Redefining Affluence in China: Carbon Emission from Private Transportation

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Abstract

This work focuses on the link between economic growth and carbon dioxide (CO2) emissions in China's transportation sector. By examining national and regional data for the twenty years from 1990 to 2010, we show that the ratios of vehicle ownership to income for Beijing and Shanghai represent the upper and lower bounds for all other Chinese provinces/cities. Through this case study and a quantitative model, we identify several key technical and policy factors that are crucial in decoupling carbon emissions from the rapid increase in affluence.

Résumé

Ces travaux portent sur le lien entre la croissance économique et les émissions de dioxyde de carbone (CO2) dans le secteur du transport en Chine. Une étude des données nationales et régionales portant sur 20 années, de 1990 à 2010, montre que les modes de développement de Beijing et Shanghai, deux des villes de Chine les plus aisées, forment une « enveloppe » en ce qui a trait aux émissions de CO2 provenant des transports. Une étude plus approfondie de la politique de planification urbaine et du transport montre que la qualité et l'envergure des réseaux de transport public, l'infrastructure que représentent les voies de circulation dans les villes et les coûts de possession d'un véhicule privé (stationnement, permis, essence et entretien) jouent un rôle important dans les habitudes de déplacement des propriétaires de véhicules.

1. Introduction

In 2006, China surpassed US to become the biggest carbon dioxide (CO2) emitter in the world [**1**]. Some studies suggest that China will at least double its CO2 emission by 2030 compared to its emission level in 2005 [**2**] due to rising income level and rapid urbanization. Many studies focus on measuring the impact of consumption on CO2 emissions. One recent study shows that consumer activities account for about 80% of the total carbon emission in US [**3**], another study shows how different categories of consumption impact CO2 emissions in China [**4**]. Little attention has been given to developing low-carbon pathways specifically for China's rising middle and upper classes, although their current consumption pattern already leads to significant carbon emissions [**2**]. This research gap will be addressed in this work with a specific focus on a major carbon-emitting sector: transportation.

According to Dargay et al. [**5**], "China's vehicle stock will increase nearly twenty-fold, to 390 million in 2030". This fast expansion implies a potentially dramatic increase in carbon emission. Globally, transportation relies almost entirely (95%) on petroleum. In 2004, transportation was "responsible for 23% of world energy-related GHG emissions with about three quarters coming from road vehicles." In addition, the greenhouse gases (GHG) emission from transportation has increased at a rate faster than any other energy-intensive sector [**6**].

Various papers document current carbon emission from the vehicle fleet and forecast future trend. He et al [**7**] estimate that 1000 million tons of CO2 will be emitted from on-road gasoline consumption in China. This number is likely to increase by at least 10% [**8**], if we look at the lifecycle emission (Well-to-Wheels). Carbon emission from road construction has not been considered in these studies. Since cement production is extremely carbon-intensive [**9**], the total carbon emission reported by He et al. is likely an underestimation of the overall effect of expanding vehicle fleet.

2. Decoupling vehicle population growth from rising income

2.1. Regional Vehicle Ownership

The following graph plots vehicle ownership levels against income levels in 31 Chinese provinces and autonomous cities for year 2008. In addition, data for Beijing and Shanghai over multiple years are shown. We make two observations:

1) Disparity in income level and vehicle ownership level is large among Chinese cities and provinces. It is likely that if provinces are further divided into cities, larger gaps between income and vehicle ownership levels will be seen.
2) Shanghai and Beijing had very different development pathways. This is likely caused by their different policies. Shanghai has focused more on controlling vehicle stock, whereas Beijing focused more on constructing highways to absorb new cars (further discussion in the next section).

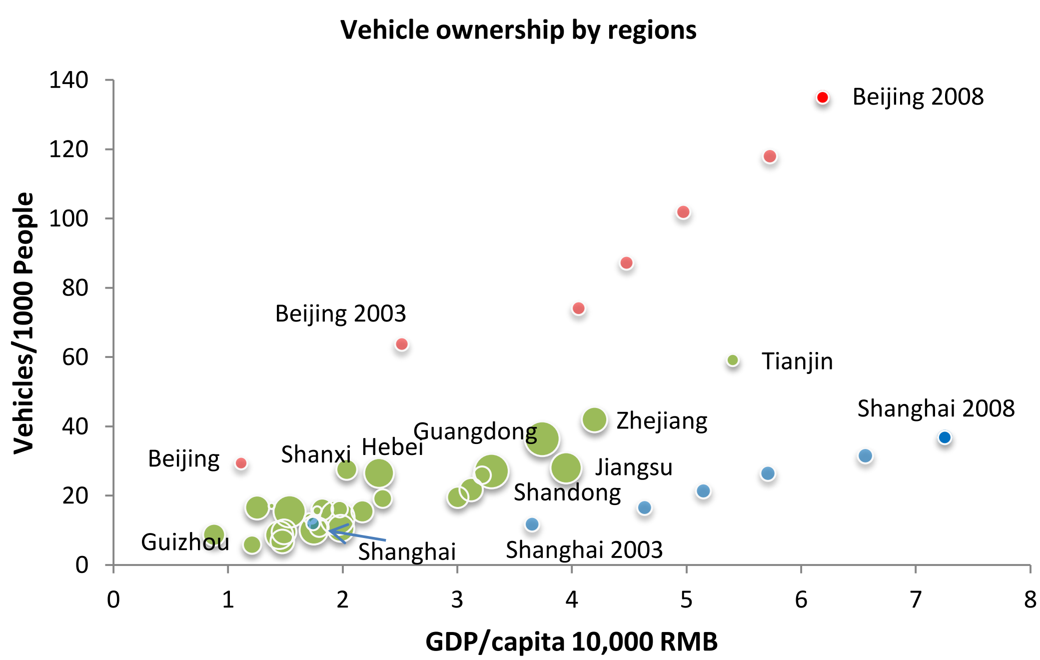

Figure 1 - China Vehicle Ownership, by Provinces and Autonomous Cities. Data from Chinese Statistical Yearbook 1990-2009. Red: Beijing, Blue: Shanghai, Green: Other provinces/cities. Areas of bubbles are proportional to population sizes.

The other provinces loosely form two clusters – a northeast and a southwest cluster. The northeast group of provinces, such as Guangdong, Zhejiang, Jiangsu, and Shandong, are mostly provinces on the coastal line. They constitute the so-called Eastern China.

2.2. Beijing and Shanghai

Beijing and Shanghai's vehicle ownership pathways are analyzed in more detail using proxies for various transportation-related factors as shown in Table 1.

Table 1 - Driving Factors of Vehicle Ownership

Factors	Potential Proxies
Travel Demand (+)	Population density
Income (+)	GDP/capita
Public Transportation (-)	Per area route length, government investment per capita
Other Alternatives (-)	Routes for bicycles and other 2-wheels
Cost of ownership (-)	Vehicle price + fees + parking and gasoline
Roads (+)	Per area road length, government investment per capita

Each factor is followed by (+)/(-), indicating their positive/negative effect on car ownership level.

2.2.1. Travel Demand

Among Chinese cities, Beijing and Shanghai have similar levels of per capita income and maturity in terms of urban development. We use population density as a proxy for travel demand.

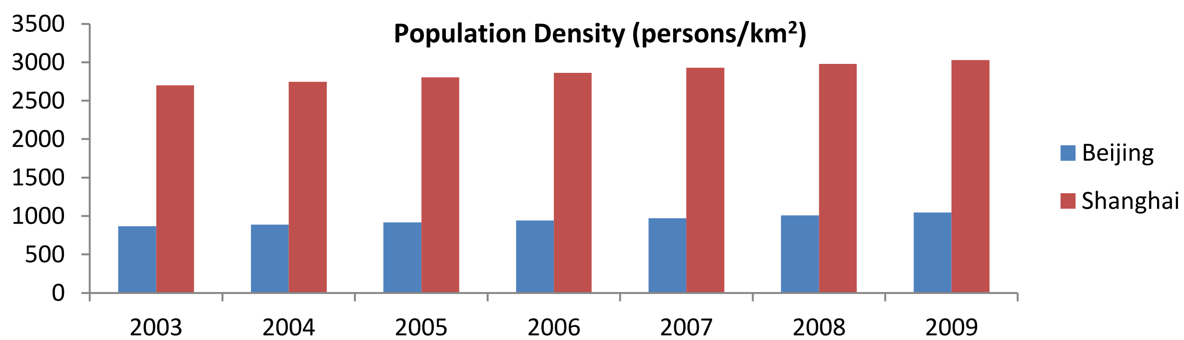

Figure 2 - Population Density, Beijing and Shanghai [**10**] [**11**]

Figure 2 shows that Shanghai's population density is much higher than Beijing's, which suggests that: 1) Shanghai is likely to have denser infrastructure, 2) Shanghai is likely to have narrower roads and a more compact road system, and 3) parking spots in Shanghai are likely to be more limited. All these factors likely suppressed the growth of vehicle stock in Shanghai.

2.2.2. Public Transportation

Figure 3 and Figure 4 show the development of subway and bus transit, respectively, for Shanghai and Beijing. Public transit route length per km^2 for Shanghai is significantly higher than in Beijing – a contrast that is consistent with the reverse relationship for private vehicle stock. Although the findings are consistent with expectations, it is recognized that price and service frequency would also influence people's transit choices.

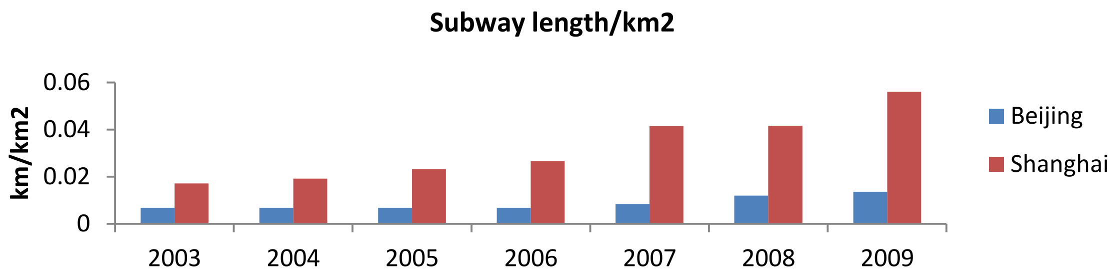

Figure 3 - Subway Route Density, Beijing and Shanghai [**10**] [**11**]

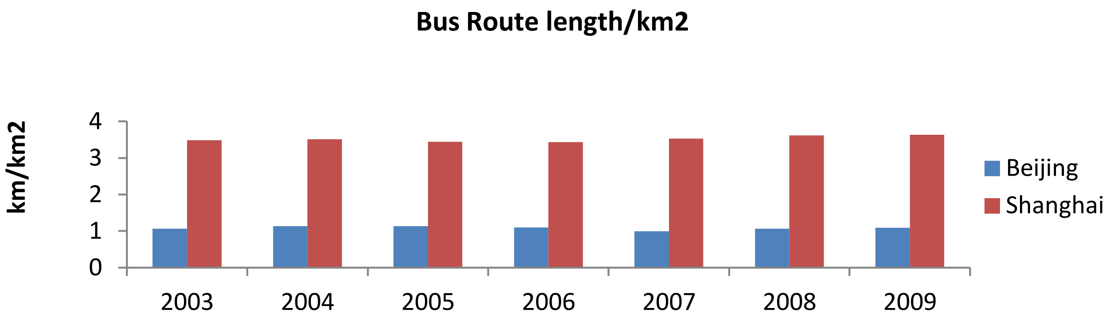

Figure 4 - Bus Route Density, Beijing and Shanghai [**10**] [**11**]

2.2.3. Policy

Table 2 summarizes four municipal policies related to cost of vehicle ownership in Shanghai and Beijing. While gasoline prices are the same, and parking fees are somewhat higher in Shanghai, vehicle licensing fees and sales tax are dramatically higher in Shanghai, again discouraging vehicle ownership.

Table 2 - Cost of Vehicle Ownership, Beijing and Shanghai [**12**] [**10**] [**11**]

Cost of Vehicle Ownership	Beijing	Shanghai
License Fee	<$50	$5,000 to 10,000
Sales Tax on Vehicle	5%	10%
Gasoline price	$1/Litre	$1/Litre
Parking	$2 to 5 per hour in downtown	$3 to 10 per hour in downtown

3. Development Pathways

This section explores a bottom-up model that quantifies China's recent (2010) carbon emission from private transportation, and shows three different emission pathways from 2010 to 2030.

3.1. National Vehicle Ownership

Figures 5 and 6 show vehicle ownership levels in 1960 and 2006 for 45 countries, including the United States and China. If China's future car ownership trends relates to income in the way shown in these two figures, there is the potential for dramatic future growth in China's vehicle stock as income levels in China rise.

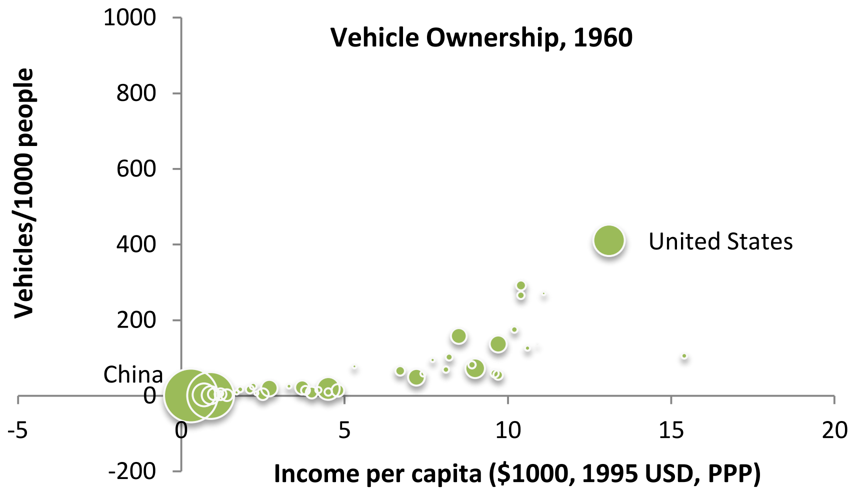

Figure 5 - World Vehicle Ownership, 1960. Areas of bubbles are proportional to population sizes [**5**]

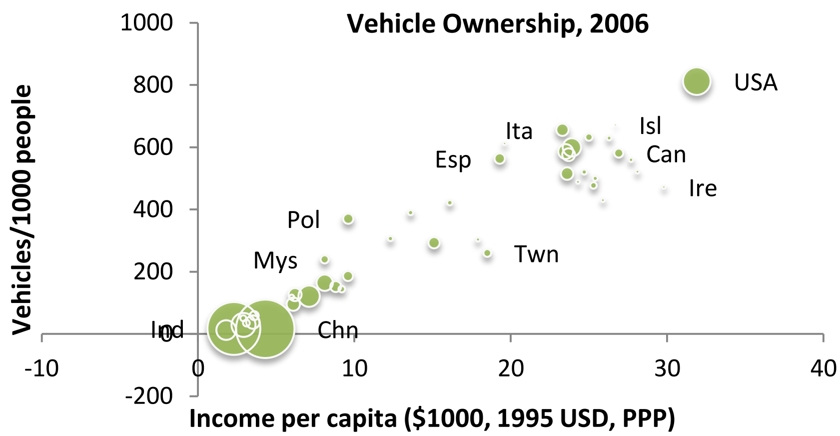

Figure 6 - World Vehicle Ownership, 2006 [**5**]

With the objective of minimizing future carbon emission, three questions can be asked to address the three dimensions of this problem:

1) Is there a way to keep *vehicle stock* low? In other words, can China's vehicle ownership level *not* go to where US is when its GDP/capita rises?
2) Is there a way to maintain or decrease *vehicle usage*?
3) To what extent can scientists, policy makers, and business leaders drive up technical efficiency and provide alternative-fuel vehicles?

It is likely that solutions to CO2 problem in transportation will involve strategies in all three dimensions. Section 2 has provided some insights regarding the first question – decoupling vehicle fleet growth from economic growth – through a case study of Beijing and Shanghai. This section (Section 3) focuses on the second and third questions in an attempt to provide insights regarding whether *carbon emissions* can be decoupled from *vehicle fleet growth*.

3.2. Bottom-up Model and Scenario Design

3.2.1. Model (National Transport CO2 Inventory)

The following diagram summarizes the bottom-up model:

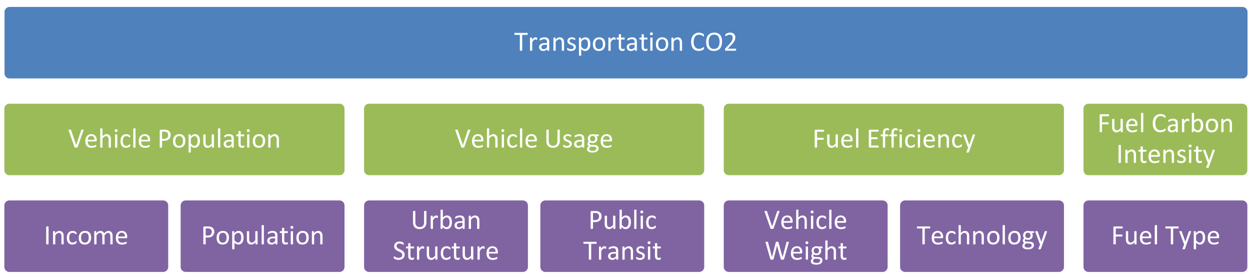

Figure 7 - Bottom-up Model for Measuring CO2 Emission in Transportation

Vehicle Population

Our vehicle population forecast is based on parameters from Hao et al [**13**], which is in turn based on the statistics provided by the Chinese Statistical Yearbook (CSY Sections 9-14). The following table lists the key parameters and assumptions we used:

Table 3 - Basic Assumption for Vehicle Population Forecast, adapted from Hao et al [**13**]

		2008	**2010**	**2020**	**2030**
Overall	Population (million)	1328	1360	1440	1470
	Households (million)	388	414	476	504
	Urbanization rate (%)	45.7	49	63	70
	GDP (billion RMB, 2008 Price)	30,067	36,163	80,864	160,715
Urban	Population (million)	607	666	907	1029
	Persons per household	2.91	2.88	2.8	2.75
	Households (million)	209	231	324	374
Rural	Population (million)	721	694	533	441
	Persons per household	4.01	3.8	3.5	3.4
	Households (million)	180	183	152	130

Notice that the assumptions for population, GDP, and urbanization rate by Hao et al. are close to the 2015 targets set by 12th Five-Year-Plan.

Based on these assumptions, and other socio-economic parameters obtained from CSY, Hao et al estimated that the vehicle population by 2010, 2020, and 2030 are 30.19, 134.4, and 307.2 million respectively.

Vehicle Usage

Vehicle usage is not documented in CSYs. Despite the lack of data, the study still remains useful if it has (1) different scenarios to capture the *range* of possible outcomes by 2030, and (2) base the vehicle usage levels on realistic basis. Numbers in this study is based on two other Asian countries – Republic of Korea and Japan. The baseline (30% decrease in Vehicle Kilometers Travelled, or VKT) is an estimate based on the most aggressive level (Japanese travel behaviour). A main factor that would reduce VKT is the reduction of proportions of taxis in the VKT calculation.

Fuel Efficiency

In 1990, China started policy and scientific research on climate change with the establishment of National Climate Change Coordination Committee [**14**]. Since then, China has implemented a set of policies on fuel intensity standards for new vehicles. These standards are strictly enforced and are likely having beneficial effects on CO2 emissions.

Fuel efficiency, or in other words VKT per unit time, depends on the weight of the vehicle and the propulsion technology. According to Ng and Schipper [**15**], the average weight of new Chinese cars is 1,500 kilograms (between 3,000 kilograms of a Hummer and 750 kilograms of a Mercedes Smart). He et al. estimated the current fuel economy is about 9.1liter/100km [**7**].

Carbon Intensity of Fuels

Yan and Crookes [**16**] summarized carbon intensities of various vehicle fuels in China. The following figure is taken from their work – life cycle assessment of CO2 emissions from various vehicle fuels in China.

3.2.2. Scenario Design

Table 4 - Scenario Design

	Scenario 1: Baseline	**Scenario 2: Reduced driving**	**Scenario 3: Integrated Transport Policy**
Vehicle Population	Vehicle fleet rises from 30.1 million in 2010 to 342.8 million in 2030		
Vehicle Use By 2030	30% decrease in Vehicle Kilometer Travelled (VKT)	40% decrease in VKT	50% decrease in VKT (Japan level)
Fuel Types By 2030	90% Gasoline 3% CNG 7% Electric/hybrid	70% Gasoline 5% CNG 25% Electric/hybrid	20% Gasoline 20% CNG 60% Electric/hybrid
Carbon intensity of Fuels	No change	20% decrease in Well-to-Wheels (WtW) emissions per 10-year period	25% decrease in WtW emissions per 10-year period

Vehicle population growth is the same across all three scenarios. The forecast for vehicle population growth is based on Hao et al. [**13**].

The design of Scenario 3's vehicle fuel types – almost 60% electric/hybrid vehicles. Even though the current market penetration of electric and hybrid vehicles is limited at the moment, it is possible that electric and hybrid vehicles will take a significant market share in the next twenty years [**17**].

Although the carbon contents of some fuels are not subject to technological improvement, the processes in which fuels are extracted, produced, and transmitted can be improved. For example, electric and hybrid vehicles take electricity as input, and the amount of carbon emission embedded in electricity depends on how electricity is generated in China and distributed to the charging stations. As China drops its overall carbon intensity [**17**], the Well-to-Wheels emissions will drop as well.

The last thing to note is the 30% reduced driving in the baseline scenario. This is a likely case. The big decrease is largely due to the fact that VKT for 2010 is calculated for all private vehicles including taxis. Since taxis generally travel much more than family vehicles, VKT will likely shrink as the percentage of taxis drops.

3.3. Results – 2010 to 2030

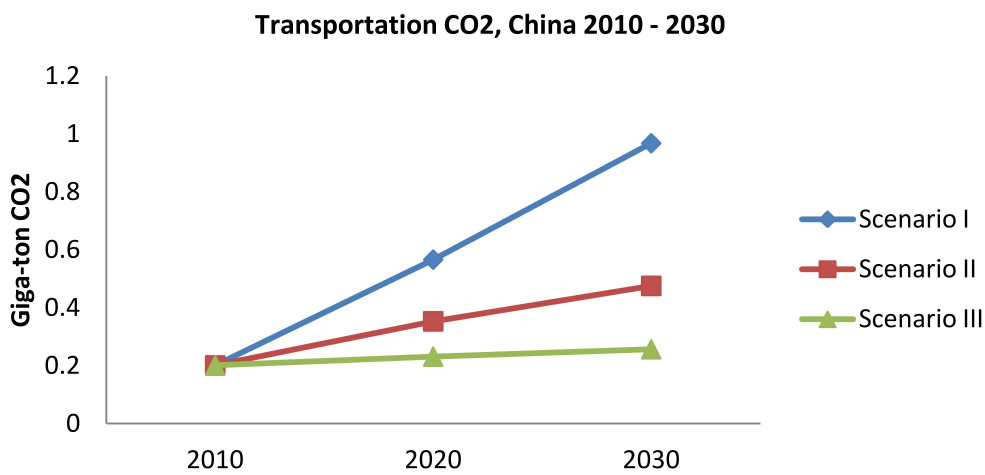

Figure 8 - Carbon emission pathways calculated from bottom-up model

In 2010, all scenarios have the same starting point – 201.03 million tonnes CO2. By 2020, emissions will be 566.3, 353.1 and 231.3 million tonnes respectively. And by 2030, emissions will be 967.8, 475.5, and 256.8 million tonnes respectively.

To put the Scenario 1 results in perspective: Scenario 1 emission is 0.9 Giga-ton CO2 (GtCO2), while China's and the global total emissions are projected to be 12 GtCO2 and 39 GtCO2 in 2030 respectively [**18**].

One important result of the analysis is that, despite the dramatic growth (600%) in vehicle fleet, carbon emission in Scenario 3 does not increase by more than 30%. In order to understand such a result, Figure 9 - Carbon emissions by fuel types, all scenarios demonstrates the factors that put upward/downward pressure on total carbon emissions.

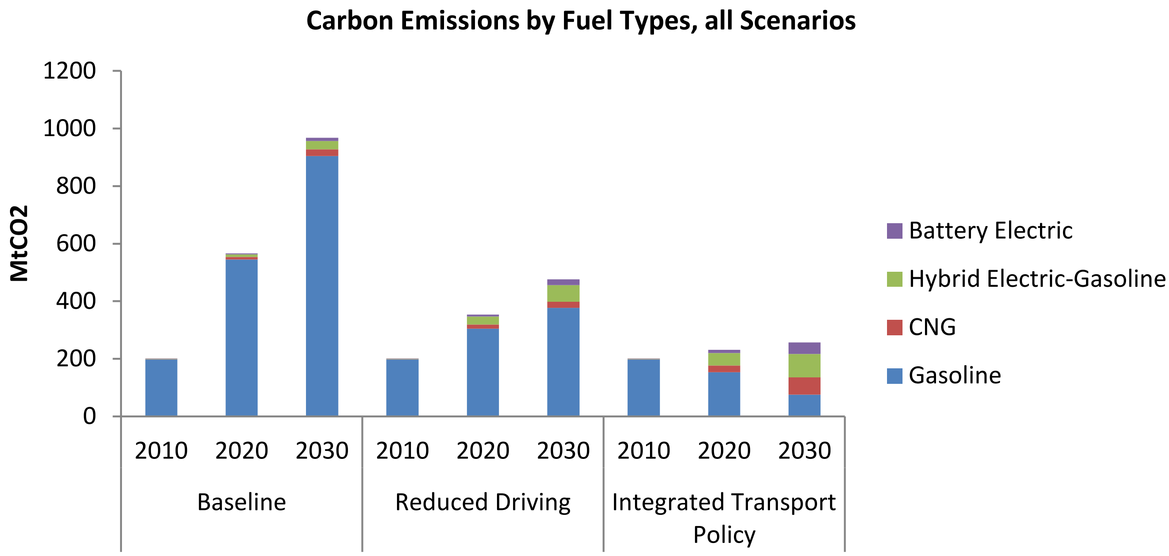

Figure 9 - Carbon emissions by fuel types, all scenarios

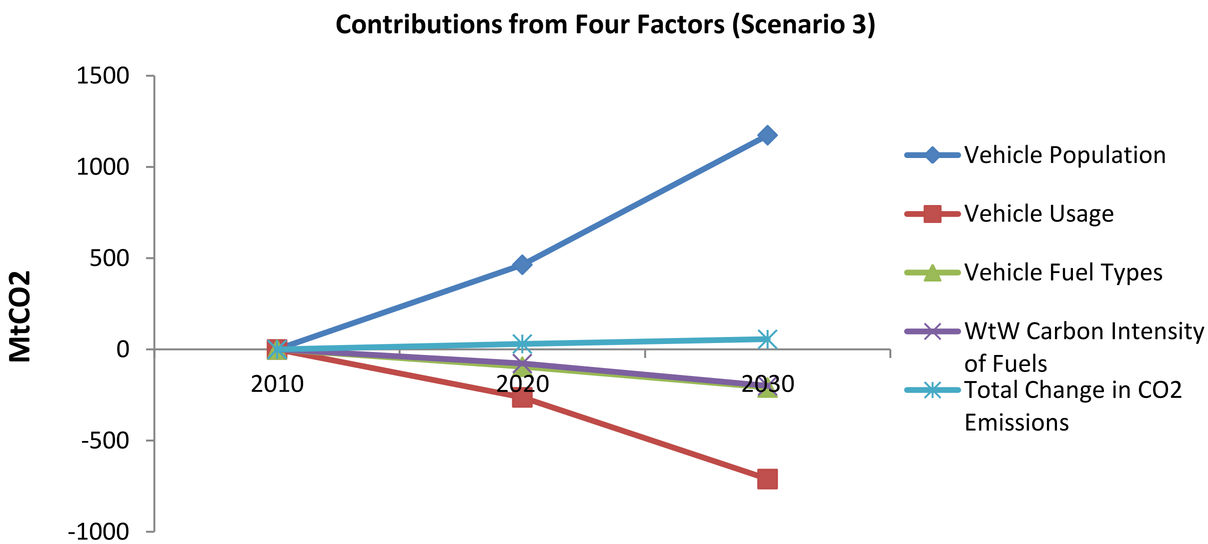

Figure 10 - Contributions from Four Factors, Scenario 3

Despite the promising case of Scenario 3, it is not hard to see that improvements in vehicle usage, fuel-types, and carbon intensity of fuels are potentially limited. In contrast, vehicle ownership level in China by 2030 (233 cars per 1000 people) will still be well below the USA and even European levels (812 and about 600 cars per 1000 people respectively in 2006).

Therefore, it is important to further examine the relationship between income growth and vehicle ownership growth. If such link can be weakened, carbon emissions will become even less dependent economic growth than Scenario 3. This in turn reinforces the ideas that we have explored in the previous section (decoupling vehicle population growth from rising income).

4. Conclusion

This work presents a case study analyzing how different Chinese cities have different vehicle fleet growth patterns. The case study shows that vehicle fleet growth can be decoupled from economic growth to a certain extend. Interestingly, Shanghai's denser population and urban infrastructure "suppressed" vehicle growth; Beijing's construction of roads, although originally intended to reduce traffic congestion, actually encouraged vehicle ownership and further increased congestion. Furthermore, a range of possible emission pathways in China's private transport up to 2030 are explored, and we conclude that carbon emissions can also be further decoupled from vehicle fleet growth.

Any plausible solution to mitigating transportation emissions will likely address many different areas. Specifically, emissions level is sensitive to (1) income levels and vehicle prices, (2) vehicle registration and maintenance cost, (3) private vehicle usage and public transit development, (4) fuel types, and (5) road system planning. Due to the long implementation period of most urban policies such as those related to public transportation, fuel efficiency, road infrastructure, cities and provinces must pay close attention to these factors at the planning phase.

Many other cities in developing countries face similar challenges from traffic capacity, congestion, air pollution and carbon emission. However, Schipper [**19**] pointed out that even in U.S. and European cities where congestion level is relatively low, CO2 externality (at $85/ton) is still much less than the cost of congestion, accidents or local air pollution per km. Therefore, future research that examines CO2 reduction as a co-benefit of, for example, congestion reduction, would provide a different perspective on carbon pathways.

China, among other developing countries, does not have the most mature data aggregation system. For example, transportation activities are still grouped under "transportation and communications" in China Statistical Yearbook. Travel distances are only included in an over-aggregated section that includes national total of rail, road, and aviation travels. Consistent effort needs to be put into improvement of managing statistical information.

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