due to the strong demand for paper products, the government started to support the development of the forest and paper industry again, the China's paper and paperboard rushed into a rapid growth phase with an annual growth rate of 18.43%, and the elasticity to GDP was as high as 1.82. China's paper and paperboard production per capita increased from 4.56 kg per capita in 1978 to 19.62 kg per capita in 2000, and 52.21 kg per capita in 2006, reaching the world's average level currently with the annual growth rate of 9.1%. While from 1978 to 2000, the annual growth rate was 6.86 %, and it was 17.72% from 2000 to 2006.

Figure 2.9 The Historical Trend of China's Paper from 1978 to 2006

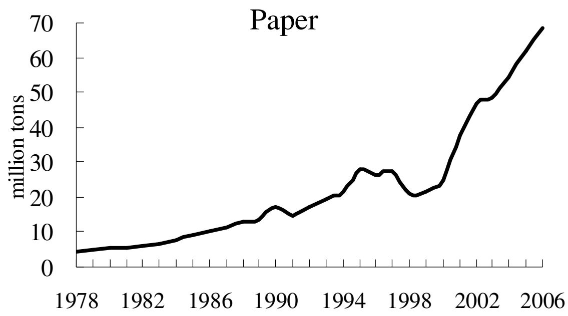
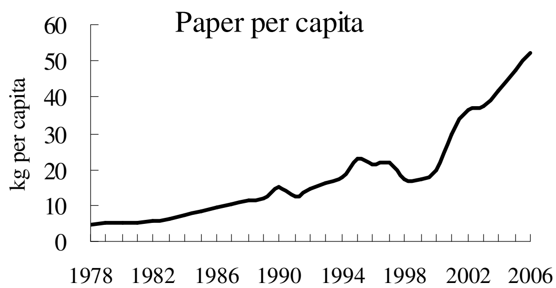


Figure 2.10 The Historical Trend of China's Paper per capita from 1978 to 2006



2.2 Transportation Sector

2.2.1 Passenger Transportation

2.2.1.1 Total

Over the past 28 years, while China's personal mobility grew rapidly, public transport infrastructure has struggled to keep pace. Passenger volume increased from 174.31 billion p•km to 1919.72 billion p•km with the annual growth rate of 8.95 % and the elasticity to GDP of 0.92 during 1978 to 2006. From 2000 to 2005, the elasticity to GDP was 0.74, while it was as high as 1.07 from 2003 to 2006. In term of passenger transport per capita, from 1978 to 2006, passenger transport per capita increased from 180 p•km per capita to 1460 p•km per capita, and the annual growth rate was 7.74%. Through constant adjustment, China's passenger transportation mix has changed a lot, as shown in fig 2.11.

Figure 2.11 Passenger Transportation Mix from 1978 to 2006

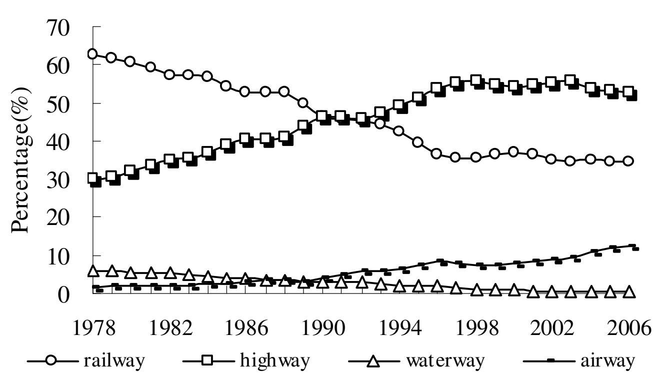


Figure 2.12 The Historical Trend of China's Passenger Transport from 1978 to 2006

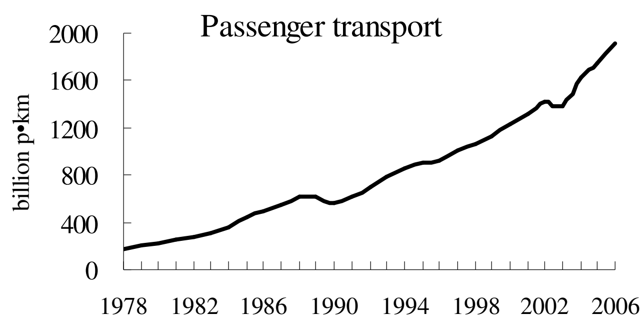
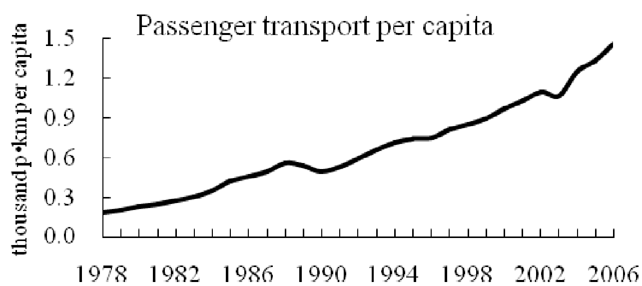


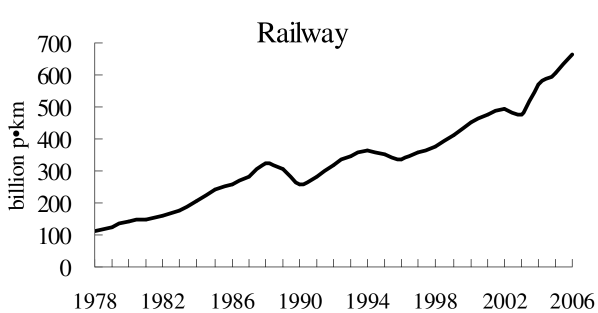
Figure 2.13 The Historical Trend of China's Passenger Transport per capita from 1978 to 2006



2.2.1.2 Railway

Over the past 28 years, China's railway passenger transport was facing fierce competition from airway and highway, but it continued to have an advantaged role in the long-distance passenger transport, maintaining a certain growth speed. From 1978 to 2006, railway passenger transport rose from 109 billion p•km to 662 billion p•km, with the annual growth rate of 6.64%, but the proportion of railway in the total passenger transportation fell from 62.72% to 34.50% gradually.

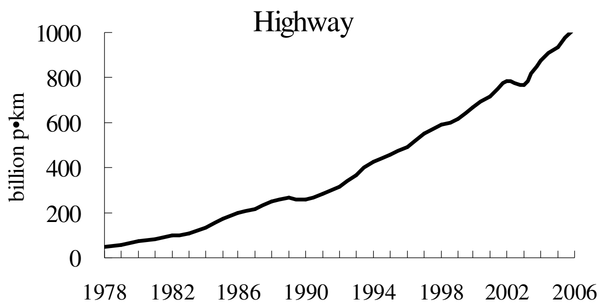
Figure 2.14 The Historical Trend of China's Railway Passenger Transport from 1978 to 2006



2.2.1.3 Highway

From 1978 to 2006, China's highway transport maintained a rapid growth rate, and there was a general shift for short-distance passenger transport into personal modes of road transportation. Over the past 28 years, highway passenger transport grew rapidly from 52 billion p•km to 1013 billion p•km, with the annual growth rate of 11.18%. And the share of highway in the total passenger transport climbed from 29.91% in 1978 to 52.77% in 2006.

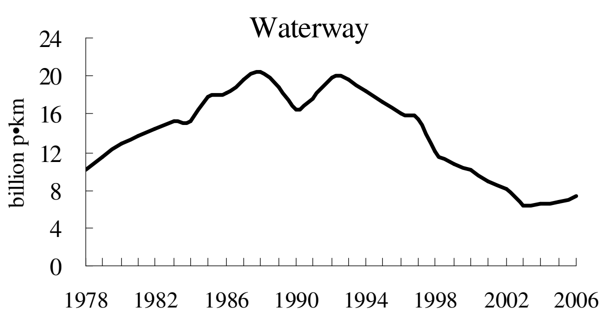
Figure 2.15 The Historical Trend of China's Highway Passenger Transport from 1978 to 2006



2.2.1.4 Waterway

From 1978 to 1988, passenger transport by waterway increased from 10.1 billion p•km to 20.4 billion p•km, with the annual growth rate of 7.32%. But since 1988, the waterway passenger transport sector lost its advantage gradually, and both its absolute amount and proportion of waterway in the total passenger transport showed a downward trend gradually. In 2000, waterway passenger transport returned to the levels in 1978, even fell to 7.4 billion p•km in 2006. From 1978 to 2006, water passenger transport reduced at an average annual rate of 1.11%, and it declined at the rate of 5.51% from 1988 to 2006. Accordingly, the proportion of the total passenger transport declined from 5.77% in 1978 to 0.38% in 2006, declining 9.23% each year.

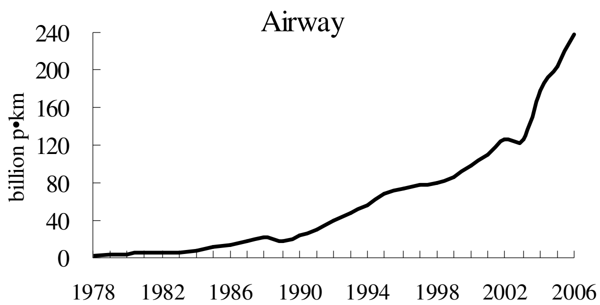
Figure 2.16 The Historical Trend of China's Waterway Passenger Transport from 1978 to 2006



2.2.1.5 Air Travel

Over the past 28 years, with its significant advantages of comfort and speed, air passenger transportation grew rapidly, in particular since 2003. During 1978 to 2003, air passenger volume increased from 2.8 billion p•km to 126.3 billion p•km, with an annual growth rate of 16.47%; but during 2003 to 2006, this rate reached as high as 23.35%, and air passenger transport reached 237.1 billion p•km in 2006. The annual growth rate was as high as 17.19 % during 1978 to 2006. Accordingly, the proportion of airway in the total passenger transport rose from 1.6 % in 1978 to 12.35 % in 2006.

Figure 2.17 The Historical Trend of China's Air Passenger Transport from 1978 to 2006



2.2.2 Freight transportation

2.2.2.1 Total freight

From 1978 to 2006, China's freight transport grew from 982 billion t•km to 8895 billion t• km, with an annual growth rate of 8.18 % and the elasticity to GDP of 0.84. Since 2003, freight transport grew rapidly; the annual growth rate during 2003 to 2006 was up to 18.2%. From 2000 to 2005, freight transport elasticity to GDP was 1.27, and it was 1.67 from 2003 to 2006, significantly higher than GDP growth. However, from 1978 to 2003, the freight transport per GDP declined steadily from 6.2 t•km/$ to 3.4 t•km/$, reaching the lowest level in history. Because of the rapid increase of the total freight transport in recent years, the freight transport per GDP increased and reached 4.2 t•km/$ in 2006. Due to the different characteristics of the various modes of goods' transportation, there is a big difference in the proportion of different transportation modes. The transport structure changed a lot through the adjusting and optimizing of the freight system continuously, as shown in figure 2.18.

Figure 2.18 The Variation of China's Passenger Traffic Structure from 1978 to 2006

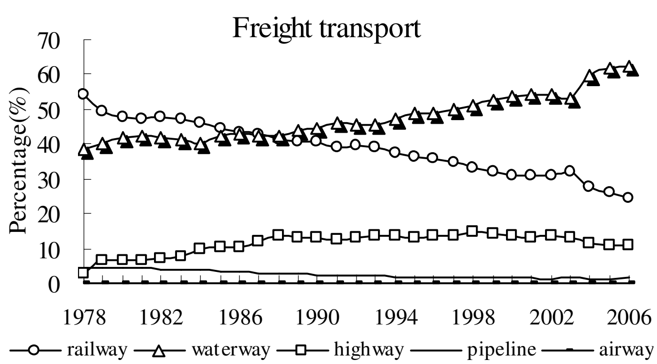


Figure 2.19 The Historical Trend of China's Freight Transport from 1978 to 2006

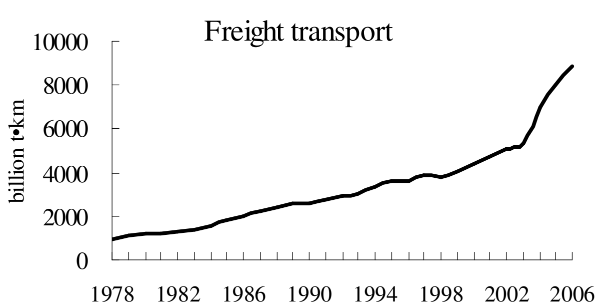
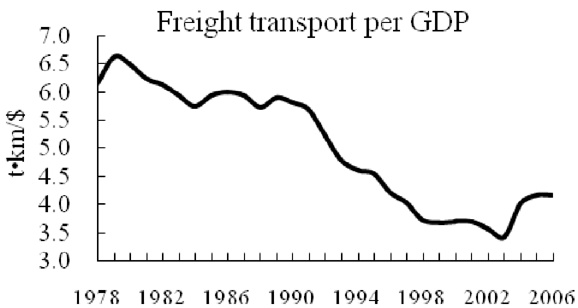


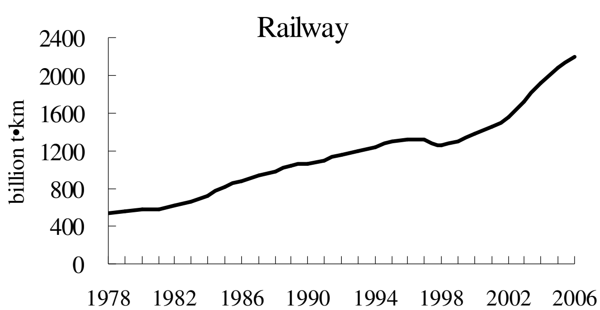
Figure 2.20 The Historical Trend of China's Freight Transport per GDP from 1978 to 2006



2.2.2.2 Railway Freight

It can be seen from the Figure 2.18 that railway transport was being displaced by water transport in the past 28 years. From 1978 to 2006, the railway freight transport grew from 534 billion t•km to 2195 billion t•km, with an annual growth rate of 5.18%. But its proportion of total transport reduced from 54.38% in 1978 to 24.68% in 2006.

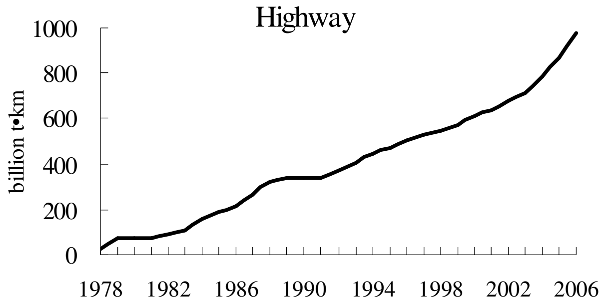
Figure 2.21 The Historical Trend of China's Railway Freight Transport from 1978 to 2006



2.2.2.3 Highway Freight

From 1978 to 2006, highway transport maintained a comparatively high growth rate and occupied the greater part of the rapid transport market with its advantages of flexibility. Over the past 28 years, the highway freight transport grew rapidly from 27 billion t•km to 975 billion t•km, with an annual growth rate of 13.61%, but the proportion of highway in total freight transport was rising steadily. From 1978 to 2006, it rose from 2.79% to 10.97%. In 1998, it reached the highest value of 14.4%. Nevertheless, China's highway freight transport in the proportion of the total freight transport is still far lower than developed countries.

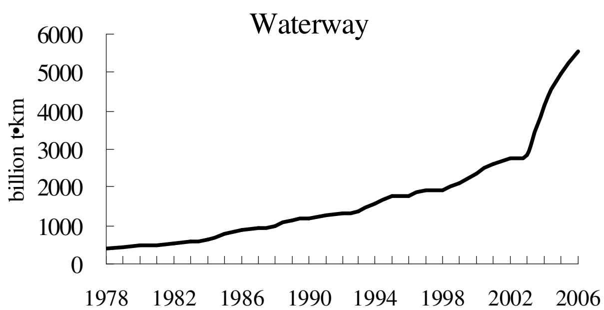
Figure 2.22 The Historical Trend of China's Highway Freight Transport from 1978 to 2006



2.2.2.4 Waterway Freight

From 1978 to 2006, China's water freight transport grew rapidly from 378 t•km to 5549 t•km, with an annual growth rate of 10.07%, higher than the freight transport growth in the same period. Particularly since 2003, the water freight transport grew much rapidly, and the annual growth rate of freight transport from 2003 to 2006 was as high as 24.55%. Accordingly, the water transport in the proportion of the total freight transport climbed rapidly in recent years, from 38.45% in 1978 to 53.55% in 2000, and 62.38% in 2006.

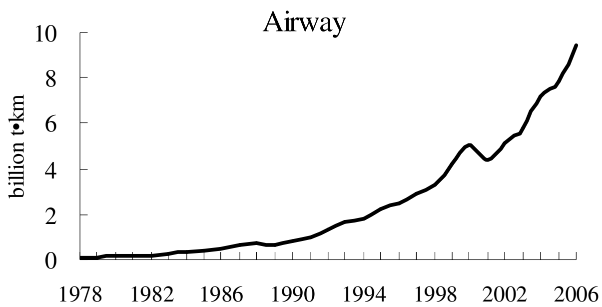
Figure 2.23 The Historical Trend of China's Waterway Freight Transport from 1978 to 2006



2.2.2.5 Air Freight

Over the past 28 years, China's air freight transport grew rapidly due to the rapid development of shipping containers. From 1978 to 2006, the annual growth rate of air freight transport was 17.76 %. And during 1978 to 2000, air freight transport grew rapidly from 0.1 billion t•km to 5 billion t•km, with an annual growth rate of 19.66 %; and reached 9.4 billion t•km till 2006. The annual growth rate during 2000 to 2006 declined slightly, but it still reached 11.05%. Accordingly, from 1978 to 2006, airway the proportion of freight transport in the whole rose gradually from 0.01% to 0.11%. During this period, it reached the same peak respectively at 2000 and 2003. But compared to other transport modes, the proportion of airway freight transport is still very low.

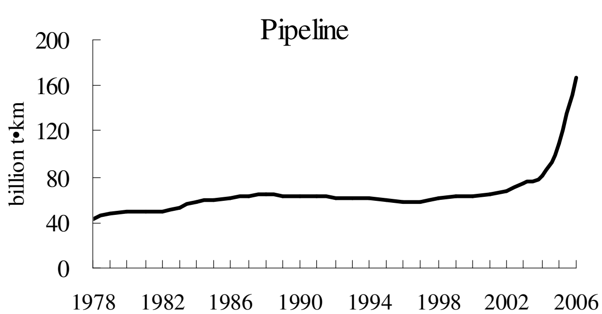
Figure 2.24 The Historical Trend of China's Air Freight Transport from 1978 to 2006



2.2.2.6 Pipeline

From 1978 to 2006, the proportion of China's pipelines in the freight transport declined every year, from 4.37□ in 1978 to 1.87□ in 2006. Before 2003, the pipeline grew slowly, from 43 t•km in 1978 to 73.9 t•km in 2003, with the annual growth rate of 2.19%. But since 2003, the pipeline freight transport has grown rapidly, reached 166.4 t•km in 2006, and the annual growth rate of freight transport was as high as 31.07% from 2003 to 2006. Accordingly, the annual growth rate from 1978 to 2006 increased to 4.95%.

Figure 2.25 The Historical Trend of China's Pipeline Freight Transport from 1978 to 2006



2.2.3 Summary

In all sectors analysed in China a similar pattern of growth has been observed, with gradual growth from 1978 to the mid 1990 followed by exponential growth up until the end of the period (2006). This reflects the rapid economic expansion in China during this period. The next section reviews, for similar sectors, the growth trends in some selected OECD countries.

3 Analysis of Historical Energy Service Demands in Selected OECD Countries

To project China's future energy service demand for different end-use sectors, it is important to not only look at China's historical trend but also to compare them with OECD countries to see what lessons can be learnt. A review of both macroeconomic trends and historical energy service demands in selected OECD countries is now presented for different end-use sectors. The relationship between energy service demand and key impact factors is analyzed.

The analysis covers a number of OECD countries. From Europe, the UK, Germany and Italy were chosen as some of Europe's larger economies covering a similar period to that analysed in the Chinese data in Chapter 2. Where possible data from earlier periods was also chosen as the growth transitions currently taking place in China is more comparable to the historical situation in OECD countries as opposed to the current one. The analysis also considers some of the larger economies of USA and Japan which in some respects have shown a similar industrialization path to China's recent growth trend.

3.1 Economic Growth

Table 3.1 and Figures 3.1-3.3 show the macroeconomic trends over the period 1980-2006 for Germany, UK and Italy. All figures are indexed against 1990 values. Gross Domestic Product (GDP) represents the output of the whole economy and the sector specific measures used are:

- Private Consumption of households
- Value added of industry
- Value added of agriculture
- Value added of tertiary sector

Table 3.1 Overall and sectoral economic growth

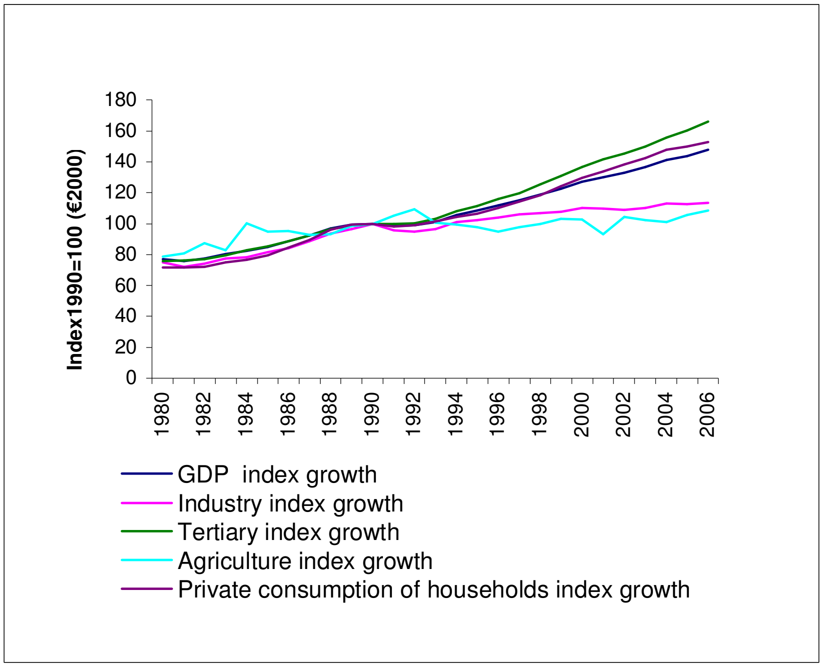
Overall and sectoral economic growth (% per year)

	1980-2006 UK	1990-2006 UK	1990-2006* Germany	1980-2006 Italy	1990-2006 Italy
GDP	3.53%	2.98%	1.72%	2.23%	1.53%
Industry	1.97%	0.85%	0.45%	1.40%	0.78%
Tertiary	4.59%	4.13%	2.81%	-0.01%	-0.02%
Agriculture	1.45%	0.54%	-0.88%	1.51%	1.36%
Households	8.20%	3.29%	1.33%	2.29%	1.47%

Source: Odyssee (http://www.odyssee-indicators.org/)

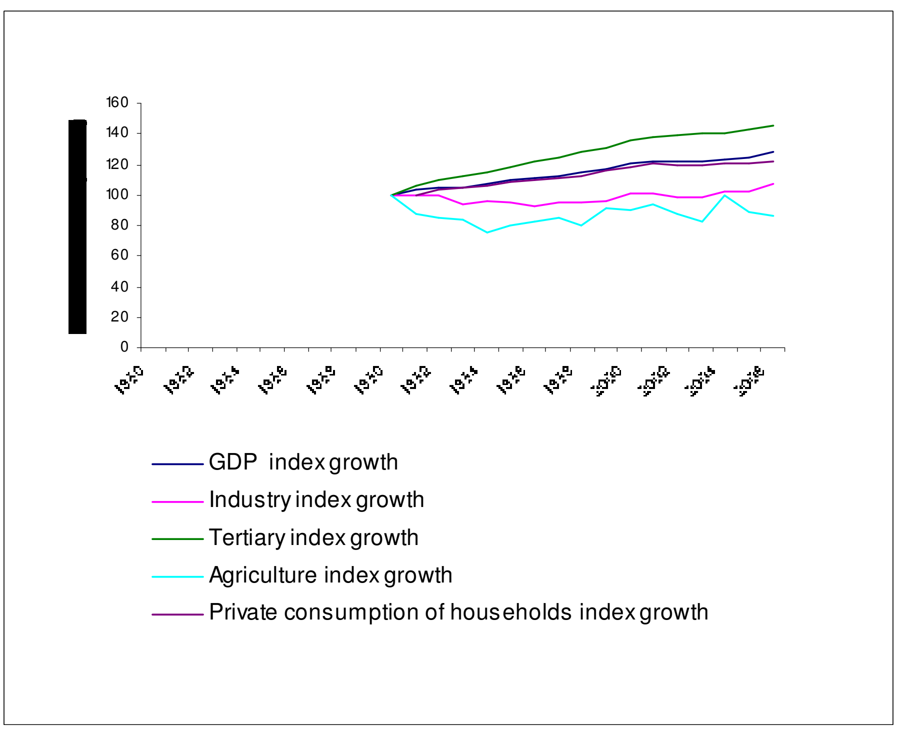
*Data prior to 1990 was not available

Figure 3.1 Macroeconomic Developments in the UK 1980-2006



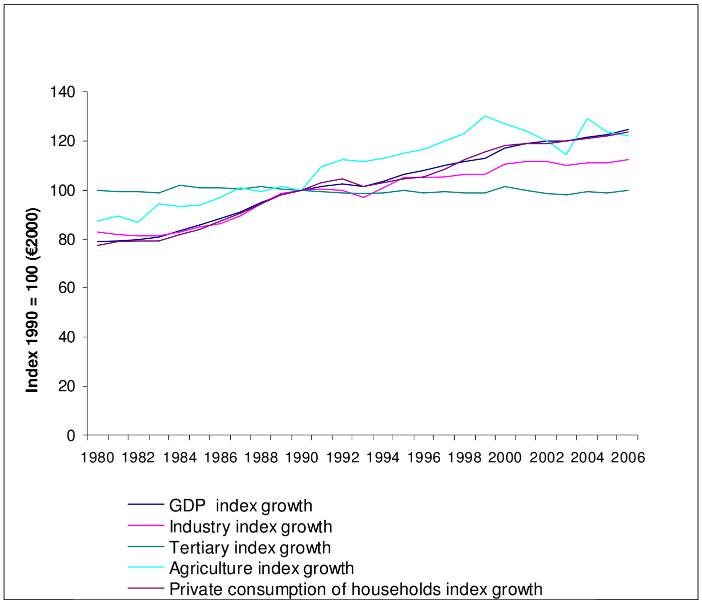
GDP has grown in the UK from the mid 1990's to 2006; this followed a slight fall in the very early 1990's due to a recession. The growth in the household sector has followed this trend, however industrial growth has been significantly slower over the period. There has been a shift in the UK towards a service economy as manufacturing and heavy industry move to countries that have lower labour costs, this is reflected in the greatest growth being seen in the Tertiary sector, which averaged 4.59% per year from 1980-2006. The agricultural sector has a net increase of just 0.54%, and there is a dip in agricultural output in 2001 due to the foot and mouth epidemic.

Figure 3.2 Macroeconomic Developments in Germany 1990-2006



GDP in Germany stagnated between 2001 and 2003; however it has increased again since 2004. The average growth rate of GDP has been around 1.7 % between 1991 and 2006. The private consumption of households increased during the 1990s, however German analysts observe that it has been more or less constant since the beginning of the century. They conclude this means that up to now, private consumption did not contribute to the rising growth of GDP, and observe that the growth is mainly triggered by exports. The agricultural sector in Germany has also faced a challenging 15 years with a -0.88% rate per year over the period, due to a large dip in 2003. The sector with the greatest growth rate is the tertiary sector. The industrial sector grew by an average of only 0.45%.

Figure 3.3 Macroeconomic Developments in Italy 1980-2006



Over the period 1980-2006 GDP has grown at an average of 2.23%. The private consumption shows the same trend of GDP: in the period 1980-2006 the increase was 2.29%. There has been low growth in both the tertiary and the industry sector, and erratic growth in the agricultural sector.

Figure 3.4 shows the trend in US GDP from 1900-2006. The average growth in the USA is provided in Table 3.2 below.

Figure 3.4 USA GDP per capita

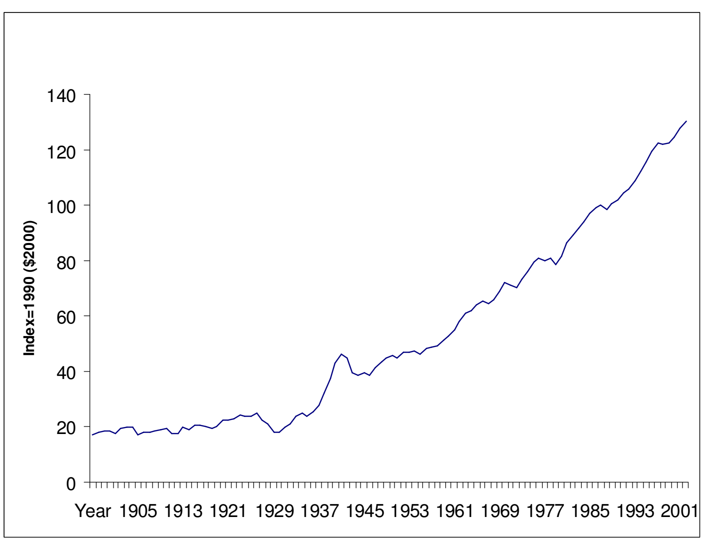


Table 3.2

Overall and sectoral economic growth (% per year)

	1980-2006 USA	1990-2006 USA
GDP	2.54%	2.03%

Since the early 1950's there has been overall growth the USA economy, growth averaged 2.54% per year from 1980-2006, however this has slowed over the more recent period of 1990-2006.

A comparison between the US and Japan shows similar trends in GDP between 1950 and the present (Figure 3.5). Each country showed approximately exponential growth since 1950. Japan showed the higher rate of growth before ~1990, departing from the exponential trend after that.

Figure 3.5 Annual GDP as a percentage of GDP in 1990, index 1990

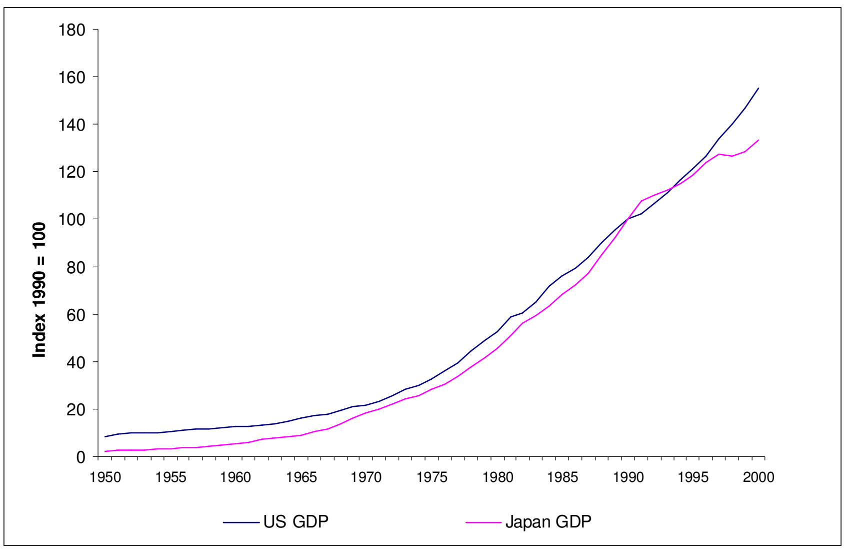


Figure 3.6 Household consumption in US and Japan

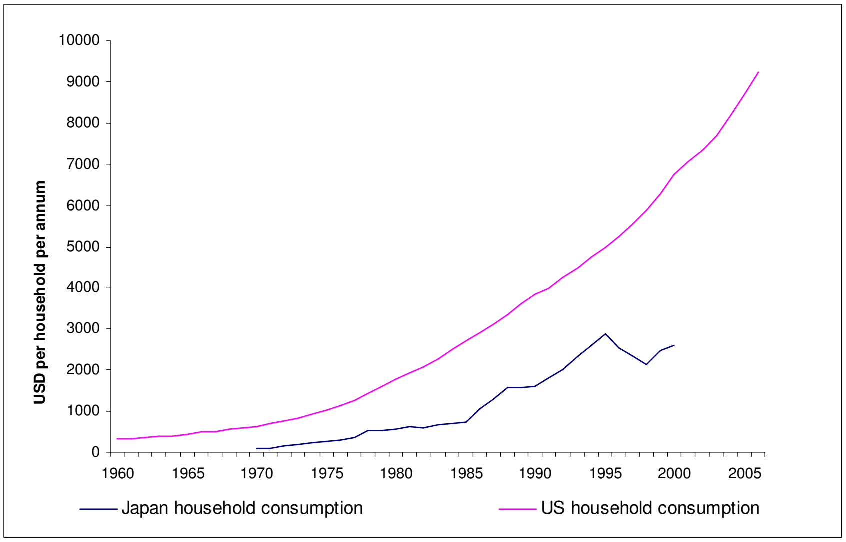
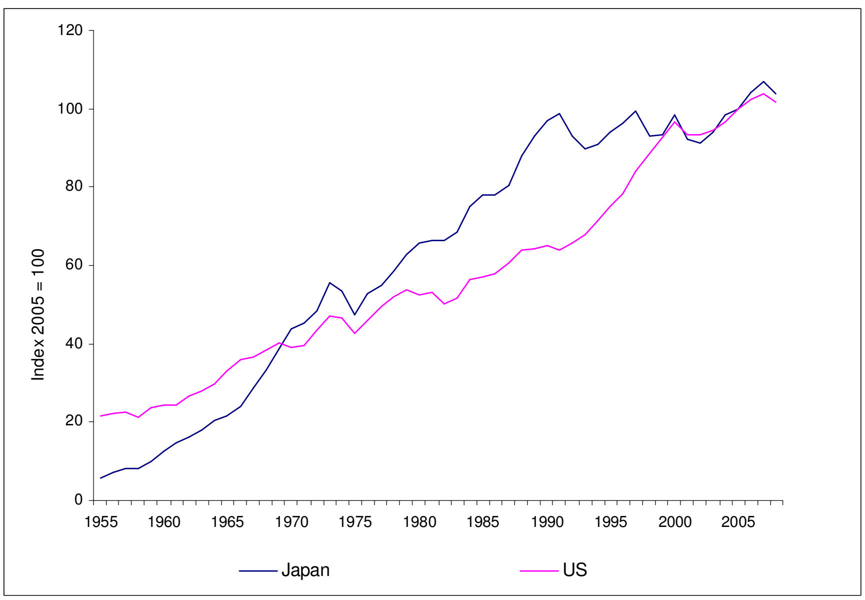


Figure 3.6 shows total consumption per household in USD; US data shows exponential growth averaging 7.5% for the period, and in excess of 10% per annum between 1973 and 1983; Japanese data shows departure from exponential trend at ~1995.

Figure 3.7 Industrial growth in US and Japan[1]

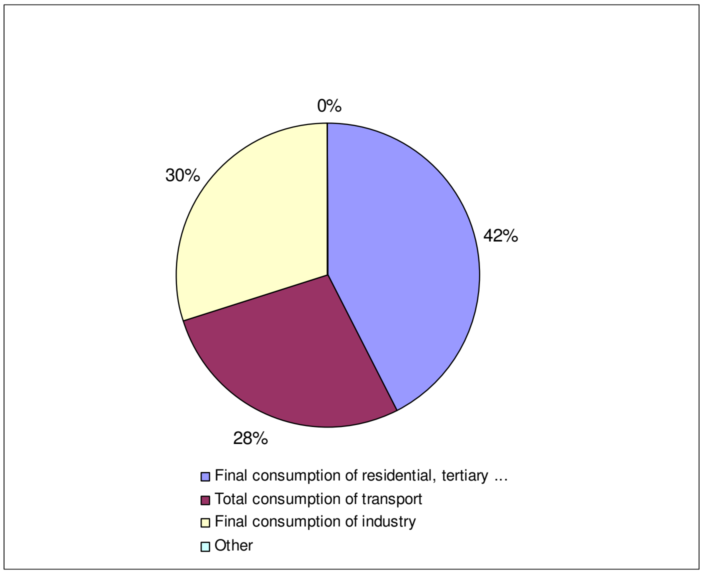


Industrial production as a percentage of 2005 shows similar trends for the US and Japan however there are some differences to note. The US shows gradual increase until mid 1990s when growth was more rapid before slowing since around 2000. Japan meanwhile showed more rapid growth than the US up to 1990 since when its growth has fluctuated.

[1] Source: Organization for Economic Cooperation and Development, Main Economic Indicators

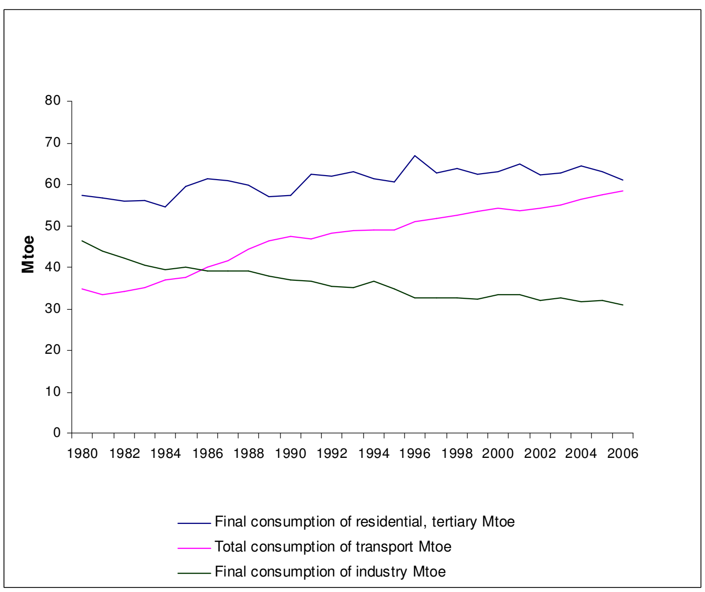
3.2 Final Consumption by End Use Sector in 2006

Figure 3.8 Final Energy Consumption by end use sector in Germany 2006



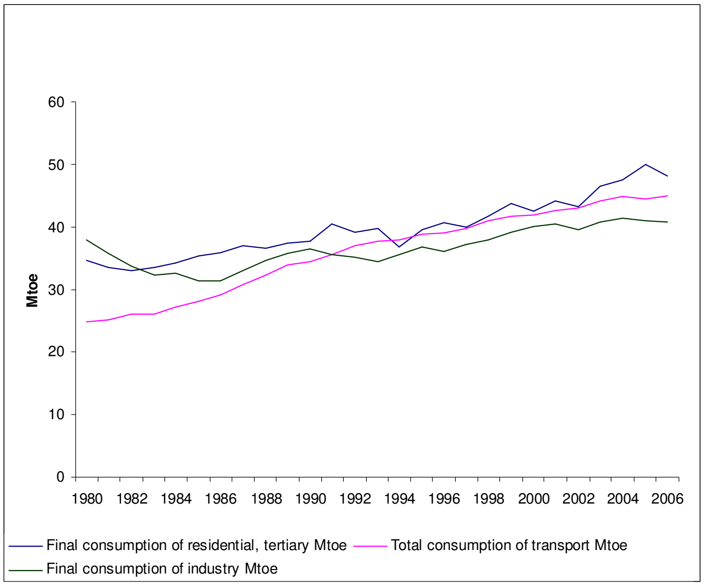
In Germany total energy consumption was 228 Mtoe in 2006, which is only slightly higher than the 226 Mtoe in 1990. An increased in consumption with the transport sector was responsible for the rise while the industrial sector share declined slightly.

Figure 3.9 Final Energy Consumption by End Use Sector: UK 1980-2006



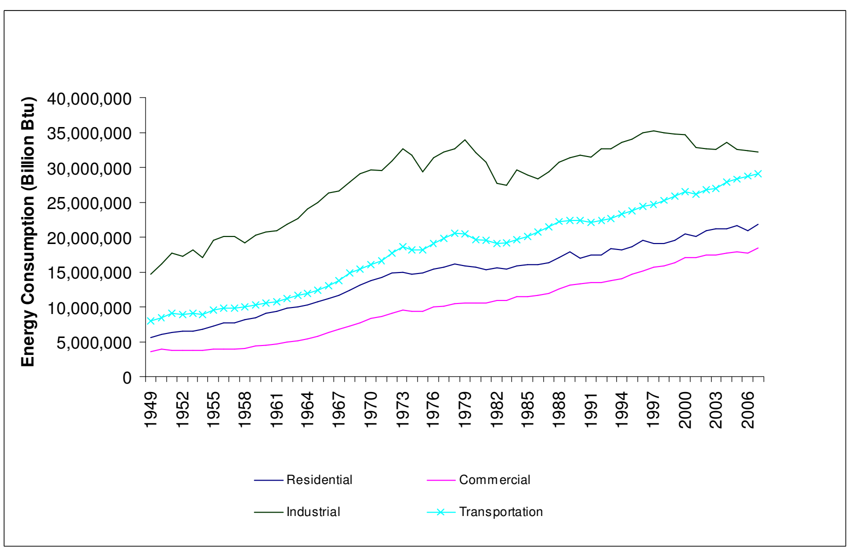
In the UK there was a slight increase in total energy consumption in 2004 and 2005, however in 2006 there has been a slight fall to 150.5 Mtoe. The household and transport sectors account for the largest proportion of energy consumed, while industry remains around 20%.

Figure 3.10 Final Consumption by End Use Sector: Italy 1980-2006



In 2004 in Italy the final energy consumption remained stable around 135 Mtoe. The transport sector had a constant growth while the other sectors were more dependent on the economic situation over the period. The tertiary sector showed the highest growth, followed by transport sector and households. Industry and agriculture showed the lowest increase.

Figure 3.11 US Final Energy Consumption by Sector, 1949-2007[2]



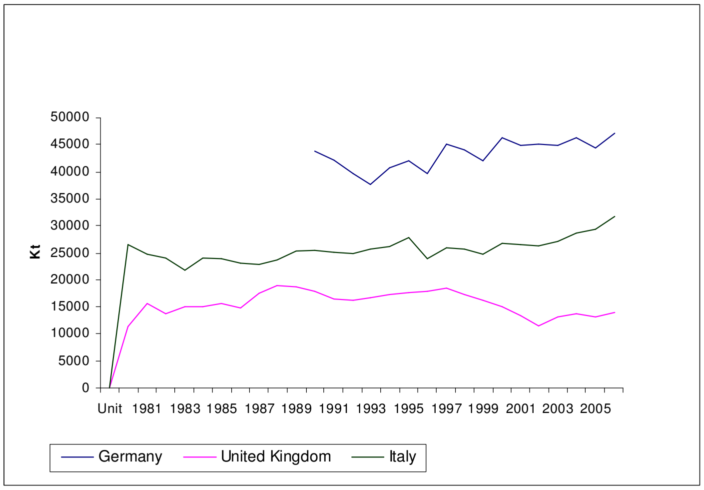
Industrial energy consumption dominates energy use in the US. However the gap between industrial energy use and the other sectors has reduced in recent years. Residential and commercial sector consumption rose steadily over the period whilst transportation energy consumption has continued to rise more rapidly. Industrial consumption appears to peak during the 1970s followed by a decline and more recent levelling off.

[2] Energy Information Administration

3.3 Steel Sector

3.3.1 Germany, Italy and UK

Figure 3.12 Steel Production in Germany, Italy and UK 1980- 2006



In Germany there has been a very gradual slight increase in production over the period since 1990, however there have been year to year fluctuations. In the UK, the period 1980-2006 overall, has seen a decline in steel production; however since 2002 steel production is gradually increasing. In comparison to other countries the UK has a very small steel industry. In Italy, since 2000, steel production has started to increase.

Figure 3.13 Steel per capita in Germany, Italy and UK

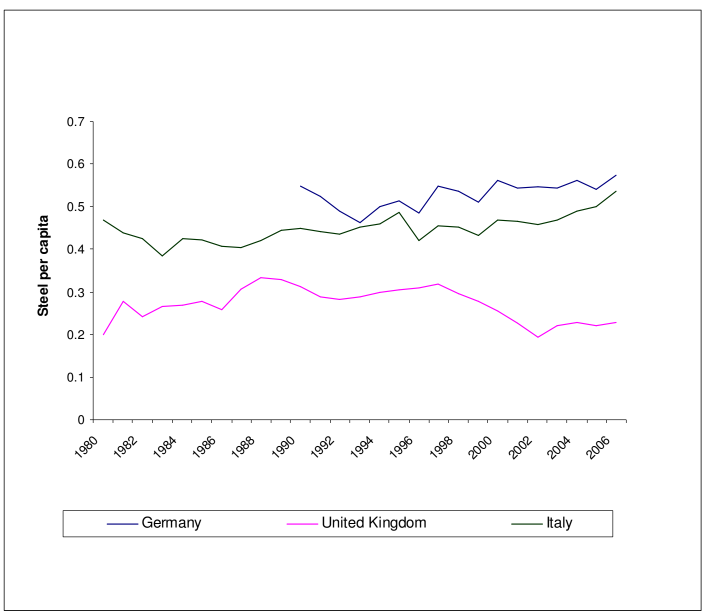
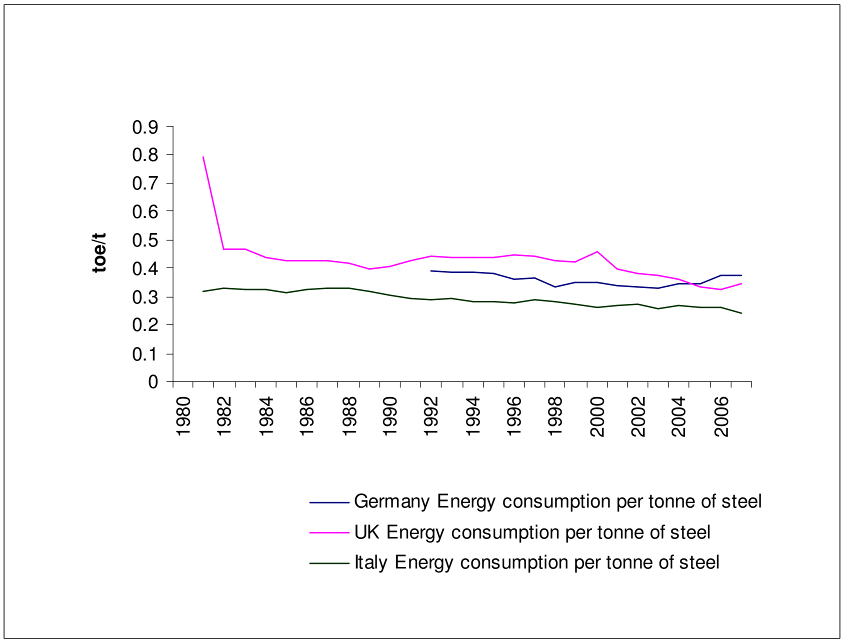


Figure 3.14 Energy Consumption per tonne of steel

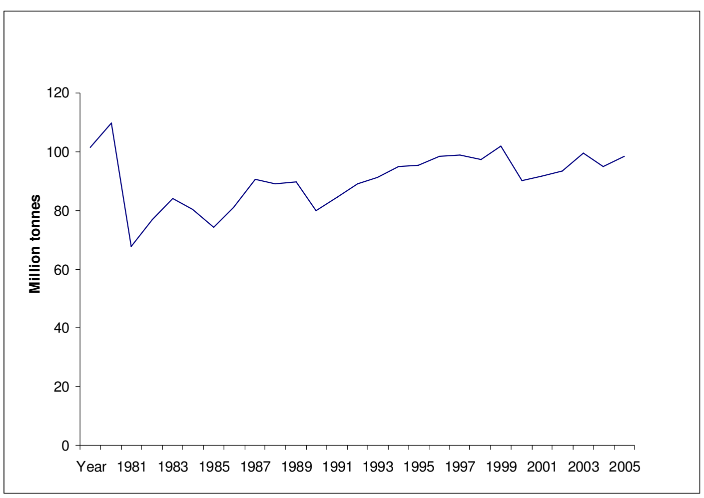


Energy consumption per tonne of steel fell in Germany from 1990 to 2003, to 0.33 per tonne of steel. However from 2004 there has been an increase in unit energy consumption. The UK's unit energy consumption per tonne of steel is higher than the EU average. This has gradually declined over the period. Most steel produced in the UK using the Basic oxygen process which uses more energy than electric arc process, which is used in other countries. In 2007 the UK produced 11.3 million tonnes using the basic oxygen process and only 3 million tonnes using electric arc.

Italy has a lower energy consumption per tonne of steel compared to Germany and the UK. Between 1980 and 1990 this was just above 0.3, and since the early 1990's it has been below 0.3.

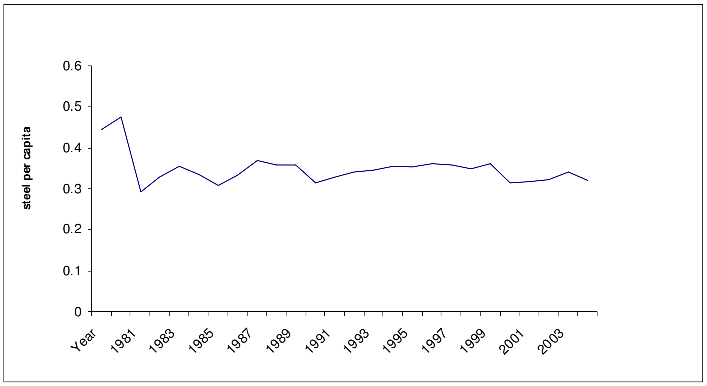
3.3.2 USA

Figure 3.15 USA: Steel Production



Steel production in the USA fell in 1982 to 64 million tonnes from over 100 million tonnes in 1981. Since then steel production has been gradually increasing over the period, fluctuating just below 100 million tonnes. However as can be seen from Figure 3.16 steel production per capita has not followed this trend since 1982 with production levelling to around 0.3 tonnes per capita. Note that this is comparable to China's current level (2006) of steel use per capita (see Figure 2.2).

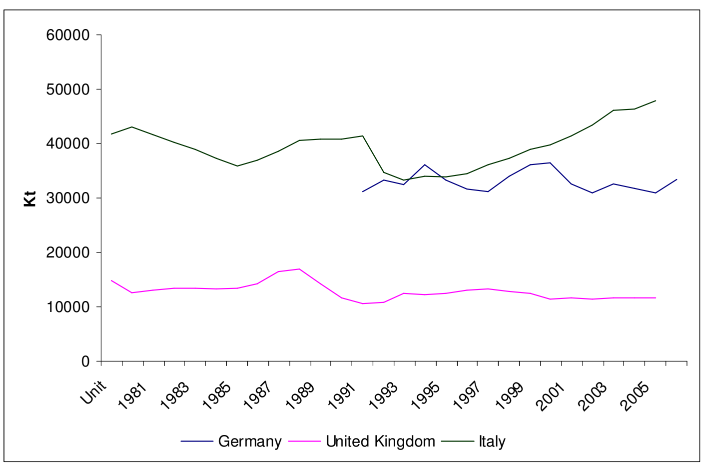
Figure 3.16 USA: Steel production per capita



3.4 Cement Sector

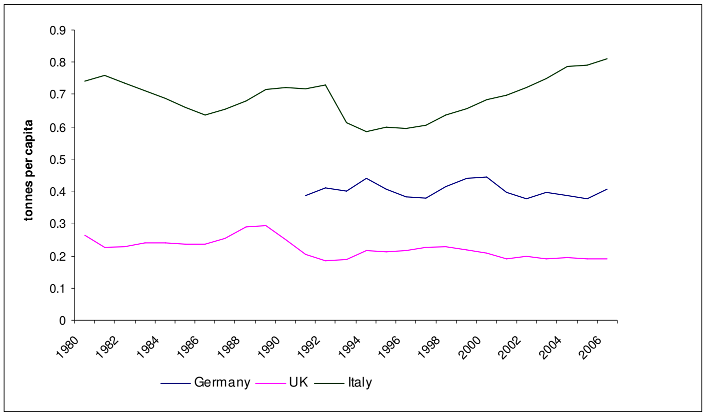
3.4.1 Germany, Italy and the UK

Figure 3.17 Production of Cement: Germany, Italy and the UK



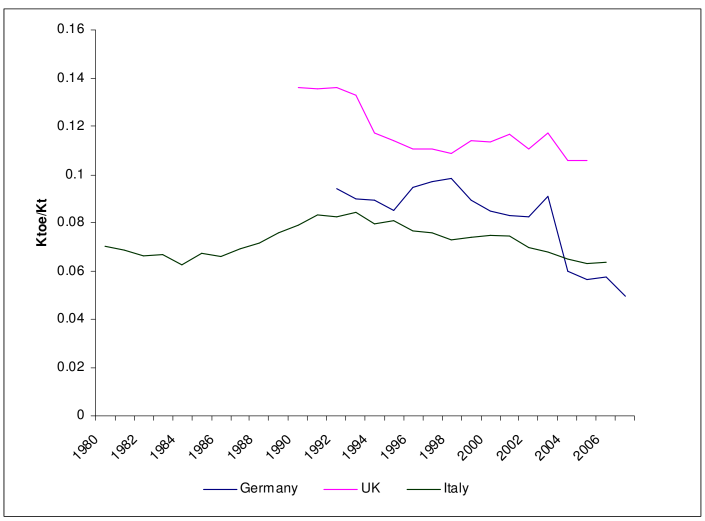
Germany's cement production has been between 30000 kt and 36000 kt since 1991. The UK's cement production is relatively lower and since 1991 has been just above 10000 kt. Italy's cement production has fluctuated more over the period, reaching a low of 35000 kt in the mid 80's and the early 90's. These dips in production could be due to wider economic reasons. Since the early 1990's however production has been steadily increasing, and was just under 50000kt in 2006.

Figure 3.18 Cement Production per capita: Germany, Italy and UK



Germany's cement production per capita has fluctuated between 0.6 and 0.75 since 1980 rising more recently to 0.8 tonnes/capita. Production in the UK in comparison is quite low and has been gradually declining to under 0.2 tonnes per capita in recent years.

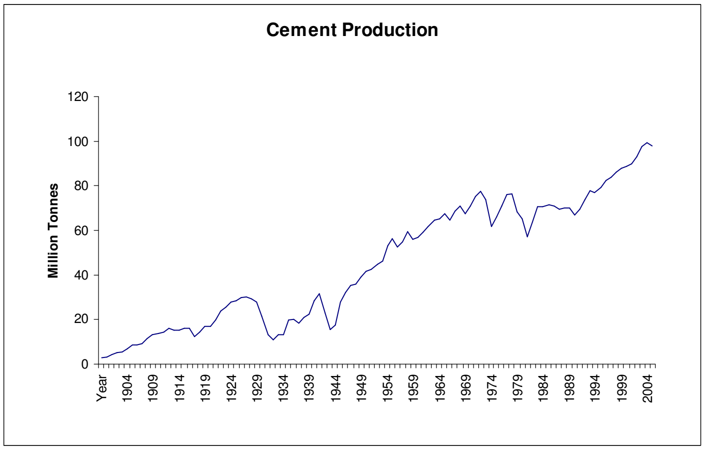
Figure 3.19 Energy Consumption per tonne of Cement: Germany, Italy and UK



The energy consumption per tonne of cement in Germany has fallen since 2002, and in 2006 was around 0.05. The UK has higher unit consumption per tonne of cement than EU-27 average. The cement industry is energy intensive mainly because of the fuel requirements of the kilns. Wet processes and long dry kilns use more energy because of the drying processes. As kilns have been replaced, energy efficiency has improved since the 1960's but this has levelled off since 1990 – however the recent commissioning of new kilns is expected to make improvements so this should be a trend that improves in the future. Italy's energy consumption per unit has been relatively steady over the period peaking in the early 1990s and falling back to lower levels in recent years.

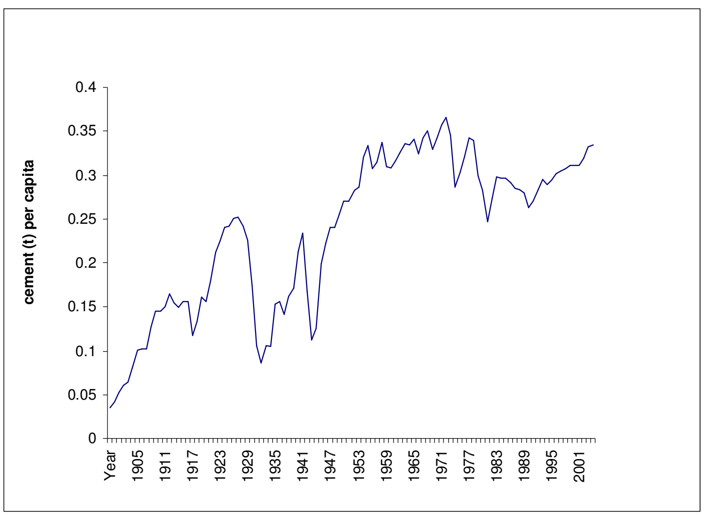
3.4.2 USA

Figure 3.20 Cement Production: USA



Cement production in the USA has been steadily increasing since 1900. There have been dips in production that coincide with global circumstances, such as the World Wars and more recently economic recessions. However since the mid 1990's US cement production has been gradually increasing.

Figure 3.21 Cement Production per capita: USA

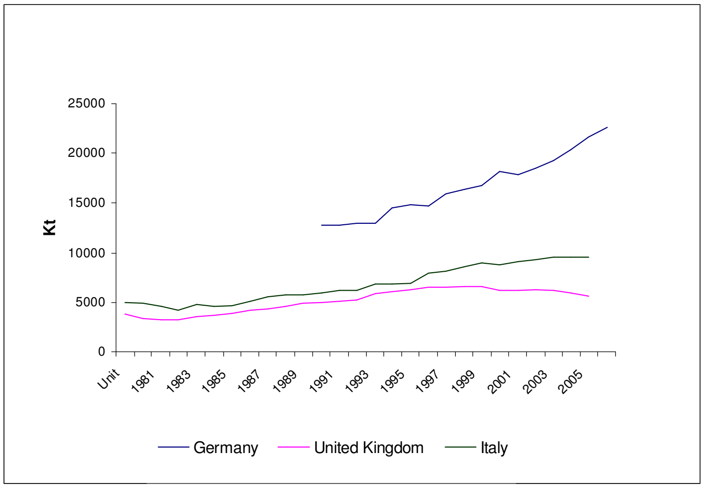


Cement production per capita in the US has fluctuated over the period, with major dips again closely coinciding with World War I and II, after which followed a period of growth that reached a peak in 1955. Since the late 1950's there has been a gradual decline in cement production per capita, however recent years have seen an increasing trend to around 0.3 tonnes production per capita. Note this is considerably less than the current production per capita in China which had risen to around 1 tonne in recent years (see Figure 2.4).

3.5 Paper

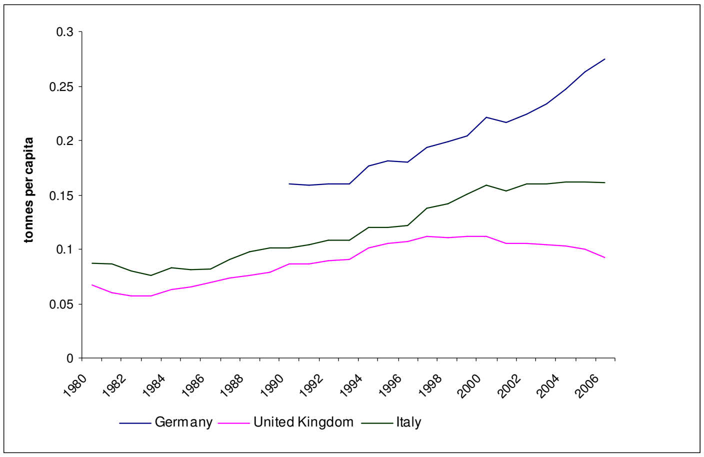
3.5.1 Germany, Italy and the UK

Figure 3.22 Paper Production: Germany, Italy and UK



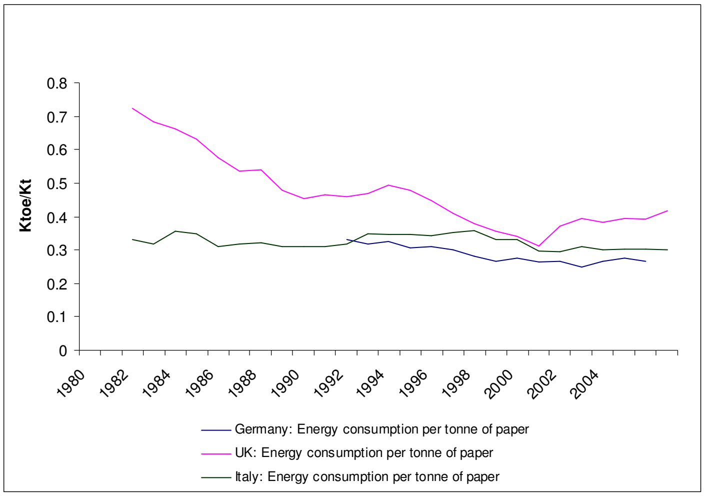
Paper production in Germany has been steadily increasing since the late 1980's. Both the UK and Italy have a much lower production of paper. In the UK this is just above 5000kt. Italy's paper production has started to gradually increase and is just below 100000kt.

Figure 3.23 Paper Production per capita: Germany, Italy and UK



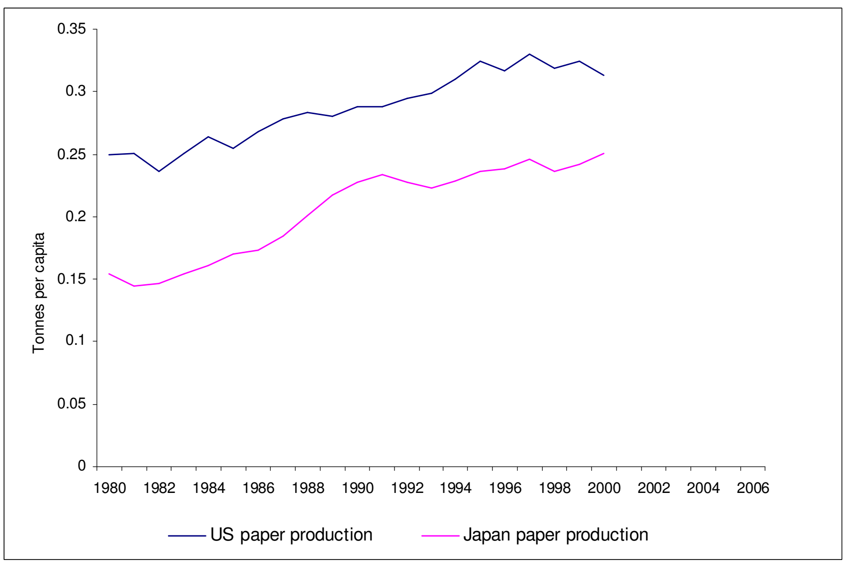
In both Germany and Italy paper production per capita has been gradually increasing since the mid 1990's. In the UK this has been much lower and seen a slight decline.

Figure 3.24 Energy Consumption per tonne of Paper: Germany, Italy and UK



Energy consumption per tonne of paper is relatively low in Germany and Italy, and this has remained quite constant in recent years. The UK has high unit consumption. The energy performance of the paper industry is linked to the share of pulp produced in the country in relation to the paper production: the higher this ratio, the higher the unit consumption.

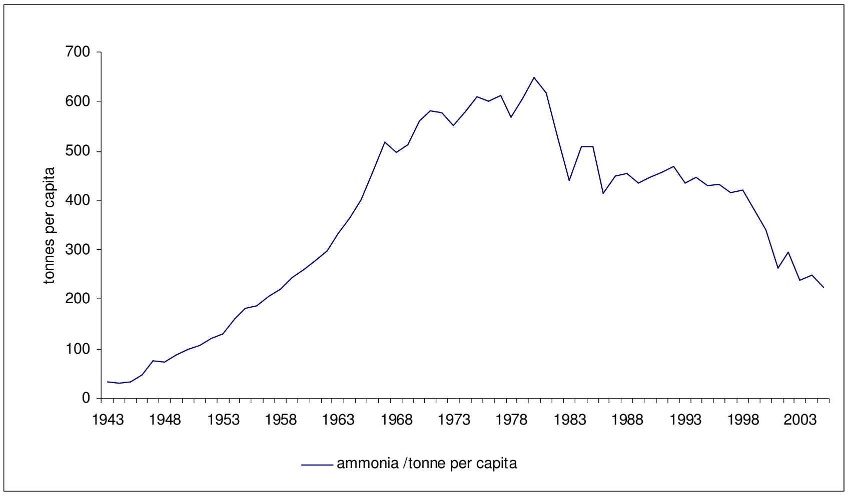
Figure 3.25 Paper production in US and Japan



The annual tonnage of paper production per capita in each country shows approximately linear growth. There is some evidence of a decrease in the rate of growth after ~1995 in both countries.

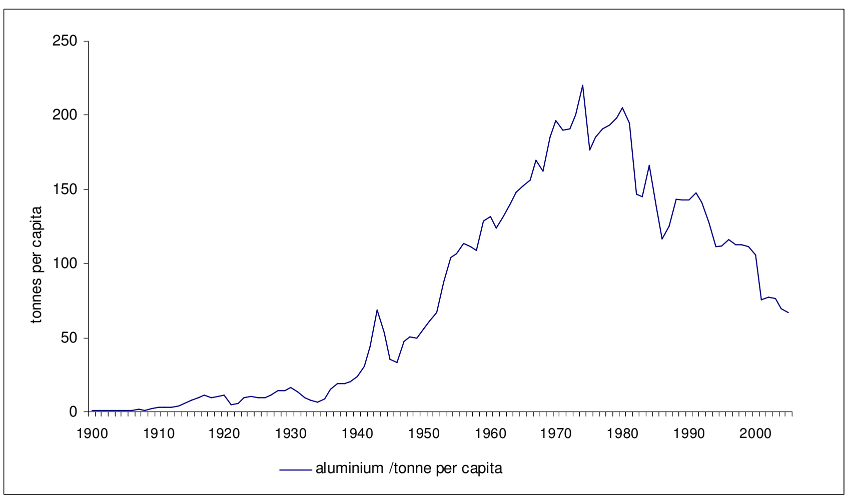
3.6 Other Industry sectors

Figure 3.26 US Ammonia production



Ammonia production in the US in tonnes per capita shows a sharp rise in production from 1940 - 1970, peaking at 1980 and falling sharply to 35% of this level in 2005.

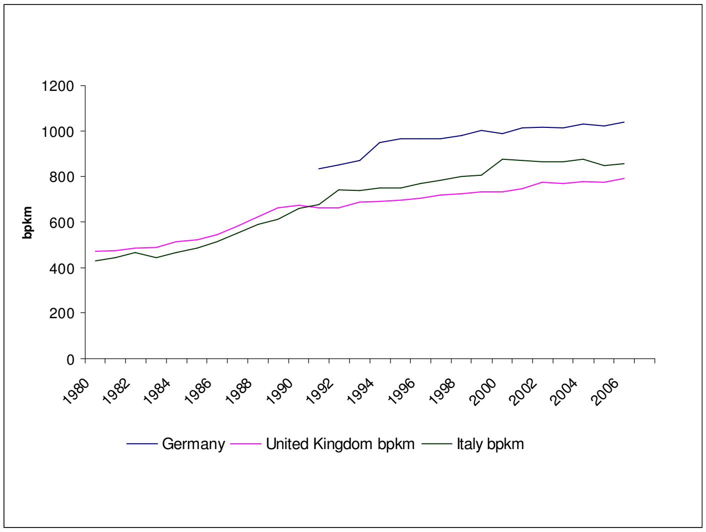
Figure 3.27 US Aluminium production



Aluminium production in the US in tonnes per capita (for the period 1900 – 2005) shows a similar pattern to Ammonia production, rising sharply from 1940 - 1970, falling to 30% of peak value by 2005.

3.7 Transport

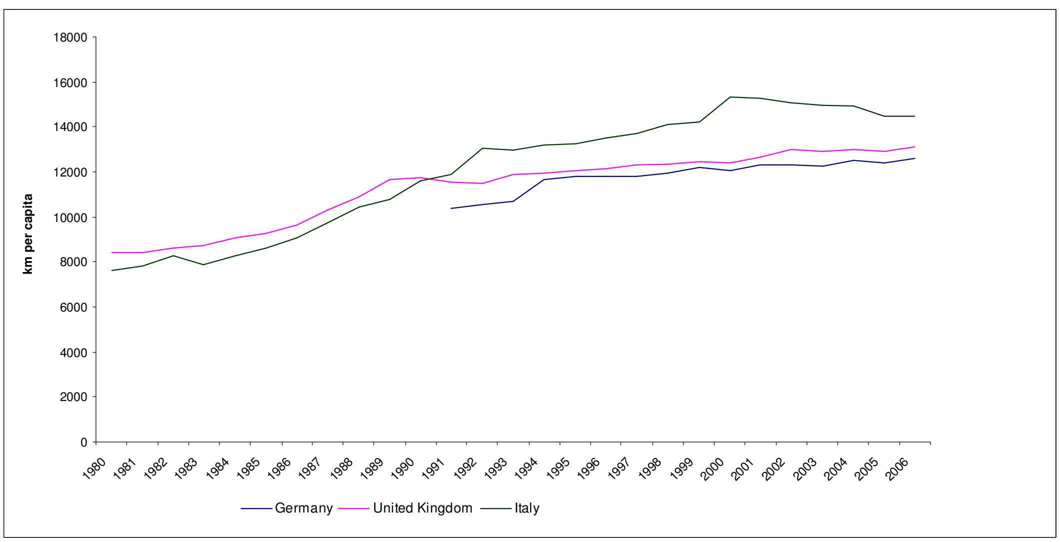
Figure 3.28 Passenger Traffic: Germany, Italy and UK



Passenger traffic is higher in Germany in comparison to the UK and Italy and since 2000 has remained relatively constant at just above 1000 bp.km. Italy's passenger traffic has been gradually increasing over the period and is now above 800 bp.km that has increased by 400 bp.km since 1980. The UK's passenger traffic is also been gradually increasing since 1980 however this has been at a slower rate.

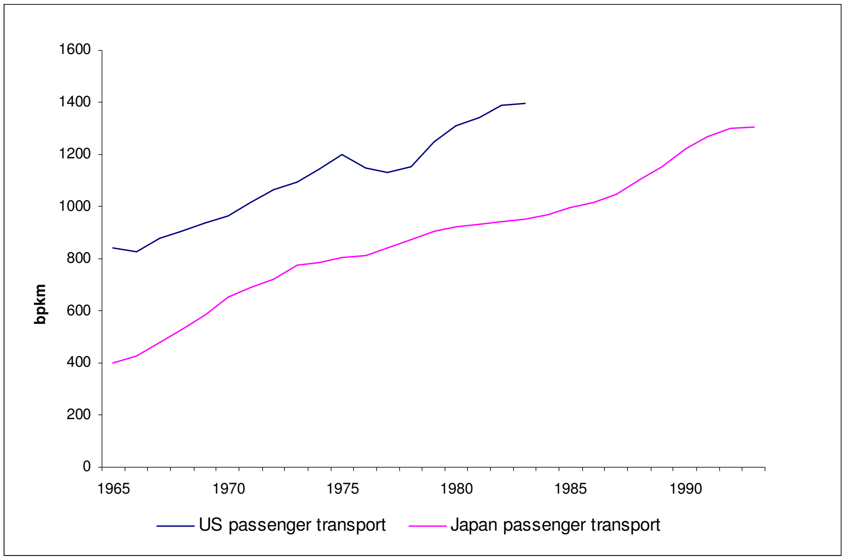
3.7.1 Passenger Transport

Figure 3.29 Passenger Transport per capita: Germany, Italy and UK



Passenger transport per capita in Italy is significantly lower than Germany and the UK; since 2000 this has stabilised following a period of growth between the 1980's and 2000.

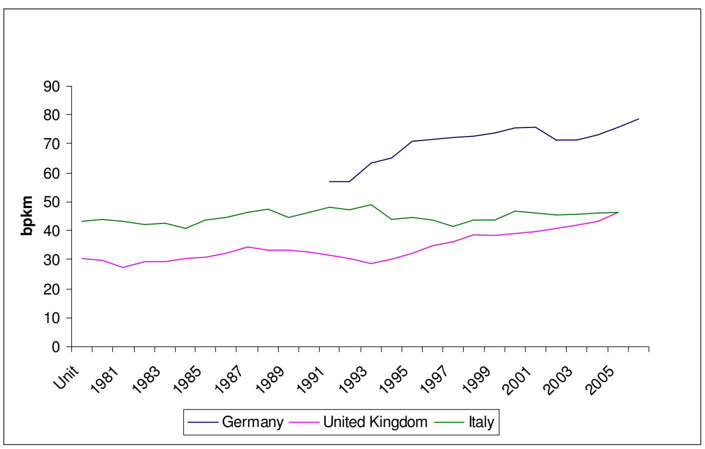
Figure 3.30 Passenger travel in US and Japan



Passenger travel in the US in billion passenger kilometres shows an approximately linear trend over the period.

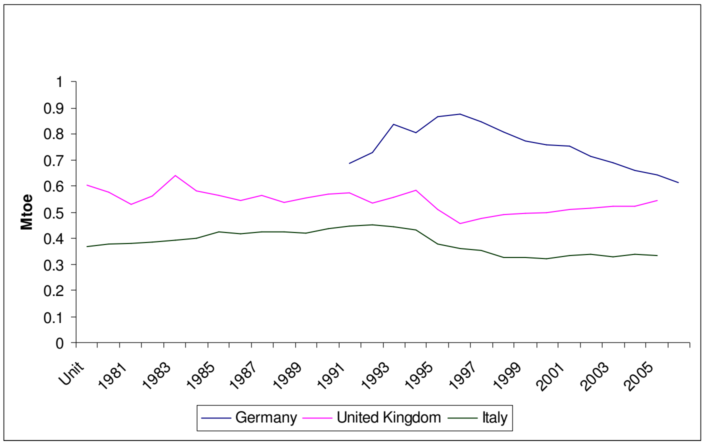
3.7.1.1 Rail Passenger Transport

Figure 3.31 Rail Passenger Traffic: Germany, Italy and UK



Rail passenger transport has been growing in Germany, there was a decline in 2001; however, since then it has started to increase once again. Italy's rail passenger transport has fluctuated between 40 bp.km and 50 bp.km for the whole period. In the UK rail passenger traffic has started to increase again since the mid 1990's.

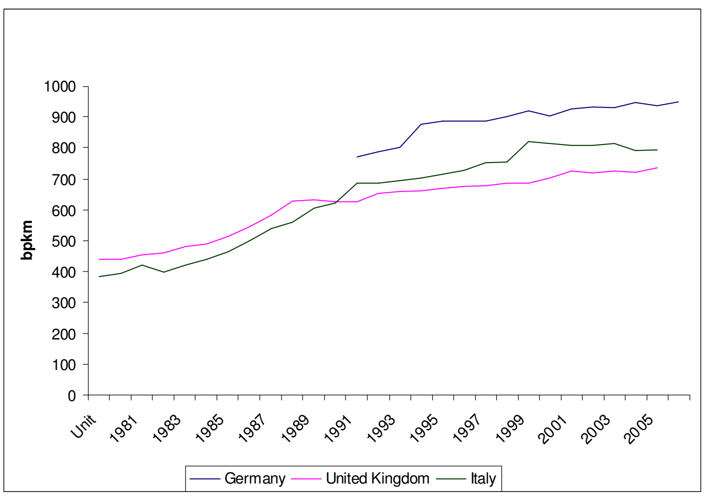
Figure 3.32 Energy Consumption of Rail Passenger Transport: Germany, Italy and UK



Energy consumption of rail passenger transport grew between 1991 and 1997. Since 1997 there has now been a gradual decline in the energy consumption, given the steady growth in numbers this might indicate more efficient trains. In the UK energy consumption of rail transport reached a low in 1997 and has now started to gradually increase. In Italy energy consumption fell in the late 1990s and has remained steady since 2000.

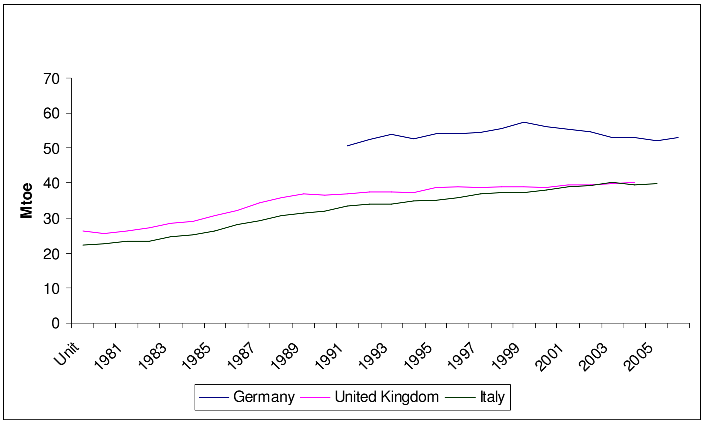
3.7.1.2 Road Passenger Traffic

Figure 3.33 Road Passenger Traffic: Germany, Italy and UK



Road passenger traffic has been increasing in all three countries; however, in recent years this has started to level out.

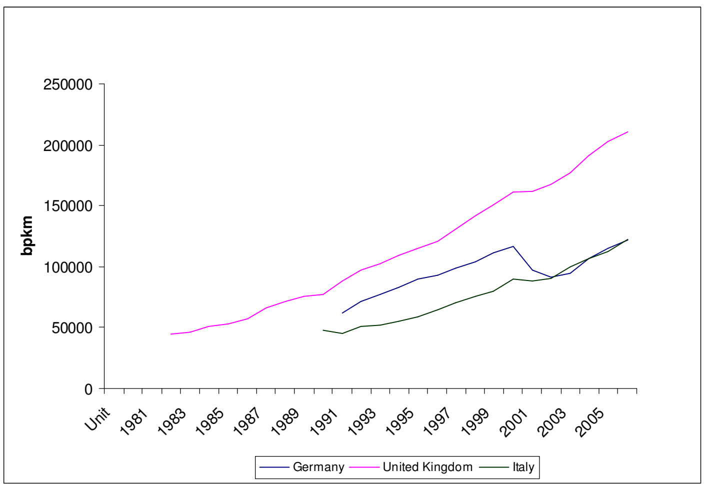
Figure 3.34 Energy Consumption of Road Transport: Germany, Italy and UK



The energy consumption of cars has started to stabilise in the 3 countries; given the growth in traffic this could indicate more efficient vehicles have resulted in improved energy consumption.

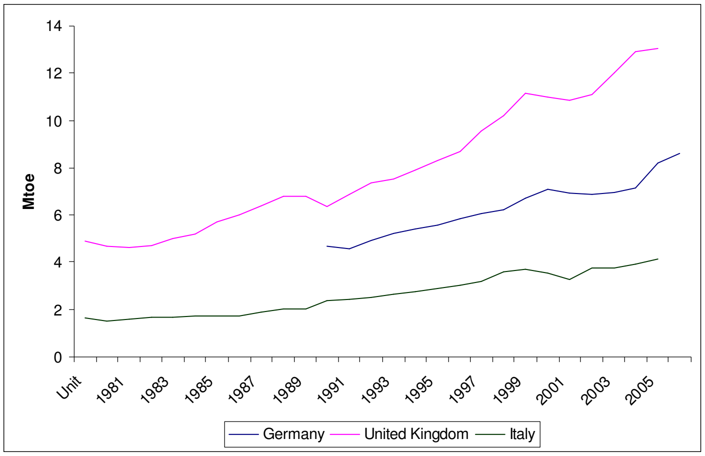
3.7.1.3 Air Passenger Traffic

Figure 3.35 Air Passenger Traffic (Domestic and International): Germany, Italy and UK



There was a sharp increase in air passenger traffic (international and domestic), particularly in the UK. Germany experienced a dip in air travel in 2000; however, this has now started to increase once again.

Figure 3.36 Jet Fuel Consumption Air Transport: Germany, Italy and UK

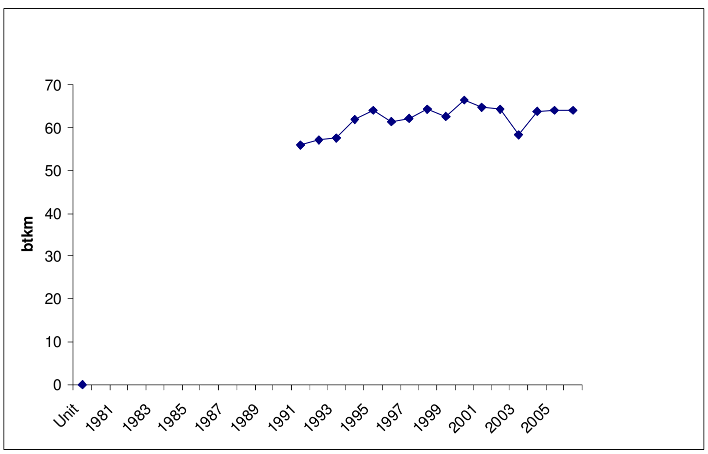


The Jet fuel consumption of air transport has been increasing in all the countries over the period.

3.7.2 Freight

3.7.2.1 Inland waterways goods traffic

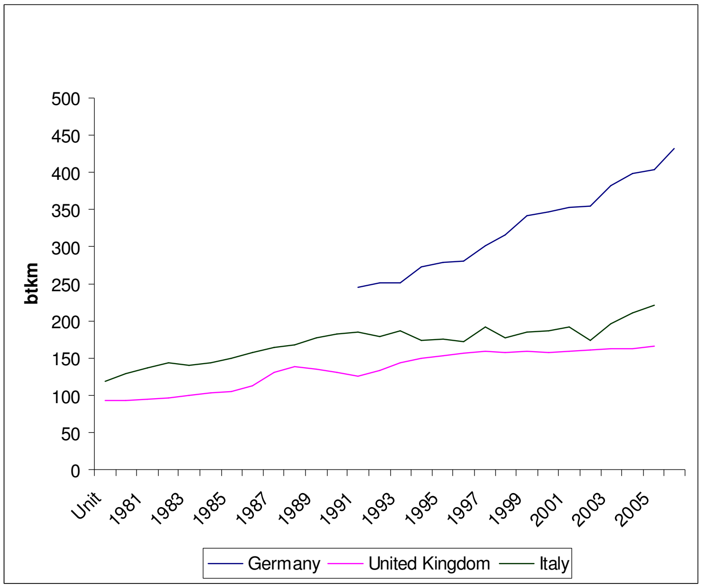
Figure 3.37 Inland Waterways Good Traffic: Germany



Germany's use of inland waterways to transport goods was about 63 bt.km in 2006; this dipped in 2003.

3.7.2.2 Road Goods Traffic

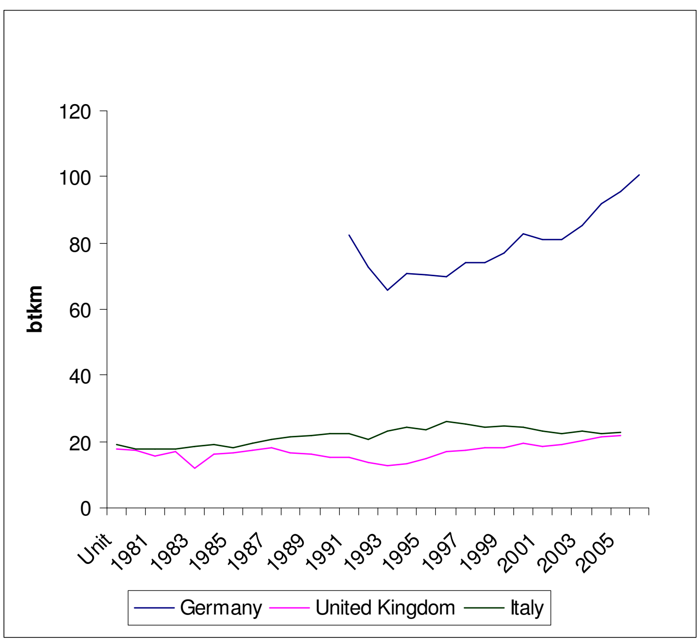
Figure 3.38 Road Goods Traffic: Germany, Italy and UK



Road goods transport has also been increasing in all of the countries with the most growth in Germany.

3.7.2.3 Rail Goods Traffic

Figure 3.39 Rail Goods Traffic: Germany, Italy and UK



Rail goods traffic is much higher in Germany when compared to the UK or Italy. Goods transported by rail have been growing in Germany; however, in Italy and the UK this has remained relatively constant over the period.

Approaches used to project future energy service demand for different end-use sectors and sub-sectors in OECD countries will now be assessed to see how they may inform the approach in China. China's future energy service demands are then projected based on the aforementioned analysis and assumptions for future social and economic growth.

4 Approaches Used in OECD to Project Energy Service Demand

To help inform the approach to energy service demand projections in China MARKAL it is informative to review approaches to projecting energy service demand elsewhere. According to Al-Rabbaie and Hunt (2006) in their review of modelling energy demands, there is no unique approach for modelling energy demand and no generally accepted consensus on the correct way to proceed. The specific characteristics of a given country's energy system and economy mean that it may not be possible to apply a given approach in one country to a different country.

4.1 UK MARKAL

The UK MARKAL model is managed by the UK Energy Research Centre[3]. The model was recently updated and part of this update included incorporating Carbon capture and storage (CCS) as a climate change mitigation option. The approach used to project energy service demand is to reverse engineer the demands using existing energy data and statistics and where available demand projections and energy models. Energy service demands by end uses are summed up to give sectoral end-use demand in the base year. For the future years, it is assumed that energy service demand will grow in line with the DTI (now DECC) final energy demand projections. The specific sectoral approaches are summarised briefly below.

There is no established data for UK energy service demands in the residential sector. Thus, the base year (2000) demands are calculated using reverse engineering. This means that from the actual final energy consumption for the base year (DUKES, 2005) their equivalent delivered energy services were calculated using typical efficiency of demand technologies and appliances. Based on actual energy consumed in the base year 2000, average space heating was calculated to be 32.73 GJ per year per household (GJ/y/hh). The ratio of space heating to hot-water demand is estimated as 71:29. Future energy demands are linearly extrapolated based on projected house stock.

The energy service demands for the service sector are calculated from the actual final energy use (DUKES, 2005) and its end-use application using the reverse engineering technique. The share of energy use for various end-use applications like space heating, hot-water, lighting, etc is adopted from a study by the Building Research Establishment (BRE)[4]. Energy service demands for the rest of the modelling period are calculated from the BRE study using household numbers.

The energy service demands for the transport sector were calculated and calibrated to known estimates of transport fuel use based on UK energy statistics (DUKES, 2005). For the subsequent periods (2005-2070), they were estimated based on projection information from the Department for Transport. The energy service demands used were estimates of actual energy service demands – growth in terms of vehicle kilometres based on data from the National Transport Model[5].

Industrial energy service demands are computed by using reverse engineering for the base year of 2000. DUKES (2005) provides the actual final energy consumption at sectoral level by fuels. An Industrial Energy End-Use Simulation Model (ENUSIM) that was developed for Defra is used for fuel use by energy services at sectoral level.

4.2 Oxford Economic Forecasting Approach

The method of estimating sectoral allocations in the first phase of the EU ETS relied on input from the DTI's Updated Energy Projections model – either directly in terms of projected emissions, or indirectly in terms of output or emissions growth rates. OEF provided detailed output projections as an input to DTI's modelling work. [6]

The OEF's International Industry Service model (OEF 2006) is greatly informed by the New International Industry Service model. The NIIS model is a statistical model that uses macroeconomic

[3] Further information on UK MARKAL may be accessed via http://www.ukerc.ac.uk
[4] Pout C and MacKenzie F (2006), Reducing Carbon Emissions from Commercial and Public Sector Buildings in the UK, BRE Client Report for Global Atmosphere Division, DEFRA.
[5] http://www.dft.gov.uk/pgr/economics/ntm/
[6] http://www.berr.gov.uk/whatwedo/energy/environment/euets/phase2/projections/page32624.html

variables and interindustry linkages to forecast sectoral output. The model ensures that forecasts for UK industries are consistent both with OEF forecasts for industries in other countries, and also with the macroeconomic projections for the UK and other countries. It is used as part of a regular forecasting service for clients from the industrial, financial and public sectors in a range of countries.

The model is used to forecast not just output, but prices, wages, employment and investment. The principal macroeconomic variables driving the industry model are the components of final demand, which directly or indirectly determine the demand facing each industry. However, other macroeconomic assumptions — in particular exchange rates, as well as world commodity prices — also feed into the industry model at appropriate points. This “top down” approach to forecasting is supplemented by a “bottom up” approach that allows OEF’s economists to adjust sectoral forecasts in the light of industry specific knowledge, ensuring that the forecasts capture real world factors that an econometric model alone could not hope to reflect.

4.3 IEA

Since 1993, the IEA has provided medium to long-term energy projections using a World Energy Model (WEM) which is used as a basis for its World Energy Outlook series. The approach used to project Energy service demands in the WEM is described in a detailed methodology available on the WEO website[7].

The industrial sector in the WEM is split into five sub-sectors: iron and steel, chemical and petrochemical, non-metallic minerals, paper, pulp and printing, and other industry. The intensity of energy consumption per unit of each sub-sector’s output and the share of each energy source are projected on an econometric basis with an incorporation of experts’ judgement. The output level of each sub-sector is modelled separately and is combined with projections of its energy intensity and end-use shares to derive the consumption of each energy source by sub-sector.

Transport energy demand is broken down among light duty vehicles, buses, trucks, two- and three-wheelers, rail, aviation and navigation. Passenger cars, trucks and buses are subdivided by fuel used – gasoline, diesel, alternative fuels, electricity or hybrids of these. The gap between test and on-road fuel efficiency is also estimated and projected. As the largest share of energy demand in transport comes from oil use for road transport the WEM contains a detailed sub-model based on an S-shaped Gompertz function, proposed in a paper entitled "Vehicle Ownership and Income Growth, Worldwide: 1960-2030" by Dargay et al. This model gives the vehicle ownership based on income (using GDP assumptions through to 2030) and 2 variables: the saturation level (assumed to be the maximum vehicle ownership of a country/region) and the speed at which the saturation level is reached.

The saturation level is based on several country/region specific factors such as population density, urbanisation and infrastructure development.

Passenger car ownership is then calculated based on the vehicle breakdown from World Road Statistics 2006 from the International Road Federation plus other regional statistics. Changes in passenger car ownership over time are modelled, based on the average current global passenger car ownership. Both total vehicle stock and passenger vehicle stock projections are then derived based on population assumptions. For each region, activity levels for each mode of transport are estimated econometrically as a function of population, GDP and price. Transport activity is linked to price through elasticity of fuel cost per km, which is estimated for all modes except passenger buses and trains and inland navigation. Energy intensity is projected by transport mode, taking into account changes in energy efficiency and fuel prices.

The residential sector’s energy consumption is in the OECD regions split into five end uses: space heating, water heating, cooking, lighting, appliances. The energy consumption related to each end use is computed as the product of an intensity variable and an activity variable – for instance the housing surface or the stock of appliances. For each end use, the intensity variable and fuel shares are projected on an econometric basis and are linked with average end-use energy prices. For modelling developing countries, the residential sector also includes projection for traditional biomass consumption, which are linked to the GDP per capita and the urbanization rate. In the services sector, energy consumption is projected on an econometric basis as a function of the value added by the sector.

[7] http://www.worldenergyoutlook.org/model.asp

4.4 USA

The National Energy Modelling System (NEMS) model in the US approach to energy service demands is described in (EIA, 2008). The Industrial Demand Module projects the consumption of energy for heat and power and for feedstocks and raw materials in each of 21 industries, subject to the delivered prices of energy and macroeconomic variables representing employment and the value of shipments for each industry. The value of shipments is based on NAICS[8]. The industries are classified into three groups—energy intensive manufacturing, non-energy-intensive manufacturing, and non-manufacturing.

The Transportation Demand Module projects consumption of fuels in the transportation sector, including petroleum products, electricity, methanol, ethanol, compressed natural gas, and hydrogen, by transportation mode, vehicle vintage, and size class, subject to delivered prices of energy fuels and macroeconomic variables representing disposable personal income, GDP, population, interest rates, and industrial shipments. The air transportation component explicitly represents air travel in domestic and foreign markets and includes the industry practice of parking aircraft in both domestic and international markets to reduce operating costs, as well as the movement of ageing aircraft from passenger to cargo markets. For air freight shipments, the model represents regional fuel use in narrow-body and wide-body aircraft. An infrastructure constraint limits overall growth in passenger and freight air travel to levels commensurate with industry-projected infrastructure expansion and capacity growth.

The Residential Demand Module projects energy consumption in the residential sector by housing type and end use, based on delivered energy prices, the menu of equipment available, the availability of renewable sources of energy, and housing starts. The Commercial Demand Module projects energy consumption in the commercial sector by building type and non-building uses of energy and by category of end use, based on delivered prices of energy, availability of renewable sources of energy, and macroeconomic variables representing interest rates and floorspace construction. The Residential Demand Module projects an increase in the average square footage of both new construction and existing structures, based on trends in the size of new construction and the remodelling of existing homes.

4.5 Indicators

Energy indicators are used to investigate past trends in energy efficiency and can also inform projections for energy demand.

The IEA employs indicators to analyse energy use intensity; these are constructed by combining energy data with data that describe factors driving consumption in end-use sectors. From these data, various types of energy intensities can be developed. Energy intensities are related to the inverse of energy efficiencies, but are not equivalent. The two are related in that the energy intensity of an activity or productive output summarizes the relationship between an overall measure of output and the energy used for a variety of processes towards that end. In contrast, each process (e.g. heating, motive power) involves one or more transformations of energy that can be described in terms of efficiencies.

Changes in intensities are affected by factors other than energy efficiency; therefore, analysing intensity trends provides important insights into how energy efficiency and other factors affect energy use. Three main components affecting energy use are distinguished: activity levels, structure (the mix of activities within a sector) and energy intensities (energy use per unit of sub-sectoral activity). Depending on the sector, activity is measured either as value added, passenger-kilometres (km), tonne-km, population or built area. This is further divided into structure such as industry sub-sectors, transportation modes or measures of residential end-use activity.

Meanwhile in the EU, the EC manages the Odyssee Project which publishes a number of energy indicators. One function of the indicators is to feed into the energy demand forecasting models and improve the quality of forecasts; technico-economic models, that are characterised by a high level of disaggregation (end-uses), make use of energy efficiency indicators to account for future changes in energy efficiency.

[8] North American Industry Classification System (NAICS) http://www.census.gov/eos/www/naics/

5 Future energy service demand projection for China

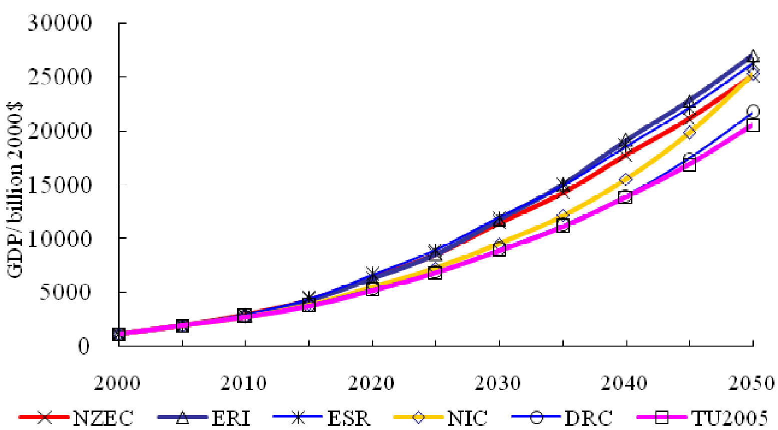
With the historical data from 1978 to 2006, this study used an aggregate model to project the production of high energy-intensive industrial sectors and transport activities to get future energy demand, which is based on the assumptions of population, urbanization, economic growth and industrial structure in the future.

5.1 Basic Assumption for Future Social and Economic Growth

5.1.1 Future GDP Growth

China's national economy has maintained a rapid growth for three decades. According to the Chinese government's economic and social development goals, China's GDP will be quadrupled from 2000 to 2020, and realize basic industrialization; and China's GDP per capita will reach the level of moderately developed countries by 2050. Based on this assumption, if China's economy growth maintains an average annual growth rate of around 7% before 2020, it will quadruple from 2000 to 2020. In fact, the real data indicated that the average annual growth rate of China's GDP was up to 9.96 % from 2000 to 2005, while the latest data indicated that GDP growth rate was even as high as 11.4% in 2007. In addition, China's economy integrated with the world's economy as a whole, and Chinese government's capacity of macro-control grew mature, thus the risk of China's economy undergoing emergency fluctuations was quite small. It's expected that China might realize the economic and social development goals ahead of schedule. Based on the real data and the related assumptions, this study assumes future economic growth as follows: from 2000 to 2010, the average annual growth rate of China's GDP is 9.5%, and it will keep a high growth rate of 8% from 2010 to 2020. After the industrialization is realized, the average growth rate will be 6%, 4.5% and 3.5% in the following 30 years. The comparison among ERI, ESR, NIC, DRC, TU2005 and this study is presented in the figure below:

Figure 5.1 The Comparison of Future GDP Growth Forecast from 2000 to 2050



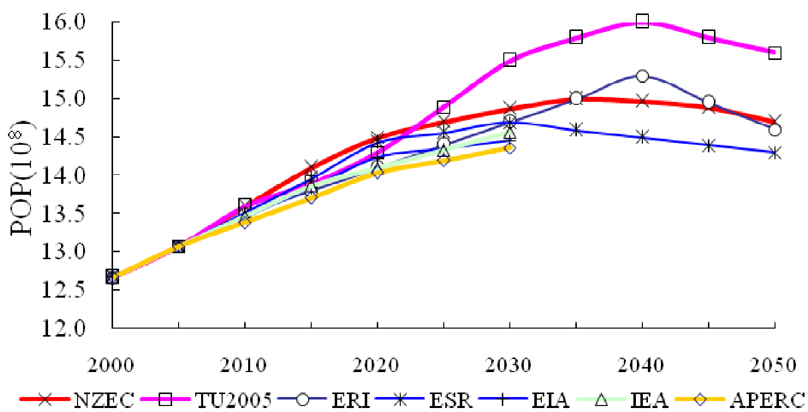
Note: NZEC (Near Zero Emissions Coal); ERI (Energy Research Institute, 2005); ESR (He Jiankun and et al, 2007); NIC (National Information Centre, 2003); DRC (Development Research Center, 2005); TU2005 (Chen Wenying, Wu Zongxin and et al, 2005).

The result shows that Chinese GDP is expected increase from 1198 billion dollars in 2000 to 25151 billion dollars in 2050, with an average annual growth rate of 6.28%. And it will be 6411 billion dollars in 2020, 5.4 times of the 2000's. While GDP per capita will increase from 945 dollars in 2000 to 17109 dollars in 2050, with an average annual growth rate of 6.28% and it will be over 10,000 dollars before 2040. It means that the government will complete the economic and social development goals ahead of schedule.

5.1.2 Future Population Growth

Population is the most basic factor in the social system, the total number of the population will have a direct effect on the final energy service demand. China's population growth rate began to decline from the 1990s year by year, and the growth rate was only 0.61% from 2000 to 2006, and the total population was 1314 million in 2006. The prediction of the future population rely on the survey statistics of the population status, the natural law of population growth and the government's policy upon population. According to the "White Paper on China's population" which was released by the government in 2000 and National Population and Family Planning Commission of China's latest forecast results, we forecast that China's total population will reach its peak around the year of 2035 at about 1.5 billion. From 2005 to 2035, the growth rate of the population will be 0.46%, and then it will stay in a negative growth stage. The comparison of population forecast among TU2005, ERI, ESR, EIA, IEA, APERC and this study is in the figure below:

Figure 5.2 The Comparison of Population Forecast from 2000 to 2050

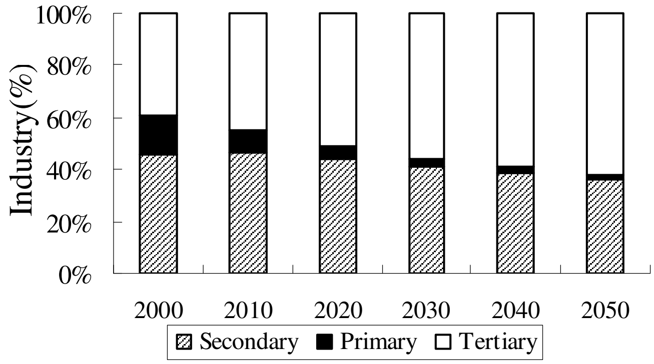


Note: NZEC (Near Zero Emissions Coal); ERI (Energy Research Institute, 2005); ESR (Energy Strategy Research, 2007); EIA (Energy Information Administration, 2007); IEA (International Energy Agency, 2007); APERC (Asia-Pacific Energy Research Centre, 2006); TU2005 (Chen Wenying, Wu Zongxin and et al, 2005)

5.1.3 Future Industry Structure Change

The reasonableness of the industrial structure will have a direct impact on the national economy development. According to the industrial structure theory, the industrial structure will be adjusted gradually with the development of economy. The proportion of primary industry's added value in total GDP would decline with the economy growth continually. While the share of secondary industry in the total GDP would rise rapidly at first, then tend to slow down or stagnate, and even decline slowly at last in the three different stages industrialization course (that is beginning, speeding up and completing of the industrialization). The proportion of tertiary industry's added value in the total GDP will rise gradually. With the development of the economy, China's industrial structure will be adjusted following the experience of most developed countries. It is expected that the proportion of primary and secondary industry will drop to 1.7% and 36.1% respectively, while the proportion of the service industry will rise to 62.2 % by 2050.

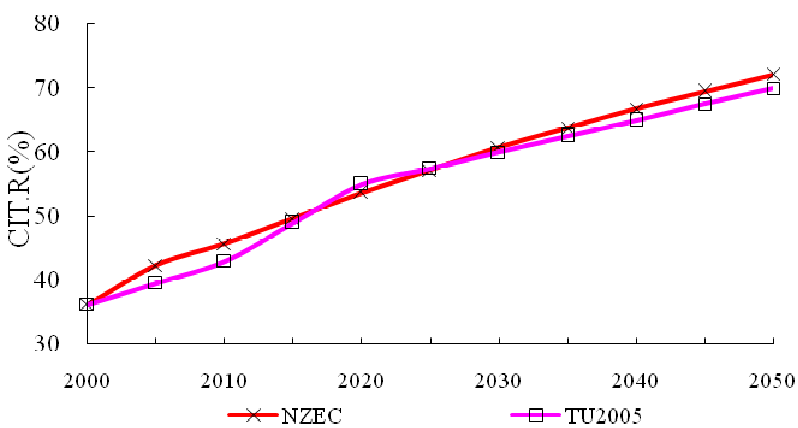
Figure 5.3 The Assumption on Future Industry Structure Change from 2000 to 2050



5.1.4 Future Urbanization Rate

From 1978 to 2006, China's total population increased from 962.59 million to 1314.48 million, and the urban population increased from 172.45 million to 577.06 million. The urbanization rate increased from 17.9% to 43.9%, with an average annual growth rate of 3.25%. After 30 years of rapid development, China's urbanization rate increased greatly, but was still lower than the world average level. At present, China's urbanization process is in an accelerated development stage. With the rapid development of the economy and the constant adjustment of industrial structure, China's urbanization will be developed steadily and rapidly. The result shows that China's urbanization level will reach 72% by 2050, which is equivalent to the current level of moderate developed countries. The comparison of this study with TU2005 is displayed in the figure below:

Figure 5.4 The Forecast Comparison of Urbanization from 2000 to 2050



Note: TU2005 (Chen Wenying, Wu Zongxin and et al, 2005)

5.2 Industry Sector Energy Service Demand Projection

The world's major developed countries' history shows that industrialization is based on the large consumption of the energy and mineral resources. The proportion of secondary industry's value added will rise up rapidly, and then tend to slow down or stop, even decline with the process of industrialization's beginning, speeding up and completion. Normally countries will follow these three steps, especially the countries who follow a catch-up strategy like China. The consumption of resources per capita will also grow up rapidly, slow down gradually, stabilize and finally decrease when the GDP per capita is close to and even more than 10,000 U.S. dollars.

Consumption of resources per capita increases with the growth of per capita GDP in an "S"-type curve. To simplify, this study assumes that the high energy-intensive production and consumption remain in balance. Thus the per capita output will also grow with per capita GDP in an "S" type curve.

In order to show the rationality of the assumption on the balance of high energy-intensive production and the consumption, we take steel as an example.

Figure 5.5 The Historical Trend of Import and Export of Steel Production from 1980 to 2005

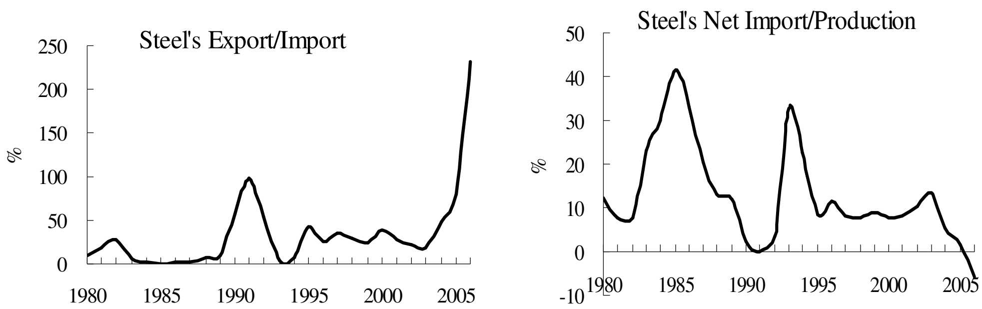


Figure 5.5 displays the historical trend of import and export of steel production from 1980 to 2005. It can be seen that steel export was lower than half of steel imports until 2005, and share of net import in relation to production was maintained around 10%. Import was 25.8 million tonnes and 18.5 million tonnes respectively in 2005 and 2006, but export increased quickly from 20.5 million tonnes in 2005 to 43 million tonnes in 2006 (Chinese iron and steel industry statistics, 2007), mainly because of the large international steel demand in recent years; so the price was higher than the national average price, which caused a great deal of steel export. The substantial increase in high energy-intensive, high-pollution products in export exacerbated the tension of coal, electricity, oil and transport resources. On the other hand, it increased domestic environmental pressure. Faced with this situation, the Chinese Government adjusted the energy-intensive products' import and export tariffs rapidly. We still take steel for example, on April 15, 2007, the Chinese Government adjusted the steel export tax rebate which related to 159 tariff lines for all steel exports; of these, 83 steel tariff export tax rebates were cancelled. The adjustments of import and export tariffs were the country's macro-control measures in a phased, to limit the too rapid growth of steel and other high energy-intensive products' export.

Considering the export of high energy-intensive products not only damaged the environment seriously, but also caused great loss of energy. Chinese government faced a serious resource and environmental pressure, so these tariff policies which can restrain the high energy-intensive products' exports excessive growth are likely to be the long-term policies. The rapid growth export of steel and other high energy-intensive products in recent years will certainly only be a short-term phenomenon. So in the long run, China's future energy-intensive products' exports will be controlled effectively; domestic supply and demand will maintain a long-term balance.

This study applies a Gompertz aggregate model to project high energy-intensive industrial products' future production. The Gompertz model is described as following:

$$I = S \cdot e^{\alpha \cdot e^{\beta \cdot PGDP}}$$

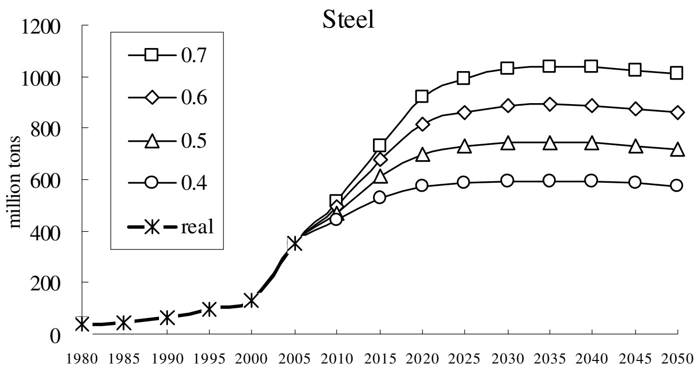
Where I is per capita demand for industrial products; PGDP is GDP per capita; S is the saturation level of per capita demand for industrial products. While α and β are the parameters which determine the shape of the curve, they are generally negative.

5.2.1 Iron & steel

Historical experience of the per capita steel production showed an increasing tendency with the growth of the per capita GDP. When the per capita GDP reached 10,000 U.S. dollars, per capita output growth slowed down significantly, and the steel production level stepped into the stable period. Taking a wide view of the United States, Japan, Britain, and other industrialized countries, all of them have these characteristics on the development of iron and steel industry. China's per capita GDP was just over 1000 U.S. dollars in 2001. Accordingly, per capita steel output grew rapidly from 2000 to 2006; and the growth rate was as high as 21.04%. In the early 21st century, our country will stay in an industrialization stage; according to the historical development trends, such high-speed growth of steel production will continue till 2030. With the per capita GDP close to 10,000 U.S. dollars, per capita steel output growth will slow down gradually, close to the saturation level, and then maintain a stable level. The peak value will be in the range of 600 Mtonnes with saturation level assumed as 0.4 t per capita and 1048 Mtonnes with saturation level assumed as 0.7 t per capita, as it's shown in the chart below.

According to review of OECD data, the saturation level per capita was selected as 0.5 t per capita. The steel production will peak at 750 Mtonnes in 2035, and the average annual growth rate of steel production and per capita steel output will be 2.54% and 2.07% from 2005 to 2035.

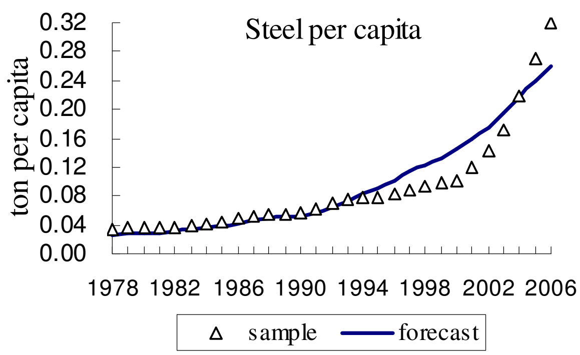
Figure 5.6 Steel Production from 1980 to 2050



The comparison of the sample values and regression results are shown in the chart below:

Figure 5.7 Comparison of the Sample Values and Regression Results from 1978 to 2006

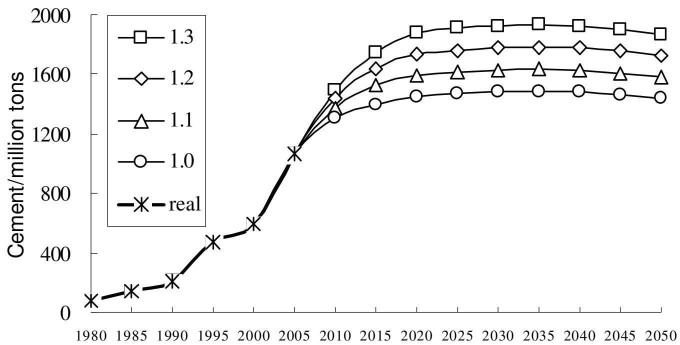
(R^2=0.9304; Adjusted R^2=0.9278; S.D=0.4425; D-W=0.2217)



5.2.2 Cement

China's cement output reached the first place in the world, while per capita cement consumption stayed at a high level and kept rapidly growing, but the cumulative consumption per capita was still relatively low. Because China is in the early or medium stage of industrialization, with an urbanization and western development strategy, the implementation of the national infrastructure will be constructed continuously. Construction and transport will be developed more rapidly, especially highways will grow rapidly. According to the report which was provided by the Chinese building materials industry's Economic research association, building materials industry growth rate will be 3%-4% higher than the national economic growth rate, and become an important growth point in the national economy in the next 10 years or even longer (2004 China's building materials industry market research report. Http://www.bm.cei.gov.cn. 2005-04-05). According to this development situation, cement production will certainly maintain further rapid growth in the process of industrialization. The peak value of cement production will be 1500 Mtonnes/year with a lower saturation level of 1.0 t per capita and 1950 Mtonnes/y with a higher saturation level of 1.3 t per capita, as shown in Figure 5.8. According to OECD data, the saturation level per capita is determined as 1.2 t per capita, and the cement production will peak at 1800 Mtonnes in 2035. From 2005 to 2035, the average annual growth rate of cement production and per capita cement output are 1.75% and 1.29%.

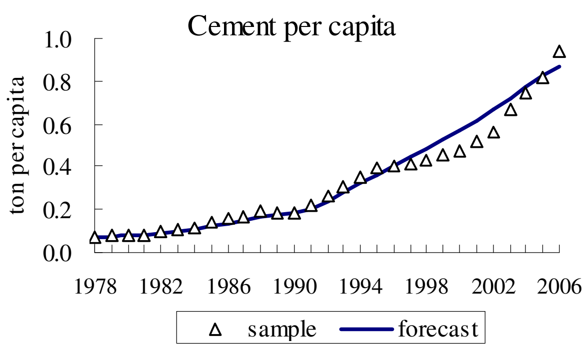
Figure 5.8 Cement Production from 1980 to 2050



The comparison of the sample values and regression results are shown in the chart below:

Figure 5.9 Comparison of the Sample Values and Regression Results from 1978 to 2006

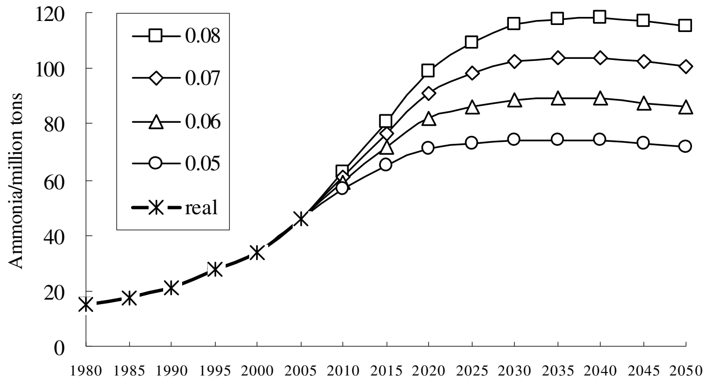
(R^2=0.9835; Adjusted R^2=0.9829; S.D=0.6352; D-W=0.4499)



5.2.3 Ammonia

After 30 years rapid growth, China's nitrogen fertilizer consumption has nearly entered a stable development stage; the production of ammonia occupies the first place in the world at present. According to the "Tenth Five-year Plan" development of fertilizer planning, the use of ammonia in fertilizer will grow a little in the future, and the use of ammonia in industry will change little (Chinese Academy of Sciences research team, 2001). Accordingly, the saturation level per capita is determined as 0.06 t per capita according to OECD data, and the ammonia production will peak at 90 Mtonnes in 2035. From 2005 to 2035, the average annual growth rate of ammonia production and per capita ammonia output are 2.26% and 1.79%. The peak value of ammonia will be 75 Mtonnes with the lower saturation level of 0.05 t per capita and 120 Mtonnes, and the upper saturation level of 0.08 t per capita, as shown in the chart below:

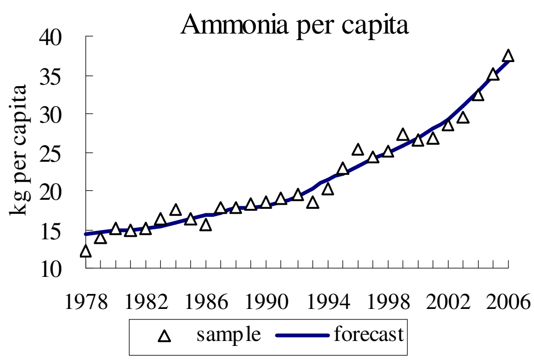
Figure 5.10 Ammonia Production from 1980 to 2050



The comparison of the sample values and regression results are shown in the chart below:

Figure 5.11 Comparison of the Sample Values and Regression Results from 1978 to 2006

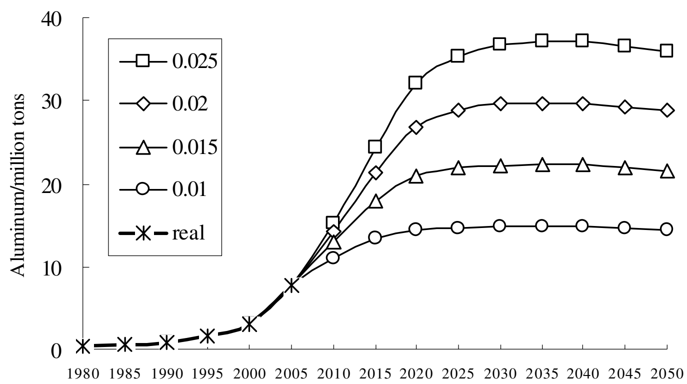
(R^2=0.9770; Adjusted R^2=0.9762; S.D=0.3132; D-W=1.1891)



5.2.4 Aluminium

Before 2000, China's electrolytic aluminium output was in a steady growth stage. In recent years, China's electrolytic aluminium output entered a rapid growth phase, and became the world's largest aluminium producer in 2002. From 2000 to 2006, the electrolytic aluminium production growth has been very rapid, with rate as high as 20.94%. In the early 21st century China will keep in an industrialization stage. As a result of the trends of the heavy chemical industry highlighted above, the manufacturing and processing power industry which will develop rapidly in the future, the demand of aluminium products will continue to be maintained at a high level. Accordingly, the saturation level per capita is determined as 0.02 t per capita according to OECD data, and the aluminium production will peak at 30 Mtonnes in 2035. From 2005 to 2035, the average annual growth rate of aluminium production and per capita aluminium output will be 4.59% and 4.12%. The peak value of aluminium will be 15 Mtonnes with the lower saturation level of 0.01 t per capita and 37 Mtonnes with the upper saturation level of 0.025 t per capita, as shown in Figure 5.12 below.

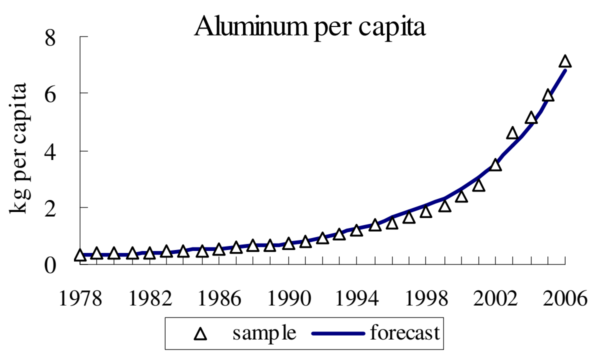
Figure 5.12 Aluminium Production from 1980 to 2050



The comparison of the sample values and regression results are shown in the chart below:

Figure 5.13 Comparison of the Sample Values and Regression Results from 1978 to 2006

(R^2=0.9933; Adjusted R^2=0.9930; S.D=0.3904; D-W=0.4481)



5.2.5 Paper

From 1978 to 2000, paper production was in a steady growth stage, with an average annual growth rate of 8.2%; the elasticity to GDP was 0.85. And since 2000, China's paper went into a rapid growth phase, China's annual production of paper was 68.63 million t in 2006, and the per capita output was 52.21kg, equal to the world's average level. From 2000 to 2006, the average annual growth rate of paper output was as much as 18.43%, the elasticity to GDP was 1.82. Historical experience shows that as paper consumption is one of the important symbols of a country's modernization, its per capita consumption will rise rapidly with the growth of per capita GDP, continue for a period after the industrialization process has been completed, and slow down and keep steady until the GDP per capita reached 30,000 U.S. dollars. At present, China's per capita paper production approaches the world's average level, but because of the enormous potential domestic market, the current production capacity can't meet the needs, so it is necessary to import a certain amount of machine-made paper and paperboard products. From the changes in the world's historical trend in use of paper, we find that the paper elasticity to GDP remained basically unchanged. The data shows that from 1960 to 2000, the world's paper elasticity fluctuated between 0.6 and 1.6, the average value being 1.03 (FAO statistical database (FAOSTAT) http://faostat.fao.org). From 1978 to 2006, the paper production elasticity to GDP of China was 1.06. Paper production will continue to maintain a rapid growth rate in the future as the paper-making industry expand the market further, and the industrial restructuring is implemented gradually. The elasticity to GDP will gradually decline from 2.02 in 2005 to about 1.0.

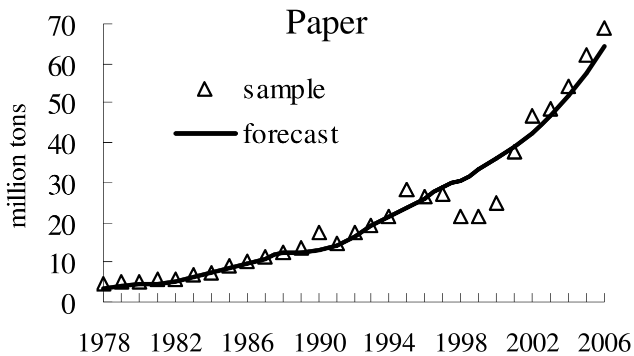
Accordingly, we use the econometric research methods to get the relationship between paper production and per capita GDP as follows:

Paper = -3.3590 + 0.0415 * PGDP

(R2 = 0.9499; Adjusted R2 = 0.9481; SD = 17.9321; DW = 0.6218)

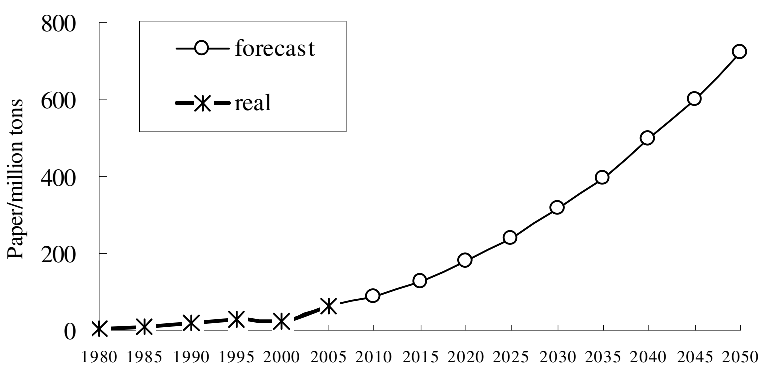
The comparison of the sample values and regression results are shown in the chart below:

Figure 5.14 Comparison of the Sample Values and Regression Results from 1978 to 2006



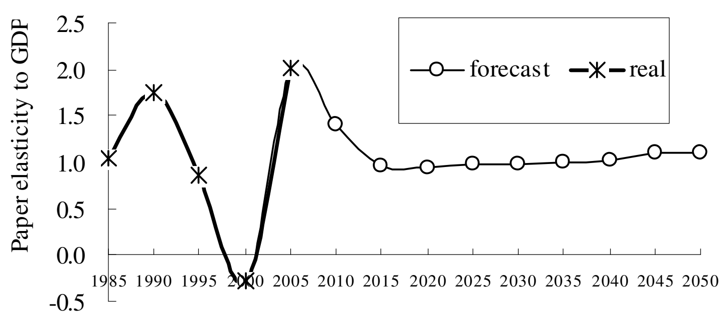
The forecast results for paper are shown in the figure below:

Figure 5.15 Paper Production during 1980 to 2050



The changing of paper production elasticity to GDP is shown in the chart below:

Figure 5.16 Elasticity of Paper Production



From the chart, we can see that paper production will have a steady growth in future, and the production will be 700 million t by 2050. During 2005 to 2050, the average annual growth rate of paper production and per capita paper output is expected to be 5.55% and 5.28% respectively. The elasticity of paper production to GDP is expected to decrease from 2.02 in 2005 to 0.95 by 2015, and then it will be maintained at about 1.0.

5.3 Transportation Sector Energy Service Demand Projection

Transport sector was divided into passenger and freight transport. According to the related studies, there was a clear positive correlation between transportation turnover and the GDP, and the passenger transport was correlated with per capita GDP, while freight transport was correlated with the total GDP. Accordingly, this study will use econometric methods to get the relationship between passenger transport and per capita GDP, and the relationship between freight transport and total GDP. A Gompertz model is used to project future car ownership.

5.3.1 Passenger Transportation

5.3.1.1 Total

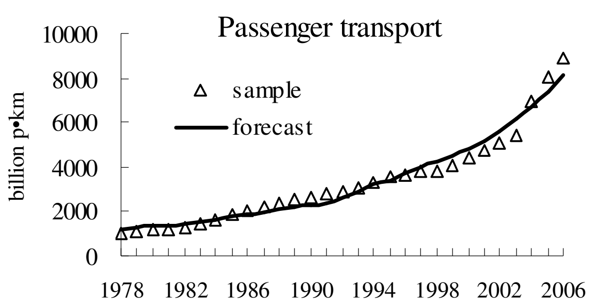
As a developing country with a huge population and a large territory, China's passenger transport demand grows rapidly, and the comprehensive transportation capacity grows gradually. The average annual growth rate of passenger turnover was 8.95% from 1978 to 2006, and the per capita passenger use increased from 180 p.km per capita to 1460 p.km per capita. The average annual growth rate reached 7.74%, but the average distance travelled remains far below the average level of developed countries. Accordingly, this study shows that passenger transport will continue to maintain a relatively high growth rate, and the linear relationship between it and GDP is as follows:

PAS.T = 91.436 + 1.1605 * GDP.P

(R^2=0.9851; Adjusted R^2=0.9845; S.D=4926.077;D-W=0.5380)

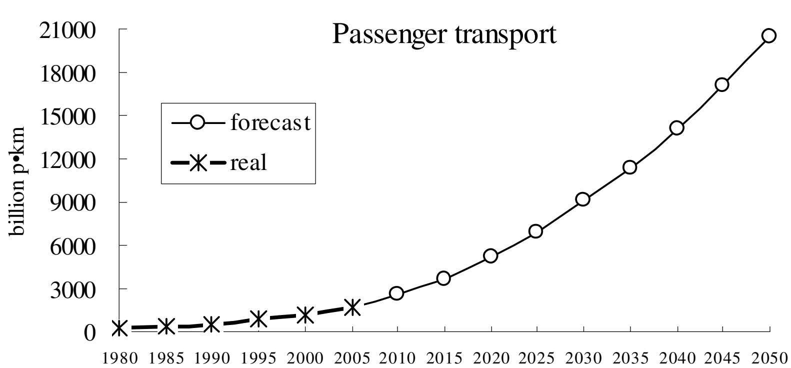
The comparison of the sample values and regression results are shown in the chart below:

Figure 5.17 Comparison of the Sample Values and Regression Results from 1978 to 2006



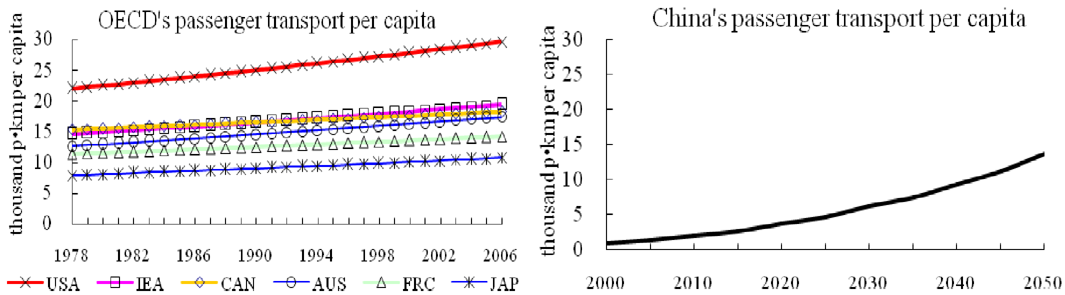
The forecast results for passenger transport are shown in the figure below:

Figure 5.18 Passenger Transport from 1980 to 2050



The forecast results shows that, from 2005 to 2050, passenger transport will grow at a rate of 5.58%, and reach 20087 billion p.km in 2050, but the average distance travelled per capita will still be relatively low.

Figure 5.19 Comparison of Passenger Transport per capita from 1978 to 2006



It can be seen from the chart that OECD countries' per capita passenger distance travelled increased steadily between 1978 to 2006. Japan was the lowest, and the United States was the highest. The IEA-average over the period was between 15000 and 17000 p.km per capita (average value of 17 IEA countries[9]). After 30 years' rapid growth, China's per capita passenger transport reached 1460 km in 2006, but this was still far below the average level of developed countries, about one tenth of the IEA average. China's passenger km per capita will continue to maintain a relatively high growth rate, and will reach 14000 p.km per capita by 2050, nearly equal to the IEA countries' current level.

5.3.1.2 Railway

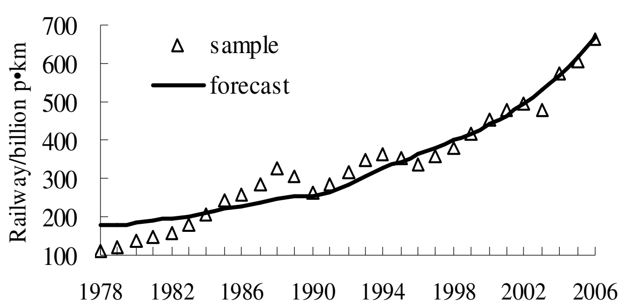
From 1978 to 2006, the average annual growth rate of the railway passenger transport was 6.64%, but the proportion of passenger declined from 62.72% in 1978 to 34.50% in 2006. Accordingly, the railway passenger will continue to maintain a certain growth speed, and it will follow a linear relationship with per capital GDP.

PAS.RL = 122.1174 + 0.336 * GDP.P

(R^2=0.9392; Adjusted R^2=0.9370; S.D=1460.663; D-W=0.4111)

The comparison of the sample values and regression results are shown in the chart below:

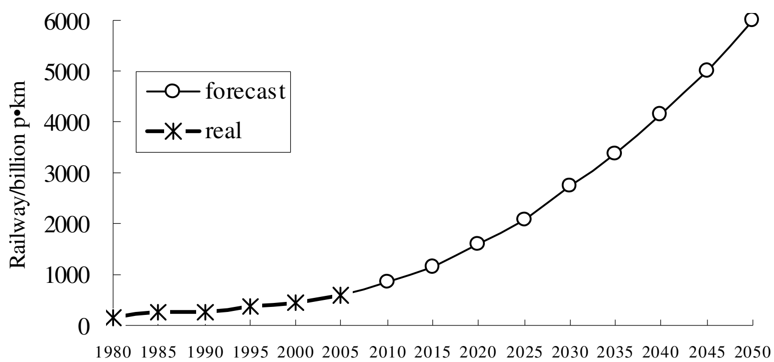
Figure 5.20 Comparison of the Sample Values and Regression Results from 1978 to 2006



The forecast results of railway passenger transport are shown in the figure below:

9 The 17 IEA countries included in the analysis of the passenger transport sector in the IEA's Energy Use in the New Millennium (2008) (Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, the United Kingdom and the United States.

Figure 5.21 Railway Passenger Transport from 1980 to 2050



The forecast results show that railway passenger will reach 5871 billion p.km by 2050, with the average annual growth rate of 5.18%.

5.3.1.3 Highway

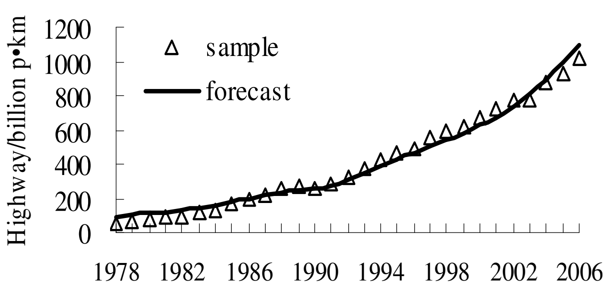
The average annual growth rate of the highway passenger transport reached 11.18% from 1978 to 2006. The proportion of highway in the total passenger transport mix rose from 29.91% in 1978 to 52.77% in 2006. Accordingly, highway passenger transport will continue to maintain a high rate of growth, and the relationship between it and GDP is as follows:

PAS.RD = -17.4014 + 0.6824 * GDP.P

(R^2=0.9846; Adjusted R^2=0.9840; S.D=2897.327; D-W=0.3344)

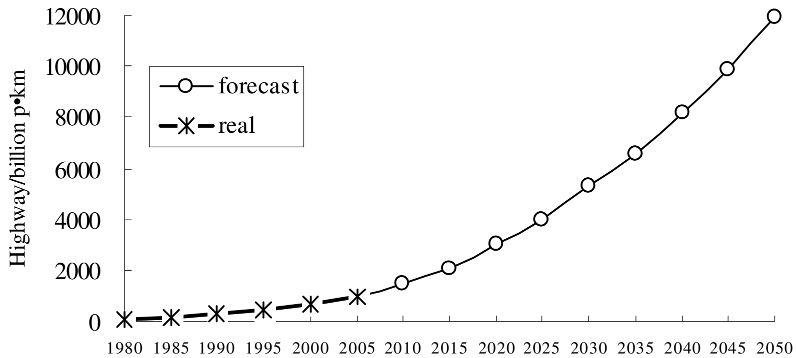
The comparison of the sample values and regression results are shown in the chart below:

Figure 5.22 Comparison of the Sample Values and Regression Results from 1978 to 2006



The projection results of highway passenger transport are shown in figure 5.23.

Figure 5.23 Highway Passenger Transport from 1980 to 2050

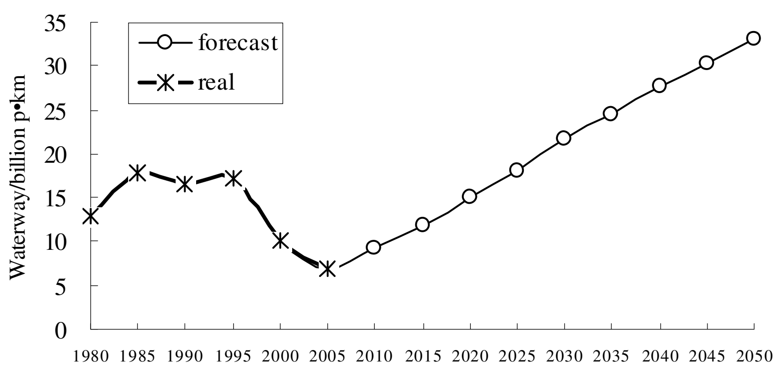


The results show that highway passenger will reach 11658 billion p.km in 2050, with the average annual growth rate of 5.78%.

5.3.1.4 Waterway

From 1978 to 2006, water transport passenger decreased at an average annual decline rate of 1.11%. Correspondingly, the proportion of waterway in total passenger transport declined from 5.77% in 1978 to 0.38% in 2006 with an average annual decline rate of 9.23%. Accordingly, this study assumes that it will maintain such decline trend and fall to 0.16% in 2050. The waterway passenger transport is expected to be 33 billon p.km by 2050 with average annual growth rate of 3.54%.

Figure 5.24 Waterway Passenger Transport from 1980 to 2050



5.3.1.5 Air travel

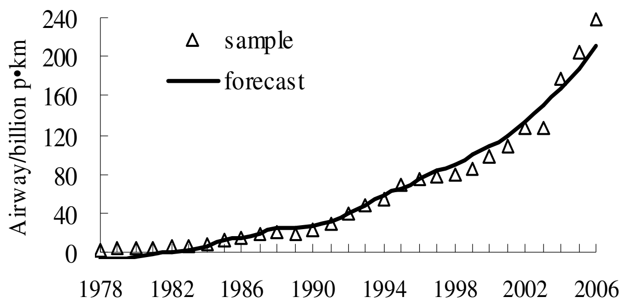
From 1987 to 2006, the average annual growth rate of air travel turnover was as much as 17.19%. Correspondingly, the proportion of air passenger transport in the total passenger transport rose from 1.6% in 1978 to 12.35% in 2006. Air passenger transport will continue to speed up and the relationship between it and per capita GDP is shown below.

PAS.AIR = -31.8849 + 0.1495 * GDP.P

(R^2=0.9765; Adjusted R^2=0.9756; S.D=637.2927; D-W=0.6659)

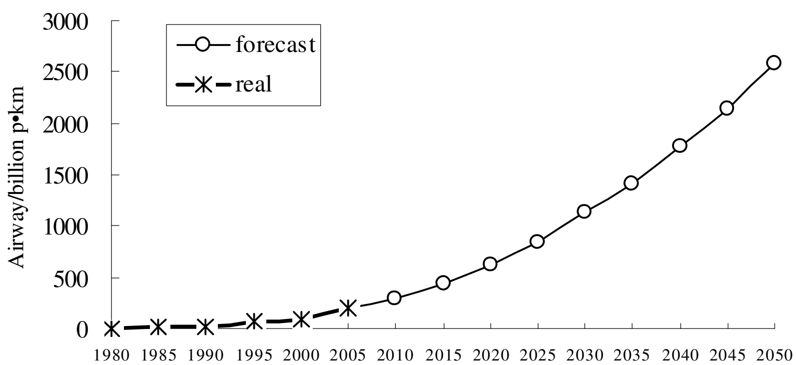
The comparison of the sample values and regression results are shown in figure 5.25.

Figure 5.25 Comparison of the Sample Values and Regression Results from 1978 to 2006



The result shows that air passenger transport is expected to reach 2525 billion p.km by 2050 with the average annual growth rate of 5.75%, as detailed in Figure 5.26.

Figure 5.26 Airway Passenger Transport from 1980 to 2050



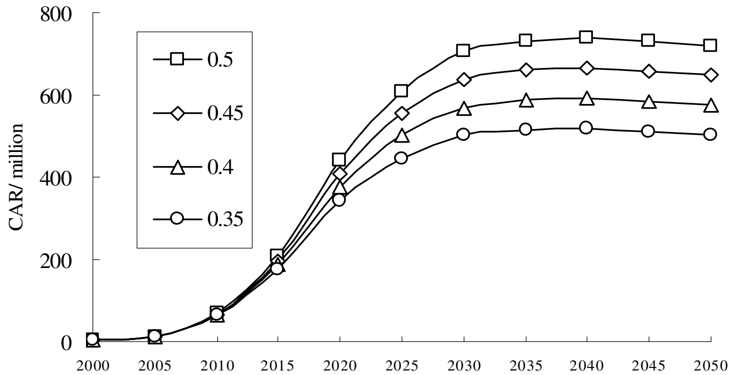
5.3.1.6 Private car

China's car ownership increased very quickly in recent years and it will continue to maintain a rapid growth rate in future. According to the review of OECD countries' car ownership, car ownership will grow with per capita income, but it will reach to a saturation level when the per capita income is close to a certain level. Therefore, this study applies a Gompertz model to project future car ownership. Here, the Gompertz model can be expressed as follows:

$$I = S \cdot e^{\alpha \cdot e^{\beta \cdot PGDP}}$$

Where I is car ownership; PGDP is GDP per capita; S is the saturation level for car ownership, and α and β are the parameters which determine the shape of the curve, they are generally negative. The result is presented in Figure 5.27 below.

Figure 5.27 Private Cars Number during 2000 to 2050

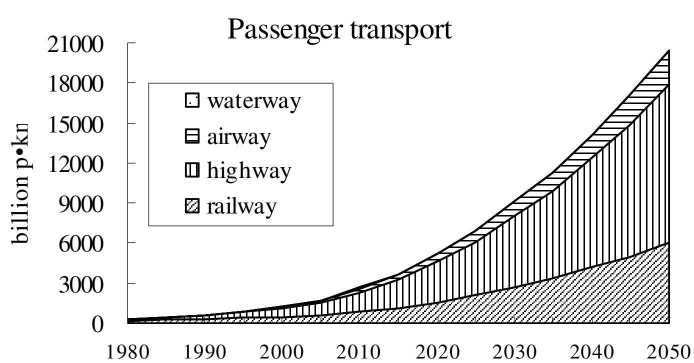


The result shows that the peak value of car number will be in the range of 523 million to 746 million with assumed saturation level varying from 0.35 to 0.5. In this study, we selected the saturation level of the car ownership rate as 0.45. The result shows that high-speed growth of car ownership will continue for decades. The growth rate of car numbers will slow down gradually when per capita GDP gets close to 10,000U.S.dollars. It will peak at 671 million in 2040, and then maintain a stable level. This study assumes that the average annual car mileage will decrease from 10,000 km to 8500 km by 2050. And the average occupancy rate is assumed to decrease from 1.5 people per car to 1 person per car by 2050. Car passenger use is expected to be 4630 billion p•km by 2050.

5.3.1.7 Summary

The total passenger flow will reach 20087 billion p•km and 24717 billion p•km respectively with private car passenger use included or not. From 1985 to 2005, the elasticity of passenger transport to GDP fluctuated between 0.6 and 1.3 with the average value of 0.85 from 1985 to 2005. Future elasticity will be 0.95, almost keeping pace with GDP growth. In respect of passenger transport structure, the proportion of railway passenger in the total passenger transport mix will decline gradually, and the proportion of highways (excluding private car) and air passengers will rise rapidly. The proportion of railway, highway and airlines in the passenger mix will be 29.23%, 58.04% and 12.57% respectively by 2050, as detailed in the figure below:

Figure 5.28 Passenger Transport from 1980 to 2050



5.3.2 Freight transportation

Over the past 30 years, China's freight transport has developed rapidly with the economic development, especially since 2003. As the use of freight transport is mainly related to the total GDP, this study used econometric methods to get the relationship between freight transport and total GDP.

5.3.2.1 Total Freight Transport

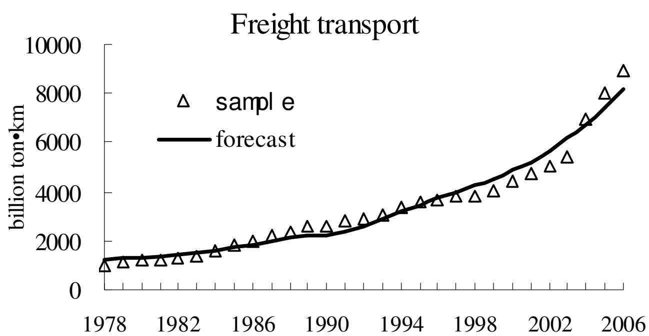
From 1978 to 2006, the average annual growth rate of freight transport was 8.18%, while Freight volume elasticity to GDP was 0.84. But it was 1.27 from 2000 to 2005, and 1.67 from 2003 to 2006. The growth rate of Freight transport was significantly higher than the GDP growth rate. Accordingly, this study shows that the freight volume will continue to maintain a relatively high growth rate, the linear relationship between it and GDP is as follows:

$$FRT.T = 699.8367 + 0.3499 * GDP$$

$$(R^2=0.9689;\ Adjusted\ R^2=0.9677;\ S.D=20330.98;\ D\text{-}W=0.4024)$$

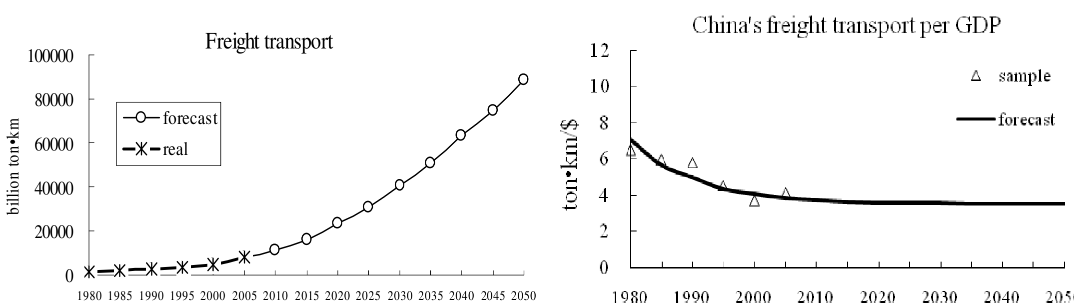
The comparison of the sample values and regression results are shown in the chart below:

Figure 5.29 Comparison of the Sample Values and Regression Results from 1978 to 2006



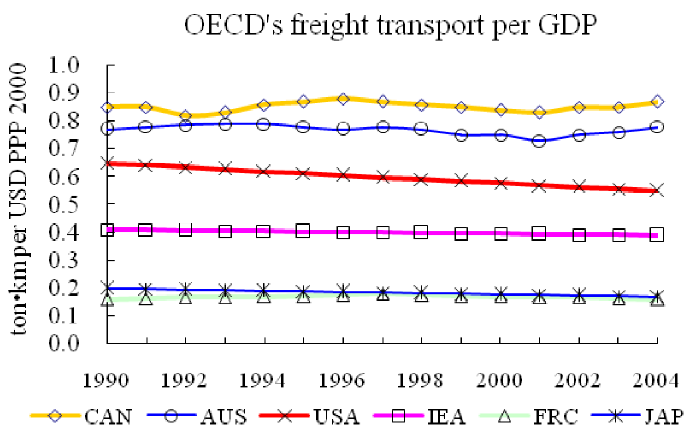
The result for freight transport is shown in the figure below:

Figure 5.30 Freight Transport and freight transport per GDP from 1980 to 2050



The result shows that freight transport will grow at a rate of 5.48% from 2005 to 2050, very close to the passenger growth rate. The freight transport will reach 88675 billion t•km in 2050, but the freight transport per GDP has been in a continuous decline trend since 1980. And in future, the freight transport per GDP will maintain a steady level, at about 4 t•km since 2000.

Figure 5.31 Freight Transport per GDP in the OECD countries from 1990 to 2004



From 1990 to 2004, the freight per GDP in the OECD countries was between 0.1 and 1.0 t•km per USD (PPP 2000). Japan was the lowest, Canada was the highest, the IEA-average and the USA were in the middle (the IEA's value was the average value of 17 IEA countries[10]). We can also see that the freight transport per GDP of all the OECD countries has maintained a stable level. When taking into account that USD PPP is about 3 times of GDP for China, then China's freight transport intensity would be around 1 t•km/US$ (PPP), close to the countries with large land area such as USA, Canada and Australia.

5.3.2.2 Railway

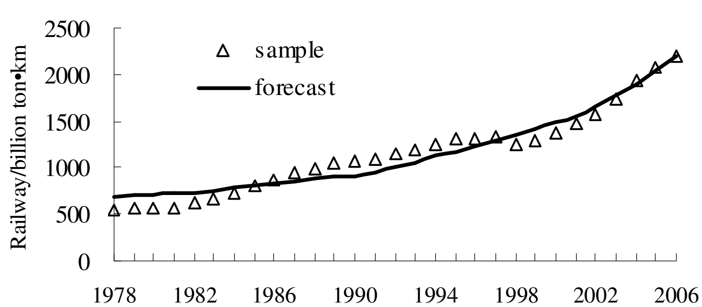
From 1978 to 2006, the average annual growth rate of the railway freight transport was 5.18%, but the proportion of railway freight transport in the total declines rapidly from 54.38% in 1978 to 24.68% in 2006. Accordingly, this study shows that the railway freight transport will continue to maintain a certain growth speed, and the relationship between it and GDP is as follows:

$$FRT.RL = 569.4238 + 0.0766 * GDP$$

$$(R^2=0.9414;\ \text{Adjusted } R^2=0.9392;\ S.D=4513.203;\ D\text{-}W=0.1337)$$

The comparison of the sample values and regression results are shown in the figure below:

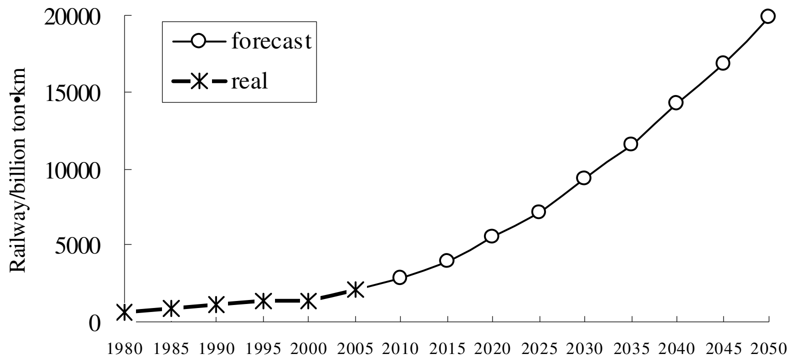
Figure 5.32 Comparison of the Sample Values and Regression Results from 1978 to 2006



The result shows that railway freight will reach 19826 billion t•km by 2050 with the average annual growth rate of 5.15%, as shown in Figure 5.33.

[10] IEA (2008) Energy Use in the New Millennium

Figure 5.33 Railway Freight Transport from 1980 to 2006



5.3.2.3 Highway

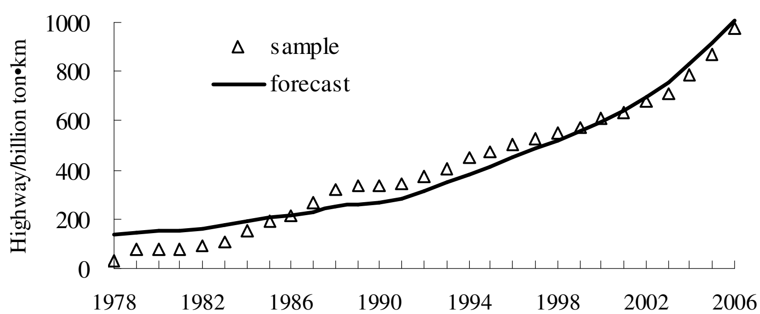
From 1978 to 2006, the highway freight transport reached an average annual growth rate of 13.61%. The proportion of highway transport in the total rose gradually from 2.79% in 1978 to 10.97% in 2006. Nevertheless, the proportion of China's highway freight transport in the total was far lower than in the developed countries. The relationship between it and GDP is as follows:

FRT.RD = 67.6088 + 0.0441 * GDP

(R^2=0.9537; Adjusted R^2=0.9520; S.D=2580.226; D-W=0.1010)

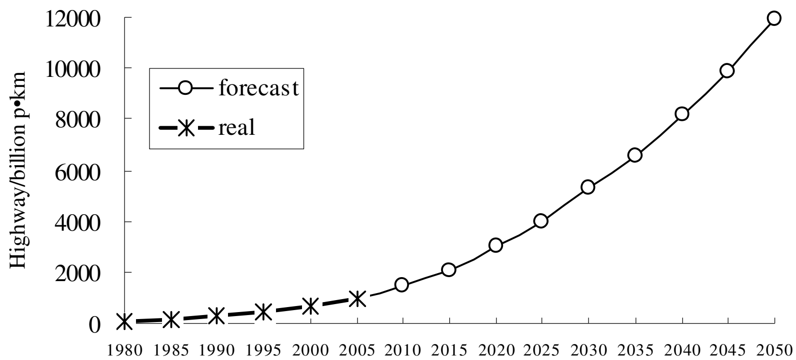
The comparison of the sample values and return results are shown in the chart below:

Figure 5.34 Comparison of the Sample Values and Regression Results from 1978 to 2006



The result shows that highway freight will reach 11148 billion t•km by 2050 with the average annual growth rate of 5.83%, as displayed in Figure 5.35.

Figure 5.35 Highway Freight Transport from 1980 to 2050



5.3.2.4 Waterway

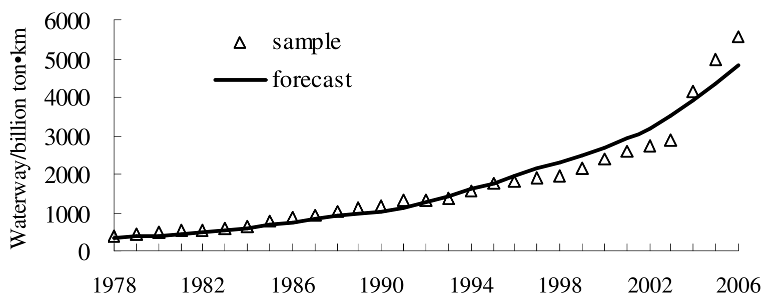
From 1978 to 2006, China's waterway freight transport reached an average annual growth rate of 10.07%, higher than the growth rate of total freight transport in the same period. Accordingly, the proportion of waterway freight transport in the total jumped from 38.45% in 1978 to 62.38% in 2006. With the rapid growth of China's trade, waterway freight transport will continue to maintain a high-speed growth. The relationship between it and GDP is as follows:

FRT.SH = -7.6279 + 0.2257 * GDP

(R^2=0.9527; Adjusted R^2=0.9510; S.D=13226.84; D-W=0.4890)

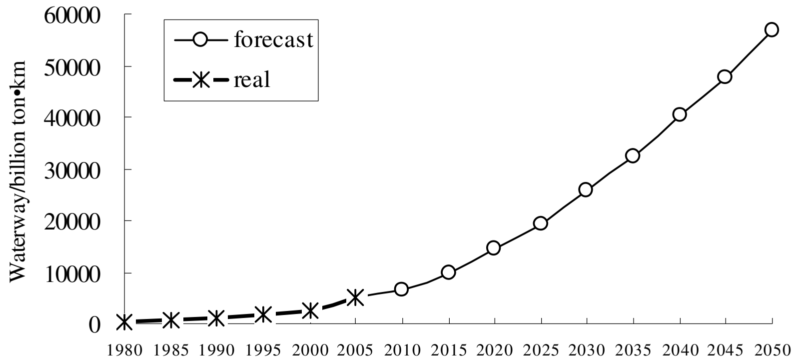
The comparison of the sample values and regression results are shown in the chart below:

Figure 5.36 Comparison of the Sample Values and Regression Results from 1978 to 2006



The result shows that waterway freight transport will reach 56767 billion ton•km by 2050 with the average annual growth rate of 5.56%, as detailed in Figure 5.37.

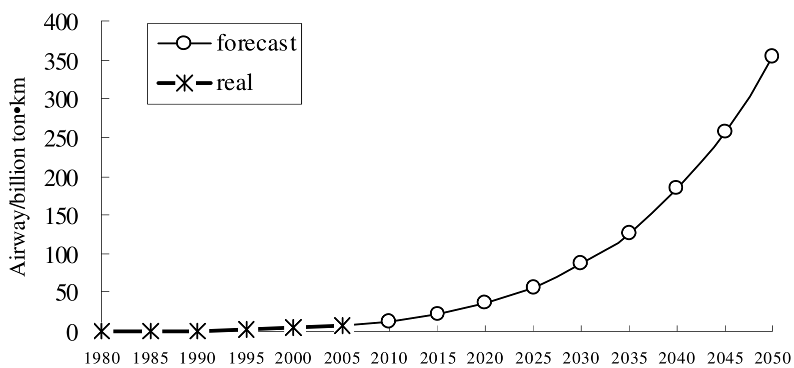
Figure 5.37 Waterway Freight Transport from 1980 to 2050



5.3.2.5 Air freight

From 1978 to 2006, the average annual growth rate of China's air freight transport was as high as 17.76%. Accordingly, the proportion of the air freight transport rose gradually from 0.01% in 1978 to 0.11% in 2006. At present, China has become the world's international container shipping centre, but compared to other transport modes and the situation in other countries, the proportion of China's freight transport moved by air is still very low. Take the United States for example, which has almost the same territory as China, the proportion of the United States' freight transport by air remained at around 0.4% since 2000. This study projects that China's air freight transport would reach 355 billion ton•km by 2050 with the average annual growth rate of 8.82%, and its share in the total would be 0.4% by 2050.

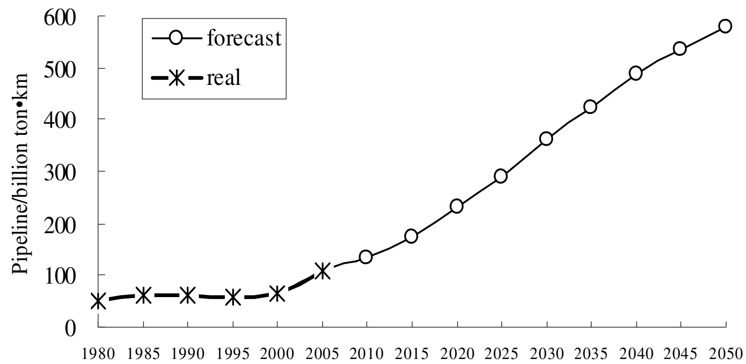
Figure 5.38 Airway Freight Transport from 1980 to 2050



5.3.2.6 Pipeline

From 1978 to 2006, the proportion of China's pipelines in the freight transport declined gradually from 4.37% in 1978 to 1.35% in 2002, but it grew rapidly after 2003 and it increased to 1.87% in 2006. This was mainly because of the rapid growth of Chinese demand for oil and natural gas in recent years, such as the West-East Gas Pipeline project which led to a change to high-speed development of pipelines. The results shows that pipeline freight transport will reach 579 billion ton•km by 2050 with the average annual growth rate of 3.78% during 2005 to 2050.

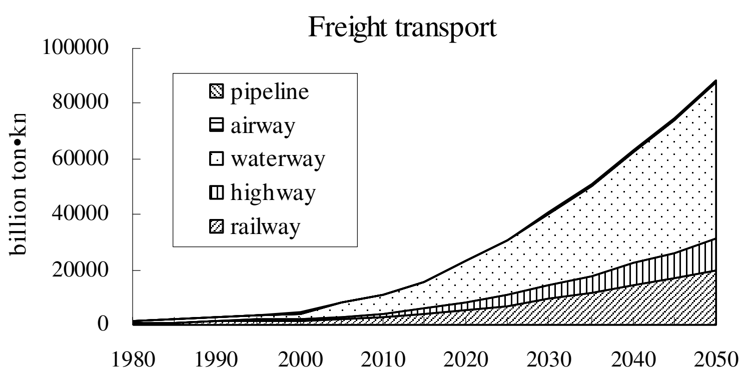
Figure 5.39 Pipeline Freight Transport from 1980 to 2050



5.3.2.7 Summary

The above results show that the freight will grow at a rate of 5.48%, and freight transport will reach 88675 billion t•km by 2050. From 1985 to 2005, the elasticity of freight transport to GDP has fluctuated between 0.5 and 1.3, with the average value of 0.81. From 2005 to 2050, the average elasticity to GDP will be 1.01. In respect of freight transport structure, the proportion of the railway freight transport in the total freight will decline gradually, while the proportions of highway and waterway in total freight transport will increase from 10.83% and 61.89% in 2005 to 12.57% and 64.02% by 2050 respectively.

Figure 5.40 Freight Transport during 1980 to 2050



6 References

Al-Rabbaie, A and Hunt, LC (2006) OECD Energy Demand: Modelling Underlying Energy Demand Trends using the Structural Time Series Model Surrey Energy Economics Centre (SEEC)

Asia-Pacific Energy Research Centre (APERC). APERC Energy Demand and supply Outlook(2002-2030) [M]. 2006.

Chen Wenying, WU Zongxin, and et al, 2005. Assessment on climate change mitigation technologies. Report for the 10th five-year key research project funded by MOST. 2005

China's building materials industry market research report 2004. Http://www.bm.cei.gov.cn. 2005-04-05

Chinese Academy of Sciences research team, 2001. Chemical Industry "Tenth Five-Year Plan". The news of Chinese Academy of Sciences institute. (9). 34 to 35

Department for Transport (DFT) Transport statistics http://www.dft.gov.uk/pgr/statistics/

Development Research Center, 2005. China energy development strategy and policy research report[M]. Beijing: Economic Science Press.

EC (2008) Definition of Energy Efficiency Indicators in ODYSSEE data base - See Definition of Data Section 8 pg 31 http://www.odyssee-indicators.org/Registred/definition_indicators.pdf

EIA (2008) Annual Energy Outlook 2008 with Projections to 2030 http://www.eia.doe.gov/oiaf/aeo/index.html

Energy Information Administration(EIA),2007. International Energy Outlook 2007 [M].

FAO statistical database (FAOSTAT) http://faostat.fao.org.

He Jiankun and et al, 2007. Carbon mitigation strategy study under UNFCCC. Internal report of 3E/Tsinghua.

IEA (2005) Energy Indicators For Sustainable Development: Guidelines and Methodologies http://www.iea.org/textbase/nppdf/free/2005/Energy_Indicators_Web.pdf

International Energy Agency, 2007. Energy Use in the New Millennium: Trends in IEA Countries.

International Energy Agency, 2007. World Energy Outlook 2007: China and India Insights.

National Bureau of Statistics of China, 2007. China Statistical Yearbook. China Statistics Press.

National Bureau of Statistics of China, 2007. China Iron and Steel Industry Statistical Yearbook 2007. China Statistics Press.

National Bureau of Statistics of China & Energy Bureau of National Development and Reform Commission of China, 2007. China Energy Statistical Yearbook 2007. China Statistics Press.

National Information Centre, 2003. China's economic development Review and Prospect.

OEF (2006) Research on Output Growth Rates and Carbon Dioxide Emissions of the Industrial Sectors of EU-ETS Final report (06/1825)

ERI/NDRC, 2005. Report for the 10th five-year key research project funded by MOST. 2005

US Geological Survey Historical Statistics for Mineral and Material Commodities in the United States http://www.usgs.gov/

US Bureau of Transportation Statistics http://www.bts.gov/

Wang Mengkui, 2005. The important issues of China's medium and long-term development(2006-2020). Beijing: China Development Press.