The Future Energy and GHG Emissions Impact of Alternative Personal Transportation Pathways in China

Paul N. Kishimoto, Sergey Paltsev and Valerie J. Karplus

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Paul N. Kishimoto,*† Sergey Paltsev* and Valerie J. Karplus*

Abstract

A major uncertainty in future energy and greenhouse gas (GHG) emissions projections for China is the evolution of demand for personal transportation modes. This paper explores the implications of divergent personal transportation scenarios, either favoring private vehicles, or emphasizing a sector including all purchased transport (including local public transit, rail and aviation) as substitute for vehicle travel. Motivated by a wide range of forecasts for transport indicators in the literature, we construct plausible scenarios with low-, medium- and high-transport demand growth, and implement them in a technology-rich model which represents opportunities for fuel economy improvement and switching to plug-in hybrid-electric vehicles (PHEVs). The analysis compares primary energy use and GHG emissions in China in the absence and presence of climate policies. We find that a policy that extends the current Chinese emissions-intensity goals through 2050 mostly affects other sectors with lower abatement costs, and so only lightly engages household transport, permitting nearly the same large increases in refined oil demand (by more than five times) and private vehicle stocks (to 430–500 million) as in the reference case. A stringent climate stabilization policy affects household transport, limiting vehicle ownership and petroleum demand, but drives up the share of household spending on transport, and carries high economy-wide costs. The large projected scale of vehicle fleets, refined oil use and transport purchases all suggest that the rate and type of travel demand growth deserves attention by policymakers, as China seeks to address its energy, environmental, and economic goals.

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1. INTRODUCTION

Policies which affect China's future energy use and associated greenhouse gas (GHG) emissions growth trajectory have the potential to substantially impact climate change outcomes at the end of this century (Paltsev *et al.*, 2012). As its energy use and GHG emissions have increased by factors of 5 and 4.6, respectively, over the past three decades, China's share of the global totals has also grown (CDIAC, 2011; BP, 2012). While China has announced energy and carbon intensity targets through 2020, meeting targets in 2020 and beyond depends on technology choices and

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behavioral responses by consumers and firms across the economy, and also on the design of government policies. How these choices and responses are likely to evolve with continued increases in disposable income is a source of considerable uncertainty in future projections of energy use and GHG emissions.

Personal mobility today is a major energy-consuming activity that tends to increase as GDP rises, although the relationship is not uniform and has been shown to depend on a range of factors such as population density or degree of urbanization (Schäfer and Victor, 2000; Dargay *et al.*, 2007; Leaver *et al.*, 2012). In recent years, demand for vehicle ownership and use, as well as purchased modes of travel, has increased rapidly. Today, the transport sector accounts for around 8% of total energy use in China, compared to 28% in the United States and 17% in the European Union (EEA, 2011; U.S. EIA, 2011). Despite its small share in China's energy mix, petroleum requirements of the existing vehicle fleet have raised policy concerns about reliance on imported resources and tailpipe contributions to poor air quality, particularly in urban areas. Policymakers in China are discussing the appropriate combination of support for new energy vehicles and purchased alternatives to vehicle transport in order to address climate, energy, and air quality goals. This analysis identifies the energy and GHG impacts of scenarios that assume different levels of reliance on purchased modes relative to privately-owned vehicles, and considers how policy will interact with these preferences.

This paper is organized as follows. Section 2 summarizes key historical trends in passenger travel volume and mode shares, in particular the recent and current rapid increase in the ownership and use of passenger vehicles. We outline the motivation for the present work by comparing the emissions intensities of these rapidly growing modes with others, and reviewing recent literature which forecasts China's personal mobility (including vehicle) demand. Section 3 introduces the EPPA model, the development of three scenarios for demand growth of vehicles relative to other modes, and the method for implementing these scenarios in the model. Section 4 describes the energy use and GHG emissions impacts in each of the scenarios in the presence and absence of a CO_2-equivalent constraint, which is implemented as an economy-wide cap-and-trade system. Section 5 offers general conclusions based on the results.

2. BACKGROUND

2.1 Evolution of transport demand in China

Figure 1 presents historical data on passenger transport in China on the basis of passenger distance traveled (PDT), the sum of the lengths of all individual trips on each mode.[1] As recently as 1980, rail travel provided the largest share of PDT, but road travel—including pur-

[1] PDT is also referred to as PKT (in kilometers) or PMT (in miles), and is related to *vehicle* distance traveled (VDT; similarly VKT or VMT) through the number of passengers per vehicle, usually termed *occupancy* for private vehicles, or *load factor* for rail and air transport.

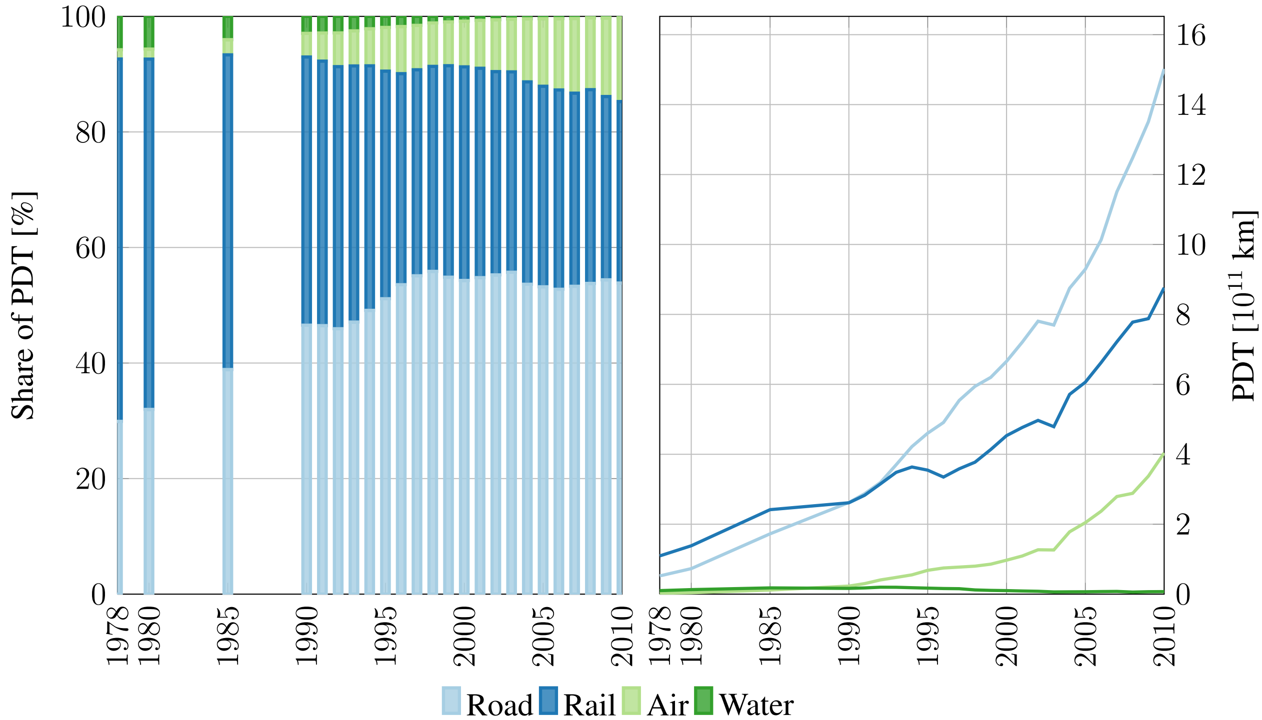

Figure 1. Historical mode share of passenger transport in China by distance travelled, 1978–2010 (National Bureau of Statistics of China, 2012a).

chased transport on buses and taxis, company- or government-owned vehicles, and private vehicle travel—overtook rail by 1990, and has since grown to nearly 55% of all travel. In absolute terms, the total travel volume has increased rapidly, accelerating with China's economic growth since 2000. While rail and air travel continue to increase—with civil aviation doubling in PDT between 2005 and 2010—road transport continues to contribute the largest total mileage increases to passenger transport demand.

2.2 Contribution of passenger vehicles

Understanding how China's vehicle fleet will grow in the future requires understanding regional disparities in travel demand. As shown in **Figure 2**, there is not a tight correspondence between annual per capita income and levels of private household vehicle ownership in China across its provinces. Beijing and Shanghai, the two provinces with the highest per-capita incomes, had very different levels of vehicle ownership in 2009. Hao *et al.* (2011) discuss how Shanghai's decade-old license plate auction policy has significantly reduced ownership by increasing the costs of vehicle ownership relative to Beijing, but other, quota-free provinces such as Tianjin display low ownership with high GDP relative to the national average. As disposable income grows, whether the less developed provinces follow a trajectory closer to Beijing or to Shanghai will—together with region-specific demands for travel—determine energy and envi-

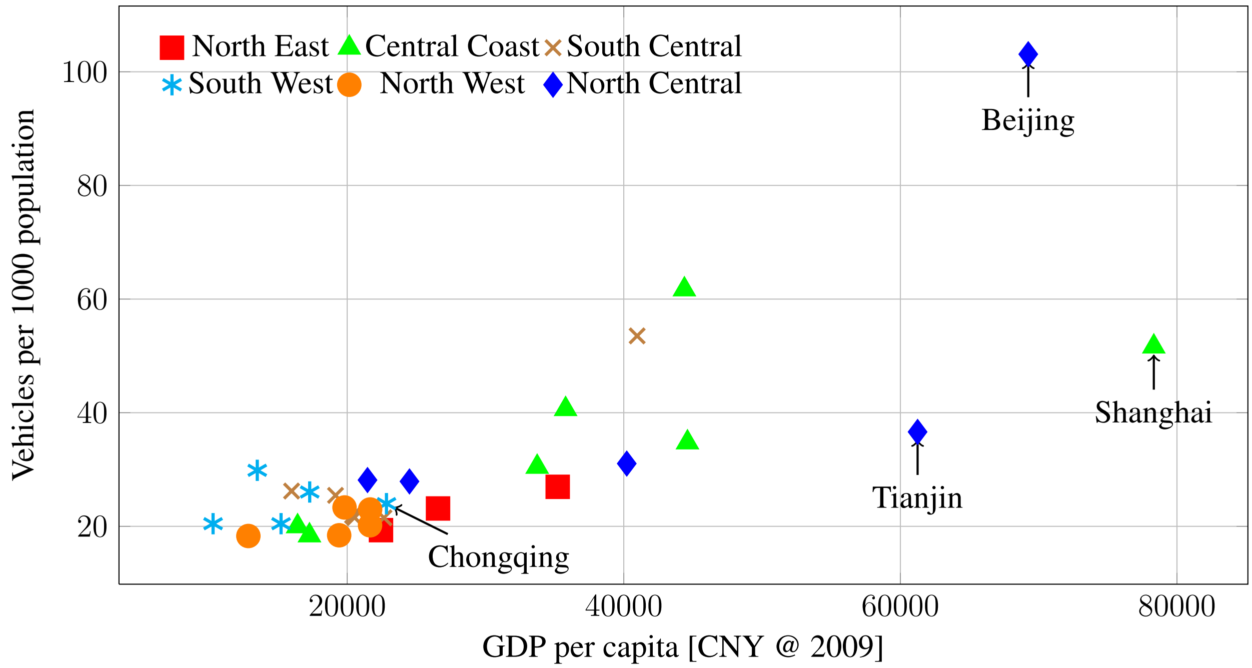

Figure 2. Static income–ownership relationship for Chinese provinces as of 2009 (National Bureau of Statistics of China, 2011). Each data point corresponds to a Chinese province, which are grouped into six regions. The four direct-controlled municipalities are labelled.

ronmental impact in the nation as a whole. Another critical source of uncertainty is consumers' willingness and ability to substitute between purchased modes and private vehicle ownership (Hu *et al.*, 2010).

The main contribution of this analysis is to understand the implications of meeting rising travel demand through different modes in a framework that allows for different assumptions about how vehicle ownership will grow with income and captures inter-modal competition for transportation fuels. Most forecasts of transportation energy use in China have been performed with bottom-up vehicle fleet and energy accounting models that take vehicle stock, distance traveled, vehicle fuel economy and powertrain technology, and fuel prices (if used) as given—including those discussed later in Section 2.4 and shown in Figure 3. A few studies of the impacts of policies on transportation energy use have been conducted using energy-economic models with broad sectoral coverage (Zhou *et al.*, 2011). Schäfer and Jacoby (2006) incorporate price feedbacks to demand and capture endogenously the impact of global climate policy on transport mode shares and technology choice using a coupled top-down bottom-up modeling approach. Here we use a technology-rich top-down model to simulate exogenously imposed relationships between income growth and shares of PDT provided by purchased modes and privately-owned vehicles. This economy-wide energy-economic framework further allows us to perform an initial assessment of the impact of emissions and other constraints on transportation energy use and CO_2 emissions outcomes under alternative mode share scenarios. Although our analysis includes a

Table 1. Energy intensity of transport, by mode (National Bureau of Statistics of China, 2012b).

	China		**Japan**	
Mode	2005	2008	2005	2008
Passenger [10^5 J/passenger·km]				
Car	39.7	35.1	25.1	23.6
Bus	6.5	6.5	7.1	6.7
Rail	1.8	1.7	2.1	2.0
Air	20.1	18.6	18.1	19.8
Freight [10^5 J/t·km]				
Automobile	44.4	43.9	32.5	30.3
Rail	2.8	2.8	2.5	2.4
Waterway	13.7	11.0	10.0	8.4
Air	225.1	208.4	216.7	211.7

plug-in hybrid-electric vehicle (PHEV) technology, we focus here on the transport sector effects of economy-wide emissions policy, as other work (Karplus *et al.*, 2012a) examines the effects of sector-specific policy for private household transport, namely fuel economy mandates, and sensitivity to the costs of alternate powertrains.

2.3 Energy & emissions factors by mode in China and discussion

The significance of historical mode shifts, as mentioned Section 2.1, with growing overall demand and an increasing popularity of private vehicles in road transport, is further emphasized when the energy- and emissions-intensities of these modes are compared. **Table 1** gives official data from the National Bureau of Statistics of China on energy intensity of transport by mode for both passenger and freight transport, including their comparison with like figures from Japan, while **Table 2** summarizes a variety of studies from recent years on the CO_2 emissions intensities of the same modes in China, or internationally where Chinese data is unavailable.

The low occupancy of private vehicles makes them several times more energy- and emissions-intensive than bus travel. Even with a constant share of PDT for passenger road transport, a shift (driven by increasing income or other factors) from purchased bus travel to own-supplied car travel would bring an attendant increase in energy use and emissions. For long-distance or inter-city travel, light duty private vehicles are also an energy-intensive choice. Also, while China has a growing suite of policies designed to promote the development and sales of alternative-fuel or “New Energy Vehicles” (NEVs)—including plug-in hybrid- and battery-electric vehicles—(Gong *et al.*, 2012), studies show that the emissions-intensity of these vehicles does not represent a large improvement on gasoline vehicles when there are recharged from China’s coal-heavy electrical grid (Ou *et al.*, 2010).

Table 2. Comparison of existing estimates of Chinese passenger transport emissions intensity, by mode. Where the cited studies provide ranges, these are reproduced; average figures are shown in parentheses. The starred figures for intercity rail are for the United States and Europe; actual Chinese values would differ according to technology, operations and—as noted by Ou *et al.* (2010)—the higher, regionally-varied emissions intensity of Chinese electricity used to drive the trains.

Mode	CO_2 emissions [g/passenger·km]	Source
Road		
Bicycle	< 4	Cherry *et al.* (2009)
Bus	24–97	”
2 wheelers		
Electric scooter	20–40	”
Gasoline moped	65	Yan and Crookes (2010)
Motorcycle	64–128	Cherry *et al.* (2009)
Cars	102–306	”
Battery-electric	35–162 (131)	Ou *et al.* (2010)
Gasoline	200	”
Rail		
Urban/metro/subway	49	Yan and Crookes (2010)
High-speed intercity*	10–120 (21)	Kosinski *et al.* (2011)
Regular-speed intercity*	14	Kageson (2009)
Air	100–500 (150)	Chester and Horvath (2010)

2.4 Previous work

The relationship between rising personal mobility demand and energy and emissions outcomes has been extensively studied in previous global, regional, national, and sub-national forecasting exercises. These studies span the transport demand modeling and energy economics literatures, and employ a wide range of methods and techniques. Studies vary in the number of different demand drivers they consider. Schäfer and Victor (2000) employ an empirically-estimated travel-time budget and travel-money budget (as a fraction of income) to forecast demand for different modes over time, modeling a shift to ever-faster modes as income increases. Other models focus on vehicle ownership and include additional factors such as urbanization and population density (Dargay *et al.*, 2007) or account explicitly for changes in the household transport expenditures and demand as disposable incomes rise (Meyer *et al.*, 2007).

Studies of China's future transport energy and CO_2 emissions begin with projections of demand for vehicle-kilometers traveled or passenger-kilometers traveled. Most China-related transport studies to date have focused on demand for vehicles and vehicle travel (Wang *et al.*, 2006; Dargay *et al.*, 2007; Han and Hayashi, 2008; Wang *et al.*, 2011; Huo *et al.*, 2011a,b; A.T. Kearney, 2011; Barclays Capital, 2011), while less attention has been focused on demand for purchased modes. As shown in **Figure 3**, projections of vehicle stock vary widely. From the early 2000s through 2011 most studies underestimated the rate of light-duty or privately-owned vehicle

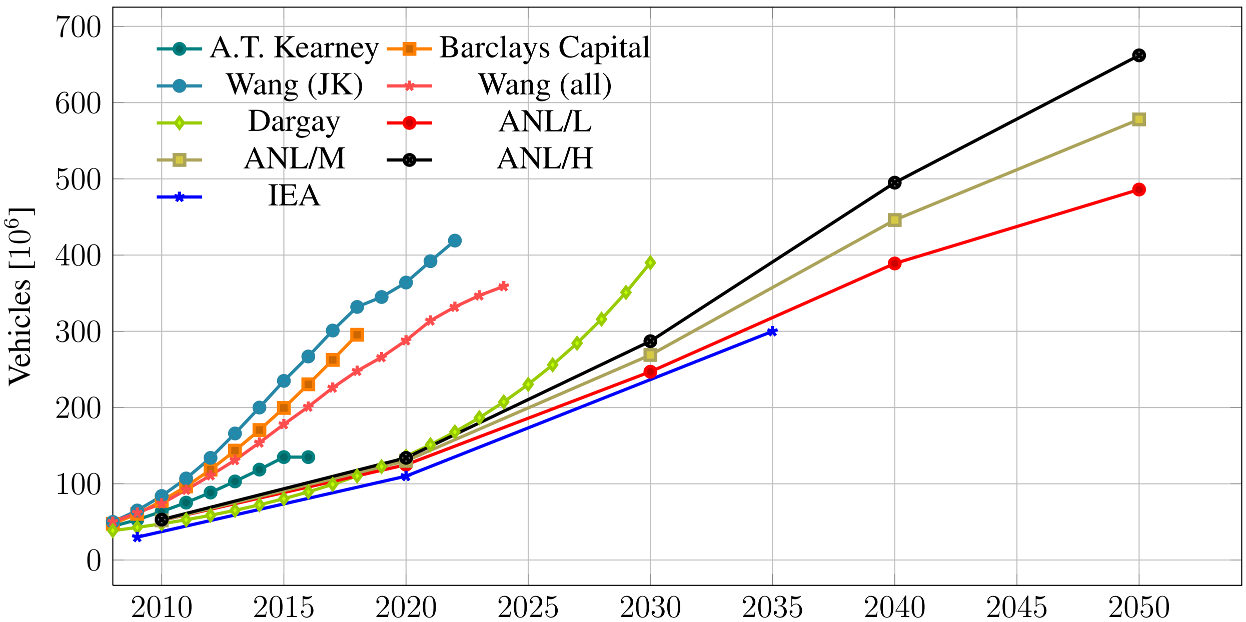

Figure 3. Projected growth of total vehicles in use (stock) through 2050 by various studies. "Wang (JK)" and "Wang (all)" refer to the projections from Wang *et al.* (2011) using the Japan/Korea and all-countries panels, respectively. The Argonne National Laboratory (ANL) Low-, Medium- and High-growth projections are from Wang *et al.* (2006); others from (Dargay *et al.*, 2007; A.T. Kearney, 2011; Barclays Capital, 2011; International Energy Agency, 2011).

fleet growth; projecting a 2010 vehicle population of 47–54 million against an actual figure of 78 million (Wang *et al.*, 2011; National Bureau of Statistics of China, 2011). This disparity is due primarily to variation in the estimates of new vehicle sales growth over the same period. Studies also differ in the assumptions on vehicle fuel efficiency and annual kilometers-traveled per vehicle, leading to a wide range of projections of refined fuel demand and CO_2 emissions.

3. METHODOLOGY

3.1 The MIT Emissions Prediction & Policy Analysis (EPPA) model

The model used in this analysis is a specialized version of the MIT Emissions Prediction and Policy Analysis (EPPA) model that includes a technology-rich representation of the passenger vehicle transport sector and its substitution with purchased modes, represented as the aggregate of aviation, long- and short-distance rail, marine and public road transport. The EPPA model is a recursive-dynamic general equilibrium model of the world economy developed by the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology (Paltsev *et al.*, 2005). The model is built using the Global Trade Analysis Project (GTAP) dataset (Hertel, 1997; Dimaranan and McDougall, 2002). For use in EPPA, GTAP data are aggregated into 16 regions and 24 sectors with several advanced technology sectors. Accounts of Kyoto Protocol greenhouse gases[2] are based on GTAP and United States Environmental Protection Agency inventory data, and air pollutants are from the EDGAR database (as documented in Waugh *et al.*, 2011).

Several features were incorporated into the EPPA model to explicitly represent passenger vehicle transport sector detail. These features include an empirically-based parameterization of the relationship between income growth and demand for vehicle-miles traveled, a representation of fleet turnover, and opportunities for fuel use and emissions abatement. These model developments, which constitute the EPPA5-HTRN version of the model, are described in detail in Karplus *et al.* (2012b).

The present work also contains a renewed calibration of the private vehicle sectors, with special attention paid to China, using up-to-date data from sources including the *World Energy Balances* (International Energy Agency, 2010), *Passport GMID* (Euromonitor International, 2011), and the *World Road Statistics* databases (International Road Federation, 2010).

3.2 Scenarios of travel demand growth

Surveying the projections for transport indicators illustrated in Figure 3, we observe that they differ greatly; are generated using a variety of methods; and, where the methods include a parameterization of hypothetical peak vehicle ownership, set that level in China at a variety of levels relative to those in other countries—from Japan's 325 per thousand capita on the low side, to the United States' 820 per thousand capita on the high side (International Road Federation, 2010). Motivated by the wide range of these projections, while not seeking to reproduce them directly, we develop three scenarios which (1) represent possible futures with low-, medium- and high demand for household transport and purchased vehicles, (2) do not repeat earlier studies' underestimation of vehicle fleet growth, and (3) do not exceed a reasonable maximum of 15% household budget share for transport[3] in the reference case. The method used is as follows.

The constant elasticity of substitution (CES) utility of the EPPA representative household results in demand shares for commodities that tend to be preserved even as total consumption grows. In the case of transport, this means that expenditure on each of purchased and private vehicle transport grows at the same rate as GDP. China's recent experience of rapidly demand growth is remarkable because, as highlighted in Wang *et al.* (2011) and elsewhere, it has held at several points above the rate of GDP growth for several years. This indicates a rising share of expenditure for transport.

To recreate this trend and its potential continuation in EPPA, the *reference* household expenditure on transport is adjusted so that output vehicle stocks match observed values. In all scenarios,

[2] Carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6.

[3] This according to a range of 5–15% for developed countries given by Schäfer (1998).

the total demand for travel is scaled upwards until the most recent model period (2010), so that outputs for private transport match available data. A final adjustment in the 2010–2015 period is different among our scenarios, and produces three trajectories in demand growth.

The scenarios also encode an assumption following Schäfer and Victor (2000) that the most rapid growth in travel demand will come with a stronger preference for faster modes (personal vehicles, fast and high speed rail, air) over slower ones (urban buses, two-wheeled vehicles, bicycles and walking). Because purchased transport in China is currently composed mostly of lower-speed modes,[4] we model this behavior by depressing the share of purchased transport in total consumption, so that the additional activity resulting from increased household transport expenditure involves a greater fraction of own-supplied than purchased transport. This effect is most pronounced in the high vehicle ownership scenario. Finally, in all scenarios the income share of transport in the overall household budget is attenuated in the later periods.

The EPPA-HTRN model structure includes a substitution elasticity of 0.2 between purchased and own-supplied transport, so these adjustments to observed activity and the per-scenario relationships between modes only hold in the absence of policy (i.e. the business-as-usual projection). In particular, vehicle stocks are allowed to change from their adjusted reference levels in response to the policies outlined below. Direct and indirect effects of policy alter the relative prices of travel obtained from the two modes, so in each successive period the representative Chinese household may shift travel activity in either direction.

3.3 Policies

Model runs for all three scenarios were conducted both with and without climate policy. Runs without policy provide a reference, business-as-usual projection. Two climate policies both involve economy-wide caps on carbon dioxide emissions, without emissions trading between Kyoto Protocol gases or between China and other EPPA regions. Both policies begin in 2020. Unlike Karplus *et al.* (2012a), which uses other capabilities of EPPA-HTRN to assess the effect of fuel economy standards imposed on household vehicles in China and other regions, the policies we study here are selected to identify the relative participation of household transport relative to other sectors in China specifically.

One policy models the extension through 2050 of current commitments under the Chinese Twelfth Five-Year Plan (12-FYP), which covers the years 2011 through 2015 inclusive. The specific 12-FYP target is to reduce the CO_2 emissions intensity of GDP by 17% over the plan's period. In the Eleventh Five-Year Plan, a 20% reduction target was specified in a similar manner, and a 19% reduction achieved (Deutsche Bank, 2011). Additionally, figures cited by China in international negotiations indicate an 11–18% reduction in the period of the Thirteenth Five-Year

[4] i.e. high speed rail and aviation have small, albeit growing, shares.

Plan (yet to be published) (Casey and Koleski, 2011), assuming the 12-FYP target is met. Accordingly, we apply a CO_2 emissions intensity reduction of 17% every five years (that is, every EPPA period) from 2020 onwards. Multiplying the business-as-usual GDP projection by the target intensity yields the capped amount of CO_2 emissions. This policy is referred to as the *FYP extension* policy, or simply "FYP" in figures.

Second, we use an aggressive climate stabilization policy derived from Clarke *et al.* (2009) via Paltsev *et al.* (2012), wherein global quotas on emissions are designed to result in end-of-century greenhouse gas concentrations of 550 parts per million CO_2 equivalent. The policy becomes active in 2020[5] and achieves 50% of reference-case emissions in 2050, where our model runs end. Every EPPA region follows the same trajectory of percentage reductions relative to reference. Such a policy imposes substantial changes to an energy system at a significant cost. There are certain ways to achieve a global target at a lower cost for China by participating in global emissions trading or through financial transfers (Jacoby *et al.*, 2009). Here we focus on an aggressive implementation to represent large emissions reductions. This ensures that other sectors with a lower marginal cost of abatement relative to household transport are engaged, so that household transport itself is eventually marginal and participates significantly in achieving the emissions target. Studying this policy allows us to examine these effects in the model outputs.

4. RESULTS

In **Figures 4–10** we present results and implications with a focus on primary energy, emissions—both in absolute terms and per unit of household travel—as well as vehicle ownership, costs, and the shares of purchased and private vehicle transport. Outcomes for each policy are compared to the reference projection, and notable differences between results under the low-, medium- and high-demand scenarios are noted.

Figure 4 gives total primary energy use in the reference (no policy) and policy cases, by source. Under business-as-usual, demand for petroleum rises sharply, to as much as 33% of all primary energy, or in absolute terms by a factor of 5.4 in the medium-demand scenario, and demand grows even in the last period projected (2045–2050). The Five-Year Plan extension policy has modest impacts, which more strongly affect emissions-intensive fuels and as well as fuels for which lower-cost abatement opportunities exist. In particular, coal use peaks by 2030–2035 under this policy and declines while oil demand is constant in later periods, with the result that refined oil has a larger share of a smaller energy total in 2050.

In contrast, the climate stabilization policy has effects which are dramatic in both the short- and long-term, which highlights the aggressive nature of this type of policy in China, and its high associated costs. The consumption of transport fuels derived from oil (in deep blue) shows reductions that are large, yet smaller than those experienced by coal-fired energy, reflecting the relative

[5] The earliest date conceivable given the state of current international negotiations.

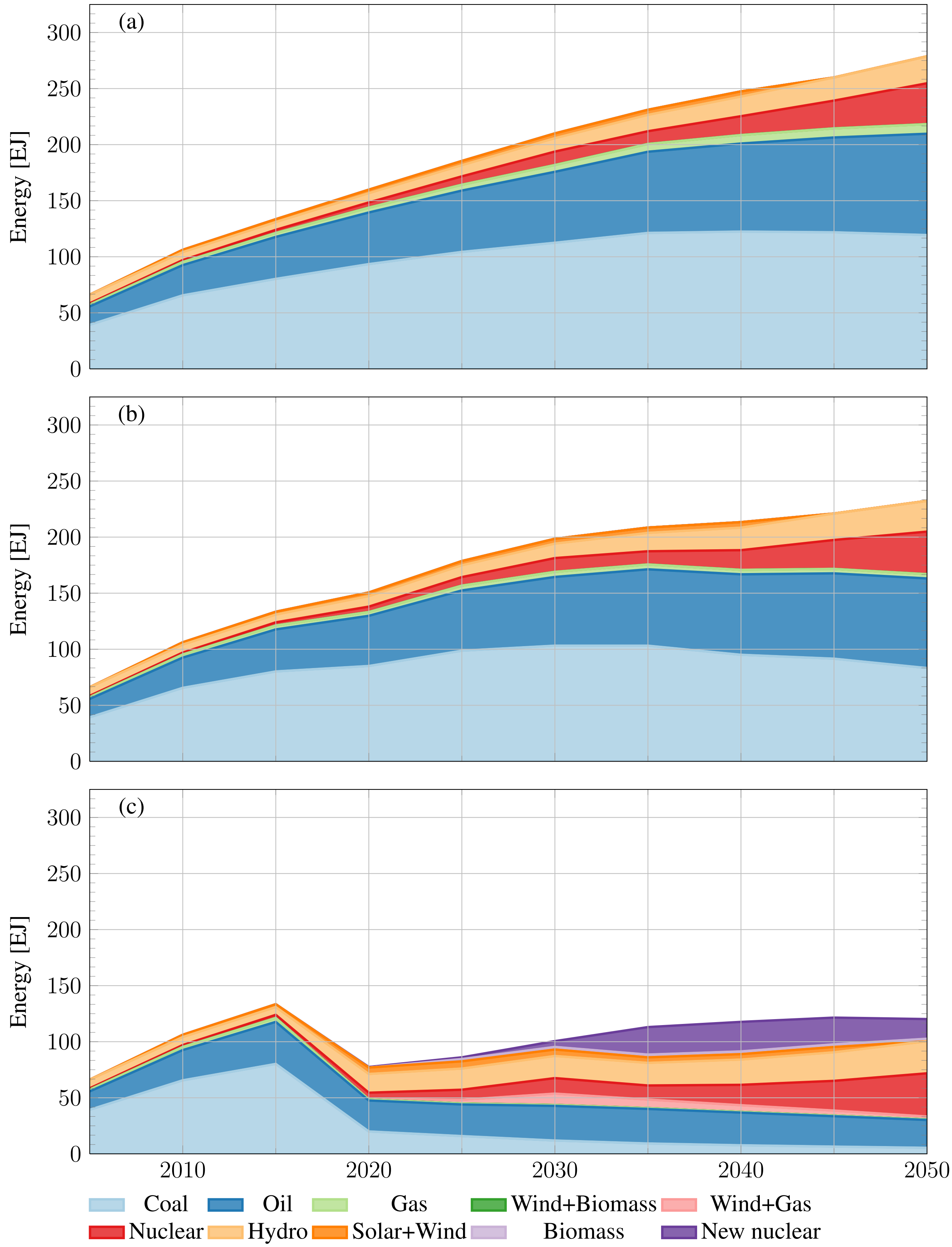

Figure 4. Total Chinese primary energy by source and year, in the medium growth scenario; under business-as-usual (a), the Five-Year Plan extension policy (b), and the climate stabilization policy (c).

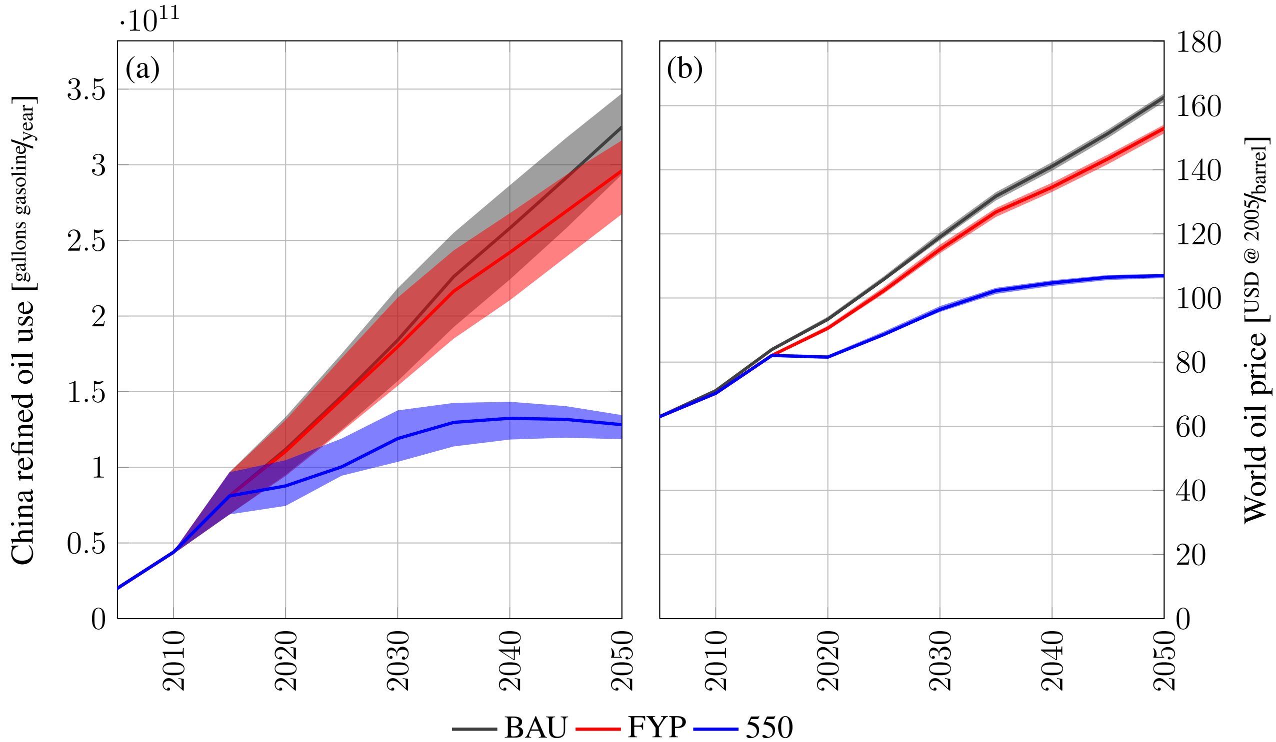

Figure 5. Oil projections, by year. (a) Chinese refined oil use in household transportation, and (b) global oil price. For visual simplicity, some projections are shown as a band between the low- and high-demand scenario results, with the medium-demand scenario as a solid line. The shaded area does not represent a range of uncertainty or indicate the likelihood of values other than those resulting from the three scenarios.

difficulty of switching to alternate fuels in transport. The effect of this policy is a sharp initial reduction in oil consumption, followed by a very gradual growth through 2030 (reaching 38–46% of reference case demand) and then slow decline to 21–24% of reference demand. Less visible in the figure is the increase in advanced, low-carbon biofuels, which are not adopted in the reference case, but peak at 2.3–3.1 exajoules (EJ) (7–8% of combined oil plus biofuel demand) under policy.

Figure 5(a) displays final, rather than primary energy, and focuses on refined oil used to power passenger vehicle transport. Under business-as-usual and the Five-Year Plan extension policy, demand continues to grow strongly through 2050, passing the current United States level of about 120 billion gallons gasoline per year (U.S. EIA, 2012) by 2025, and approaching or exceeding 2.5 times that level by 2050. With the FYP policy providing incentives to both reduce driving activity and also invest in more expensive vehicle capital with greater fuel economy, refined oil use is slightly lower. The climate stabilization policy eventually halts growth in refined oil demand in absolute terms, by 2040 at a level of 130 billion gallons per year in the medium-demand scenario, slightly above the current level for all U.S. light duty vehicles. **Figure 5(b)** demonstrates the global effect of China's large demand by showing the market price for crude oil. The slight

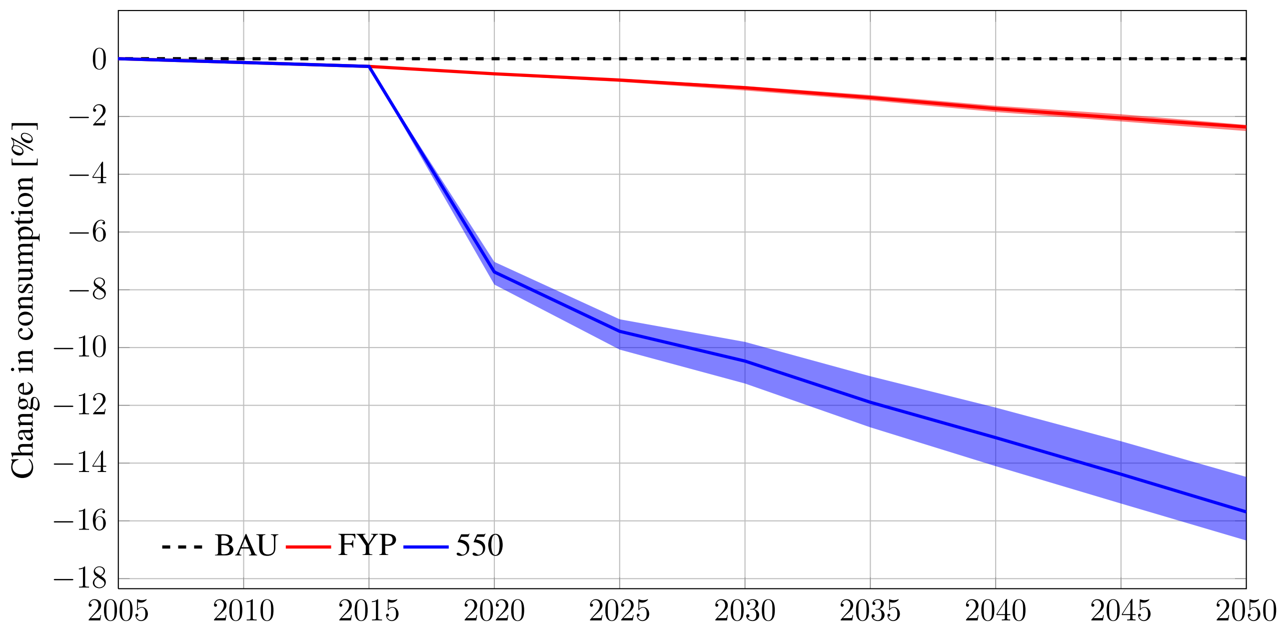

Figure 6. Change in consumption due to policy relative to reference case, by year. The low-demand projections result in *smaller* percentage decreases, so the shaded band is inverted in comparison to other figures.

decrease in domestic refined oil use under the FYP policy reduces the global price by about 6%, and the effectively capped demand under the climate stabilization policy lowers the world price by over 45 USD, both by 2050. Even in this scenario, the global oil price stays in the range of 80–100 USD.

Figure 6 shows the percentage change in aggregate consumption measured as equivalent variation relative to the business-as-usual value. Consumption is one measure of welfare in EPPA, and change in consumption a measure of policy cost. The Five-Year Plan extension policy is notable for its small impact on overall consumption, reducing it by only 1% in 2030 and 2.2% by 2050. The stringent climate policy, on the other hand, has a large impact in the initial period (2015–2020) of 7–8% of consumption relative to reference, with consumption falling to 15–17% below the business-as-usual value in the final period. Compared to the base effect of each policy, the incremental effect of stronger travel demand on the policy cost is small.

The magnitude and relative demand for travel by purchased and private vehicle transport are illustrated in **Figure 7**, with each case evolving from the current situation in the lower left. The unadjusted reference trend is also shown, to illustrate a hypothetical situation of growth with constant shares for purchased and own-supplied modes. Under business-as-usual, each scenario shows its designed, increased preference for own-supplied transport, as well as higher or lower levels of total travel demand.

Under the Five-Year Plan extension policy, total travel volume decreases, while the relative departure from constant mode shares remains the same; the points on the FYP trajectories fall between the corresponding points on the BAU projections and the origin. The climate stabilization policy, however, has an opposite effect; the mode preference imposed in each scenario cannot be met to the same degree as household budgets are stretched to cover both fuel with high carbon price attached and more expensive vehicles which provide travel with less fuel. Overall household transport activity reaches, by 2050, a level comparable to the 2025 state of the reference projection, and the imposed high demand is met with a greater reliance on purchased modes.

Within the own-supplied portion of these volume projections, though not shown in Figure 7, PHEV technology is adopted in response to policy, and by mid-century 5.2–6.3% of PDT under the FYP policy, and 15–17% under the climate stabilization policy, are supplied by plug-in hybrid vehicles.

Figure 8 shows per-capita vehicle ownership under each policy, resembling Figure 5 aside from some key differences. Households investing in more efficient vehicles under each policy can satisfy their higher demand for travel with lower fuel input; this allows own-supplied transport volume and vehicle ownership to grow at a greater rate than refined oil demand. Consequently, while Figure 5 shows a peak in fuel use under the climate stabilization policy, vehicle ownership continues to increase to the level of 200 vehicles per thousand capita by mid-century. Likewise, the Five-Year Plan extension policy projections more closely overlay the business-as-usual projections, with per-capita ownership continuing to increase steadily in 2045–2050. However, the level of household vehicle ownership at this point—below 400 per thousand capita—still remains low in comparison to the that of current mature markets with constant ownership, such as the European Union at 475 per thousand capita (International Energy Agency, 2011).

Energy and emissions intensities are given in **Figure 9** and **Figure 10** respectively. The reference projections in both cases reflect the combined effects of autonomous energy efficient improvement (AEEI), a representation in the EPPA model of technology and other improvements made in the household transport and other sectors which do *not* occur in response to price, yet result in decreasing energy intensity of production (in this case, of passenger travel volume) with time. In Figure 10, AEEI can be observed within the own-supplied transport subsector; however, because of the mode shift from purchased transport with a low emissions-intensity to own-supplied transport, the mode-weighted average emissions intensity of household transport increases in the reference case. In Figure 9, a small effect of higher demand is visible: faced with higher costs to provide that demand, households invest slightly more in vehicles with better fuel economy.

The effect of the Five-Year Plan extension policy is a slight improvement in the overall energy intensity of household transport, by about 5% across cases relative to business-as-usual or 16% over time from 2015 to 2050. The FYP extension policy achieves a 70% reduction in energy intensity of GDP across the same period. While GDP and transport volume do not evolve identi-

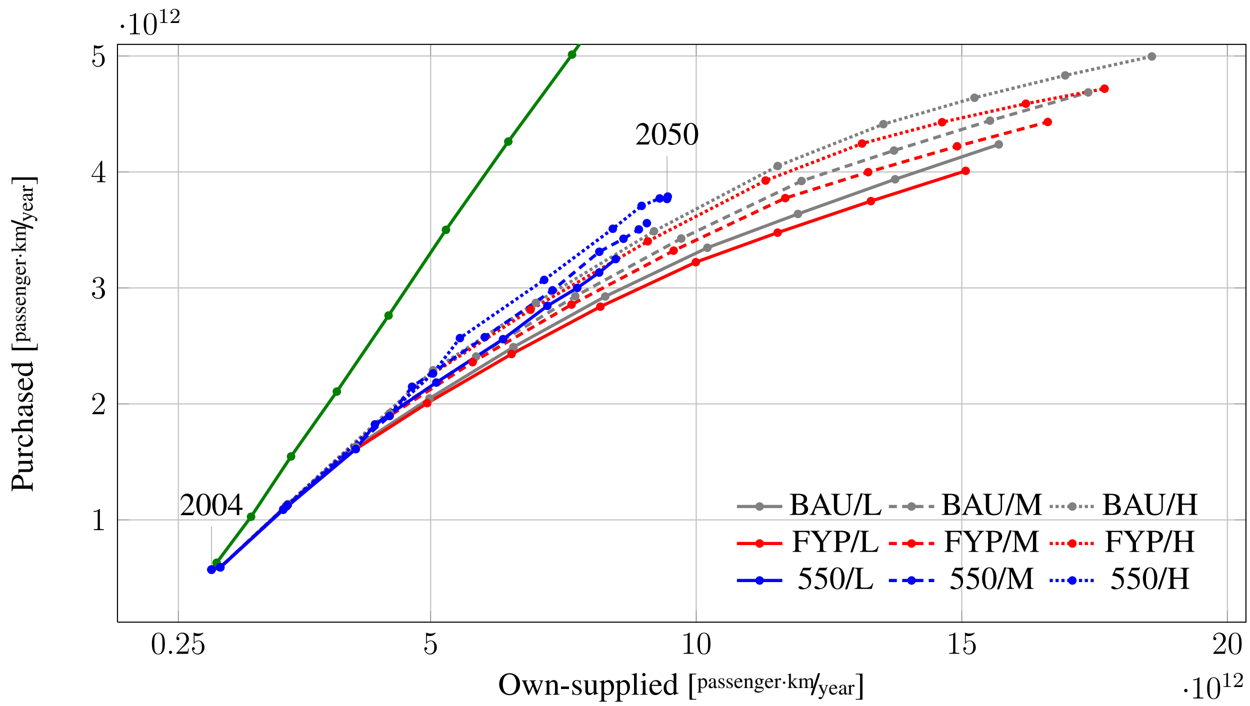

Figure 7. Trajectories of purchased and own-supplied transport, by scenario, with "constant mode share" unadjusted reference projection (green).

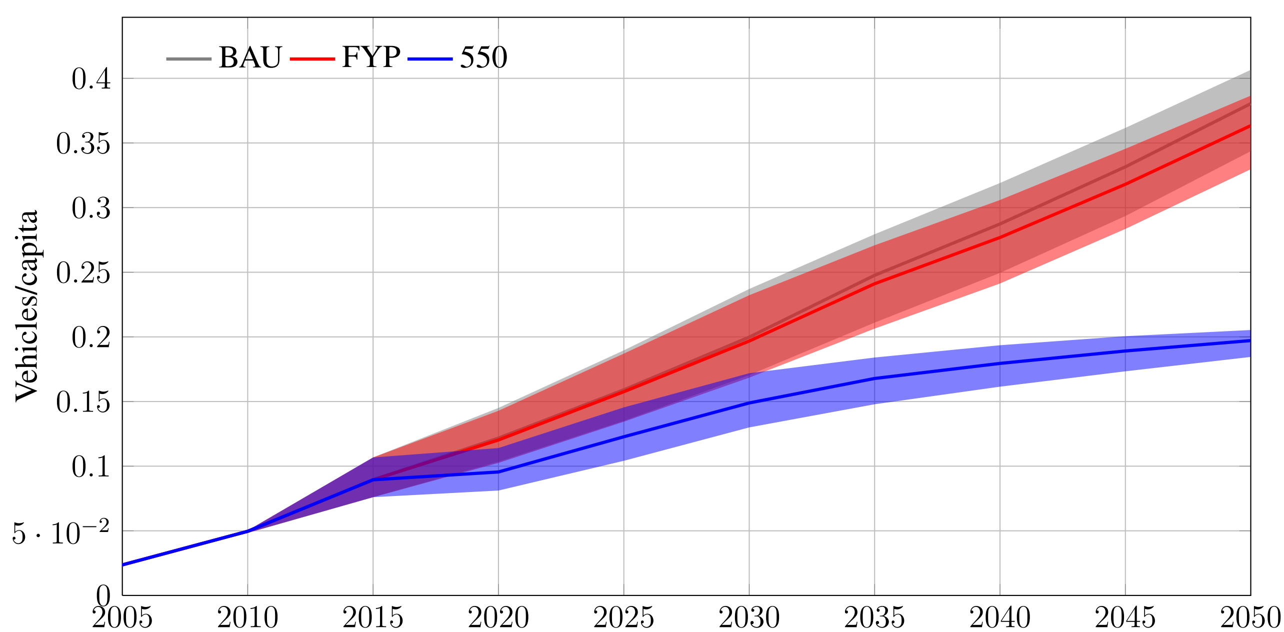

Figure 8. Per-capita vehicle ownership, by year.

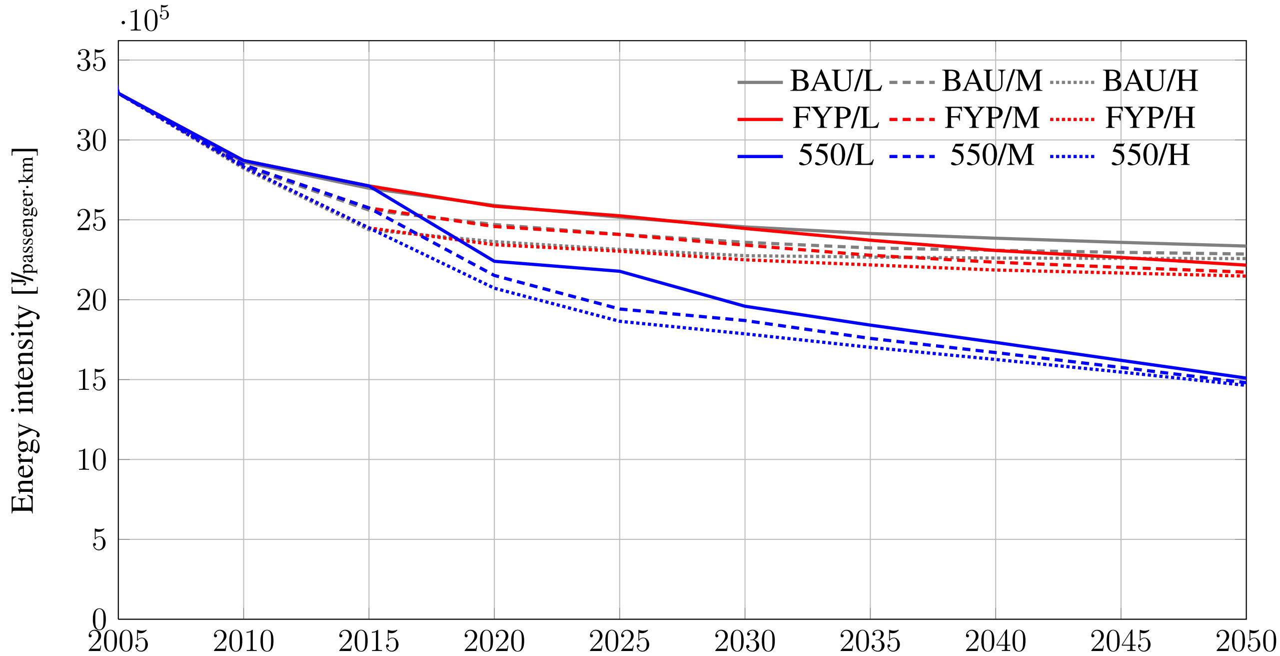

Figure 9. Average energy intensity of household transport, by year, under the Low-, Medium- and High demand growth scenarios.

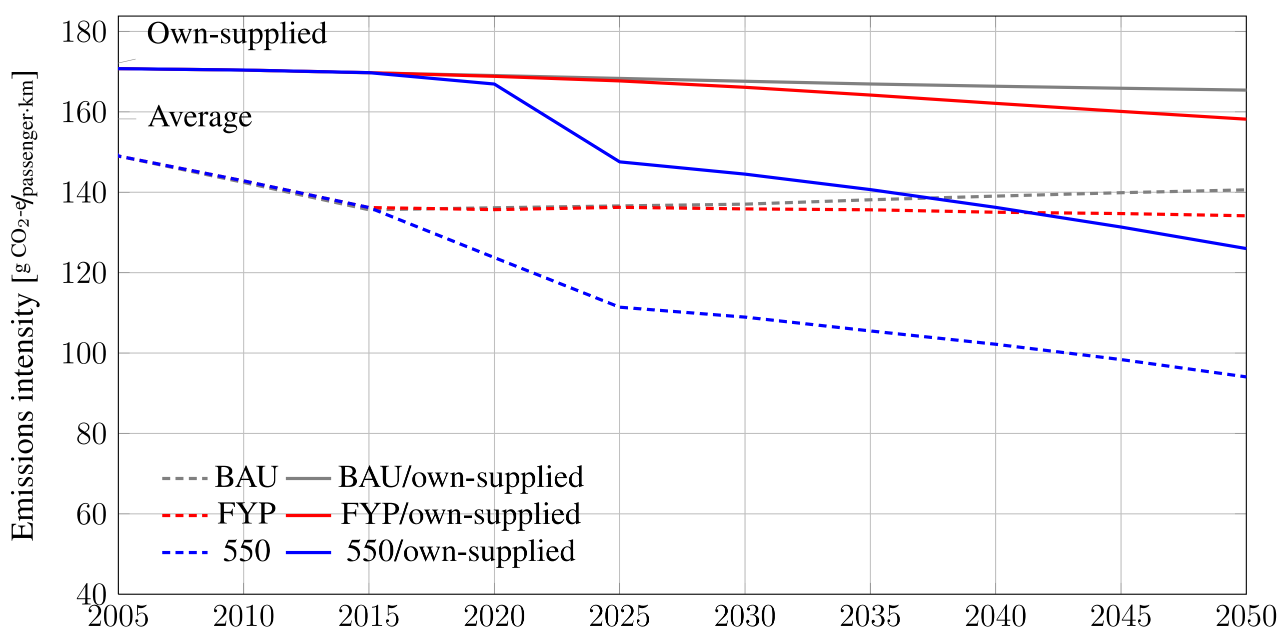

Figure 10. Emissions-intensity of transport, by year for the high-growth scenario, with and without policy.

Table 3. Other projection outcomes summarized.

	Low demand			**Medium demand**			**High demand**		
	BAU	FYP	550	BAU	FYP	550	BAU	FYP	550
Expenditure share of transport [%]									
2030, total	10.5	10.3	12.9	12.1	12.0	15.4	14.0	14.0	18.6
purchased	3.1	3.1	3.0	3.6	3.5	3.5	4.1	4.0	4.0
own-supplied	7.4	7.3	9.9	8.5	8.5	11.9	9.8	9.9	14.5
2050, total	10.2	10.2	18.5	11.2	11.3	21.5	11.9	12.1	23.7
purchased	2.2	2.2	2.0	2.4	2.4	2.2	2.6	2.5	2.3
own-supplied	8.0	8.1	16.5	8.8	9.0	19.3	9.3	9.6	21.4
Vehicle stock [10^6]									
2030	239	236	182	280	276	209	332	325	241
2040	342	331	221	394	379	246	437	419	265
2050	448	430	241	496	474	257	530	505	268

cally, the large disparity reflects the high cost of energy use reductions in the household transport sector. The slight gains from improved vehicle energy efficiency serve to offset the noted effect of mode shift, so that emissions intensity is essentially flat under this policy.

The climate stabilization policy results in a large improvement in average energy intensity of transport, by about 35% between 2015 and 2050. Under higher demand for transport, these improvements occur sooner than with low demand, and as expensive powertrain improvements become an economic substitute for more expensive fuel, the emissions intensity of own-supplied transport shows a continued decline that more than offsets the effect of a less pronounced shift away from low-emissions purchased modes.

Expenditures on own-supplied transport can also be converted into estimates of vehicle stock, under an assumption that the amount of non-powertrain capital per individual vehicle remains the same as in the base period. **Table 3** contains these data, as well as the share in overall household consumption for each type of transport. Examining the expenditure share under the aggressive 550/stabilization policy, it is notable that households consume considerably more own-supplied transport—up to ten times as much as purchased transport—even as the total travel budget goes to the unrealistically high level of 21.4% in the medium-demand scenario. This is a reflection of the EPPA model's previously-calibrated elasticity of substitution $\sigma = 0.2$ between purchased and own-supplied transport. Testing the sensitivity to much easier modal substitution ($\sigma = 0.8$), we find the ratio of own-supplied to purchased consumption drops to about 3.5, while the total travel budget drops to 18%.[6] In practice, action by government, technology development or other factors might arise in the face of combined high fuel costs and transport demand to ease the sub-

[6] Still, however, outside the range of 5–15% noted in Section 3.2.

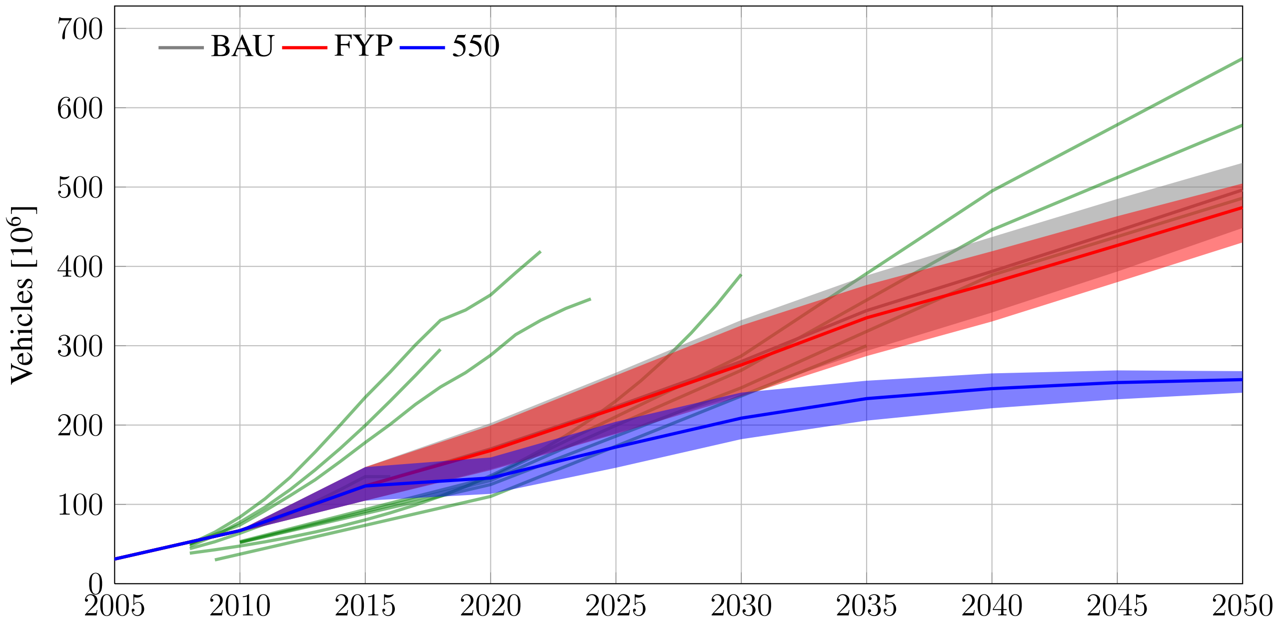

Figure 11. Total China vehicle stock, by year. Range of EPPA projections displayed as shaded bands; overlaid on projections from literature as in Figure 3 (green).

stitution from vehicles to purchased modes.

Figure 11 shows that the vehicle stock results for the reference scenarios are, by design, within the range of the projections from literature, aside from not repeating the under-prediction of earlier studies to 2010, and not pushing reference case household transport expenditure share above the maximum plausible level of 15% in early periods. The model tracks constant-quality vehicles, where spending on vehicle luxury is, at present, assumed to be captured elsewhere in the consumption bundle. If, as in the United States, Chinese consumers buy more expensive vehicles on average as their wealth increases, actual stock may be lower. Regardless, the figures illustrate the large impact of even moderate levels of ownership in a very large country. In later periods, high costs cause our scenarios to yield lower stocks than most other projections which run to 2050; with policy, this difference is more pronounced.

5. CONCLUSIONS

In this paper, we studied three pathways of increasing travel demand in China, both on their own and in the absence of a representative climate policy required for stabilization. Across model outcomes, the policy example which continues through 2050 the economy-wide emissions intensity reductions in current Chinese policy does not significantly affect transport, and permits continued growth in amounts of own-supplied vehicle travel, as well as attendant growth in refined oil use and emissions from transport. In contrast, a stringent policy in which China participates in significant emissions reductions affects overall economic welfare, including transport growth, heavily—highlighting the trade-off between promoting development and environmental goals. These conclusions are robust across a range of assumptions about differing growth in demand for household transport and mode emphasis, although the highest forecast demand results in especially acute choices for household expenditure.

When rapid growth in Chinese household transport follows the elsewhere observed shift away from purchased modes to private vehicles, overall emissions intensity of travel grows even as the intensity of the individual modes declines. Conversely, changes in passenger travel mode share induced by policy can limit or reverse this effect. However, more detailed analysis which represents low- and high-speed purchased modes (and their substitutability) separately is necessary to estimate these effects with precision.

More particular results include a larger role for biofuels under policy, with the stabilization policy arresting growth in fuel use and overall demand for both own-supplied and purchased PDT by about 2030. Without policy, oil becomes nearly as prominent as coal in the primary energy mix, and even with a very large share of income devoted to transport in the high-ownership scenario, per-capita vehicle ownership levels remain well below those in mature markets. Under the climate stabilization policy, approximately 16% of household vehicle transport is derived from hybrid vehicles, but under the emissions intensity policy this alternate vehicle technology only supplies 5% of passenger travel distance.

In light of an objective to reduce energy intensity by 45% between 2005 and 2020 and other targets (Deutsche Bank, 2011; Paltsev *et al.*, 2012), we find that even under aggressive climate policy the extent to which the household transport sector can offer reductions is limited. The high growth and resilience to policy in this segment will be a factor which offsets the impact of targeted measures in other areas. Given the great uncertainty in the literature about the range in future demand, and its consequences on emissions as shown here, alternative pathways for growth deserve attention as an important component of overall policy.

6. REFERENCES

A.T. Kearney, 2011: China Solutions. Presentation slides, unpublished.

Barclays Capital, 2011: BRIC exposure provides mid-term growth: U.S. autos & auto parts industry update. Presentation slides, unpublished.

BP, 2012: *Statistical Review of World Energy*. BP p.l.c.: London, UK, June 2012 edition.

Casey, J. and K. Koleski, 2011: Backgrounder: China's 12th Five-year Plan, U.S.-China Economic and Security Review Commission.

CDIAC, 2011: *Global, Regional, National Fossil-Fuel CO_2 Emissions*. Carbon Dioxide Information Analysis Center, Environmental Science Division: Oak Ridge, TN, USA. doi:10.3334/CDIAC/00001_V2011. Available at: .

Cherry, C. R., J. X. Weinert and X. Yang, 2009: Comparative environmental impacts of electric bikes in China. *Transportation Research Part D: Transport and Environment*, **14**: 281–290. doi:10.1016/j.trd.2008.11.003.

Chester, M. and A. Horvath, 2010: Life-cycle assessment of high-speed rail: the case of California. *Environmental Research Letters*, **5**(1): 014003. doi:10.1088/1748-9326/5/1/014003.

Clarke, L., J. Edmonds, V. Krey, R. Richels, S. Rose and M. Tavoni, 2009: International climate policy architectures: Overview of the EMF 22 International Scenarios. *Energy Economics*, **31**: S64. doi:10.1016/j.eneco.2009.10.013.

Dargay, J., D. Gately and M. Sommer, 2007: Vehicle ownership and income growth, worldwide: 1960-2030. *The Energy Journal*, **28**(4): 143–170.

Deutsche Bank, 2011: 12th Five Year Plan: Chinese leadership towards a low carbon economy. Available at: http://www.dbcca.com/dbcca/EN/_media/China_12th_Five_Year_Plan.pdf. Accessed 25 July 2012.

Dimaranan, B. V. and R. A. McDougall, 2002: Global trade, assistance, and production: the GTAP 5 data base. Center for Global Trade Analysis, Purdue University .

EEA, 2011: Structure of the efficiency of transformation and distribution of energy from primary energy consumption to final energy consumption, EU-27, 2008. European Energy Agency .

Euromonitor International, 2011: Passport Global Market Information Database. Statistics retrieved 16 October 2011 from http://www.euromonitor.com/passport-gmid.

Gong, H., M. Q. Wang and H. Wang, 2012: New energy vehicles in China: policies, demonstration, and progress. *Mitigation and Adaptation Strategies for Global Change*. doi:10.1007/s11027-012-9358-6.

Han, J. and Y. Hayashi, 2008: Assessment of private car stock and its environmental impacts in China from 2000 to 2020. *Transportation Research Part D: Transport and Environment*, **13**(7): 471. doi:10.1016/j.trd.2008.09.007.

Hao, H., H. Wang and M. Ouyang, 2011: Comparison of policies on vehicle ownership and use between Beijing and Shanghai and their impacts on fuel consumption by passenger vehicles. *Energy Policy*, **39**(2): 1016–1021. doi:10.1016/j.enpol.2010.11.039.

Hertel, T. W., 1997: *Global Trade Analysis: Modeling and Applications*. Press Syndicate of the University of Cambridge: Cambridge, UK.

Hu, X., S. Chang, J. Li and Y. Qin, 2010: Energy for sustainable road transportation in China: Challenges, initiatives and policy implications. *Energy*, pp. 4289–4301. doi:10.1016/j.energy.2009.05.024.

Huo, H., K. He, M. Wang and Z. Yao, 2011a: Vehicle technologies, fuel-economy policies, and fuel-consumption rates of Chinese vehicles. *Energy Policy (in print)*. doi:10.1016/j.enpol.2011.09.064.

Huo, H., Q. Zhang, K. He, Z. Yao and M. Wang, 2011b: Vehicle-use intensity in China: Current status and future trend. *Energy Policy (in print)*. doi:10.1016/j.enpol.2011.09.019.

International Energy Agency, 2010: World Energy Balances 1970-2009. doi:10.1787/data-00512-en.

International Energy Agency, 2011: *World Energy Outlook 2011*. OECD Publishing: Paris, France. doi:10.1787/20725302.

International Road Federation, 2010: World Road Statistics 2010 and electronic files.

Jacoby, H. D., M. H. Babiker, S. Paltsev and J. M. Reilly, 2009: Post-Kyoto International Climate Policy. Cambridge University Press: Cambridge, UK, Chapter 23: Sharing the Burden of GHG Reductions, 753–785 p. Natural resource and environmental economics. ISBN 9780521138000.

Kageson, P., 2009: Environmental Aspects of Inter-City Passenger Transport. OECD/ITF Joint Transport Research Centre *Discussion Paper #2009-28*, December.

Karplus, V. J., P. N. Kishimoto and S. Paltsev, 2012a: The global energy, CO2 emissions, and economic impact of vehicle fuel economy standards. *15th Annual Conference on Global Economic Analysis*.

Karplus, V. J., S. Paltsev, M. Babiker, J. Heywood and J. M. Reilly, 2012b: Applying Engineering and Fleet Detail to Represent Passenger Vehicle Transport in a Computable General Equilibrium Model. MIT Joint Program on the Science & Policy of Global Change *Report No. 216*.

Kosinski, A., L. Schipper and E. Deakin, 2011: Analysis of High-Speed Rail's Potential to Reduce CO_2 Emissions from Transportation in the United States. *90th Annual Meeting*, Paper #11-3720.

Leaver, L. H., R. Samuelson and J. D. Leaver, 2012: Potential for low transport energy use in developing Asian cities through compact urban development. *Third IAEE Asian Conference*.

Meyer, I., M. Leimbach and C. Jaeger, 2007: International passenger transport and climate change: A sector analysis in car demand and associated emissions from 2000 to 2050. *Energy Policy*, **35**(12): 6332–6345. doi:10.1016/j.enpol.2007.07.025.

National Bureau of Statistics of China, 2011: China Statistical Yearbook 2010.

National Bureau of Statistics of China (ed.), 2012b: *China Energy Statistical Yearbook*. China Statistics Press: Beijing, China, 2011 edition. ISBN 9787503764592.

National Bureau of Statistics of China, 2012a: China Statistical Yearbook 2011.

Ou, X., X. Zhang, Y. Qin and Q. T, 2010: Life cycle analysis of electric vehicle charged by advanced technologies coal-power in future China. *Journal of China Coal Society*, **35**(1): 169–72.

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005: The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. MIT Joint Program on the Science and Policy of Global Change *Report 125*.

Paltsev, S., J. Morris, Y. Cai, V. Karplus and H. Jacoby, 2012: The role of China in mitigating climate change. *Energy Economics*. doi:10.1016/j.eneco.2012.04.007.

Schäfer, A., 1998: The global demand for motorized mobility. *Transportation Research Part A: Policy and Practice*, **32**(6): 455–477. doi:10.1016/S0965-8564(98)00004-4.

Schäfer, A. and H. D. Jacoby, 2006: Vehicle technology under CO2 constraint: a general equilibrium analysis. *Energy Policy*, **34**(9): 975. doi:10.1016/j.enpol.2004.08.051.

Schäfer, A. and D. Victor, 2000: The future mobility of the world population. *Transportation Research Part A: Policy and Practice*, **34**(3): 171. doi:10.1016/S0965-8564(98)00071-8.

U.S. EIA, 2011: Annual Energy Review 2011. U.S. Department of Energy, Energy Information Administration .

U.S. EIA, 2012: Monthly Refinery Report. U.S. Department of Energy, Energy Information Administration *Form EIA-810*, July.

Wang, M., H. Huo, L. Johnson and D. He, 2006: Projection of Chinese Motor Vehicle Growth, Oil Demand and CO_2 Emissions Through 2050. Argonne National Laboratory *Report ANL/ESD/06-6*, 12.

Wang, Y., J. Teter and D. Sperling, 2011: China's soaring vehicle population: Even greater than forecasted? *Energy Policy*, **39**(6): 3296. doi:10.1016/j.enpol.2011.03.020.

Waugh, C., S. Paltsev, N. Selin, J. Reilly, J. Morris and M. Sarofim, 2011: Emission Inventory for Non-CO_2 Greenhouse Gases and Air Pollutants in EPPA 5. MIT Joint Program on the Science and Policy of Global Change *Technical Note #12*, July.

Yan, X. and R. J. Crookes, 2010: Energy demand and emissions from road transportation vehicles in China. *Progress in Energy and Combustion Science*, **36**: 651–676. doi:10.1016/j.pecs.2010.02.003.

Zhou, N., D. Fridely, M. McNeil, N. Zheng, J. Ke and M. Levine, 2011: China's Energy and Carbon Emissions Outlook to 2050. Lawrence Berkeley National Laboratory 4.

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