Overview of Existing Research Activities of Energy and Environmental Impact Assessment of Electric Vehicles in China

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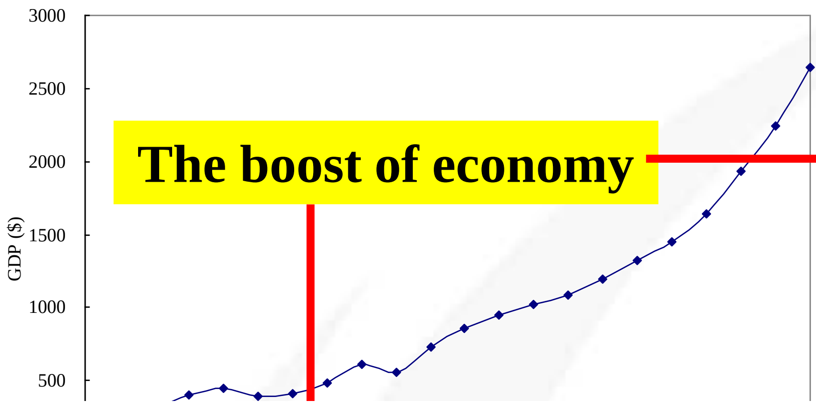
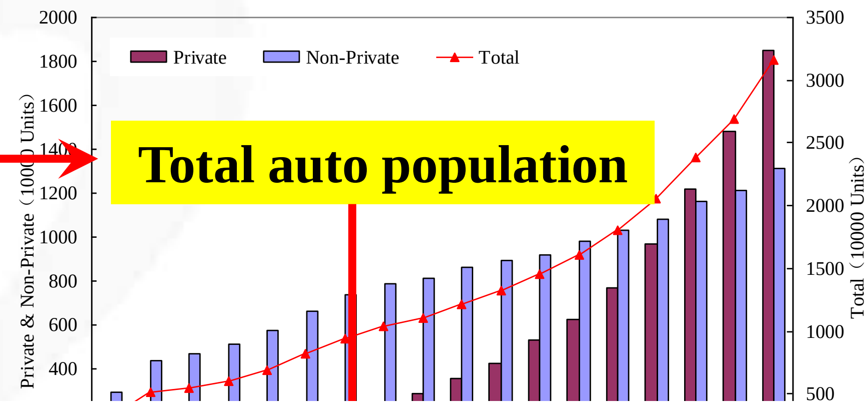
Outline

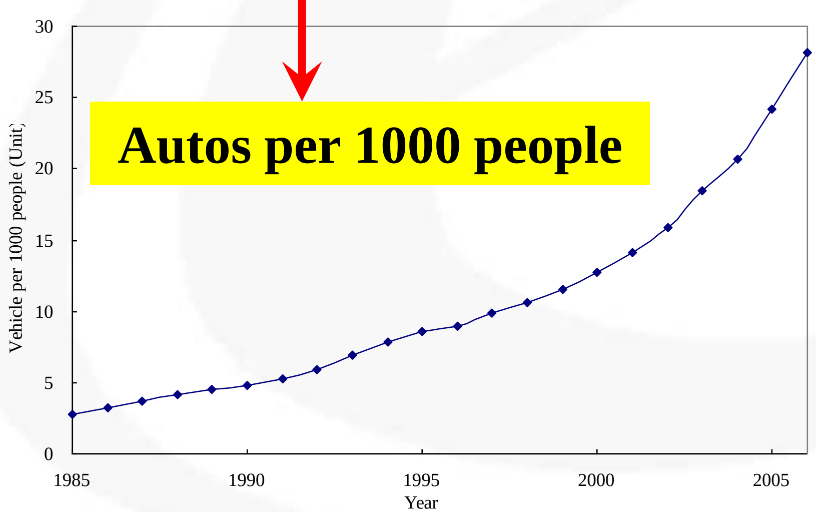
- Background: the challenges we are facing
- Projection of growth in vehicle fleet
- Projection of oil consumption and CO_2 emissions
- Projection of the energy and climate impacts of EVs in China

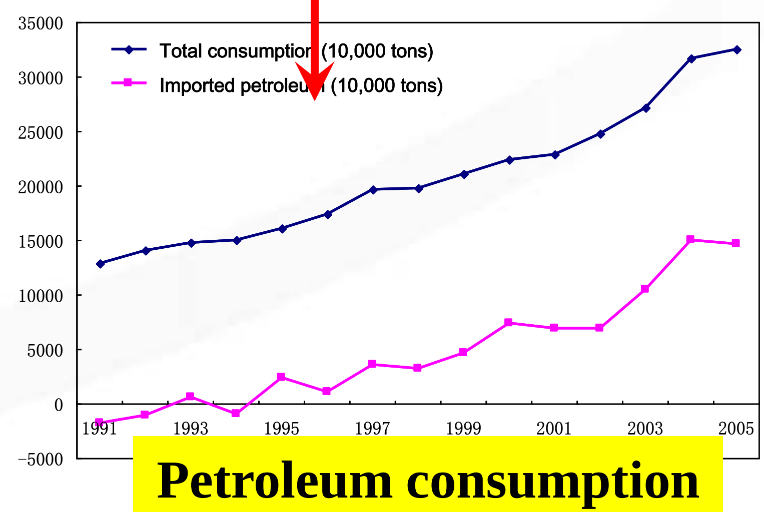
Background



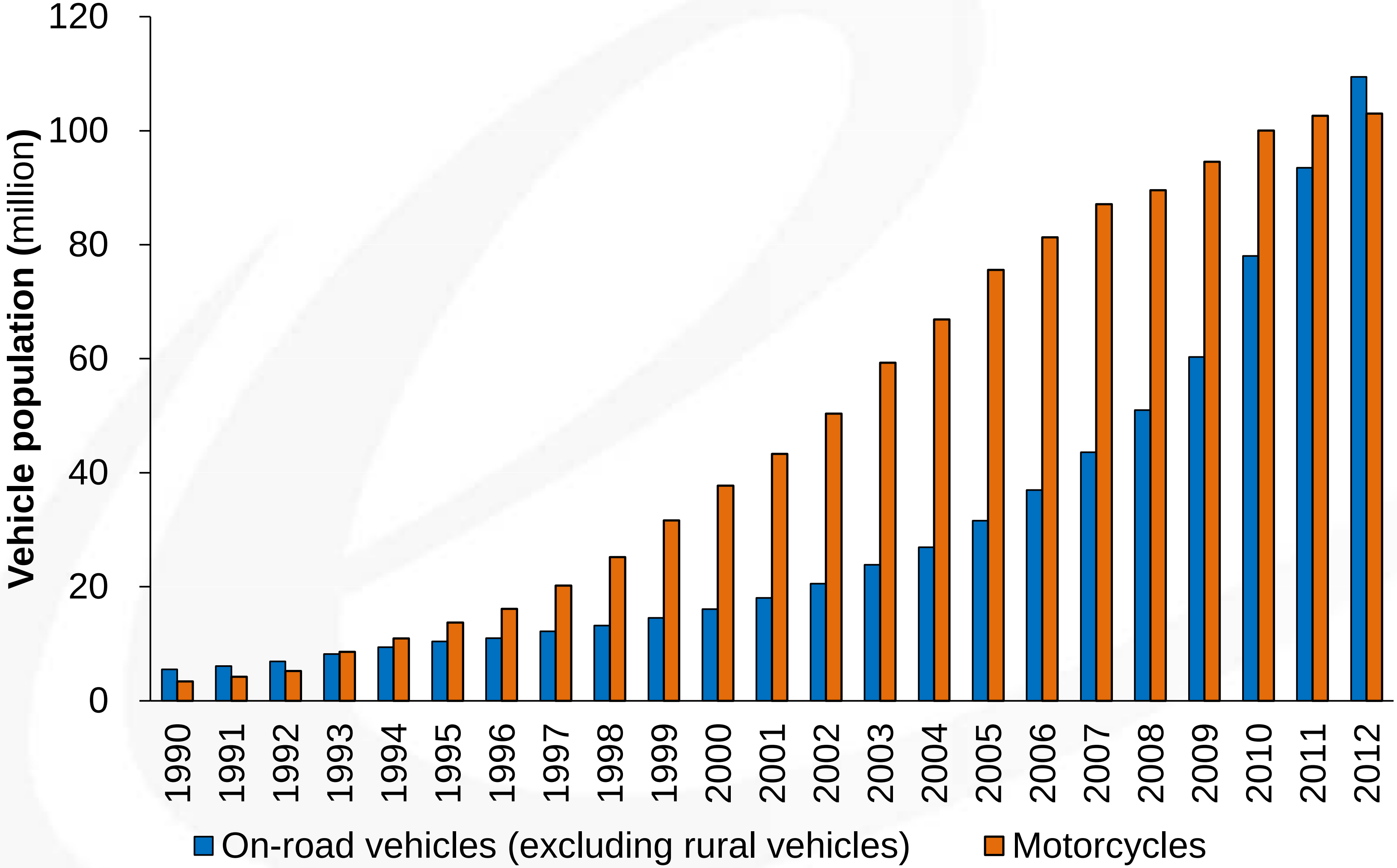


The rapid increase in vehicle population in China has been severely taxing the energy and material resources, and also posing a challenge to the mitigation of CO_2 and urban criteria air pollutants.





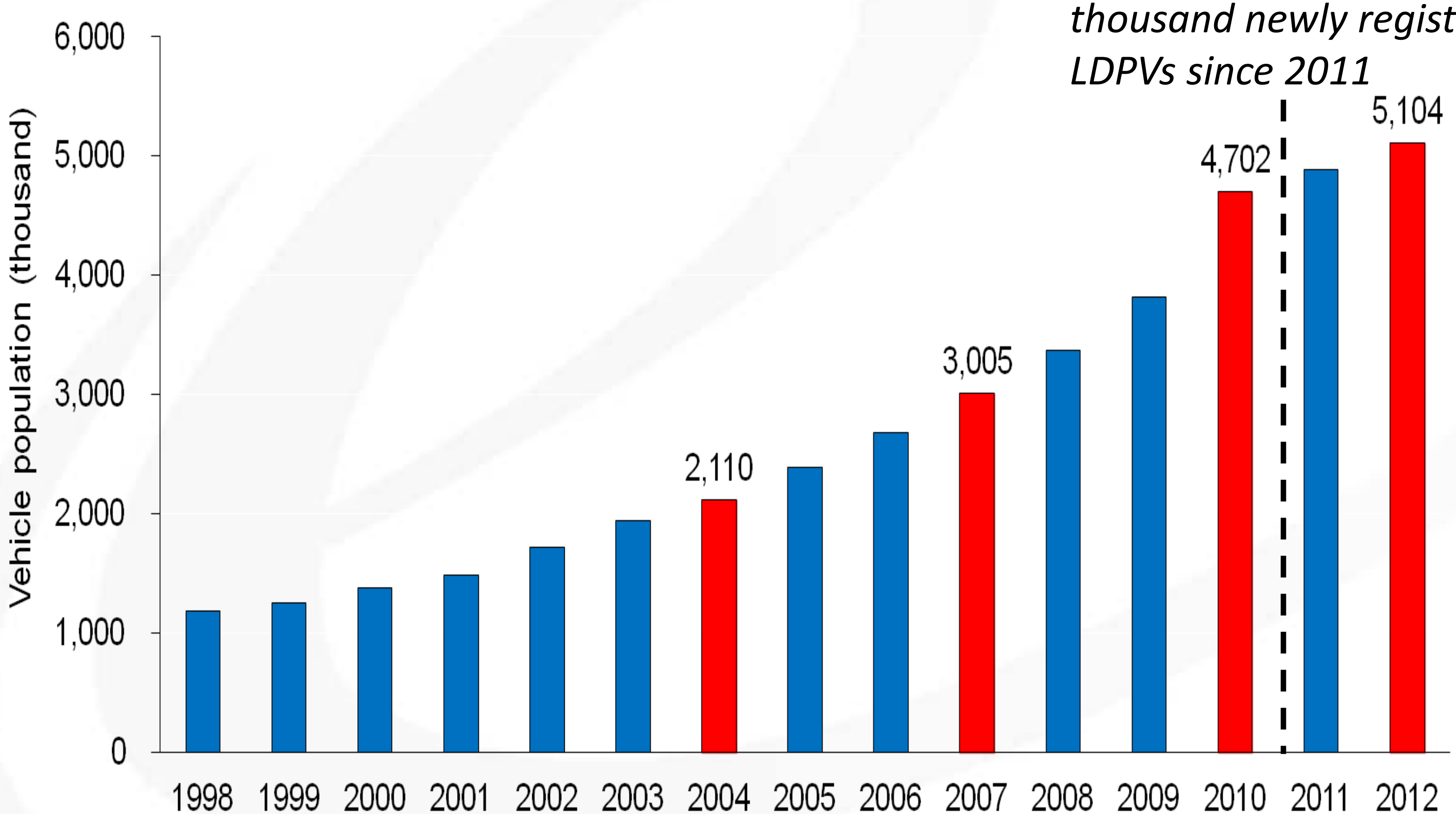
Historical trends in China's total vehicle population, 1990-2012



Source: NBS, 2012.

Historical trends in Beijing's total vehicle population, 1990-2012

"License control policy": *an annual quota of 240 thousand newly registered LDPVs since 2011*



Note: Rural vehicles and other specific vehicles are not included in this figure.

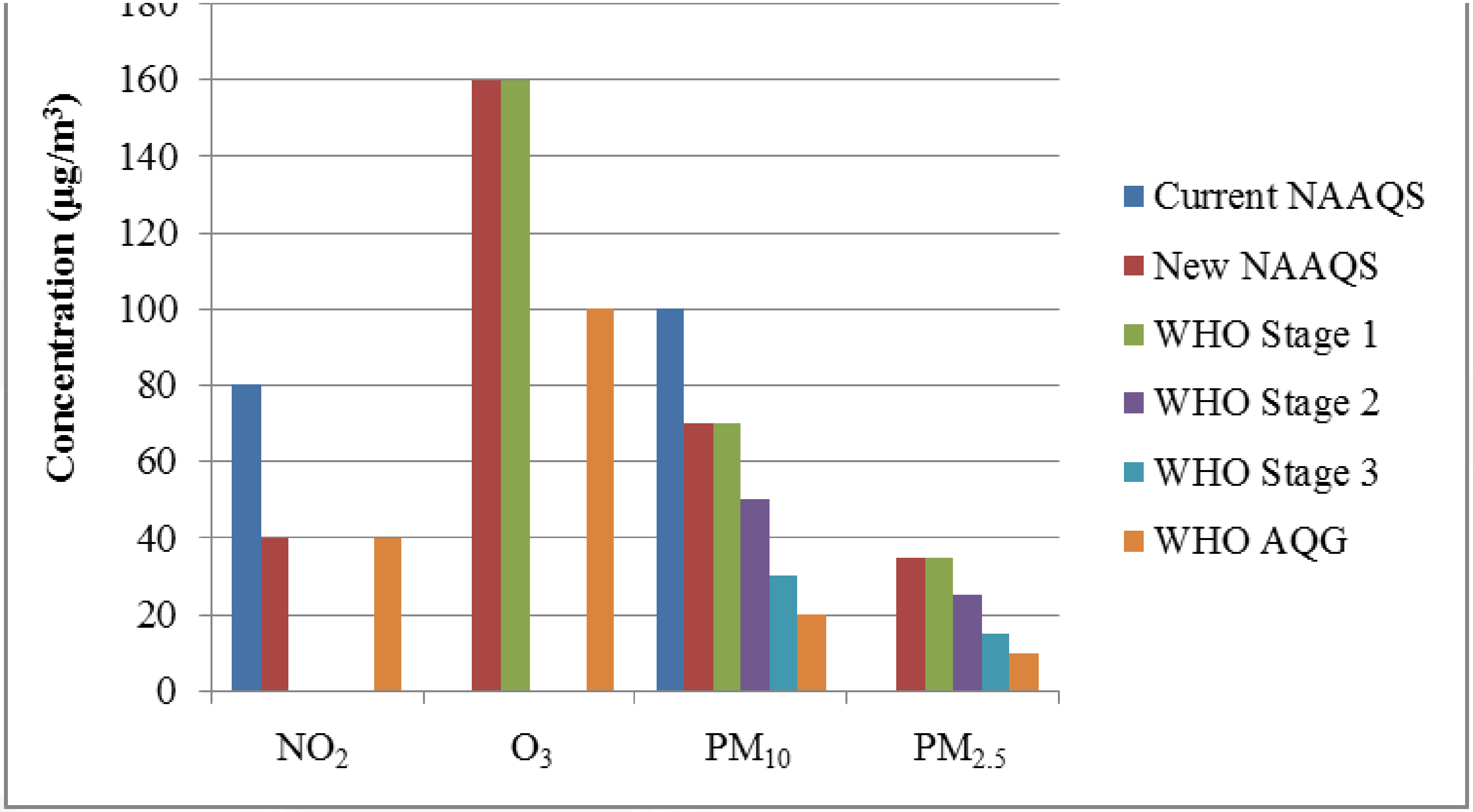
Source: BMSB, 2012.

The challenges we are facing

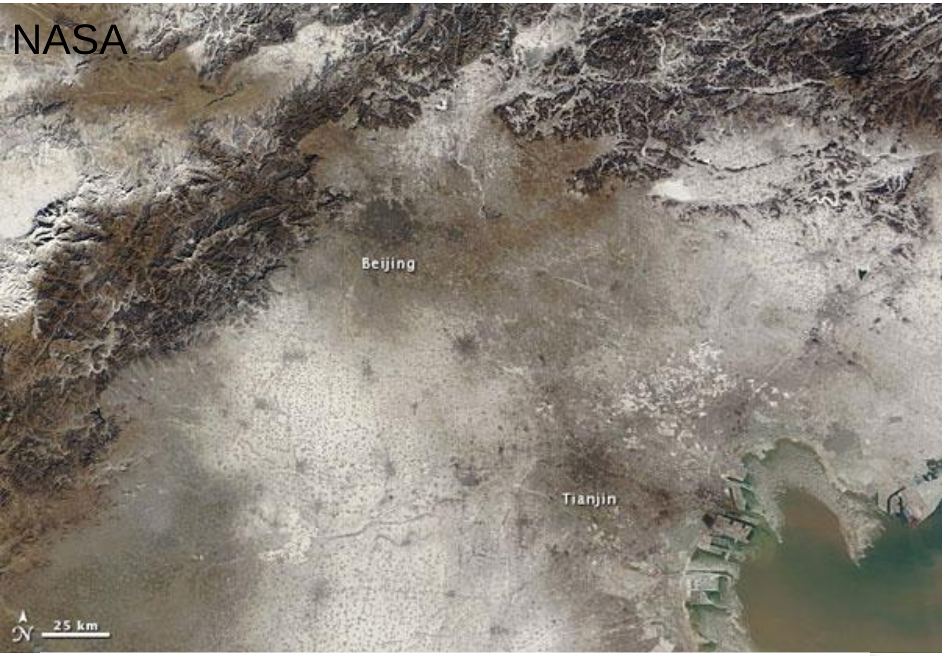
- Short of crude oil resources and energy safety issue
  - Dependence in imported oil: NOW IS 57%
  - Fuel economy: 6.9 L/100 km by 2015 and 5.0 L/100 km by 2020
- Climate change and global warming
  - CO_2
  - CH_4 and N_2O
  - BC…
- Urban air pollution and urban mobility and sustainability
  - CO, HC, NO_X: total NO_X emissions cut by 10% by 2015
  - PM_{10}/$PM_{2.5}$/PM_1
  - EC/OC
  - PAHS/HCHO…

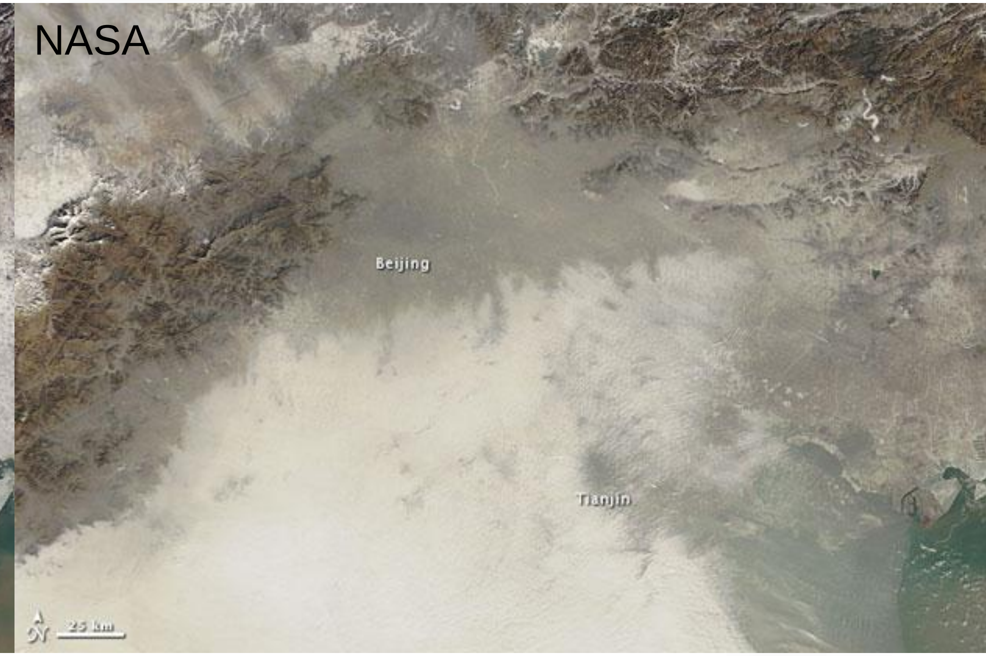
NAAQS is now tightened!!!

The new National Ambient Air Quality Standard tightens NO_2 and PM_{10}, and add two new items: $PM_{2.5}$ and 8-hour O_3. All these three air pollutants have a strong link with vehicles.



$PM_{2.5}$ now becomes a hot topic in China





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中国局部雾霾污染严重 央视《新闻联播》头条聚焦

BBC NEWS CHINA

12 January 2013 Last updated at 08:14 ET

Beijing air pollution soars to hazard level

The New York Times

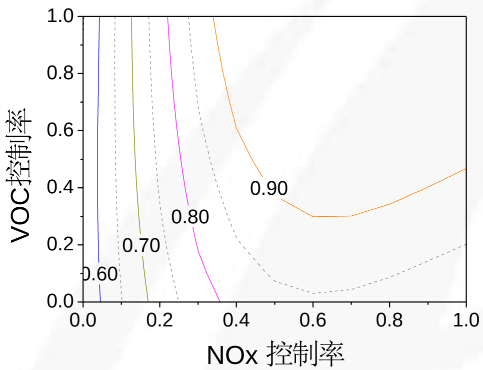
January 12, 2013

On Scale of 0 to 500, Beijing's Air Quality Tops 'Crazy Bad' at 755

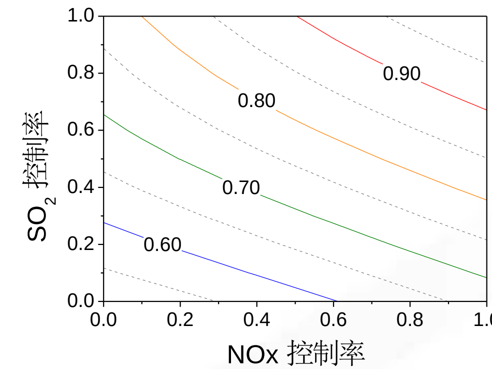
Significant reductions in emissions need to be achieved to comply with new NAAQS

Goal	Concentration（μg/m^3）		
	NO_2	O_3	$PM_{2.5}$
NAAQS II	40	200 (1h)	35
90% achievement	40	236 (1h)	40

O_3 reduction curve



$PM_{2.5}$ reduction curve



Goal	Emission reduction ratio（%）		
	NO_X	$PM_{2.5}$	VOC
NAAQS II	65%	70%	75%
90% achievement (a)	25%	65%	70%
90% achievement (b)	30%	65%	65%

A case study for Yangtze River Delta Region

(base year 2005)

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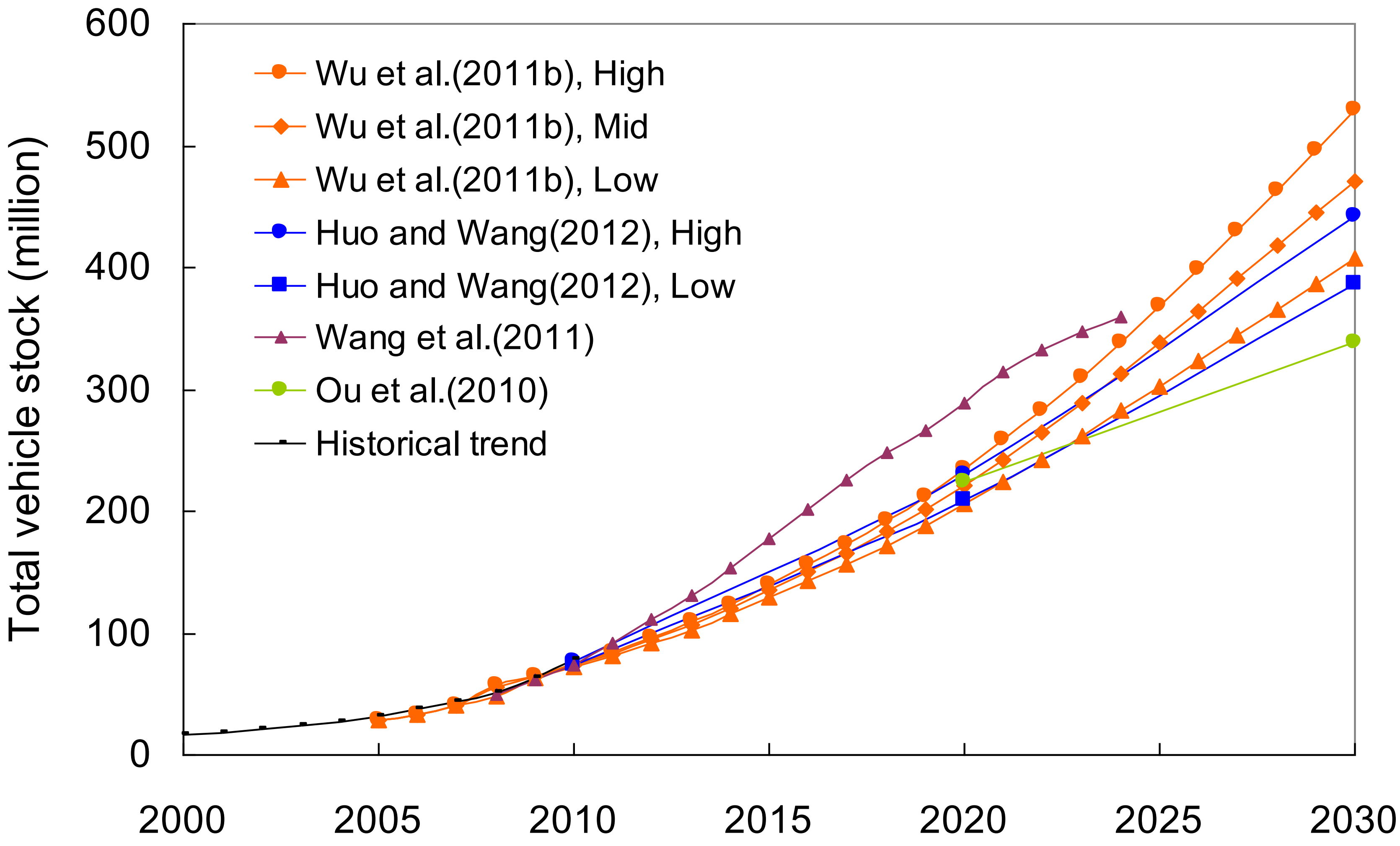
Projection of China’s vehicle stock through 2030

The methodology and key parameters of different researchers

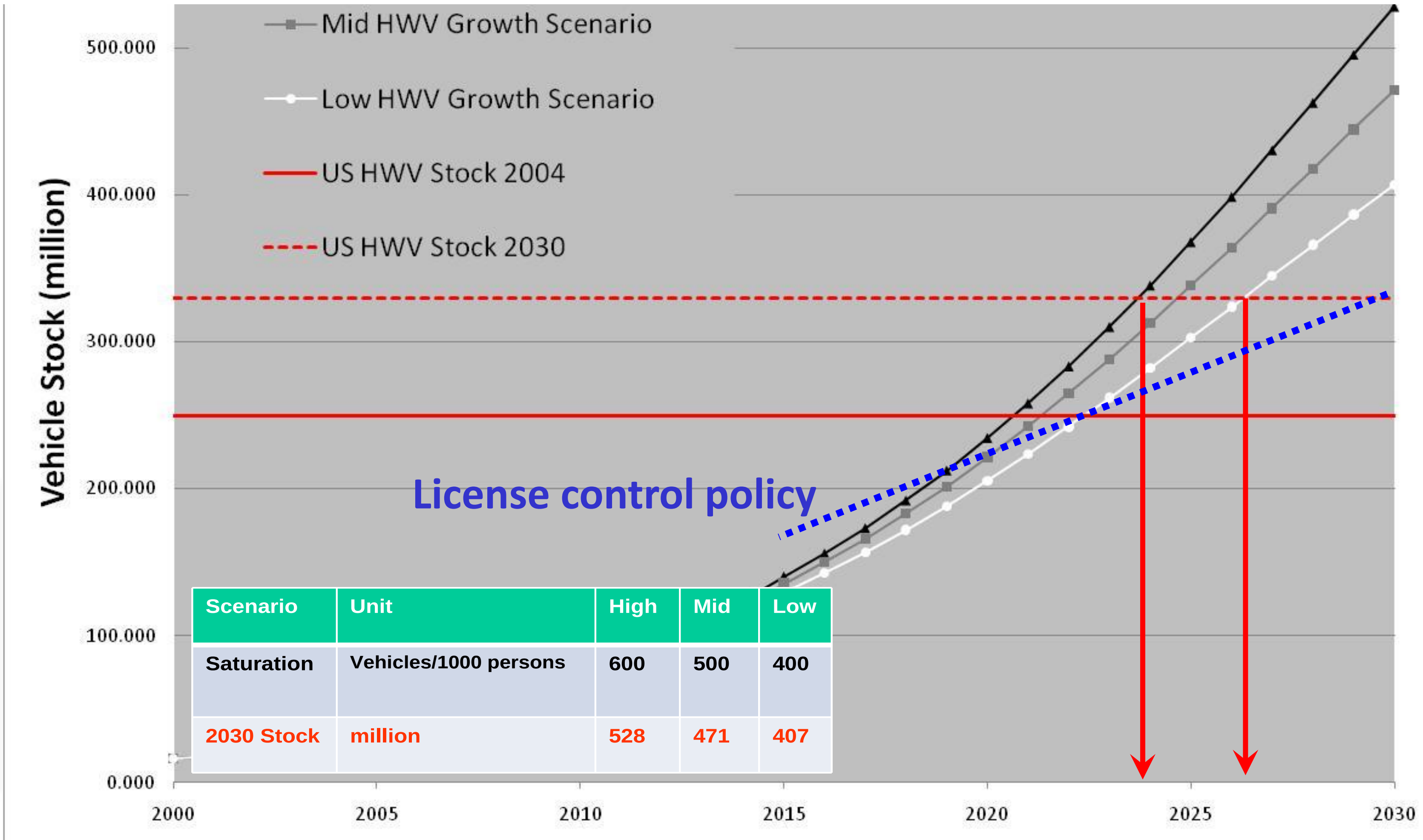
Study	Key Methodology	Saturation level of automobiles per 1000 people	Base Year	Stock in the future/million
Dargay and Gately, 1997	Based on GDP, using Gompertz function	690	1995	597 in 2015
Ou et al., 2010	Using a bottom-up model based on future sales projection of all vehicle types	NA	2007	338 in 2030 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

Projection of China's vehicle stock through 2030



Projection of China's vehicle stock through 2030

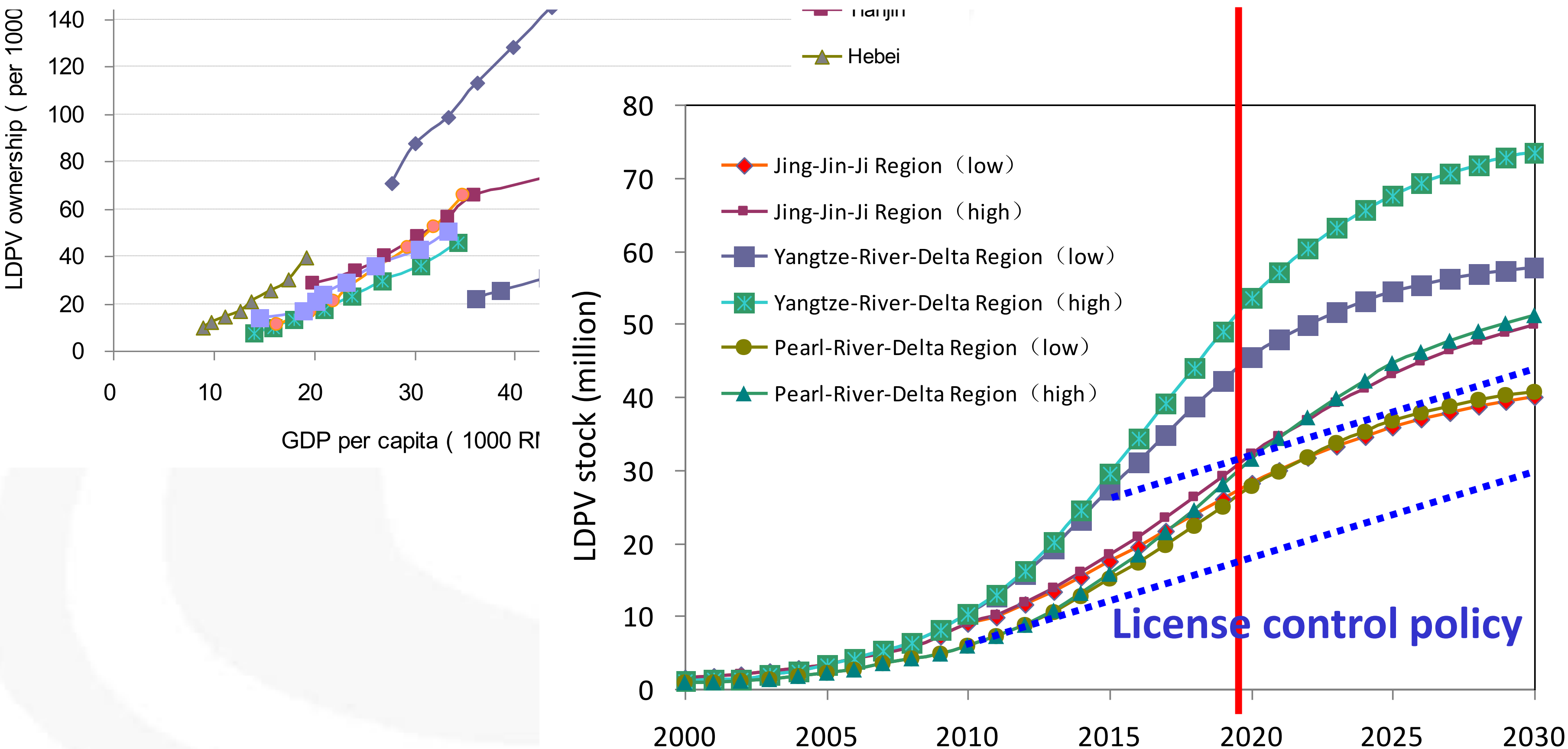
No matter which growth scenario, China will become the leading country in automobile population within the next 15 years.



Scenario	Unit	High	Mid	Low
Saturation	Vehicles/1000 persons	600	500	400
2030 Stock	million	528	471	407

Regional variation in vehicle stock in China needs to pay attention

The fast growth in automobiles in developed regions in China will slow down after 2020. By 2030, the three well-developed regions will be the leading regions to move into the vehicle saturation period.



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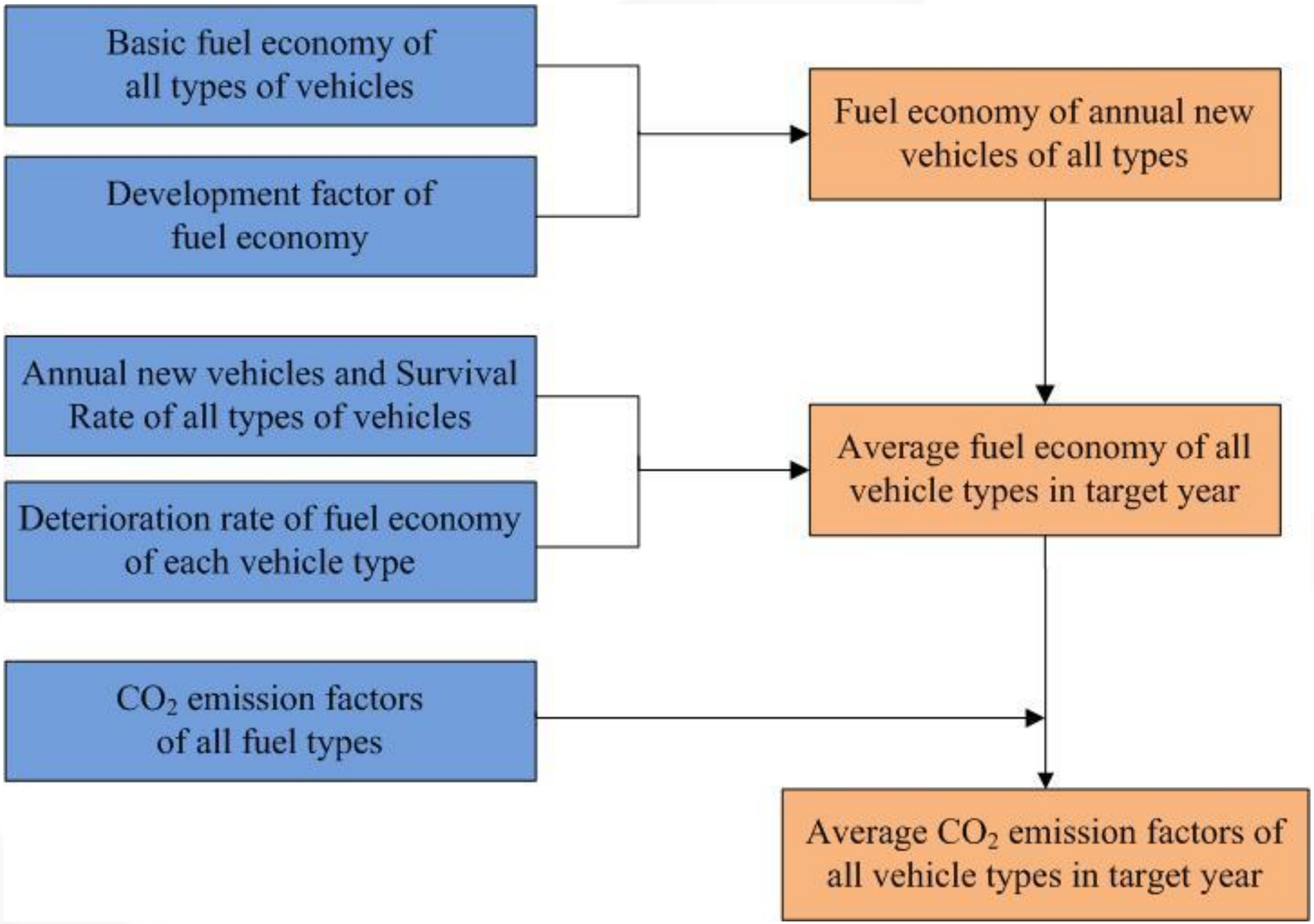
The logistics of oil consumption and CO_2 emission calculation

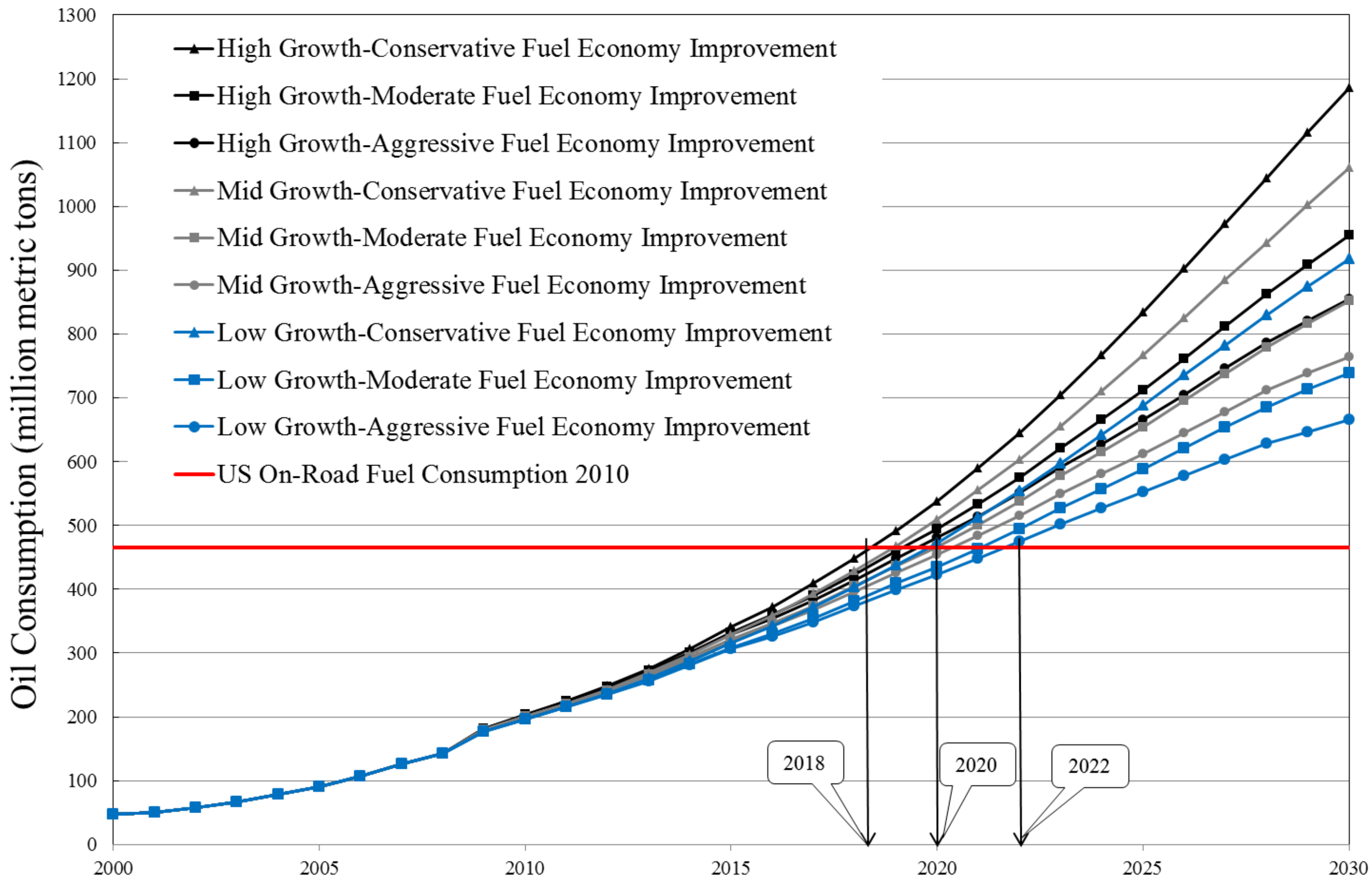


Major data sources of fuel economy estimate

- The implementation of stage I and II fuel economy standards since 2004
  - Wang et al. (2010) reported 8.1 L/100 km in 2006, 12% lower than that in 2002 (9.1 L/100 km)
  - Wagner et al. (2009) and Huo et al. (2011) further reported 7.9 and 7.8 L/100 km in 2009
- The goal of fuel economy for future
  - 2015: 6.9 L/100 km
  - 2020: 5.0 L/100 km
- U.S. National Academy of Science (NAS) scenarios and other data sources are taken into account for future fuel economy in China
- Adjustment of on-road fuel economy vs. lab-tested fuel economy needs to be considered (~15% higher on road)

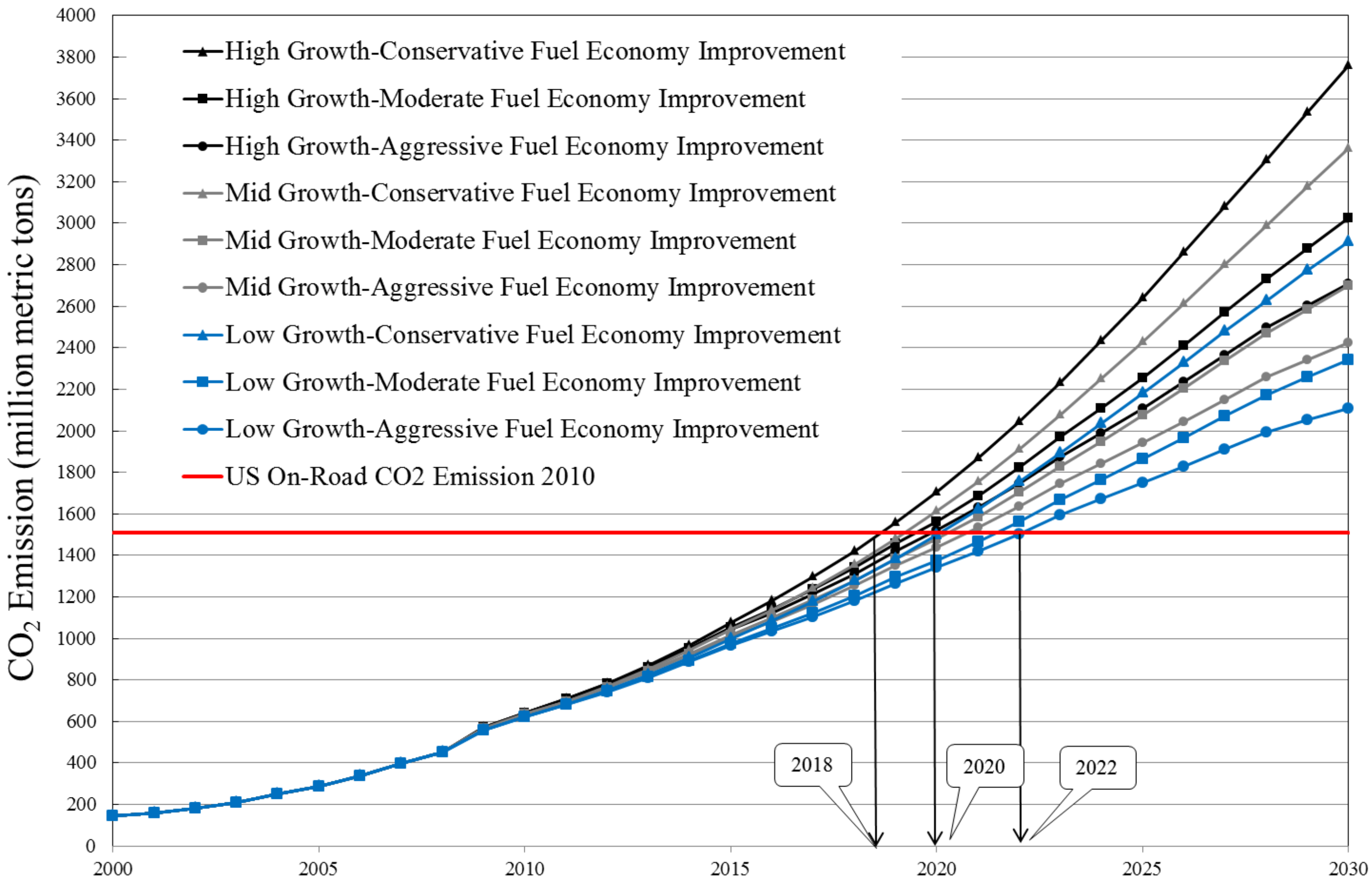
Projection of oil consumption in China, 2010-2030

Without penetration of advanced propulsion/fuel systems, oil consumption might reach as high as 0.67-1.19 billion tons, and trigger a much higher dependence with imported oil !



Projection of CO_2 Emissions through 2030

Without penetration of advanced propulsion/fuel systems, CO_2 emissions might reach as high as 2.11-3.76 billion tons, about 7.4-13.1 times of 2005's data ！



Comparison of oil demand and CO_2 emissions for on-road vehicles by different researchers

The differences in these results are primarily due to the variance in selection of key parameters such as vehicle growth rates, fuel economy, dieselization rates, and so on!

The oil demand and CO_2 emissions of different researchers

Study	Oil demand/ million metric tons		CO_2 emissions/ million metric tons		Base year
	2030	2050	2030	2050	
Huo et al.,2011	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

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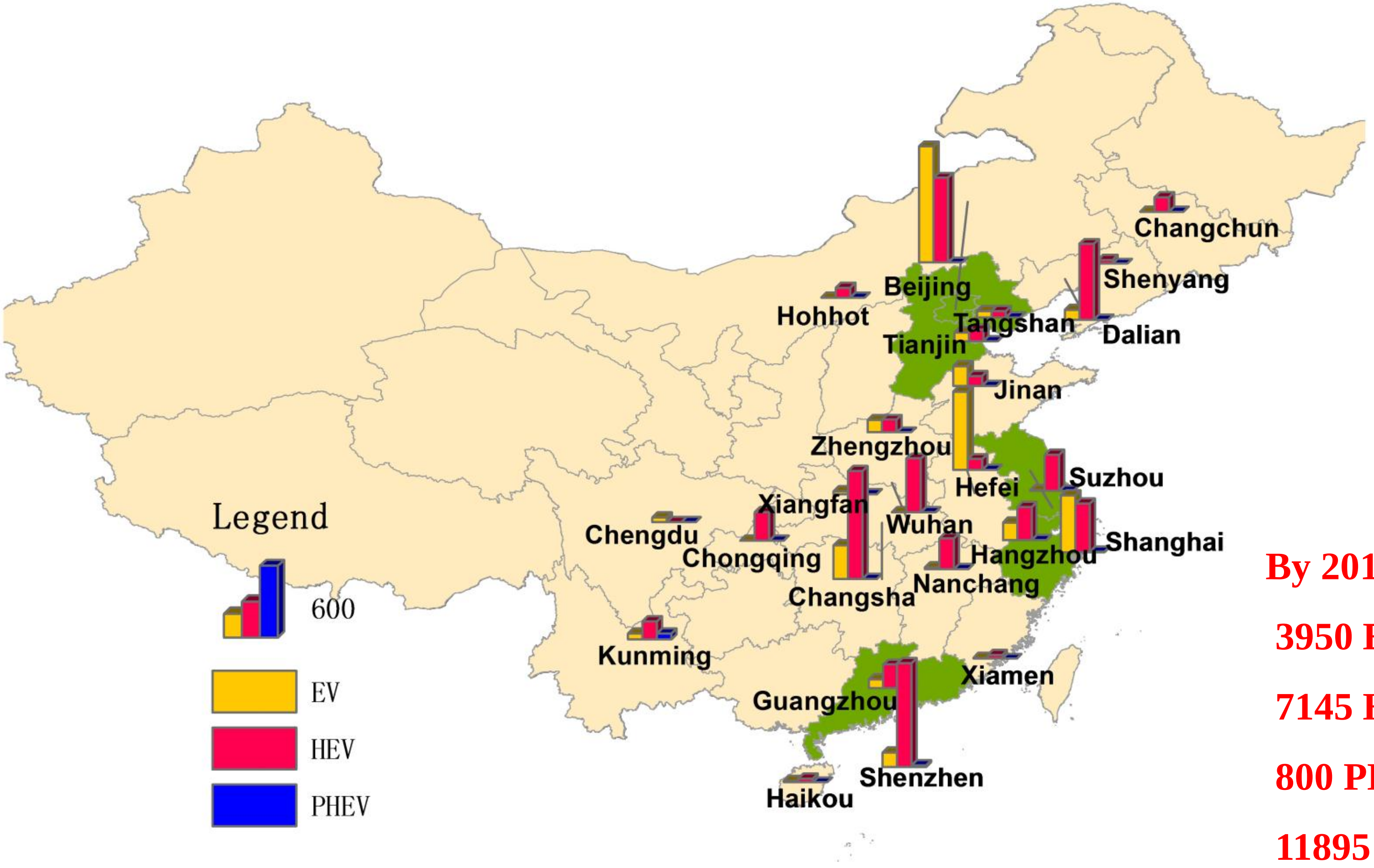
HEV/PHEV/EV demonstration in China



By 2010, 25 cities:

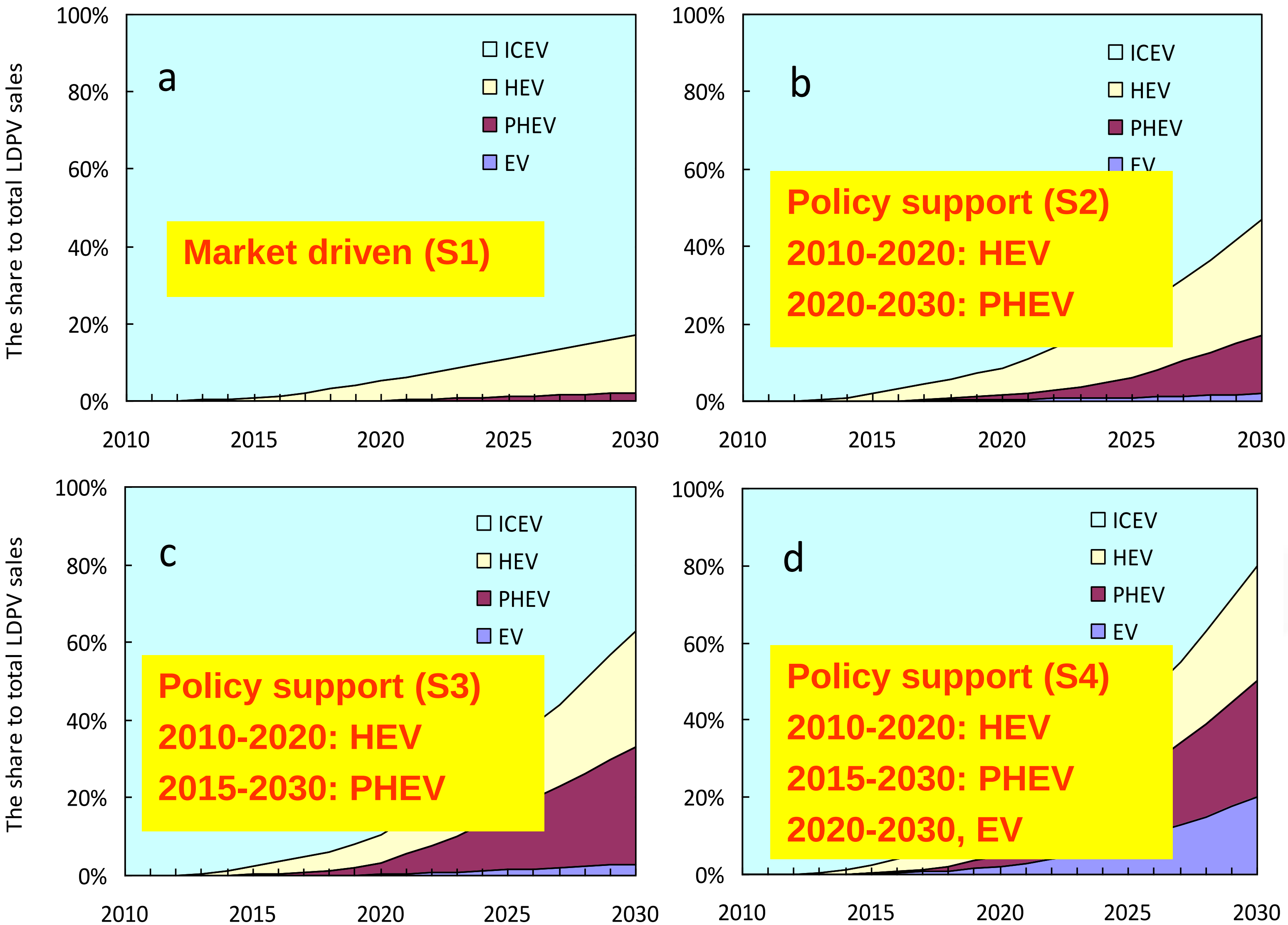
3950 EVs,

7145 HEVs

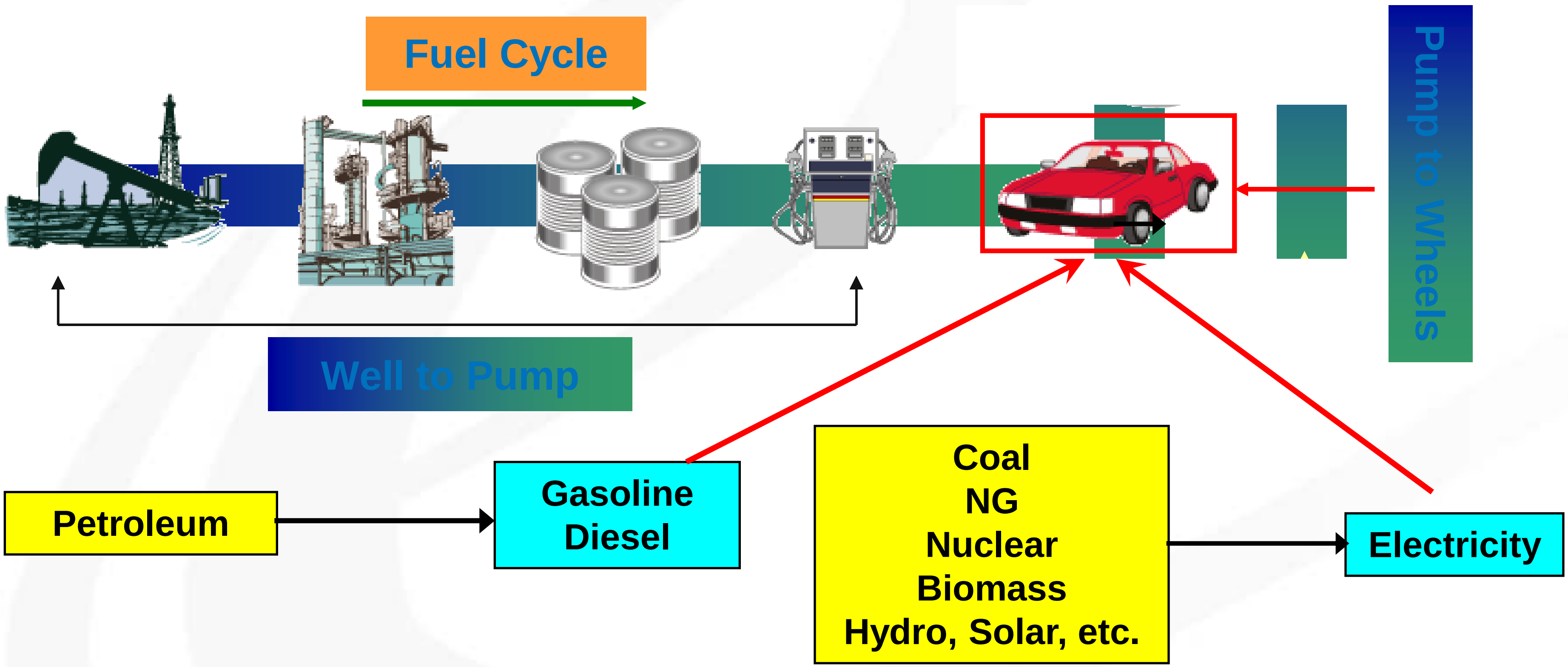
800 PHEVs

11895 in Total

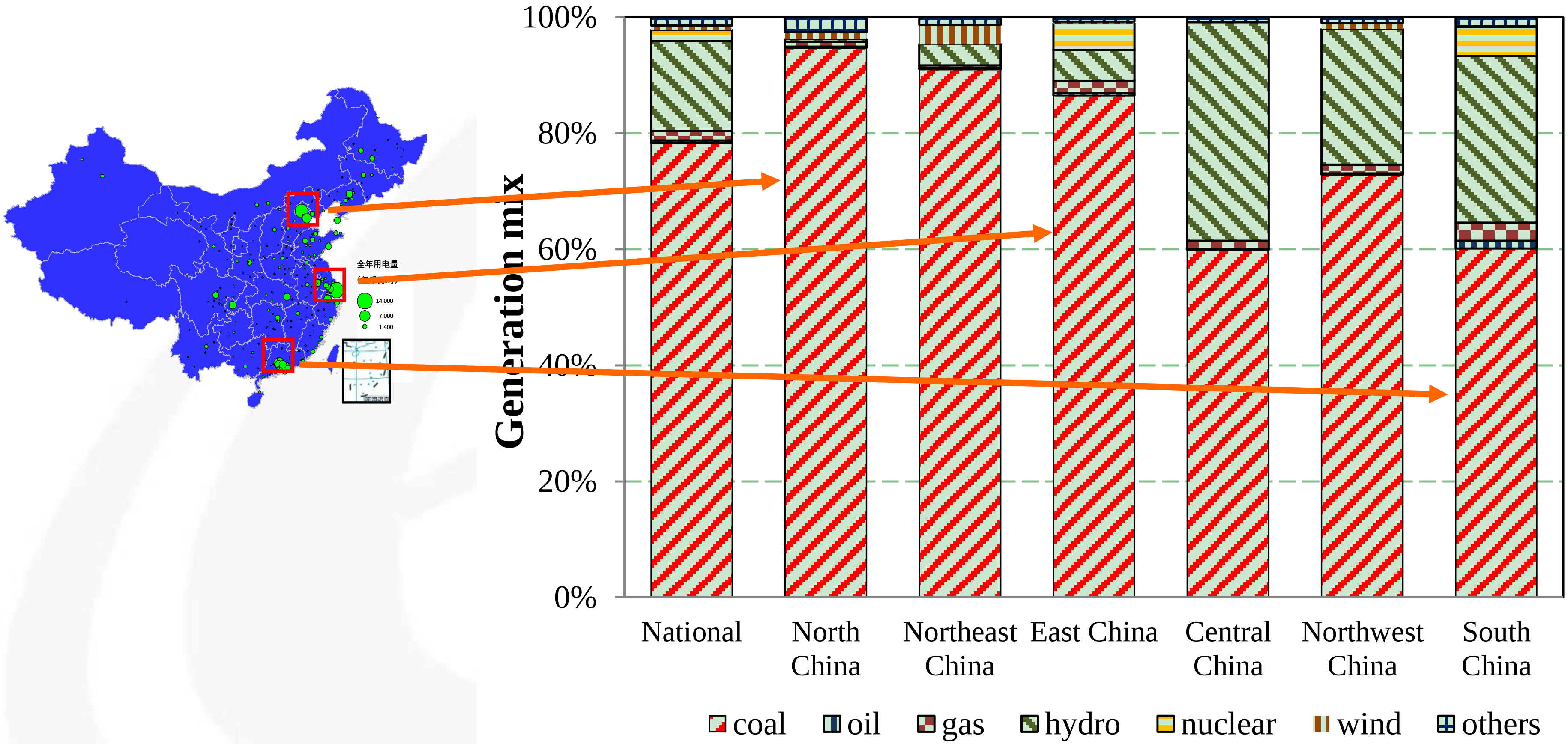
Penetration of HEV/PHEV/EV to auto market could be totally different



The boundary of LCA analysis for electric vehicles

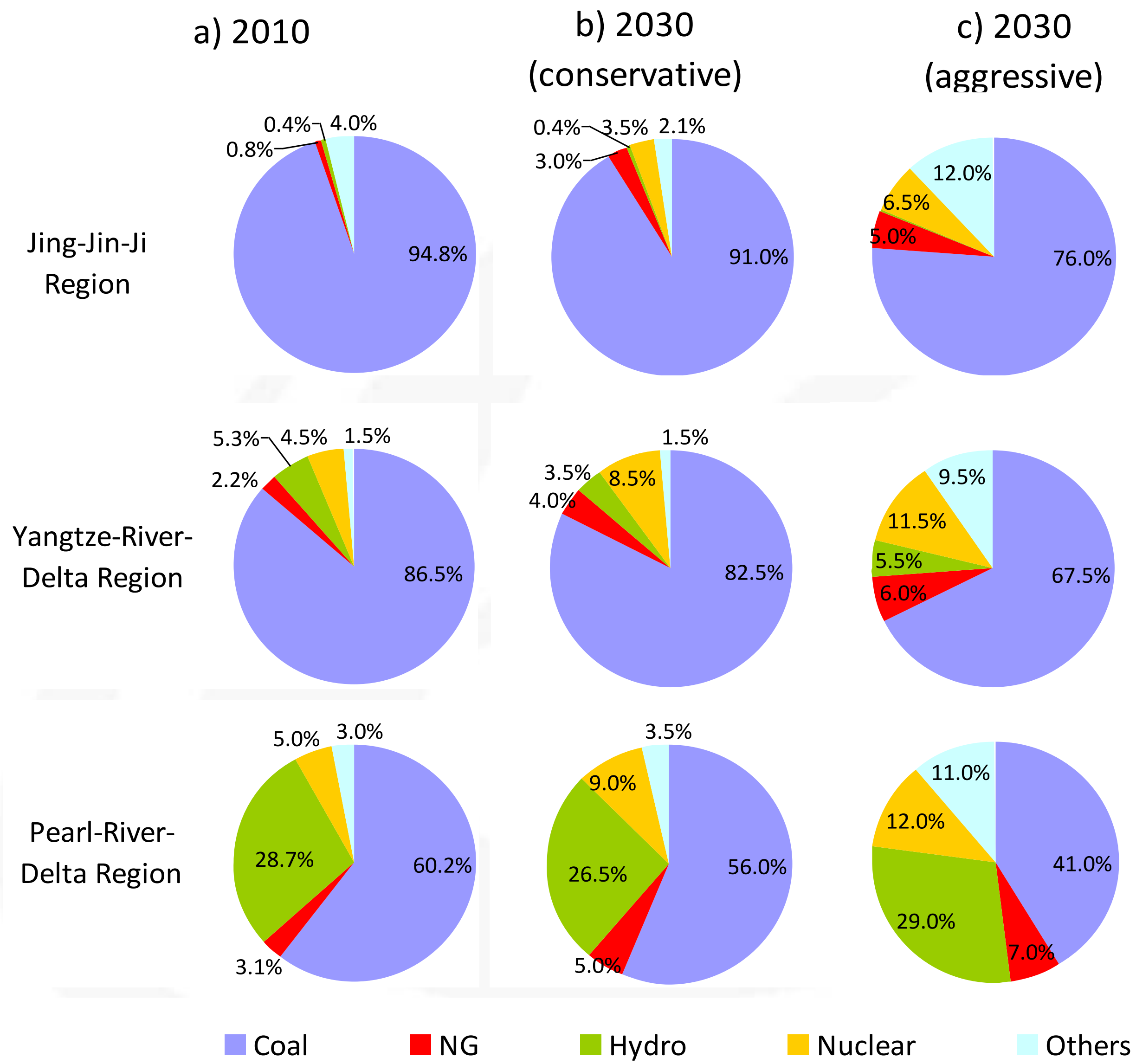


Electricity generation mix in China in 2009



Source: China Energy Statistical Yearbook (2009)

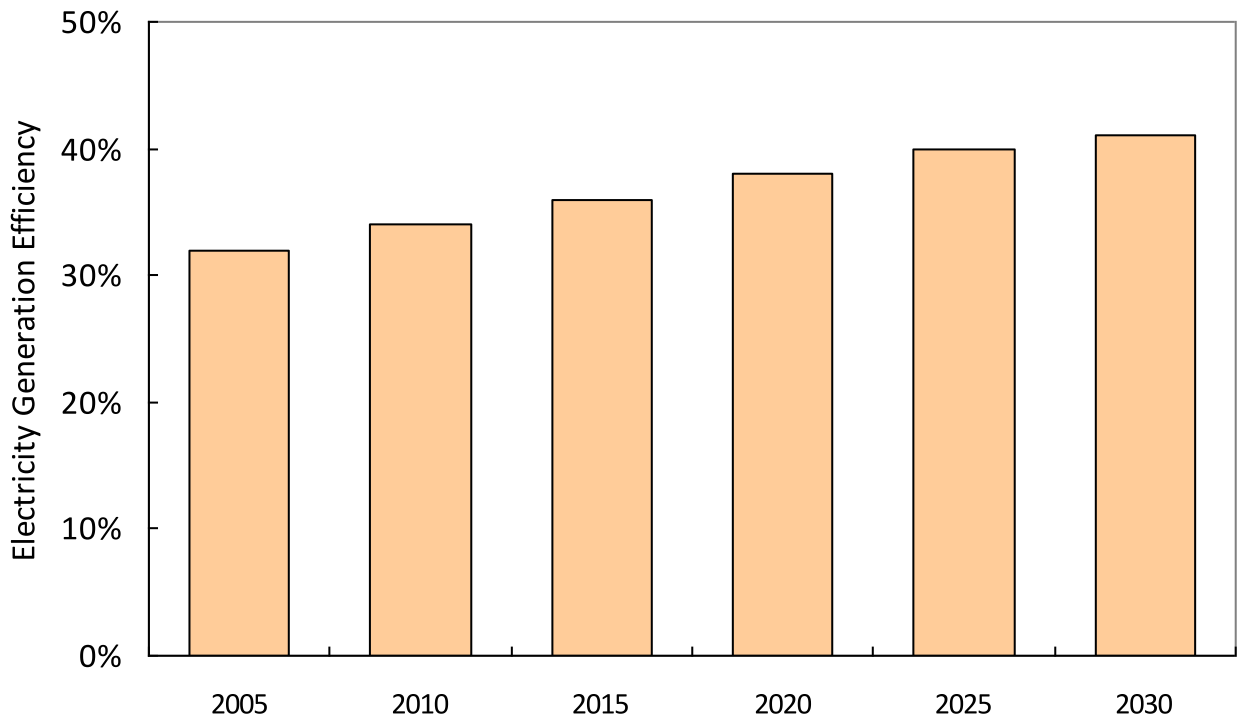
Electricity generation mix forecast by region in 2030



Data Sources:

1) International Energy Agency (IEA)
2) Chinese Academy of Engineering (CAE)
3) Energy Research Institute (ERI)
4) China Electric Power Research Institute (CEPRI)
5) …

Forecast of generation efficiency of coal power, 2010-2030



Data Sources:

1) 2010's data (34%): China Energy Statistical Yearbook

2) Generation efficiency for supercritical (39%), ultra supercritical (42%) and IGCC (47%): IEA, ANL, local test data, etc.

3) The forecast of capacity of each major technology: IEA, CAE, ERI, CEPRI, etc.

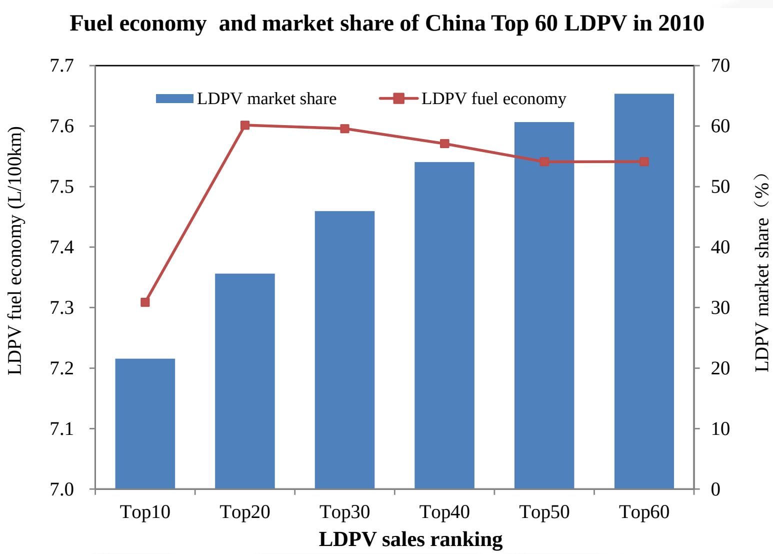
CO_2 emission factors from power plants will continue to decrease in China

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

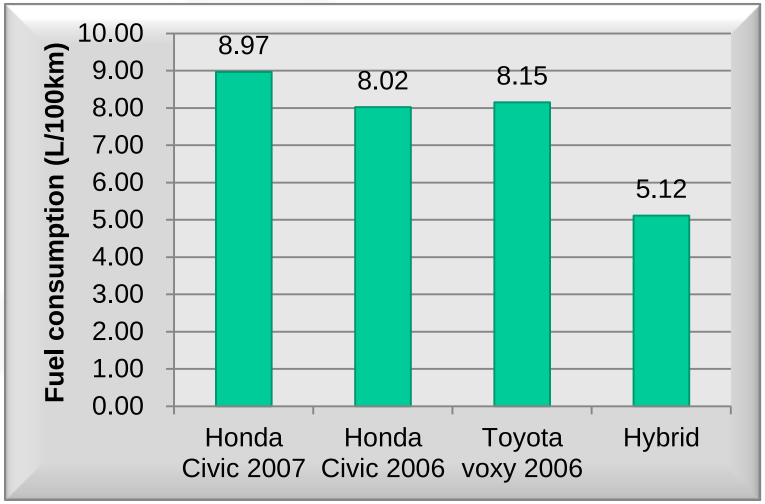
CO_2 Emission Factors (g/kWh)	2010	2015	2020	2025	2030
	Conservative generation mix scenario				
National	790	740	690	650	630
Jing-Jin-Ji Region	950	890	840	790	760
Yangtze-River-Delta Region	870	810	760	710	670
Pearl-River-Delta Region	610	560	520	490	470
	Aggressive generation mix scenario				
National	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

Fuel economy of ICEV, HEV, PHEV and EV

LDPV (lab-test fuel economy)



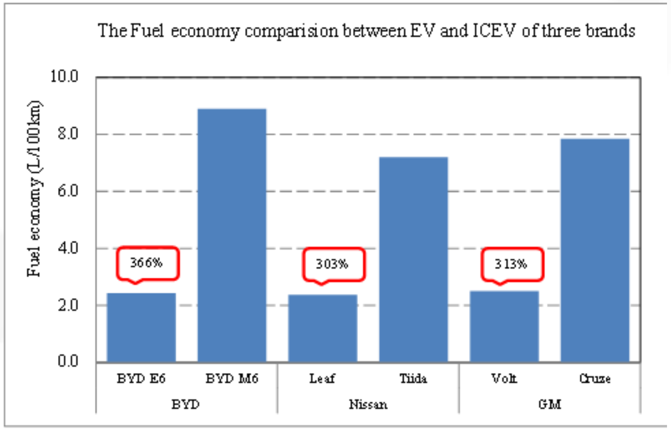
LDPV (on-road fuel economy)



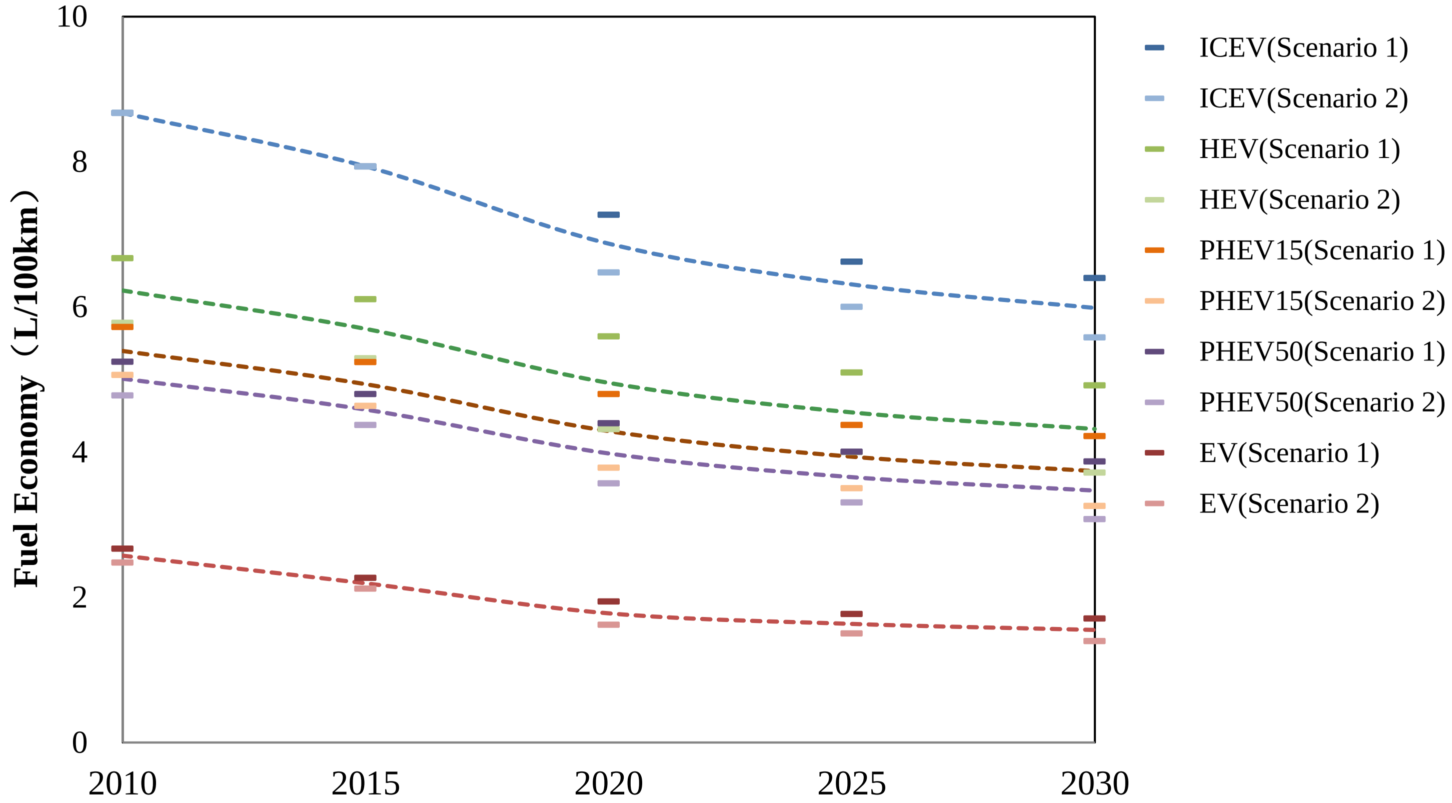
HEV (fuel economy)

Brand	Vehicle	Comparison Vehicle	Fuel Economy Improvement: User-Reported	Fuel Economy Improvement: Old EPA Combined	Fuel Economy Improvement: New EPA Combined	Fuel Consumption Decrease: User-Reported	Fuel Consumption Decrease: Old EPA Combined	Fuel Consumption Decrease: New EPA Combined
Ford	Escape	Escape 2WD V6	65%	55%	50%	-39%	-36%	-33%
	Mariner	Mariner 4WD V6	53%	48%	42%	-35%	-33%	-30%
GM	Aura	Aura 3.6L 4-spd Auto	34%	27%	29%	-25%	-22%	-22%
	Sierra	GM Sierra 2WD 5.3L	31%	7%	6%	-24%	-7%	-6%
	Vue	Vue 2WD 6 cyl. Auto	28%	27%	30%	-22%	-21%	-23%
Honda	Accord	Accord 3L Auto.	-9%	32%	29%	10%	-24%	-22%
	Civic	Civic 1.8L Auto.	52%	48%	45%	-34%	-32%	-31%
	Insight	Civic 1.8L Auto.	138%	85%	62%	-58%	-46%	-38%
Nissan	Altima	Altima V6 Auto	35%	60%	55%	-26%	-38%	-35%
Toyota	Camry	Camry V6 3.5L Auto.	53%	54%	48%	-34%	-35%	-32%
	GS 450h	GS430	28%	28%	21%	-22%	-22%	-17%
	Highlander	Highlander 2WD 3.3L	38%	39%	37%	-27%	-28%	-27%
	LS 600hL	LS 460 L	10%	11%	11%	-9%	-10%	-10%
	Prius	Corolla 1.8L Auto.	47%	68%	59%	-32%	-40%	-37%
	RX 400h	RX 350 2WD	28%	34%	30%	-22%	-26%	-23%
Average			42%	42%	37%	-27%	-28%	-26%

PHEV and EV (fuel economy)



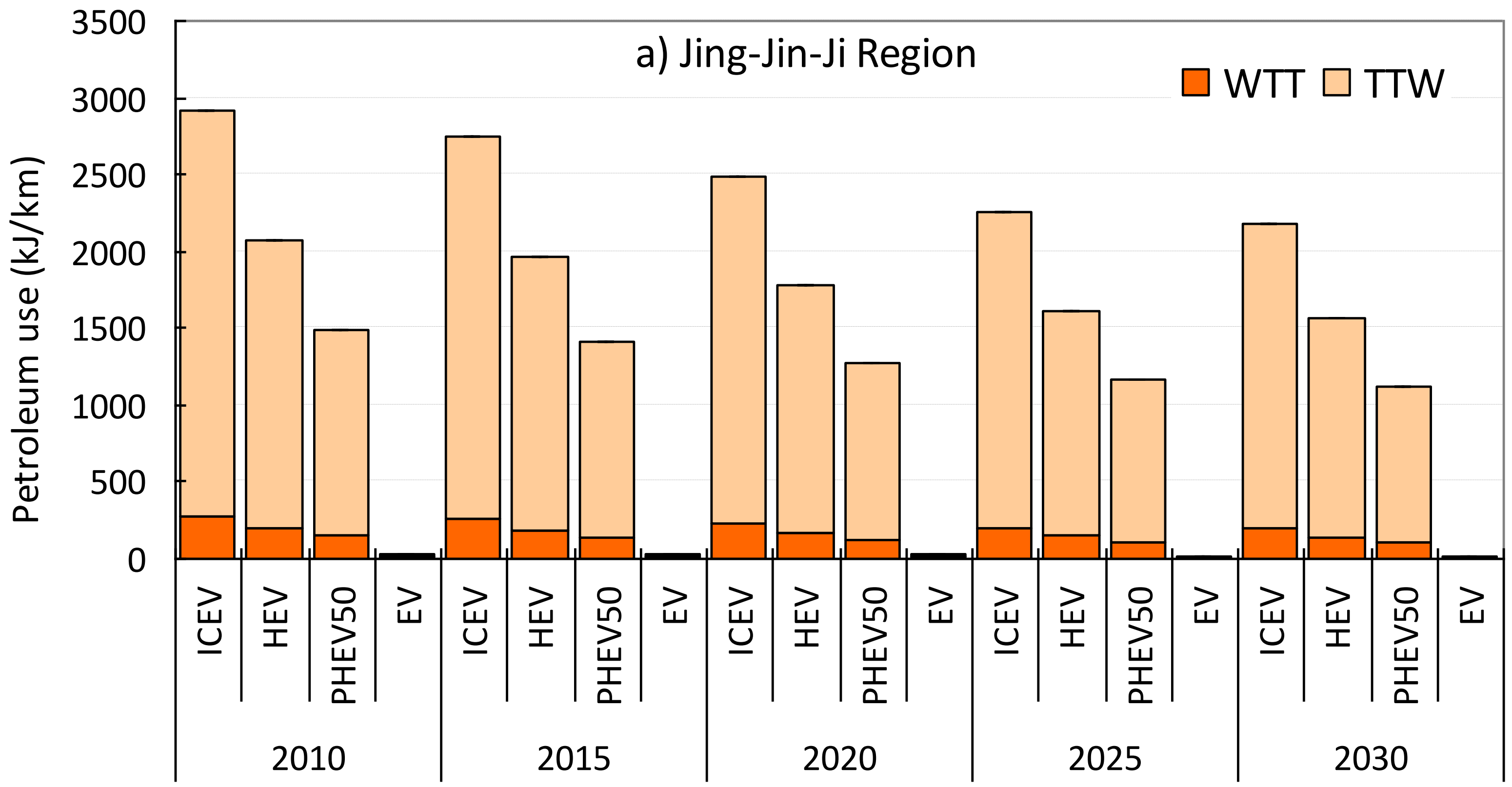
Fuel economy of ICEV, HEV, PHEV and EV



Data Sources:

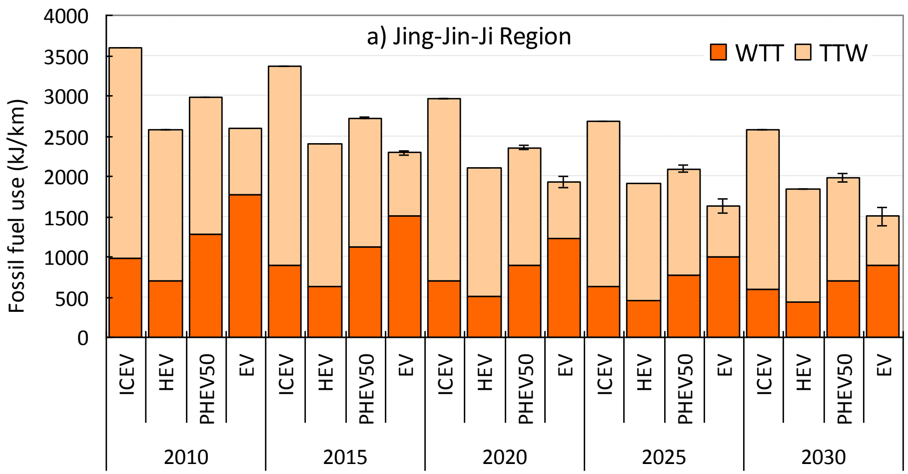
1) ICEV: CARTARC, NAS, local test data, etc.
2) HEV (ranging from 135%-145% relative to ICEV): NREL, ANL, local test data, etc.
3) PHEV and EV (EV ranging from 325%-400%): ANL, local test data, etc.

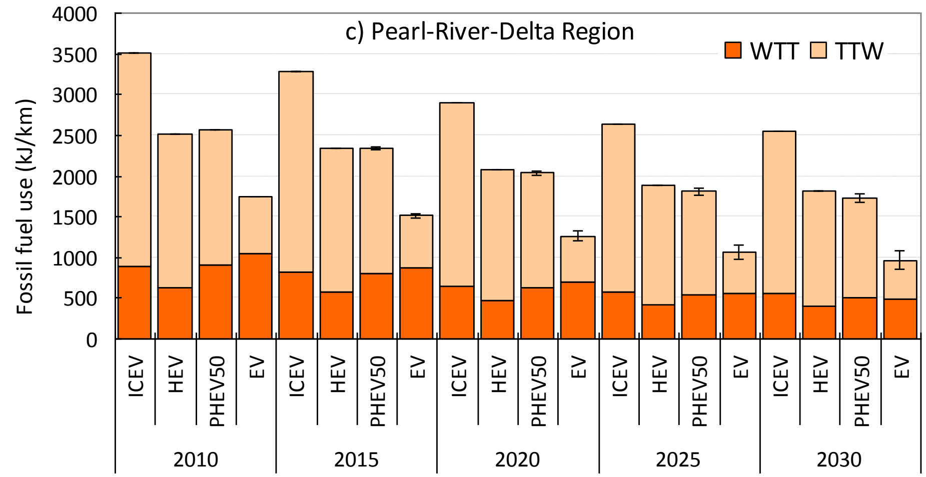
Well-to-Wheels petroleum use of HEV/PHEV/EV

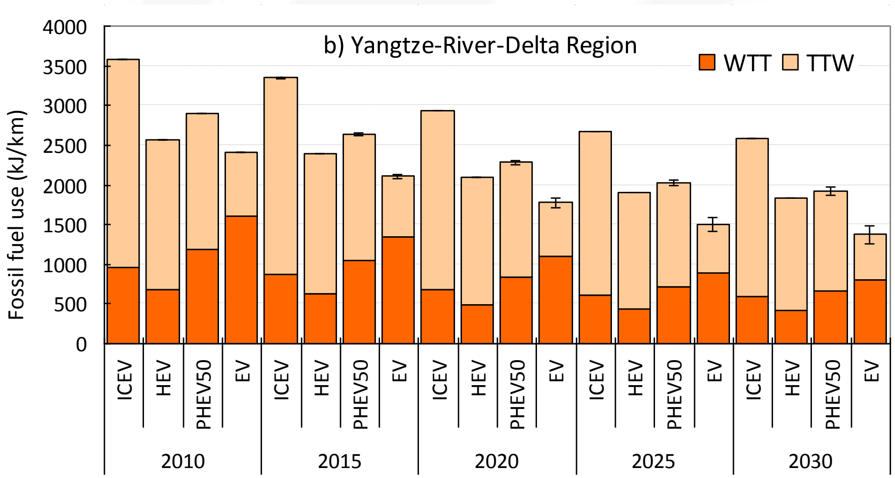


HEV can achieve 30% reduction in petroleum use relative to ICEV; while PHEV50 can achieve 50% reduction, and EV almost eliminates the petroleum use.

Well-to-Wheels fossil energy use of HEV/PHEV/EV



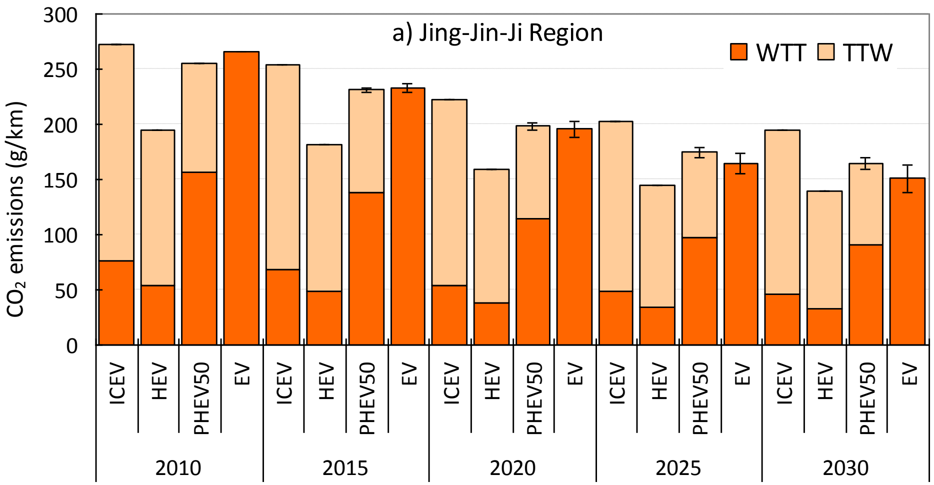


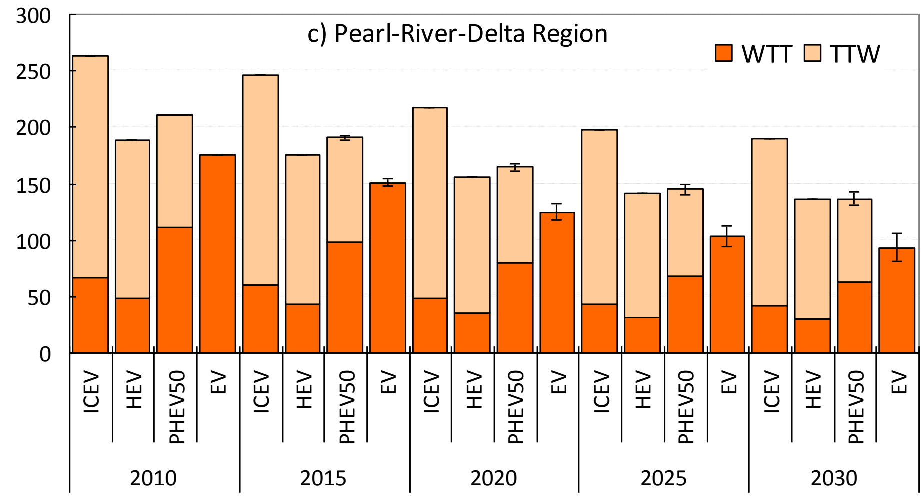


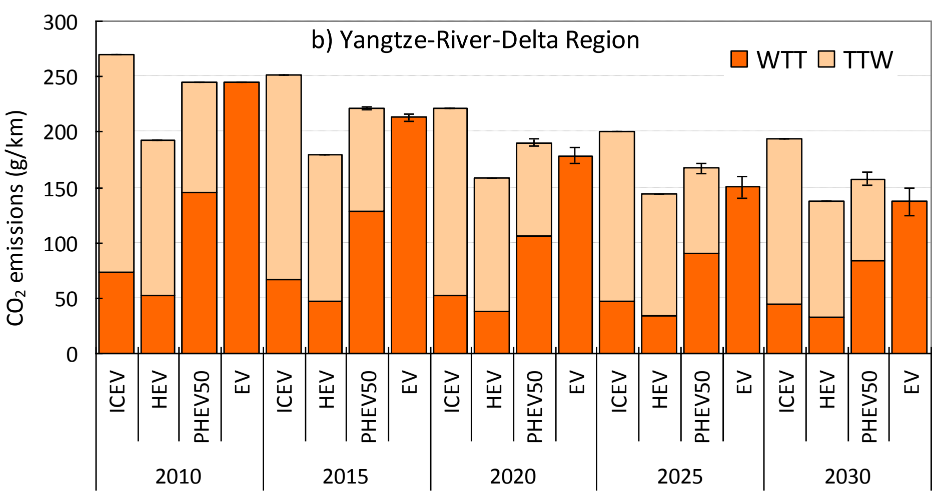
The WTW fossil energy use reduction benefit is less than that of petroleum use for PHEV/EV.

In those regions that already have a sizeable proportion of clean electric energy (e.g., Pearl-River-Delta region) will have considerable reduction benefit with promotion of EV compared to HEV.

Well-to-Wheels CO_2 emissions of HEV/PHEV/EV



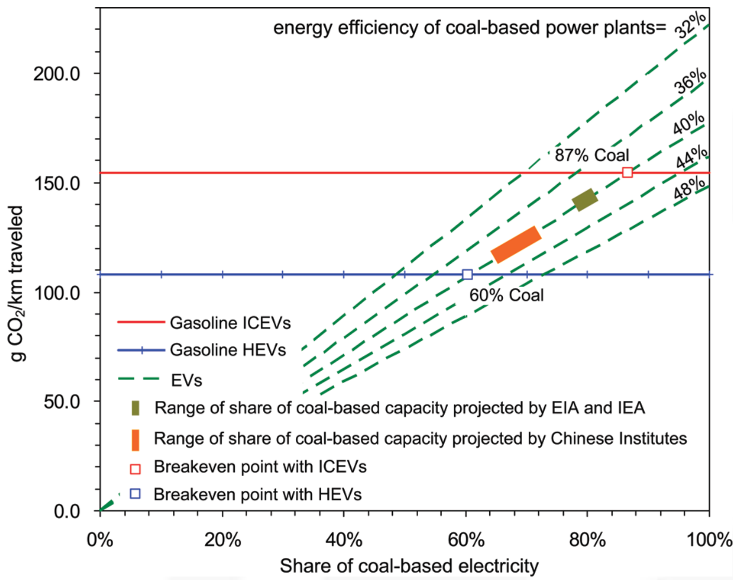


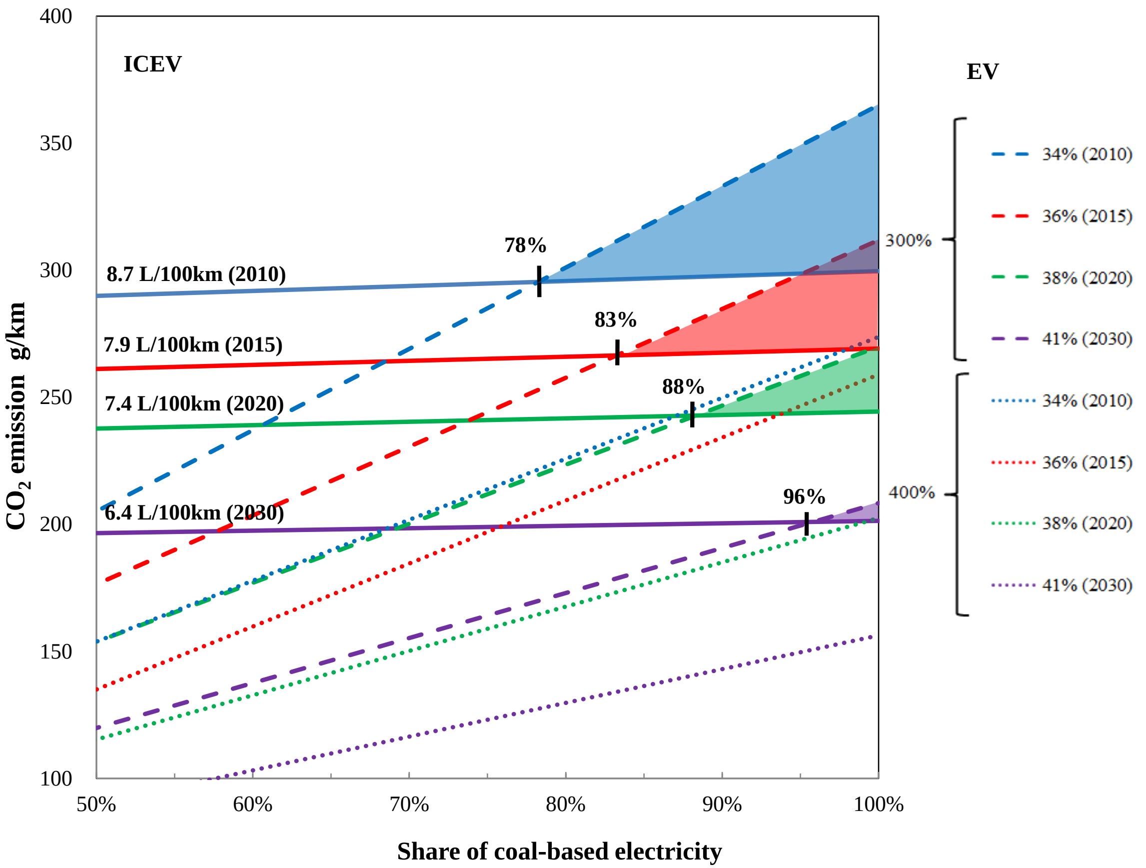


The WTW CO_2 reduction benefit is much less for PHEV/EV for those regions (e.g., Jing-Jin-Ji region) with dominant coal-fired power plants.

However, in those regions that already have a sizeable proportion of clean electric energy (e.g., Pearl-River-Delta region) will relieve the overall CO_2 burden substantially with promotion of PHEV and EV in the future.

CO_2 breakeven points between EVs and ICEVs





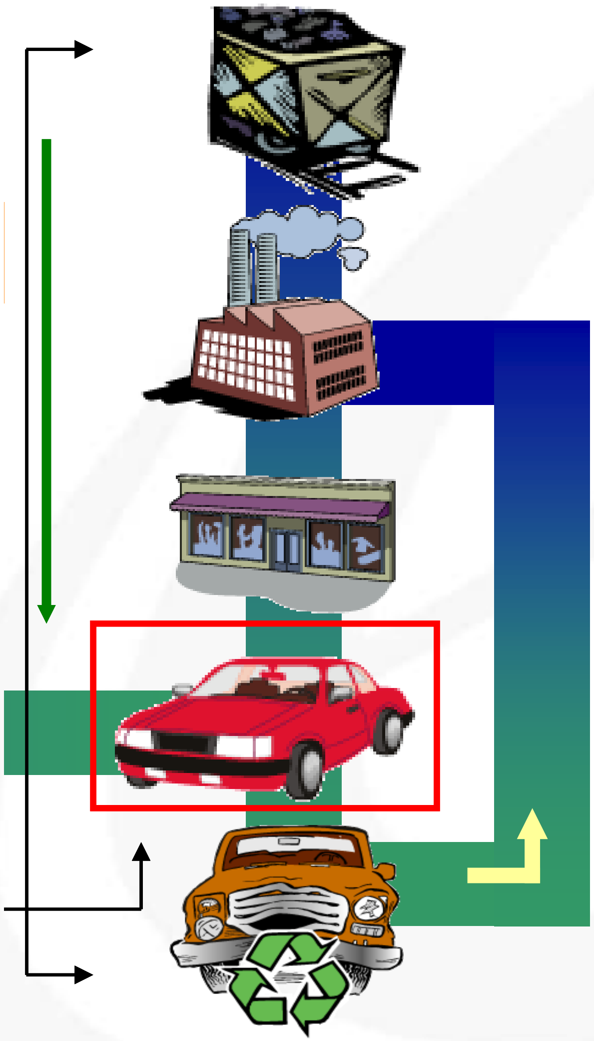
Data Sources:

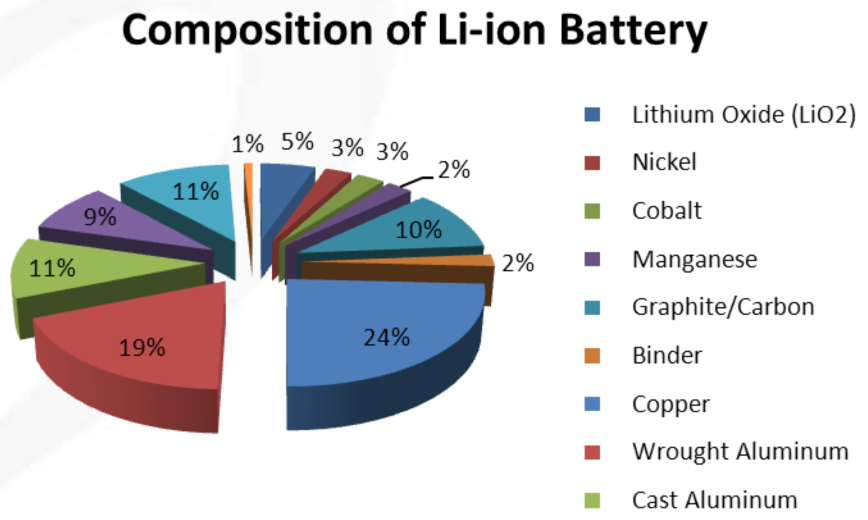
1) Left figure: Huo et al., ES&T, 2010.

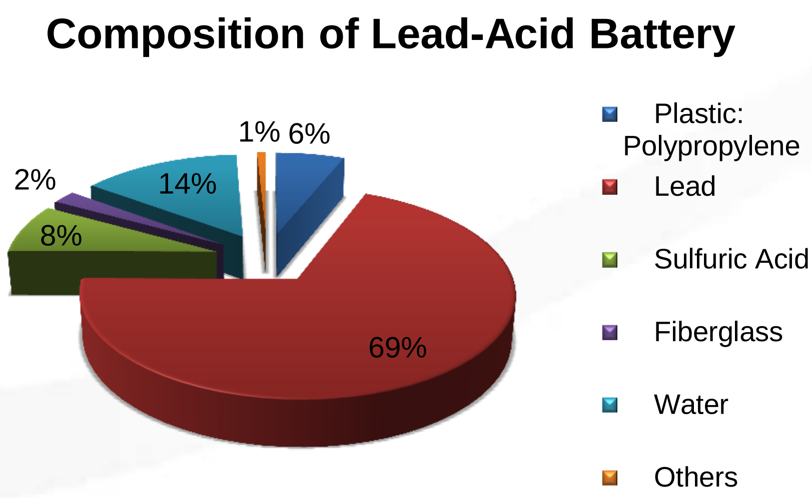
2) Right figure: Wu et al., Tsinghua University and SAE-China, supported by Energy Foundation, 2013.

The CO_2 breakeven points between EVs and ICEVs are relevant to several key parameters: fuel economy of ICEVs and EVs, share of coal-fired power to total generation mix, and the generation efficiency of coal power.

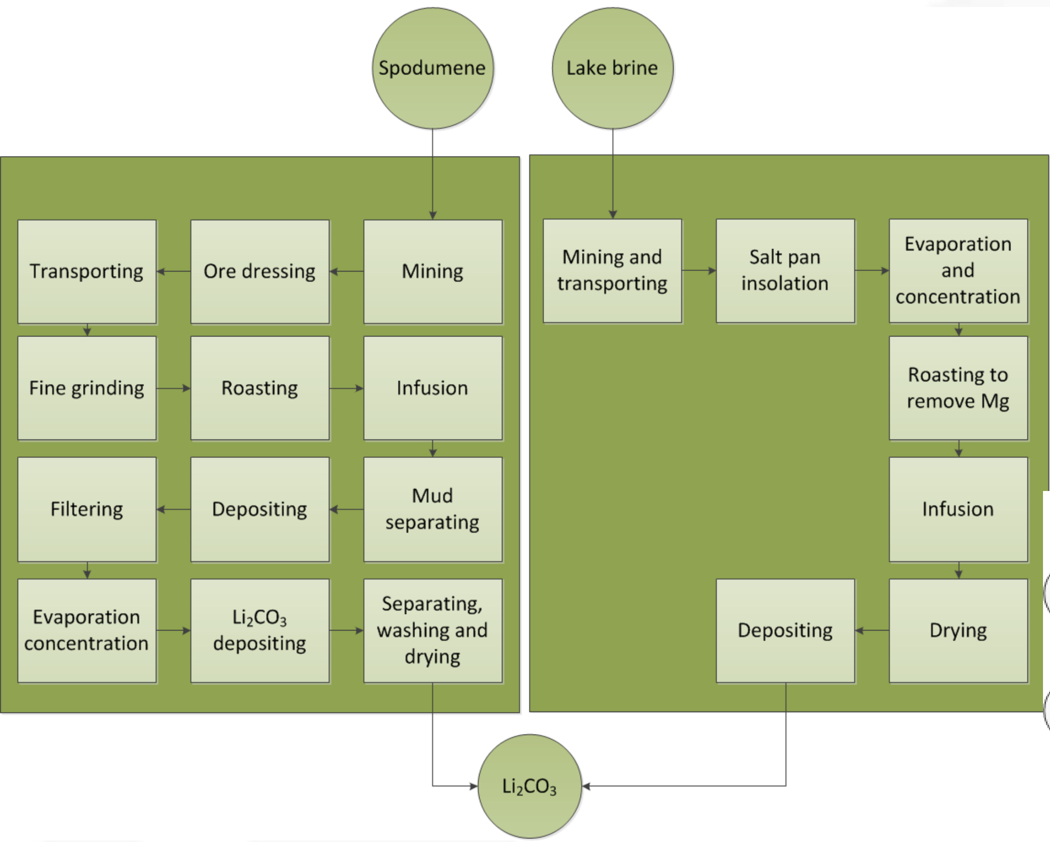
The boundary of LCA analysis for electric vehicles: vehicle material cycle

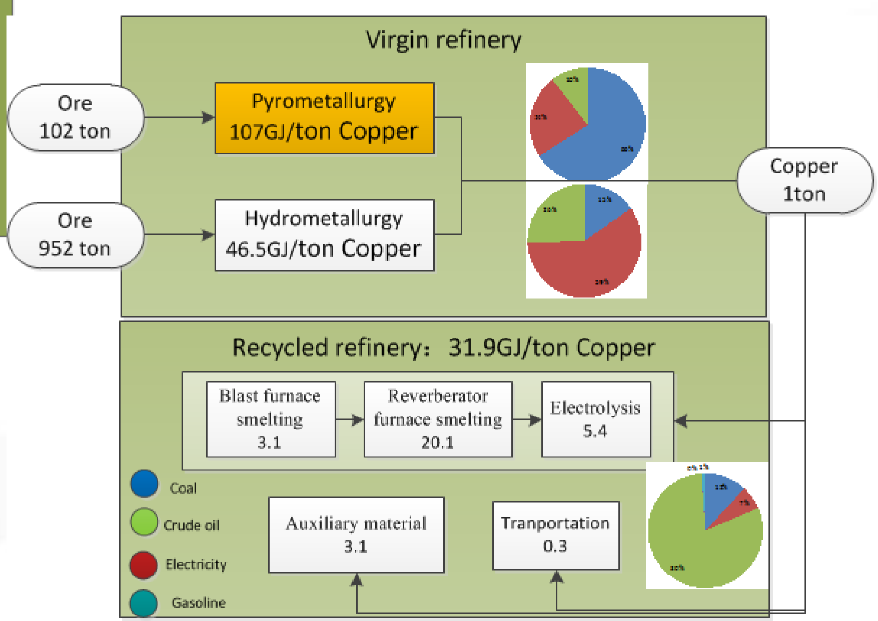




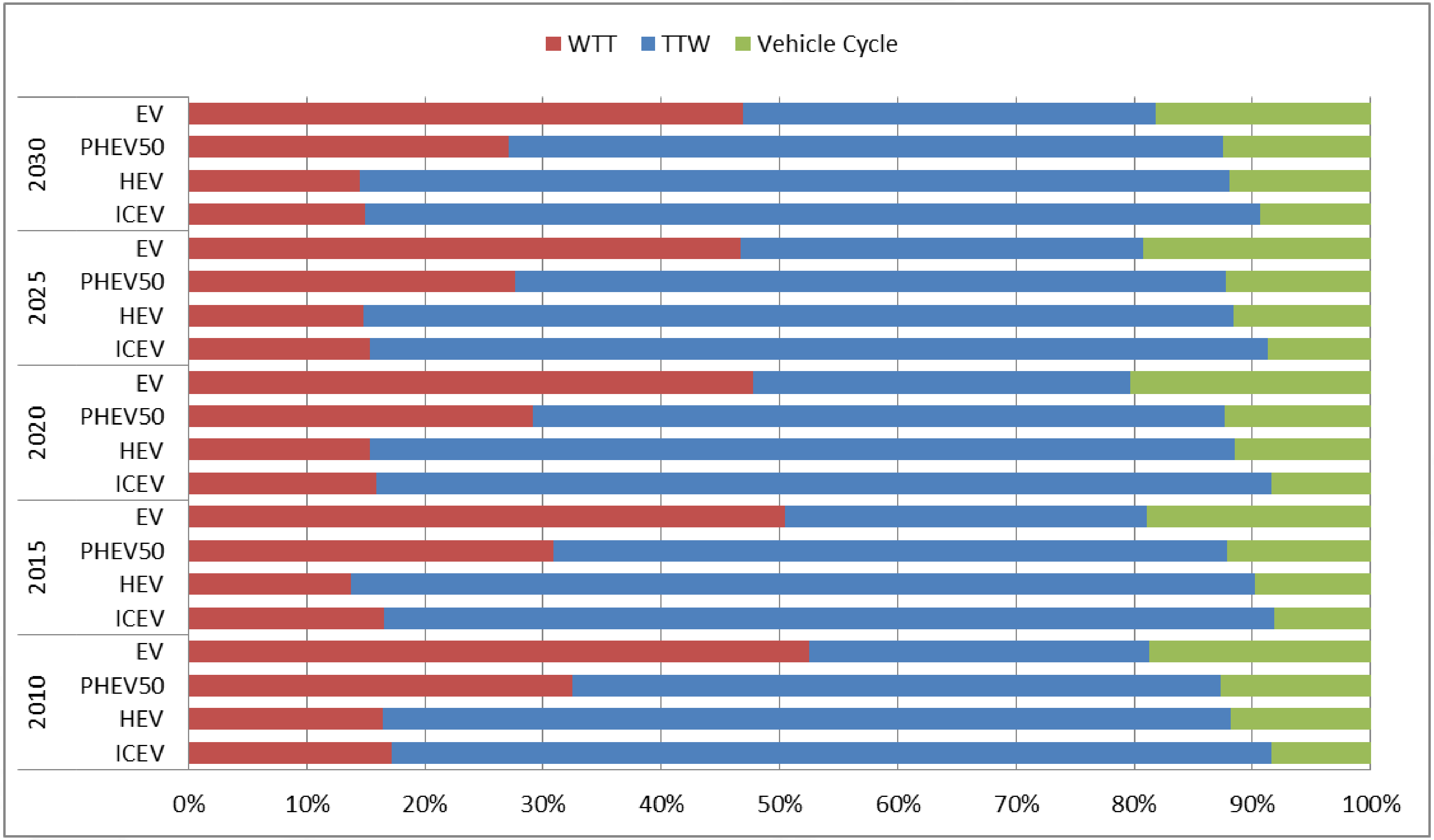


Energy use of key materials by major process: lithium and copper as an example





Life-cycle fossil energy use of HEV/PHEV/EV: well-to-tank, tank-to-wheels plus vehicle cycle



Data Sources: Wu et al., Joint report by Tsinghua University and Ford Motor Company, 2013

Outlook for further research activities

- **A complete material flow model needs to be developed and updated**
  - ✓ **Vehicle operation, fuel cycle plus vehicle material cycle**
  - ✓ **Energy consumption (oil vs. fossil energy), CO_2 emissions plus criteria air pollutants emissions (CO, NO_X, SO_2, VOC and $PM_{2.5}$)**
- **A complete Chinese-specific database needs to be updated and improved**
  - ✓ **Development of the power sector and electricity grid**
  - ✓ **EV and ICE technologies (efficiency, emission factors, costs)**
  - ✓ **Growth of future auto fleet and market penetration of EVs**
  - ✓ **Mobility behavior and use pattern**
  - ✓ **…**

Thank you for your attention !

Questions ?