

# Modeling regional transportation demand in China and the impacts of a national carbon constraint

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## Abstract

Climate and energy policy in China will have important and uneven impacts on the country's regionally heterogeneous transport system. In order to simulate these impacts, transport sector detail is added to a multi-sector, static, global computable general equilibrium (CGE) model which resolves China's provinces as distinct regions. This framework is used to perform an analysis of national-level greenhouse gas (GHG) policies. Freight, commercial passenger and household (private vehicle) transport are separately represented, with the former two categories further disaggregated into road and non-road modes. The preparation of model inputs is described, including assembly of a provincial transport data set from publicly-available statistics. Two policies are analyzed: the first represents China's target of a 17% reduction in GHG emissions intensity of GDP during the Twelfth Five Year Plan (12FYP), and the second China's Copenhagen target of a 40–45% reduction in the same quantity during the period 2005–2020.

We find significant heterogeneity in regional transport impacts. We find that both freight and passenger transportation in some of the poorest provinces that rely heavily on energy-intensive resource and raw materials exports are most adversely affected, as they offer many of the least cost abatement opportunities and the transformation of their energy systems strongly affects transport demand. At the national level, we find that of all the transport-related sectors, road freight transport activity is affected most by policy, likely due to its high energy intensity and limited low cost opportunities for improving efficiency.

The type and degree of regional disparity in impacts is relevant to central and provincial government decisions which set and allocate climate, energy and transport policy targets. We describe how this research establishes a basis for further regional CGE analyses of the economic, energy and environmental impacts of transport-focused policies including vehicle ownership restrictions, taxation of driving activity or fuels, and the supply of public transit.

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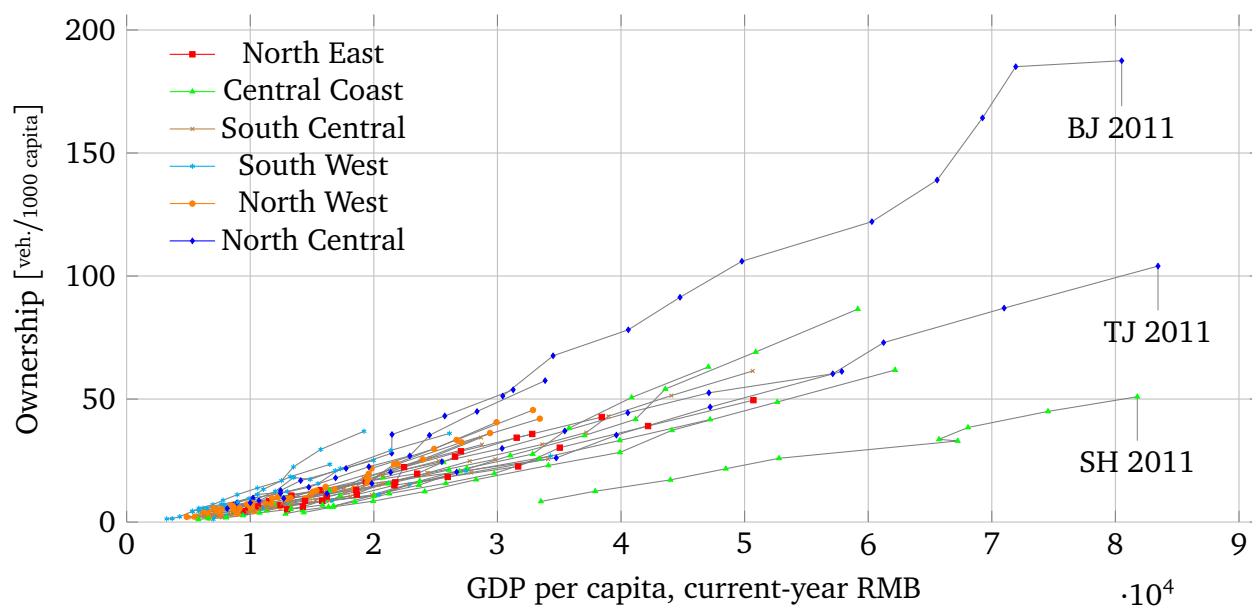
## 1 Introduction

China has replaced the United States as the world’s largest auto market, and transport contributes an increasing share of its energy use and greenhouse gas (GHG) emissions. Yet motorization proceeds unevenly, as heterogeneity in household income growth across provinces affects travel and transport-related consumption. **Figure 1** illustrates this heterogeneity during the period 2002–2011 as it pertains to ownership<sup>1</sup> of private vehicles. The most recent data show an order of magnitude between the provinces with lowest and highest ownership. Three of China’s provincial-level municipalities—Beijing, Tianjin and Shanghai—have similarly high per-capita gross regional product (GDP<sup>2</sup>) but widely different ownership. Finally, growth in income and ownership over the last decade has been rapid, as has growth in other transport activity (**Figure 2**).

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<sup>1</sup>By ‘ownership’ we always intend the number of vehicles *per capita*; ‘stock’ is used for the *total number* of vehicles.

<sup>2</sup>We use ‘GDP’ for both China’s domestic product and that of individual provinces, sometimes called a Gross Regional Product (GRP), including in the China Statistical Yearbooks.



**Figure 1** – Private passenger vehicle ownership of Chinese provinces, 2002–2011. Annual data points for each province are connected to show trends in increasing GDP and ownership over this period. The three provinces with highest per-capita GDP are labelled: Beijing, Tianjin and Shanghai; for the regional grouping, see Figure 20. Data collated from China Communications & Transportation Association (2008); National Bureau of Statistics of China (2008) and earlier and subsequent editions from 2003 to 2012 inclusive.

Freight transport also holds an important relationship to China’s energy system and economy. The coal which supplies a large share of industrial and electrical energy is moved by rail from domestic mines or imported by sea; goods for domestic consumption or export are moved by a variety of modes, and freight traffic is commensurate with China’s large quantity of exports.

Previously, we investigated household vehicle transport using a recursive-dynamic computable general equilibrium (CGE) model in which China is represented as single region, and found that CO<sub>2</sub>-intensity targets on China’s transport sector have very modest impacts. Reducing emissions intensity of GDP by 17% each five years results in a passenger activity reduction of less than 8% by 2050 relative to a no policy baseline which more than triples from 2010 (Kishimoto et al., 2012). Recognizing that national-level analysis omits the regional differences described above, and also the contribution of freight to total transport activity and energy use, we have undertaken the regional CGE modelling described here. We demonstrate the new analysis capacity by examining the differences in provincial impact of two national policies on emissions intensity of GDP.

Our findings illustrate the importance of a regional approach. Some of China’s poorest provinces rely heavily on energy-intensive resource and raw materials exports, and are most adversely affected by the national-level instruments we study, in part because they offer the least cost abatement opportunities. At the national level, we find that of all the transport-related sectors, road freight transport activity is affected most by policy, likely due to its high energy intensity and limited low cost opportunities for improving efficiency. Throughout, significant heterogeneity in regional conditions and outcomes motivates attention to provincial detail in further analysis of China’s transport system.

The paper continues as follows: the remainder of the introduction surveys trends of the Chinese transport system, and transport-related policies in place or under discussion, including recent analysis from the literature. Section 2 includes a description of the China Regional Energy Model (C-REM) developed for this research (Section 2.1), methodology of new transport sector disaggregation (Section 2.2), and the preparation of a data set of transport activity and energy quantities (from publicly-available statistics and other literature estimates) which we use to calibrate the new sectors (Section 2.3). In Section 3 we outline our policy analysis (Section 3.1), and detail our findings, first regarding changes at the national level (Section 3.2) and then from inspection of variation in response across regions (Section 3.3). Section 4 discusses implications of our results, and also planned future work (Section 4.1) which builds on the new regional modelling capacity.

## 1.1 Chinese transportation growth & policy

Figure 2 shows the strong trend of historical growth in transport activity in China. The decade ending in 2011 saw an average 8.8% annual growth in freight tonne-kilometres and 12.3% annual growth in passenger-kilometres. The freight transport rate reflects strong, underlying GDP growth, while the passenger rate also includes changes in mobility behaviour of consumers as their per capita income has increased. The drivers of transport activity growth are projected to continue into the future, although there is considerable uncertainty in how they will emerge as changes in specific transport indicators (Kishimoto, 2012). For instance, while Xinhua News Agency (2012) estimate that the total private vehicle stock in China will grow to 350 million in 2030 from 50 million in 2010, our own previous recursive-dynamic CGE work agrees more closely with the lower bound of projections by Wang et al. (2006), with a figure closer to 240 million in 2030 (Kishimoto et al., 2012)—but regardless of which figure is realized, the magnitude of increases in all modes will be large.

Along with freight and passenger activity growth, the impacts and externalities of transport—including high oil demand, congestion (of both road and non-road systems, and especially in cities), and local air pollution—have become policy concerns for Chinese governments. Non-transport-specific policies arising from national economic objectives also interact with China’s transport sector. Aside from the national climate policies we discuss later, freight transport activity and patterns change with the export of goods, which will in turn be altered by plans to shift away from export-oriented manufacturing to growth driven by services and domestic demand (Qi et al., 2012). Rail freight is also the predominant mode for moving the large amounts of coal used in China’s industrial and electric power sectors between domestic locations of extraction and use.

China has designated vehicle manufacturing as a “pillar industry” (Steinfeld, 2008), and arranged joint ventures (JVs) between foreign manufacturers and domestic firms in order to improve productive capacity and encourage technology transfer (Nam, 2011). At the same time, concerned with a high reliance on oil imports (59% as of 2010, Xinhua News Agency, 2012; Daojiong, 2006), the government has moved to set aggressive targets for vehicle fuel economy (Oliver et al., 2009; Hu et al., 2010), and heavily subsidized the purchase of both consumer and commercial “New Energy Vehicles” (NEVs, elsewhere sometimes referred to as “alternative fuel vehicles”). Gong et al. (2012) note that this latter effort promotes the development of advanced vehicle technology—yet has resulted in only limited progress towards sales targets. Among other factors, the post-subsidy cost of NEVs may yet compare unfavourably with other options for newly-motorizing households. For long-distance passenger transport,

airports and a national, high-speed rail network have been expanded rapidly through direct government spending (Campos and de Rus, 2009).

At the provincial and municipal level, transport externalities including air pollution (Sun et al., 2004) and congestion are acute concerns. Although walking, cycling, and two-wheel electric vehicles retain a non-trivial mode share in Chinese cities (Peng, 2004; Weinert et al., 2007, 2008), their regulation appears to be a less pressing policy matter. Instead, the negative consequences of growth are often addressed through policy entrepreneurialism (Chien and Ho, 2011), with decision makers studying historical international and recent domestic responses to similar problems while experimenting with a variety of measures. For instance, in the capital, Beijing, and China’s largest city, Shanghai, policies have been enacted which limit the sale of new vehicles by auctioning license plates, or awarding them by lottery (Hao et al., 2011); other cities are actively studying the effectiveness of these measures and considering hybrid systems (Caixiong, 2012). Policies on retirement of old vehicles, cordon exclusion of high-polluting vehicles (including certain classes of freight vehicles), and the limitation of driving through rotating bans, pricing and/or tolls have been tried in different locations (Yin et al., 2011; Hao et al., 2011; Suen, 2012). To affect the fuels used in both freight and passenger road transport, some regions have taken the initiative of adopting standards more stringent than those set nationally (Xin, 2012). Municipalities have taken advantage of high subsidies and new financing opportunities including public-private partnerships to increase the supply of subways and other public transport (Wang et al., 2011; de Jong et al., 2010).

Viewed next to the differences in statistical characteristics of provincial transport detailed below in Section 2.3, the extensive suite of unevenly-applied policy instruments with sometimes countervailing purposes suggests that impacts may differ across provinces and targeted transport sectors. Motivated by the need to properly represent these effects in a CGE model which can also capture the interaction of transport sector energy transformation with the rest of the Chinese and world economy, we undertook the modelling effort described in the next section.

## 2 Method

### 2.1 The China Regional Energy Model (C-REM)

The C-REM is a multi-sector, multi-region static numerical computable general equilibrium economic model of the world. Thirty Chinese provinces are represented individually, along with six international regions (**Table 1**). Sixteen sectors are represented, including main types

Code	Region
---	<i>(30 individual Chinese provinces; see Appendix, Figure 20)</i>
APD	Asian and Pacific developed countries
ASI	Other Asian countries
CAA	Former Soviet Union, Central Asia and Africa
EUR	Europe
NAM	United States and Canada
ROW	Latin America, Eastern European countries, rest of the world

**Table 1** – Regions in the C-REM.

of primary energy, electricity and—prior to this research—transportation (Table 2). Like the

Code	Sector	Code	Sector
AGR	Agriculture	OID	Other industries
COL	Coal mining & processing	OIL	Refined oil
CRU	Crude petroleum products	OMN	Metal, minerals, other mining
EID	Energy-intensive industries	OTH	Other service industry
ELE	Electricity	TME	Transport machinery & equipment
GAS	Natural gas products	TRD	Wholesale & retail trade, hospitality
GDT	Gas production & supply	TRP	Transportation
LID	Light industries	WTR	Water production & supply

Table 2 – Sectors in the C-REM, prior to transport disaggregation.

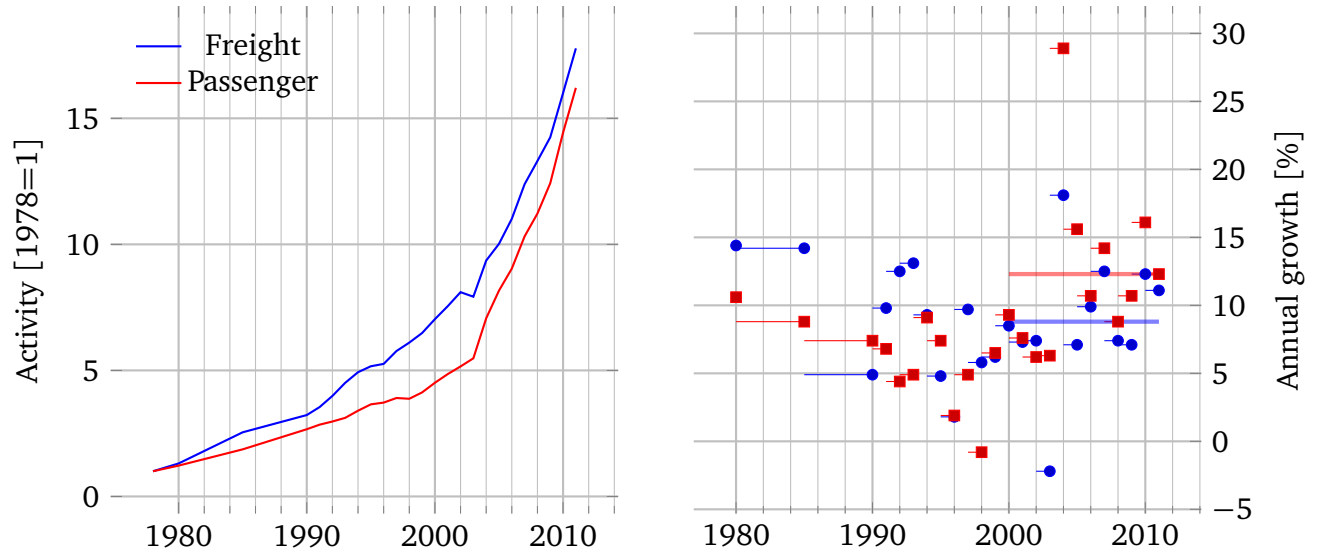
MIT United States Regional Energy Policy (USREP) and Emissions Prediction & Policy Analysis (EPPA) models (Rausch et al., 2010; Paltsev et al., 2005), the C-REM includes supplemental physical accounts of energy and GHG emission quantities to support analysis of policies which directly price or affect the cost of energy use or emissions. C-REM has also previously been used to simulate an emissions intensity constraint (Zhang et al., 2012). The static version of the C-REM used for this research has a 2007 base year.<sup>3</sup> The model is implemented in the Model Programming System for General Equilibrium (MPSGE) and GAMS, and solved using the GAMS/PATH solver on a desktop computer.

The C-REM social accounting matrix (SAM) is prepared using a code which makes least-squares adjustments to data from the 2007 China Input/Output Tables (China State Information Council, 2011), the 2007 China Energy Statistical Yearbook (National Bureau of Statistics of China, 2008), and the GTAP 8 Data Base (Narayanan G. et al., 2012), such that economic value and physical quantities are consistent. Specific quantities may be designated as fixed and are not subject to any adjustment. These include the GTAP 8 quantities for China’s national economic totals, international trade flows and all data for non-Chinese regions. However, quantities designated as fixed presently *do not* include transport sector outputs or inputs (including energy), or the household consumption that we (below) assign to a new household private vehicle transport sector. Given the necessity of using adjusted statistical data—as described in Section 2.3—we have chosen not to have the balancing code hold fixed any transport-related quantities. One consequence is the apparent absence of household private vehicle transport in some provinces with low motorization, which we note in Section 3.2.

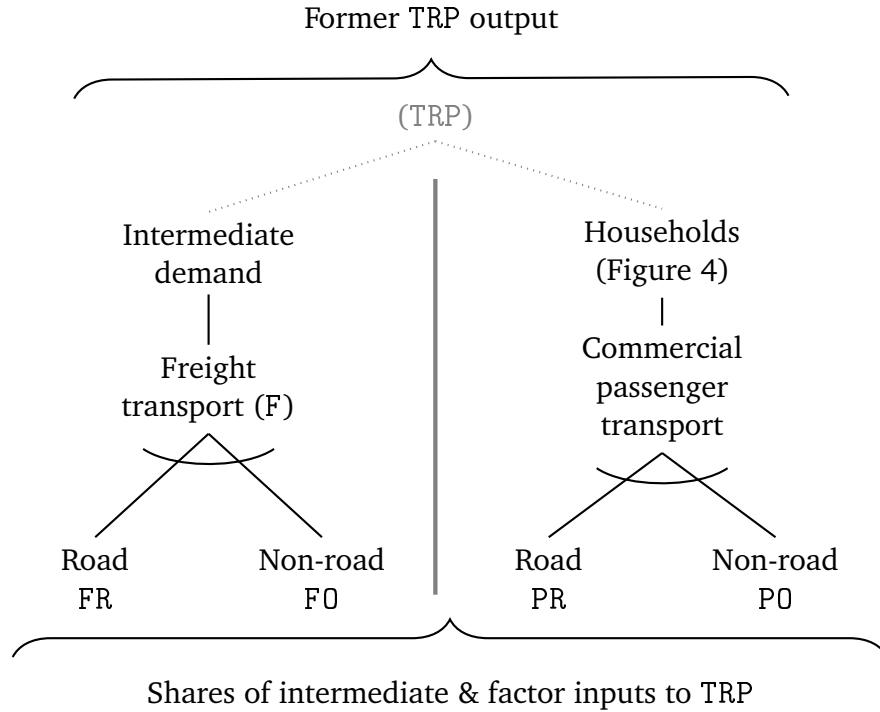
## 2.2 Transport sector disaggregation in C-REM

Our transport disaggregation has two aspects. By *commercial transport*, we denote the activity of the former C-REM TRP sector. The portion of this sector’s output which was consumed as an intermediate in other production we assume to be *freight transport*, while the portion directly consumed by households is assumed to be *commercial passenger transport*. As shown in Figure 3, we further disaggregate each of these portions into road and non-road sectors, with the latter comprising rail, marine, air and (for freight only) pipeline transport. By *household transport*, we denote the consumption by households of commercial passenger transport (output from the former TRP sector), as well as from other sectors from which we construct a

<sup>3</sup>A recursive-dynamic version, solving in 2007, 2010 and five-year increments thereafter, is in development.



**Figure 2** – Left, historical growth in overall Chinese passenger and freight transport activity, indexed to activity in pass·km or t·km. in 1978, Right, annual growth rates, with the 2001-2011 average.



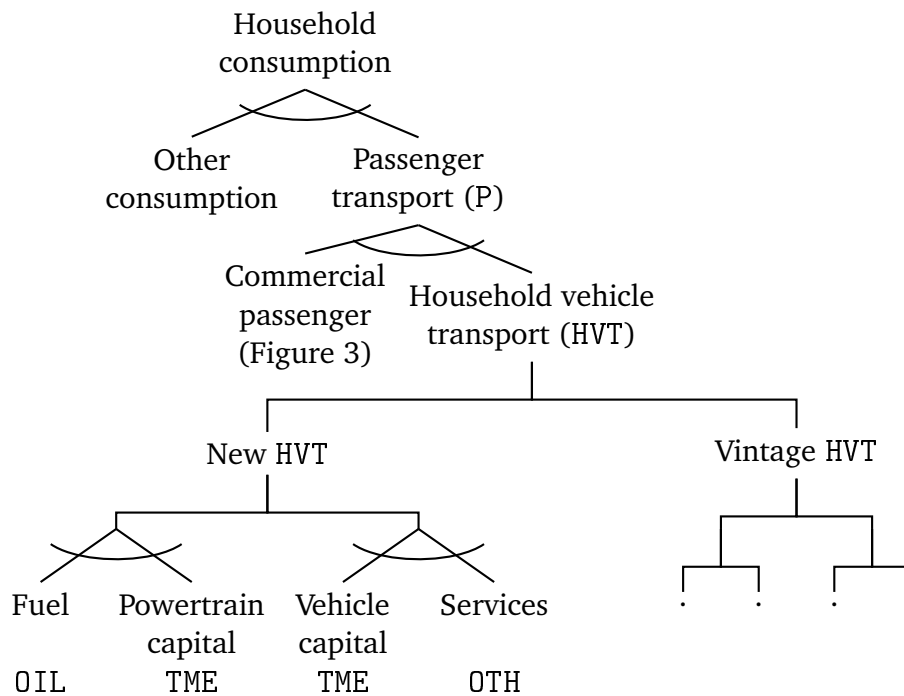
**Figure 3** – Disaggregation of the C-REM TRP sector. The original sector is eliminated, and all intermediate demand from other sectors is satisfied from the new non-road and road freight sectors. Inputs to the four commercial sectors are shared as described on page 11.

*household vehicle transport sector*. In the supplemental physical accounting, the activity levels for the two freight transport sectors are in tonne-kilometres, and the activity levels for the two commercial passenger sectors and the household vehicle transport sectors are in passenger-kilometres. We assign each sector a new code:

Code	Sector	Units
FO	Non-road freight	tonne·km
FR	Road freight	tonne·km
PO	Non-road (commercial) passenger	passenger·km
PR	Road commercial passenger	passenger·km
HVT	Household vehicle (transport)	passenger·km

**Table 3** – New household transport sectors in the C-REM.

The household vehicle transport structure is adapted from one used in the EPPA model as detailed by Karplus et al. (2013) and applied to China by Kishimoto et al. (2012) for the representation of light duty vehicle technology detail in CGE. This structure is illustrated in **Figure 4**. Households obtain an “own-supplied [vehicle] transport service” from a vehicle



**Figure 4** – Structure of household consumption, including transport sector detail.

capital stock, supplied by inputs from the transport mechanical equipment (TME) and services (OTH) sectors. The capital stock is divided into two parts, one representing the non-propulsion components of the vehicle transport service. The other part, designated powertrain capital, is combined with fuel (refined oil sector output, OIL) to provide the propulsion component of the service. In response to increases in OIL price, households substitute more powertrain capital, obtaining a more expensive vehicle with improved fuel economy. They may also shift consumption to other sectors, including the two modes of commercial passenger transport,



or reduce consumption. The structure separately represents the service derived from used or vintage vehicle stock, for which fuel economy is fixed.

For this research, we applied the transport disaggregation to China's provinces only, preserving the existing TRP structure for the six C-REM international regions.

## 2.3 Data collection & model calibration

Reliable transport data are important if models are to provide credible transport policy analyses, but the statistics on China's economy, energy use and transport system present challenges in their level of detail and sometimes questionable accuracy. Guan et al. (2012) famously noted a "gigaton gap" in reported CO<sub>2</sub> emissions—equivalent to Japan's national total—between a sum of provincial totals and the national figure given by the National Bureau of Statistics (NBS). Li and Cheng (2012) note that local and provincial officials, who are graded on a points system which includes progress on development targets, thereby face incentives to over- or under-report various quantities. In turn, provincial statistical bodies and the NBS apply corrections for this mis-reporting or perform other adjustments, which are not documented, for a variety of sources of error (Holz, 2004).

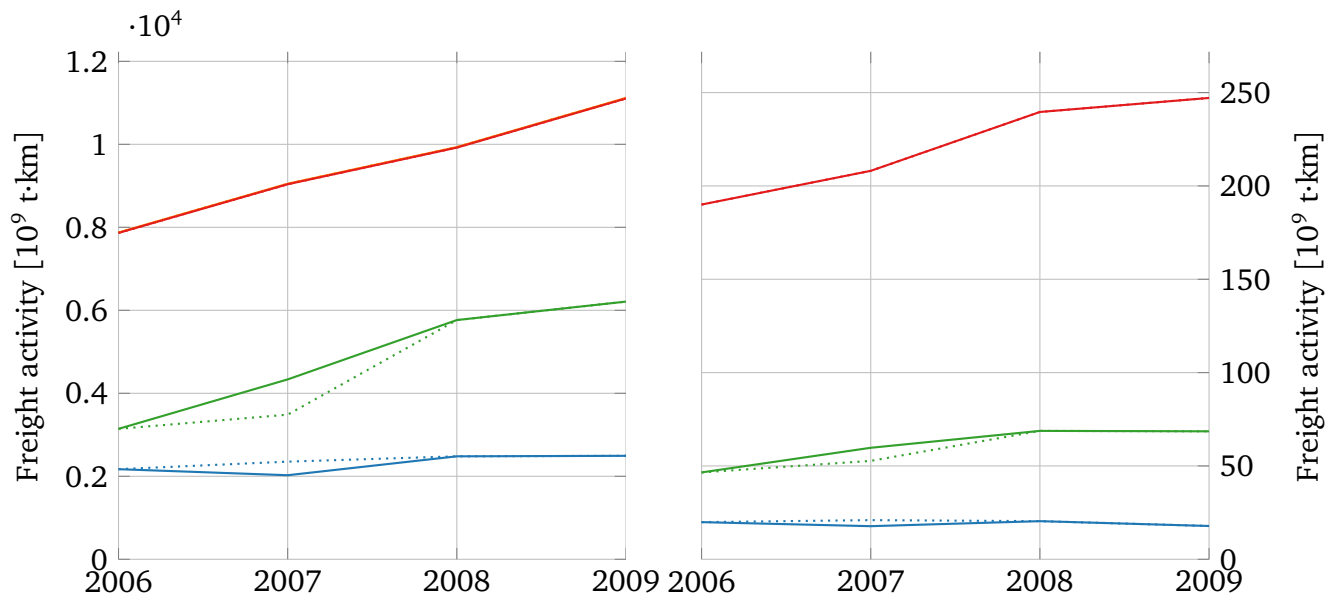
These challenges were encountered during development of the C-REM (more detail is given in Zhang et al., 2012), and again in disaggregating the transport sector for this research. Our approach was to produce a provincial data set by collating publicly-available information from NBS yearbooks (CCTA 2008; 2009 and earlier and subsequent editions from 1999 to 2012 inclusive), and examine it to identify necessary adjustments.

Data coverage is also an issue. While supplemental transport energy and physical activity accounts for national-level CGE can be based on NGO- or privately-maintained international databases such as Passport GMID, IEA World Energy Balances and the International Road Federation's World Road Statistics (Euromonitor International, 2011; International Energy Agency, 2010; International Road Federation, 2010), the analogous statistics for China, if not reported by the NBS, national ministries, or lower-level agencies, may be entirely unavailable. To correct this deficit, we turn to the extensive literature on Chinese transport energy use and emissions for conversion factors, intensities and other quantities, which we combine with adjusted statistics to produce the quantities required for model calibration.

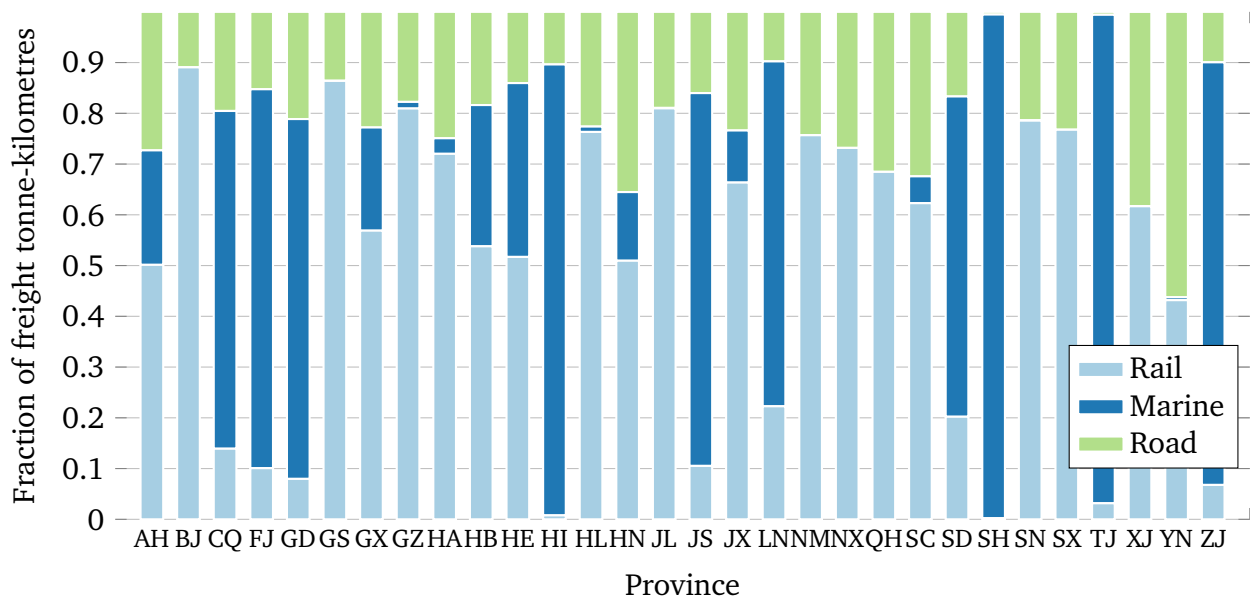
This process is explained for commercial transport and household vehicle transport in the following two subsections.

### 2.3.1 Commercial transport

Year 2008 statistics reported by the NBS show significant decreases relative to 2007 in marine freight transport activity (**Figure 5**). This could be explained as the impact of reduced Chinese exports due to falling global demand at the beginning of the 2008–2010 global recession—except that there were corresponding increases in road freight activity, such that the growth in overall totals remained steady from 2007 through 2009 (Figure 5, solid lines). The growth rates of individual modes have also paralleled the national total in subsequent years. We instead interpret this change as a statistical adjustment—for a former over-reporting of marine traffic, under-reporting of highway traffic, or both—and adjust the 2007 data by sharing out the total freight activity in the same proportion as in 2008, province by province (Figure 5, dotted lines). The resulting 2007 mode shares of freight and passenger traffic are shown in **Figures 6** and **7** respectively.



**Figure 5** – Freight activity in China (left) and Fujian (FJ, right), 2006–2009, showing reported (dotted line) and share-adjusted (solid line) 2007 quantities.



**Figure 6** – Adjusted mode shares of freight traffic, Chinese provinces, 2007.

The China Energy Statistical Yearbook’s energy balance tables report provincial transport energy consumption by fuel; there is no disaggregation by mode. The C-REM sectoral aggregation and balancing code (see Section 2.1) also aggregates some of these quantities (combining, for instance, both diesel and gasoline to OIL sector energy) and adjusts them along with other, non-energy inputs to transport. We estimate the energy intensity of the four commercial transport sectors FO, FR, PO and PR using the adjusted activity levels and bottom-up modal energy intensity figures from literature (see Appendix, **Table 5**), then divide TRP output and input among the four sectors while maintaining a balanced SAM, as follows:

1. TRP sector supply consumed by households is designated the commercial passenger part, and remaining supply the freight part.
  - (a) FO and FR are assigned shares of the freight part in proportion to their relative activity levels.
  - (b) PO and PR are assigned shares of the commercial passenger part in proportion to their activity levels.
2. All TRP sector intermediate and factor demand is divided among FO, FR, PO and PR, in proportion to their outputs.
3. Intermediate demand from the energy sectors COL, CRU, ELE, GAS, GDT, and OIL is rebalanced between FO and FR such that their relative energy intensities match our estimate from statistics and literature. (Likewise PO and PR.)
4. Intermediate consumption of OIL in FO is reassigned to FR, and a corresponding sum of COL, CRU, ELE, GAS and GDT reassigned from FR to FO. (Likewise PO and PR.)

This final step represents the observation that very little Chinese road transport in 2007 used non-liquid fuels such as coal, natural gas or electricity.

### 2.3.2 Household vehicle transport

Given a paucity of regional data, we assign 95% of household OIL consumption to household vehicle transport, and designate all TME consumption as vehicle capital, of which 20% is powertrain capital. Because households in Liaoning (LN, 辽宁) and Ningxia (NX, 宁夏) consume no refined oil in the C-REM balanced SAM, household vehicle transport detail is omitted for these provinces.<sup>4</sup> In Karplus et al. (2013); Kishimoto et al. (2012), the services (OTH) input to household vehicle transport is calibrated as a residual between OIL and TME consumption and data on total household expenditure on transport from Passport GMID. Since this latter quantity is not available for Chinese provinces, we assume the ratio of OTH to TME in each of China’s provinces to be the same as the national average. We also adopt the assumption that used vehicles provide 60% of vehicle travel, implying the fuel–powertrain capital substitution is only available for the 40% of travel from new vehicles. In future work, identifying province-by-province sources for these quantities will allow us to improve our results.

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<sup>4</sup>The absence of OIL consumption in the SAM for these regions is related to a very small value in the raw statistical data read into the SAM balancing code, indicating that households in these provinces contribute little to total OIL demand.

In calibrating the household vehicle transport sector, we faced an absence of comprehensive provincial private vehicle activity statistics. Instead, we constructed activity levels using the vehicle stock, an estimate of occupancy, and survey-based data on the annual distance travelled per vehicle from Huo et al. (2011), with national averages and specific figures for some, but not all, provinces. Dividing the sectoral input quantities to household vehicle transport by this activity level data gives their contribution to the levelized cost per distance (LCPD) of household vehicle transport, as shown in **Figure 8**. LCPD data reflect variation in several quantities across provinces, including distance travelled per vehicle and the characteristics of private vehicles. For instance, in Shanghai the large overall cost may reflect both the expense of luxury vehicles and a lower driving distance denominator. In **Figure 9**, we note that the share of household consumption devoted to transport is between 5% and 11%,<sup>5</sup> a similar range to Travel Money Budgets (TMB) observed for entire countries in the literature (e.g. by Schäfer, 1998).

## 3 Policy analysis

### 3.1 National emissions intensity policies

As outlined in Section 1.1, an extensive suite of policies using many instruments targets China’s transport system and the technologies and users it comprises. We developed a transport sector disaggregation in order to support comparison of policies (some of which we anticipate in Section 4.1) which narrowly target transport modes, technologies or provinces. However, the transport sector also responds to economy-wide policy which affects the costs of energy or emissions; and the character of these effects provides important context for evaluations of targeted policy. Applying economy-wide policy allows us to examine the distinct responses of the disaggregated transport sectors.

In addition to a base case, we model two policies. The first, denoted “Policy 1” or “P1” in figures, represents the 12FYP target of a reducing the GHG emissions intensity of GDP by 17% between 2010 and 2015. The second policy, denoted “Policy 2” or “P2”, represents the lower bound of a targeted 40–45% reduction from 2005–2020 that China first stated at the 2009 UN Climate Change Conference in Copenhagen (UN FCCC Secretariat, 2011). This is an additional 27.3% reduction beyond the 2015 target.

To date, these policies are implemented by China’s central government as provincial targets explicitly assigned such that the national targets are met, with wealthier provinces (generally in the East) facing a higher reduction burden than poorer ones. However, we model the policies using a national-level constraint and an endogenous tax on CO<sub>2</sub> embodied in energy use, representing a nation-wide allowance trading market in which the provincial changes in emissions intensity depend on the relative costs of reductions across provincial economies, including their transport sectors. For details on the differences between these two implementations of a national intensity target, see Zhang et al. (2012).

Because we use the static version of C-REM for this research, the analysis omits growth in the overall economy and in transport activity, which we noted in Section 1.1 to be large. Along with growth, the relative levels of production from economic sectors—including transport sectors—in China have changed, both endogenously and as a result of deliberate policy.

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<sup>5</sup>With some exceptions such as Liaoning and Ningxia, as discussed, and Hainan (HI, 海南), an island province with a high share of air travel.

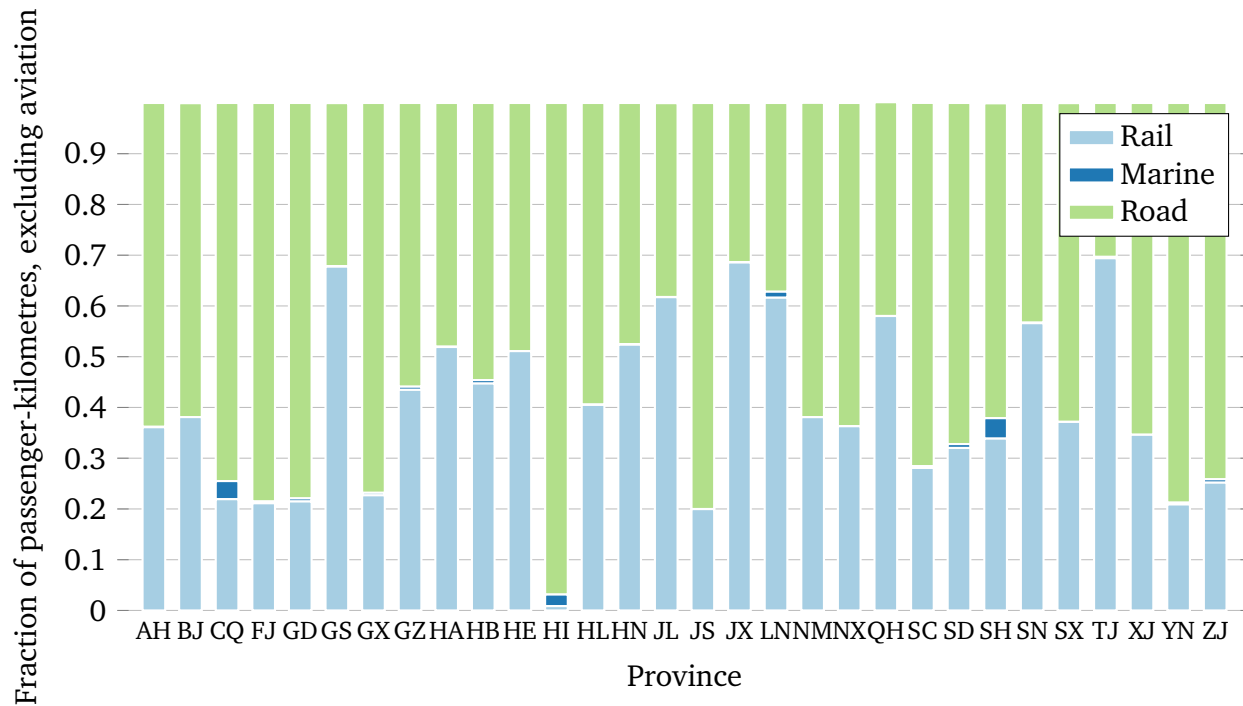


Figure 7 – Adjusted mode shares of passenger traffic, Chinese provinces, 2007.

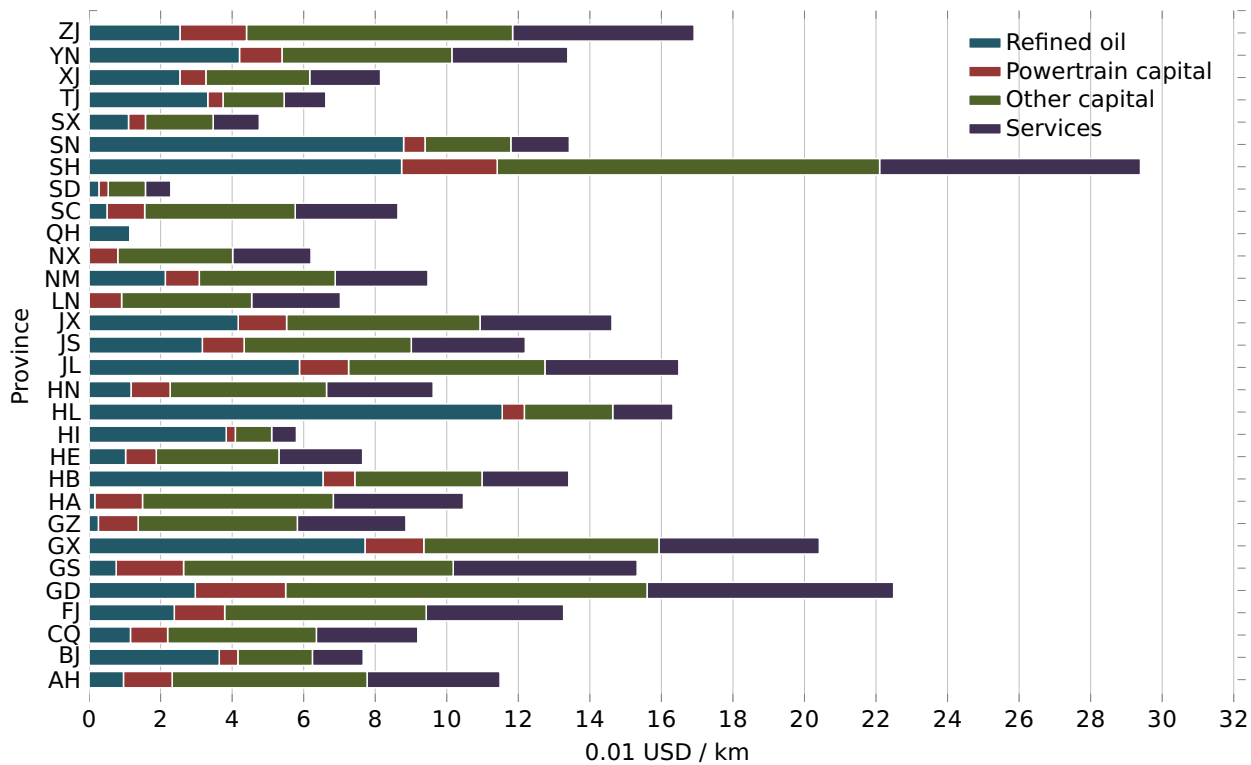


Figure 8 – Calibrated components of levelized cost per distance in household vehicle transport.

The static analysis assumes that the relative levels of output across sectors and provinces remain as they were in 2007.

Finally, although the emissions intensity instrument rewards fuel switching from high- to low-emissions intensity energy sources (for instance, from CO<sub>2</sub> to OIL or GAS), for simplicity we focus mainly on energy intensity in the following discussion, while noting that activity- and value-based emissions intensity reductions are in line with the energy results and the effects of the substitution of energy sources with lower emissions intensity.

## 3.2 National impacts

### 3.2.1 Changes in transport activity

We begin our discussion of model outputs with changes at the national level. As a consequence of Policy 1, total Chinese CO<sub>2</sub> emissions decreased 25.4% (47.9% under Policy 2), with values larger than the intensity constraints indicating that reductions were made in part by reducing production. Overall energy intensity decreased 16% and 35% as the carbon intensity of energy decreased 10.5% and 17.9% under Policy 1 and Policy 2, respectively.

**Figure 10** gives changes in total China freight and passenger activity under each policy. For a 17% reduction in economy-wide emissions intensity of GDP, freight activity decreases 3.0% and passenger activity decreases 2.2%; for a 40% reduction the respective figures are 8.6% and 8.5%. In both cases road freight experiences the largest change, and household vehicle transport and non-road passenger decrease more than road commercial passenger. These changes are partly explained by examining the energy intensity of transport modes on an activity basis, and on the basis of sectoral output value, as shown in **Figure 11**. Although household vehicle transport has an activity-level energy intensity much higher than other passenger modes, as a value-added sector with significant non-energy components it offers slightly *less* energy reduction for a given reduction in consumption of its output. In contrast, because the road and non-road freight sectors have a similar balance of energy and non-energy inputs, the high activity energy intensity of road freight translates to a high value energy intensity, with the observed larger share of activity reduction under national policy.

### 3.2.2 Comparison with impacts in other sectors

In **Figure 12** we show the reductions in energy intensity by total freight and total passenger transport, compared with that in the energy intensive industry (EID) and electricity (ELE) sectors and the economy as a whole. Both categories of transport reduce energy intensity less in relative terms than the economy as a whole, indicating that transport does not offer the lowest-cost opportunities for energy use abatement. In contrast, electricity production, a highly emissions-intensive sector, undergoes a much larger energy-intensity reduction than the entire economy, and almost twice as large as passenger transport.

### 3.2.3 Oil demand

Focusing on demand for refined oil products, **Figure 13** shows contributions of individual transport sectors to a total reduction of 1.2 EJ (5.1%) under Policy 1 and 3.558 EJ (15%) under Policy 2. Despite the reductions in energy intensity made by passenger modes, their contribution to oil demand reduction is small due to the low level of passenger activity relative

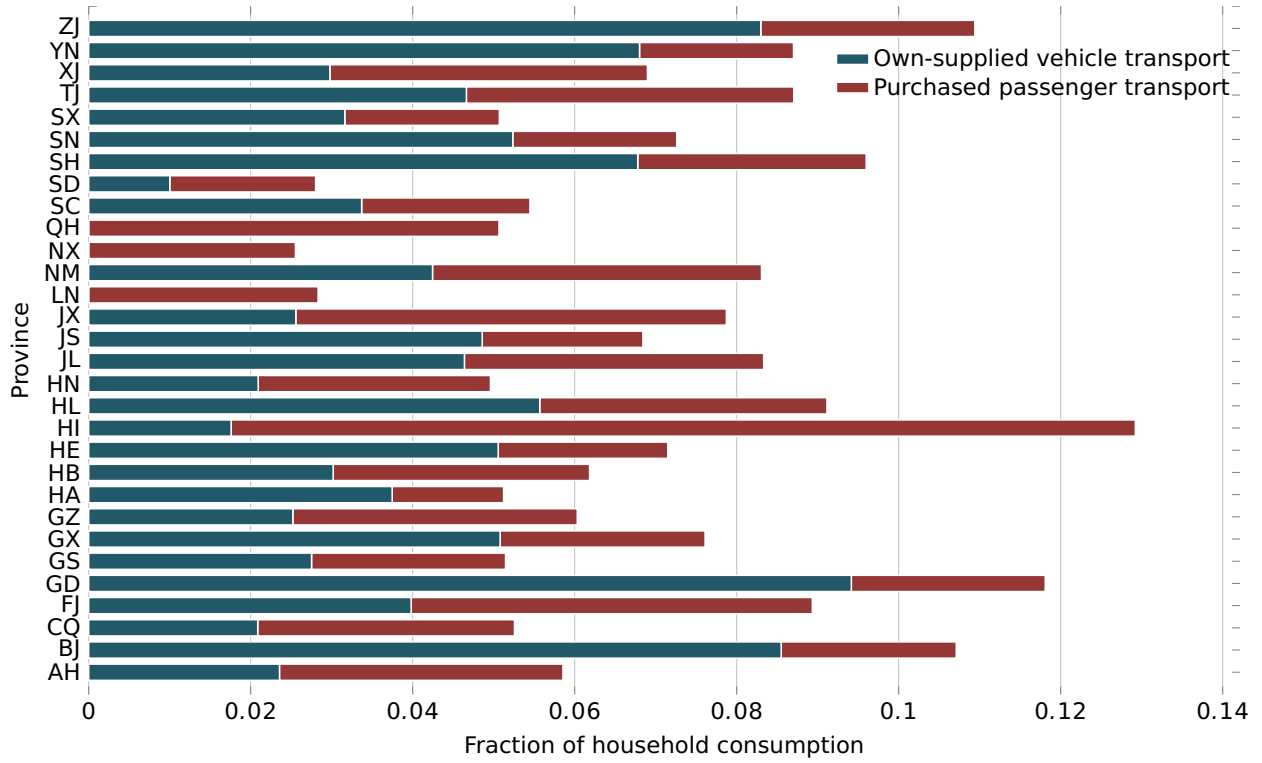


Figure 9 – Calibrated share of household expenditure household vehicle, commercial road and commercial non-road transport.

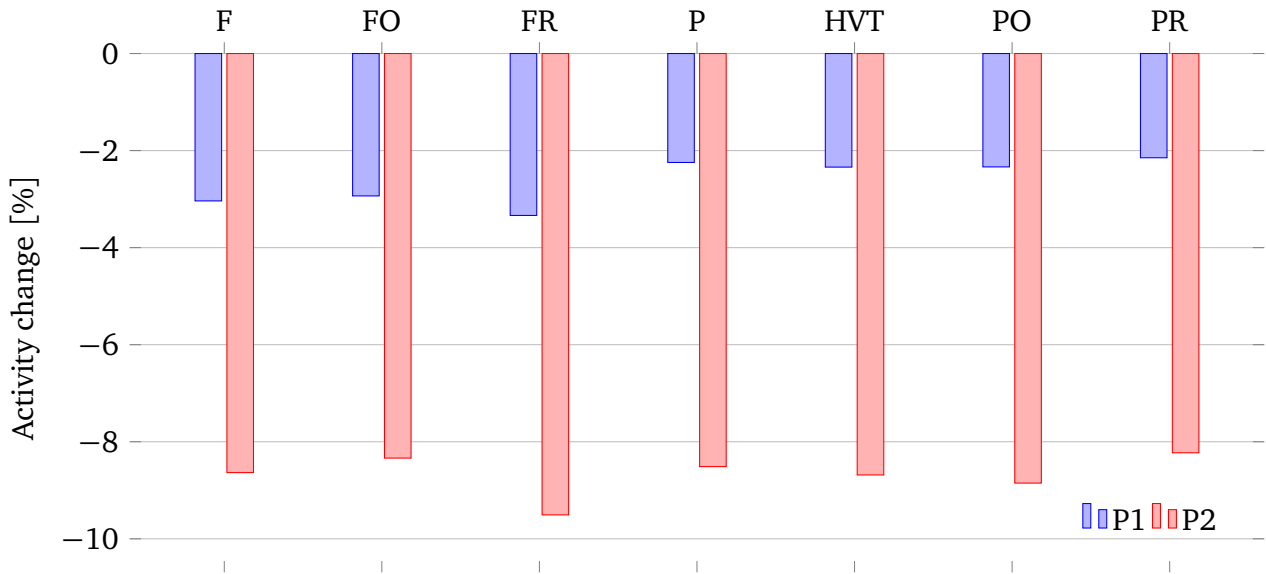
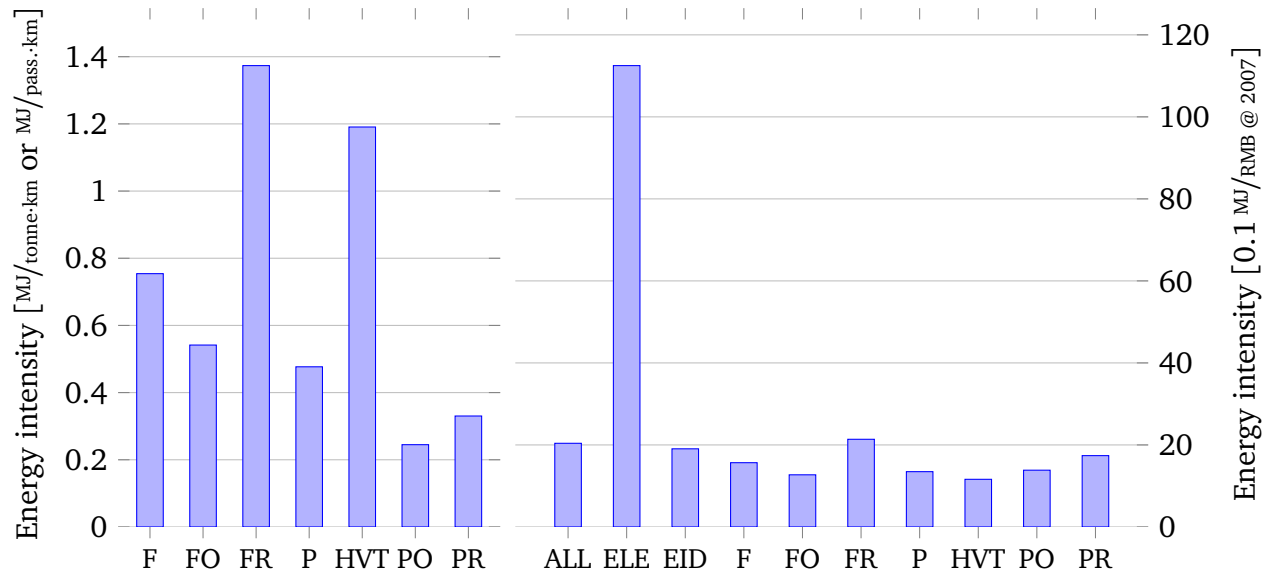
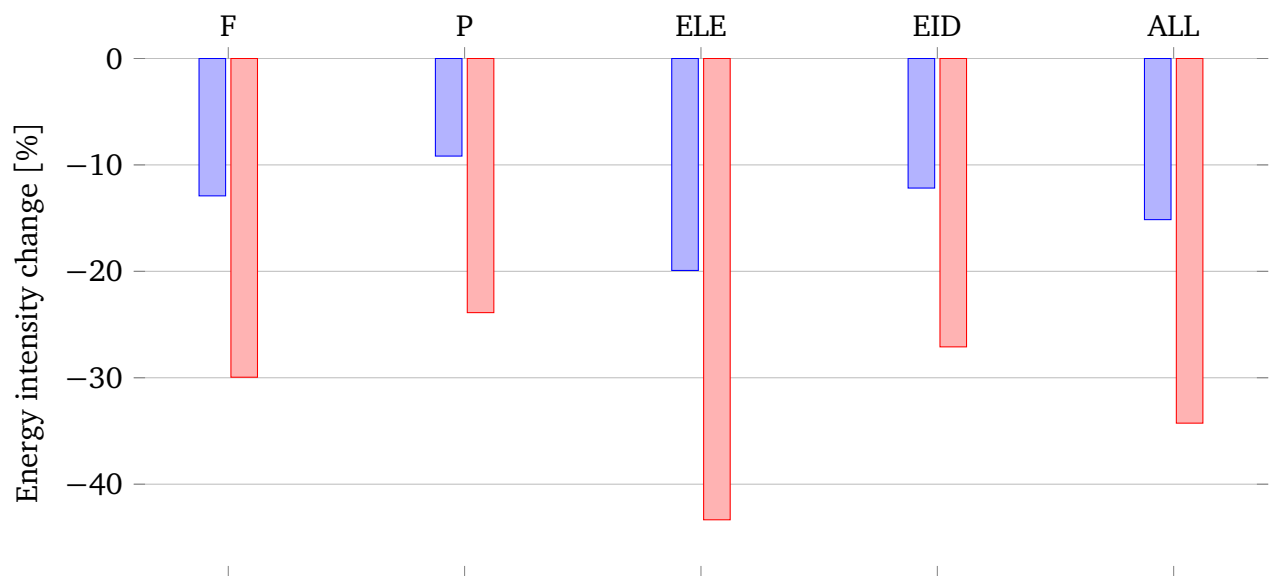


Figure 10 – Impact of policy on China total transport activity levels by transport sector, including a freight total (F) and passenger total (P).



**Figure 11** – Energy intensity of transport modes. Left, in physical terms (per freight tonne-kilometre or passenger-kilometre); right, per unit output value and compared to the energy intensity of electricity, energy-intensive industry, and all GDP.



**Figure 12** – Energy intensity reductions in transport versus other sectors.



to other oil consumption. About 40% of the reduction is made in freight modes—slightly more in road freight—and over 50% of reductions are made in non-transport sectors.

Absent any growth, national climate policy would make a significant contribution to reducing China’s dependence on oil imports; however, these reductions are more than offset by expected growth in total Chinese oil demand over the periods for which the targets are set. These results indicate that climate policy impacts may help China towards energy “self-sufficiency” (i.e. a limited share of imports in oil consumption), but also suggest that policies targeted at passenger vehicles (private or commercial) may not contribute significant reductions towards such a target unless the share of oil consumed by passenger vehicles grows. Sectoral policy aimed at oil demands by freight modes and non-transport activity, on the other hand, may have larger impact.

### 3.3 Provincial impacts

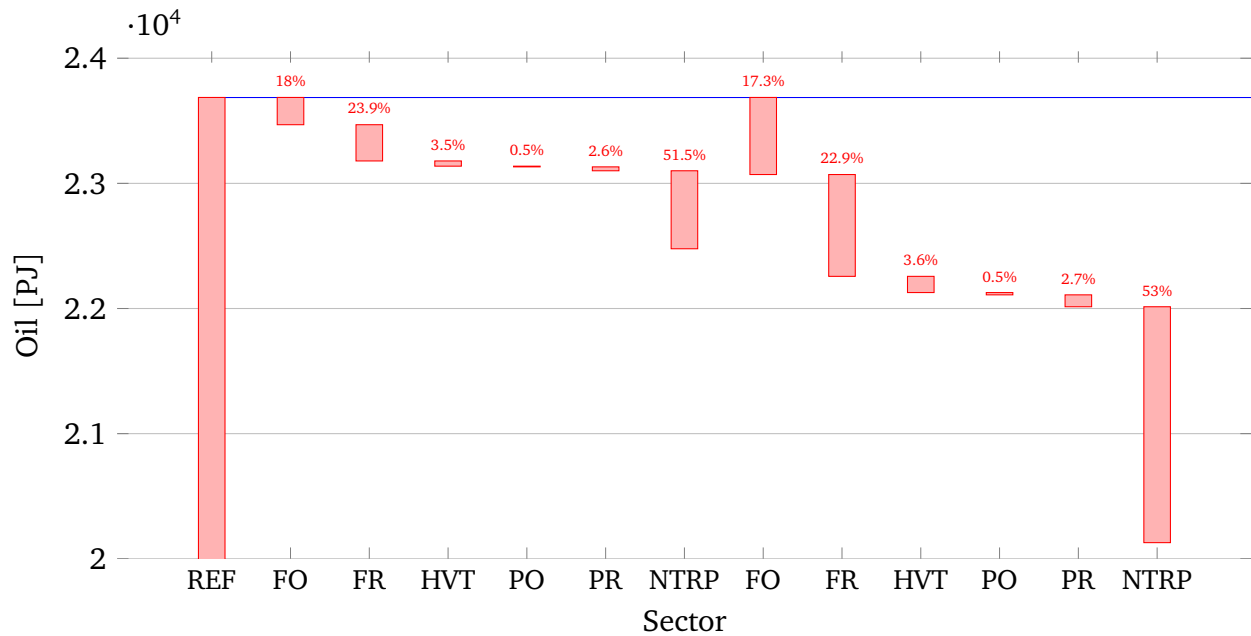
#### 3.3.1 Freight transport

We now turn to the regional impacts of policy. In **Figure 14**, we show the provincial-level impacts of each policy on road, non-road and total freight activity by province. In both cases, Gansu (GS, 甘肃), Guizhou (GZ, 贵州), Inner Mongolia (NM, 内蒙古), Shanxi (SX, 山西) and Yunnan (YN, 云南) experience the largest reductions. In general, road freight activity decreases more than non-road freight activity, although this pattern is reversed in some provinces, such as Gansu, Yunnan, Guizhou, Shaanxi (under Policy 2). Some provinces—Fujian, Jiangxi—experience increases in freight activity in some or all modes.

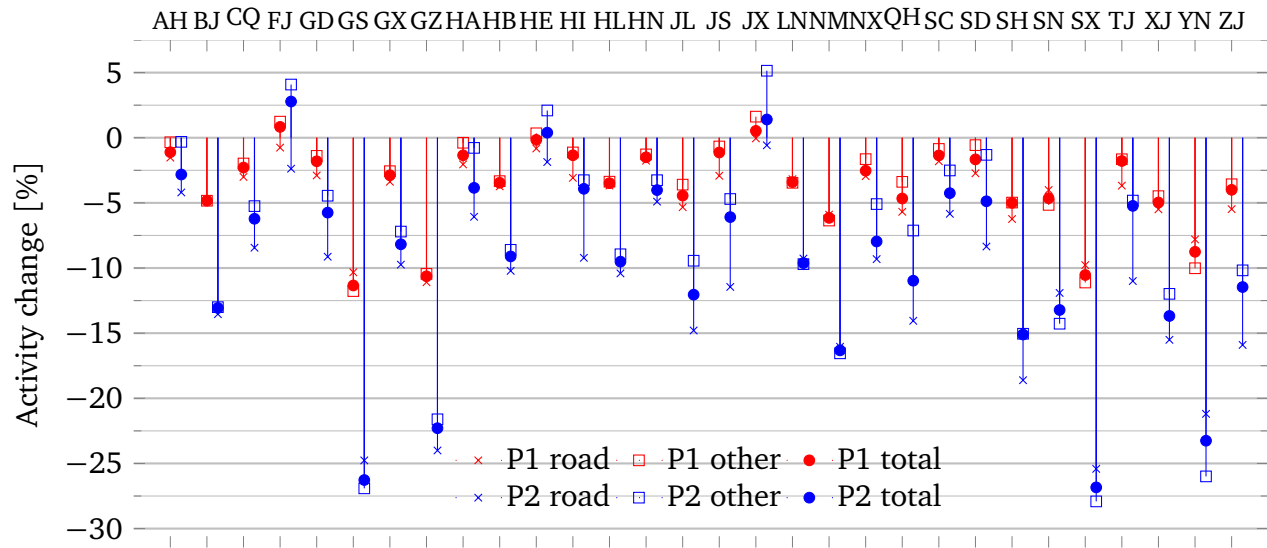
To interpret these results, we turn to **Figure 15**, which compares the change in freight activity by province against four other properties: total provincial GDP, the ratio of industry (EID, LID and OI) output to GDP, the energy intensity of all provincial GDP and the energy intensity of the provincial freight sector. The provinces experiencing the greatest reductions in freight activity have high energy intensity of production overall (**Figure 15**, bottom left) although not of freight particularly (**Figure 15**, bottom right). They are required by the policy instrument to transform (de-carbonize) their economy to greater degrees, in turn affecting demand for freight transport. All of the above-listed provinces have relatively lower abatement costs and contribute significantly to achieving the national reduction target.

#### 3.3.2 Passenger transport

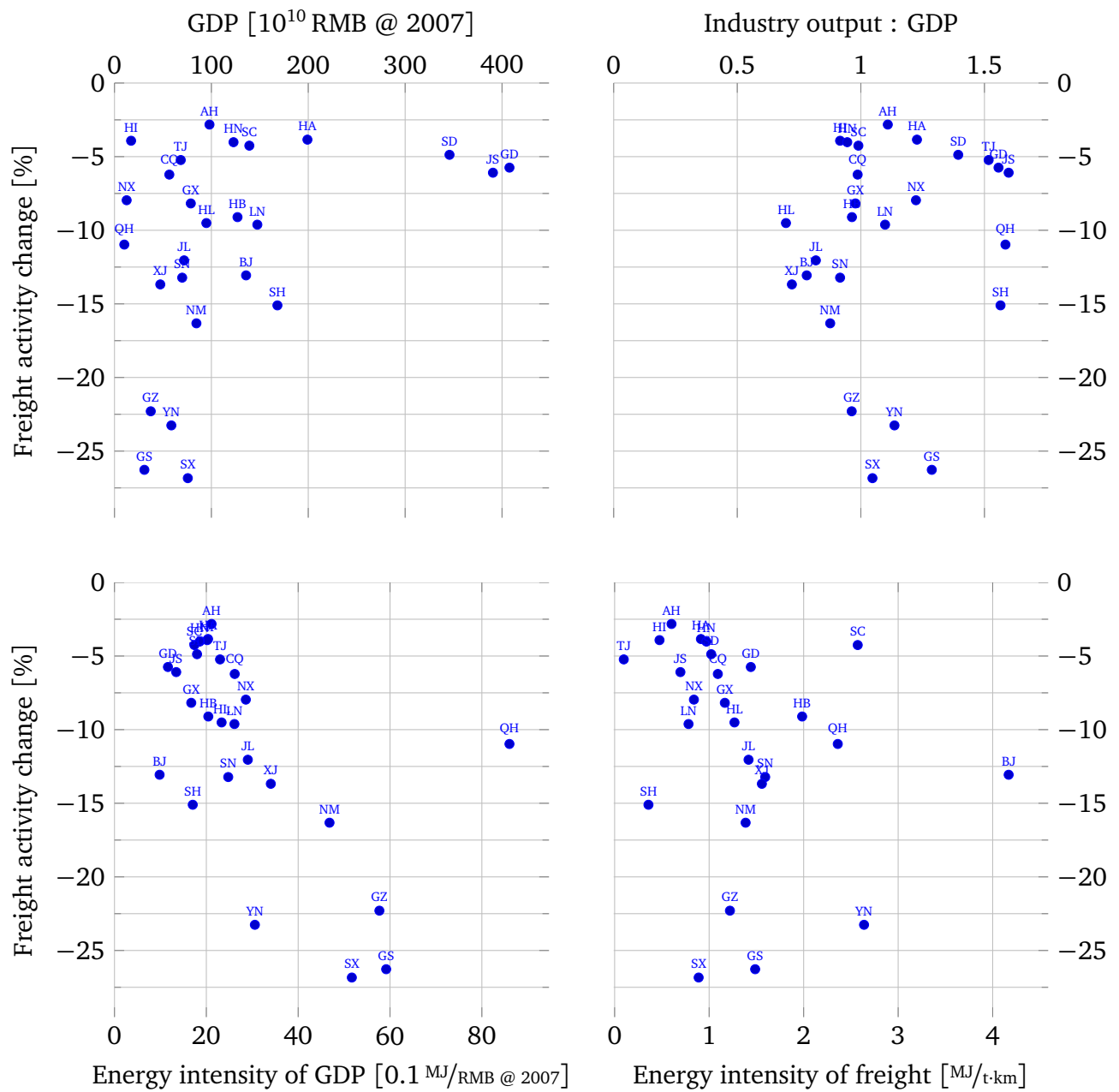
**Figure 16** shows the impacts on all three passenger modes of each policy, by province. Shanxi, Heilongjiang, Gansu, Beijing, and Xinjiang display the largest reductions in passenger transport generally, including household vehicle transport. Shanxi, in particular, reduces activity by 7.5% under Policy 1 and 23% under Policy 2, respectively 2.5 and 12 points more than the next-most-affected province, Heilongjiang. Again, there is an instance of a province *increasing* transport activity under policy, about which more shortly. Generally, tightening the intensity policy does not significantly change the share of modes between road, non-road and household vehicle passenger activity—the activity reduction (or increase) is similar across passenger modes, an effect constrained by the substitution elasticities between the commercial passenger modes, and between these and household vehicle transport. In the case of Qinghai, transport activity decreases even with a slight consumption increase under Policy 1, then further as consumption decreases under the tighter policy.



**Figure 13** – Contributions to oil energy demand reduction under policy from each transport sector, and the sum from all other, non-transport (NTRP) sectors. Labels indicate the portion of the reduction contributed by each sector; REF gives the reference level of consumption.



**Figure 14** – Policy impact on freight transport by mode and Chinese province.



**Figure 15** – Total freight activity vs. GDP (top left), the ratio of industrial output to GDP (top right), energy intensity of GDP (bottom left) and energy intensity of total freight (bottom right), Chinese provinces.

To assist with interpretation of the passenger transport results, **Figure 17** juxtaposes the change in activity with the change in total household consumption, showing a generally strong relationship with some nuances. For the slight majority of provinces below the line of proportional decrease, a substitution away from transport to other consumption occurs in response to a reduced household budget, due to the high energy/carbon intensity of transport relative to other goods in the consumption bundle. If this relationship is symmetric, it would indicate that a situation—such as economic growth—which increased household income in these provinces would induce a shift of consumption into transport, increasing the travel money budget. For provinces *above* the line in Figure 17, the inverse relationship exists.

### 3.3.3 Combined results for provincial transport systems

To consider the effects on the entire transport systems of individual provinces, we return to the lens of aggregate refined oil demand for all transport sectors.

**Figure 18** gives the change overall and for the combined transport sectors. Recalling the observation from Figure 13 that the contribution of transport to oil demand reduction is about half, in absolute terms, of the national total, we see that the *percentage* reduction from transport is much higher than the total in most provinces. This relationship represents both the effect of reduced demand for transport sector output and improvements in emissions intensity of transport coming from substitution away from OIL to lower-intensity fuels (GAS), or away from energy- to non-energy inputs.

**Figure 19** illustrates the relationship between freight and passenger transport systems impacts in individual provinces. We observe significant heterogeneity across provinces in terms of the absolute and relative impact on the transportation system, as well as whether freight or passenger travel are most affected. In many provinces, freight and passenger activity are fairly evenly affected (close to the 45-degree line of Figure 19) under Policy 1. Among those exhibiting uneven reductions in freight and passenger activity, some (e.g. Yunnan) see the effects become more even as the stringency of policy increases, while others (e.g. Heilongjiang) experience the opposite. Finally, some provinces experience effects of opposite sign: in Guizhou passenger activity increases while freight activity decreases, while in Fujian and Jiangxi the opposite is the case.

The magnitude of freight sector impacts can also potentially be explained by whether the province is a supplier of raw materials (especially if energy-intensive) to other provinces, and if and this activity is large relative to total provincial GDP—Inner Mongolia, Gansu, Guizhou, and Shanxi are all in this category, so the impact on freight could be more severe.

## 4 Discussion & conclusions

CGE models such as the C-REM assume reductions—to emissions intensity, in this case, but equivalently to energy intensity, total energy or total emissions—are taken starting from the most cost-effective opportunities. It may be difficult in practice to assess whether or where within the transport sector these opportunities lie, and further to properly incent them. The success of any transport-focused policy or economy-wide policy which includes the transport sector, however, depends critically on how individual actors experience and respond to the incentives policy creates.

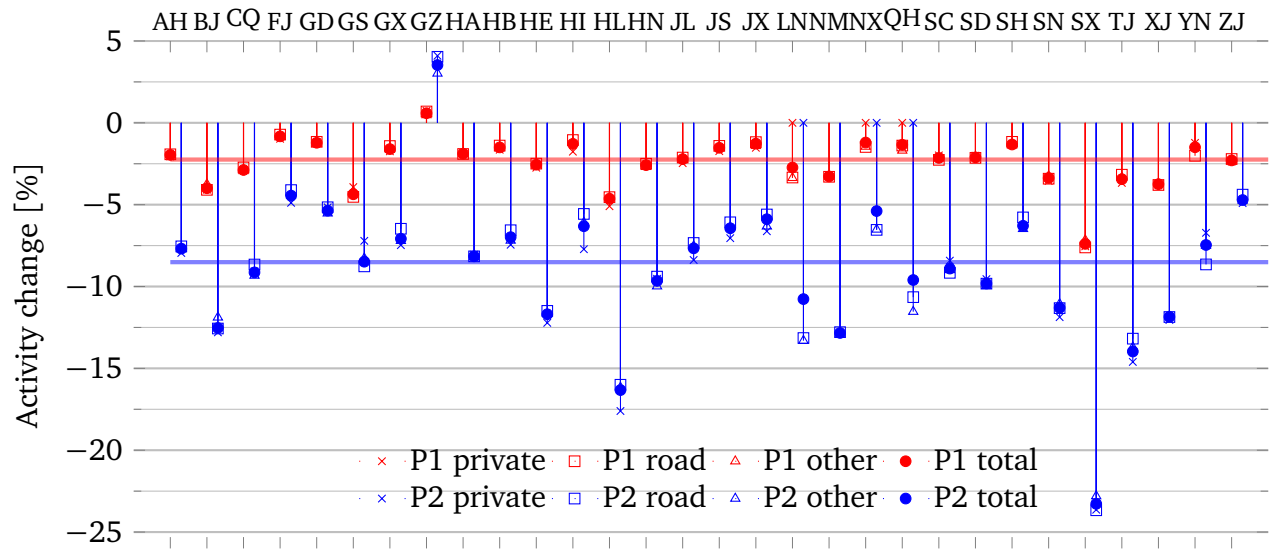


Figure 16 – Policy impact on passenger transport by mode and Chinese province.

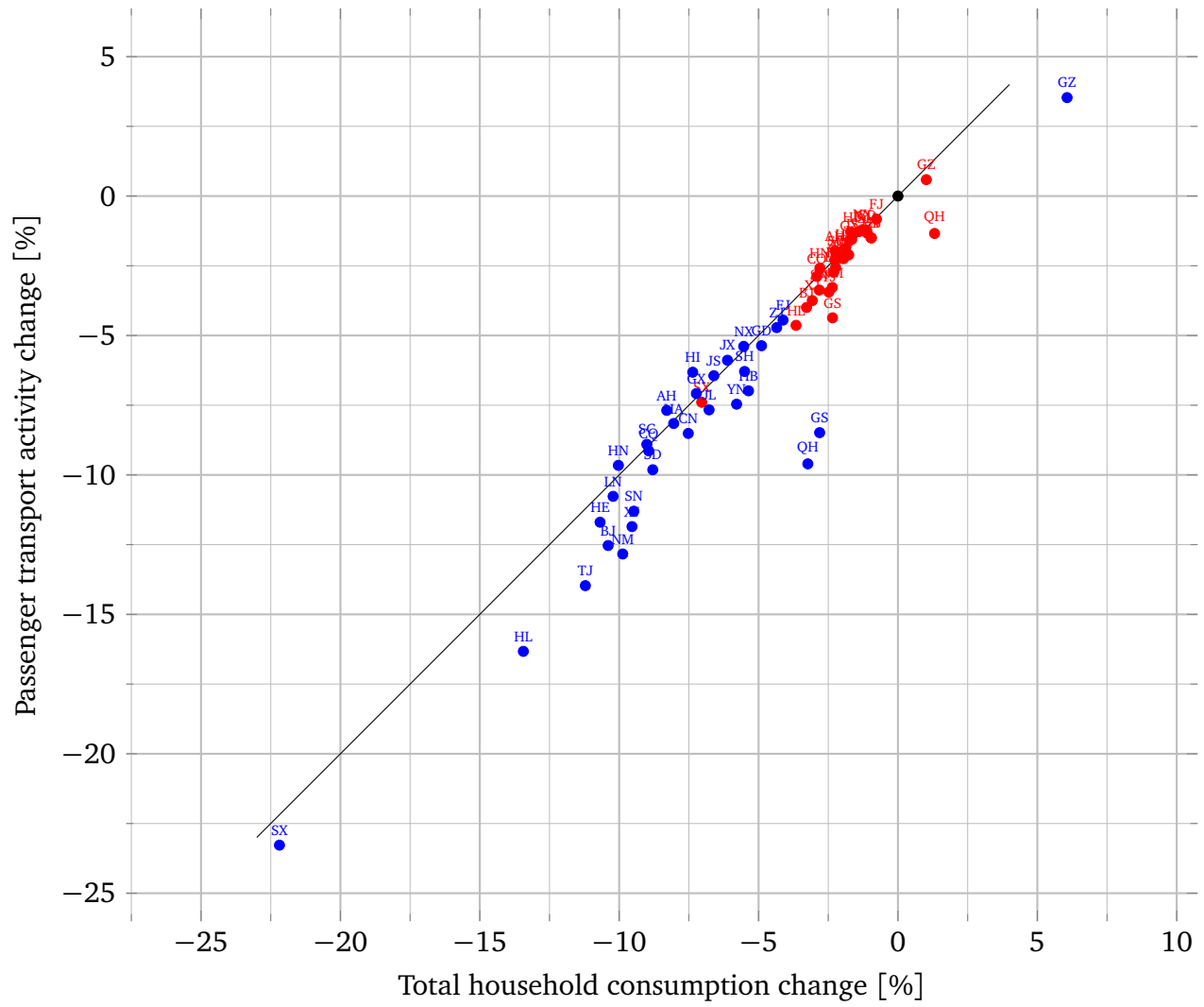


Figure 17 – Change in consumption versus change in passenger activity level.

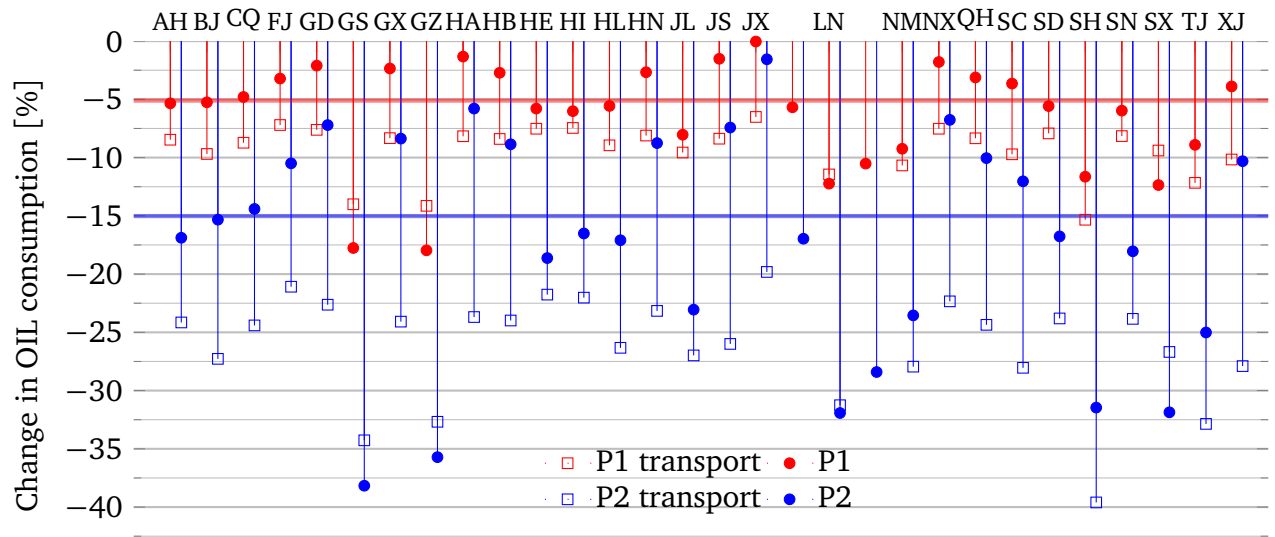


Figure 18 – Change in total refined oil use, Chinese provinces, with the aggregate change in the national total (solid lines).

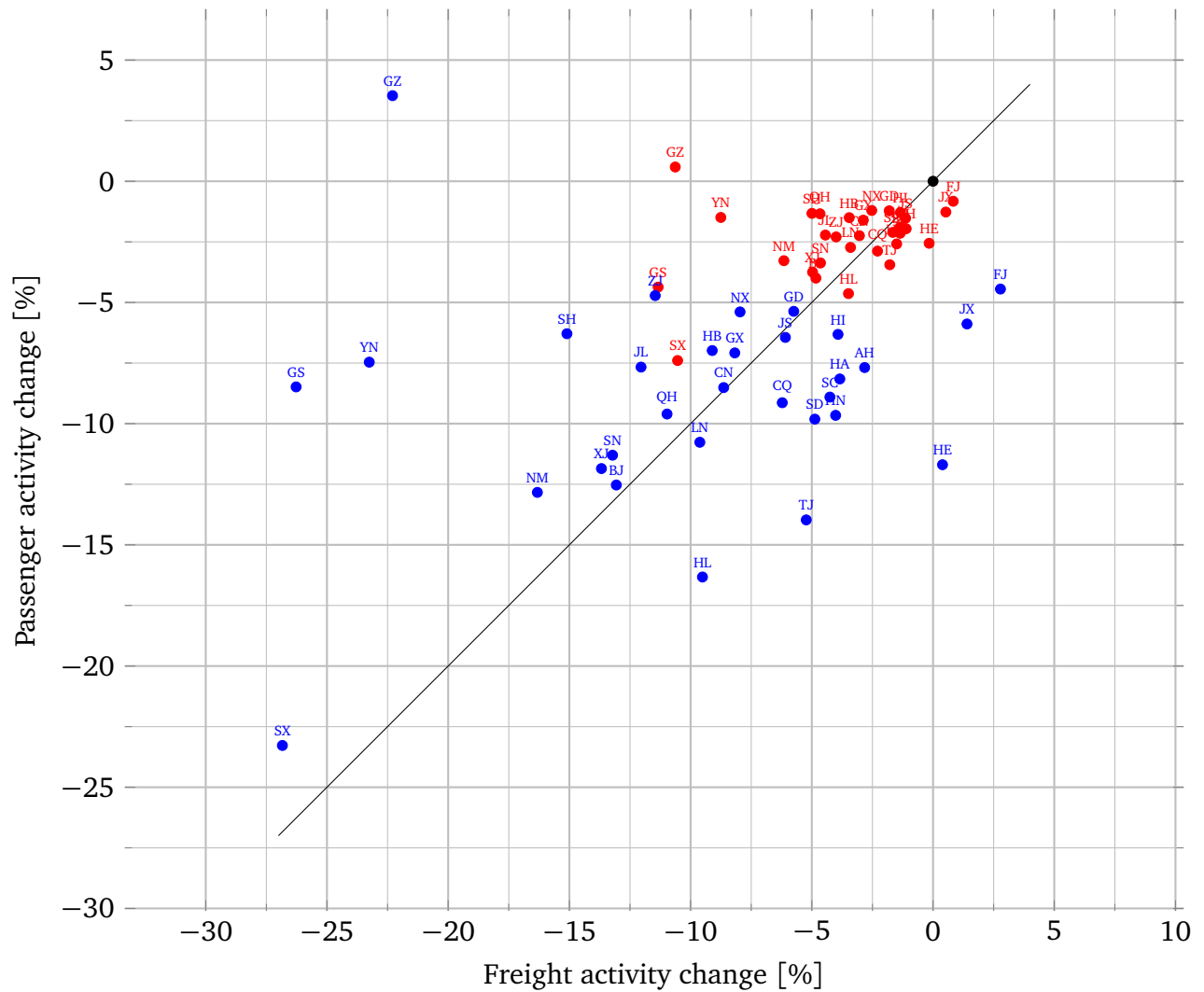


Figure 19 – Policy impact in freight vs. passenger activity, by province.

In the foregoing, we use the same value of 0.2 for the elasticity of substitution between household vehicle transport and commercial passenger transport as in the MIT EPPA model from which our household vehicle transport sector is derived. We also use a substitution elasticity of 0.2 between the commercial passenger modes, while we model a greater substitutability (unity elasticity) between freight modes. These choices are somewhat reflected in the results. The sensitivity of outputs to changes transport elasticities is an initial task for verification of our conclusions; better still would be values derived from empirical research specific to China.

Reviewing national level results, a relatively larger contribution to emissions abatement may suggest that it is important to consider how to include freight transportation in any cost-effective national carbon reduction effort. If so, the challenges of accounting for (and assessing reductions in) emissions in the transport sector will need careful consideration in national policy. Some regions—Europe, for instance—initially excluded transport and its opportunities for emissions abatement from trading systems using the rationale that fuels were already heavily taxed, which resulted in a high implicit carbon price (Abrell, 2010). A refined oil tax that has been harmonized with a cap-and-trade system may also be an option for China.

The results also indicate the relative cost of improving energy intensity is higher in transport in other sectors. These results are consistent with China’s transport system currently being relatively efficient per mile delivered. A reliance on smaller vehicles may allow the fleet to be more fuel efficient on average than, for instance, that of the United States. However, as manufacturers bring to market more spacious, heavier, higher performance vehicles with more amenities and consumers develop tastes for these, it is uncertain how the future will evolve.

Regarding provincial impacts, while we find ready explanations for many of the differences in impacts across modes and provinces, the identified drivers vary across provinces, sector uses, and modes. The energy-intensity of provincial GDP, industrial structure, and present mode share and energy-intensity of modes all affect changes in freight transport activity. Further study is warranted on the intermediate demand for freight transport services, to identify whether the movement of certain goods (for instance, raw materials including coal) is responding more strongly to climate policy than other freight activity.

Passenger road transport is more carbon-intensive at present, so we would expect to see any policy focused on carbon reducing the road share. Regardless, purchased modes generally offer lower carbon intensity and mode shifting could reduce emissions per passenger-kilometre, although estimating this at the provincial level is left to future research.

China’s transport system and its response to policy is hardly uniform, reinforcing the point that treating the entire system as an undifferentiated whole leads to a “flaw of averages.”<sup>6</sup> Regional detail reveals relative “winners” and “losers”—sometimes both in one province. These results could inform the discussion between provincial and central government officials the on type, stringency, and allocation (if any) of policies on climate, energy, and particular transport technologies and modes.

## 4.1 Future work

In addition to providing the insights about different responses of transport in Chinese provinces to a national emissions intensity target, this research has established a framework for planned further study of regional transport. The newly developed modelling capacity will allow future work to (1) represent existing policies which differ from province to province, or are piloted

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<sup>6</sup>For a detailed treatment of this term, see de Neufville and Scholtes (2011, Chapter 2).

in some provinces before being adopted more widely; (2) represent policies proposed or considered by individual provinces, or national policies which may have regionally heterogeneous impact; and (3) incorporate improved understanding of the characteristics of regional transport systems. The latter point includes improving calibration with additional data sources, aggregation of bottom-up data, or survey-based information on—for instance—mobility habits and preferences of consumers; but also endogenous representation of phenomena such as congestion (as demonstrated by Conrad (1997) generally and Gorman (2008) for freight) or increasing the supply of non-road modes according to statistics on investment in urban and intercity rail.

Karplus et al. (2012) described a production function in which additional powertrain technologies—including pure electric (EV), hybrid electric (HEV), and compressed natural gas (CNGV) vehicles—provide household vehicle transport with different energy inputs, emissions intensities and costs. Our present analysis included only an internal combustion (ICE) household vehicle technology, but the expected adoption of NEVs in response to policy can be assessed by calibrating these backstop alternatives to ICE technology with reference to information on available Chinese NEVs.

Finally, in addition to GHGs, road vehicles and other energy inputs to transport are associated with emissions of precursor pollutants which contribute to the variable and occasionally dangerously poor air quality in some of China’s cities. Categories of transport sources admit to different methods of pollution control, with distinct costs per unit abatement. Assigning emissions factors of these pollutants to individual transport modes will yield total emissions of precursors pollutants by province, a critical step in assessing whether policies such as those in **Table 4** can improve air quality—and if so, where.

Policy	C-REM Sectors(s)
1 Tailpipe emission standards/fuel quality standards	HVT
2 New vehicle fuel economy (CO <sub>2</sub> emissions) standards	HVT, FR, and/or PR
3 Alternative fuel vehicle subsidies	HVT, FR, and/or PR
A. Pure electric (EV) and hybrid electric (HEV) vehicles	”
B. Methanol vehicles	”
C. Compressed natural gas (CNG) vehicles	”
4 Vehicle ownership or usage taxes	HVT and/or PR
5 National cap-and-trade system focused on CO <sub>2</sub> emissions	(all)
6 Incentives to retire high emitting vehicles early	HVT, FR, and/or PR

**Table 4** – Transport sector policies for future study.

## 4.2 Summary

Motivated by rapid growth, a variety of policies both national and regional, and heterogeneity in regional characteristics of China’s transport system (Section 1, Section 2.3), we added detail in both household vehicle transport and commercial freight and passenger transport to the C-REM CGE model of China’s provinces (Section 2). To investigate the variation of responses across provinces and sectors (including the new transport sectors), we imposed national policies on the emissions intensity of GDP (Section 3). Among our results was a finding that percentage changes in provincial freight activity related strongly to the demand for the freight



transport service, which decreased most in provinces with high energy (and thus emissions) intensity of production and low-cost opportunities for emissions abatement. While passenger modes decreased in both activity and energy intensity under policy, their small share of transport energy demand meant that their contributions to transformation of the overall transport energy system were modest. While our work here focused on the impacts of national and economy-wide policy, we outlined how the additional transport detail will allow further study of China's existing transport policies, some of which are narrowly targeted at particular provinces and/or transport subsectors (Sections 1.1 and 4.1).

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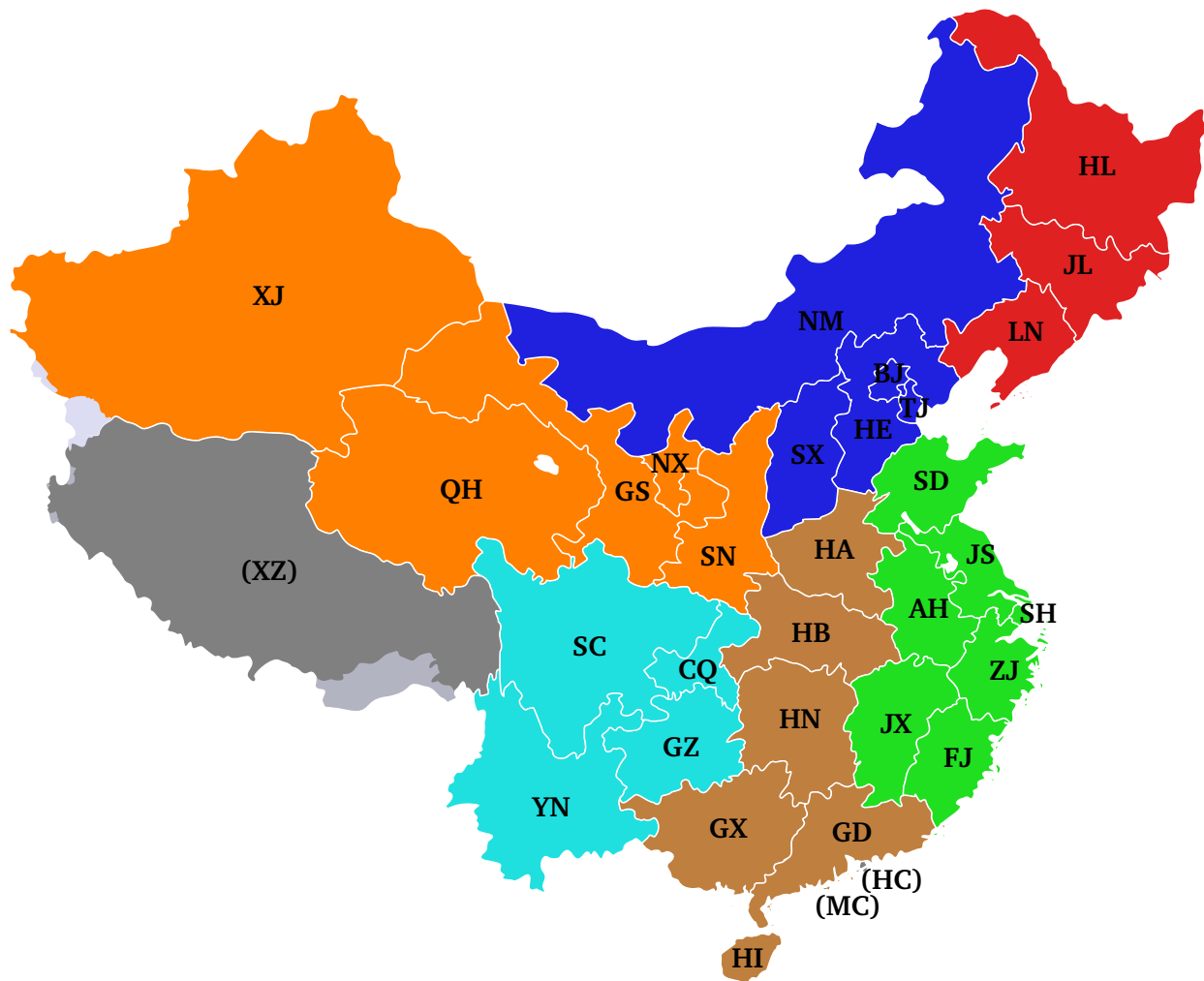
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## Appendix

Source	Mode			
	Air	Road	Rail	Water
<i>Freight [MJ/t·km]</i>				
Cai et al. (2012)	<b>9.01</b>	<b>1.7</b>	<b>0.1694</b> <sup>(1)</sup>	0.219
Ou et al. (2010)	—	1.362	0.24	<b>0.148</b>
<i>Passenger [MJ/pass·km]</i>				
Cai et al. (2012)	—	—	—	$\frac{1}{3} \frac{\text{t·km}}{\text{pass·km}} = \mathbf{0.073}$
Yan & Crookes(2010)	—	0.31–0.94 <sup>(2)</sup> 0.53 <sup>(3)</sup> 1.658 <sup>(4)</sup> 3.411 <sup>(5)</sup>	—	—
Girod et al. (2012)	—	<b>0.9</b>	<b>1.04</b>	—
CCTA (2008; 2009)	$0.09 \frac{\text{t·km}}{\text{pass·km}} = \mathbf{0.81}$ <sup>(6)</sup>	—	—	—

**Table 5** – Energy intensity by mode from literature, with values used in this study in bold. (1) Citing the China Ministry of Railways Statistical Bulletin for 2008, a value of 5.78 t coal equivalent per  $10^5$  t·km. (2) Citing Cherry et al. (2009), for bus. (3) For heavy-duty gasoline or diesel bus in Shanghai, (4) for light-duty bus, (5) for liquid propane gas (LPG) taxi, all citing Huang et al. (2005). (6) This official statistical publication reports an aggregate indicator of air traffic in t·km which includes pass·km converted at the given rate.



Code	Name	Code	Name	Code	Name
AH	安徽 Anhui	HE	河北 Hebei	QH	青海 Qinghai
BJ	北京 Beijing	HI	海南 Hainan	SC	四川 Sichuan
CQ	重庆 Chongqing	HL	黑龙江 Heilongjiang	SD	山东 Shandong
FJ	福建 Fujian	HN	湖南 Hunan	SH	上海 Shanghai
GD	广东 Guangdong	JL	吉林 Jilin	SN	陕西 Shaanxi
GS	甘肃 Gansu	JS	江苏 Jiangsu	SX	山西 Shanxi
GX	广西 Guangxi	JX	江西 Jiangxi	TJ	天津 Tianjin
GZ	贵州 Guizhou	LN	辽宁 Liaoning	XJ	新疆 Xinjiang
HA	河南 Henan	NM	内蒙古 Inner Mongolia	YN	云南 Yunnan
HB	湖北 Hubei	NX	宁夏 Ningxia	ZJ	浙江 Zhejiang

**Figure 20** – Provinces of China, with regional colouring scheme used in Figure 1. Hong Kong (HK), Macau (MC) and Xizhang (Tibet, XZ) are not included in the C-REM.