Climate and Environmental Impact Assessment of Electro-Mobility in China

Benchmark Report

Version 2.0

On behalf of

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

CATARC

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Glossary

AEO2009	Annual Energy Outlook 2009
AER	All Electric Range
ANL	Argonne National Laboratory
BEV	Battery Electric Vehicle
CAAM	China Association of Automobile Manufacturers
CAE	Chinese Academy of Engineering
CAFE	Corporate Average Fuel Economy
CATARC	China Automotive Technology & Research Center
CCS	Carbon Capture and Storage
CD	Charging Depleting
CS	Charging Sustaining
EIA	Energy Information Administration
EPRI	US Electric Power Research Institute
FE	Fuel Economy
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GREET	The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
Jing-Jin-Ji	Region consisting of Beijing, Tianjin, and Hebei province
LCA	Life Cycle Assessment
LDPV	Light-Duty Passenger Vehicle
MEP	Ministry of Environmental Protection
MIIT	Ministry of Industry and Information Technology
NAS	U.S. National Academy of Science
NBSC	National Bureau of Statistics of China
NDRC	National Development and Reform Committee

Pearl-River-Delta	Region including Guangdong province
PHEV	Plug-in Electric Vehicle
PHEV50	Plug-in Electric Vehicle with AER equal to 50 miles
RMI	Rocky Mountain Institute
SAE	US Society of Automotive Engineers
SOC	State of Charge
TTW	Tank to Wheel
US	United States
USNRC	United States Nuclear Regulatory Commission
VKT	Vehicle-Kilometre-Travelled
VOC	Volatile Organic Compounds
WTT	Well to Tank
WTW	Well to Wheel
Yangtze-River-Delta	Region consisting of Shanghai, Jiangsu and Zhejiang province

Abstract

The electrification of motor vehicles is considered as an industry revolution to achieve sustainable transportation in China. Hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) are being demonstrated in pilot cities throughout China.

The aim of this study is to provide a broad overview of the current status and future prospects of this electrification revolution, summarize the results of relevant environmental impact assessments, and propose recommendations for the most promising scenarios for tackling China's climate and environmental issues. First, the projected growth in the number of vehicles in China is presented and discussed. By 2030, the total vehicle stock in China (excluding two-wheelers) is projected to reach 400-500 million. As a result, the total oil consumption and CO_2 emissions associated with on-road transportation will continue to increase significantly throughout the next two decades if advanced vehicle technologies or clean alternative fuels are not marketed in China. Second, the well-to-wheel (WTW) method (i.e., life cycle assessment method) is applied to better evaluate upstream energy savings and CO_2 emissions reduction potential of advanced propulsion/fuel vehicle systems. Key inputs, such as the fuel economy and emission factors of various vehicle technologies, energy efficiency and emission factors of upstream electricity generation mix, are updated according to a Chinese specific database. Furthermore, a case study is being conducted of WTW analysis of energy consumption and CO_2 emissions for HEV, PHEV and BEV, comparing them with their conventional internal combustion engine vehicle (ICEV) counterparts in three highly-developed regions of China (Jing-Jin-Ji region, Yangtze-River-Delta region and Pearl-River-Delta region). Promotion of PHEV and EV could help greatly reduce per-kilometre petroleum use.

However, the effort to mitigate CO_2 emissions is much more difficult than lowering oil consumption. This is especially true for the Jing-Jin-Ji Region, where coal is a key source of electric power. In regions which rely heavily on coal power, HEV could be a better option than BEV to reduce WTW CO_2 emissions, while in the Pearl-River-Delta region, which has a much cleaner electricity mix, a promotion of BEV could reduce CO_2 emissions more greatly.

1. Background

1.1 Aim

China has experienced a substantial increase in the number of motor vehicles over the past two decades, and this trend is forecasted to continue. This rapid increase is severely alleviating the energy and material resources in China and elsewhere. Vehicle sales increased by 32% to 18.1 million in 2010, topping all previous worldwide records and securing China's position as the world's largest auto market (CATARC and CAAM, 2011). By 2010, the share of imported oil to total oil consumption in China increased to 57% (NBSC, 2011). The associated potential increase of CO_2 emissions also poses a severe challenge for the effort to mitigate CO_2 emissions. Due to the fact that the majority of vehicles are concentrated in cities, serious problems with air pollution have arisen in urban areas throughout China. The vehicles in mega-cites such as Beijing and Guangzhou, for example, are the primary source of VOCs and NO_X, two major precursors of ozone.

Advanced vehicle technologies, such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV), are being promoted in a great effort to alleviate China's dependence on imported oil, reduce greenhouse gas (GHG) emissions, and solve urban air pollution problems. Starting in 2008, the Chinese government launched a large-scale demonstration program called "Ten Cities & Thousand Units" to promote these new vehicle technologies (also called "Energy-saving and New-energy Vehicles" in China); the scope of this program has since been expanded to 25 Chinese cities. Among various new energy vehicle technologies which are being evaluated, HEV, PHEV and BEV have been selected as the top priority by almost all cities, and these three technologies are the predominant technologies used in the demonstration vehicles. According to the most recent development plan for new energy vehicles, China is strongly pushing the process of vehicle electrification within the next 20 years.

This benchmark study develops a framework for profiling the studies and research activities associated with the energy and environmental assessment of Electro-Mobility in China on a macro-scale, and determines the future trends and research needs for such a climate and environmental impact assessment.

1.2 Introduction of the Electro-Mobility and Climate Protection Project

Against the background of rapid growth in transport demand and related Greenhouse Gas (GHG) emissions, China faces the challenge of protecting the environment and reducing its dependence on oil consumption. The Chinese government is focusing on the promotion of electric vehicles as a core technology in order to address these challenges (e.g. the 12th Five Year Plan designated the electric vehicle industry as one of the seven strategic emerging industries). Integrated policies and strategies need to be developed to ensure that the full potential of electric vehicles is harnessed; however, even in economies with leading automotive industries, these technologies have not been yet fully utilized.

The Sino-German technical cooperation project "Electro-Mobility and Climate Protection in China" aims at supporting Chinese decision-makers in gaining access to the conceptual and technical information and strategies for introducing electric vehicles to China in an environmentally sound manner.

The project is composed of four components:

The first component assesses the environmental impact of promoting electric vehicles in China and identifies the relevant policies and measures which must be implemented in order to maximize environmental protection. These policies and measures shall be chosen based on sound data analysis and modelling approaches. Therefore, the project uses the approach of participatory scenario analysis, which is a well-established scientific approach used to analyse future development pathways, e.g. for describing the market penetration of electric vehicles while taking the emission factor of the electricity grid into account. The study puts forth recommendations for the design of the scenario process, which will be elaborated on in 2013.

In the second component, joint studies and workshops provide recommendations regarding how to build up the methodological and technical capacities for integrating the operation of electric vehicles into the environmental regulations in China. The main focus is on developing approaches mitigating GHG emissions, such as new fuel economy standards beyond 2015.

The third component analyses the feasibility of implementing and operating an environmentally sound and resource efficient pilot system for traction batteries of electric vehicles. As a result, the project will develop policy recommendations for the design of pilot recycling projects.

The fourth component investigates possible applications of electric vehicles in sustainable multi-modal urban transport systems. It establishes an active exchange of research and practical experience on EV pilot projects in Germany and China. Furthermore, this component elaborates upon guidelines for developing environmentally sound solutions to integrate electric vehicles into existing sustainable urban transport systems.

1.3 Structure and Methodology of the Benchmark Study

The aim of this study is to give an overview of the relevant activities and results of such environmental impact assessments on a macro scale in China and derive some recommendations for the most promising set up of the Scenario Process to be started in 2013.

According to the detailed discussion between Tsinghua University, GIZ and CATARC, the benchmark report is structured as shown in Figure 1.

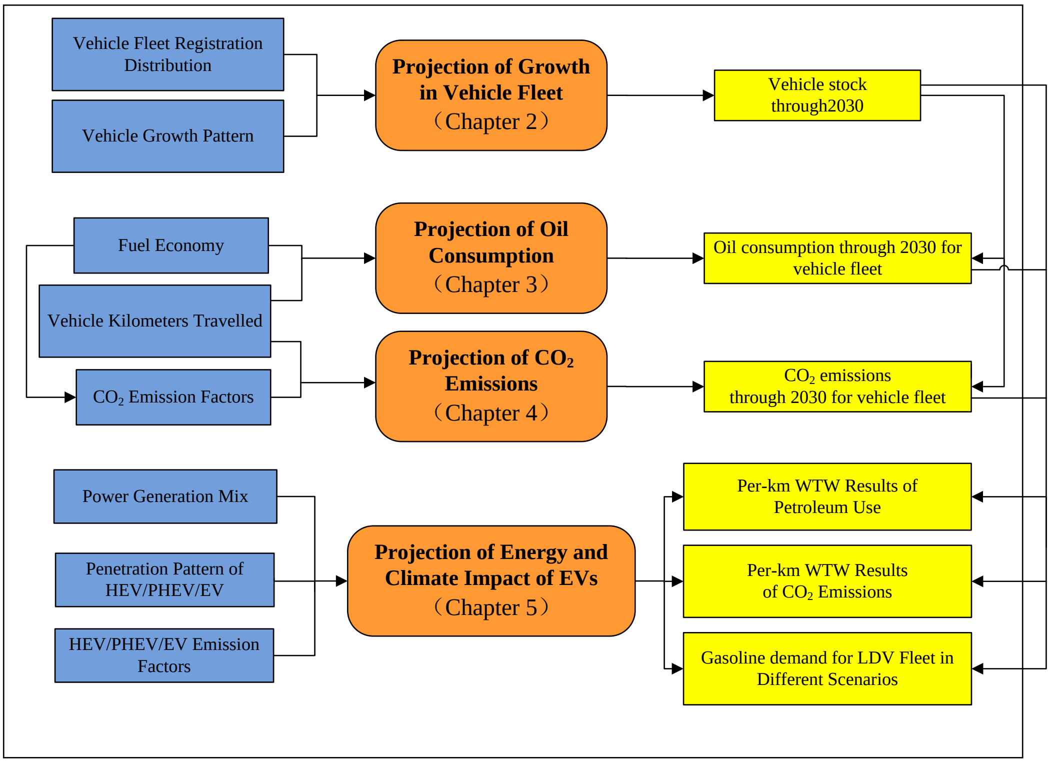

Figure 1:

Structure of the benchmark study

To project the growth of vehicle stock in China, the authors rely heavily on previous efforts which developed a comprehensive database of historical vehicle registration data and vehicle activity data in China. The basic algorithm for calculating growth in automobile ownership is based on several major factors, such as the economy, population, the retirement of old automobiles, traffic infrastructure, urban planning, etc. In this report the Gompertz function is used to simulate the level of automobile growth in China, with automobiles per 1000 people representing the automobile development level and the GDP per capita representing the economic level. The trends in fuel economy in China are reviewed and different scenarios in fuel economy improvement are designed to project the oil consumption for the vehicle fleet in the future. The calculation of CO_2 emissions is primarily based on the carbon balance method. In this report, an extensive literature review was also conducted to compare the major parameter assumptions as well as the results of different studies concerning vehicle growth, oil use and CO_2 emissions in China.

In order to better evaluate upstream energy savings and CO_2 emissions reduction potential of advanced propulsion/fuel vehicle systems, a Life Cycle Assessment (LCA) method was used. This report further applies the GREET 1.8d model as a platform to calculate the fuel cycle energy consumption and CO_2 emissions of advanced propulsion/fuel automobile systems. Key inputs, such as the fuel economy and emission factors of various vehicle technologies, energy efficiency and emission factors of upstream electricity generation mix, are updated with the Chinese specific database, which were also developed through our previous efforts and will be updated in this study. Furthermore, Tsinghua conducts a case study of WTW analysis of energy consumption and CO_2 emissions for HEV, PHEV and BEV compared with their conventional internal combustion engine vehicle (ICEV) counterparts in three highly-developed regions in China (Jing-Jin-Ji region, Yangtze-River-Delta region and Pearl-River-Delta region).

2 Projection of Growth in Vehicle Fleet

2.1 Methodology

The projection of the vehicle fleet is the foundation for forecasting the oil consumption as well as the CO_2 emissions. The vehicle stock level and growth rate vary with the levels of economy and social development in different countries. The basic algorithm for automobile growth is generally based on several major factors, such as the economy, population, the retirement of old automobiles, traffic infrastructure, urban planning, etc.

Many researchers have performed forecast studies on China's vehicle stock using different methods (He et al., 2005; Huo and Wang, 2011; Joyce Darga et al., 1997; Ou et al., 2010; Wang and He, 2000; Wang et al., 2006; Wang et al., 2007; Wang et al, 2011; Wu et al., 2011a). Table 1 summarizes the key methodology, key parameter assumptions (e.g. saturation level) and forecasted vehicle stock of several studies.

Table 1:

The methodology and key parameters of different researchers

Study	Key Methodology	Saturation level of automobiles per 1000 people	Base Year	Future stock /millions
Dargay and Gately, 1997	Based on GDP, using Gompertz function	690	1995	597 in 2015
Ou et al., 2010	Using a bottom-up model based on future sales projection of all vehicle types	NA	2007	338 in 2030 and 499 in 2050
Wang et al., 2011	Follow historical growth patterns of a set of countries with comparable growth dynamics	NA	2008	419 in 2022
Wu et al., 2011a	Based on GDP, using Gompertz function	400, 500, and 600	2007	407-528 in 2030
Huo and Wang, 2012	Based on GDP, using Gompertz function	400 and 500	2009	387-442 in 2030 and 530-623 in 2050

In these studies, the approach utilizing the Gompertz curve is considered the optimal method for projecting the mid- and long-term trends in China's vehicle stock. Huo and Wang (2011) reviewed the historical Chinese vehicle stock data with three functions: the Gompertz function, the logistic function, and the Richards function; the Gompertz function fit the original data better than the other two. The Gompertz curve is an S-shaped curve, representing three periods of vehicle growth. When the income levels are relatively low in the beginning, the vehicle stock grows slowly. In the second period (also called the boom period), the fast development of the economy influences a rapid vehicle stock growth. In the third period, the vehicle growth slows down and approaches a saturation level.

The Gompertz function was also applied (see Equation 1 below) to relate per-capita LDPV ownership to per-capita GDP for China (Wu et al., 2011a).

$$VS_i = VS_S \times e^{\alpha e^{\beta EI_i}} \quad (1)$$

where VS_i represents the per-capita LDPVs in target year i; VS_s represents the saturation level of LDPV ownership; EI_i represents an economic indicator, which, in this study, is the per capita GDP; α and β are two parameters, which were obtained during the process of fitting this S-shaped curve with the historical data.

The historical population and GDP data for China are usually obtained from the China Statistical Yearbook (NBSC, 2011). To project future regional population and GDP growth, the authors relied heavily on other relevant literature (Li et al., 2010; Lin, 2010; Ma and Hou, 2004; Yang et al., 2006; Zhou, 2002).

As an indicator of the saturation level of automobile growth in a country, "the saturation level of automobiles per 1000 people" is a key factor in the Gompertz Function. Wang et al. (2006) took three developing modes for China by surveying the growth pattern of automobiles in many developed countries, and set the saturation level of automobiles per 1000 people as 400, 500 and 600. Figure 2 represents the relationship of automobiles per 1000 people and GDP per capita in several developed countries. From this figure it can be seen that the saturation level of automobile per 1000 people in many developed countries, including European countries and developed countries within Asia, has a value between 400 and 600. For the U.S., this value is 800. Some researchers believe that the saturation level of China will not reach the levels seen in other developed countries, especially the United States, due to China's large population and high population density.

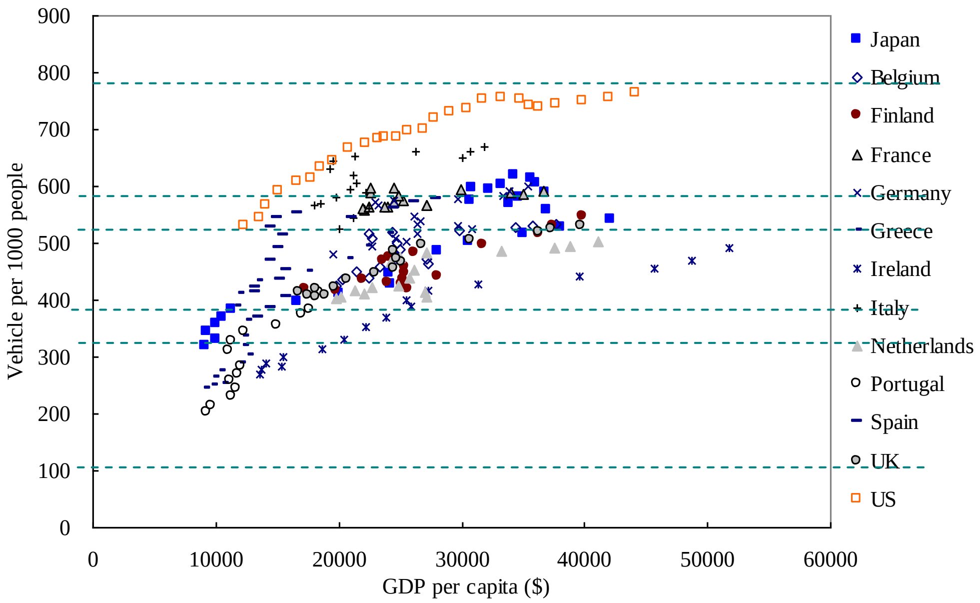

Figure 2:

GDP per capita and vehicle stock per 1000 people in different countries

The authors also adopted this method to project the future automobile development pattern of China. Three scenarios were set up which show three potential automobile growth rates in China. The high-growth scenario applied a saturation level of automobiles per 1000 people of 600, which is similar to the pattern seen in European countries. The mid-level growth scenario set the saturation level of automobiles to 500, close to developed Asian countries such as Japan. The low-growth scenario set the saturation value at 400, which is approximately equal to the value in South Korea. 2007 has been set as the base year.

The total automobile stock is predicted based on the historical automobile stock and other relevant information, such as the prediction of market share for each major vehicle classification and automobile survival rate (Wu et al., 2011a). The calculation logistics are listed in Figure 3.

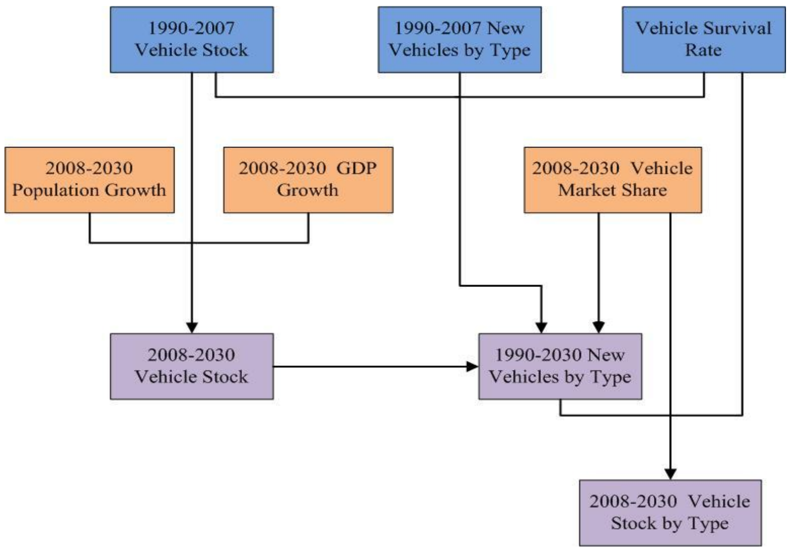

Figure 3:

Flow chart of the automobile stock calculation

In order to calculate the automobile stock, including a breakdown of detailed vehicle types, the methodology developed by Wang et al. (2006) was applied. In this model, the change of annual automobile stock is defined by the elimination of old automobiles and the sales of new automobiles. The automobile stock by detailed types in the target year is predicted through automobile survival rate and the sales of new automobiles by detailed types. As it can be obtained the annual sales of new automobiles by type from the statistical yearbooks, the total sales of new automobiles in the target year can be obtained from the survival rate. Through the prediction of the automobile market share, the automobile stock by detailed types can be calculated. Figure 4 shows the calculation flow chart.

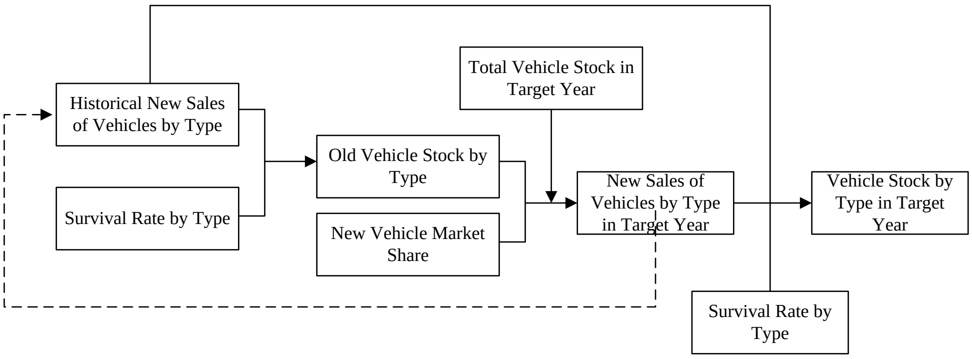

Figure 4:

Calculation flow chart of automobile stocks by type

The principle is shown in Equation 2

$$VehicleStock_i = \sum_j \sum_{k=base}^{i} NewVehicle_k \times MarketShare_{k,j} \times SurvivalRate_{i-k,j} \quad (2)$$

After transforming Equation (2) the following equation can be derived:

$$NewVehicle_i = VehicleStock_i - \sum_j \sum_{k=basic}^{i-1} \left(NewVehicle_k \times MarketShare_{k,j} \times SurvivalRate_{i-k-1,j} \right) \quad (3)$$

And: $$NewVehicle_{i,j} = NewVehicle_i \times SurvivalRate_{0,j} \times MarketShare_{i,j} \quad (4)$$

Where i represents the target year, $basic$ the base year, j the types of automobiles, $VehicleStock_i$ the total automobile stock in the target year i, $NewVehicle_k$ represents the total new sales of automobiles in year k, $MarketShare_{k,j}$ represents the new automobile market share of automobile type j in year k, and $SurvivialRate_{i-k,j}$ represents the survival rate in year i of the automobiles of type j which were sold in year k.

2.2 Vehicle Stock until 2030

Figure 5 shows the results of the Chinese vehicle stock (excluding motorcycles) projected under each of the three growth scenarios (low-, mid- and high-growth) (Wu et al., 2011a). By 2030, the total vehicle stock is projected to reach between 407 and 528 million. Chinese vehicle ownership will be 285, 330 and 370 per 1000 people by 2030 under the low-, mid- and high-growth scenarios, respectively.

Figure 5 also compares the projected stock in China with the vehicle stock of the United States (U.S.) in 2010. Around 2021-2023, according to the projections, the vehicle stock in China will reach the 2004 level of stock in the U.S. According to the projection of the Energy Information Administration (EIA 2006), the U.S. vehicle stock will be around 330 million by 2030. Our projection indicates that between 2023 and 2027, China's total vehicle stock will exceed the projected stock of the U.S. for 2030.

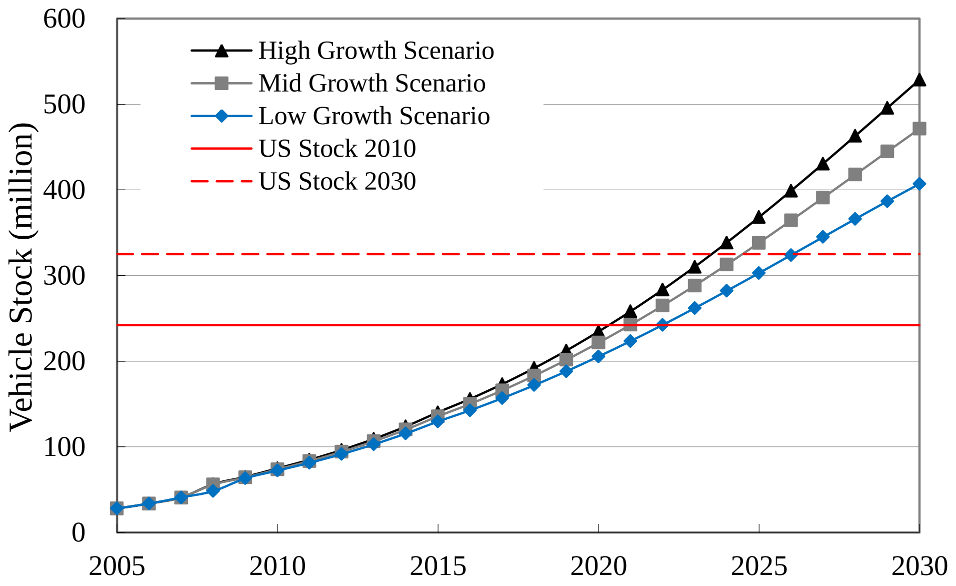

Figure 5:

Projected Chinese vehicle stock until 2030

Figure 6 further summarizes the forecast of China's vehicle growth from various recent studies including our study (Huo and Wang, 2011; Ou et al., 2010; Wang et al, 2011; Wu et al., 2011a). Unsurprisingly, all of these studies forecast that the Chinese vehicle population will continue to increase over the next two decades, and the only uncertainty is regarding the specific rate of growth. The results vary widely, depending on the assumptions used for key parameters, such as saturated vehicle ownership, population and GDP per-capita, The total vehicle stock in China is projected to be between ~200 and ~300 (with an average of 230) million by 2020 and between ~350 and ~550 (with an average of 430) million by 2030. Using the averaged estimates, the vehicle ownership in China will reach about 120 per 1000 people by 2020 and 300 per 1000 people by 2030.

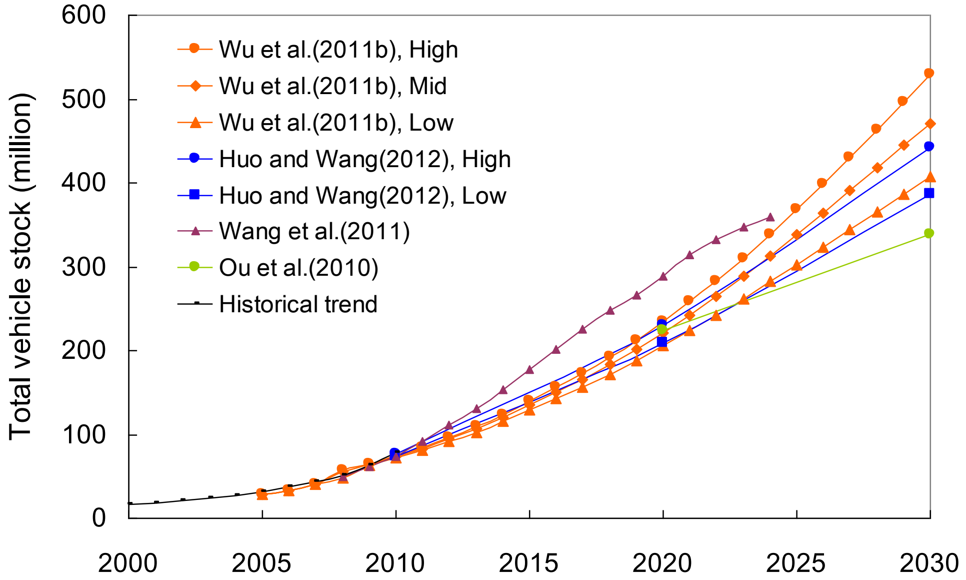

Figure 6:

Projections of China's vehicle stock (2010-2030) by several recent studies

Taking the mid-growth scenario as an example, Figure 7 further illustrates the specific details of the projected vehicle stock. In 2005, there were only 11 million cars in China. This number will increase to 357 million by 2030, which means that the amount of vehicles on the road will be 32 times higher than the 2005 value. The current low rate of car ownership provides a substantial increment potential driven by China's expanding economy.

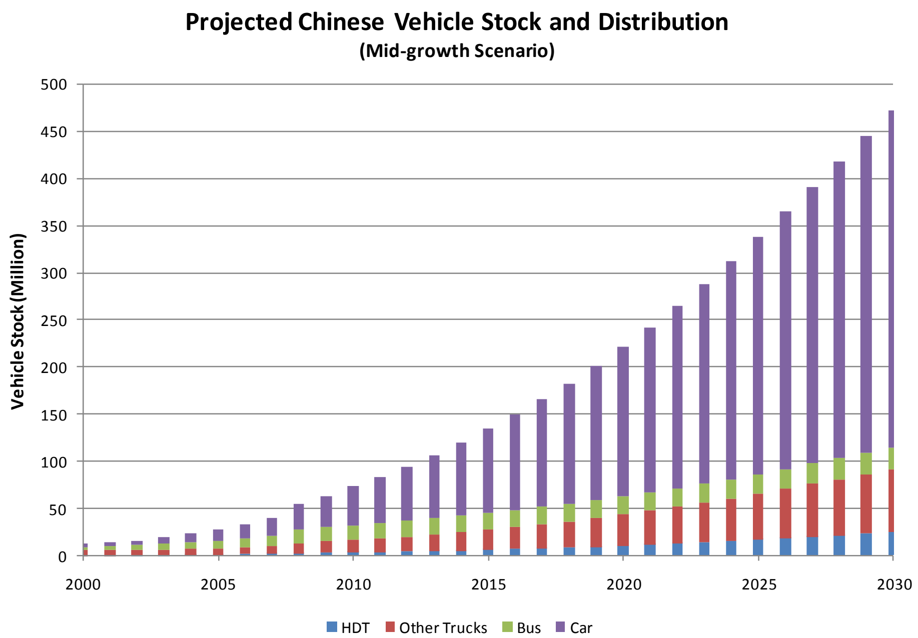

Figure 7:

Projected Chinese vehicle stock by category under the mid-growth scenario

Figure 8 shows the projected Chinese vehicle stock share under the mid-growth scenario. It indicates that the bus stock will increase slightly and its share of the total vehicle population will drop over time. From 2005 to 2030, the bus population is projected to increase from 8 million to 23 million. At the same time, the number of buses as a percentage of total vehicles will drop from 28.5% to 5%. The truck population will remain low but experience a steady growth. The demand for transporting freight will expand with the expanding economy. From 2005 to 2030, truck stock will rise from 8.7 million to 91.7 million, with an average annual growth rate of just under 10%.

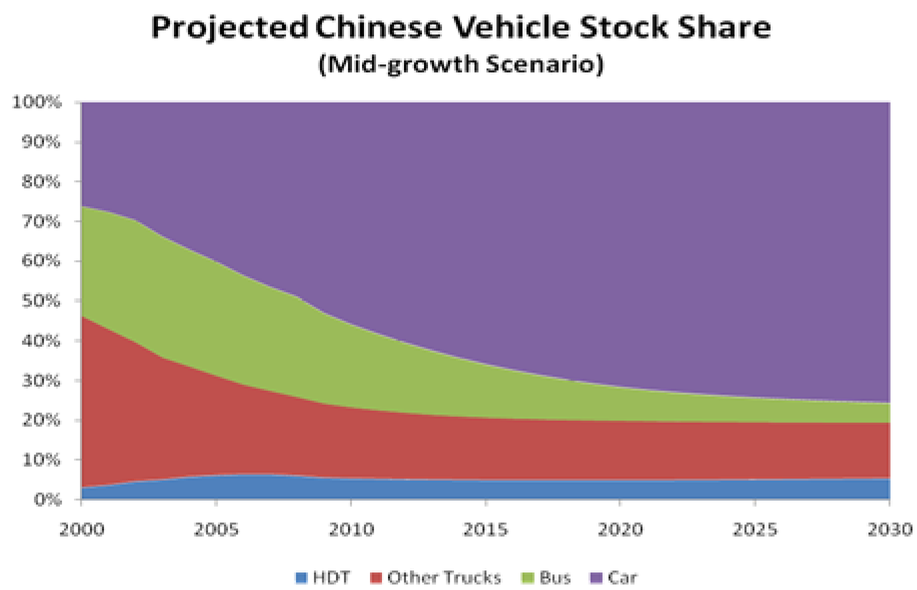

Figure 8:

Projected Chinese vehicle stock share under the mid-growth scenario

3 Projection of Oil Consumption

3.1 Methodology

Aside from the vehicle stock, fuel economy is another key factor in projecting the oil consumption of vehicle fleets in China. The flow chart of the fuel economy simulation is shown in Figure 9.

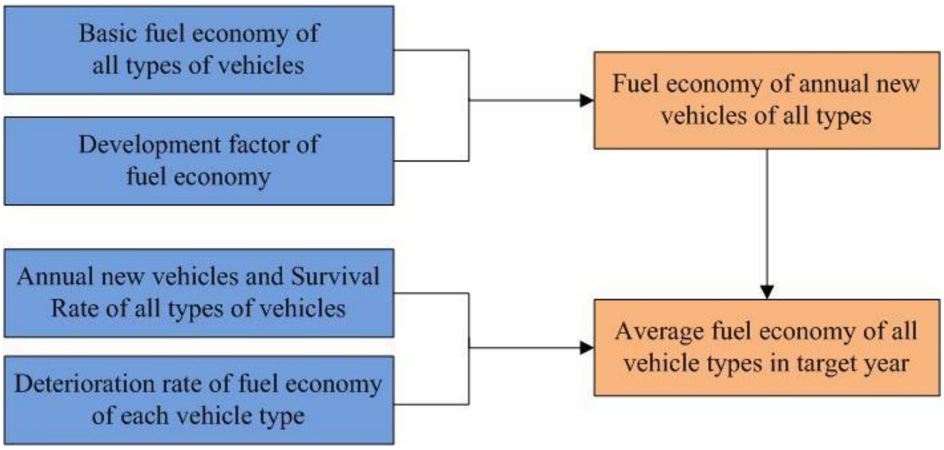

Figure 9:

Flow chart of fuel economy calculation

Equation 5 below shows the fuel economy calculation procedure.

$$AvgFuelEconomy_{i,j} = \frac{\sum_{k=base}^{i} \left(NewVehicle_{k,j} \times FuelDet_{i-k,j} \times SurvivalRate_{i-k,j} \times FuelEconomy_{k,j} \right)}{TotalVehicle_{i,j}} \qquad (5)$$

i represents the target year, j represents the target vehicle type, $base$ represents the base year, k is the target year, $NewVehicle_{k,j}$ represents the new sales of vehicles in year k in millions, $SurvivalRate_{i-k,j}$ is the survival rate of new sales of vehicles in the year of i, $FuelEconomy_{k,j}$ represents the level of fuel economy in year k, $AvgFuelEconomy_{i,j}$ represents the average level of fuel economy of the vehicle type j in the year of i, $FuelDet_{i-k,j}$ is the deterioration rate of the fuel economy, and $TotalVehicle_{i}$ represents the automobile stock of type j in the year of i.

Due to uncertainty regarding future fuel economy improvements in China's vehicle fleet, three potential scenarios were designed. Under the conservative scenario, there is no control over fuel economy except the current Passenger Vehicle Fuel Consumption Limits (such as GB19578-2004). Under the moderate scenario, improvements in fuel economy corresponding to the U.S. National

Academy of Science's (NAS) Path Two were assumed for Chinese passenger cars, light-duty buses and mini buses in 2012; and improvements in fuel economy corresponding to NAS's Path One were assumed for Chinese mini trucks and light-duty trucks in 2012, and NAS's Path Two in 2016. Regulations equivalent to the fuel consumption limits of new Japanese heavy duty vehicles were assumed for Chinese heavy-duty vehicles (including medium-duty trucks, heavy-duty trucks, medium-duty buses, and heavy-duty buses) in 2020. Under the aggressive scenario, potential improvements in fuel economy corresponding to NAS's Path Three were assumed for Chinese passenger cars and light-duty trucks in 2012. For detailed discussions about potential fuel economy improvements in the future, please refer to these documents (Lin 2010; USNRC, 2002; Wu et al., 2011a).

Amongst different vehicle categories, the fuel economy for conventional light-duty gasoline vehicles in China is improving most rapidly due to the implementation of first and second phases of the vehicle fuel-economy standards since 2004 (Jin et al., 2005; Wang et al., 2010). Wang et al. (2010) reported the average fuel-consumption rate in China as being 8.1 L/100 km in 2006, about 12% lower than the average rate in 2002 (9.1 L/100 km). Wagner et al. (2009) and Huo et al. (2011a) reported a slightly lower value of 7.9 and 7.8 L/100 km, respectively, for the year 2009. As China will tighten the fuel economy standards stage by stage (e.g. the third-phase standard) in the future, the fuel economy of light-duty vehicles will continue to improve during the next two decades (Wang et al., 2010). However, it should be noted that the values mentioned above are based on laboratory test results with a fixed certification cycle. Real-world fuel consumption will be higher than rates measured in laboratory testing. For example, Lin (2010) and Huo et al. (2011a) both indicated that the real-world fuel consumption as measured via surveys from domestic websites was ~15% higher than the rates indicated by laboratory certificate data. Tsinghua developed a method to calculate real-world fuel consumption rates for new LDPV between 2010 and 2030, which includes several adjustment factors, such as vehicle weight, driving cycles and real-world driving patterns (Lin, 2010; Wu et al., 2011a). The authors estimated that real-world fuel consumption was ~15% higher than the rates indicated by laboratory certificate data.

For other parameters, such as the annual VKT by each major vehicle category, please refer to previous documents (Lin, 2010; Wang et al., 2006; Wu et al., 2011a, 2011b).

After determining the average fuel economy and VKT as well as the vehicle stock, the oil consumption was calculated using Equation 6.

$$OilCon_i^f = \sum_{j^f} \left(VehicleStock_{i,j^f} \times VKT_{i,j^f} \times AvgFuelEconomy_{i,j^f} \right) \times Density_i^f \quad (6)$$

i is the target year, j represents the type of vehicle, f represents the type of fuel, j^f is the vehicle type which uses the fuel type f, $OilCon_i^f$ represents the consumption of fuel type f in year i, $VehicleStock_{i,j^f}$ is the vehicle stock of type j^f in year i, VKT_{i,j^f} represents the annual vehicle kilometres travelled of type j^f in year i, and $AvgFuelEconomy_{i,j^f}$ is the average level of real-world fuel economy of vehicle type j^f in year i.

3.2 Oil Consumption until 2030

By combining the three different vehicle stock growth scenarios and three different fuel economy improvement scenarios, nine projection scenarios are generated for the oil demand in China up to 2030. Figure 10 shows the results of the projected oil demand by Chinese vehicle fleets (excluding motorcycles) with these nine scenarios. The oil demand for Chinese on-road transportation (excluding motorcycles) will rise rapidly, with an annual growth rate of ~8–11% between 2005 and 2030, reaching 665–1,186 million metric tons a year by 2030. As shown in Figure 10, between 2019 and 2023 the oil demand for the Chinese automobile sector will reach the U.S. 2004 levels, depending on different selections of vehicle growth rates and fuel economy. This potential growth in oil demand will strain the balance of Chinese — and global — oil supply and demand.

Oil consumption distributions by vehicle types under different scenarios in 2030 are presented in Table 2. There are several notable conclusions which can be drawn from the results.

First, cars and trucks have the greatest potential for oil saving. Though oil consumption varies greatly between scenarios, the percentage of total savings attributed to each vehicle category is approximately the same across the different scenarios. Trucks and cars are the two major oil consumers, accounting for 53% and 35% of total consumption, respectively. Though cars have better fuel economy than buses and trucks, the predominant share of the total stock (76% under mid growth scenario in 2030) offsets the fuel economy benefit. This causes a significant total oil use. On the other hand, trucks account for only 19% of the total automobile stock under the mid growth scenario in 2030, but consume about 53% of the oil due to their low fuel economy.

Second, fuel economy policies effectively reduce oil consumption. In each vehicle stock growth scenario, the oil demand in 2030 can be reduced by 28% from the aggressive fuel economy scenario as compared to the conservative fuel economy scenario. Oil savings from fuel economy improvements in the high-, mid- and low-stock scenario are 331, 295 and 253 million metric tons, respectively. For comparison, in 2010 China consumed 215 million metric tons of oil (gasoline plus diesel) (NBSC and NDRC, 2011).

Third, stock growth control is also an effective tool for reducing oil consumption.

For each fuel economy scenario, low growth can provide a 22% oil consumption reduction compared to the high growth. The stock-control oil savings are 268, 213 and 190 million metric tons in the conservative, moderate and aggressive fuel economy scenarios respectively. However, stock growth control means restricting the trip demand; this could negatively affect economic growth and standards of living.

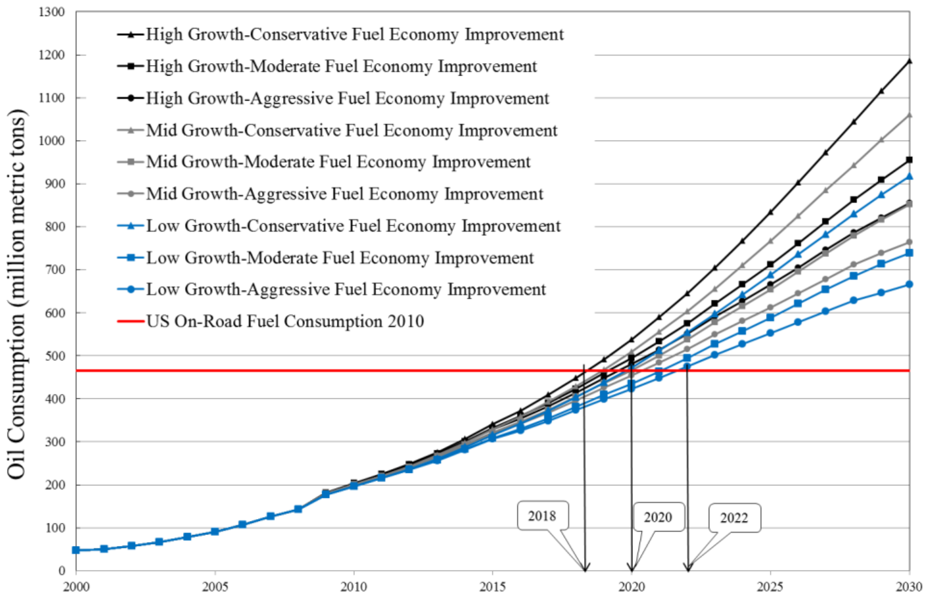

Figure 10:

Projected annual oil demand under the nine combinations of scenarios

Table 2:

Projected oil consumption by vehicle type under different scenarios

Stock Growth Scenarios	Fuel Economy Scenarios	Oil Consumption (Million Metric Tons)			
		Total	Car	Bus	Truck
High	Conservative	1186	421 (36%)	139 (12%)	626 (53%)
	Moderate	952	335 (35%)	112 (12%)	504 (53%)
	Aggressive	855	292 (34%)	101 (12%)	462 (54%)
Mid	Conservative	1060	375 (35%)	124 (12%)	560 (53%)
	Moderate	852	299 (35%)	101 (12%)	453 (53%)
	Aggressive	766	260 (34%)	90 (12%)	415 (54%)
Low	Conservative	918	324 (35%)	108 (12%)	486 (53%)
	Moderate	739	258 (35%)	87 (12%)	394 (53%)
	Aggressive	665	225 (34%)	79 (12%)	362 (54%)

Figure 11 presents oil consumption and share change by vehicle type from 2000 to 2030. The curve is plotted using the mid vehicle stock growth data and the moderate fuel economy improvement scenario. It is clear that oil consumption from cars and trucks will experience tremendous increases. For cars, the oil consumption in 2005 was 18 million metric tons. For the next several 5-year periods (years 2010, 2015, 2020, 2025 and 2030), the consumption values will rise to 58, 111, 167, 230 and 299 million metric tons. Total oil consumption rises 16 times over the 25 year period. For trucks, the oil consumption rises 8 times over the 25 year timeframe. Oil consumption from heavy-duty trucks grows by a factor of 11 times from 2005 to 2030.

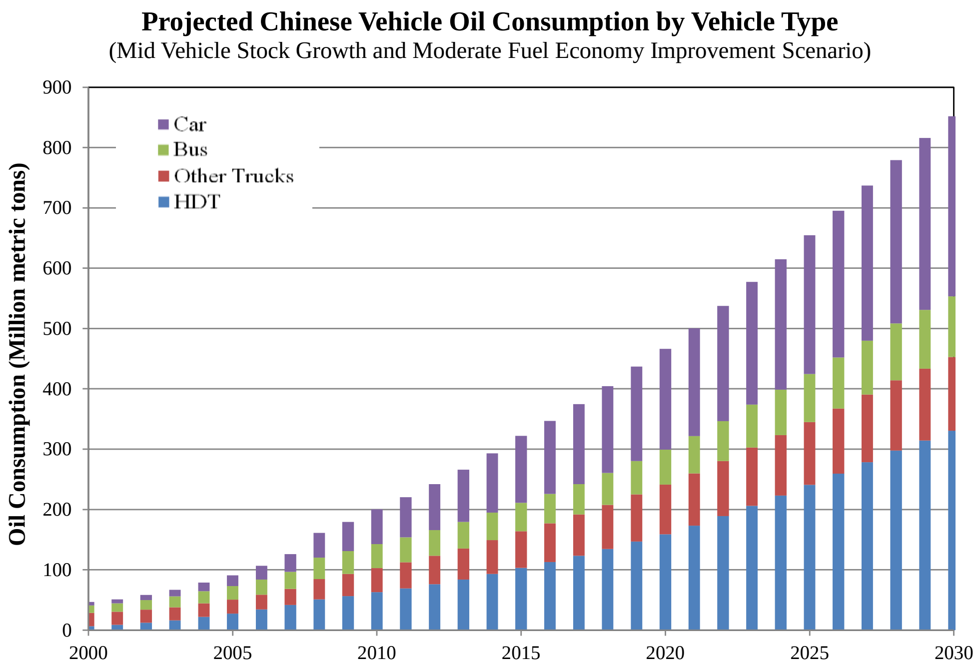

Figure 11:

Projected Chinese automobile oil consumption by vehicle type

4 Projection of CO_2 Emissions

4.1 Methodology

In this study, the calculation of CO_2 emissions is based on the carbon balance method. From the oil density and carbon content in the fuel, as well as the fuel economy, the CO_2 emission factors of vehicles can be obtained. The calculation flow chart is shown in Figure 12, and it is similar to that of the fuel economy calculation.

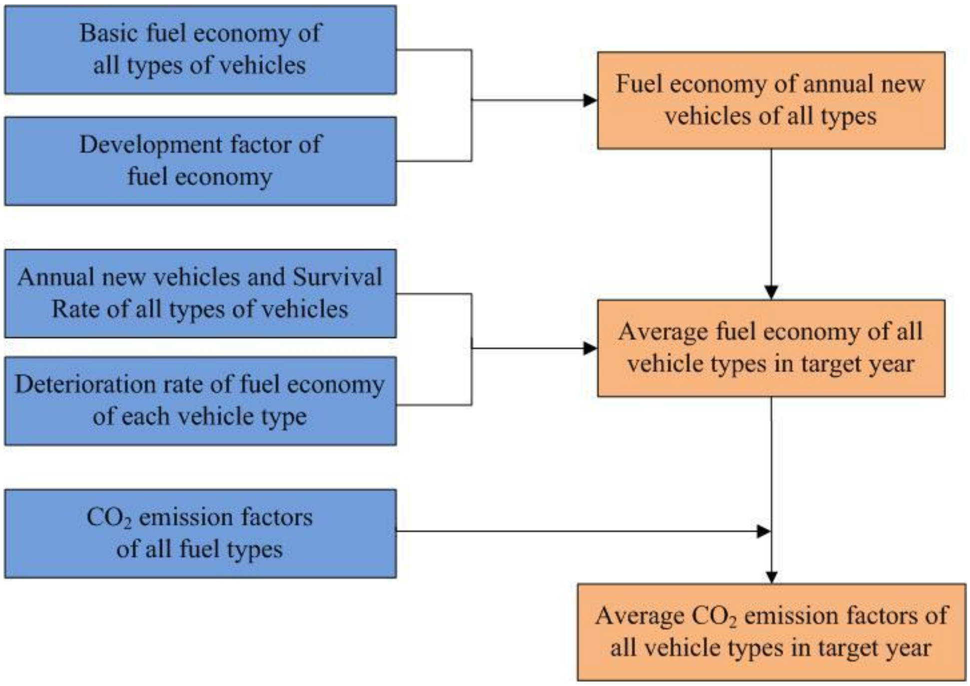

Figure 12:

Flow chart of the CO_2 emission factors calculation

The CO_2 emission factor is derived from Formula 7.

$$CO_2EF_{i,j^f} = \left(\sum_f \left(Density_i^f \times Carbon_i^f \times FuelEconomy_{i,j^f} \right) \right) \times 44/12 \qquad (7)$$

i represents the target year, j represents the vehicle type, f represents the fuel type, CO_2EF_{i,j^f} represents the CO_2 emission factors of vehicle type j with the fuel type f in year i, $FuelEconomy_{i,j^f}$ represents the average fuel economy of vehicle type j with fuel type f in year i, $Density_i^f$ represents the density of fuel type f in year i, and $Carbon_i^f$ represents the carbon content of fuel type f in year i.

Table 3 presents the CO_2 emission factors of new automobiles in 2005 as an example.

Vehicle Types		CO_2 Emission Factor (kg/km)	
		Diesel	Gasoline
Truck	HDT	0.841	0.757
	MDT	0.652	0.767
	LDT	0.427	0.389
	miniT	0.473	0.199
Bus	HDB	0.924	1.038
	MDB	0.714	0.856
	LDB	0.284	0.233
	miniB	0.145	0.166
Car		0.140	0.188

Table 3:

CO_2 emission factors of new automobiles in 2005

The total CO_2 emissions for the vehicle fleet can be calculated using Equation 8.

$$CO_{2i} = \sum_{j^f}\left(VehicleStock_{i,j^f} \times VKT_{i,j^f} \times CO_2EF_{i,j^f}\right) \tag{8}$$

i is the target year, j represents the type of vehicle, f represents the type of fuel, j^f is the vehicle type which uses fuel type f, $VehicleStock_{i,j^f}$ is the vehicle stock of type j^f in year i, VKT_{i,j^f} represents the annual vehicle mileage travelled of type j^f in year i, CO_{2i} are the emissions of CO_2 in year i, and CO_2EF_{i,j^f} are the CO_2 emission factors of vehicle type j with fuel type f in year i.

4.2 CO_2 emissions until 2030

By combining the three different automobile stock growth scenarios and three different fuel economy improvement scenarios, nine scenarios for projected CO_2 emissions in China until 2030 are provided. Figure 13 shows the growth of CO_2 emissions from vehicles in China until 2030. Between the scenarios, CO_2 emissions vary from 2109 to 3758 million metric tons. Similar to the oil consumption projections, trucks and cars are the main contributors, accounting for 53% and 35% of total emissions. Under the mid vehicle stock growth and moderate fuel economy improvement scenario, the heavy-duty trucks emit 39% of the total CO_2 – the largest single contributor as shown in Figure 14. Policies aimed at reducing vehicle carbon emissions may be similar to those aimed at reducing oil consumption when referring to conventional gasoline vehicles or diesel vehicles.

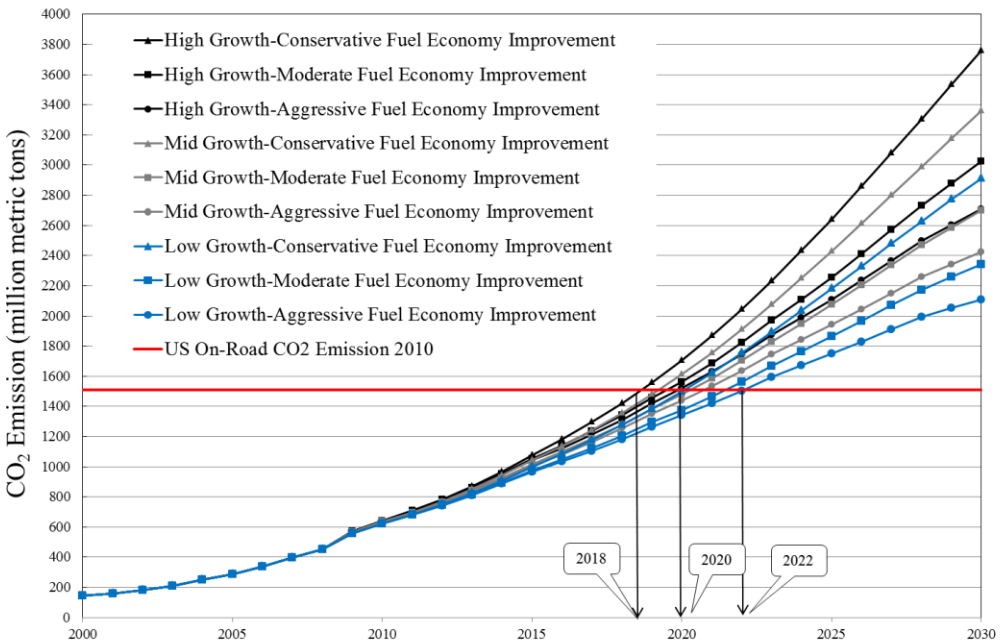

Figure 13:

Projected annual CO_2 emissions by Chinese automobiles under various scenarios

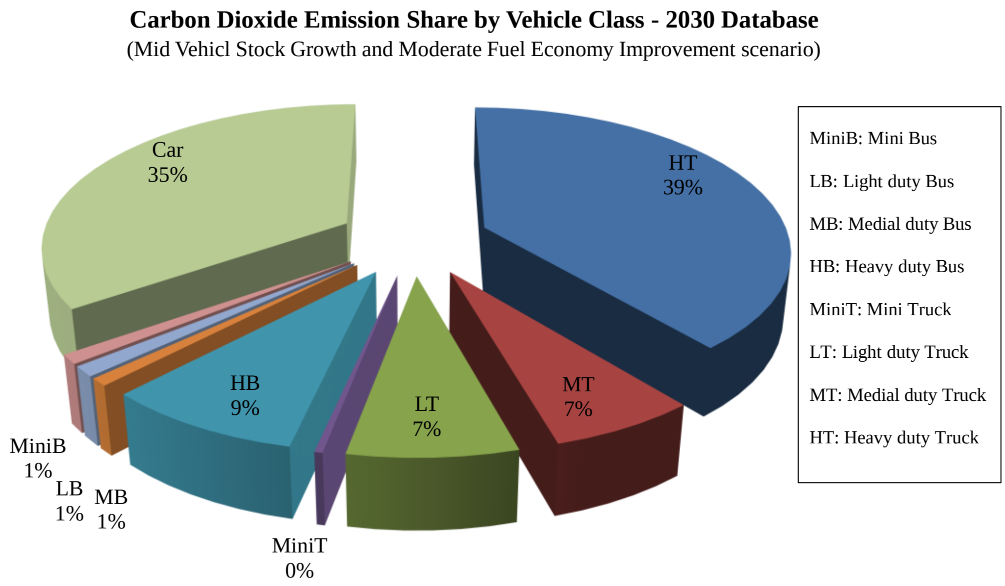

Figure 14:

Projected annual oil demand by Chinese automobiles by vehicle type

Table 4 lists the forecasted oil consumption and CO_2 emissions in China, as calculated by several other researchers (Huo et al., 2011b; Ou et al., 2010; Wang et al., 2006). The differences in these results are primarily due to variance in selection of key parameters such as vehicle growth rates, fuel economy, etc.

Table 4:

The projected oil demands and CO_2 emissions as calculated by different researchers

Study	Oil demand/ million metric tons		CO_2 emissions/ million metric tons		Base year
	2030	2050	2030	2050	
Huo et al.,2011b	370-460	400-520	1650-2050	1850-2350	2009
Ou et al.,2010	430	460	1430	1640	2007
Wang et al.,2006	320-500	610-1020	1170-1560	1930-3190	2004

5 Projection of the Energy and Climate Impact of EVs

5.1 Methodology

In order to better evaluate upstream energy savings and the potential for CO_2 emission reductions of advanced propulsion/fuel vehicle systems, a well-to-wheels (WTW) method is used. In this study the GREET 1.8d model is used, developed by Argonne National Laboratory (ANL), as a platform to calculate the fuel cycle (WTW) energy consumption and CO_2 emissions of advanced propulsion/fuel automobile systems (Wang, 1999; Elgowainy, 2010). Key inputs, such as the fuel economy and emission factors of various vehicle technologies, energy efficiency and emission factors of the upstream electricity generation mix will be updated with the Chinese specific database, which is developed by the Tsinghua University (Huo et al., 2010; Lin, 2010; Wu et al., 2011a, 2011b) and will be updated in this study.

The GREET WTW modelling boundary includes well-to-tank (WTT) and tank-to-wheels (TTW) stages. The WTT stage includes feedstock recovery and processing, feedstock transportation and storage, fuel production as well as fuel transportation, storage, and distribution. The TTW stage covers vehicle operation activities (Wang, 1999; Brinkman et al., 2005; Wu et al., 2006). Figure 15 shows the processes included in full WTW assessment. Tsinghua conducted a case study of WTW analysis of energy consumption and CO_2 emissions for HEV, PHEV and BEV, and compared them with their conventional ICEV counterparts within three highly-developed regions (Jing-Jin-Ji region, Yangtze-River-Delta region and Pearl-River-Delta region).

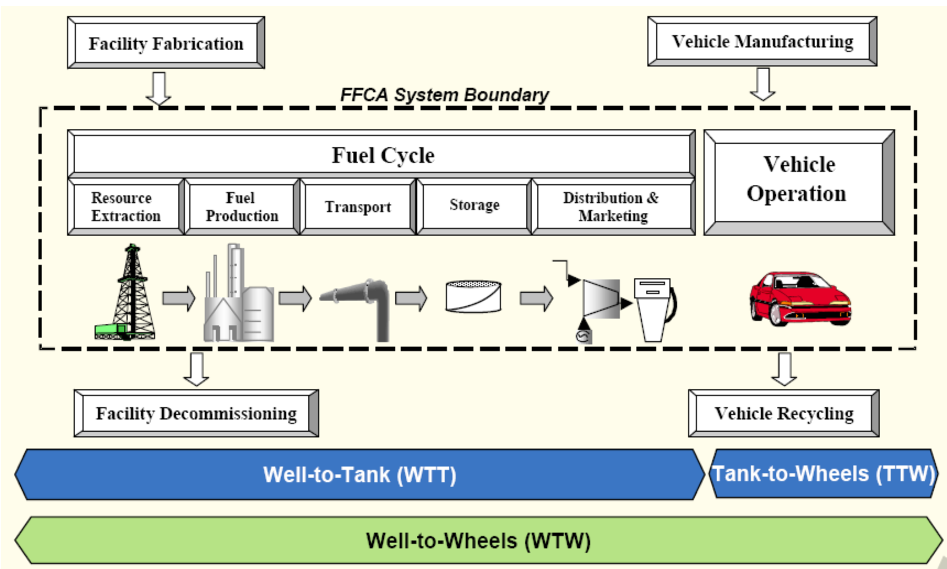

Figure 15:

Processes included in the well-to-wheels analysis

5.2 Projection of the EV Market

HEVs can significantly improve the fuel economy because the engine used in the HEV operates close to constant speed and is a highly efficient power source. Regenerative braking results in higher overall energy efficiency from the system. The battery or capacitor size in the HEV determines the power management strategy. The HEV is already a commercially available technology, best known for its implementation in the successful Toyota Prius. Another advantage of the HEV is that no additional charging infrastructure is needed; therefore, the HEV is usually considered more competitive than PHEVs and BEVs in the short-term.

The BEV only uses a battery and a motor to drive the vehicle, demanding a large energy storage capacity. BEVs consume electricity generated by the grid while maintaining high energy conversion efficiency during vehicle operation. The PHEV combines the characteristics of the HEV and BEV: it is capable of only using electricity when depleting its electric charge, and operates like an HEV when the state of charge (SOC) is low. Currently, battery technology is the bottle-neck for PHEVs and BEVs. Battery energy density, battery lifetime, safety and costs are the limiting factors. Another disadvantage is the extensive charging infrastructure network which would be required, especially for BEVs.

Generally, there are two points of view about the future of these three technologies. One view is represented by the US Energy Information Agency (EIA). In reference to oil price scenarios, EIA's published Annual Energy Outlook (2009) projected that HEV, PHEV and BEV together will account 40% of total new sales of LDPV in the U.S. by 2030, and could range from 38-45% depending on the fluctuation of oil price. However, such a market share is dominated by HEV. PHEV is assumed to have a small share of only ~2% of total new sales, and for BEVs the share is negligible. However, several other institutes, such as the Electric Power Research Institute (EPRI), Rocky Mountain Institute (RMI), etc., have a more optimistic outlook on the future of PHEVs. They assume that by 2020 PHEVs could reach ~30% of total new LDPV sales in the U.S., and by 2030 the market share could even climb to 50-70% (Anderson, 2008; Duvall, 2007; Kramer, 2009).

The Chinese government is also strongly supporting the process of vehicle electrification. In 2009, the State Council released the Automotive Industry Restructuring and Revitalization Plan (State Council, 2009). In August 2010, the Ministry of Industry and Information Technology of China (MIIT) released a draft of "Energy-Saving and New-Energy Vehicle Development Plan (2011-2020)" (MIIT, 2010). It proposed that the stock of PHEV and BEV in China will reach 500,000 by 2015, and the whole stock for energy-saving and new energy vehicles should exceed 5 million by 2020.

In 2008, the Chinese government launched a large-scale demonstration program called "Ten Cities & Thousand Units" to promote these new vehicle technologies (also called “Energy-Saving and New-Energy Vehicles” in China); the number of demonstration cities has now expanded to 25. Figure 16 illustrates the current status of the vehicle stock for HEV, PHEV and BEV for this program (CATARC, 2011). By 2010, a total of about 12,000 HEVs, PHEVs and BEVs were among China’s vehicle stock. It should be noted that at this stage, most of the demonstration vehicles are commercial vehicles, such as buses and taxis.

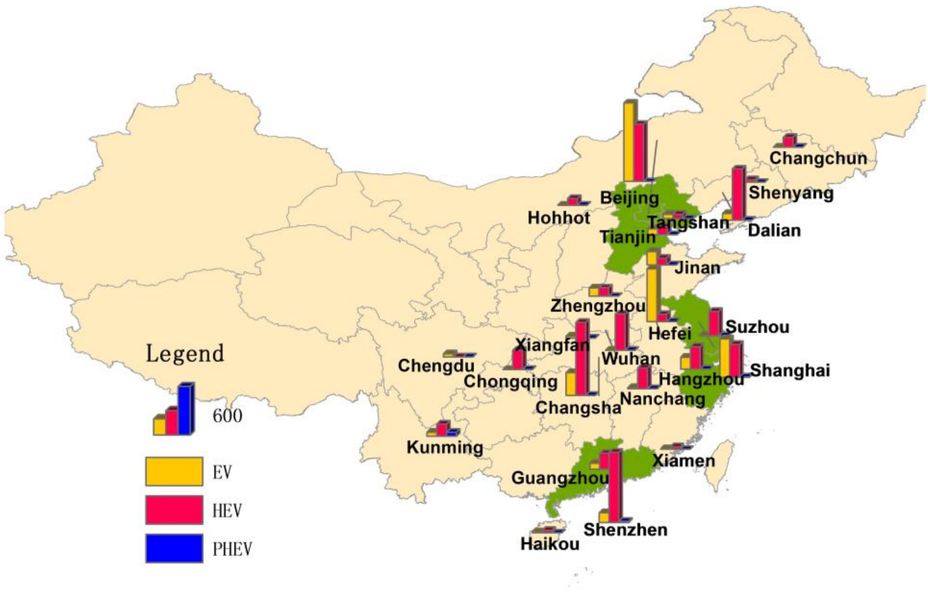

Figure 16:

Stock for HEV, PHEV and BEV in 25 demonstration cities in China as of 2010

(Note: the three areas in green from North to South are Jing-Jin-Ji region, Yangtze-River-Delta region, and Pearl-River-Delta region, respectively.)

Due to great uncertainties regarding battery technology, charging infrastructure and policy support, the authors designed four different scenarios for the penetration of HEV, PHEV and BEV into the LDPV market in China. Figure 17 illustrates the share of ICEV, HEV, PHEV and BEV among total new LDPV sales during the period of 2010 to 2030. Scenario 1 is a conservative option, and the penetration of these new technologies is primarily market driven (see Figure 17a). With the gradual improvement of technology and the decline of automobile costs, it is assumed that HEV would reach 1% of total sales by around 2015 and increase its share gradually to 15% by 2030. PHEV and BEV would contribute minimal shares, about 2% and 0.1% by 2030 respectively, within this scenario. Scenario 2 represents a more optimistic outlook (see Figure 17b). It assumes that the government will provide strong policy support (e.g. financial subsidies) to promote the development of these new technologies. Scenario 2 assumes that the share of HEV, PHEV and BEV among total LDPV sales will reach 30%, 15% and 2% by 2030, respectively. Due to the restraints on the evolution of battery technology and charging infrastructure, a much slower penetration for PHEV and BEV than HEV is estimated in scenario 2. However, the Chinese government is paying special attention to the promotion of PHEV and BEV. Tsinghua specifically designed two more scenarios to reflect a faster penetration of PHEV and BEV. Scenario 3 assumes that the commercialization of PHEV will start about five years later than the commercialization of HEV, but the share of PHEV to total LDPV sales will reach 30% by 2030, the same value as that of the HEV (see Figure 17c). Scenario 4 is an ideal option depicting rapid EV development, and supposes that manufacturers will overcome all battery technology bottlenecks in a short period and the charging infrastructure will be extensive (see Figure 17d). In this scenario, as much as 20% of LDPV sales will come from BEV by 2030, and PHEV and HEV maintain their high market shares as in scenario 3.

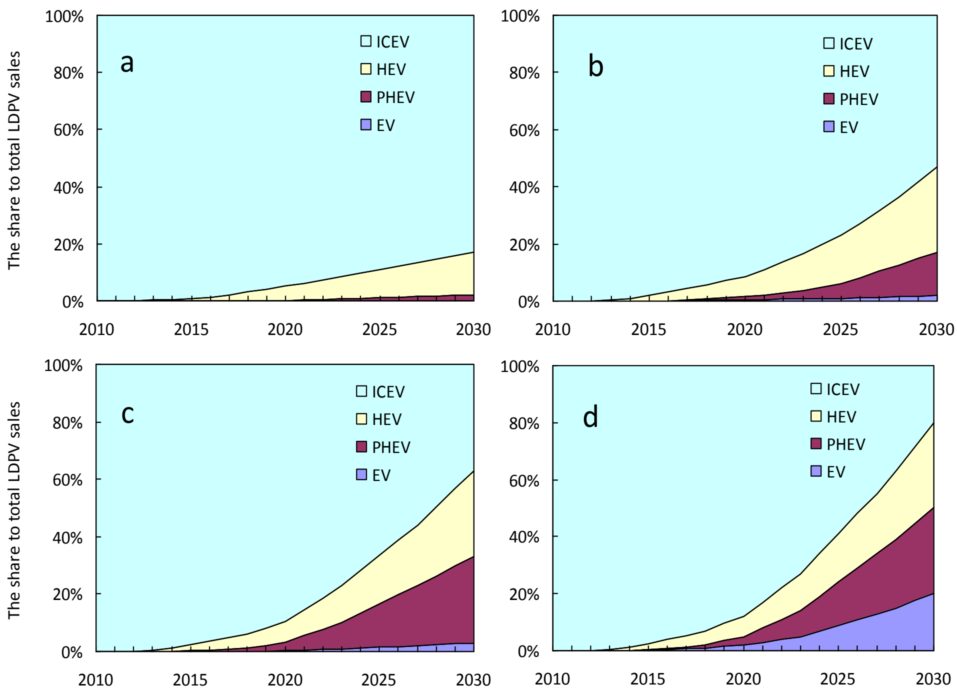

Figure 17:

The share of different powertrain technologies among total LDPV sales under four different scenario designs, 2010-2030

For HEV, PHEV and BEV, the fuel economy improvement ratios relative to conventional ICEV was reviewed. In this study, only full-hybrid models (e.g. Toyota Prius) were considered. Bennion and Thornton (2009) summarized various hybrid vehicles sold in the U.S. and concluded an average improvement rate at 37-42%, depending on the evaluation method, which is consistent with the GREET1.8d default value at 40% (Elgowainy, 2010). Tsinghua uses an improvement rate of 40% for HEV in this study. For PHEV, first a proper value for all electric range (AER) had to be defined. According to the surveys on vehicle activities in different cities (such as Beijing and Guangzhou), the current daily-averaged vehicle-kilometre-travelled (VKT) for a private passenger car is about 50 km (Wu et al., 2011a). Therefore, a PHEV50 with series-configuration (AER=50 km) was selected for this study. The fuel economy improvement ratio is about 280% for charging-depleting (CD) mode and 120% for charging-sustaining (CS) mode, derived from Elgowainy et al. (2010). For BEV, a ratio of

375% is applied for this study, derived from the GREET1.8d model (Elgowainy, 2010). Both ratios mentioned above for PHEV50 and BEV already took into account the on-road adjustment with a degradation factor of 0.7 (Elgowainy, 2010; Elgowainy et al., 2010), to ensure that the fuel consumption for all four types of vehicles reflect real-world values.

5.3 Projection of Power Generation and Emissions

Figure 18 presents the total power generation in China from 1980 to 2010 (NBSC, 2011). Over the past three decades, the Chinese power industry has developed rapidly with power generation increasing from 300 billion kWh in 1980 to 4200 billion kWh in 2010.

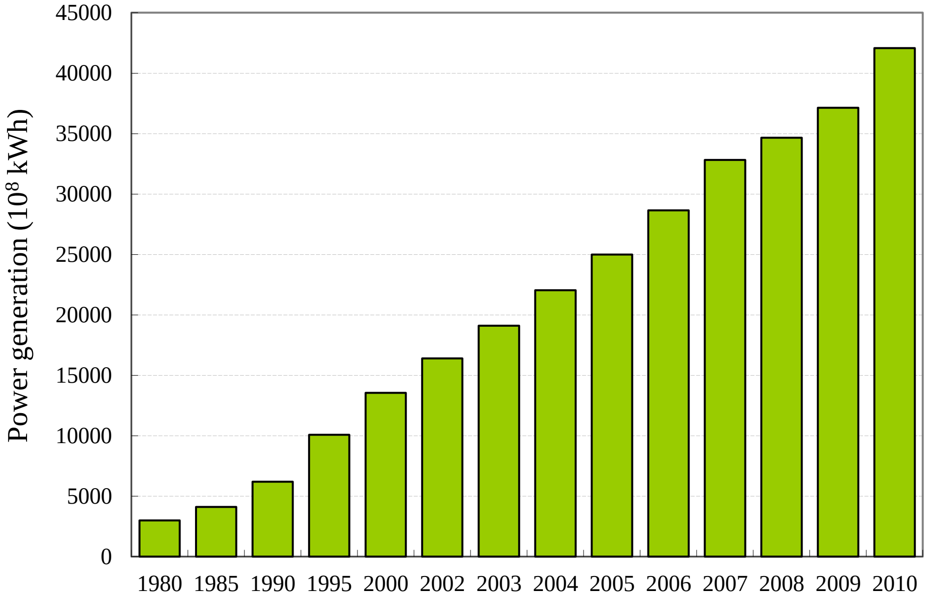

Figure 18:

Power generation in China, 1980-2010

The electricity generation mix is a key parameter affecting WTW energy use as well as CO_2 emissions of PHEV and BEV. The historical energy generation mix by region within China has been collected with data taken from the China Energy Statistical Yearbooks. Figure 19 shows the electricity generation mix in 2009 for each major region in China. In 2009, coal was the leading source, accounting for 79% of total electricity generation nationwide. Hydro-power ranked second at 15%. Other sources, such as NG power and nuclear power, account for a very small share—less than 2% (NBSC and NDRC, 2010). It should be noted that regional differences in electricity generation are significant. In this study, Tsinghua selected three regions to represent the variance in regional electricity generation mix. Those are 1) Jing-Jin-Ji Region in North China: including the two municipalities of Beijing and Tianjin, and Hebei province; 2) Yangtze-River-Delta Region in East China: including the municipality of Shanghai, Jiangsu province and Zhejiang province; and 3) Pearl-River-Delta Region in South China: including

Guangdong province. As shown in Figures 19 and 20a, the Jing-Jin-Ji region belongs to the Northern China Grid, which has a large amount of coal-fired power plants in this area, accounting for 95% of the total electricity generation. The Pearl-River-Delta region (belonging to Southern China Grid), however, is much cleaner in its generation mix. Coal power only accounts for 60%; while hydro, NG, and nuclear power account for 29%, 3% and 5%, respectively. For the Yangtze-River-Delta region (within Eastern China Grid), the electricity generation mix is between those of the Jing-Jin-Ji region and the Pearl-River-Delta region (see Figure 20a).

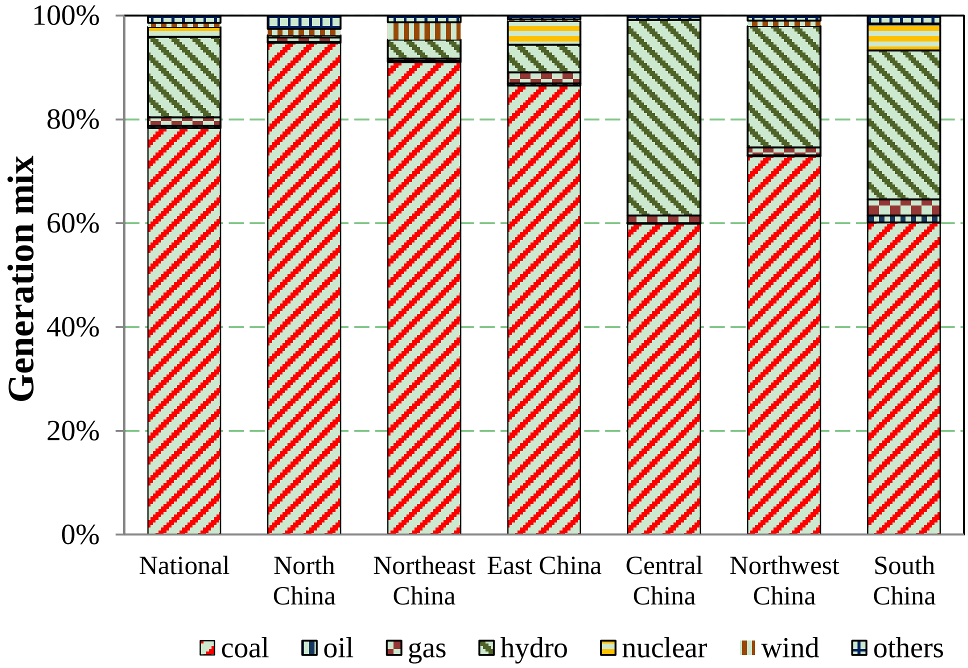

Figure 19:

Electricity Generation Mix by Region in China, 2009

The future of the electricity generation mix is uncertain. Wu (2007) and the reference scenario from International Energy Agency (IEA, 2007) both assumed a conservative trend for the penetration of cleaner power in China. The share of coal power will remain high, ranging from 70% to 80% by 2030. However, the Chinese Academy of Engineering (CAE and MEP, 2010) and the high scenario from IEA (2007) assumed an optimistic trend towards cleaner power. By 2030, coal power may account for a lower percentage of total nationwide electricity generation, from 60% to 65%. In this study, two scenarios of electricity generation mix for the three regions by 2030 were assumed. One is a conservative scenario regarding the penetration of cleaner power (see Figure 20b) while the other one is more progressive in the penetration of cleaner power (see Figure 20c).

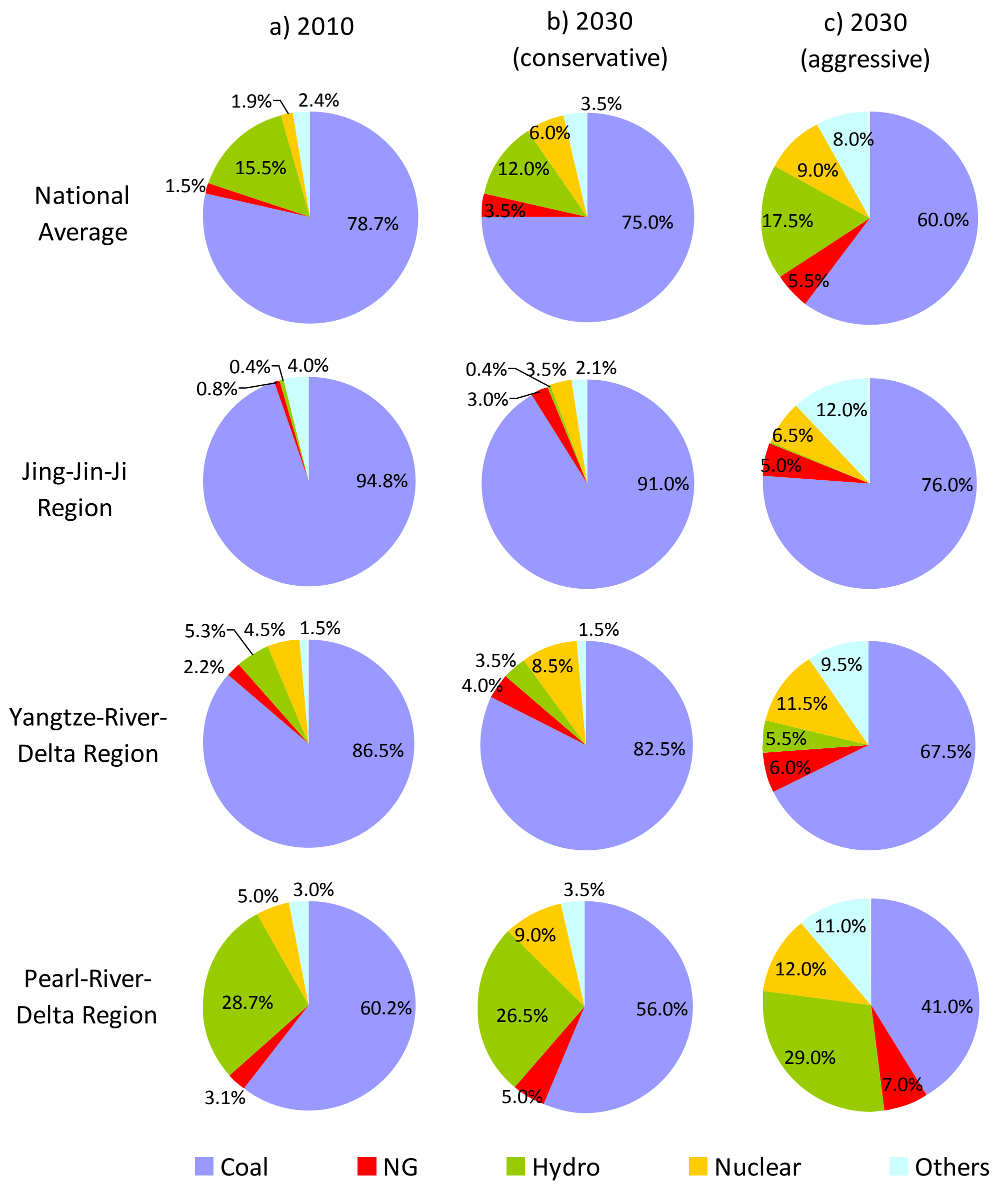

Figure 20:

Electricity generation mix in China and three selected regions in:

a) 2010,

b) 2030 with conservative scenario, and

c) 2030 with aggressive scenario

The electricity generation efficiency for coal power plants in China will be improved considerably in the future. New advanced technologies, such as supercritical and ultra supercritical power, have rapidly penetrated the power market. The authors use 39% and 42% of electricity generation efficiency for these two technologies, separately, these values being derived from Feng (2011), Han et al. (2012) and IEA (2007). These two electricity generation efficiency values are higher than that of conventional power plants (usually in 30-36%). It should be noted that the energy data in this study are all based on lower heating values of fuels. Due to the rapid increase of electricity demand, the share of supercritical and ultra supercritical power will take the lead by 2030 (IEA, 2009). In this study, it is assumed that 55% of total coal power in 2030 will be from these two technologies. For another new technology, integrated gasification combined cycle (IGCC), the authors followed similar assumptions by other sources (IEA, 2009). It is assumed that the share of IGCC power will reach 10% of coal-fired generation by 2030. As a result, the average electricity generation efficiency of coal power plants will gradually increase, reaching 40% in 2030, compared to the current value of 34%. Table 5 lists CO_2 emission factors of the average national generation mix and three regional generation mixes from 2010 and 2030.

CO_2 Emission Factors (g/kWh)	2010	2015	2020	2025	2030
			Conservative generation mix scenario		
Nationwide	790	740	690	650	630
Jing-Jin-Ji Region	950	890	840	790	760
Yangtze-River-Delta Region	870	810	760	710	670
Pearl-River-Delta Region	610	560	520	490	470
			Progressive generation mix scenario		
Nationwide	790	710	630	560	500
Jing-Jin-Ji Region	950	870	770	690	630
Yangtze-River-Delta Region	870	780	700	620	560
Pearl-River-Delta Region	610	530	460	390	340

Table 5:

CO_2 emission factors of national average grid mix and three regional grid mix

5.4 Projection of EV-related energy consumption and CO_2 Emissions

5.4.1 WTW Petroleum Consumption

Petroleum consumption has become a major energy security issue as the dependence of imported petroleum in China intensifies. Figure 21 shows the per-kilometre WTW results in petroleum energy use for HEV, PHEV50, and BEV relative to their ICEV counterpart in each of the three regions and in different calendar years from 2010 to 2030. In all of the charts, for each vehicle technology option, the bottom part of the bar (the dark colour) represents WTT per-kilometre results; the top part the bar (the light colour) represents TTW per-kilometre results. For WTW analysis, Tsinghua used the average fuel consumption rates of 7.3 L/100 km by 2020 and 6.4 L/100 km by 2030 relative to the current value at 8.5 L/100 km for light-duty ICEV (Lin, 2010). In general, the trends in WTW petroleum used for these three regions are very similar, so the discussion below has been primarily based on the Jing-Jin-Ji region's results, which can generally be considered representative of the whole.

The consumption of petroleum is concentrated in the vehicle operation stage (i.e. TTW). For example, the petroleum consumption of a gasoline car and a PHEV50 in the TTW stage both account for more than 90% of WTW petroleum consumption. Over time, the WTW petroleum consumption is gradually decreasing, primarily due to the improvement in fuel economy for all the powertrain technologies. For example, ICEV in 2030 would consume 2180 kJ/km, 25% lower than that of 2010 (2910 kJ/km). Naturally, the WTW petroleum consumption of a BEV is almost zero (~20-30 kJ/km). This is because the BEV completely relies on electric power during vehicle operation and China's upstream oil-fired electric power is negligible. Although PHEV50's energy supply is heavily reliant on traditional gasoline in the vehicle operation stage, its oil reduction potential is still very high. In this study, WTW petroleum consumption for PHEV50 is nearly 50% lower than that of a gasoline car. It should be noted that the reduction in WTW petroleum usage for the PHEV is closely related to the size of the battery. Elgowainy et al. (2010) pointed out that the WTW petroleum energy reduction ratio would increase when the AER values become higher (i.e. through a larger battery). For example, an AER value of 16 km compared to an AER of 64 km in their case would show a reduction in WTW petroleum use for a PHEV versus an ICEV from ~40% to ~60%. An HEV could also achieve a considerable reduction in petroleum consumption relative to its ICEV counterpart. In this study the reduction is 29%. To reduce the dependence on foreign oil, promotion of these three technologies, especially plug-in hybrids and pure electric vehicles will be of great significance.

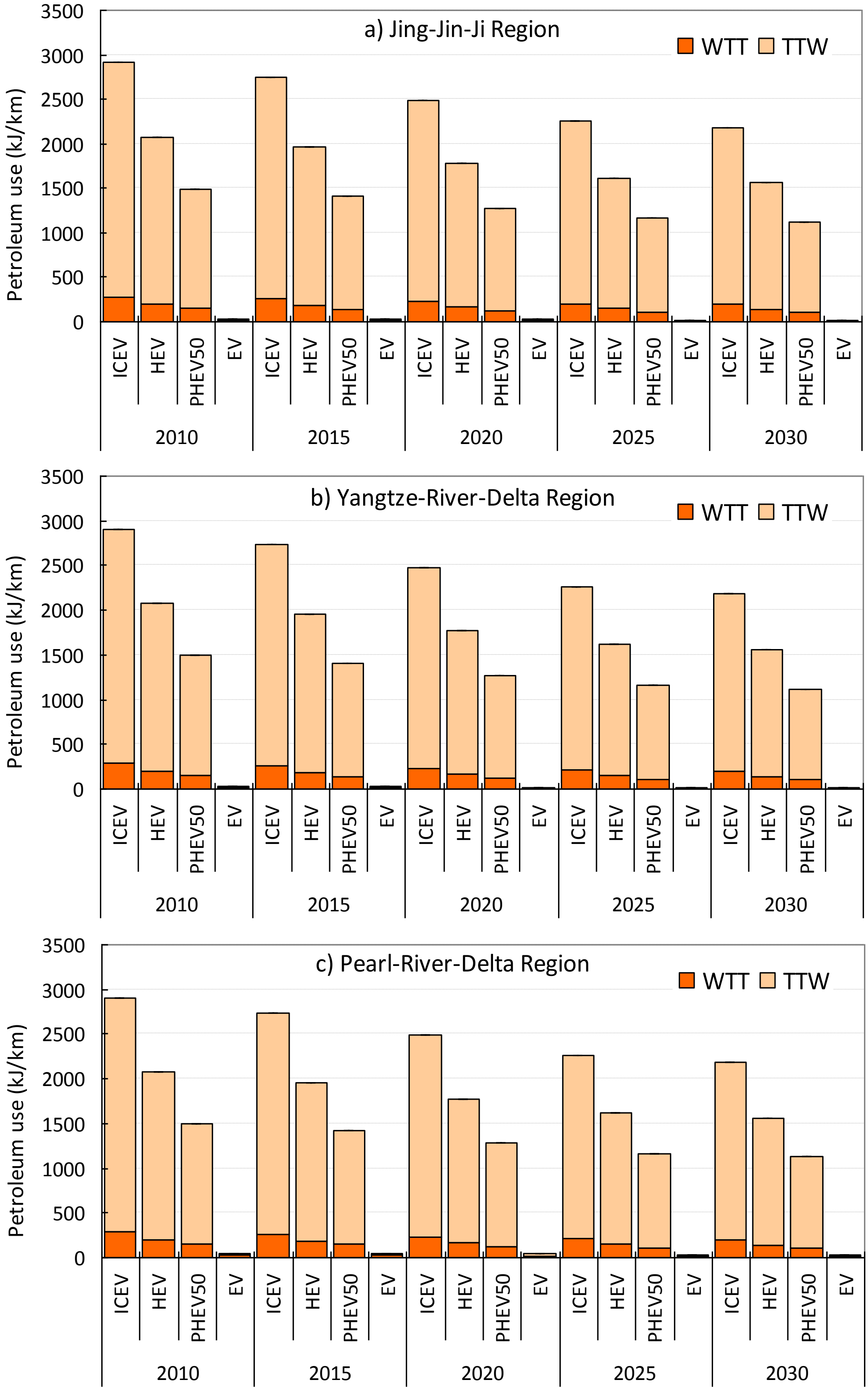

Figure 21:

WTW petroleum consumption of HEV, PHEV and BEV relative to ICEV in:

a) Jing-Jin-Ji region,

b) Yangtze-River-Delta region, and

c) Pearl-River-Delta region, 2010-2030

5.4.2 WTW CO_2 Emissions

Figure 22 presents the per-kilometre WTW results in CO_2 emissions for HEV, PHEV50, and BEV relative to their ICEV counterpart for each of the three regions over the period from 2010 to 2030. CO_2 emissions are primarily from fossil fuel (i.e. coal, petroleum and natural gas) combustion. The WTW CO_2 emissions of all the four vehicle technologies will continue to decrease over the next two decades with the improvement in fuel economy, the increase of upstream power generation efficiency and the contribution of clean electricity. In this chart, the line superimposed over each bar represents the WTW uncertainty range for PHEV50 and BEV options during the period from 2015 to 2030 due to the two different scenarios for electricity generation mix mentioned above. The conservative scenario assumes that the share of coal power among the total generation mix will remain at high levels in the upcoming two decades, while the other one predicts a more progressive penetration of clean energy (such as wind, nuclear, NG power, etc.). The bar represents the average of two scenarios' results.

Similar to the petroleum use, the HEV could achieve a considerable reduction of 29% in WTW CO_2 emissions compared to the ICEV. However, a different story was found for PHEV and EV. First, coal power plants in the WTT stage burn a large amount of coal. Second, coal has the highest carbon content per unit of energy generation among the three fossil fuels (coal, petroleum and natural gas). Taking into account these two factors, the WTW CO_2 emission reduction benefits from promoting PHEV and BEV will be much less than the potential petroleum reduction. This is especially true for the Jing-Jin-Ji region with its high share of coal power. Currently, the WTW CO_2 emissions of EV in the Jing-Jin-Ji region could not show any greater reduction than an ICEV. In the Yangtze-River-Delta region, the reduction rate for both PHEV50 and BEV with about 10% is also small. PHEV50 and BEV can achieve a significant reduction benefit of 20% and 33% compared to their ICEV counterpart in 2010 in the Pearl-River-Delta region.

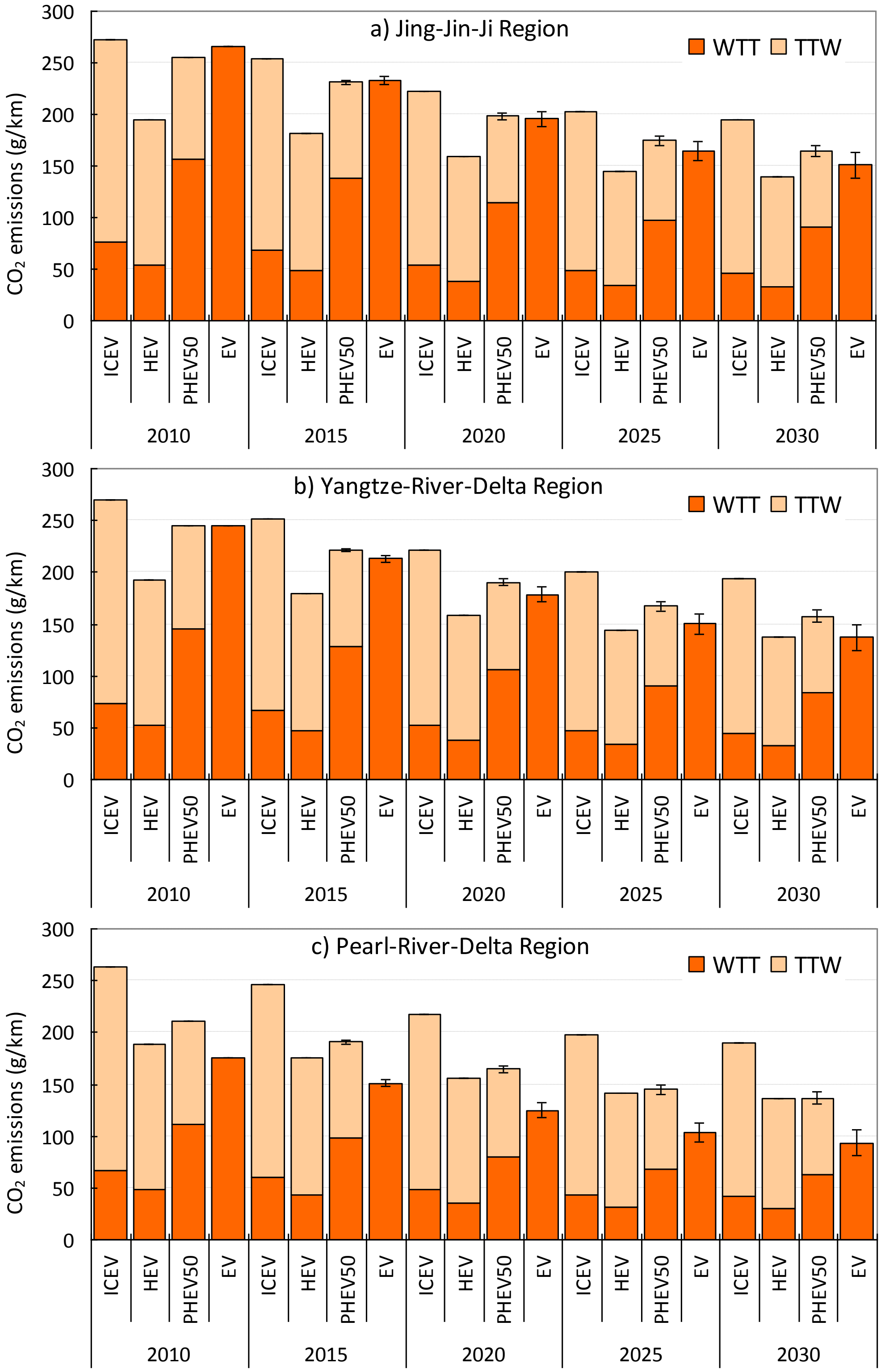

Figure 22:

WTW CO_2 emissions of HEV, PHEV and BEV relative to ICEV in

a) Jing-Jin-Ji region,

b) Yangtze-River-Delta region, and

c) Pearl-River-Delta region, 2010-2030

With the improvement of upstream coal power generation efficiency and the rising share of cleaner electricity, PHEV and BEV show more rapid decreases in WTW CO_2 emissions over time than ICEV. If more clean power is promoted for these three regions with the progressive scenario in the power generation mix as well as improvement in electricity generation efficiency for coal power plants, by 2030 EV in Jing-Jin-Ji region, Yangtze-River-Delta region and Pearl-River-Delta region could cut WTW CO_2 emissions by 27%, 34% and 56%, respectively, compared to ICEV. If the authors only take into account the improvement in the electricity generation efficiency for coal power plants and assume the share of coal power to the total generation mix will still remain high (conservative scenario in the power generation mix) by 2030, the reduction rates would be narrowed to 15%, 22% and 43% for these three regions, respectively. Therefore, to substantially reduce CO_2 emissions, the promotion of PHEV and BEV in China should be combined with much cleaner electricity energy and/or the use of carbon capture and storage (CCS) to lower upstream CO_2 emissions from coal-fired power plants.

In most cases, the HEV is a better solution than the PHEV and BEV to mitigate WTW CO_2 emissions in all three regions (especially in the Jing-Jin-Ji region) in the short-term. Experience indicates that the regional generation mix in China will be difficult to change, which means that reducing the share of coal power in any region could be challenging. Thus, over the next two decades, those regions that already have a relatively large percentage of clean electric energy (e.g. Pearl-River-Delta region) will contribute most to the possible relief of the overall CO_2 burden, and this can be achieved with the promotion of PHEV and BEV. In this context, an influential study by Huo et al. (2010) pointed out that regions with smaller percentages of coal-based electricity should be the priority EV markets, such as the Southern China and Central China regions. Huo et al. (2010) further provided the theoretical CO_2 breakeven points between EVs and ICEVs, which are illustrated in Figure 23.

For example, when the energy efficiency of a coal power plant is at 40%, the breakeven point is at an 87% coal power share, which means that EVs would have a CO_2-reduction advantage over gasoline ICEVs if the percentage of coal used is below 87%. The 78-81% coal shares projected by EIA (2007) and IEA (2007) translate to a CO_2 reduction of 10% compared to ICEVs. Under the more progressive projections made by Chinese institutes (65-72%) (Development Research Center of the State Council of China, 2009; Ye, 2004), the CO_2 emissions of EVs are 18-25% lower than the emissions of ICEVs, but 7-18% higher than HEV emissions.

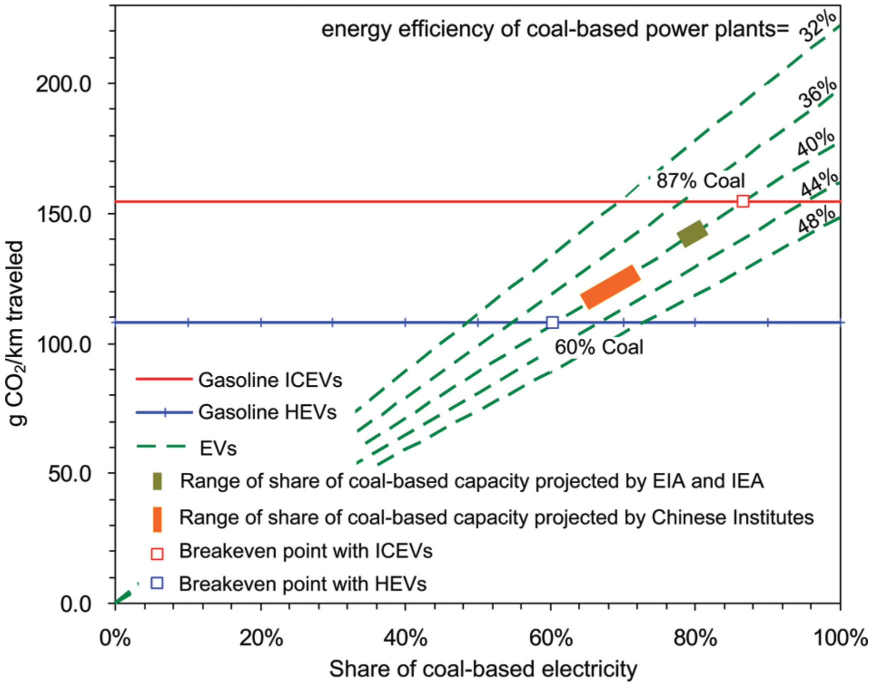

Figure 23:

Future fuel-cycle CO_2 emissions of EVs as a function of the fraction of coal-based electricity (Huo et al., 2010)

6 Outlook

Advanced electric vehicle technologies are promoted in a great effort to help relieve dependence on imported oil, reduce GHG emissions and solve urban air pollution problems in China. According to the most recent development plan for new energy vehicles, China will strongly push the process of vehicle electrification during the next 20 years.

The Sino-German cooperation project Electro-Mobility and Climate Protection in China is a comprehensive program which analyzes the climate and environmental impacts of Electro-Mobility in China. The benchmark report provides an overview of the current status and future prospects of the electrification of China's vehicles, summarizes the results of relevant environmental impact assessments, and propose recommendations for the most promising scenarios for tackling China's climate and environmental issues.

As the next step, the project is going to conduct the following working steps:

1. Material Flow Model
   First of all, the project will set up a Material Flow Model ("the Model") in order to calculate the total GHG emissions and selected environmental impacts of the vehicle fleet in China. As discussed before in this report, emissions from upstream fuel production, vehicle production as well as vehicle operations need to be taken into consideration in order to assess emission effects of different vehicles and fuel systems. Therefore, the Model will include the following aspects:
   - Prospection of the vehicle fleet in China
   - Prospection of the electric vehicle fleet in China
   - Prospection of transport activities in China
   - Prospection of future electricity supply (by primary energy source and region) in China
   - Prospection of the development of fuel economy of ICE vehicles
   - Prospection of the energy efficiency of electric vehicles
   - Prospection of energy demand and emissions for transport applications over the whole life cycle (production of fuel, production of vehicles, use of vehicles)

   During the elaboration of the Model, the following issues play an important role:

   - System boundary parameter:
     a. Geographic scope: Focus on national level with partial focus on

demonstration cities;

b. Timeframe: From the year 2010 to 2030;

c. Energy sources: Electricity and petroleum;

d. Emissions: Critical air pollutants ($PM_{10/2.5}$, SO_2, NO_x, O_3)

– Energy consumption components:

a. Electricity generation

b. Vehicle operation

c. Vehicle production and recycling.

2. Elaboration of scenarios

The second part deals with the design of a baseline scenario in order to describe the business as usual (BAU) scenario for China. Moreover, the project team will design two alternative scenarios, which include more ambitious emission reduction measures.

The design of EV penetration scenarios on national level seriously depends on, inter alia, the development plans of relevant authorities (since the EV market still needs promotional incentives) and input from other stakeholder groups (e.g. the auto industry). Therefore, there will be a series of stakeholder workshops during the project implementation phase.

3. Assessment of different environmental impacts

After the design and calculation of the scenarios, the project team will assess the environmental impacts for the different scenarios on national level and on the level of selected pilot cities.

4. Policy recommendations

Building on the comprehensive assessment and results of the different scenarios, the project team will provide a proposal for policy recommendations on how electro-mobility in China can be introduced to contribute best to climate and environmental protection. The policy recommendations shall be distinguished for different decision makers like national ministries, provincial and local governments and enterprises.

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