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Transport in China: Energy Consumption and Emissions of Different Transport Modes

Final Report

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in Cooperation with

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1 Summary and Conclusions

1.1 Background and Task

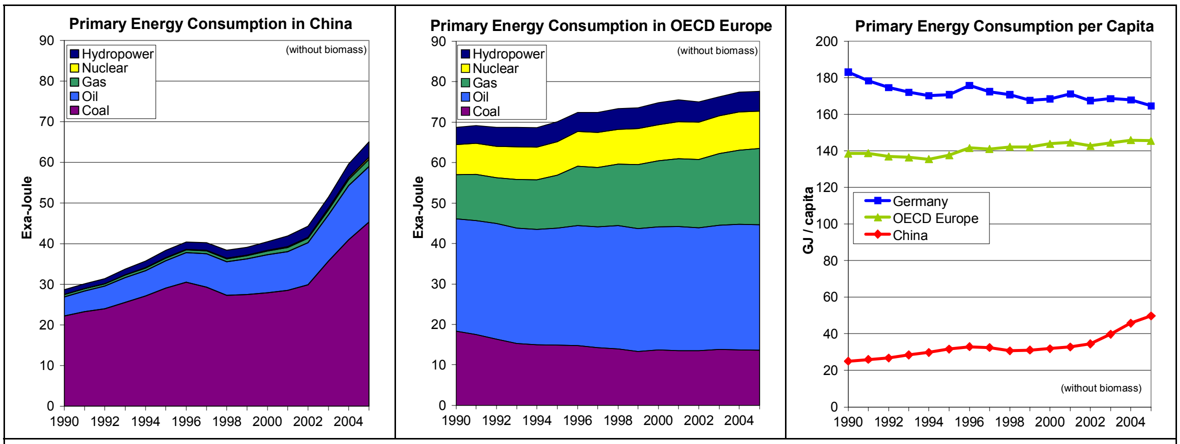
Transport volumes and structures in China change drastically as a result of economic and social development in the country. These changes are associated with increasing energy consumption and negative impacts on the environment, e.g. emissions of greenhouse gases and toxic air pollutants affecting not only the micro and macro climate but also health. For the preparation of strategies to minimize these environmental and health impacts, information about the transport system in China and its contribution to energy consumption and emissions are necessary.

This study delivers information, background material and scenarios on the current transport situation in China compared to Germany and OECD Europe (see glossary, page 71) and possible future developments, considering the following aspects:

- Contribution of transport to total energy consumption and related CO_2 emissions in China and Europe.
- Energy consumption and emissions of the transport sector in China for all transport modes from 1990-2005 and projections until 2030.
- Determination of specific energy consumption and CO_2 emission factors of relevant means of transportation in typical situations in China. Differences to Germany taking into account the prevailing local conditions such as e.g. energy carrier mix on the supply side or load factors on the consumer side.
- Analysis of energy consumption and CO_2 emissions in case studies for long-distance passenger and freight transport relations (Shanghai-Wuhan) and for the passenger transport in an urban agglomeration (Shanghai).

1.2 Total energy consumption in China and Europe

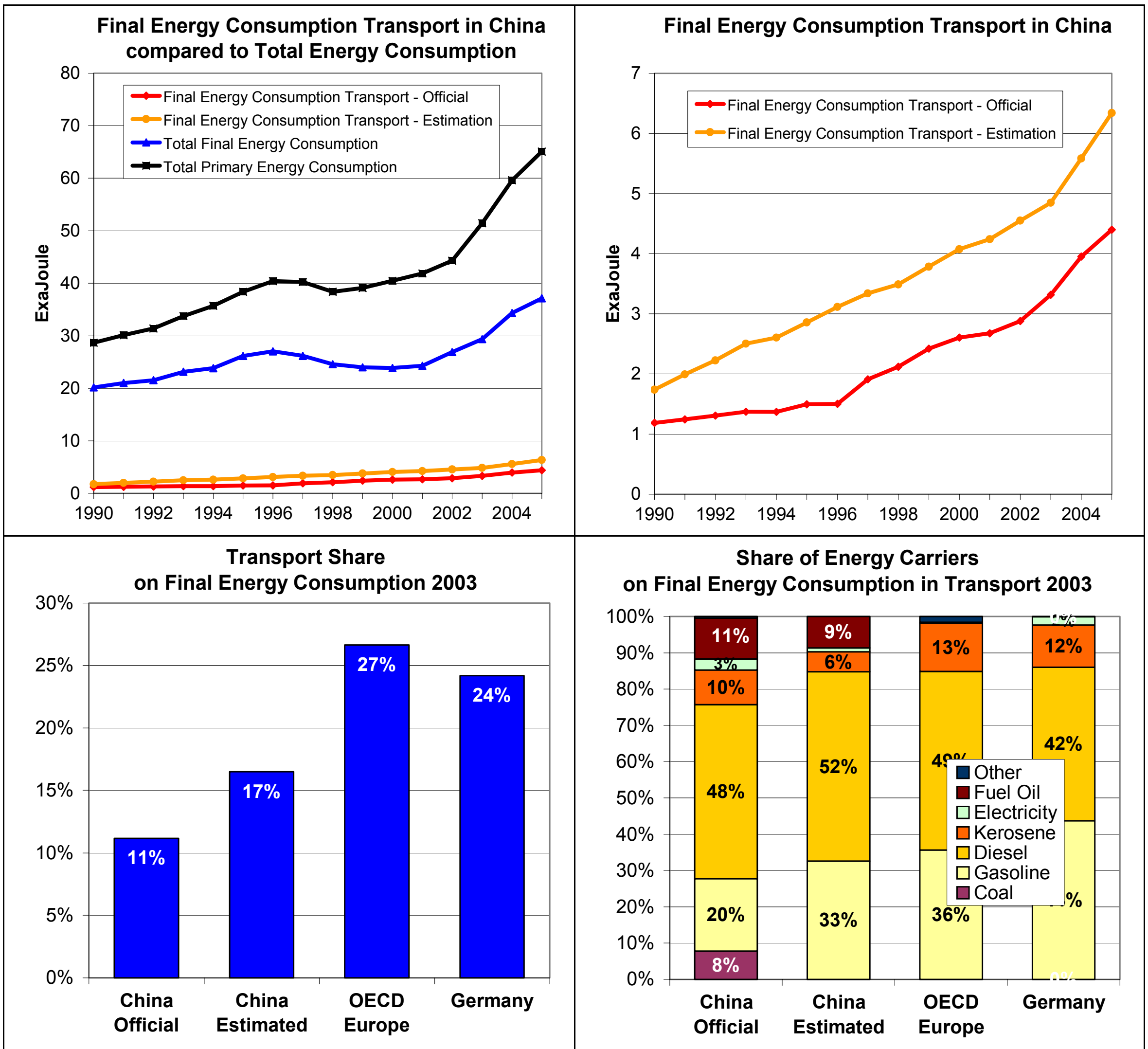
- Primary energy consumption (see glossary, page 71) in China rose from 1990 to 2005 around 127%. Most important primary energy carrier is coal (70%), followed by oil (20%). The comparison to OECD Europe shows large differences concerning the most important sources of energy (less coal, higher portion of oil, gas and nuclear power).
- Primary energy consumption per capita doubled 1990-2005 in China. The rise in OECD Europe was only 5%, in Germany there was a decrease around 10%. Nevertheless, energy consumption per capita is still much smaller in China than in Europe.



Sources: [BP 2006], [OECD 2006], [CSY 2006] IFEU Heidelberg 2008

1.3 Final Energy Consumption of Transport in China

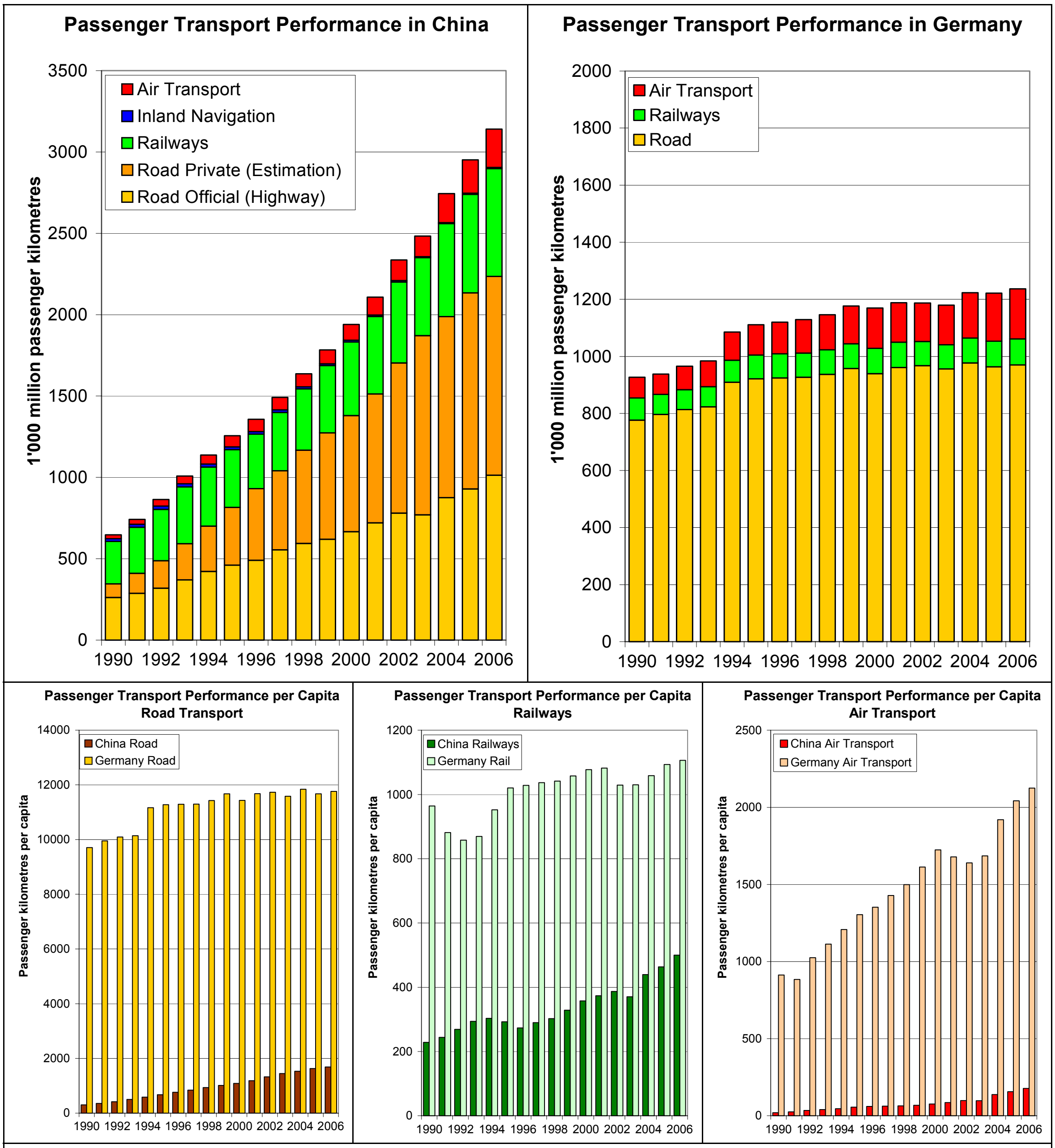
- Energy consumption in transport is only partly documented in official Chinese statistics. Main reason is the demarcation of consumer sectors. In China, energy consumption is not registered according to the kind of its consumption (e.g. freight transport with trucks = transport) but assigned to the originating sector (freight transport with trucks = industry). For passenger transport only the public sector is included but not the private passenger transport.
- Several Chinese and international publications estimated the additional consumption of private transport and the other sectors. Exact numbers are not available. Therefore, estimations are made in order to determine the actual share of transport on the final energy consumption in China. The estimated final energy consumption for the transport sector is about 1/3 higher than the official statistical values
- From 1990 to 2005, final energy consumption of the transport sector in China rose by factor 3.5. Main energy carriers of the transport sector in China are gasoline (33%), diesel (52%), fuel oil (8.7%), kerosene (5.6%) and electricity (1.1%).
- In China the transport sector consumed 17% of the total final energy in 2003. This is still a lower share than in Europe (27%) or Germany (24%).



Sources : [BP 2006], [OECD 2006], [CSY 2006] IFEU estimations IFEU Heidelberg 2008

1.4 Passenger Transport Performance in China and Germany

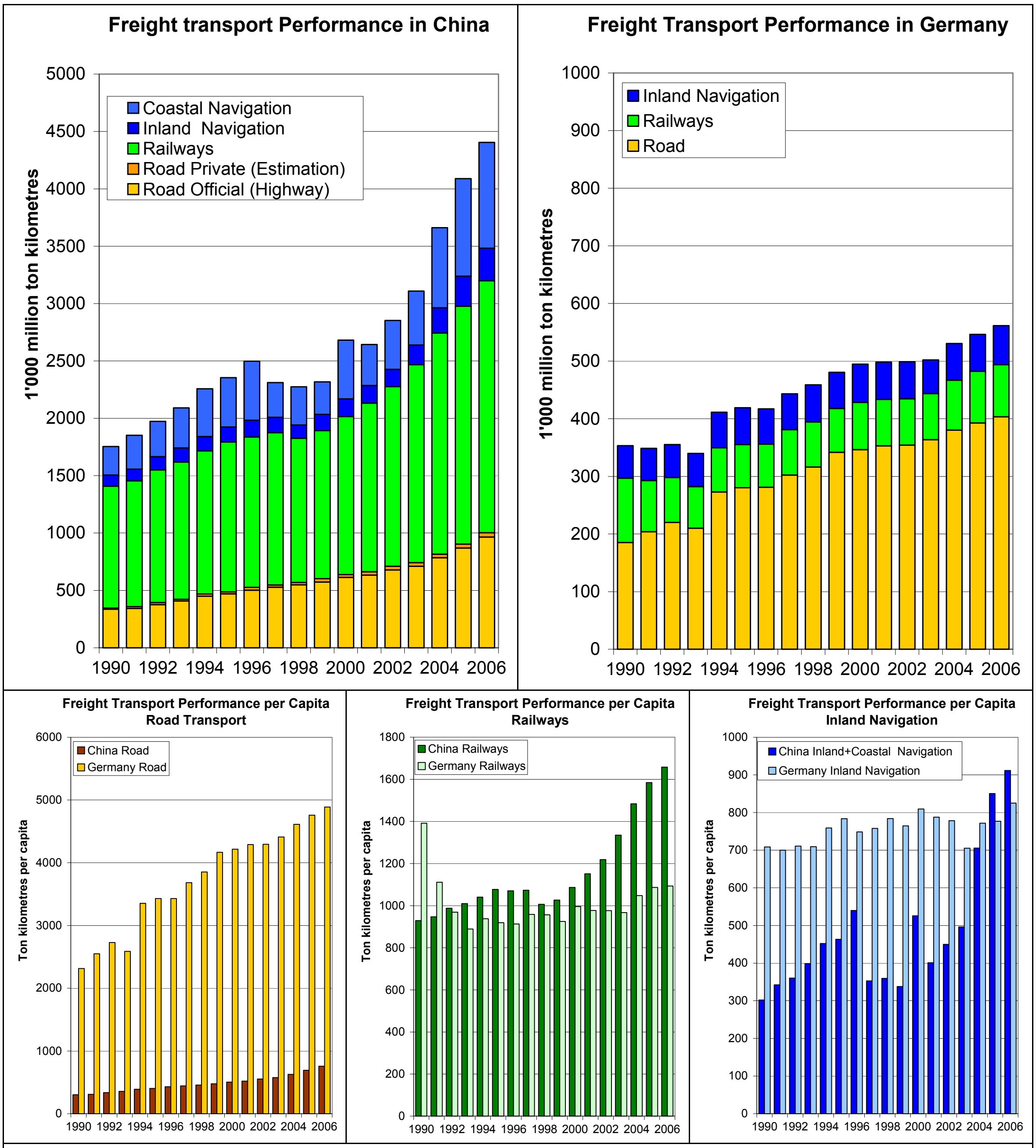
- Passenger transport performance in China increased strongly from 1990 to 2006. Officially registered transport performance (“Highway”) rose by 240%. If the private transport is included the total increase is 390%.
- Even including the private passenger road transport performance in the year 2006, per-capita road transport performance in China reaches only about 15% of the respective value for the same year in Germany.
- Also for air transport the per-capita transport performance in China is only one tenth of the respective value of Germany.
- However, regarding passenger transport by rail the average per-capita transport performance in China is about half of the respective value for the same year in Germany.



Sources: [CSY 2006], IFEU estimation IFEU Heidelberg 2008

1.5 Freight Transport Performance in China and Germany

- Transport performance in freight transport increased likewise strongly in China. Nevertheless, the total freight transport performance of about 3,300 ton-kilometres (tkm) per capita in 2006 has so far only reached less than 50% of the German level which amounts to 6,800 tkm per capita. In China, railway is the dominating transport mode whereas road transport plays a relatively small role so far.

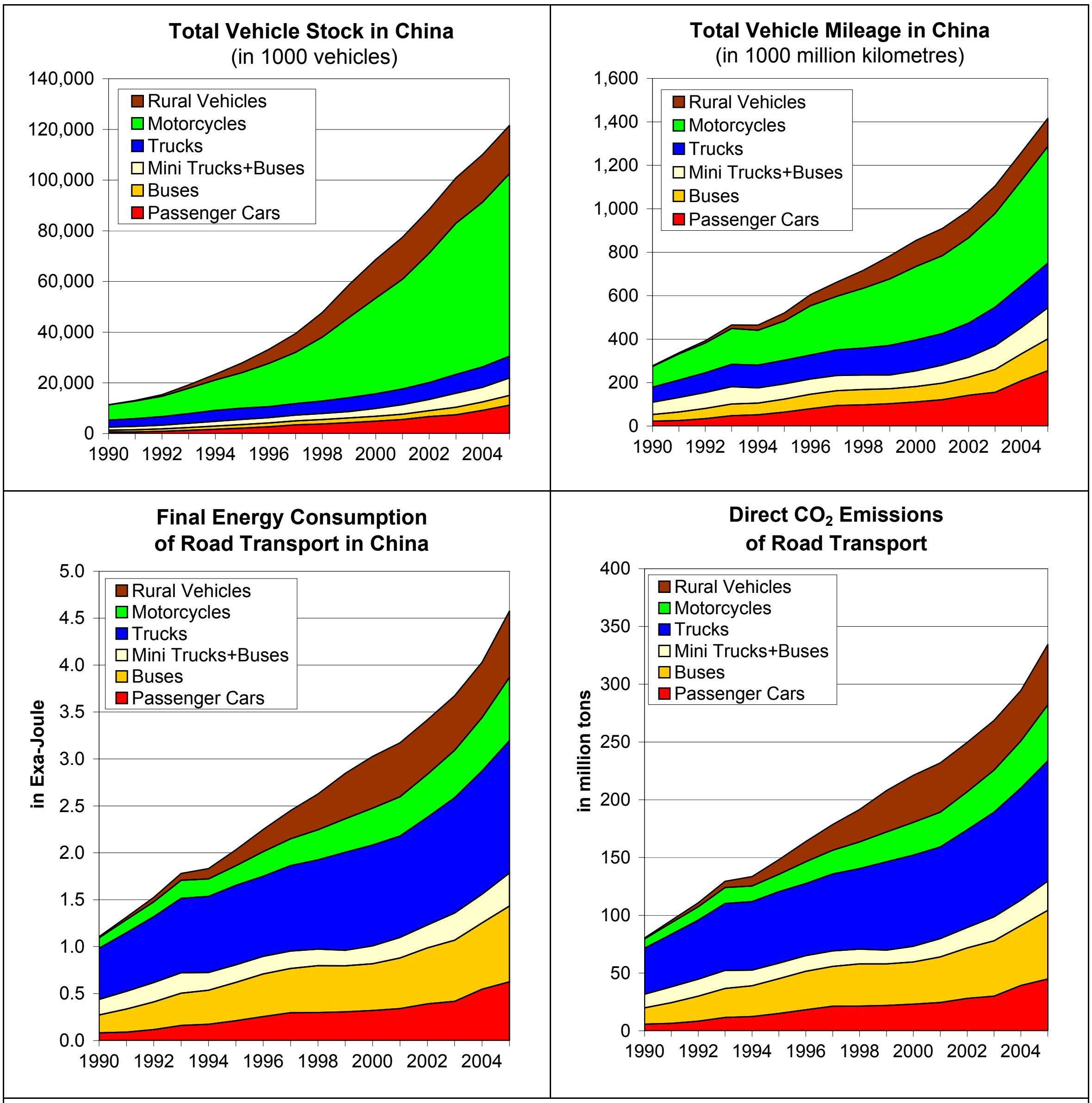


Sources: [CSY 2006], IFEU estimation IFEU Heidelberg 2008

- It can be expected that Chinese economy will face structural changes with complex production processes and the interchange of high valued semi-final and final products in the future. The freight transport demand of such a high complex production system will most likely be significantly higher than today with the focus on raw materials and other bulk goods.
- Due to the expected economic growth in China the industrial sector may require an additional freight transport demand linked purely to the industrial sector. This may well force the total demand for freight transport performance per capita up to the same or beyond the German level, which would mean about doubling the present level. Due to the much longer transport distances in China (compared to Germany) this effect may even be more significant.
- In addition, the transport of energy and raw materials will also increase due to the expected economic growth (e.g. expected growth of primary energy demand coal by factor 2.2 from 2005 to 2030 in the IEA reference scenario [IEA 2007], see chapter 5).

1.6 Final Energy Consumption and CO_2 Emissions of Road Transport in China

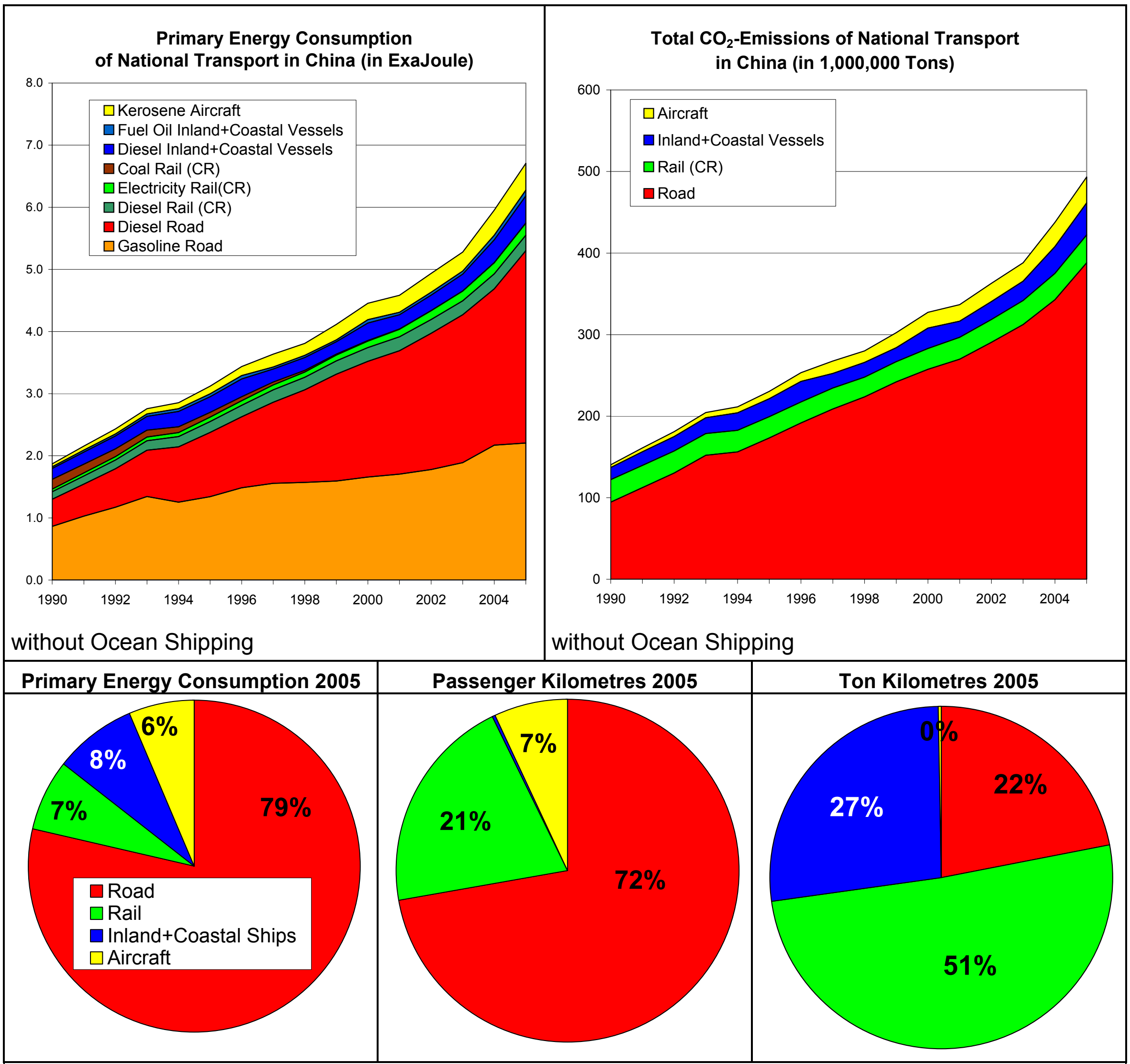
- The stock of road vehicles in China strongly increased by factor 10 between 1990 and 2005. Motorcycles have the highest share on total vehicle stock, followed by rural vehicles, buses and passenger cars.
- As a result, the vehicle mileage travelled in road transport increased by about factor 5, final energy consumption and CO_2 emissions increased by factor 4.
- Trucks and buses are the main contributors to energy consumption in road transport. However, in the last years the share of passenger cars and rural vehicles has been increasing as a result of their higher-than-average mileage increase.



Sources:
IFEU Estimations, based on [Kebin He et al. 2005], [Hong Huo et al. 2006], [CSY 2006] IFEU Heidelberg 2008

1.7 Primary Energy Consumption and CO_2 Emissions of All Transport Modes in China

- Since 1990, primary energy consumption and CO_2 emissions of the transport sector in China have increased strongly (1990-2005 factor 3.5), primarily in road transport (factor 4), inland navigation (factor 2.5) and air transport (factor 10). In rail transport the increase was only factor 1.4 as a result of the change from coal traction to diesel and electricity.
- In 2005 road transport had the highest share on energy consumption and CO_2 emissions in transport (79%) followed by ship (8%), rail (7%) and air transport (6%). Due to its higher energy-efficiency (i.e. lower specific energy-demand) the share of energy consumption of railways is significantly lower than the railway share on transport performance of passenger transport (21%) and freight transport (51%).



Total CO_2 including emissions of fuel and electricity generation ("well-to wheel").

Sources: IFEU Estimation, based on [Kebin He et al. 2005], [Hong Huo et al. 2006], [CSY 2006], [ICT 2007] et al.

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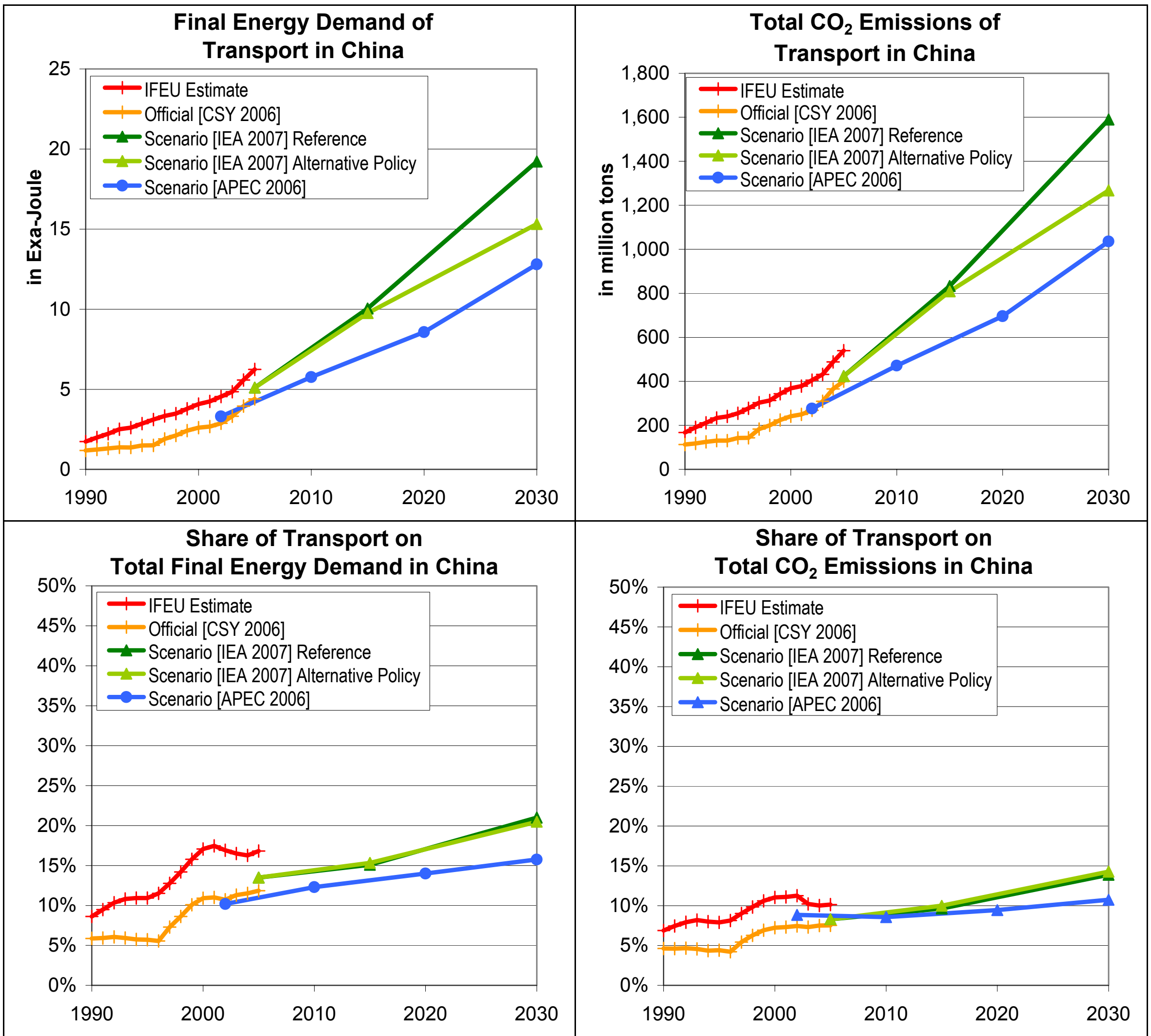
1.8 Scenarios for Possible Future Development until 2030

- Scenarios for future traffic demand and thus future energy consumption in China in general and in the transport sector in particular are associated with high uncertainties due to the very dynamic economic and social development in the country.
- Recent energy scenarios estimate more than a doubling of energy consumption and CO_2 emissions in China up to 2030 compared to 2005. For transport, in the same time period an increase of energy consumption and CO_2 emissions by factor 3-4 is estimated.
- According to these scenarios, the transport sector will have a considerably increased share on future total energy consumption – and thus CO_2 emissions – in China. Despite this sharp increase, transport energy consumption per capita in China in 2030 will still be less than half compared to OECD Europe and Germany.



Total CO_2 including emissions of fuel and electricity generation (“well-to wheel”).

Sources : [IEA 2007], [APEC 2006], [CSY 2006], IFEU Estimations IFEU Heidelberg 2008

1.9 Specific Primary Energy Consumption and CO_2 Emissions for Relevant Transport Systems in China and Germany

Urban Passenger Transport

- Urban rail transit systems (metro, light rail) in China are highly energy efficient and have low CO_2 emissions compared to bus and passenger car. Only very optimized BRT systems with high passenger capacities (270 persons per vehicle, 25 m long, articulated, 3 sections), separate lanes and fly-overs at major road crossings can reach or exceed the energy efficiency of metro transport. Metro systems in general offer higher passenger transport capacities per line compared to BRT systems, but need higher investment costs.
- Even if energy consumption of stations (ventilation, airconditionig, illumination, escalators, etc.) is included, metro systems in China are more energy-efficient than the average urban bus and passenger cars.
- Passenger cars in urban traffic of Chinese mega-cities are very inefficient. This effect is increased by low vehicle occupation (1.3 persons/vehicle) and high traffic load (congestions and slow traffic flow).
- Chinese metro systems have higher capacity utilization due to a less space being occupied by seats and considerable higher average load factors. (39% compared to 17%). Therefore, the specific primary energy consumption of metro systems in China is three times lower than in Germany.

Long distance passenger transport

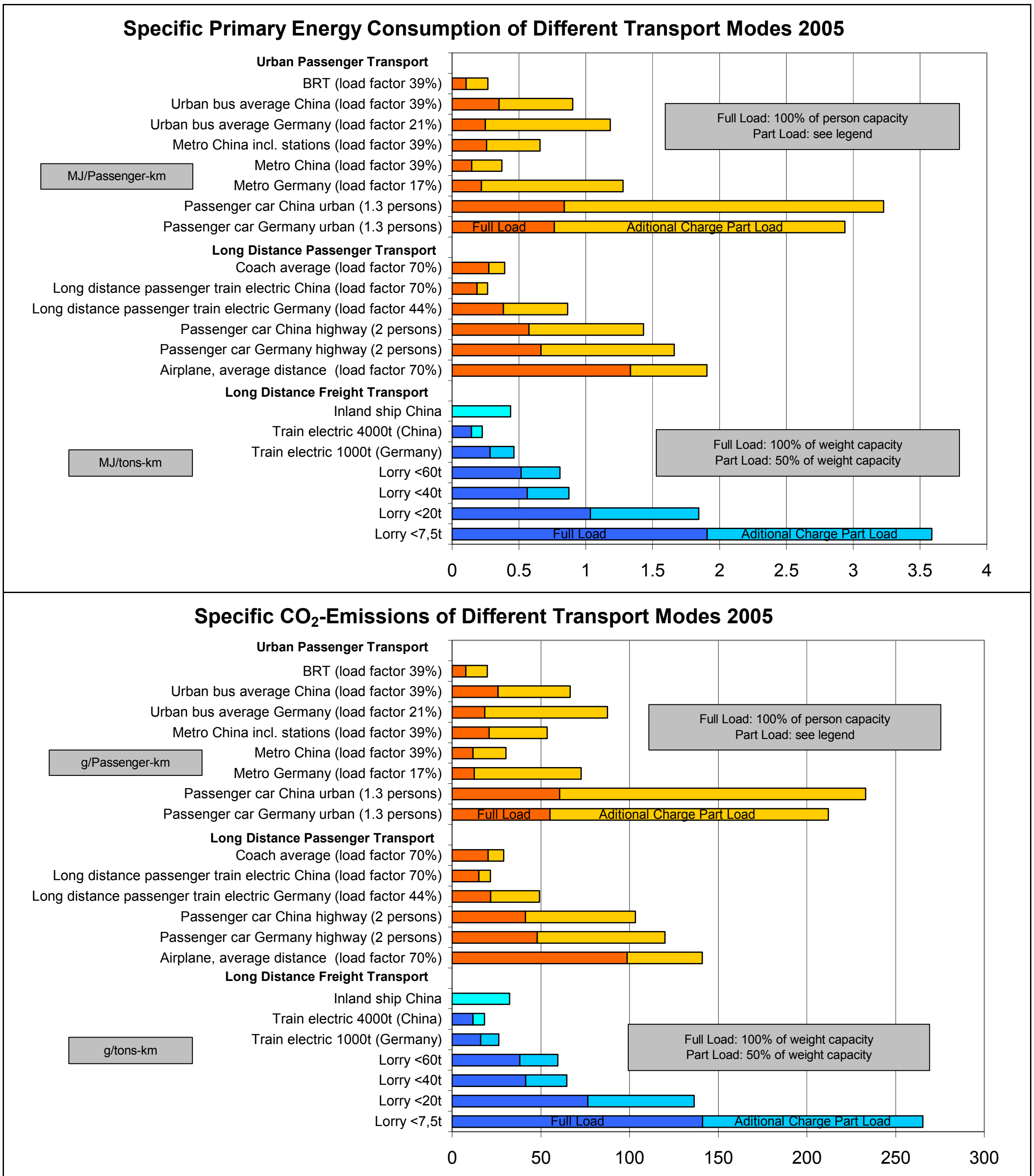
- Passenger trains in China have a high energy efficiency and low CO_2 emissions compared to coach and passenger car due to high capacities per train and high load factors of 70% [ICT 2007].
- Compared to Germany passenger trains in China are more efficient due to a higher seat capacity and higher average load factors.
- Long distance trips with passenger cars on highways are probably more energy-efficient than in Germany due to the speed limit of 120 km/h in China and a more evenly driving behaviour.

Freight Transport

- Chinese freight trains benefit from high train loads. Double stack container trains with a load of 4,000 t have about half the specific energy consumption than average German freight trains with a load of 1,000 t.
- The specific energy consumption of 40 ton lorries is about four times higher compared to the double stack container train. Smaller lorries will have an even higher specific energy consumption compared to the freight train.

All Transport Modes

- In general, urban rail transit and railways in China are very energy-efficient systems, due to high transport capacities and high load factors. Therefore, rail transport in China has from the outset a much higher energy saving potential vis a vis road transport than in Europe.
- Due to the high share of coal in electricity generation in China, electric trains have similar specific CO_2 emissions as diesel trains. Thus, the advantages of electric railways concerning CO_2 emissions are resulting mainly from increased line capacity. The energy mix, however, is expected to change in future in favour of less CO2 emitting energy carriers and power plants.



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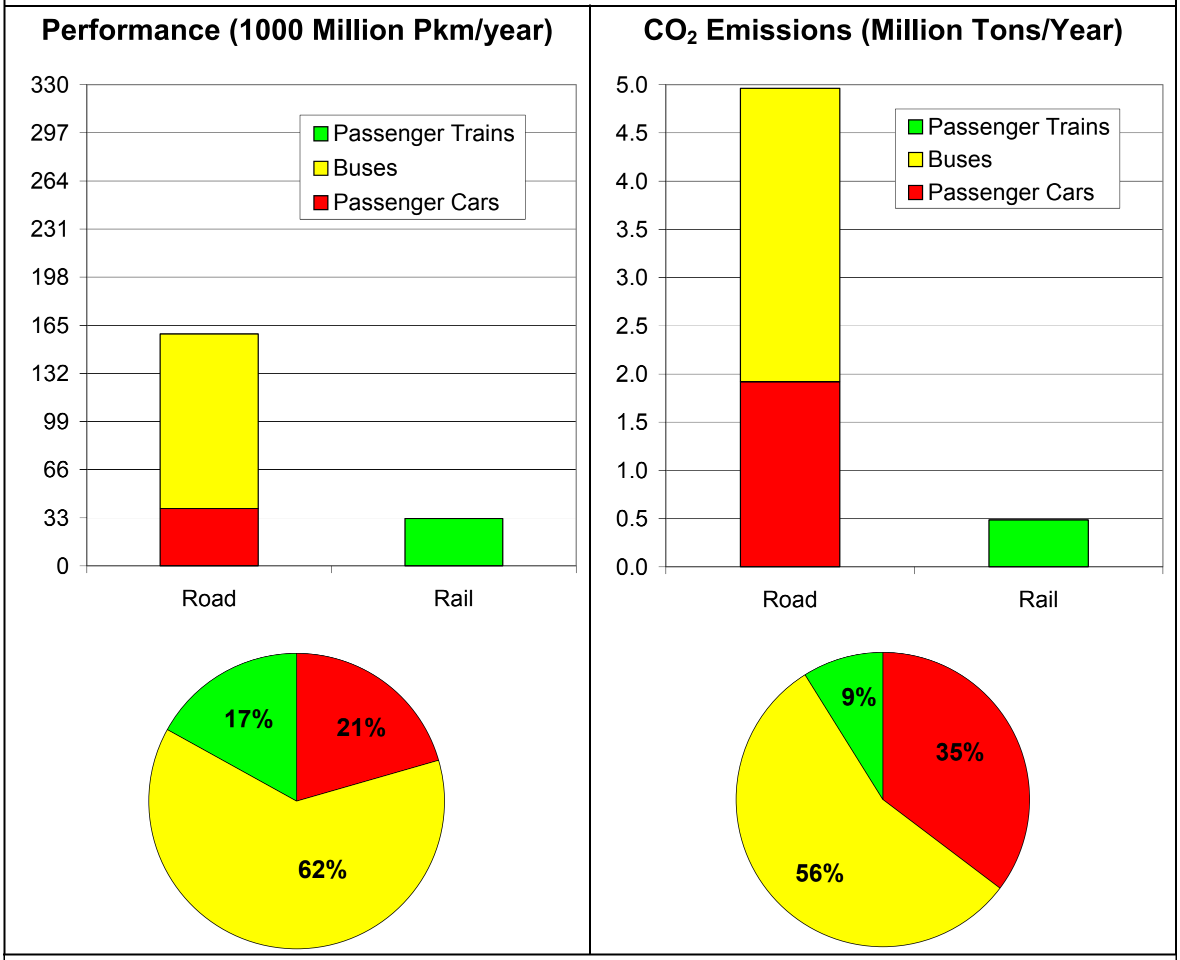
1.10 Case Study: Long Distance Transport Shanghai-Wuhan

Energy consumption and CO_2 emissions were estimated for passenger and freight transport on the long distance relation Shanghai-Wuhan on highway and on the new railway line. The following results can be stated:

Passenger Transport

- The passenger transport performance on the highway is expected to be about five times higher in 2020 than on the railway line. About three-quarter of the future transport performance on the road is expected to be delivered by buses of different size classes from mini to large bus.
- The calculated CO_2 emissions of road passenger transport are about ten times higher than the emissions of rail transport. The larger difference between road and rail compared to the transport performance is mainly due to the higher specific CO_2 emissions of passenger cars.
- Whereas rail delivers 17% of passenger transport performance, it only contributes 9% of the transport related CO_2 emissions in the corridor.

Passenger Performance and CO_2 Emissions of Shanghai-Wuhan Highway and Railway in 2020

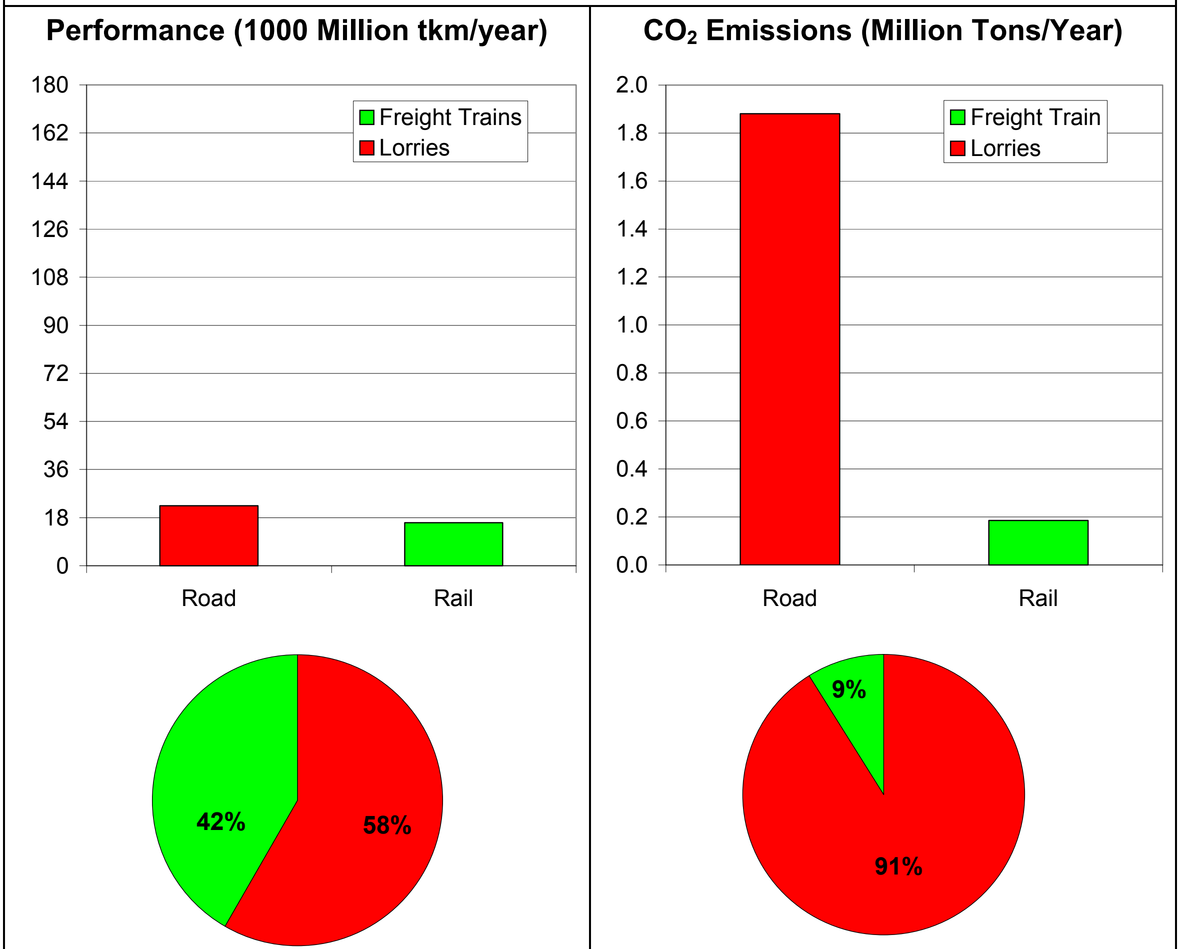


Source: [ICT 2007], IFEU estimations IFEU Heidelberg 2008

Freight Transport

- The expected freight transport performance is about one-third higher for road transport than for rail transport.
- The use of efficient freight trains, e.g. double stack container trains with a comparable high pay load factor leads to significantly lower CO_2 emissions in rail transport than in road transport for the same transport performance.
- As a result railways will account for 42% of transport volume but only for 9% of the related CO_2 emissions in the corridor.

Freight Performance and CO_2 Emissions of Shanghai-Wuhan Highway and Railway in 2020



Source: [ICT 2007], IFEU estimations IFEU Heidelberg 2008

Special Benefits from New Railway Line

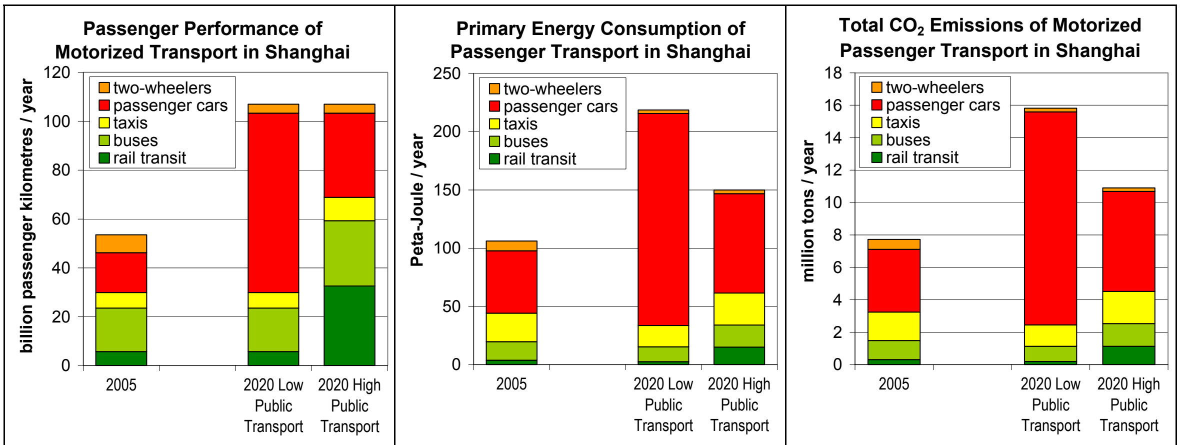
- The construction of the new railway lines Nanjing-Hefei and Hefei-Wuhan reduces the distance between Shanghai and Wuhan by 30%. Energy savings due to these new lines can be expected to be even higher than 30% since they allow for the use of modern electric trains with higher train loads.
- Additional energy savings are also induced by less longitudinal gradients of the new line and a more economic operation due to double track operation with less train stops for train crossings.

1.11 Case Study: Urban Transport Shanghai

The current state of urban passenger transport in Shanghai was characterized and assessed. Environmental performance of different transport systems regarding primary energy consumption and CO_2 emissions was compared. Possible future developments of passenger transport demand with different shares of energy-efficient public transport were compared in order to point out the high importance of a well-developed public transport system.

- Urban rail transit in Shanghai is nearly 5 times more energy-efficient than passenger cars, public bus transport about 4 times. Specific CO_2 emissions per passenger-km are proportional to primary energy consumption.
- In the year 2005, urban rail transit accounted for less than 4% of CO_2 emissions but delivered 11% of passenger performance. Buses accounted for 15% of CO_2 emissions, while they delivered 33% of passenger performance. Contrary to public transport, passenger cars delivered only 30% of the passenger performance, while being responsible for more than 50% of CO_2 emissions. For taxis, the comparison is even more unfavourable with only 12% of passenger performance and 23% of CO_2 emissions.
- Two future scenarios were calculated for 2020, both assuming a duplication of total transport demand:
  Low public transport: All increase of passenger performance by passenger cars.
  High public transport: Strong growth of public transport, esp. urban rail, as assumed in the ICT field research [ICT 2007]. Moderate increase of transport with passenger cars.
  In both scenarios, a 20-25% reduction of specific energy consumption was considered for all transport modes.
- In the *low public transport scenario* with no growth of public transport, CO_2 emissions more than double 2005-2020. The share of passenger cars on passenger performance increases from 30 to 69% and they contribute 83% to CO_2 emissions.
- In the *high public transport scenario*, primary energy consumption and CO_2 emissions increase only by 40%. Energy-efficient urban rail transit will carry out 30% of passenger performance causing only 10% of the total CO_2 emissions.

Total primary energy consumption and CO_2 emissions of passenger transport in Shanghai in the year 2020 are in the *high public transport scenario* about 30% lower than in the *low public transport scenario* – providing both the same total passenger performance.



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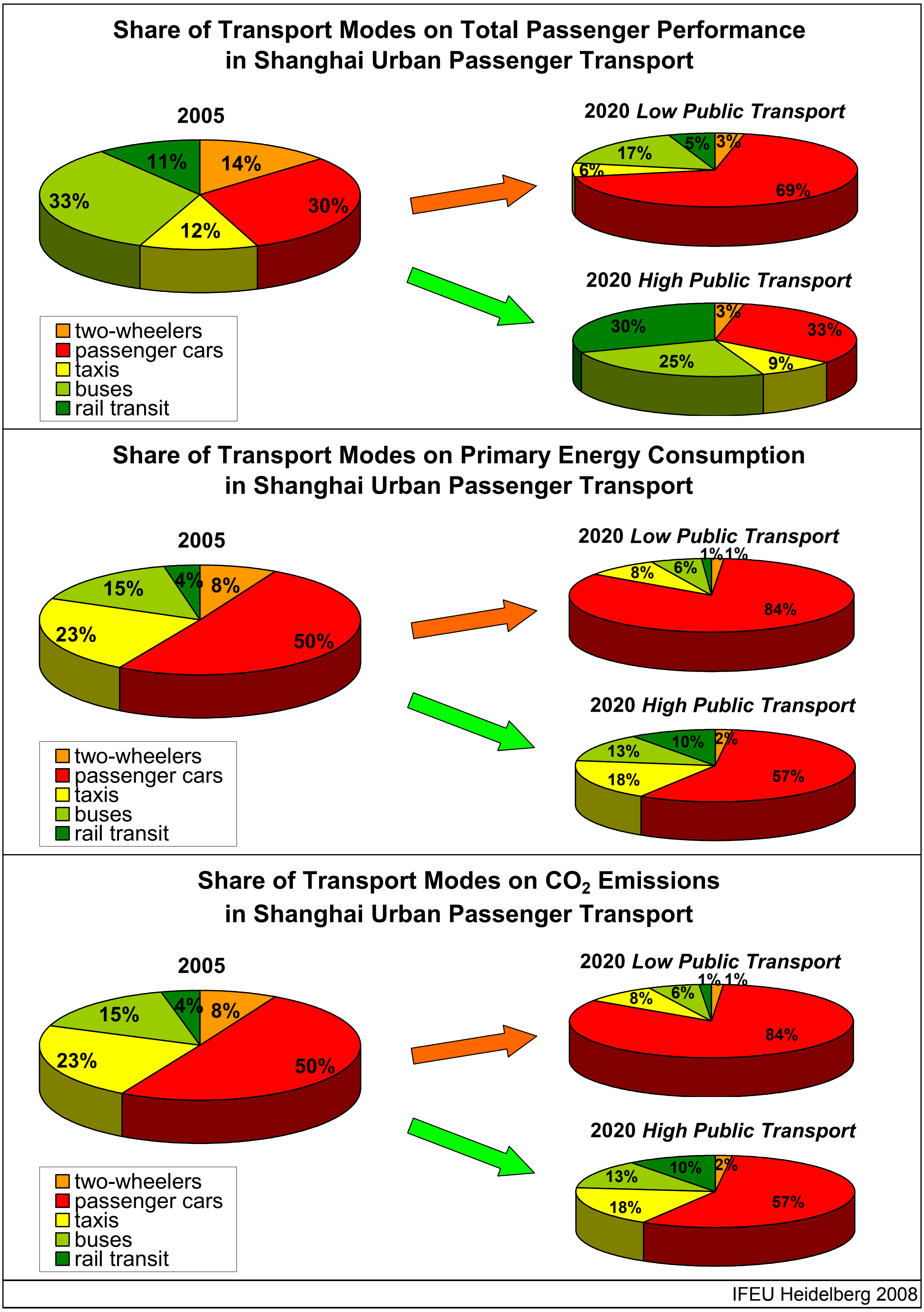

Share of Transport Modes on Total Passenger Performance
in Shanghai Urban Passenger Transport
2005
11%
14%
33%
30%
12%
2020 Low Public Transport
17%
5%
3%
6%
69%
2020 High Public Transport
30%
3%
33%
25%
9%
two-wheelers
passenger cars
taxis
buses
rail transit
Share of Transport Modes on Primary Energy Consumption
in Shanghai Urban Passenger Transport
2005
15%
4%
8%
23%
50%
2020 Low Public Transport
1%
1%
8%
6%
84%
2020 High Public Transport
13%
10%
2%
18%
57%
two-wheelers
passenger cars
taxis
buses
rail transit
Share of Transport Modes on CO_2 Emissions
in Shanghai Urban Passenger Transport
2005
15%
4%
8%
23%
50%
2020 Low Public Transport
1%
1%
8%
6%
84%
2020 High Public Transport
13%
10%
2%
18%
57%
two-wheelers
passenger cars
taxis
buses
rail transit
IFEU Heidelberg 2008

1.12 Conclusions for environmental strategies in the transport sector

Energy consumption and CO_2 emissions of transport in China increase rapidly, dominated by the less energy efficient modes road and aircraft traffic. Thus measures are necessary to limit the growth of greenhouse gases.

The development of transport in transition countries like China with drastic changes within very short time-frames cannot be compared to the recent development in Europe. To a certain extent, however, a comparison is possible to the longer term dynamic development in OECD Europe in the second half of the last century. For this reason, recent environmental strategies in Europe cannot be simply transferred to China but lessons can be learnt from the development in Europe over the last 60 years. Hence, some important principal strategies can be specified that partly already are being implemented and should be followed up intensively:

Overall strategies for the transport sector

- Development of nation-wide transport sector strategy:
    - Enhance the network capacity of environmentally friendly and energy-efficient means of transport (i.e. water transport, long-distance and urban rail transport) to cope with growing transport demand specifically on major trunk transport corridors.
    - Extend transport networks with the aim to reduce energy- and time-consuming detours.
    - Identify and define a network of high capacity corridors where traffic loads justify investment in high capacity railways and/or waterways.
    - Railway-lines and waterways in general require much longer lead times for planning and implementation compared to roads and airports. Moreover, the benefit of investments into railways and waterways will only be realized if they are really completed and efficiently interlinked into a well-performing transport network. Hence, design and approval procedures for such projects must be started well in advance so that these transport modes can compete successfully as and when required or when new roads or airports are becoming available.
- Technical improvement of vehicles: Increase of the energy efficiency of the vehicle, reduction of toxic air pollutant emissions – e.g. by using aftertreatment technology, improved inspection and maintenance programs.
- Optimization of vehicle operation, e.g. handling, optimal speeds and reduction of travel stops.
- Ensuring of high vehicle loads in public transport and improvement of vehicle load in private transport (utilization of the maximum place and/or loading capacity, avoidance of empty travels).
- Promote the “user/polluter shall pay principle” to avoid excessive transport demand and ensure funding of energy-efficient and environmentally friendly transport technologies.

Urban transport

- Integration of environment-friendly transport modes in planning processes for urban development (incl. routes for Suburban Railways, Metros, BRT, tram, bicycles).
- Concentration and development of housing areas, commercial and business centres in urban areas along future high capacity public transport corridors.
- Introduction and retention of high fees for the registration of new cars to limit the increase of private car ownership and usage in highly populated urban agglomerations.
- Limitation and pricing of parking areas in core cities and in business districts in order to reduce car usage and attract the use of public transport systems.
- Reduction of air pollution from road traffic by restraining the access to urban areas for high-emitting vehicles (e.g. low emission zones, emission-graded congestion charge).
- Maintaining a high level of non-motorized passenger transport with bicycles and walking in urban areas, especially for short distances < 5km.

Road transport

- Design and promotion of low-energy and –emission small vehicles (2-4 wheels) for people with low incomes to continuously replace high-emitting conventional motorcycles, rural vehicles and passenger cars.
- Technical standards for fuel consumption and quality in order to reduce specific consumption of new cars and enable the application of modern after-treatment technologies.
- Modification of the road traffic taxation (fuel and/or license plate) in order to better cover the micro- and macro-economic costs, applying e.g. the "user shall pay principle".
- Regulative standards to reduce emissions of air pollutants– at least adoption of European legislation (especially for motorcycles and three-wheelers). As development in Germany shows, implementation of stringent emission standards leads to a high reduction of air pollution and is an important component of strategies to improve air quality.
- Advancement and promotion of low-emission transport modes (incl. no discrimination of bicycles as zero-emission vehicles in cities).

Railway transport

- Identify corridors and define a network development strategy where railways can offer best service to the economy.
- Implement railway projects at high design standards which allow railways to compete successfully with air transport and road transport for both passenger as well as freight transport.
- Electrification of railways to improve capacity of lines, to reduce dependency on oil imports, and use of local and renewable energy for transport.
- Implement technologies which improve capacity, safety and availability of existing or new lines.
- Early adaptation to structural changes in production and mobility, i.e. market oriented flexible services, further expansion of containerisation (terminals, multi-modal transport), expansion of high speed passenger railway lines.

2 Background and Focus of the Project

Transport volumes and transport structures in China change drastically as a result of economic and social development in the country. These changes are often associated with negative impacts on the quality of life, e.g. traffic jam and accidents with injuries and deaths, as well as on environmental issues, e.g. energy consumption and emissions of greenhouse gases, toxic air pollutants and noise. Furthermore, this will go hand in hand with a strong increase of costs for oil imports, increased dependencies on oil producing countries and hence vulnerability of the economy. To minimize these impacts, means of transportation and energy carriers should meet ecological requirements.

The German Government through KfW Development Bank of Germany has co-financed within the frame of Sino-German Financial Cooperation several metro and railway projects in China, for example

- Shanghai metro lines1 and 2
- Guangzhou metro line 1
- Electrification of existing railway line Harbin – Dalian
- New railway line Huaihua – Chongqing
- New railway line Hefei – Wuhan

Furthermore modern construction technologies were introduced with the support of Sino-German Financial Cooperation in order to enhance capacity, efficiency and safety of the respective local industry.

These projects should support the improvement of energy efficiency and the reduction of CO_2 emissions in the fast growing transport sector in China. For a reliable estimation of the reduction effects information of the transport sector and its contribution to total energy consumption and CO_2-emissions are needed.

In this regard, this study delivers information, background material and scenarios on the current transport situation in China and possible future developments, considering the following aspects:

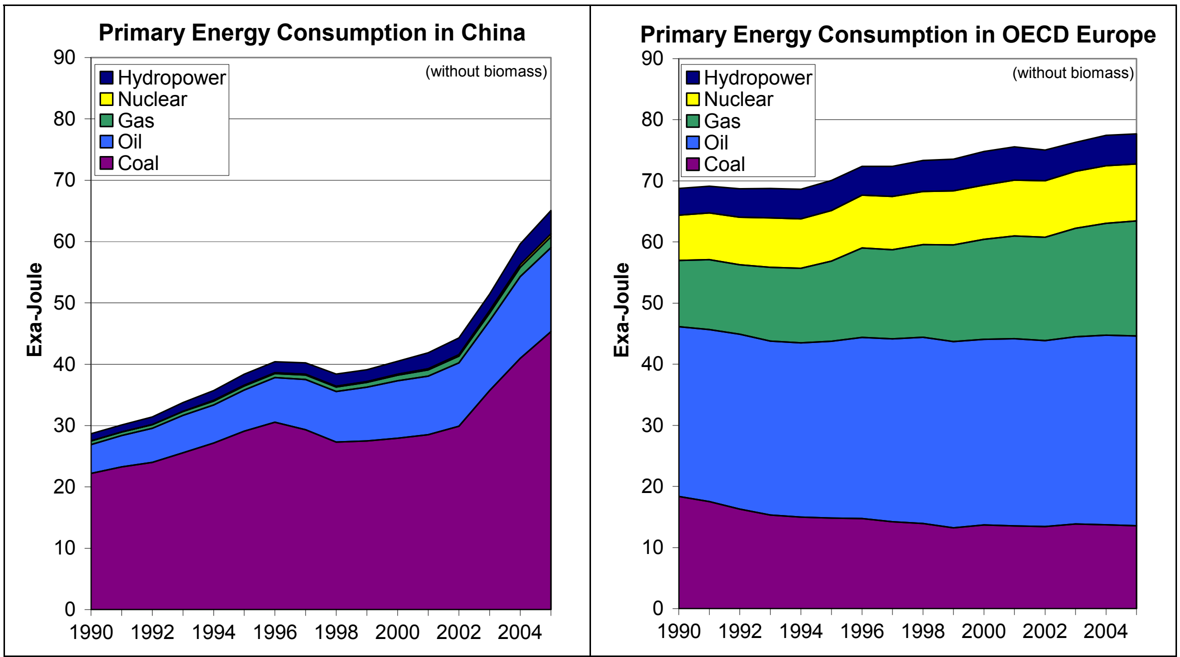
- Analysis of energy consumption and CO_2 emissions in the transport sector in China from 1990 until today as well as possible tendencies of development in the future.
- Contribution of the transport sector to total primary energy consumption and CO_2 emissions in the country.
- Detailed analysis of energy consumption and emissions for the main transport modes.
- Analysis of energy consumption and CO_2 emissions on a transportation relation for long-distance road and railway transport. Focus is on the effects of new railway lines, the shift of transport from road to rail and its contribution to the reduction of the environmental effects of transport.
- Analysis of energy consumption and CO_2 emissions of the local traffic in a selected urban agglomeration. The emphasis is placed on the possible contribution of urban rail systems to reduce the environmental effects of increasing urban transport.

3 Energy Consumption in China

Basis of each environmental balance for countries is the domestic energy consumption. Therefore, the energy balances of China were prepared in time series starting from 1990 with consideration of internationally common standards. Most important objective was the determination of the share of the transport sector on the final energy consumption.

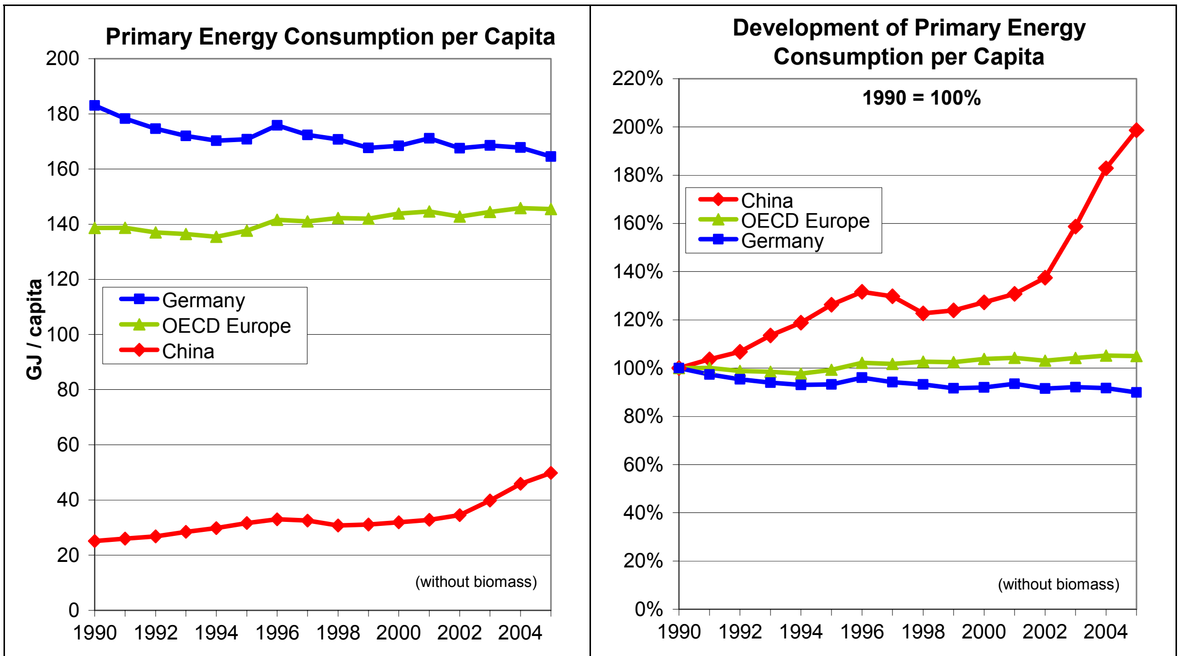
The values for China were compared with appropriate time series of OECD Europe (see glossary, page 71) and Germany. The most important results are:

- Primary energy consumption (see glossary, page 71) in China rose from 1990 to 2005 around 127%. Most important primary energy carrier is coal (70%), followed by oil (20%). The comparison to the countries of OECD Europe shows large differences concerning the most important sources of energy (less coal, higher portion of oil, gas and nuclear power) (Figure 1).
- Primary energy consumption per capita doubled 1990-2005 in China. The rise in OECD Europe was only 5%, in Germany there was a decrease around 10%. Nevertheless, the consumption per capita is still much smaller in China than in Europe (Figure 2).
- Final energy consumption in China rose 1990-2005 around 84%. Coal is further on the most important source of final energy; however the portion of oil products (gasoline, diesel and fuel oil, kerosene) and electricity has been increasing strongly (Figure 3). In Europe, final energy consumption of coal has only a small contribution. In return, the portion of oil products and of natural gas is substantially higher in Europe than in China.
- Final energy consumption per capita shows a similar picture as primary energy consumption. A strong rise in China, however final consumption per capita is still substantially lower than in Europe (Figure 4).
- The share of transport on final energy consumption as stated in official Chinese statistics is clearly lower in China than in OECD Europe and in Germany (Figure 5). However, actual energy consumption in transport is only partly documented in the official statistics. Main reason is the demarcation of consumer sectors. In China, energy consumption is not registered according to the kind of its consumption (e.g. freight transport with trucks = transport) but assigned to the originating sector (freight transport with trucks = industry). For passenger transport only the public sector is included, but not the private passenger transport.
- Several Chinese and international publications indicate a considerably higher energy consumption for the road transport sector, estimating the additional consumption of private transport and the other sectors (Figure 6). Exact numbers are not available.
- Therefore, own estimations are made in order to determine the actual share of transport on the final energy consumption in China (see subsequent sections to transport).



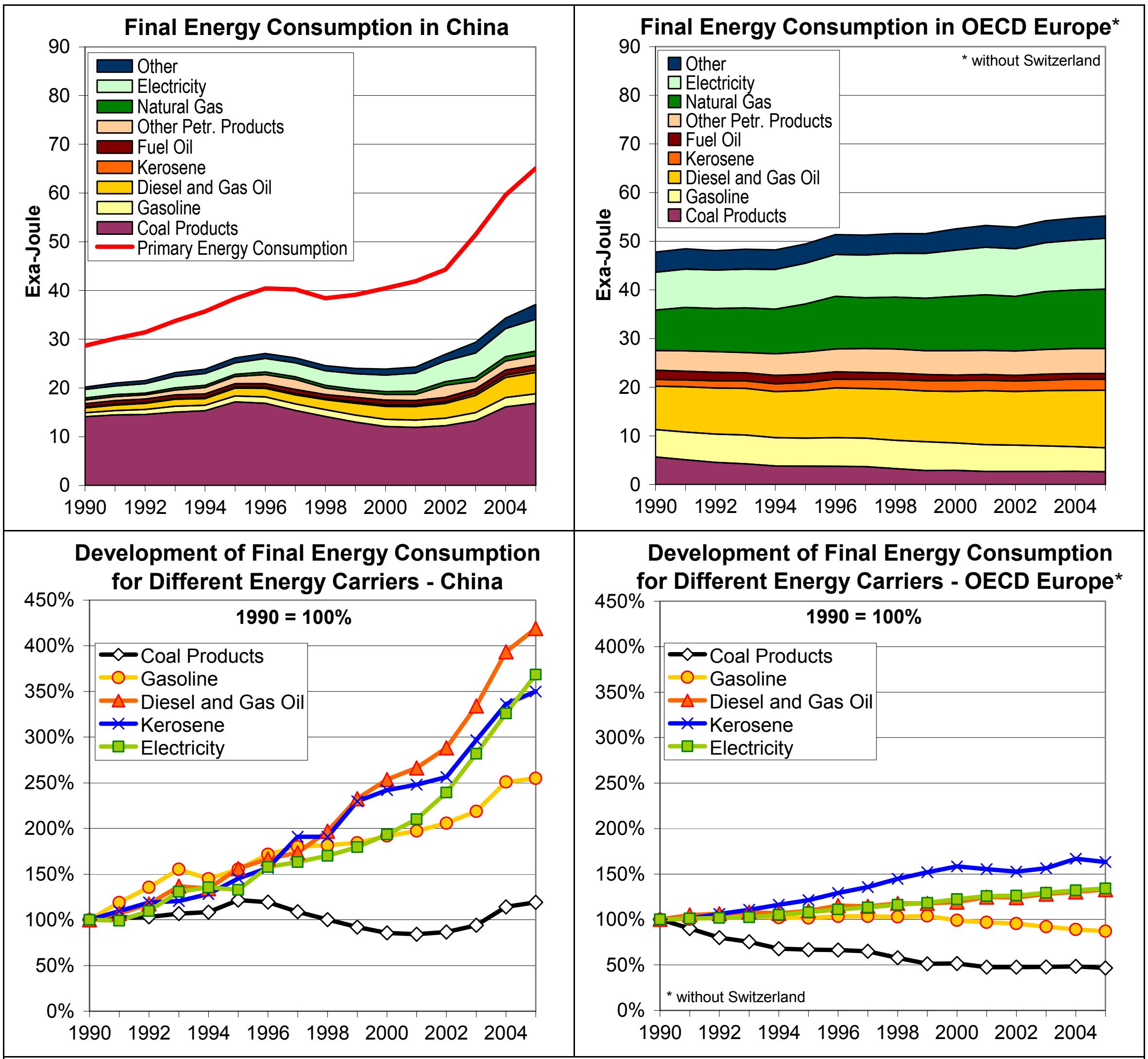
Source: [BP 2006] IFEU Heidelberg 2008

Figure 1 Primary Energy Consumption in China and OECD Europe



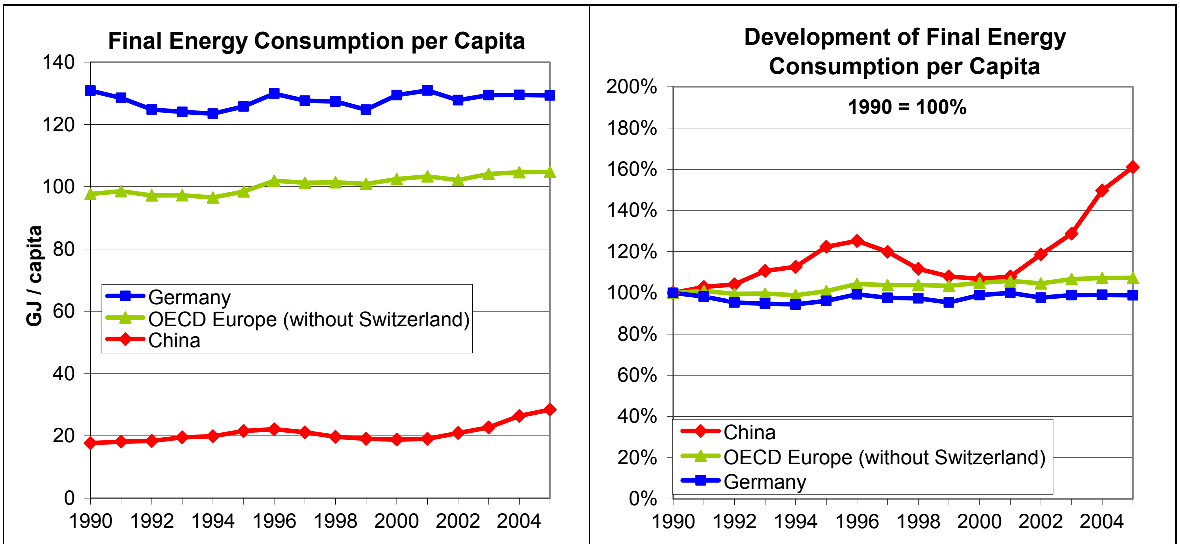
Sources: [BP 2006], [OECD 2006], [CSY 2006] IFEU Heidelberg 2008

Figure 2 Primary Energy Consumption per Capita in China, OECD Europe and Germany



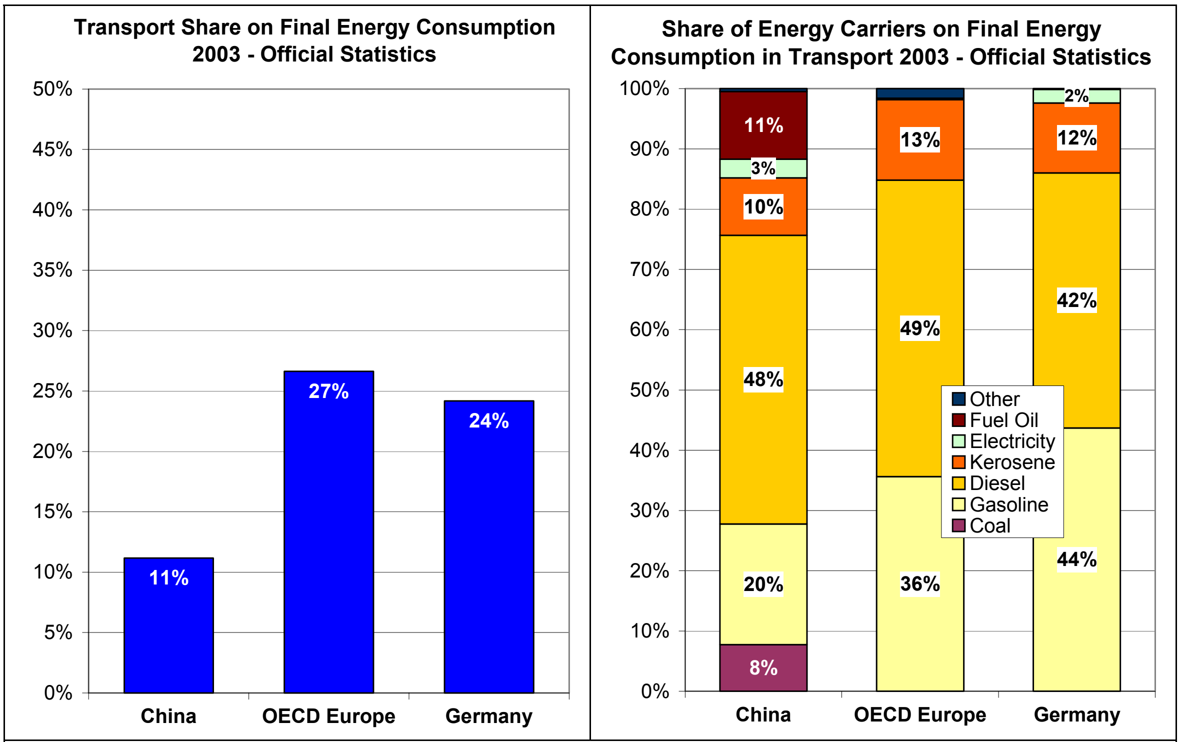
Sources : [CED 2004], [CSY 2006], [APEC 2006b], [Eurostat 2006] IFEU Heidelberg 2008

Figure 3 Final Energy Consumption in China and OECD Europe



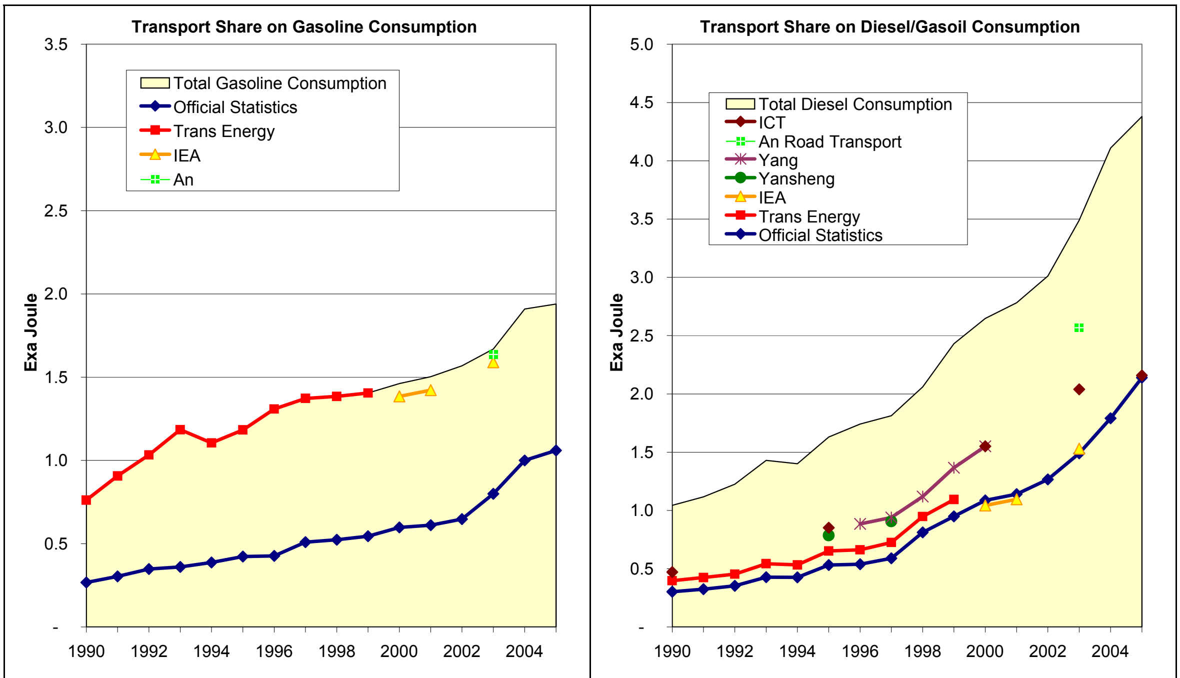
Sources : [CED 2004], [CSY 2006], [APEC 2006b], [Eurostat 2006] IFEU Heidelberg 2008

Figure 4 Final Energy Consumption per Capita in China, OECD Europe and Germany



Sources: [CSY 2006], [Eurostat 2006] IFEU Heidelberg 2008

Figure 5 Final Energy Consumption of Transport in China (Official Statistics) and in OECD Europe



Sources: [CSY 2006], [ICT 2007],[APECC 2006a,b], [Trans-Energy 2002][, [IEA 2003],
IFEU Heidelberg 2008

Figure 6 Final Energy Consumption of Transport in China – Different Estimates in Literature

4 Development of Transport in China 1990-2005

For the analysis of energy consumption and emissions of a country's transport system, data must be collected for vehicle stock and mileage, transport performance (passenger kilometres, ton kilometres) and technical characteristics (vehicle size, specific energy consumption, emission behaviour) and linked to each other. The obtained transport framework needs to be compared with the energy statistics of the country.

A transport framework for China was estimated by IFEU based on the official Chinese statistics and several additional publications. The most important results are presented in the following chapters.

4.1 Road Transport Sector

Road transport is the most important sector in environmental balances of transport, but has usually the most uncertain data situation. The composition of the vehicle stock in size classes, engine type (diesel, gasoline) and emission standard is an important number. Furthermore, information about the mileage of the vehicles is necessary for energy and emission inventory estimations.

The data situation for road transport in China is insufficient:

- Transport performance (passenger and ton kilometres) is only recorded for highway transport (mainly non-private vehicles).
- Vehicle stock: No statistical differentiation of passenger vehicles in cars and buses, no statistics about motorcycles and rural vehicles available.
- Few information about vehicle use (vehicle mileage, load factor).

Therefore, energy statistics are the most important base for the estimation of energy consumption and emissions. As mentioned above, the official energy statistics for transport do not include all activities of vehicles. In particular parts of road transport are allocated to other sectors. Using the official energy statistics induces an underestimation of the environmental impact of transport, particularly road transport.

In our analysis of energy consumption and emissions from transport in China we use the definitions of transport which is the base in European and German statistics. In this definition the transport sector includes all transport activities with vehicles on public infrastructure, (roads, railways, waterways and airports), excluding military, agriculture and other working activities.

The following chapters describe the information we used for the energy and emission estimation of road transport.

4.1.1 Vehicle Stock

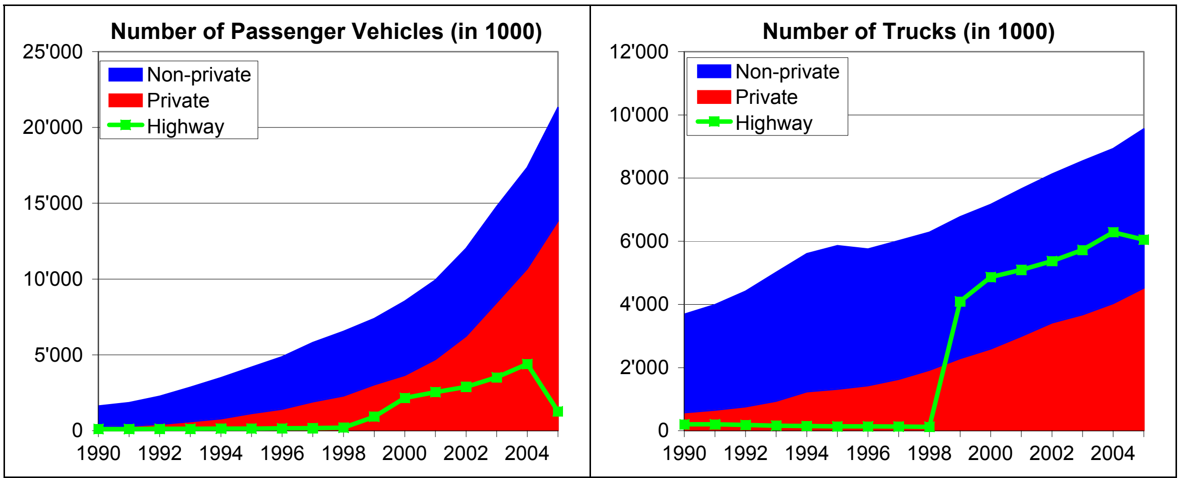
Official Chinese Statistics

The China Statistical Yearbook [CSY 2005] provides information on the vehicle stock in the country in the following classification:

- Vehicle categories: passenger vehicles (cars and buses), trucks and other vehicles,
- Civil vehicles and sub-group private vehicles (see Figure 7),
- Size classes of passenger vehicles: large, medium, small, minicar (Figure 8),

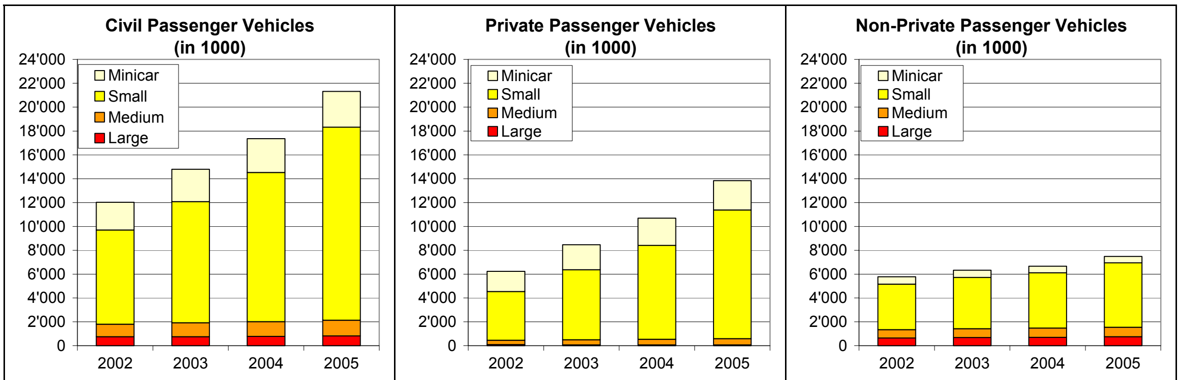
- Size classes of trucks: heavy, light-heavy, light, mini trucks, (Figure 9),
- Additional information on passenger vehicles and trucks for highway transport: number of vehicles, number of seats (passenger vehicles) and load capacity (trucks),
- First registration data for passenger vehicles and trucks (Figure 10).

The following figures show the development of vehicle stock according to official statistics between 1990 and 2005.



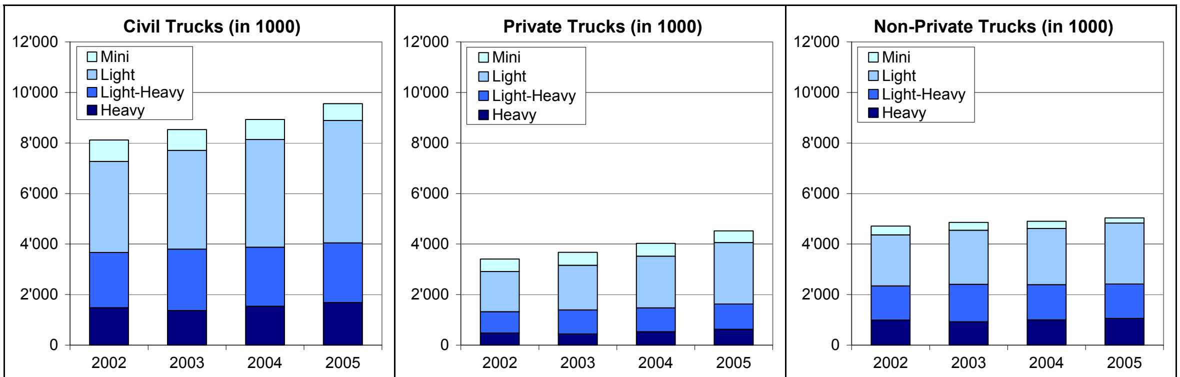
Source: [CSY 2006] IFEU Heidelberg 2008

Figure 7 Civil Private and Non-private and Highway Vehicle Stock in China 1990-2005



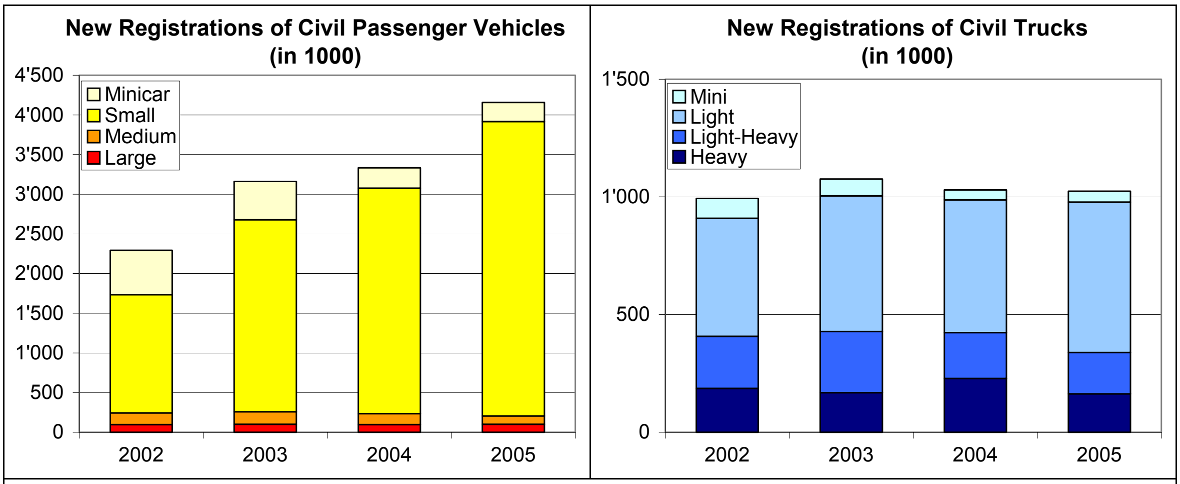
Source: [CSY 2006] IFEU Heidelberg 2008

Figure 8 Passenger Vehicle Stock in China 2002-2005



Source: [CSY 2006] IFEU Heidelberg 2008

Figure 9 Freight Vehicle Stock in China 2002-2005



Remark: including private vehicles
Source: [CSY 2006]
IFEU Heidelberg 2008

Figure 10 New Registrations of Vehicle Stock in China 2002-2004

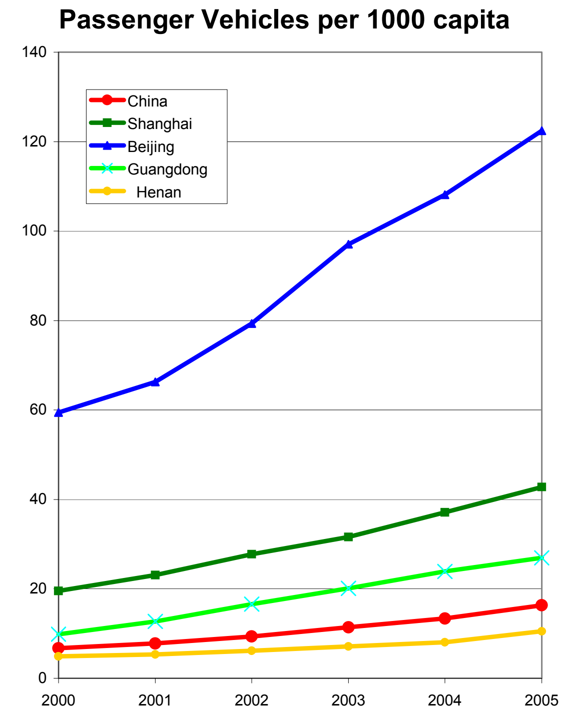


Figure 11 Vehicle Stock in China 2000-2005 in different regions [CSY 2006]

Regional Differences in China

The motorization in China shows big regional differences:

In Beijing the motorization is about six times higher than on country's average.

The level in Shanghai is much lower than in Beijing, but still more than twice as high than the average.

Also the heavily industrialised province Guangdong has a significantly higher motorization than the average and shows higher increase rates than China in total.

An example for a large province with a low motorization rate is Henan.

Despite these differences, all regions shown here had a big increase of motorization between 2000 and 2005 from about 100% (Beijing) up to more than 200% (Guangdong), +142% in average.

Estimation of Total Vehicle Stock

The China Statistical Yearbook provides no differentiation of passenger vehicles into cars and buses. Furthermore, it contains no vehicle stock data for motorcycles and rural vehicles. More differentiated statistics are not publicly accessible (see [CAIN 2007]). Therefore, additional information is required for a detailed classification of the vehicle stock.

The development of the total vehicle stock in China 1990-2004 can be estimated based on several publications. The number of vehicles and the publications used for each number are shown in the following table. These values are used for the energy and emission estimation.

Table 1 Vehicle Stock for Road Transport in China 1990-2004 (in million)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Trucks	3.7	4.0	4.4	5.0	5.6	5.9	5.8	6.0	6.3	6.8	7.2	7.7	8.1	8.5	8.9
Passenger Vehicles	1.6	1.9	2.3	2.9	3.5	4.2	4.9	5.8	6.5	7.4	8.5	9.9	12.0	14.8	17.4
- Bus	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.7	3.1	3.6	4.4	5.3	7.4	
- Car	0.6	0.7	0.9	1.3	1.7	2.2	2.7	3.4	3.8	4.3	4.9	5.5	6.7	7.4	
Motor-cycles	6.0	7.0	8.0	10.0	12.0	14.0	17.0	20.2	25.2	31.6	37.7	43.3	51.0	59.6	
Rural Vehicles	0.5	1.0	1.8	2.8	4.2	6.5	9.0	11.5	14.5	18.5	21.0	22.0	22.1	22.2	
“Other Vehicles”	0,2	0,2	0,2	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,5	0,6

Sources:
- Trucks, Passenger Vehicles and “Other Vehicles”: [CSY 2005]
- Bus, car: 1990-2002: [Kebin He et al. 2005], Table 2+3; 2003: [APECC 2006a]
- Motorcycle: 1990-1996: IFEU Estimation, based on figure in: [Hao 2004]; 1997-2002: [Kebin He et al. 2005]; 2003: [APECC 2006a]
- Rural Vehicles: 1990-2001: IFEU estimation, based on vehicle production (figure in: [ITS 2004]); 2000: [Hong Huo et al. 2006]; 2001: [APECC 2003]; 2003: [APECC 2006a]

Differentiation by Vehicle Size

In the official Chinese statistics [CSY 2006], the vehicle stock of trucks and passenger vehicles (cars + buses) is differentiated into four size classes. [Kebin He et al. 2005] give a definition of size classes for truck and buses. [CAE 2003] gives a definition of size classes for cars. These definitions of vehicle sizes are summarized in the following table.

The composition of vehicle stock in [CSY 2006] and [Kebin He et al. 2005] are different for single categories (trucks) or are not comparable (buses vs. passenger vehicles).

Table 2 Classification of Vehicles Sizes in China

Trucks [1, 2]			Buses [1, 2]			Cars [3]	
Class	**Description**	**Gross Vehicle Weight**	**Class**	**Description**	**Total Vehicle Length**	**Class**	**Cubic capacity**
HDT	heavy	>=14 tons	HDB	Large/heavy	>=10m	Large	2.5-4.0 litres
MDT	light-heavy/medium	6-14 tons	MDB	medium	7-10m	Medium	1.6-2.5 litres
LDT	light	1.8-6 tons	LDB	small/light	3.5-7m	Small	1.0-1.6 litres
MT	mini	<1.8 tons	MB	mini	<3.5m	Mini	<1 litre

Source: [1] [Kebin He et al. 2005], [2] [CSY 2005], [3] [CAE 2003], [DRCSC et al 2001b]

Differentiation by Engine Type

Passenger cars and motorcycles in China are equipped with gasoline engines. Rural vehicles use simple diesel engines [ITS 2004]. No official information is available about the engine type (diesel, gasoline) of trucks and buses. [Kebin He et al. 2005] made estimations based on publications by China Automotive Technology and Research Center (CATARC) and others (Table 3).

For air pollutant emissions of gasoline vehicles, the share of two-stroke and four-stroke engines is important. Passenger cars, buses and trucks are mainly equipped with four-stroke engines. For motorcycles, [DRCSC et al. 2001b][1] estimates a two-stroke share of 50%.

Table 3 Estimation of engine type share of truck and bus stock in China (1997-2002)

	Truck						Bus						
	HDT-D	MDT-G	MDT-D	LDT-G	LDT-D	MT-G	HDB-G	HDB-D	MDB-G	MDB-D	LDB-G	LDB-D	MB-G
1997	100%	37%	63%	52%	48%	100%	2%	98%	48%	52%	73%	27%	100%
1998	100%	36%	64%	48%	52%	100%	5%	95%	48%	52%	71%	29%	100%
1999	100%	36%	64%	42%	58%	100%	5%	95%	48%	52%	70%	30%	100%
2000	100%	35%	65%	38%	62%	100%	7%	93%	46%	54%	70%	30%	100%
2001	100%	32%	68%	34%	66%	100%	7%	93%	43%	57%	70%	30%	100%
2002	100%	26%	74%	26%	74%	100%	9%	91%	32%	68%	70%	30%	100%
Source: [Kebin He et al. 2005]													

4.1.2 Vehicle Mileage

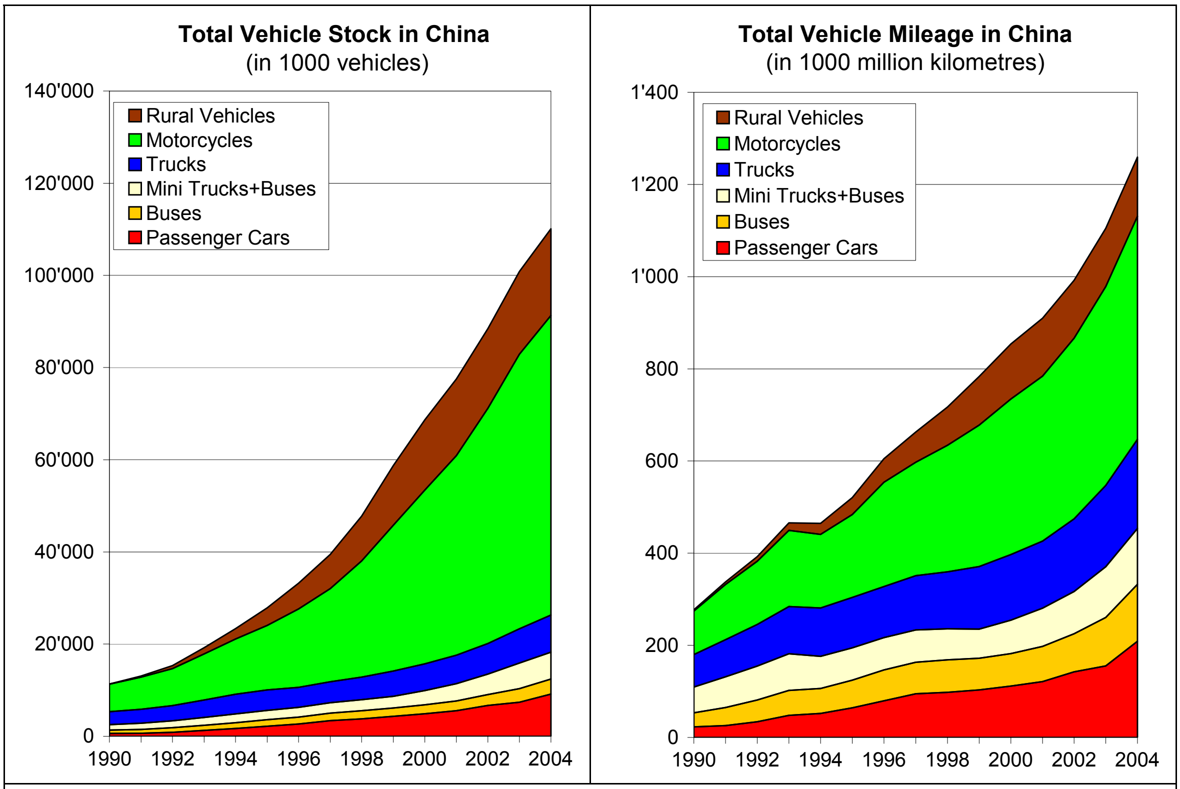
The China Statistical Yearbook provides no data of vehicle mileage (neither kilometres travelled per vehicle and year nor total kilometres per year for each vehicle category). These values are needed, however, for the calculation of energy consumption and emissions in road transport.

Estimations of average vehicle miles travelled (VMT) in China as per [Kebin He et al. 2005] and [Hong Huo et al. 2006] are listed hereafter:

- The annual VMT of cars in cities has been about 24’000-27’000 in the past years. This value is very high because of the high percentage of taxis in the Chinese car fleet with a high annual mileage [Hong Huo et al. 2006].
- For trucks and busses the annual VMT ranges between 50’000 km (heavy) and 20’000 km (medium and light), whereas VMT data vary between different studies as described in [Hong Huo et al. 2006].
- The VMT of motorcycles lies in the range of 4’000-10’000 km.

Thus, available information on vehicle mileage in China has a large range of possible values, which in addition will change very fast with the rapid growing motorization. For the energy and emission estimations of road transport in this study we apply the same VMT values as in [Hong Huo et al. 2006].

[1] Page 51



Sources:
IFEU Estimations, based on [Kebin He et al. 2005], [Hong Huo et al. 2006], [CSY 2006] IFEU Heidelberg 2008

Figure 12 Vehicle Stock and Vehicle Mileage of Road Transport in China 1990-2004

4.1.3 Estimation of Energy Consumption and Emissions of Road Transport

Energy consumption and emissions of road transport in China were estimated using the transport emission model TREMOD [IFEU 2006]. TREMOD includes detailed energy consumption and emission factors for the typical vehicle fleet in Germany. It is therefore suitable only with limitations for an emission estimation of road transport in China. However, the uncertainties of emission factors correspond to the uncertainties of estimated vehicle mileage for different vehicle categories in China. Therewith, they allow an acceptable estimation of emission levels and contribution of all vehicle categories to energy consumption and emissions of total road transport in China. A more precise estimation is not possible in the context of this study.

Basic assumptions for vehicle stock and average mileage in each vehicle category were made based on [Kebin He et al. 2005] and [Hong Huo et al. 2006] as described in the previous chapters.

The following table gives an overview of basic assumptions for energy and emission estimation with TREMOD.

Table 4 Assumptions for Energy and Emission Estimation of Road Transport, China 2003

		VMT 1.000 Mio km	Stock Mio Veh	VMT/Veh km/year	Fuel consumption g/km	l/100 km	Fuel Cons. MT
Mopeds	Petrol	317.4	44.7	7,100	25.9	3.5	8.2
Motorcycles	Petrol	137.1	14.9	9,200	30.1	4.1	4.1
Bus	Petrol	48.4	1.79	27,028	94.8	12.8	4.6
Bus	Diesel	46.6	1.16	40,264	245.8	29.5	11.5
Lorry	Petrol	26.2	1.32	19,797	173.7	20.9	4.5
Lorry (single truck)	Diesel	122.3	4.11	29,768	136.6	18.4	16.7
Light duty Bus+Lorry	Petrol	116.0	5.55	20,900	60.7	8.2	7.0
Truck Trailer	Diesel	37.1	1.99	18,622	242.8	29.2	9.0
Passenger Car	Petrol	163.5	7.40	22,100	62.2	8.4	10.2
Rural Vehicles	Diesel	133.2	17.95	7,420	107.7	12.9	14.3
Total	Petrol	808.6	75.7				38.7
Total	Diesel	339.3	25.2				51.5
Total	All	1147.8	100.9				90.2
IFEU estimations based on different sources, e.g. [Kebin He et al. 2005], [Hong Huo et al. 2006], [APECC 2006a,b]							

Additional assumptions were needed for emission behaviour of road vehicles. In China, several regulations and measures were adopted and are planned for the future in order to reduce energy consumption and emissions of road vehicles. A brief description of important measures can be found in the annex.

China has adopted emission standards from Europe, though with a delay of implementation dates. The share of emission standards on new vehicle registrations was estimated as follows:

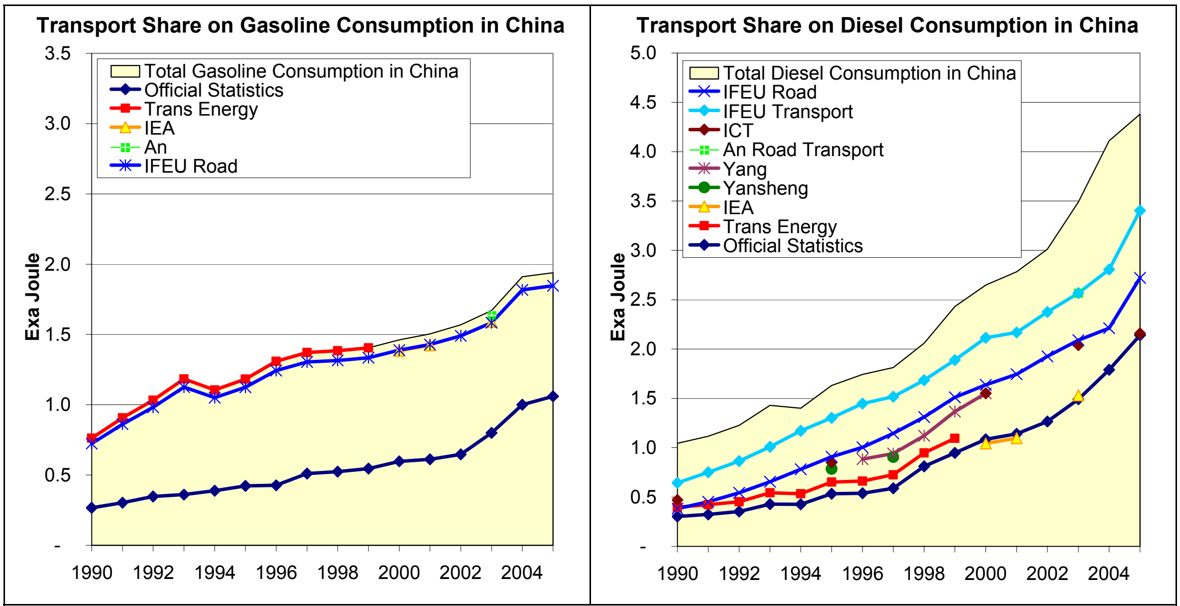
- Passenger cars: Starting from 2000 EURO 1, starting from 2003 EURO 2 in Beijing (approx. 10% country-wide), starting from 2004 additionally in Shanghai and first vehicles country-wide (15% of all new registrations).
- New buses and trucks: EURO I starting 2000, EURO II starting 2002.

Most important data base for energy and emission estimations of national transport is the energy balance of a country. The emissions calculations with TREMOD were adjusted in a way that energy consumption stands in a plausible relationship to the Chinese energy balance.

- For gasoline the assumption was made that 95% of consumption go into road transport (according to estimation in IEA statistics [IEA 2003]).
- The assumptions for diesel consumption in road transport are more complex as diesel fuel is used in road vehicles, railways and inland navigation as well as other mobile and stationary machines outside the transport sector. We adapt the estimation for road transport in the current publication of [Kebin He et al. 2005] as we also used information for fleet composition and average vehicle mileage from this research.

The following Figure 13 shows the total gasoline and diesel consumption in China, the share of transport estimated in different investigations and the estimation used for emission calculations in this study.

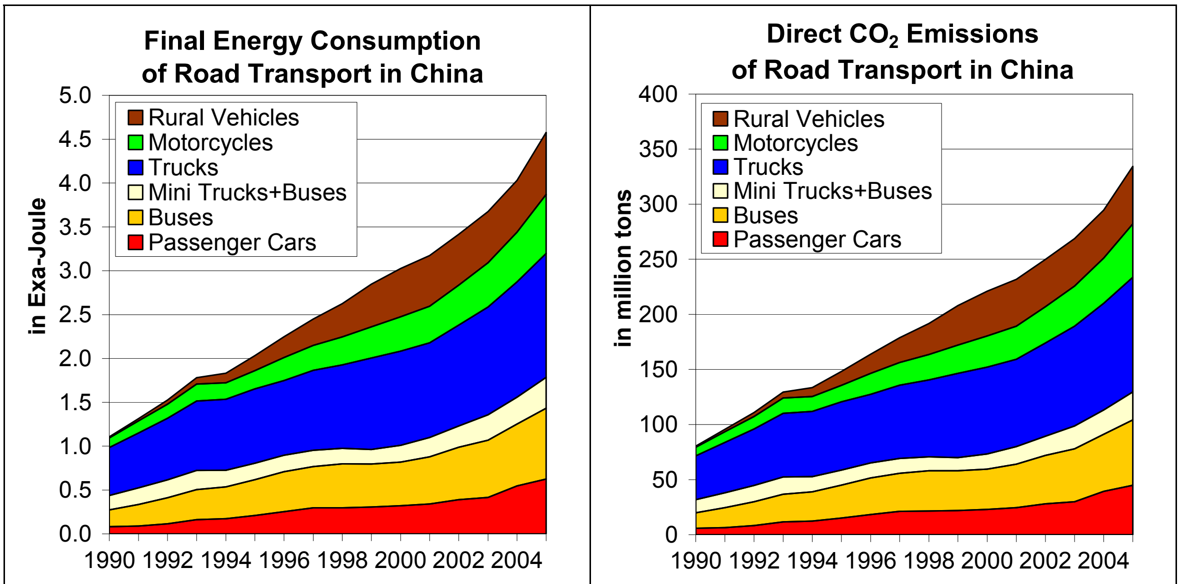
The gasoline consumption estimate for road transport is in good correlation to total gasoline consumption in energy statistics. The attribution of diesel fuel to the transport sector is much more uncertain. Here, the IFEU estimate is at the top margin of all investigations. The results are nevertheless seen to be plausible. Including diesel for railways and inland navigation (see the following chapters) consumption for transport is clearly below total diesel consumption in China. The remaining difference for consumption in other sectors (agriculture, fishery, industry etc.) is between 40% (1990) and 22% (2005) of total consumption.



Sources: [CSY 2006], [ICT 2007],[APECC 2006a,b], [Trans-Energy 2002][, [IEA 2003], IFEU estimations
IFEU Heidelberg 2008

Figure 13 Final Gasoline and Diesel Consumption of Transport in China – Estimates in different Investigations and IFEU Estimates

Total energy consumption and CO_2 emissions of road transport in the year 2005 were more than the fourfold of 1990 (see Figure 14). Trucks and buses are the main contributors to energy consumption so far. However, passenger cars have had a higher-than-average increase of energy consumption, same for rural vehicles (which are widely used in small cities and rural areas [CAE 2004]). This has led to an increasing share of these vehicle categories on energy consumption of road transport in the last years.



Remark: 2005 estimated from total fuel consumption IFEU Heidelberg 2008

Figure 14 Energy Consumption and CO_2 Emissions of Road Transport in China 1990-2005

Several investigations state that road transport contributes more than half to air pollutant emissions in Chinese cities (e.g. [Hao 2004], [WRI 2004]). The emission calculations in this study (see Figure 15) should despite their uncertainties give a good indication of the development of air pollutant emissions from road transport and the contribution of different vehicle categories.

Road transport emissions of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) doubled to tripled from 1990 to 2004. CO and HC come to more than 50% from motorcycles though emissions of passenger cars have increased in the last years, too. NO_x emissions come mostly from trucks and buses.

Particle (PM) exhaust emissions come from diesel-fuelled vehicles. The increase of particle emissions from trucks and buses was relatively moderate. However, a drastic increase was calculated for rural vehicles as a result of strong increasing mileage and insufficient emission regulations.

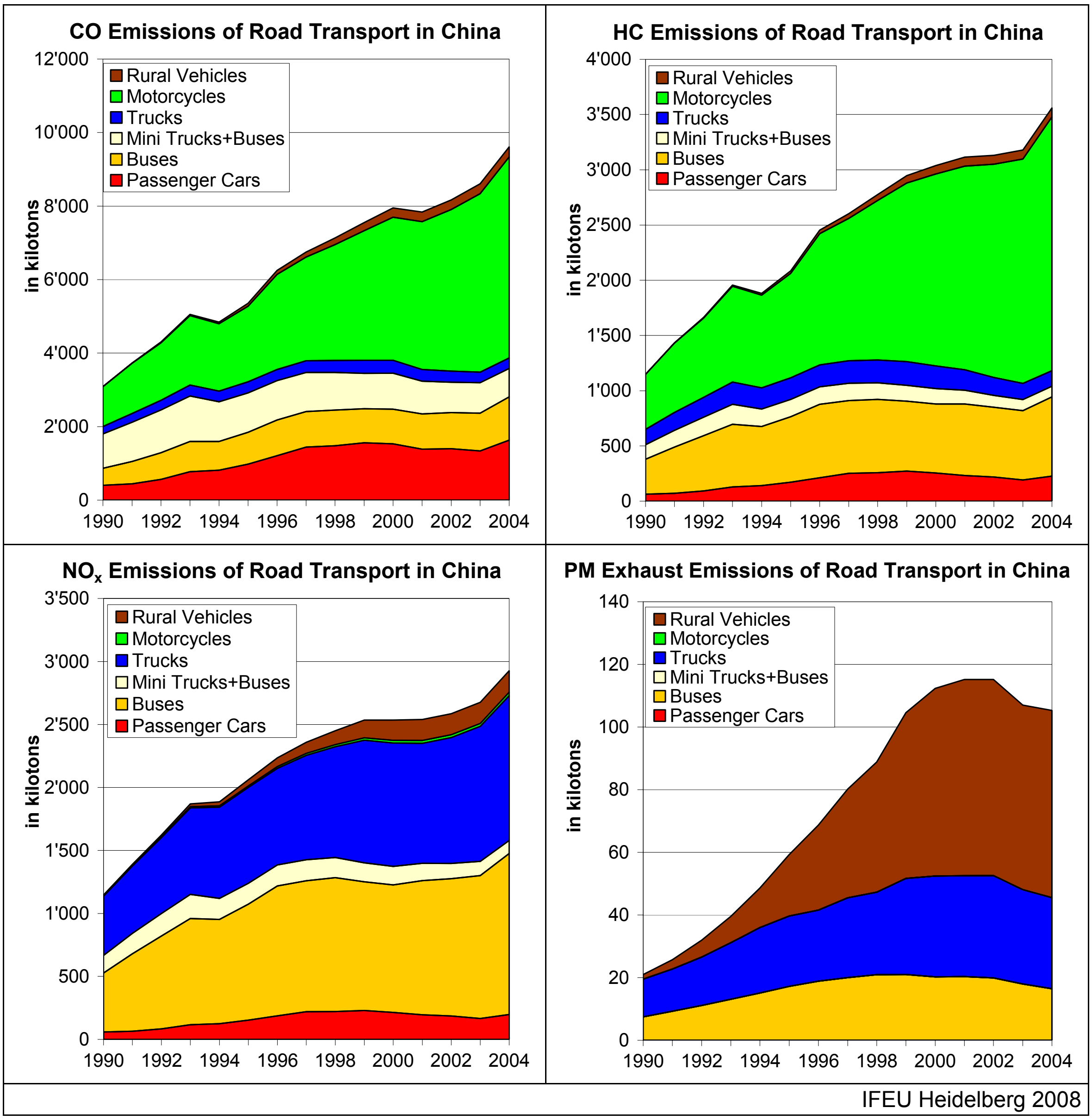


Figure 15 NO_x, CO, HC and PM Exhaust Emissions of Road Transport in China 1990-2004

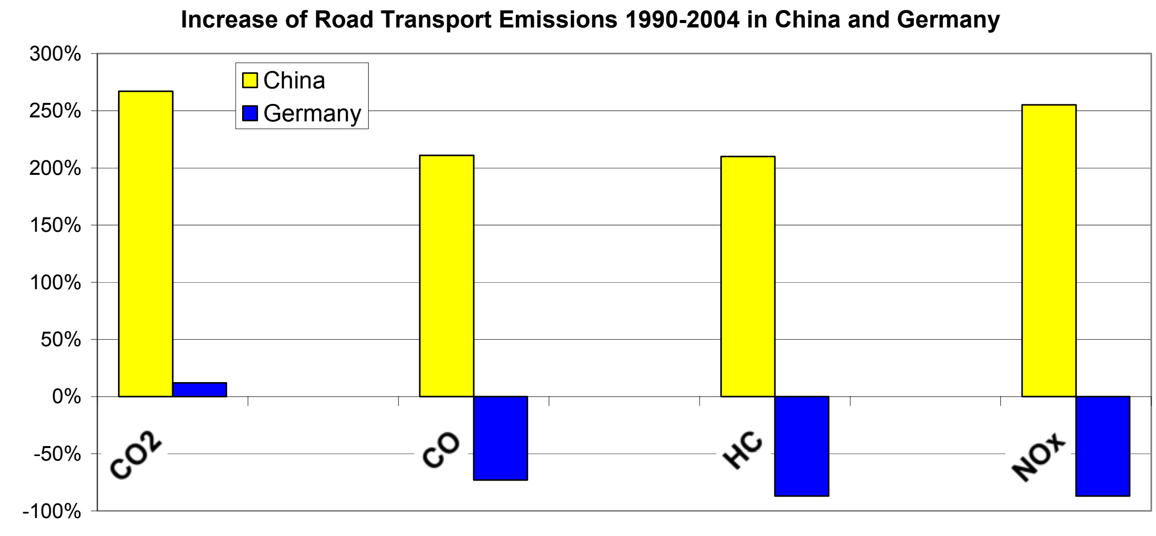
A comparison of the results of energy and emission calculations between China and Germany is shown in Table 5 and Figure 16:

- Energy consumption and CO_2 emissions of road transport in China more than tripled from 1990 to 2004. In Germany, there was still an increase of about 12%.
- Air pollutant emissions in China increased by factor 2.5-3, whereas in Germany they were reduced drastically.

This comparison clarifies the relevance of current developments in China. In the year 2004, road transport emissions of NO_x and HC per capita were higher in China than in Germany although energy consumption was about 9 times higher in Germany.

Table 5 Emissions of Road Transport 1990-2004: Comparison China – Germany

	1990	2004	1990-2004
CO_2 (Mt)			
China	81	297	+267%
Germany	143	160	+12%
China / Germany	57%	186%	
CO (kt)			
China	3'091	9'610	+211%
Germany	6'396	1'746	-73%
China / Germany	48%	550%	
HC (kt)			
China	1'148	3'561	+210%
Germany	1'433	181	-87%
China / Germany	80%	2000%	
NO_x (kt)			
China	1'147	2'926	+155%
Germany	1'246	160	-87%
China / Germany	92%	1800%	
Sources: IFEU Estimates, TREMOD		IFEU Heidelberg 2008	



Sources: IFEU Estimates IFEU Heidelberg 2008

Figure 16 Development of Road Transport Emissions 1990-2004 in China and Germany

4.2 Railway Transport Sector

For rail transport in China, data of total transport performance (passenger kilometres, ton kilometres), train operation (locomotive running kilometres and gross ton kilometres) and energy consumption (electricity, diesel, coal) are available ([CSY 2005/2006], [ICT 2007], and Ministry of Railways [MoR 2005]).

From 1990 to 2006 the transport performance of railway passenger and freight transport doubled, with an increasing share of other railway companies (see the following figure).

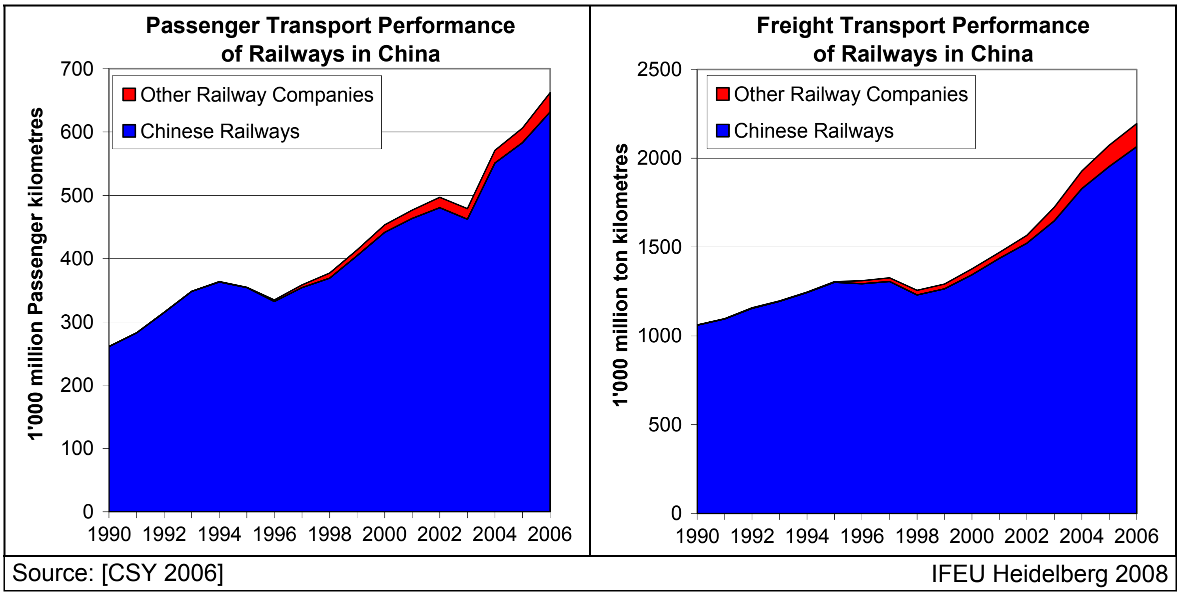


Figure 17 Passenger and Freight Transport Performance of Railways in China

From 1990 to 2005 steam traction was replaced completely by electric and diesel traction. Diesel traction currently dominates, but the share of electric traction increases: In 2005, 39% of the locomotive running kilometres and 43% of the gross ton kilometres (gross ton = total train weight) were done by electric traction.

Freight transport is the dominating sector in train operation. In 2005, 68% of locomotive running kilometres and 83% of gross ton kilometres were performed in the freight sector. The development of train operation of Chinese National Railways is shown in Figure 18 and Figure 19 (Source: [ICT 2007]).

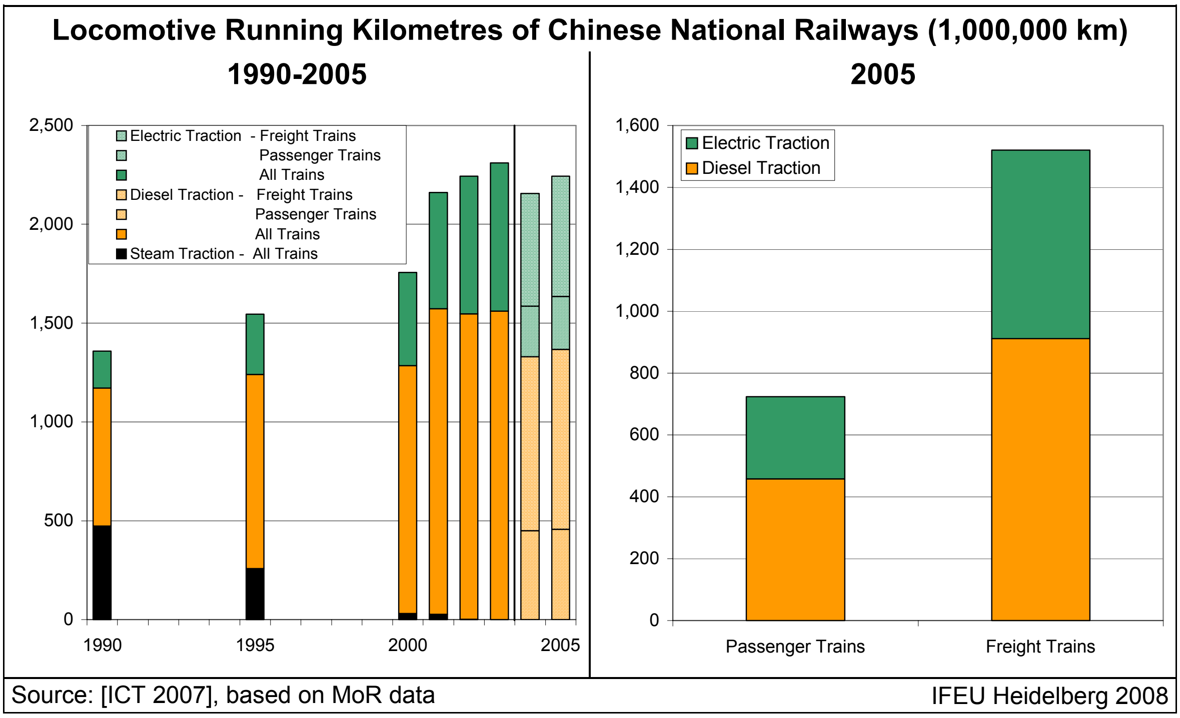


Figure 18 Locomotive Running Kilometres of Chinese National Railways

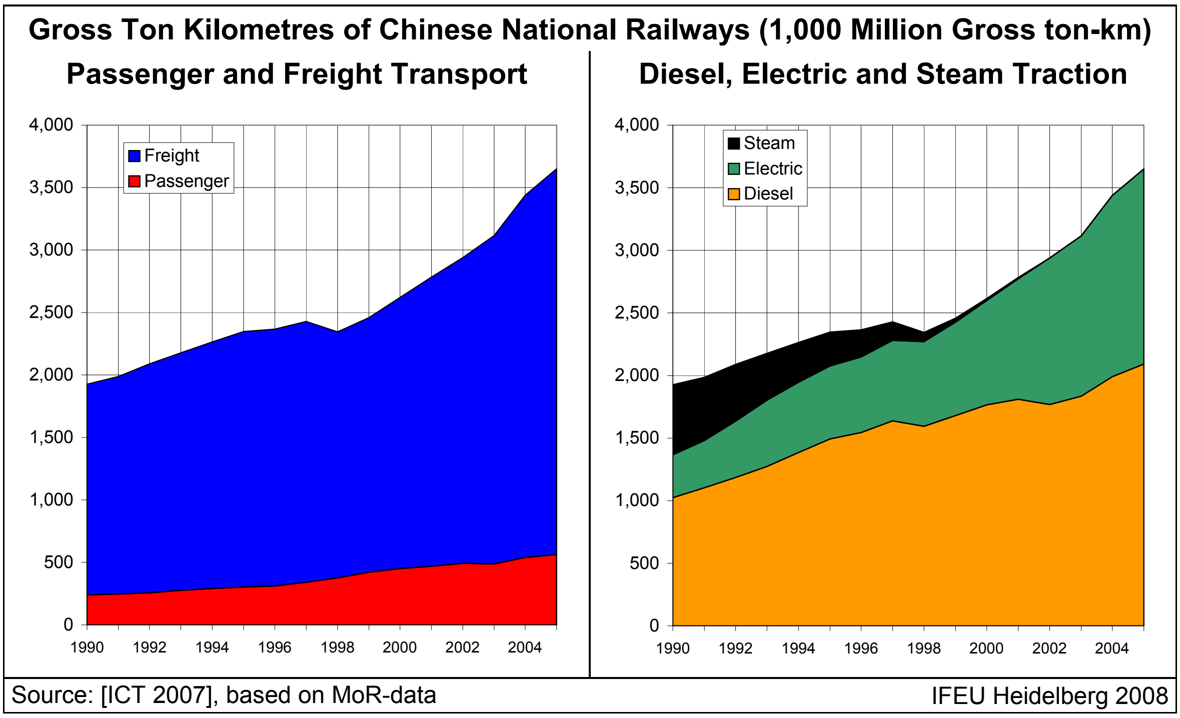
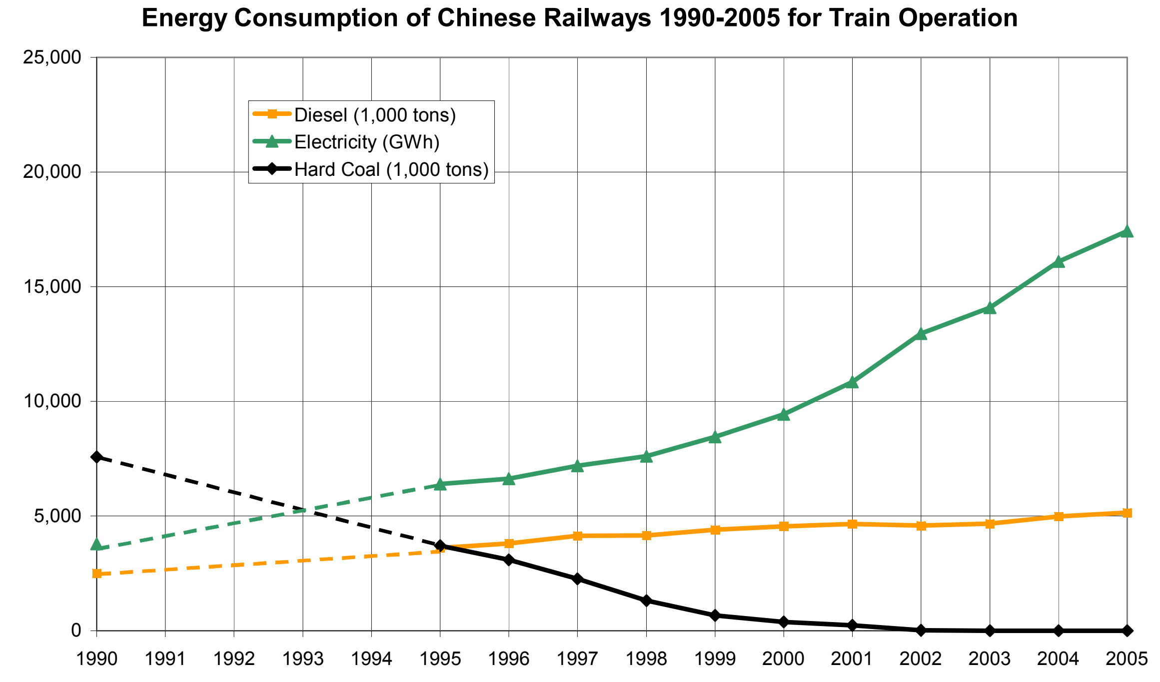


Figure 19 Gross Ton Kilometres of Chinese National Railways

The development of the energy consumption shows the structural change of Chinese Railways between 1990 and 2005 from steam traction to electricity and diesel traction ([MoR 2005], [ICT 2007], see the following figure).



Remarks: Values for train operation recalculated from gross ton kilometres and specific energy consumption
Source: [MoR 2006], [ICT 2007] IFEU Heidelberg 2008

Figure 20 Energy Consumption of Chinese National Railways 1990-2005

The energy consumption values in Figure 20 are recalculated from specific energy values per gross ton kilometre and the total gross ton kilometres per traction type, because the energy statistic of the Ministry of Railway include the consumption of all activities of hinese National Railways [MoR 2006] and not only traction. The energy consumption of railway operation has been about 80-95% of the total value ([ICT 2007]) in 2004 and 2005.

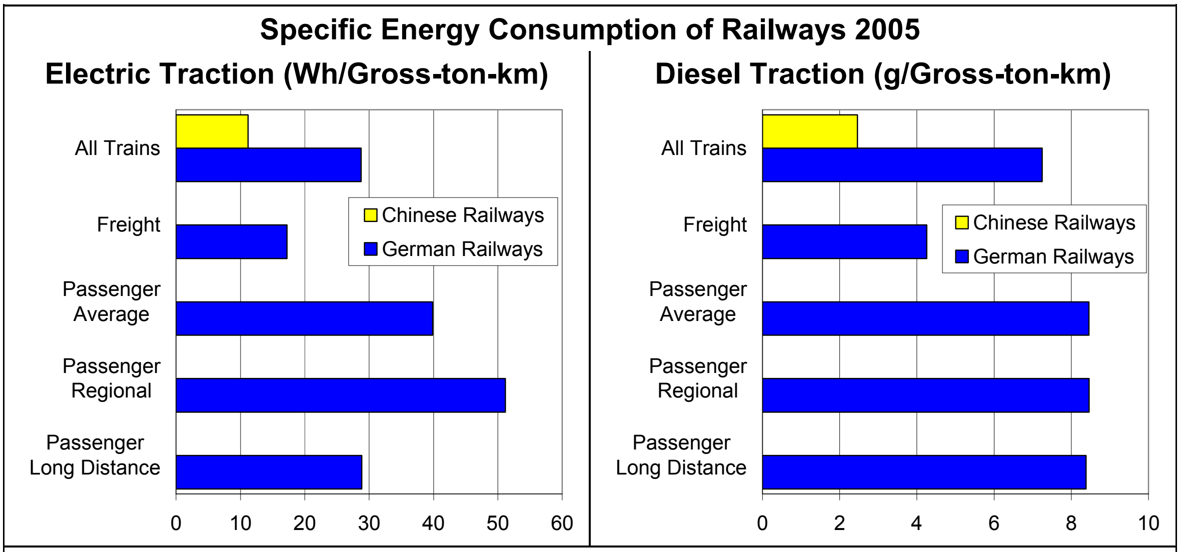
Energy consumption values for the other railway companies are not available. Therefore the total energy consumption of train operation in China will be higher than the values based only on the locomotives of Chinese National Railways.

Analysis of Railway Energy Efficiency in China

Statistical departments in China do not separate energy consumption of passenger transport from freight transport [ICT 2007]. Therefore it is not possible to derive separate values for specific energy consumption from the overall statistical data base.

The overall energy efficiency of Chinese Railways was 2.46 g diesel per gross ton kilometre and 11.18 Wh electricity per gross ton kilometre in 2005 ([ICT 2007]). Since 1990 the efficiency of diesel and electric traction did not change significantly.

Compared to German Rail the efficiency of Chinese Railway per gross ton kilometre is clearly higher (see the following Figure). The comparison of key values influencing the energy consumption of trains explains for the large difference to some extent (see Table 6).



Source: [ICT 2007], based on MoR-data, German Railways [DB AG 2007] IFEU Heidelberg 2008

Figure 21 Specific Energy Consumption per Gross-Ton-Kilometre in China and Germany

Table 6 Key figures of railway operation in China and Germany in 2005

	Chinese Railway	German Railway
Share of freight transport – locomotive kilometres – gross ton kilometres	 68% 83%	 21% 47%
Average gross train weight (tons) – passenger trains – freight trains	 780 2000	 290 930
Average load factor – passenger trains (passenger-km per seat-km) – freight trains (Ton-km per gross-ton-km)	 79.8% 65.4%	 28.1% 45.3%
Specific energy consumption operation – electric traction (Wh/gross ton kilometre) – diesel traction (g/gross ton kilometre)	 11.2 2.46	 28.8 7.24
Source: [ICT 2007],[DB 2007]		IFEU Heidelberg 2008

The main aspects of the difference are as follows:

- German rail transport has a higher efficiency per gross ton kilometre for freight trains than for passenger trains. With a share of 83% of gross ton kilometres, freight transport dominates the overall railway operation in China, in contrast to German Railway with a 53% share in passenger transport. Therefore freight transport dominates the overall specific energy consumption in China.
- Higher average train weights and higher load factors are more efficient (see e.g. [IFEU 2005a]). With 2000 tons for freight trains and 780 tons for passenger trains, the average train weight of Chinese Railways is 2-3 times higher than in Germany, with significant higher load factors at the same time.
- The energy efficiency related to the passenger and freight performance (in g Diesel or Wh electricity per net ton-km or passenger-km) in China is much higher than in Germany because of higher load factors.

The comparison between China and Germany is delimited by possible statistical differences. It can not be ensured that Chinese and German values are completely comparable, but the differences of key figures are significant enough for the explanation of high differences in energy efficiency between China and Germany.

4.3 Water Transport Sector

The China Statistical Yearbook contains values for the passenger and freight transport performance of inland and coastal navigation and ocean shipping.

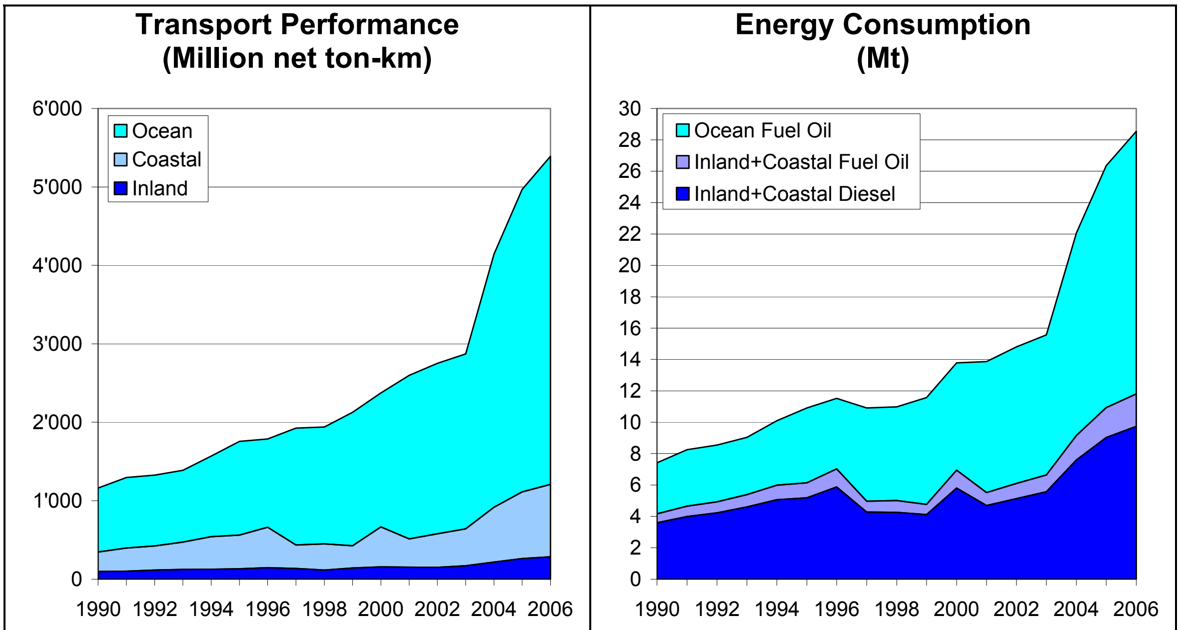
The passenger transport performance has a low share on total passenger transport and decreased from 16'000 million Pkm (1990) to 7'500 million Pkm in the year 2006.

In contrast, total freight transport performance of inland and coastal navigation has a high share on freight transport in China with a strong increase from 1990 to 2006 (see Figure 22). Ocean shipping also increased rapidly. It is added only in this chapter for information.

Statistics on the total energy consumption of navigation are not available. Thus the energy consumption is estimated based on the following assumptions:

- Experts from the Institute of Water Transport Research of MoC and the Energy Institute of ICT estimate that more than 95% of inland vessels and 70% of coastal vessels consume diesel oil [ICT 2007].
- The average energy consumption of all vessels in China varies between 6 g/net ton-km and 8 g/ net ton-km from 1999 to 2005 [ICT 2007]. In Germany an average value of 10 g/ net ton-km for inland vessels is used [IFEU 2006]. The energy consumption for coastal and ocean vessels is lower depending on the ship size and kind of freight. In this study we use average values of 9 g/ net ton-km for inland vessels, 7 g/ net ton-km for coastal and 4g/ net ton-km for ocean vessels [IFEU 2005a].

The transport performance and the results of the energy estimation are shown in the following figure.



Source: [CSY 2006],[ICT 2007], IFEU estimations IFEU Heidelberg 2008

Figure 22 Transport performance and energy consumption of ship transport in China

4.4 Air Transport Sector

Civil aircraft machines use kerosene. The Chinese statistics show a large increase of transport performance and energy consumption of air transport. A recalculation of the total energy consumption with specific energy values for air transport (Source: TREMOD, Deutsche Lufthansa) shows a good correlation with the Chinese energy statistics. Therefore, we assume that statistics of transport performance and kerosene consumption of air transport are related.

The following figure shows the transport performance of air transport in China and the energy consumption. The total energy consumption is equal to energy statistics. The share of passenger and freight transport was recalculated with specific values from TREMOD. As a result of the recalculation the specific energy consumption for air transport was 35 g kerosene per passenger km and for freight 210.g per net ton-km in 2006.

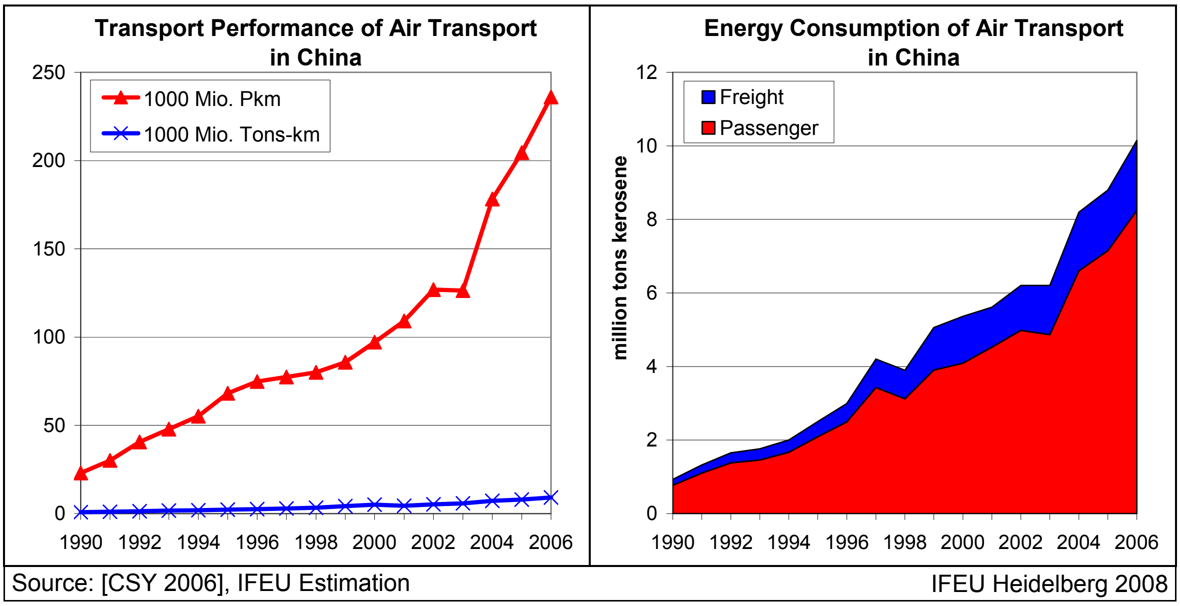


Figure 23 Transport performance and energy consumption of aircraft transport in China

4.5 Transport Performance, Energy Consumption and CO_2 Emissions

4.5.1 Transport Performance in China and Germany

Passenger transport performance (passenger kilometres)

Transport performance in passenger traffic increased strongly from 1990 to 2006 in China. According to official Chinese statistics, road transport (passenger cars and buses) has the largest contribution. Nevertheless, passenger transport performance per capita in China is still clearly lower compared to an OECD country such as Germany.

According to our understanding, official statistics clearly underestimate road transport performance. They contain only one part of traffic with passenger cars and buses – essentially the public and commercial operators (“Highway”). The increasing number of private cars appears not to be covered in statistics as well as whole transport with motorcycles and rural vehicles. In consideration of the estimated mileage in road transport (see chapter 4.1.2), actual passenger transport performance in China probably should be the two-fold compared with the official information.

Observations:

- Even when assuming a twofold higher passenger transport performance on roads in year 2006 China road transport performance per capita would only reach about 15% of the respective value for the same year in Germany.
- Also for air transport the per capita transport performance in China is only one tenth of the respective value of Germany.
- However, regarding passenger transport by rail the average per capita transport performance in China is about half of the respective value for the same year in Germany.
- The overall actual passenger transport performance per capita in China amounts to about 2,400 passenger km per capita compared to 15,000 passenger km per capita in Germany, i.e. about 16%.

Freight transport performance (ton kilometres)

Transport performance in freight transport increased likewise strongly in China. However, the total freight transport performance of about 3,300 tkm per capita in 2006 has so far only reached less than 50% of the German level which amounts to 6800 tkm per capita. In China, railway is the dominating transport mode whereas road transport plays a relatively small role so far.

For railway as well as inland navigation, transport performance per capita is even higher in China than in Germany. This might be associated with different structures: In China, a large part of energy and raw material transportation takes place „domestically“. In contrast, German energy resources and raw materials come predominantly from overseas. Thus, only a small portion of the total transportation distance of raw materials takes place inside Germany. It can be expected that the Chinese economy will face structural changes with complex production processes and the interchange of high valued semi-final and final products. The freight transport performance demand of such a high complex production system is most likely significant higher than today with the focus on raw materials and other bulk goods.

Observations:

- Due to the expected economic growth in China the industrial sector may require an additional per capita transport demand of freight linked purely to the industrial sector which may well force the total demand for freight transport performance per capita up to the same or beyond the German figure, which would mean as much as double of the present level.
- In addition the transport of energy and raw materials will also increase due to the expected economic growth (e.g. expected growth of primary energy demand coal by factor 2.2 from 2005 to 2030 in the IEA reference scenario [IEA 2007], see chapter 6).

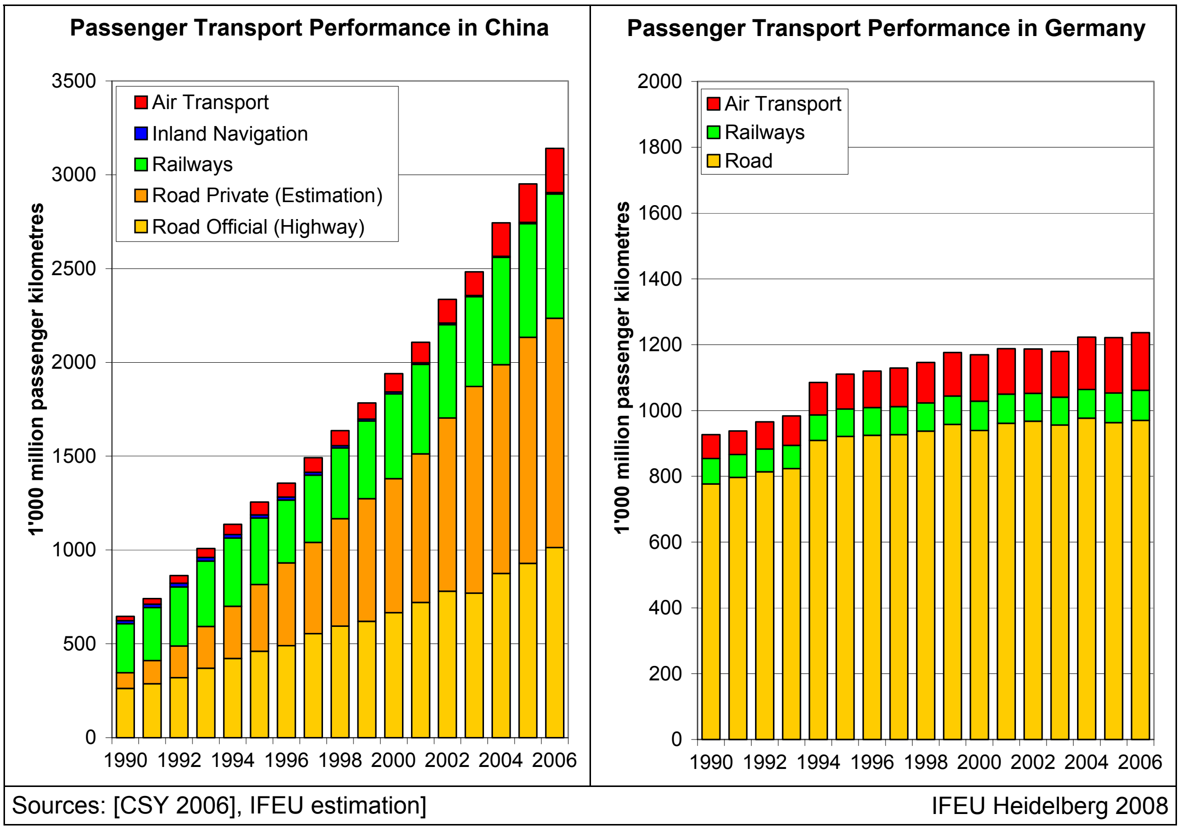


Figure 24 Passenger Transport Performance in China and Germany

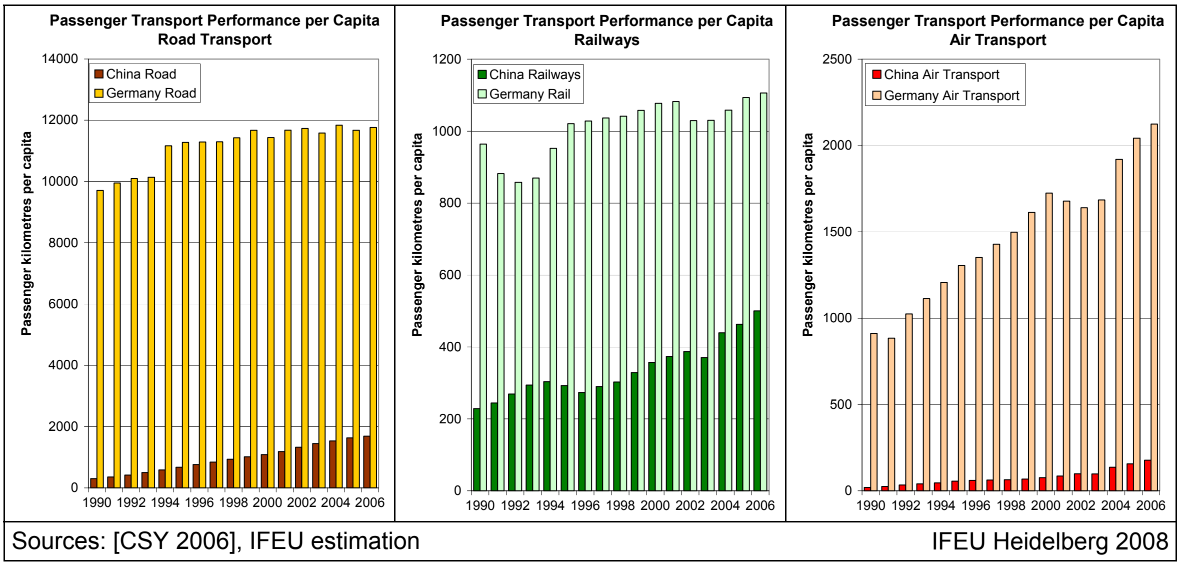
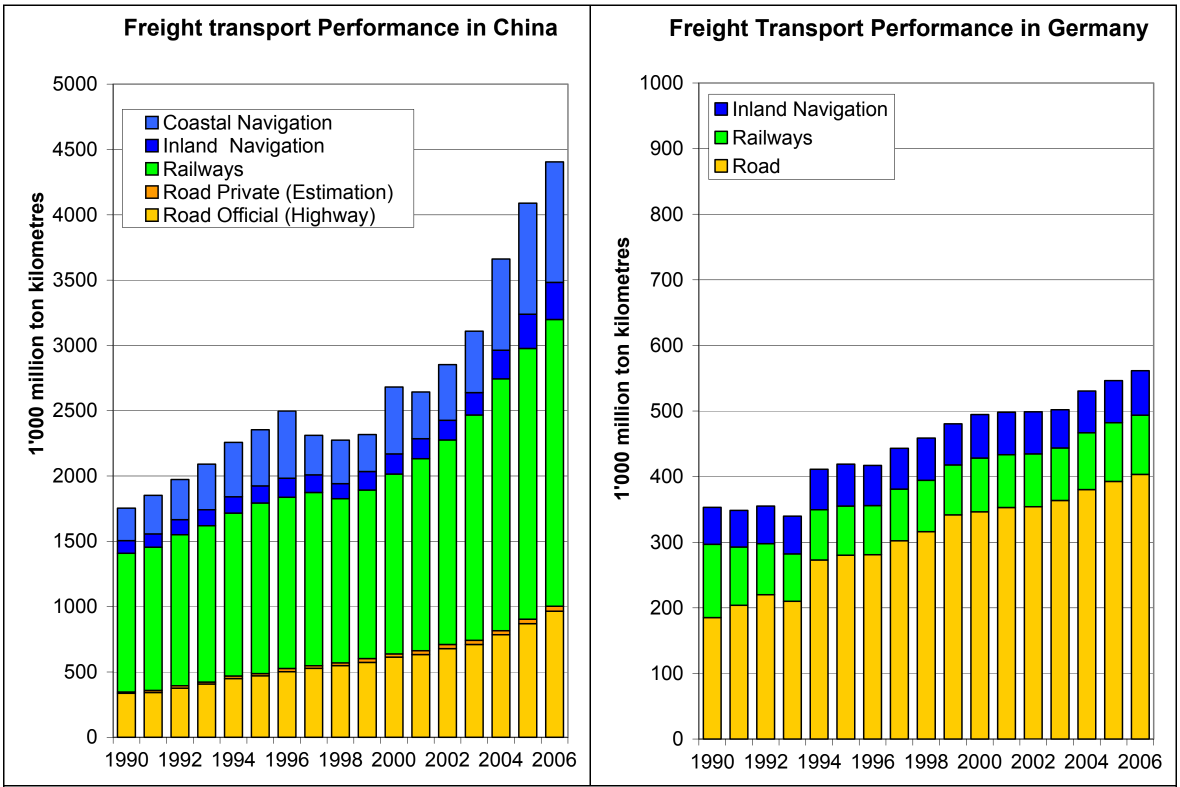
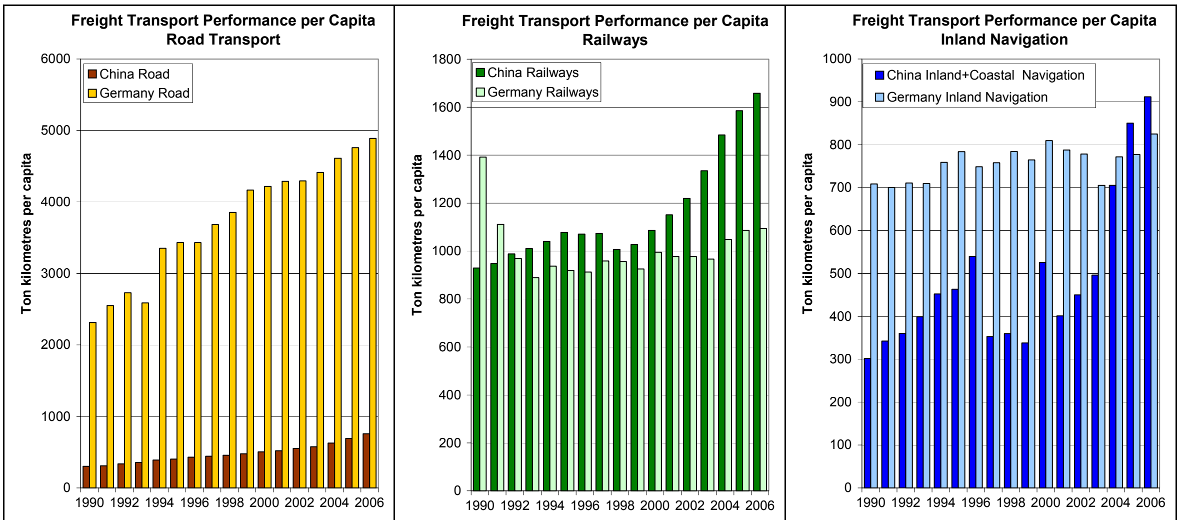


Figure 25 Passenger Transport Performance per Capita in China and Germany



Sources: [CSY 2006], IFEU estimation IFEU Heidelberg 2008

Figure 26 Freight Transport Performance in China and Germany



Sources: [CSY 2006], IFEU estimation IFEU Heidelberg 2008

Figure 27 Freight Transport Performance per Capita in China and Germany

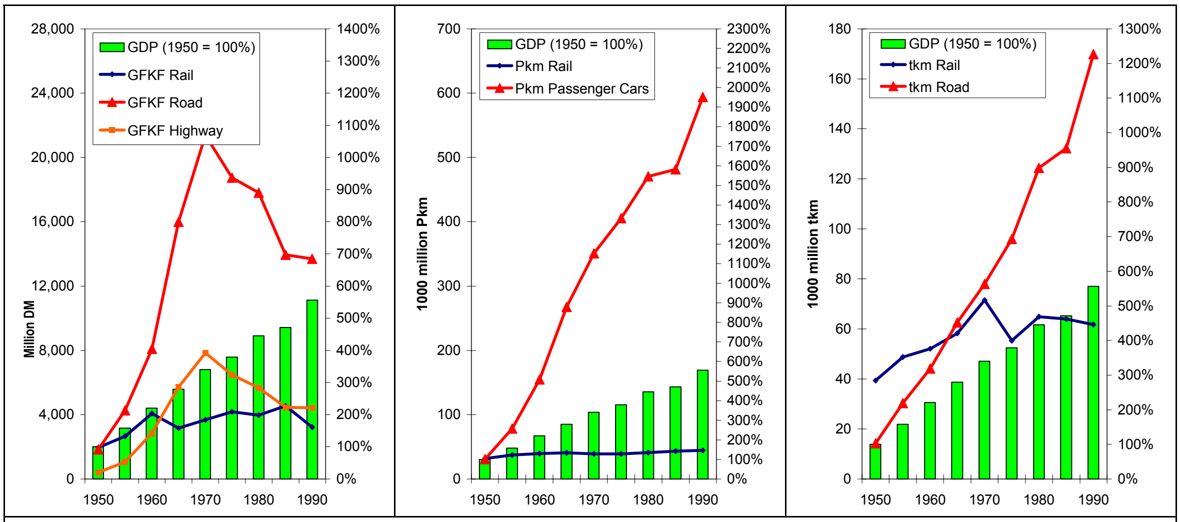
Past Development of Transport in Western Germany 1950-1990: Preference of Road

The Modal Split in Western Germany in 1990 was dominated by road transport. This was a result of the development in the decades after World War II: The prosperity of the population in Germany increased; the Gross Domestic Product (GDP) grew by factor 6 from 1950 to 1990. The government in Germany (and most other European countries) decided to advantage road transport and invested in the road sector more than in railway lines (see development of gross fixed capital formation (GFCF) in Figure 28. In consequence

- the length of railway lines decreased from 1950 to 1990 by nearly 20%, whereas the length of highways grew by factor 4 and of all roads by 36%,
- the road vehicle stock increased from 2.2 million vehicle to 35.6 million (factor 16),
- passenger transport performance with cars grew by factor 19, with railway only by 40%,
- freight transport performance with trucks grew by factor 12, with railway only by 60%.

The consequences for air pollution and energy consumption were impressive: Energy consumption and CO_2 emissions of road transport grew by factor 20, emissions of other air pollutants like NO_x, CO, VOC by factor 8-18. The legislation of the European Union and Germany against air pollution led to a strong reduction of these emissions from 1990 to 2005 (see Table 5, page 35).

Investments in long-distance and urban rail systems, which started in the seventies of the last century, resumed at a stage when already much of the traffic was lost to other modes of transport. Hence, at this stage re-routing of traffic to environment-friendly modes was all the more difficult. For this reason the increase of CO_2 emissions caused by transport could be decelerated, but not stopped (Table 5, page 35).



Sources: Statistical Federal Office, German Federal Ministry of Transport, IFEU Heidelberg 2008

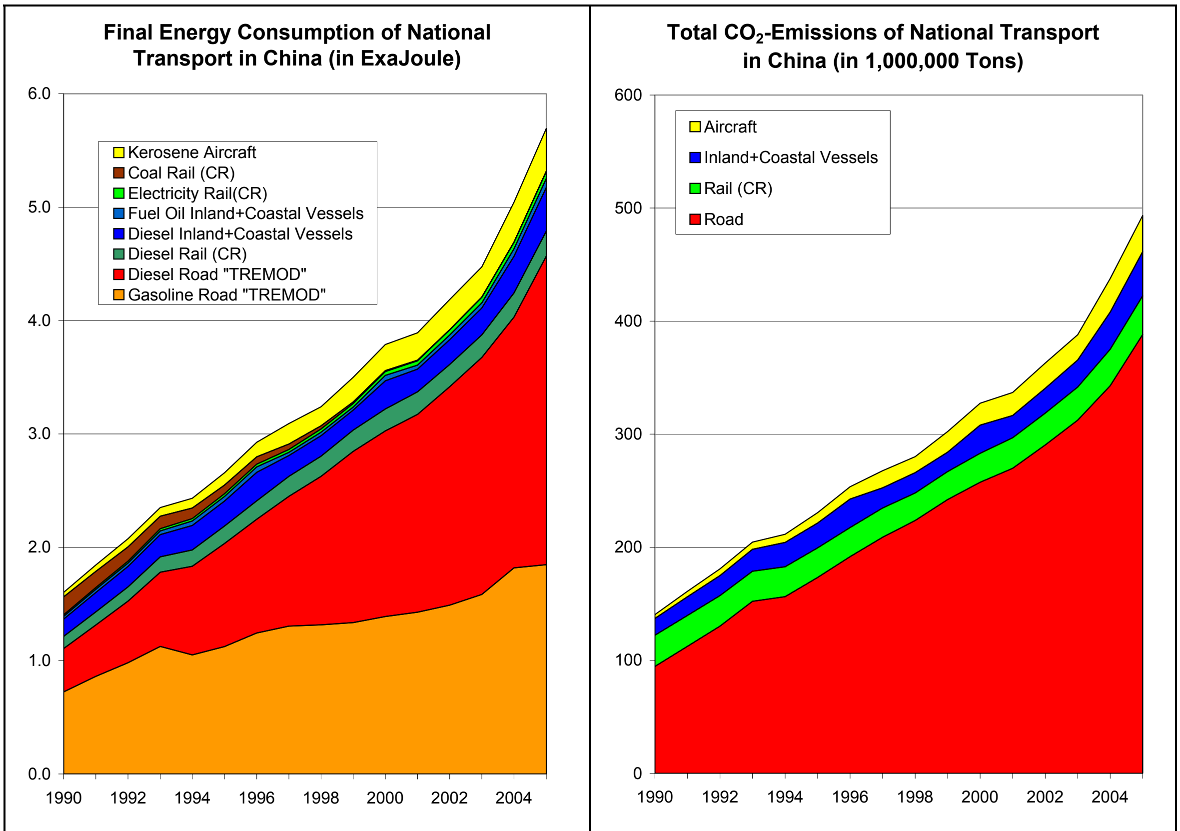
Figure 28 Developments 1950-1990 in Western Germany

4.5.2 Energy Consumption and CO_2 Emissions

In this chapter, the results of the energy estimation for road, rail, inland navigation and air transport in China are summarized. Furthermore, an estimation of total CO_2 emissions[2] of national Transport in China is added.

Since 1990, energy consumption and CO_2 emissions of the transport sector in China have increased strongly, primarily in road transport, inland navigation and air transport. In rail transport, energy consumption decreased as a result of the change from coal traction to diesel and electricity.

Road transport is the main contributor to energy consumption and CO_2 emissions in all years with an increasing share of 60% in 1990 to 75-80% in 2005.



without Ocean Shipping | without Ocean Shipping

Total CO_2 including emissions of fuel and electricity generation (“well-to wheel”).

Sources: IFEU Estimation, based on [Kebin He et al. 2005], [Hong Huo et al. 2006], [CSY 2006], [ICT 2007] et al. IFEU Heidelberg 2008

Figure 29 Estimation of Energy Consumption and CO_2 Emissions of National Transport in China 1990-2004

[2] Total CO_2 emissions include: Direct CO_2 emissions during combustion and indirect CO_2 emissions related to energy production (power plant, refinery) and delivery.

5 Scenarios for Possible Future Developments of Energy Demand in China and the Share of National Transport

A look into the future of transport in China is like “to read tea leaves”.· A lot of estimations for China are available. Because of rapid transport growth, estimations have to be updated very quickly. Following questions are on the focus of the survey:

- Which growth is estimated by experts for the future development of total energy consumption in China and of final energy consumption in the transport sector up to 2030?
- What does this mean for the share of transport on total final energy consumption and on total CO_2 emissions in China?
- How should the projected development of transport energy consumption in China be assessed compared to projected developments in OECD Europe and in Germany?

We look at several up-to-date scenarios with future trends for China:

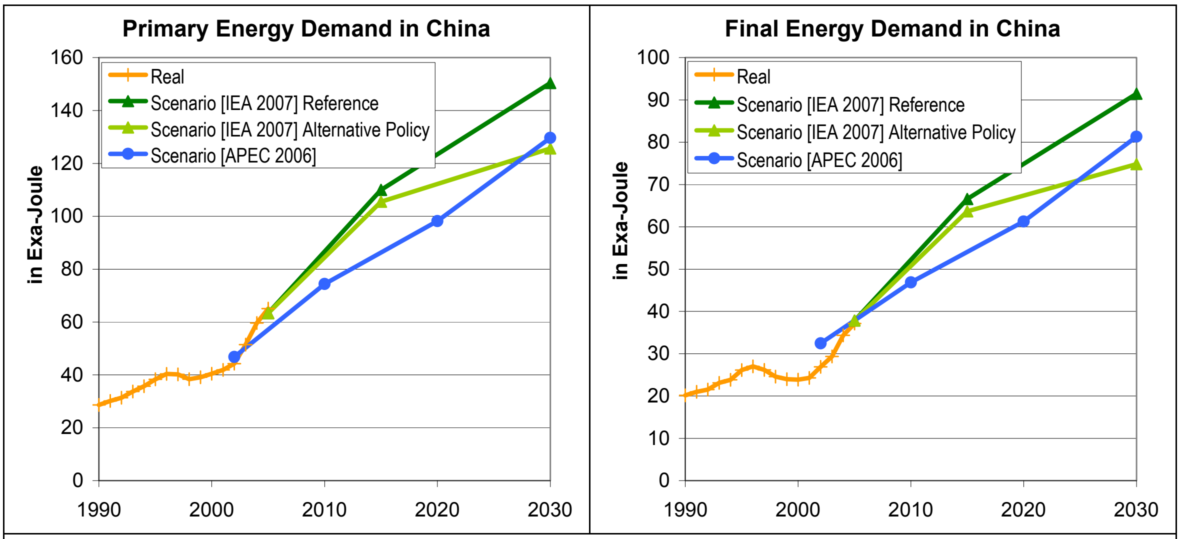
- [Hong Huo et al. 2006] made estimations for road transport in China, including different assumptions for the development of vehicle stock, average vehicle mileage and fuel economy. The scenarios with alternating combinations of these parameters come to an increase of energy consumption in road transport 2005-2030 by factor 3–4.
- [IEA 2007] *World energy Outlook 2007* contains future energy scenarios for all regions of the world in two variants: *Reference* and *Alterative Policy*. For China the following growth rates are estimated:
  - Total primary and final energy consumption in China will increase by factor 2.0-2.4 between 2005 and 2030,
  - Final energy consumption of transport will increase by factor 3.0-3.8 between 2005 and 2030.
- A current outlook in [APEC 2006] estimates the following development:
  - Total primary and final energy consumption in China will increase by factor 2.5-2.8 between 2002 and 2030,
  - Final energy consumption of transport (based on “Official Transport”) will increase by factor 3.8 between 2002 and 2030

It can be stated that the main trends are similar in all surveys. For a better comparison, the estimates of the energy studies are summarized in the following figures.

In all scenarios, the increase of final energy consumption in transport will be considerably higher than total energy consumption in the country. Hence, the share of the transport sector on total energy demand will increase. According to IEA estimations, transport share will increase 2005-2030 from 13 to 21% of total final energy consumption. APEC estimates an increase 2002-2030 from 10 to 16%.

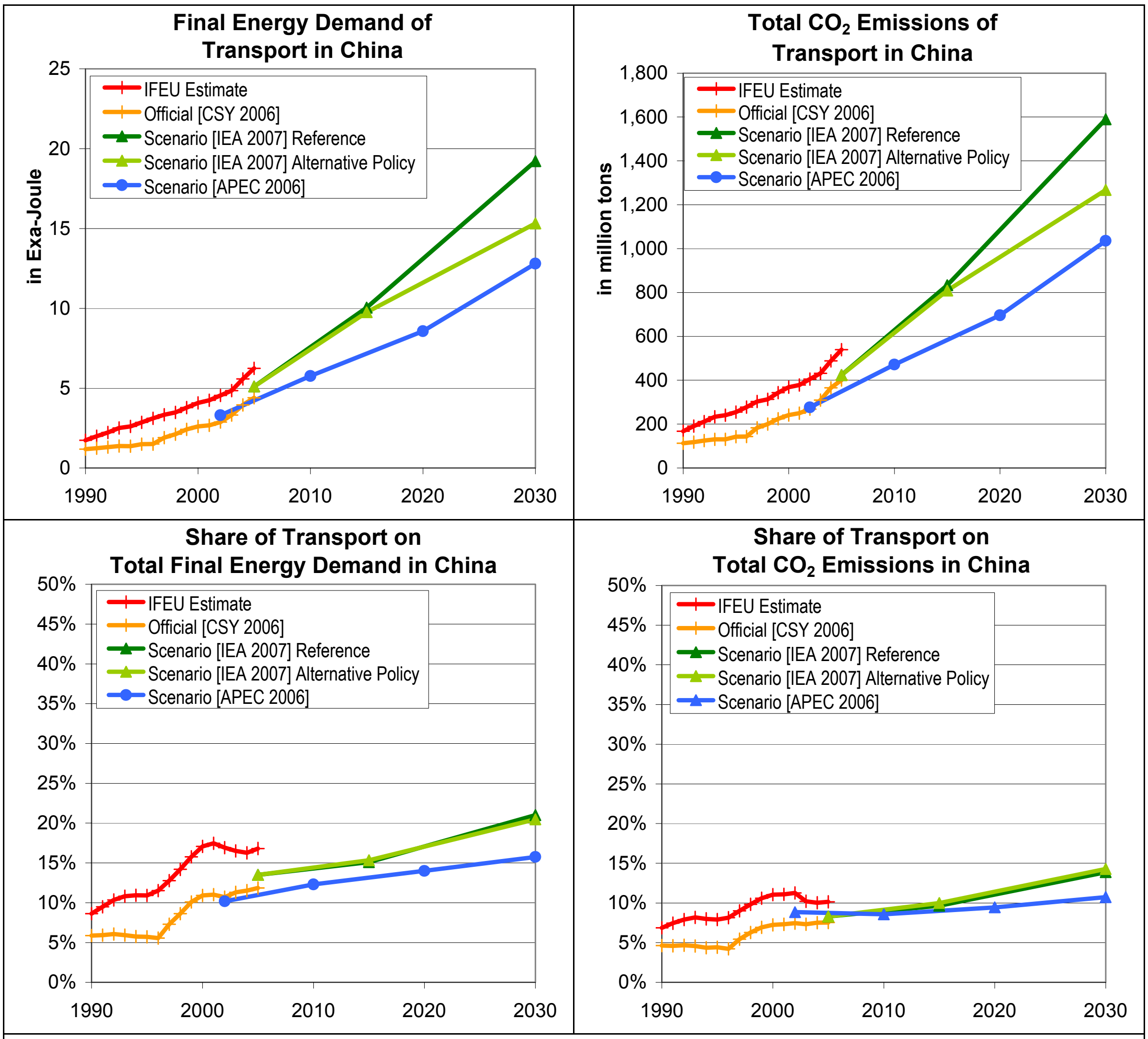
The transport share on total CO_2 emissions in China is somewhat lower. This can be explained by the used primary energy carriers for the supply of final energy. Transport final energy is mainly oil-based and, thus, less CO_2 intensive than electricity or direct consumption of CO_2 intensive coal. Nevertheless, the share of transport on total CO_2 emissions of China is expected to increase as well.

IEA and APEC scenarios do not cover the – compared to official statistics – actually higher energy consumption in transport to the full extent, as determined in our estimates for current transport energy consumption (chapter 4.1.3) and shown in Figure 31. Therefore, the actual share of transport on total energy consumption in China (and related CO_2 emissions) is underestimated in both studies.



Sources: [IEA 2007], [APEC 2006], [CSY 2006] IFEU Heidelberg 2008

Figure 30 Primary and Final Energy Demand in China, Scenarios up to 2030



Total CO_2 including emissions of fuel and electricity generation (“well-to wheel”).

Sources : [IEA 2007], [APEC 2006], [CSY 2006], IFEU Estimations IFEU Heidelberg 2008

Figure 31 Final Energy Demand & CO_2 Emissions of Transport in China, Scenarios up to 2030

The future scenarios for China can be compared with scenarios of OECD Europe and with Germany. We use the IEA reference scenario for the comparison. The following relations can be stated (see figure below):

- In 2005, final energy consumption of transport in China was according to IEA about 2 times higher than in Germany and 30% of transport energy consumption in OECD Europe.
- In 2030, final energy consumption in the IEA reference scenario would be factor 7.4 higher than in Germany and reach the transport energy consumption in OECD Europe.

Nevertheless the energy consumption of transport per capita in China will not reach the level of Germany and OECD Europe until 2030: Final energy consumption per capita in transport will be about 2.5 times higher in Europe than in China. So a further strong growth of transport energy consumption in China after 2030 is considered possible.

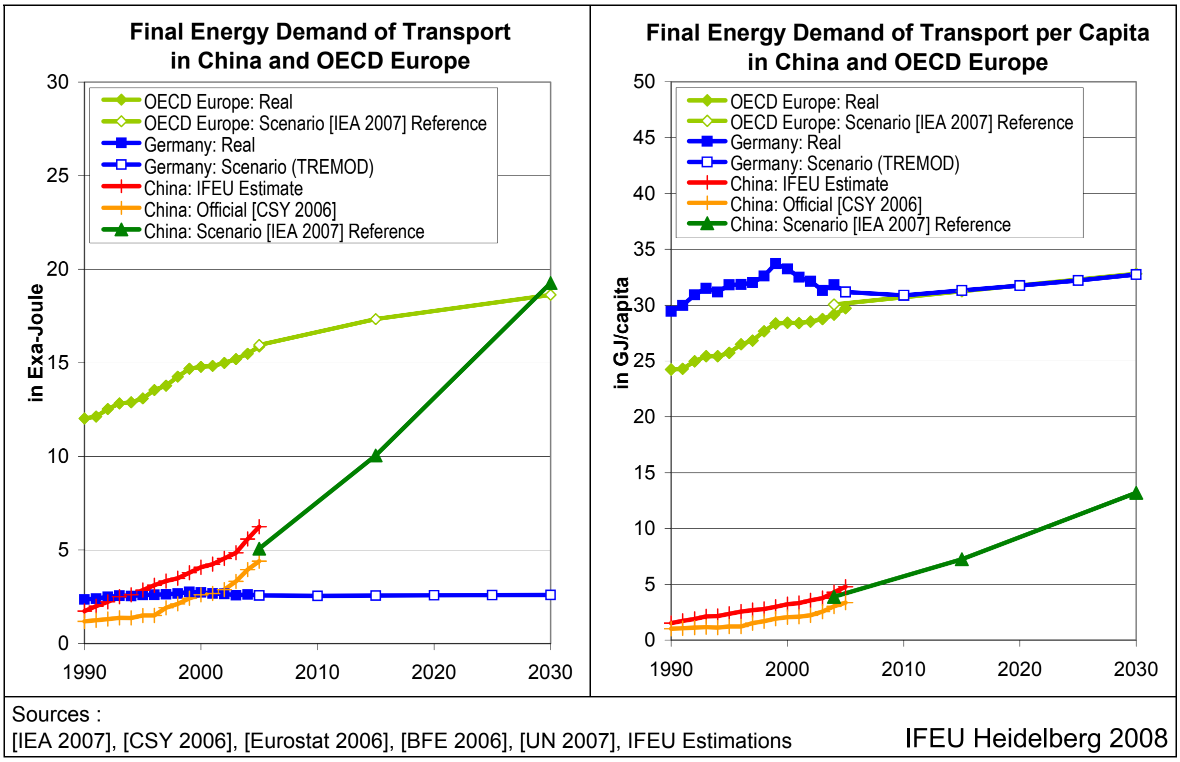


Figure 32 Final Energy Demand of Transport in China and OECD Europe, Scenarios up to 2030

6 Specific Primary Energy Consumption and CO_2 Emissions of Relevant Transport Systems in China and Germany

6.1 Overview

This chapter summarises specific energy and CO_2 emission values for transport processes in China including a comparison with related values in Germany. The values were prepared for the case studies “Long Distance Transport Shanghai-Wuhan” and “Urban Passenger Transport in Shanghai” and further tasks in the context of environmental comparisons of different transport modes. The following means of transport are considered:

Transport Sector	Means of Transportation
Urban passenger transport	Passenger Car, Urban Bus, Metro
Long Distance Passenger Transport	Passenger Car, Coach, Long Distance Train, Airplane
Long Distance Freight Transport	Lorry, Freight Train, Inland Ship

Key values for this survey are

Final energy consumption vehicle: in litre per 100 vehicle-km (l/100 km), kilowatt-hours per vehicle-km (kWh/km) or gram fuel per vehicle-km (g/km)

Load factor or capacity utilisation: in persons per vehicle or percent of used person or mass capacity

Primary energy consumption (including energy production and delivery): in Mega Joule per passenger-kilometre or tons-kilometre

Total CO_2 emissions (including energy production and delivery): in gram per passenger kilometre or g per tons-kilometre.

All values are estimated for the reference year 2005 and as scenario for 2020.

6.2 Assumptions and Data Sources

Passenger Car

The values of average fuel consumption of passenger cars are taken from a recent survey of real-world vehicular emissions in Chinese cities [Kebin He et al. 2007b]. In the study energy consumption and emissions of 49 vehicles were measured under real driving conditions in seven Chinese cities. The values used here come from four vehicles which are measured on freeways, arterial and residential roads in the city of Beijing. For the average urban traffic we estimate a relation of 30% freeway: 70% arterial/residential. For long distance transport the average energy consumption of freeways is used.

For comparison energy values of average petrol cars in Germany 2005 are taken from the TREMOD-Model [IFEU 2006].

The energy consumption per passenger kilometre is calculated with estimated load factors of 1.3 Person per car in urban situations and 2 Persons per car for long distance transport.

For 2020 we estimate a reduction of specific energy consumption by 25% compared to 2005.

Passenger car petrol		Fuel Cons.	Capacity	PE	CO_2	Source
		l/100 km	Persons	MJ/Pkm	g/Pkm	
China	Arterial/Residential Roads	12.5	5	0.95	68.9	Kebin He et al 2007
China	Freeway	7.5	5	0.57	41.2	Kebin He et al 2007
China	Urban Roads average	11.0	5	0.84	60.6	Kebin He weighted
Germany	Urban Roads	10.0	5	0.76	55.1	IFEU 2006
Germany	Highway	8.7	5	0.66	48.0	IFEU 2006
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization						

Urban Bus, Coach and Lorry

For urban buses, coaches and lorries we could not get reliable values for China. Thus average values for different bus types from the TREMOD model [IFEU 2006] are used. For comparisons a large BRT Bus with a capacity of 270 persons is added [Volvo 2006]. For 2020 a reduction of 20% for buses and 15% for lorries compared to 2005 is estimated.

Urban Bus	Fuel Cons.	Capacity	PE	CO_2	Source
	l/100 km	Persons	MJ/Pkm	g/Pkm	
Average China	35.0	40	0.35	26.0	ICT 2007
Average Germany	37.0	60	0.25	18.4	IFEU 2006
BRT	70.0	270	0.10	7.7	Volvo 2006
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization					

Coach	Fuel Cons.	Capacity	PE	CO_2	
	l/100 km	Persons	MJ/Pkm	g/Pkm	
Average	30.0	44.0	0.27	20.3	IFEU 2006
Small	21.0	25.0	0.34	25.0	IFEU 2006
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization					

Lorry	Fuel Cons.	Capacity	PE	CO_2	Source
0	l/100 km	Persons	MJ/tkm	g/tkm	
Lorry 7.5t	14.2	3.0	1.91	141.1	IFEU 2006
Lorry 14-20t	24.3	9.5	1.03	76.5	IFEU 2006
Lorry, 40t	39.0	28.0	0.56	41.5	IFEU 2006
Lorry, 60t	48.8	45.0	0.44	32.3	IFEU 2006
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization					

Metro

For metro transport a detailed statistic of the Shanghai metro lines in 2007 [Shanghai Metro Operation 2007] and results of the ICT survey [ICT 2007] can be used. The statistics include the energy consumption of Shanghai metro lines 1-3 for traction and stations without commercials. These higher values are used for the Shanghai case study (see chapter 8). For the comparison with Germany the specific values without stations are performed as well. For 2020 we estimate a reduction of the specific energy consumption of 20%.

Metro	Final Energy Cons.	Capacity	PE	CO_2	Source
	kWh/wagon-km	Persons	MJ/Pkm	g/Pkm	
China incl. stations	5.0	216	0.26	20.9	ICT 2007, Shanghai Metro Operation
China	2.8	216	0.15	11.8	ICT 2007, Shanghai Metro Operation
Germany	2,3	117	0.22	12.4	VDV 2007
PE: specific primary energy consumption with full capacity utilization CO_2: specific CO_2 emissions with full capacity utilization China incl. stations: energy consumption of stations without commercials included					

Long Distance Passenger Train

The Chinese Railways do not differentiate the energy consumption between passenger and freight transport (see Chapter 4.2). Hence no reliable average energy values for the passenger transport of railways in China are available.

In this study values are estimated from typical European key values per gross hauled ton kilometre and transferred to typical trains in China (longer trains, more seats, higher load factors than in Germany.

Today typical long distance passenger trains in China have 18 wagons. The average weight per wagon is 48 tons. The capacity per wagon is about 100 seats [ICT 2007]. Therefore the average weight per seat is less than 0.5 tons, which is below an average long distance train in Germany (e.g. IC about 0.8 tons/seat, ICE more than 1 ton/seat) The average load factor is about 70%.

The high speed passenger train is a motor unit with 8 wagons and 610 seats. The total weight is 400 tons. The average load factor is about 70%. The maximum speed on the new lines is 200 km/h. Two units can be connected to a long train.

For the estimation of the specific energy consumption, the Chinese high speed train can be compared with a German ICE 3 (8 wagons; total weight 409 t; 456 seats). With a similar total weight the Chinese train has a seat capacity which is 35% higher than the German ICE.

The specific energy consumption per seat-km is estimated based on European trains. In Germany, the energy consumption of IC and ICE trains with a maximum speed of 200 km/h is about 30 Wh per gross ton km [IFEU 2006]. Similar values can be found at other European railways [IFEU 2008]. In this study we use the same value as best estimate for Chinese trains.

For 2020 for all trains in China a reduction of specific energy consumption of 12% is estimated compared to 2005 [ICT 2007].

	Final Energy Cons.	Capacity	PE	CO_2	Source
	kWh/km	Persons	MJ/Pkm	g/Pkm	
Long Distance Train, Germany	24.2	700.0	0.38	21.8	IFEU 2006
Highspeed Train, Germany	11.5	410.0	0.31	17.7	IFEU 2006
Long Distance Train China	30.0	1800.0	0.19	15.0	ICT 2007, IFEU Estimation
Highspeed Train China	11.4	610.0	0.21	16.9	ICT 2007, IFEU Estimation
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization					

Airplane

The technical standard of airplanes in China is similar to Europe. Therefore European average values are used [IFEU 2006]. The reduction of specific energy consumption between 2005 and 2020 is estimated 20%.

	Final Energy Cons.	Capacity	PE	CO_2	Source
	g/Seat-km	Persons	MJ/Pkm	g/Pkm	
Aircraft	27.2	average	1.33	98.6	IFEU 2006, Estimation
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization					

Freight Trains

Typical freight trains in China have considerable higher average weights than in Europe which leads to lower specific energy consumption values. In this study specific values for mass transport trains and double deck container trains are derived. The double container train has 39 wagons, each wagon can load 4 TEU (four 20-feet or two 40-feet container). The maximum total train weight is 4.000 tons. The energy consumption per gross-ton-km for a full loaded train is stated as 9.8 Wh/gross ton-km [ICT 2007]. This value is about 8% lower than the result for a 4000 tons train simulated with the EcoTransIT model [IFEU 2005a]. The average value for a freight train in Germany (less than 1.000 gross-tons, half loaded) is 22 Wh/gross-ton-km. For 2020 a reduction of 12% is estimated [ICT 2007].

	Final Energy Cons.	Capacity	PE	CO_2	Source
	kWh/km	Tons	MJ/tkm	g/tkm	
Double Deck Container, Electric	39.3	3042.0	0.14	11.7	ICT 2007
Mass transport freight trains, Electric	41.4	4127.1	0.11	9.0	ICT 2007
Double Deck Container, Diesel	106.3	3042.0	0.14	10.5	ICT 2007
Mass transport freight trains, Diesel	111.9	4127.1	0.11	8.2	ICT 2007
Freight Train Germany , Electric	26.1	1020.0	0.28	16.2	IFEU 2005a
PE: Specific primary energy consumption with full capacity utilization CO_2: specific CO_2 Emissions with full capacity utilization					

Inland Ship

For inland ships the average energy consumption is recalculated from total fuel consumption and total transport performance. In China an average value of 9 g/tkm is stated [ICT 2007], about 10% below the average value of Germany.

	Final Energy Cons.	Capacity	PE	CO_2	Source
	g/tkm	Tons	MJ/tkm	g/tkm	
Inland Ship average China	9.0	average	0.44	32.3	ICT 2007
Inland Ship average Germany	10.0	average	0.49	35.9	IFEU 2006
PE: Specific primary energy consumption with average capacity utilization CO_2: specific CO_2 Emissions with average capacity utilization					

6.3 Results

Urban Passenger Transport

Primary energy consumption and specific CO_2 emissions are presented for passenger cars, metro, bus and BRT. The figures show specific values per passenger-km with full load and typical load factors. For China, average load factors for 2005 from the Shanghai case study (see chapter 8) are used. The following results can be stated:

- Urban rail transit systems (metro, light rail) in China are highly energy efficient and have low CO_2 emissions compared to bus and passenger car. Only very optimized BRT systems with high passenger capacities (270 persons per vehicle, 25 m long, articulated, 3 sections), separate lanes and fly-overs at major road crossings can reach or exceed the energy efficiency of metro transport. Metro systems in general offer higher passenger transport capacities per line compared to BRT systems, but need higher investment costs.
- Even if energy consumption of stations (ventilation, airconditionig, illumination, escalators, etc.) is included, metro systems in China are more energy-efficient than the average urban bus and passenger cars.
- Passenger cars in urban traffic of Chinese megacities are very inefficient. This effect is increased by low vehicle occupation (1.3 persons/vehicle) and high traffic load (congestions and slow traffic flow).
- Chinese metro systems have higher capacity utilization due to a lower number of space consuming seats and considerable higher average load factors. (39% compared to 17%). Therefore, the specific primary energy consumption of metro systems in China is three times lower than in Germany.

Long distance passenger transport:

Primary energy consumption and specific CO_2 emissions are presented for passenger cars, long distance trains, coaches and airplanes. The figures show specific values per passenger-km with full load and typical load factors. The following results can be stated:

- Passenger trains in China have a high energy efficiency and low CO_2 emissions compared to coach and passenger car due to high capacities per train and high load factors of 70% [ICT 2007].
- Compared to Germany passenger trains in China are more efficient due to a higher seat capacity and higher average load factors.
- Long distance trips with passenger cars on highways are probably more energy-efficient than in Germany due to the speed limit of 120 km/h in China and a more evenly driving behaviour.

Freight Transport

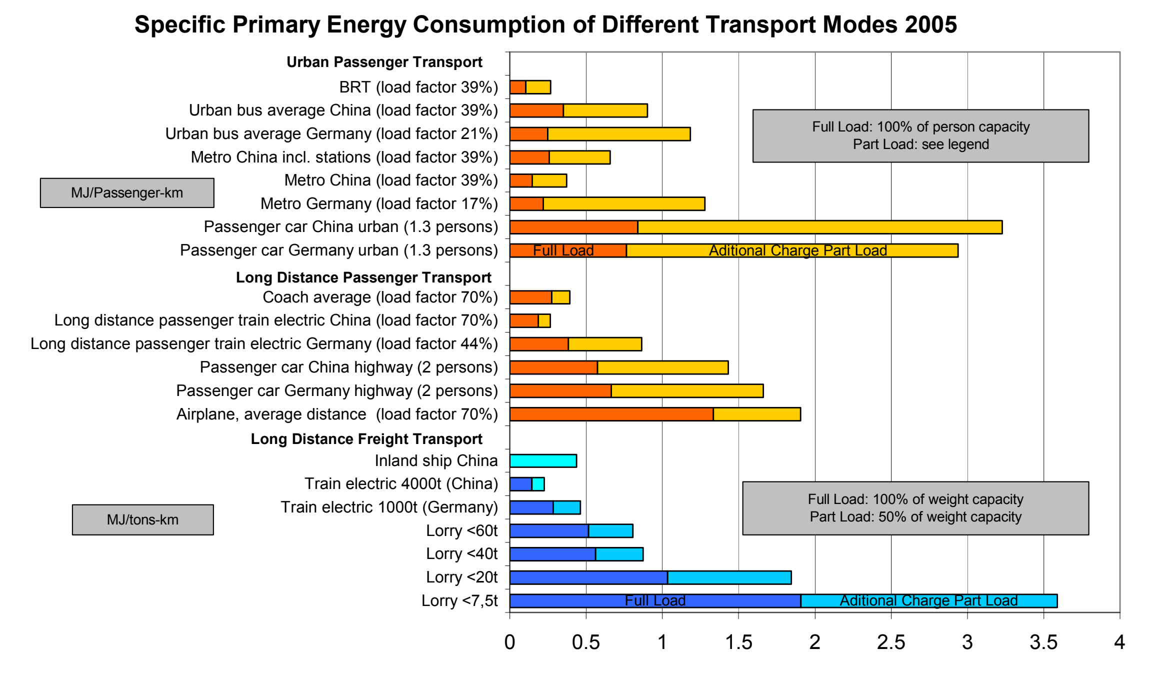
Primary energy consumption and specific CO_2 emissions are presented for freight trains, lorries with different sizes and inland ships. The figures show specific values per ton km with full load and half load. The following results can be stated:

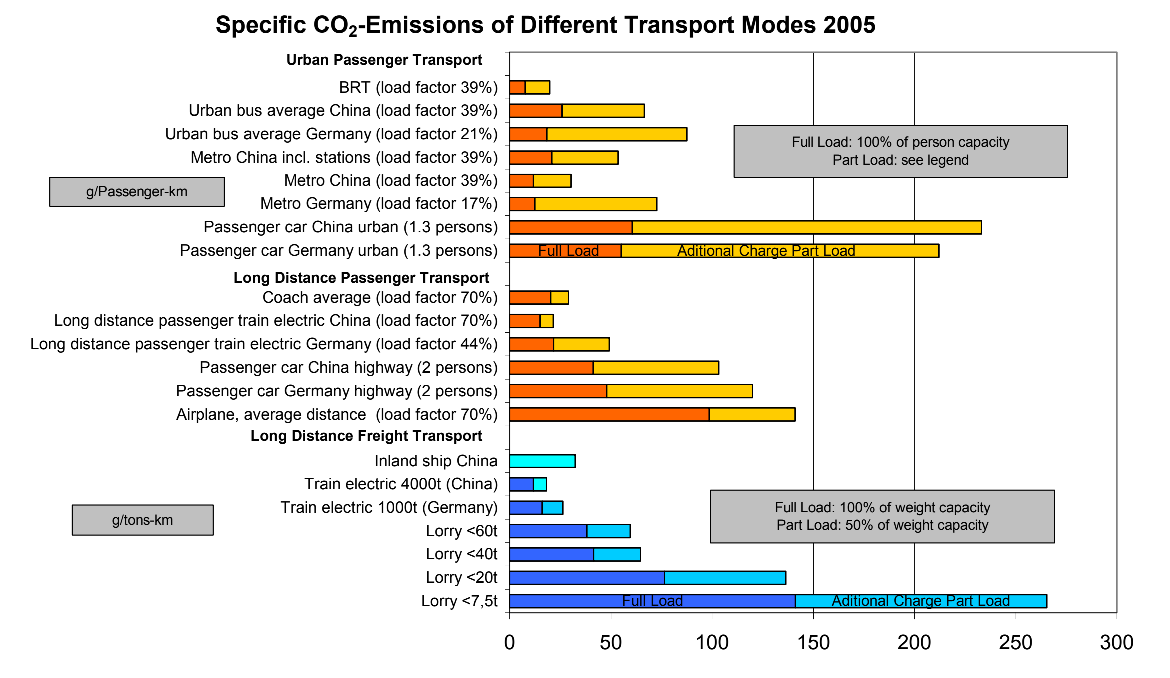
- Chinese freight trains benefit from high train loads. Double stack container trains with a load of 4,000 t have about half the specific energy consumption than average German freight trains with a load of 1,000 t.

- The specific energy consumption of 40 ton lorries is about four times higher compared to the double stack container train. Smaller lorries will have an even higher specific energy consumption compared to the freight train.

All Transport Modes

- In general, urban rail transit and railways in China are very energy-efficient systems, due to high transport capacities and high load factors. Therefore, rail transport in China has from the outset a much higher energy saving potential vis a vis road transport than in Europe.
- Due to the high share of coal in electricity generation in China, electric trains have similar specific CO_2 emissions as diesel trains. Thus, the advantages of electric railways concerning CO_2 emissions are resulting mainly from increased line capacity. The energy mix, however, is expected to change in future in favour of less CO2 emitting energy carriers and power plants.


Specific Primary Energy Consumption of Different Transport Modes 2005
Urban Passenger Transport
BRT (load factor 39%)
Urban bus average China (load factor 39%)
Urban bus average Germany (load factor 21%)
Metro China incl. stations (load factor 39%)
Metro China (load factor 39%)
Metro Germany (load factor 17%)
Passenger car China urban (1.3 persons)
Passenger car Germany urban (1.3 persons)
Long Distance Passenger Transport
Coach average (load factor 70%)
Long distance passenger train electric China (load factor 70%)
Long distance passenger train electric Germany (load factor 44%)
Passenger car China highway (2 persons)
Passenger car Germany highway (2 persons)
Airplane, average distance (load factor 70%)
Long Distance Freight Transport
Inland ship China
Train electric 4000t (China)
Train electric 1000t (Germany)
Lorry <60t
Lorry <40t
Lorry <20t
Lorry <7,5t
MJ/Passenger-km
MJ/tons-km
Full Load: 100% of person capacity
Part Load: see legend
Full Load: 100% of weight capacity
Part Load: 50% of weight capacity
Full Load
Aditional Charge Part Load
0
0.5
1
1.5
2
2.5
3
3.5
4


Specific CO_2-Emissions of Different Transport Modes 2005
Urban Passenger Transport
BRT (load factor 39%)
Urban bus average China (load factor 39%)
Urban bus average Germany (load factor 21%)
Metro China incl. stations (load factor 39%)
Metro China (load factor 39%)
Metro Germany (load factor 17%)
Passenger car China urban (1.3 persons)
Passenger car Germany urban (1.3 persons)
Long Distance Passenger Transport
Coach average (load factor 70%)
Long distance passenger train electric China (load factor 70%)
Long distance passenger train electric Germany (load factor 44%)
Passenger car China highway (2 persons)
Passenger car Germany highway (2 persons)
Airplane, average distance (load factor 70%)
Long Distance Freight Transport
Inland ship China
Train electric 4000t (China)
Train electric 1000t (Germany)
Lorry <60t
Lorry <40t
Lorry <20t
Lorry <7,5t
g/Passenger-km
g/tons-km
Full Load: 100% of person capacity
Part Load: see legend
Full Load: 100% of weight capacity
Part Load: 50% of weight capacity
Full Load
Aditional Charge Part Load
0
50
100
150
200
250
300

7 Case Study Long Distance Transport Shanghai – Wuhan

7.1 Railway and Highway Lines

Focus of this chapter is the analysis of energy consumption and CO_2 emissions on a transportation relation for long-distance road and railway transport, in particular the effects of new railway lines, the shift of transport from road to rail and its contribution to the reduction of the environmental effects of transport.

The Shanghai – Wuhan relation has been chosen as a case study, because:

- The railway line will be modernised within the next years and two completely new sections are build (Hefei-Nanjing and Hefei-Wuhan). These sections will reduce the total transport distance by 30%.
- A highway runs parallel to the railway line.
- Data on traffic loads and projections of future transport volume are available.

Three sections of the railway line can be distinguished (see [ICT 2007]):

- Shanghai – Nanjing: The existing line.
- Nanjing – Hefei: There is currently no direct railway between Nanjing and Hefei. One line passes Bengbu in the north, the other Wuhu in the south. For this analysis we choose the northern line. The new direct line will shorten the distance from 312 kilometres to 164 kilometres.
- Hefei – Wuhan: There currently is no direct railway line. Three alternative lines exist. In this analysis we choose the line via Jiujiang. The new direct line will reduce the distance from 565 kilometres to 362 kilometres.

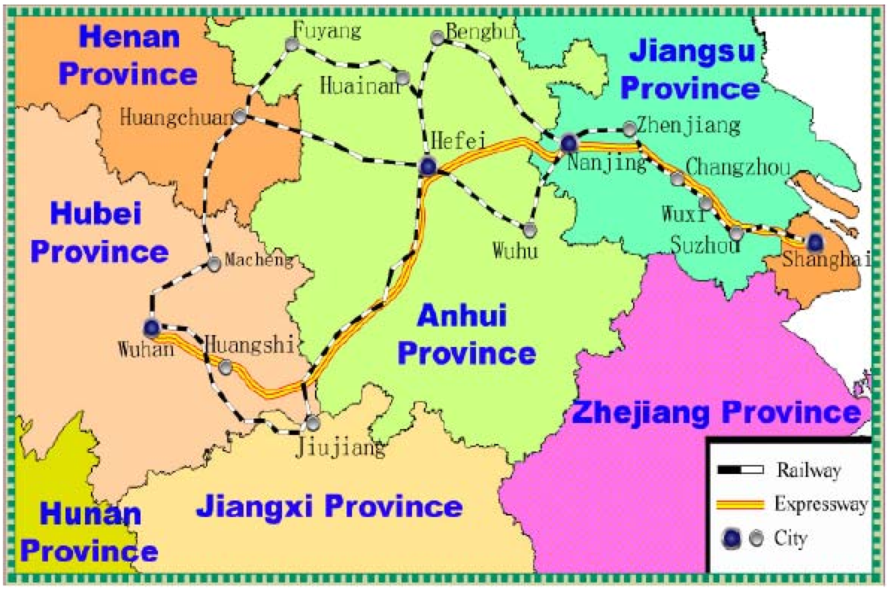


Figure 33 Existing railway and expressway in the Shanghai-Wuhan corridor (ICT 2007)

The total distance Shanghai-Wuhan is thus currently 1167 kilometres. With the new lines mentioned above, the distance will be reduced to 816 kilometres. While in 2005 only diesel trains could be used, the new lines will allow for electric traction on the entire line.

The expressway Shanghai-Wuhan has a length of 827 km which is similar to the railway length after the construction of the new lines.

Table 7 Length of Highway and Railway Shanghai-Wuhan

Distances	Rail		Road
	2005	**2020**	
Shanghai-Nanjing	290	290	
Nanjing-Hefei*	312	164	
Hefei-Wuhan**	565	362	
Total	**1167**	**816**	**827**
Source: [ICT 2007], [FSDICR 2005a], [FSDICR 2005b]			

7.2 Transport Volume

Highway

The Shanghai – Wuhan highway has four lanes with a maximum speed of 120 km/h and covers the four provinces Shanghai, Jiangsu, Anhui and Hubei. In 2005, the highest traffic volume was observed on the short Shanghai section. The Shanghai and Jiangsu section were dominated by passenger vehicles, the Anhui and Hubei Section by goods vehicles. The average traffic volume was about 20.000 PCU per day (Table 8). For comparison, the average traffic volume on highways in Germany is about three times higher.

Table 8 Status of Shanghai-Wuhan-Highway 2005

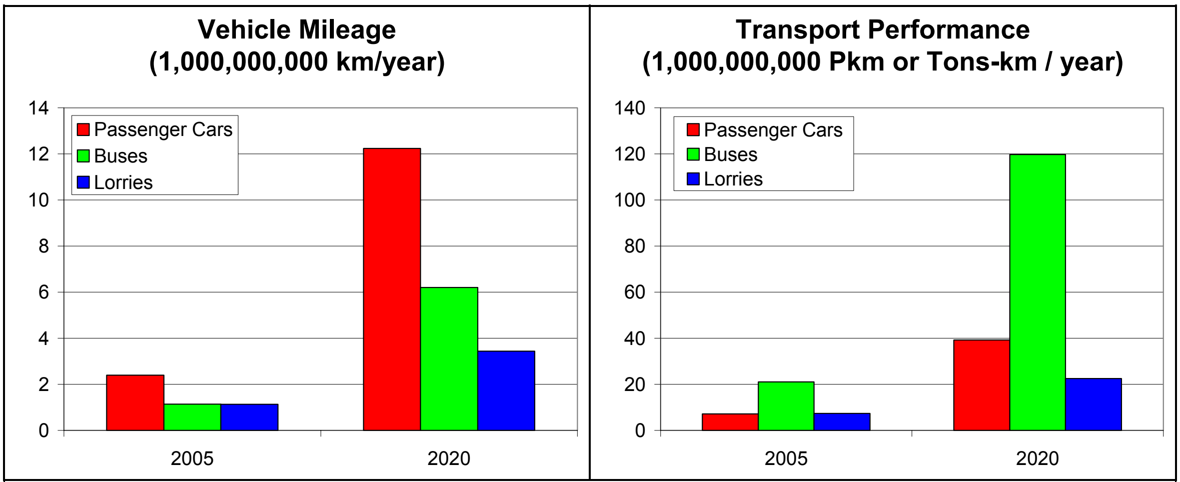
		Traffic volume	Proportion	
Section	**Length (km)**	**PCU (Vehicles/day)**	**Goods Vehicles**	**Pass Vehicles**
Shanghai	24	80,490	8.40%	91.60%
Jiangsu	250	22,997	4.40%	95.60%
Anhui	370	11,752	71.80%	28.20%
Hubei	183	26,830	68.50%	31.50%
Total	**827**	**20,483**	**48.9%**	**51.1%**
PCU = passenger car unit Source : [ICT 2007]				

The total vehicle mileage per year can be recalculated from the PCU per day, assuming 1.2 PCU for the average bus and 2 PCU for a lorry. With this assumption, the total vehicle mileage for the Highway Shanghai-Wuhan was about 4.700 Million vehicle kilometre in 2005, thereof 50% passenger cars, 25% buses and 25% lorries. The average load factors was recalculated from the transport performance. For a passenger car the average load was 3 persons, for a bus 18 persons and for a lorry about 6.5 tons per vehicle (Table 9).

Table 9 Traffic Load of the Shanghai-Wuhan Highway 2005

	Passenger Cars	Busses	Lorries
PCU (1,000,000 km/day)	6.6	3.8	6.2
Vehicle Mileage* (1,000,000 km/day)	6.6	3.1	3.1
Vehicle Mileage (1,000,000km/year)	2,397	1,145	1,137
Transport Performance	**1,000,000 Pkm** 7,177	**1,000,000 Pkm** 21,042	**1,000,000 tons-km** 7,426
Load Factor	**persons/vehicle** 3.0	**persons/vehicle** 18.4	**tons/vehicle** 6.5
*Vehicle mileage estimated from PCU (passenger car unit) with 1.2 PCU/bus and 2 PCU/lorry Source: [ICT 2007]			

The Institute of Comprehensive Transportation of the National Development and Reform Committee of China has estimated the future development of the traffic volume on the highway Shanghai-Wuhan [ICT 2007]. Accordingly, the vehicle mileage and transport-performance will be five times higher in 2020 compared to 2005 for passenger cars and buses and three times higher for lorries. The average load factor will not increase significantly. Thus, no major changes in the fleet composition – such as an increase in the average size of lorries – are assumed. The estimates for vehicle mileage and transport-performance are summarised in Figure 34.



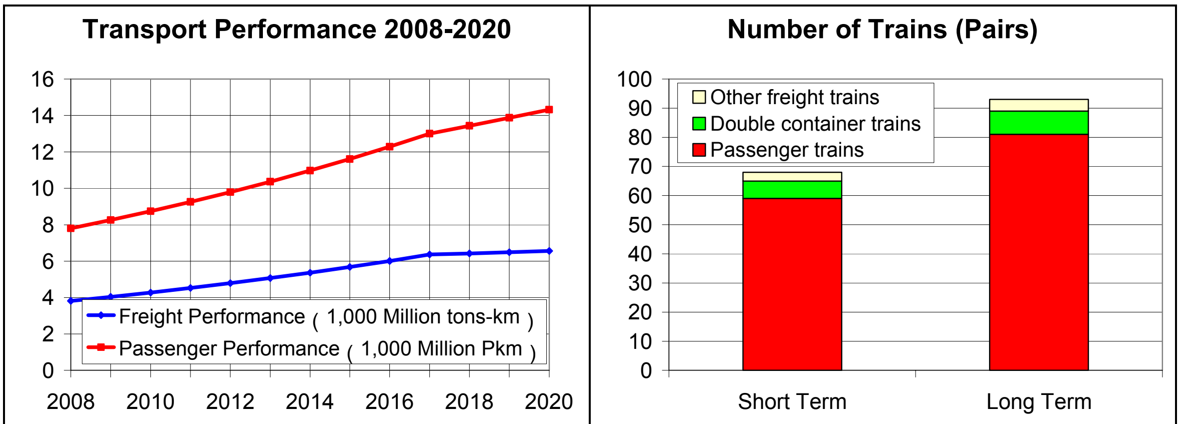
Source : [CSY 2006],[ICT 2007], IFEU estimations IFEU Heidelberg 2008

Figure 34 Vehicle Mileage and Transport Performance of the Shanghai-Wuhan Highway 2005 and 2020

Railway

The Hefei Nanjing and Hefei-Wuhan railway projects are supposed to be finished in 2008. Estimations on transport volumes for the Hefei-Wuhan section for the timeframe 2008-2020 are available from [FSDICR 2005a, b]. Since there is no information available on the transport volume for the year 2005, the analysis must focus on the future situation.

In passenger transport, normal long distance trains and high speed trains, in freight transport double container trains and other freight trains mainly with electric traction will be used. Figure 35 shows the expected transport volumes.



Source: [FSDICR 2005b] IFEU Heidelberg 2008

Figure 35 Transport Volumes for the New Railway Line Hefei-Wuhan

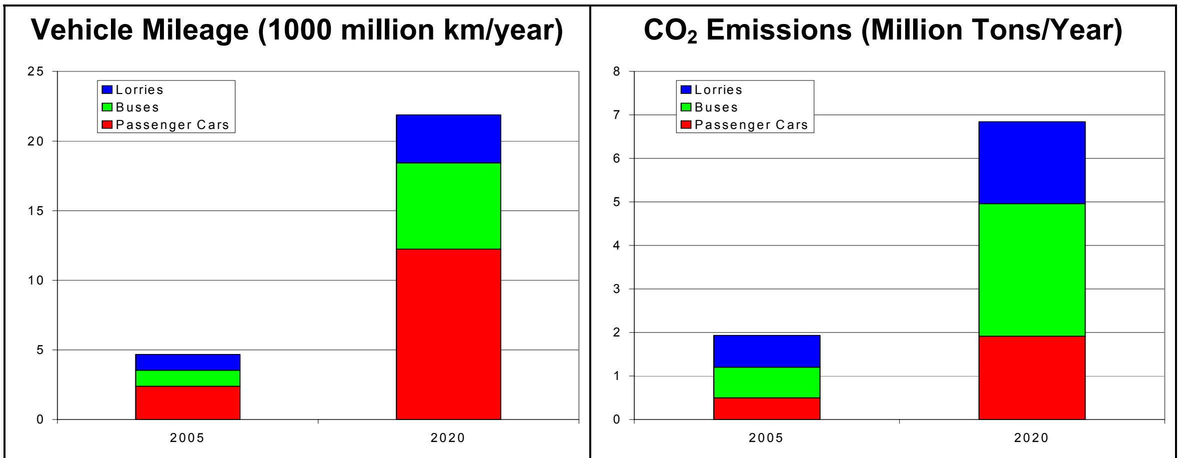
7.3 Energy Consumption and CO_2 Emissions

The calculations of energy consumption and CO_2 emissions in this analysis are first rough estimates, because detailed basic data of traffic volume and fleet composition are not available. The following values for specific energy consumption are used (for more details see chapter 6):

- Passenger cars: freeway traffic.
- Lorries: mixture of different size classes, therefore the lorry 14-20 tons is taken as reference.
- Bus and Coach: mixture of different size classes, therefore the small coach is taken as reference.
- Passenger rail transport: long distance passenger train electric is used as reference, load factor 70%.
- Freight rail transport: double deck container train electric is used as reference; with an estimated capacity utilisation of 67% (mass related).

Results Highway 2005 and 2020

The CO_2 emissions of highway traffic between Shanghai und Wuhan are estimated based on the assumption made in the previous chapters. Accordingly, the fivefold respectively threefold (for lorries) increase in vehicle mileage between 2005 and 2020 leads to an increase in CO_2 emission by 280 %. The results are presented in the following figure.



Source: [ICT 2007], IFEU estimations IFEU Heidelberg 2008

Figure 36 Vehicle Mileage and CO_2 Emissions of Shanghai-Wuhan Highway 2005 and 2020

Results Highway and Railway 2020

Traffic volume figures for the railway line Hefei-Nanjing-Shanghai are not available. For a comparison of the CO_2 emissions of the highway Shanghai-Wuhan with the railway line, we assume the same traffic load for the railway sector Shanghai-Hefei as for the sector Hefei-Wuhan. With this assumption, traffic volumes of the railway relation Shanghai-Nanjing-(Beijing) are, contrary to the highway, not included in the analysis. Therefore the analysis potentially underestimates the railway transport performance of the Shanghai-Wuhan line. The results of the estimate are presented in Figure 37 for passenger transport and in Figure 38 for freight transport.

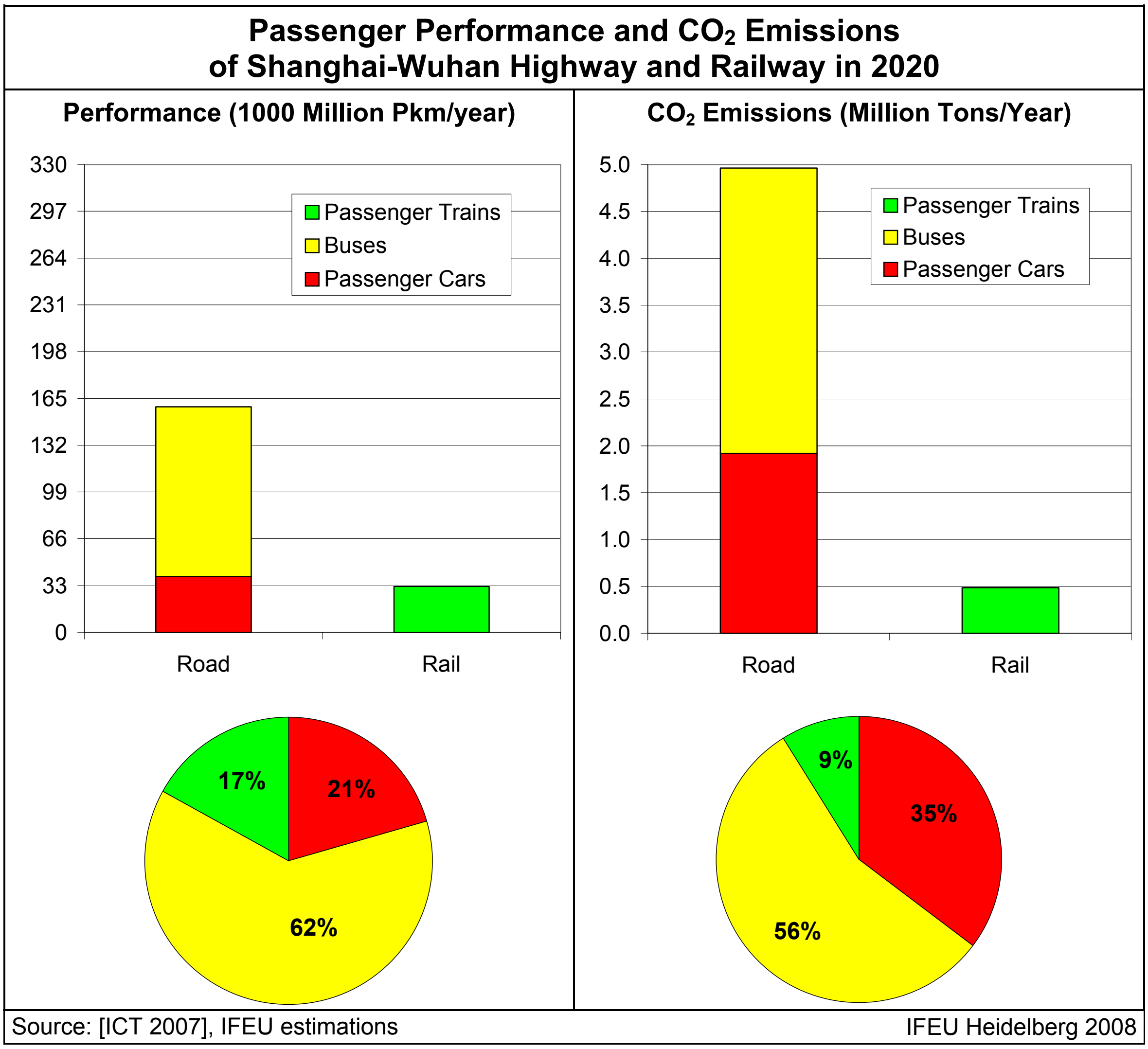


Figure 37 Passenger Performance and CO_2 Emissions of Shanghai-Wuhan Highway and Railway in 2020

Conclusions for Passenger Transport:

- The passenger transport performance on the highway is expected to be about five times higher in 2020 than on the railway line. About three-quarter of the transport performance on the road is delivered by buses of different size classes from mini to large bus. The load factor is similarly high for all considered vehicles (bus and train 70%, car with 3 passengers, including professional drivers [ICT 2007].
- The calculated CO_2 emissions of road passenger transport are about ten times higher than the emissions of rail traffic. The larger difference between road and rail compared to the transport performance is mainly due to the higher specific CO_2 emissions of passenger cars.
- Whereas rail delivers 17% of passenger transport performance, it only contributes 9% of the transport related CO_2 emissions in the corridor.

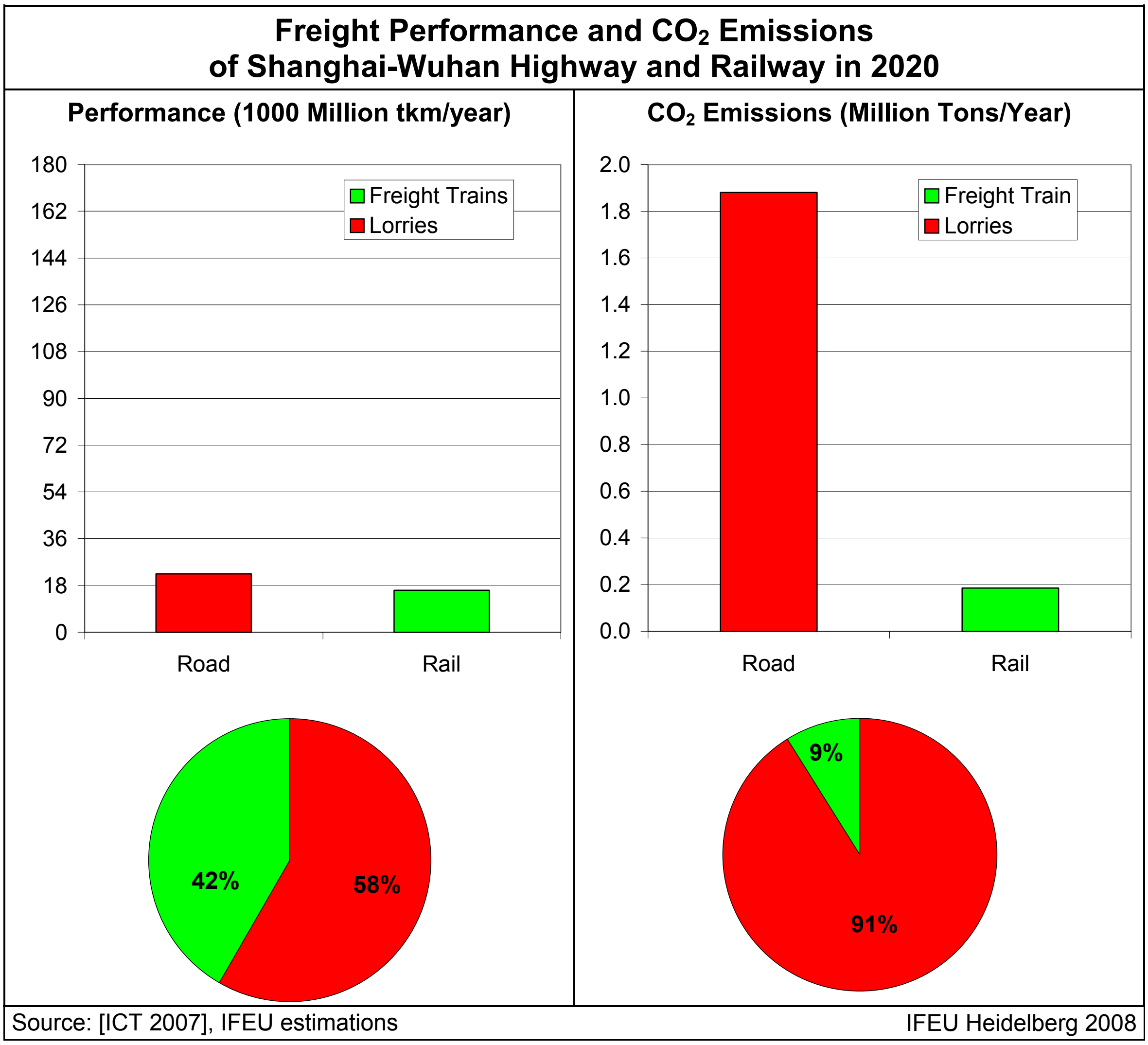


Figure 38 Freight Performance and CO_2 Emissions of Shanghai-Wuhan Highway and Railway in 2020

Conclusions for freight transport:

- The expected freight transport performance is about one-third higher for road transport than for rail transport.
- The use of efficient freight trains, e.g. double container trains with a high load, and at the same time no improvement in the road transport load factor (average load of 6.5 t per vehicle) leads to significantly lower CO_2 emissions in rail transport than in road transport compared to the transport performance.
- As a result railways will account for 42% of transport volume but only for 9% of the related CO_2 emissions in the corridor.

7.4 Evaluation of results

The available data on transport volumes, vehicle fleet composition and specific energy consumption do not allow for a detailed calculation of different scenarios on the future development of energy consumption and CO_2 emissions of road and rail transport on the relation Shanghai-Wuhan. The calculations presented in this chapter can only be used as rough estimates. Some conclusions, however, can be drawn from the results which are summarised below:

- The construction of the new railway lines Nanjing-Hefei and Hefei-Wuhan reduces the distance between Shanghai and Wuhan by 30%. Energy savings due to these new lines can be expected to be even higher than 30%, since they allow for the use of modern electric trains with higher average train loads, also induced by less gradients of the new line. The layout as a double-track line will further reduce the energy consumption, because the required number of stops to let trains in the opposite direction pass, is reduced. Furthermore, shunting is reduced due to the possibility for direct trains. The resulting increase in transport capacity and decrease in travel time will make the railway line more competitive against the highway and thus gain a relevant share of the expected increase in transport volumes.
- Due to the fact that most of the main railway lines in China are operated close to the limit of their capacity any increase of capacity or any additional new railway line in general will help to shift traffic from road (or even from air) to rails where it will be transported with the least specific energy consumption.
- A significant increase in traffic volume until 2020 is expected for road as well as for rail transport. Energy consumption and CO_2 emissions of road and rail traffic on the relation Shanghai-Wuhan will therefore increase.
- Under the assumptions made in this analysis, rail transport with large and highly loaded freight trains will have a special advantage over road transport in 2020.
- For passenger transport, the advantage of the railway is less significant than for freight transport, since buses have a high share on the passenger transport performance on the highway and buses (as well as some of the passenger cars have a high load factor. However, travel speeds are higher for trains than for buses and passenger cars, so that e.g. in case of new high speed corridors railways will be in a position to successfully compete with short to medium range domestic flights.

8 Case Study Urban Passenger Transport in Shanghai

8.1 Introduction

Shanghai is the largest megacity in the People's Republic of China and one of the largest in the world. Shanghai is a direct-controlled municipality with status equal to that of the provinces. The total administrative region has more than 18.6 million inhabitants. In the core city live about 9.5 million inhabitants (data for 1. January 2006).

As one of the economic boomtowns of China, Shanghai has had a strong population increase since end of 1980s and, thus, a strong increase of transport demand. A large portion of the increase in passenger transport is handled by motorcycles and especially private passenger cars. As a result, traffic congestion and environmental pressure due to traffic have been increasing in the last years and have gained a high importance for the city's current and future policy.

In order to cope with the expected future traffic increase and to minimize accompanying environmental impacts, Shanghai must strive towards a sustainable urban transport system. For this, a continued expansion of the public transport system with bus and metro and an optimized network of all transport systems will play an important role.

This case study will characterize the current state of urban passenger transport in Shanghai and compare the environmental performance of the different transport systems regarding energy consumption and CO_2 emissions. Possible future developments of passenger transport demand with different shares of public transport are compared in order to point out the high importance of a well-developed public transport system for limiting Shanghai's energy consumption and CO_2 emissions in passenger transport.

8.2 Passenger Performance in Motorized Passenger Transport

Data sources for passenger transport in Shanghai are manifold and often contradictory. Hence, it is difficult to draw a coherent and consistent picture of urban passenger transport in this megacity. All here given information should therefore only be seen as estimates, but not as exact figures. Nevertheless, they give a good overview of current passenger transport situation in Shanghai.

Before 1990, urban passenger transport in Shanghai was dominated by bicycling and walking and public bus transport. According to [ITS 2001], Shanghai had the largest bus network worldwide. In the following years, total passenger transport increased strongly, the share of walking declined due to the increasing trip distances. The share of public bus transport decreased as well, whereas motorized individual transport with two-wheelers and especially passenger cars increased.

Analyses of the Shanghai Academy of Environmental Sciences ([SAES 2004], [SAES 2005]) contain **passenger volumes** (number of passenger trips) of all motorized passenger transport modes for 1996-2003. These data were complemented by the year 2005 for public transport modes and for taxi with results of a field research, conducted for the present study by ICT ([ICT 2007]) and with data from Shanghai Urban Transport Bureau [SUTB 2008]. Passenger volumes 2005 for individual transport modes (cars, two-wheelers) were estimated on the basis of changes in the vehicle stock (Figure 39, left).

Passenger performance (passenger kilometres travelled) was estimated by combining passenger volumes with average trip distances. [SUTB 2008] indicates a trip distance for public buses of about 4.3 km in 1995 increasing to 6.2 km in 2004. These values were adopted and interpolated for intermediate years. For taxis, [SUTB 2008] gives a trip distance of 6.2 km which matches well with the value of 6.3 kilometres in [SAES 2004]. In urban rail transit, average trip distances are considerably higher. In the current field research [ICT 2007], passenger performance of urban rail is given directly. The therewith recalculated trip distance of 9.7 km matches well with the value of 9 km in [SAES 2004].

No reliable information was available for trip distances with two-wheelers and passenger cars in Shanghai. For two-wheelers we assume a trip distance of 5.4 kilometres according to [UniDuE 2006] for the average of motorized individual transport modes in China. Average trip distances of passenger cars probably lie in-between public bus and urban rail. In the calculations of passenger performance, it is therefore assumed that trip distances of cars are about 20% higher than for public bus (e.g. 7.7 km/trip in 2005).

Calculated passenger performance has more than doubled since 1996 and reached in 2005 more than 50 billion passenger kilometres. The development was very different for the single transport systems. Transport with passenger cars increased by factor 8 whereas bus transport increased only by about 70%. Taxi transport tripled in this time period. A very strong increase was also calculated for metro. From 1996 (one year after opening the first metro line) to 2005 passenger performance increased to the sevenfold.

According to the different developments, the share of single transport modes on total passenger performance has changed drastically. Passenger cars share increased from 10 to 30%. Metro share increased from 4 to 11%. The share of bus transport declined from 55% to 33%. The total share of public transport (without taxi) decreased from 59% to 44%.

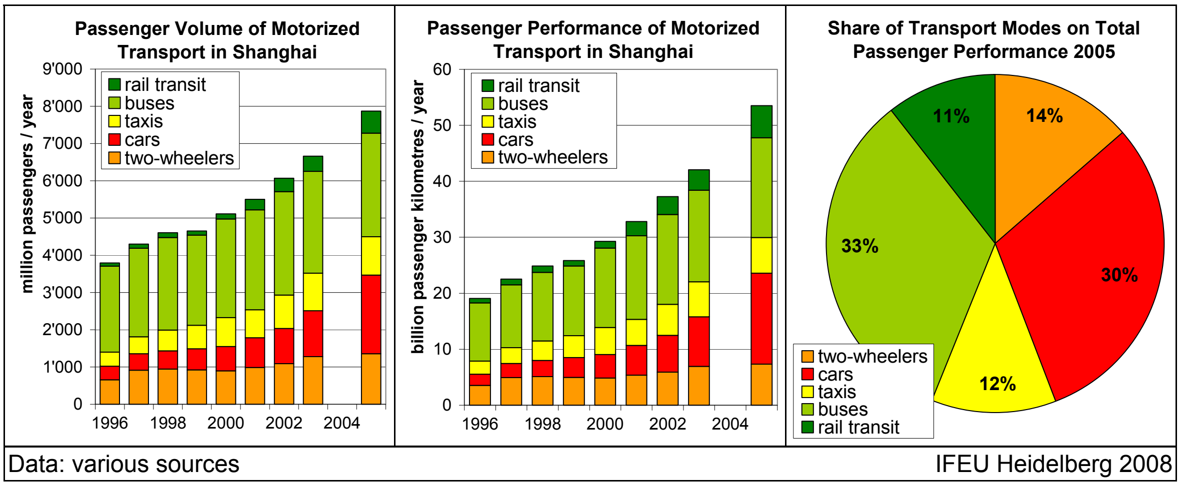


Figure 39 Passenger Volume and Passenger Performance in Shanghai 1990-2005

8.3 Vehicle Mileage and Loads in Motorized Passenger Transport

Energy consumption and CO_2 emissions in transport are directly related to the mileage driven by the vehicles to generate the passenger performance. The needed mileage depends on the utilization of vehicle's capacity (vehicle load). In case of a high vehicle load a lower mileage is needed for the same passenger performance. The public transport systems bus and metro have a considerably higher passenger capacity than two-wheelers and passenger cars.

Total **operation mileage in road transport** was estimated for the year 2005 with vehicle stocks from statistics and information on the average daily mileage. For public buses, operation mileage was given directly in [ICT 2007]. Afterwards, **average vehicle loads** were calculated as the quotient of passenger performance and mileage of each transport mode.

[Huang 2005] and [Kebin He et al. 2007a] estimate the average daily mileage for ***two-wheelers*** at 12 km/day. For the 2005 stock of 1'204 million motorcycles [SSY 2007] and about 300 million mopeds (estimated based on stock 1996-2003 in [SAES 2005]), the calculated mileage of two-wheelers in 2005 was 6.2 billion kilometres. Recalculated vehicle is 1.2 persons.

For ***passenger cars***, [Huang 2005] and [Kebin He et al. 2007a] estimate a daily mileage of 49 km. For the 715'000 official and private passenger cars in 2005 [SUTB 2008][3], this means a total mileage of about 12.8 billion kilometres. The calculated vehicle load is 1.3 persons. This is significantly lower than other estimates (e.g. 2.3 persons [SUTB 2008]). However, it must be bear in mind that many official and company cars in China have professional chauffeurs who do not count for the passenger times but are included in indicated vehicle loads.

Operation mileage of ***taxis*** is indicated directly in [SAES 2005]. Related to the vehicle stock, the average daily mileage increased 1996-2003 from 195 km to 320 km. [Huang 2005] estimates an average daily mileage of 300 km based on a field survey in 2004. To the year 2005, average daily mileage of taxis increased to 333 km [SUTB 2008]. Relating to the about 47'800 taxis registered in 2005, total mileage was 5.8 billion kilometres. Recalculated vehicle load for total taxi mileage is 1.1 persons (without driver). This matches well with information in [SUTB 2008]. There, an average load of 1.8 persons is indicated – however without the high share of about 40% empty taxi runs with no passengers.

Yearly operation mileage and average daily mileage of ***public buses*** are given in several studies. [ICT 2007] indicates an operation mileage 2005 of 1.13 billion kilometres. The recalculated daily mileage for the stock of 17'987 buses is 170 km. [Kebin He et al. 2007a] estimates a similar daily mileage in the range of 130-200 km/bus depending on the size of a bus. The recalculated vehicle load of urban buses in Shanghai is 16 persons. Assuming a capacity of 40 places, this means a load factor of 39%. Besides, [ICT 2007] indicates directly a significantly higher average bus load of 24 persons. A clarification of these differences is not possible. It seems plausible that total bus transport is considered to a different extent. In case for the core city average vehicle load should be higher against considering the whole metropolitan region including more sparsely populated rural areas.

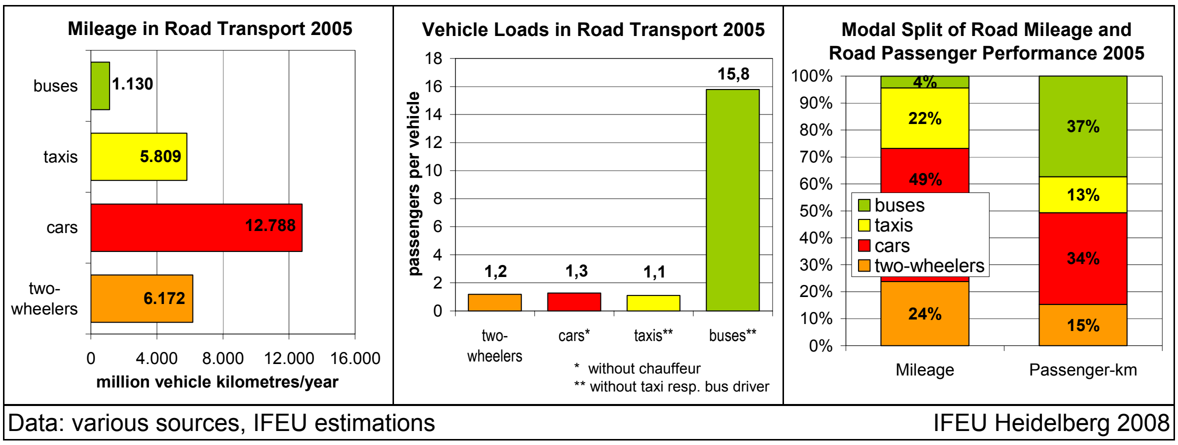


Figure 40 Vehicle Mileage and Vehicle Loads 2005 in Motorized Road Transport in Shanghai

3 The number of passenger cars in Shanghai Statistical Yearbook [SSY 2007] is only 535'900. However, the total number of passenger vehicles is the same as in [SUTB 2008]. According to Mr Shi Yong (SUTB), this difference is probably due to a different attribution of minibuses.

The comparison of vehicle mileage and passenger performance in road transport in Figure 40 (right) shows the importance of high-capacity public transport modes for urban passenger transport. In 2005, public buses had only a 4% share on mileage, though contributing 37% to passenger performance in road transport. Passenger cars handled about the same passenger performance but road mileage was 12 times higher.

Operation mileage 2005 of ***urban rail transit*** is given in [ICT 2007]. Relating to the passenger performance, this is a load of 500 persons/train – a 39% utilization of the train capacity[4]. A load factor of 80% as indicated by [ICT 2007] is not realistic and probably only related to a single metro line or to the transport during rush hour.

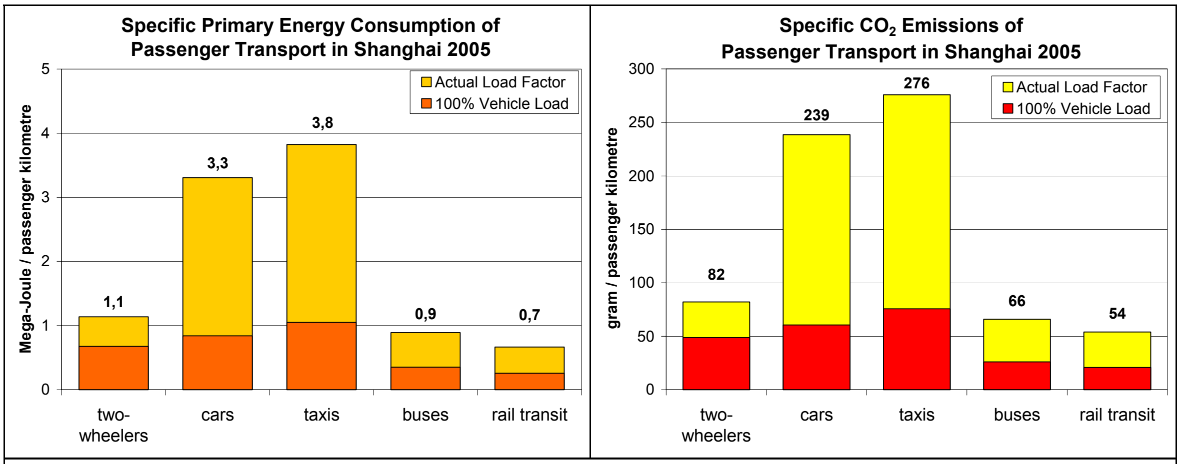
8.4 Energy Consumption and CO_2 Emissions

Energy consumption and CO_2 emissions of Shanghai urban passenger transport can now be calculated based on the vehicle mileage for each transport mode derived above and the respective specific energy consumption of the vehicles. The results include pre-chain energy consumption and CO_2 emissions in order to allow for a comparison of vehicles using different energy carriers. Exact energy consumption data for China are not available, but have already been estimated for the overall assessment of transport in China. This case study uses the estimates for urban transport (values for metro include energy consumption for stations, see explanations in chapter 6).

Results

The comparison of specific primary energy consumption and CO_2 emissions (Figure 41) demonstrates a clear environmental advantage of public transport vehicles over passenger cars. Urban rail transit potentially (100% vehicle load) has the lowest energy consumption followed by the bus. All other modes have significantly higher energy consumption per offered passenger performance.

Also if the average vehicle load is considered, public bus and rail transit lead to the lowest energy consumption per passenger-performance. In 2005, urban rail transit in Shanghai was nearly 5 times more energy-efficient than passenger cars. Specific CO_2 emissions per passenger-km show the same basic pattern as energy consumption.



Data: various sources IFEU Heidelberg 2008

4 Train capacity in China is generally calculated with 6 persons/m². For comparability with load factors in Europe (e.g. Germany), train capacity was converted to 4 persons/m².

Figure 41 Specific Primary Energy Consumption and CO_2 Emissions of Motorized Passenger Transport in Shanghai in 2005

Due to the comparably lower passenger specific energy consumption of public transport, urban rail transit accounted for less than 4% of the Shanghai transport primary energy consumption in 2005, while it delivered 11% of the passenger performance (see Figure 42). The CO_2 emission share of metro is slightly higher than primary energy consumption share due to the intensive use of coal for electricity production in China.

Likewise, buses accounted for only about 15% of the primary energy consumption and CO_2 emissions, while they delivered 33% of the passenger performance. Also two-wheelers have a higher share on passenger performance (14%) than on energy consumption and CO_2 emissions (about 8%).

Contrary to public transport, passenger cars delivered only 30% of the passenger performance, while being responsible for more than 50% of the energy consumption and CO_2 emissions. For taxis, the comparison is even more unfavourable with only 12% of the passenger performance and about 23% of the energy consumption and CO_2 emissions.

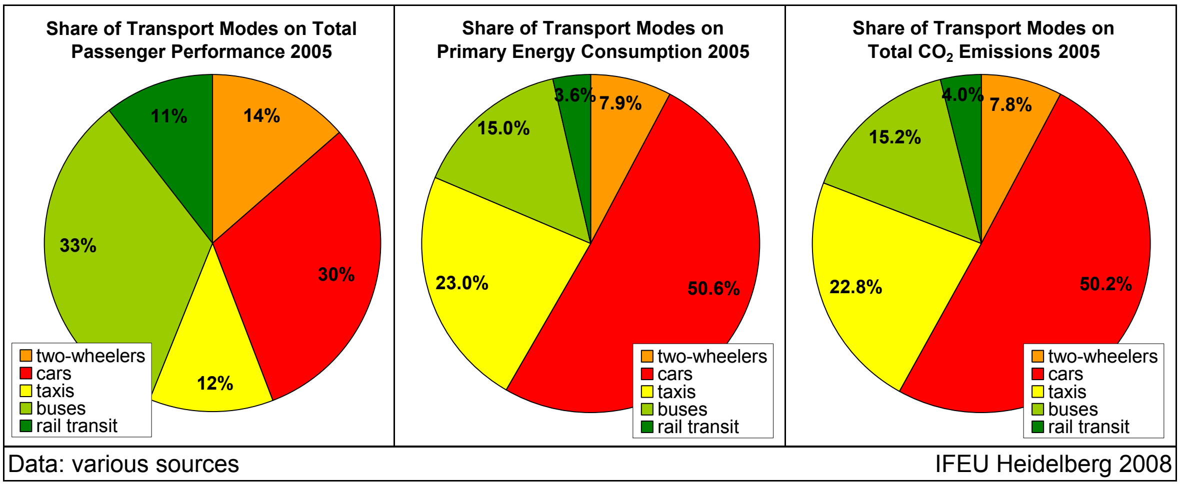


Figure 42 Share of Transport Modes on Passenger Performance, Primary Energy Consumption and CO_2 Emissions of Motorized Passenger Transport in Shanghai in 2005

8.5 Future Development

Passenger Performance and Share of Transport Modes

The future development of Shanghai transport is uncertain. Transport will most certainly continue to grow, but the future level of growth is uncertain as well as how the different transport modes will develop. This also depends on the Shanghai transport policy which is specified in the Shanghai Metropolitan Transport White Paper.

The public transport system will definitely be further expanded during the next few years. The metro network is supposed to be expanded to over 400 km until 2010 and to 510 km until 2012 ([SUTB 2006]). Also the length of bus-only lanes is supposed to increase from 40 to 300 km until 2012 ([SUTB 2006]). Any further development is still uncertain. Especially the development of private passenger transport is currently very dynamic and difficult to predict. Similarly unclear is the total level of future passenger transport in Shanghai. Total passenger transport is assumed to double between 2005 and 2020 by [SAES 2004]. This assumption was adopted for scenario calculations in the present study.

In order to show the importance of public transport in Shanghai for future energy consumption and CO_2 emissions, two different scenarios for the development of Shanghai urban passenger transport between 2005 and 2020 have been calculated:

- ***Low public transport***: This scenario calculates the future development of passenger transport in Shanghai assuming that public transport with public buses and urban rail transit would not further increase but remain at the same level as in the year 2005. In this case, the total increase of transport demand up to 2020 is handled by passenger cars.
- ***High public transport***. This scenario calculates the future development of passenger transport in Shanghai assuming the growth rate of urban rail transit as in [ICT 2007]. Furthermore, an increase by 50% is assumed for public buses and taxis.

In both scenarios, passenger transport with motorcycles and mopeds will decrease in relative as well as in absolute terms as assumed by [SAES 2005]. Average vehicle load factors of all transport modes are assumed to be the same in 2020 as in 2005.

Specific energy consumption and CO_2 emissions per passenger performance

For future specific fuel consumption and specific CO_2 emissions of road vehicles, a 25% improvement is assumed for passenger cars and motorcycles and 20% for public buses. In urban rail transit, the assumed improvement of final energy consumption 2005-2020 is 20%. Besides, the CO_2 emission factor has been adjusted to the expected changes in the energy carrier split for electricity production in China (analyses in [ICT 2007]).

Hence, specific CO_2 emissions per passenger performance for a passenger car in Shanghai in 2020 are about 3.5 times higher than with public bus and 5.4 times higher than with urban rail transit.

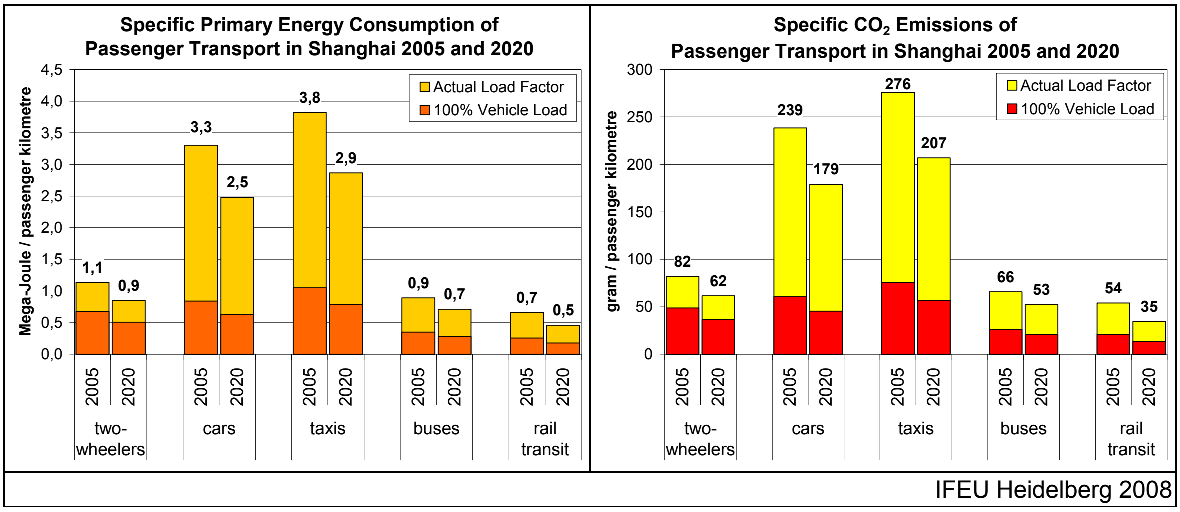


Figure 43 Specific Primary Energy Consumption and CO_2 Emissions of Motorized Passenger Transport in Shanghai 2005 and 2020

Results

With a doubling of total passenger performance and taking into account the assumptions made above, passenger transport in Shanghai until 2020 will develop as follows:

- Passenger performance of two-wheelers will be reduced by half.
- Passenger car performance will increase by 350% in the low public transport scenario, and still more than double in the high public transport scenario – thus requiring additional road capacity and parking facilities which will have a major impact on the current and future city patterns.
- Bus and taxi remain constant compared to 2005 in the low public transport scenario. Alike, in the high public transport scenario, they increase only by 50% due to their already high transport share in 2005.
- Urban rail transit will remain constant compared to 2005 in the low public transport scenario. However, in the high public transport scenario it will have the highest increase of all transport modes by about 470%.

The increase in public transport performance is of great importance for the total energy consumption and for CO_2 emissions of passenger transport in Shanghai. For the assumed duplication of total passenger performance 2005-2020, extending the energy-efficient transport modes public bus and urban rail transit will lead to considerable savings of energy and reductions future CO_2 emissions.

If public transport would not grow in future but all increase is handled by passenger cars, total primary energy consumption would increase from 106 to 219 Peta-Joule – thus more than double. CO_2 emissions would also double from 7.7 to 15.8 million tons. The share of passenger cars on passenger performance would increase from 30 to 69% and they would contribute 83% to primary energy consumption and CO_2 emissions.

If public transport, especially urban rail, will increase until 2020 as assumed in [ICT 2007], total primary energy consumption and CO_2 emissions will only increase by 40% compared to 2005. Energy-efficient urban rail transit will carry out 30% of passenger performance causing only 10% of the total CO_2 emissions. The total share of public transport on passenger performance will increase to 55% – despite the simultaneous strong increase of transport with private passenger cars.

Total primary energy consumption and CO_2 emissions of passenger transport in Shanghai in the year 2020 are in the high public transport scenario about 30% lower than in the low public transport scenario – providing both the same total passenger performance.

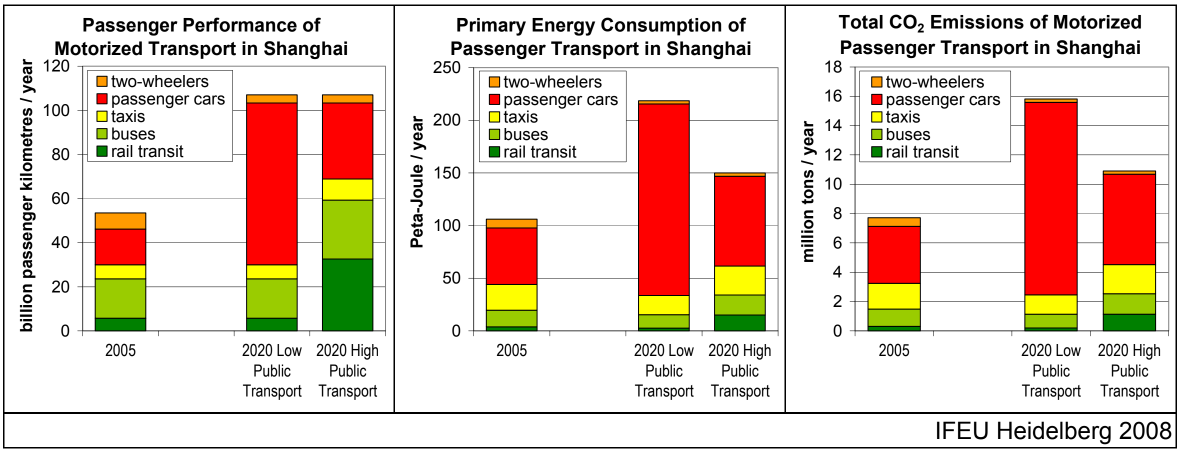


Figure 44 Passenger Performance, Primary Energy Consumption and CO_2 Emissions of Motorized Passenger Transport in Shanghai 2005 and 2020 (in different scenarios)

9 Abbreviations and Explanations

BRT	Bus Rapid Transit:
CO	Carbon Monoxide
CO_2	Carbon Dioxide
D	Diesel
Exa-Joule	Exa-Joule = 10^{18} Joule (10^{6} Joule = 29.3 kg SCE)
G	Gasoline
GDP	Gross domestic product
GFCF	Gross fixed capital formation
GJ	Giga-Joule = 10^{9} Joule (10^{6} Joule = 29.3 kg SCE)
HC	Hydro Carbons
HDB	Heavy bus (≥ 10m)
HDT	Heavy duty truck, gross vehicle weight >= 14 tons
kWh	Kilo-Watt hour
LDB	Small/light bus (3.5-7m)
LDT	Light-duty truck (1.8-6 tons)
MB	Mini bus (<3.5m)
MDB	Medium bus (7-10m)
MDT	Light-heavy/medium truck, gross vehicle weight 6-14 tons
MT	Mini truck (<1.8 tons)
Mt	Mega tons = 10^{6} tons
NO_x	Nitrogen Oxides
OECD	Organisation for Economic Co-operation and Development
OECD Europe	OECD-Europe comprises all European Union Member countries of the OECD, i.e. countries in EU15 plus the Czech Republic, Hungary, Iceland, Norway, Poland, Slovak Republic, Switzerland, Turkey
PCU	Passenger car unit
PE	Primary energy consumption
Peta-Joule	Peta-Joule = 10^{15} Joule (10^{6} Joule = 29.3 kg SCE)
Pkm	Passenger kilometres = passenger performance
PM	Particulate matter
tkm	Ton kilometres or tons kilometres = freight performance
VMT	Vehicle mileage travelled
Wh	Watt hour

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11 Appendix

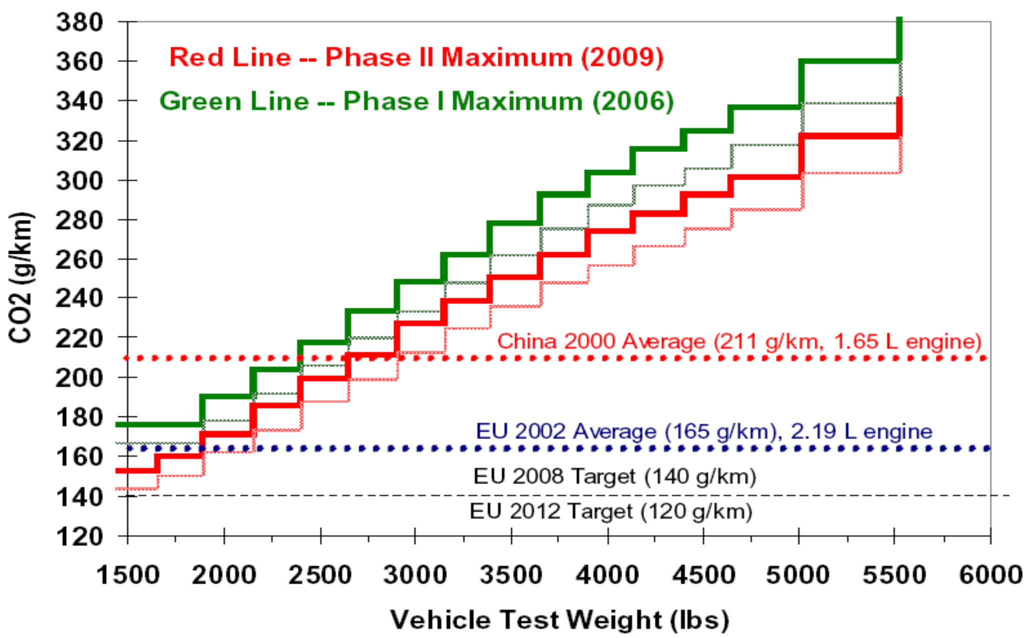
11.1 Energy and Emission Regulations for Road Vehicles in China

In China, several regulations and measures were adopted and are planned for the future in order to reduce energy consumption and emissions of road vehicles. It is not possible to summarize and analyze all relevant measures in the context of this study. Consecutively, some important measures are briefly described including a general evaluation of their potential efficiency.

Regulations for Energy Consumption of Passenger Cars

The Chinese Government adopted a Chinese Vehicle Fuel Consumption Regulation for passenger cars in September 2004. This regulation sets standards for the CO_2 emissions per kilometre (measured in New European Driving Cycle NEDC) for different vehicle weight classes. Compared with the standards planned for Europe the Chinese values are not very ambitious.

[APECC 2006a] states that the vehicle fleet in China is less efficient than in Europe. Thus, the regulations can have a positive effect on fuel consumption, mainly of larger vehicles. For fundamental changes, advanced regulations and other measures are necessary.



Source: [APECC 2006a]	IFEU Heidelberg 2008

Figure 45 Chinese Fuel Consumption Standards compared with Planned EU Standards

Emission Standards and Fuel Quality

Emission Standards for road vehicles in China are prepared by the Vehicle Emission Control Center (SEPA). The regulations are similar to European legislation but are implemented 3-5 years later than in Europe. Implementation dates are different for the big cities Beijing and Shanghai than for the rest of China. The following tables summarize the current emission legislation for road vehicles in China.

Table 10 Implementation Dates for Light-Duty Vehicle Emission Standards

Euro 1	2000.01 (2000.07†)	Nationwide
Euro 2	2002.08	Beijing
	2003.03	Shanghai
	petrol: 2004.07[a] (2005.07†) diesel: 2003.09	Nationwide
Euro 3	2005.01	Beijing
	2007.07	Nationwide
Euro 4	2008.01	Beijing
	2010.07	Nationwide

† conformity of production
[a] first registration
New gasoline vehicles must also meet an evaporative emission limit of 2 g/test (SHED test).
Source: www.dieselnet.com

Table 11 Emission Standards for Heavy-Duty Engines, g/kWh

Reference	Date	CO	HC	NOx	PM
Euro I	2000	4.5	1.1	8.0	0.36[a]
Euro II	2002	4.0	1.1	7.0	0.15
Euro III	2007	2.1	0.66	5.0	0.1
Euro IV	2010	1.5	0.46	3.5	0.02

[a] 0.612 for engines of less than 85 kW
At the Euro I/II stages, emissions were tested over the 13-mode ECE R-49 or the Chinese 9-mode test
Source: www.dieselnet.com

Table 12 Emission Limits and Implementation Dates for Motorcycles (g/km)

Exhaust Pollutant	First phase [1]				Second phase [2]	
	Two-wheel MC		Three-wheel MC		Two-wheel MC	Three-wheel MC
	Two-stroke	Four-stroke	Two-stroke	Four-stroke		
CO	8	13	12	19.5	5.5	7
HC	4	3	6	4.5	1.2	1.5
NO_X	0.1	0.3	0.15	0.45	0.3	0.4

[1] TA test in the first phase will be brought into effect after Jan 1st, 2003, COP test in the first phase will be bring into effect after Jul 1st, 2003.
[2] TA test in the Second phase will be brought into effect after Jan 1st, 2004, COP test in the Second phase will be bring into effect after Jan 1st, 2005.
Source: http://www.vecc-sepa.org.cn/eng/new/index.jsp

Table 13 Emission Limits and Implementation Dates for Mopeds (g/km)

Exhaust Pollutant	First phase		Second phase	
	Two-wheel moped	Three-wheel moped	Two-wheel moped	Three-wheel moped
CO	6	12	1	3.5
$HC+NO_X$	3	6	1.2	1.2

[1] TA test in the first phase will be bring into effect after Jan 1st, 2003, COP test in the first phase will be bring into effect after Jan 1st, 2004.
[2] TA test in the Second phase will be bring into effect after Jan 1st, 2005, COP test in the Second phase will be bring into effect after Jan 1st, 2006.
Source: http://www.vecc-sepa.org.cn/eng/new/index.jsp

In addition to the emission limits for vehicles, regulations were set to improve fuel quality. So the sulphur content of diesel fuel in China is limited to 50 ppm since 2002 (Source: http://www.vecc-sepa.org.cn/eng/news/news_detail.jsp?newsid=e00339. The current European level is “sulphur free” (< 10 ppm) which is necessary to meet the emission standards of modern EURO 4 and EURO 5 vehicles.

Evaluation

The legislation already adopted in China points to the right direction. Due to the urgent problem of air pollution and the expected growth rates of road transport, further legal measures are essentially needed and should be introduced as fast as possible.

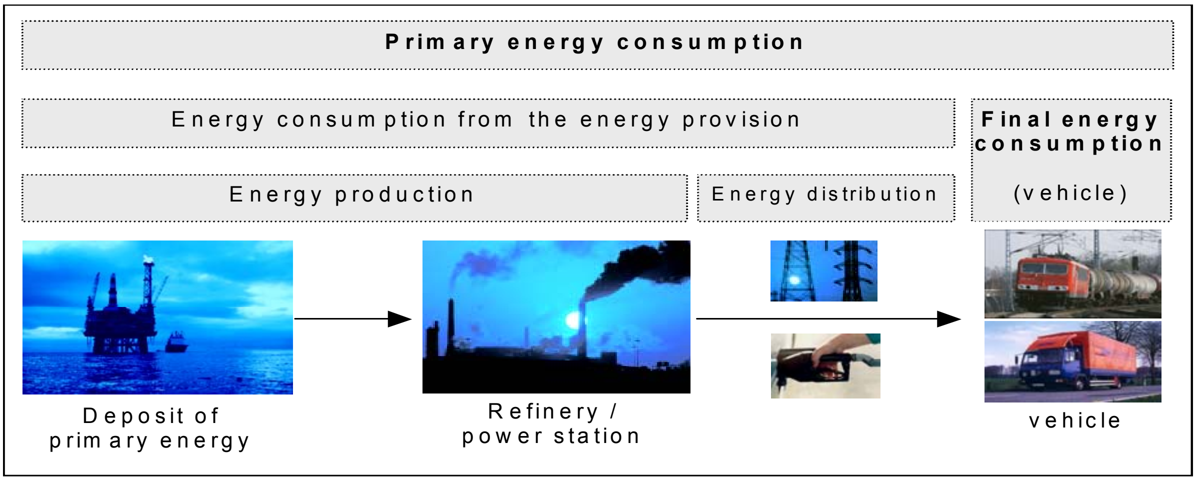
11.2 Electricity and Fuel Supply

Consumption of electricity causes no direct emissions, because emissions of electricity result from electricity production. Fuels cause direct emissions and emissions during the production process. These processes are also joined with different amounts of energy losses. Therefore impacts of energy production have to be included into the comparison of energy consumption and CO_2 emissions of transport systems.

The following kinds of energy can be distinguished:

Final energy consumption means energy that is consumed directly during the use of the vehicles, e.g.litres gasoline or diesel for passenger cars, kWh electricity or litre diesel for railways.

Primary energy consumption includes final energy and besides that energy prechain, needed to provide this final energy. The following figure shows the total energy chain for electricity and fuel production.



When coal is burned in powerplants or gasoline and diesel in cars, the carbon of the energy carrier reacts with oxygene (O_2) to carbon dioxide CO_2. Electricity consumption causes CO_2 emissions completely during the energy prechain (energy production and distribution). Specific CO_2 emissions depend on the mix of energy carriers. For fuels about 85% of the CO_2 emissions results from burning process in the vehicle.

The specific primary energy consumption and CO_2 emissions of the energy supply for China were estimated with the following information:

- Data for energy share and efficiency of electricity production in China were delivered by [ICT 2007].
- Additional information for the efficiency of energy exploration, electricity delivery and CO_2 emission factors were taken from [IFEU 2006], because specific values for China were not available.
- The Efficiency and CO_2 emission factors for the fuels are also taken from [IFEU 2006] due to lack of data for China.

The following tables show the basic values for the estimation of primary energy and CO_2 emissions of energy supply in China.

Table 14 CO_2 Emission Factors and Efficiency of Electricity Supply in China

	2005	2020	2005	2020	CO_2 Emission Factors kg/TJ input		Exploration and Delivery Conversion Efficiency	
	Share of energy carriers on electricity supply		Conversion Efficieny (%) – kWh output/Input power station		Explo-ration	Con-version	Exploration Effort (incl. Raw Energy) /Input power station	Delivery (Input traction/output power station)
Hard Coal	81.5%	70.3%	34.1%	38.9%	4,700	92,000	108%	
Gas		3.6%	49.2%	54.9%	5,400	56,000	110%	
Oil		0.2%	37.0%	40.0%	8,500	78,000	111%	
Water	16.0%	19.6%	100.0%	100.0%	0	0	100%	
Nuclear	2.1%	5.2%	33.0%	33.0%	2,900	0	104%	
Other	0.4%	1.0%	57.3%	85.4%	3,000	54,000	110%	
Sum/ Average	**100.0%**	**100.0%**	**38.7%**	**44.6%**				**90%**
Result: Overall Values (Input traction/raw energy)								
	Efficiency TJ/TJ		CO_2 Emission Factors kg/TJ					
	2005	2020	2005	2020				
	3.0	2.7	250,000	200,000				
Source: [ICT 2007],[IFEU 2006]								

Table 15 CO_2 Emission Factors and Efficiency of Fuels

	CO_2 Exploration and Delivery kg/TJ	CO_2 Fuel kg/TJ	CO_2 total kg/TJ	Overall Efficiency TJ/TJ
Gasoline	14,193	72,000	86,193	1.194
Diesel	10,126	74,000	84,126	1.138
Source: [IFEU 2006]				

11.3 Field Research in Beijing and Shanghai – Workshops and Meetings

Workshop in Beijing, 2008-02-26

Subject: Energy consumption of road and rail transport in China

- Presentation of KfW-Study “Transport in China” by IFEU and ICT
- Discussion of results and data gaps
- Presentation of calculation methodology for environmental comparisons of transport modes by IFEU

Attendees:

Mr. Jiang Zhengcai, Vive Director General, Plannung Department, MOR

Mrs. Liu Li, Senior Engineer, Research Institute of Highway, MOC

Mr. Qu Hong, Post-doctorate, Chinese Research Academy of Environmental Sciences

Mr. Wu Wenhua, Vice director, Institute of Comprehensive Transportation, NDRC

Mr. Guo Wenlong and Mr. Yang Wen Zie, ICT

Mr. Wolfram Knörr and Mr. Frank Dünnebeil, IFEU

Meetings in Beijing, 2008-02-28

Visit to Mr. He Kebin, Tsinghua University
Subject: Energy consumption and emissions of road transport

Visit to Mr. Vance Wagner, Innovation Center for Energy and Transportation (ICET)
Subject: Energy consumption and emissions of road transport

Workshop in Shanghai, 2008-03-03

Subject: Transport performance and energy consumption of urban transport in Shanghai

- Presentation of KfW-Case Study “Transport in Shanghai” by IFEU amd ICT
- Discussion of results and data gaps
- Presentation of calculation methodology for environmental comparisons of transport modes by IFEU

Attendees:

Mr. Jiao Min, Doctorate, Shanghai Municippal Development & Reform Commission

Mr. Shi Yong, Shanghai Urban Transport Bureau

Mr. Jing Jiancheng, Shanghai Metro Operation

Mr. Chen Changhong, Shanghai Acedemy of Environmental Science (SAES)

Mr. Guo Wenlong and Mr. Yang Wen Zie, ICT

Mr. Wolfram Knörr and Mr. Frank Dünnebeil, IFEU